

December 1969

Attached are page changes to Apollo Guidance and Navigation Flow Charts E-2456, updating Program Colossus 2C charts to Colossus 2D.

The substitution of the sheet changes attached, marked Rev. 0 for (November 1969) will bring this document to Rev. 1 (December 1969).

INSTRUMENTATION LABORATORY  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
CAMBRIDGE, MASSACHUSETTS 02139

# APOLLO

## GUIDANCE, NAVIGATION AND CONTROL

Submitted by: Margaret H. Hamilton Date: 12-11-69  
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APOLLO GUIDANCE AND NAVIGATION PROGRAM

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E-2456  
(Rev. 1)

APOLLO GUIDANCE AND NAVIGATION  
FLOW CHARTS

PROGRAM COLOSSUS 2D  
COMANCHE 7Z

DECEMBER 1969

**MIT** INSTRUMENTATION  
LABORATORY

CAMBRIDGE 39, MASSACHUSETTS



#### ACKNOWLEDGEMENT

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The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

## FOREWORD

The latest edition of flowcharts, table of contents and foreword to update the Colossus 2C (Rev 0) APOLLO Guidance and Navigation Flowcharts to Colossus 2D (Rev 1) are enclosed within. Remove FC- 2595 from existing volume, as it is no longer part of program Colossus, Remove FC- 2682 and FC- 2710 since they are not accurate for Colossus 2D. Flowcharts not yet completed or included within the current edition are denoted by an asterisk on the table of contents. The index to the present volume is an alphabetical listing of flag bits, subroutines, and major entries. In addition to the flowchart and sheet number for each entry, the index gives the flowchart and sheet number where each flag bit is set (S), cleared (C), or tested (T).

*J. C. Reed*  
Jack C. Reed  
Group Leader

APOLLO Documentation

## CONTENTS

Section	Pages
1.0 INTRODUCTION . . . . .	none
2.0 GENERAL MANAGEMENT AND SERVICE ROUTINES . . . . .	total (1+168)
FC-2020—Fresh Start and Restart . . . . .	1-50
FC-2030—Phase Table Maintenance . . . . .	1-16
*FC-2041—V69—Cause Hardware Restart . . . . .	none
FC-2050—Executive . . . . .	1-20
FC-2060—Waitlist . . . . .	1-24
FC-2070—Service Routines . . . . .	1-14
FC-2080—Inter-bank Communication . . . . .	1- 5
*FC-2090—Interpreter . . . . .	none
FC-2100—RTB Op Codes . . . . .	1-17
FC-2110—Single Precision Subroutines . . . . .	1- 4
FC-2120—AGC Block Two Selfcheck . . . . .	1-18
3.0 INPUT-OUTPUT ROUTINES . . . . .	total (1+80)
*FC-2130—Display Interface Routines . . . . .	none
FC-2140—Alarm and Abort . . . . .	1-16
FC-2150—Keyrupt and Uprupt . . . . .	1- 9
*FC-2160—Update Program (P27) . . . . .	none
*FC-2165—V55—Align Time . . . . .	none
*FC-2170—Down-telemetry Program . . . . .	none
*FC-2176—V74—INITIALIZE Erasable Dump via Downlink . . . . .	none
*FC-2190—Extended Verbs . . . . .	none
*FC-2180—Pinball Game Buttons and Lights . . . . .	none
FC-2200—T4RUPT . . . . .	1-55
4.0 IMU AND OPTICS ROUTINES . . . . .	total (1+35)
*FC-2210—IMU Mode Switching Routines . . . . .	none
FC-2220—P06 GNCS Power Down . . . . .	1- 8
*FC-2230—IMU Compensation Package . . . . .	none
FC-2235—IMU Extended Verbs (V40, V41, V42) . . . . .	1-10
FC-2240—SXTMARK . . . . .	(+1) 1- 9
FC-2242—R57 Optics Calibration Routine . . . . .	1- 7

5.0	GEOMETRY TRANSFORMATIONS	total	(1+25)
*	FC-2250-CSM Geometry	none	
*	FC-2260-Inflight Alignment Routines	none	
*	FC-2270-Powered Flight Subroutines	none	
	FC-2280-Latitude Longitude Subroutines	1-13	
	FC-2283-Planetary Inertial Orientation	1-9	
	FC-2286-Lunar and Solar Ephemerides	1-3	
6.0	CONIC AND INTEGRATION ROUTINES	total	(1+110)
	FC-2280-Integration Initialization	1-26	
	FC-2300-Orbital Integration	1-50	
*	FC-2310-Conic Subroutines	none	
*	FC-2315-Integration Extended Verbs	none	
	FC-2320-TFFCONICS	1-20	
	FC-2325-Rendezvous Parameters Displays	1-14	
7.0	MANEUVER ROUTINES	total	(1+56)
	FC-2330-R62 Crew Defined Maneuver (V49)	1-4	
	FC-2340-R60 Attitude Maneuver	1-9	
	FC-2350-Maneuver Calculations and Steering	1-27	
	FC-2360-R64 (R05)-S-Band Antenna	1-6	
	FC-2361-V89 (R63)	1-7	
	FC-2363-V76,V77 (Manipulate Preferred Attitude Flag)	1-3	
8.0	RCS AUTOPILOT	total	(1+73)
	FC-2370-DAP Interface and Service Routines	1-34	
	FC-2380-RCS DAP Initialization and Phase I	1-8	
	FC-2390-RCS DAP Phase 2	1-12	
	FC-2400-RCS DAP Jet Selection Logic	1-19	
9.0	TVC AUTOPILOT	total	(1+64)
	FC-2430-TVC Start-up Executive, and Service Routines	1-36	
	FC-2440-TVC DAP	1-19	
	FC-2450-Stroke Test Package	1-2	
	FC-2460-Roll Autopilot	1-7	

10.0 ALIGNMENT AND TEST ROUTINES .....	(1 + 47)
*FC- 2520-System Test Extended Verbs (V43,V91) .....	none
FC- 2530-Prelaunch Initialization and Gyro Compassing .....	1-47
11.0 BOOST PROGRAMS .....	(1 + 45)
FC- 2540-P11 Earth Orbit Insertion Monitor .....	1-27
FC- 2545-P17/P77-TPI Search Programs .....	1-18
12.0 NAVIGATION PROGRAMS .....	total (1 + 150)
FC- 2550-P20 Rendezvous Navigation .....	1-46
FC- 2580-P21 Ground Track Determination .....	1- 7
FC- 2590-P22 Orbital Navigation .....	1-44
*FC- 2595-R35 Lunar Landmark Selection Routine .....	none
FC- 2600-P23 Cislunar Midcourse Navigation .....	1-27
FC- 2605-Navigation Extended Verbs .....	1- 7
FC- 2606-V94 (R64) .....	1- 3
FC- 2610-Measurement Incorporation .....	1-16
13.0 PRE-THRUST TARGETING PROGRAMS .....	total (1+192)
FC- 2620-P30, P31 .....	1-12
FC- 2626-P32, P72-CSI .....	1-26
FC- 2627-P33, P73-CDH .....	1- 7
FC- 2630-P34/P74-TPI Targeting .....	1-20
FC- 2631-R36 (V90) .....	1- 7
FC- 2640-P35/P75-TPM Targeting .....	1- 3
FC- 2641-Common Targeting Subroutines .....	1-18
FC- 2642-P37 Return To Earth .....	1-53
FC- 2644-P38/P78-P39/P79 .....	1-15
FC- 2650-Orbital Parameters Display .....	1-25
FC- 2670-P76 Target Delta V Program .....	1- 6
14.0 THRUST PROGRAMS .....	total (1 + 122)
FC- 2680-Thrust Programs (P40,P41) .....	(+1) 1-58
FC- 2681-Cloktask and Clockjob .....	1-17
*FC- 2682-Steering .....	none
FC- 2683-Servicer .....	1-37
FC- 2700-P47 Thrust Monitor .....	1-10

15.0 ALIGNMENT PROGRAMS .....	total	(1+ 51)
*FC- 2710-P51, P53 IMU Orientation Determination .....	none	
FC- 2720-P52 IMU Realignment Program .....	(+1)	1-32
FC- 2730-R52, R53, R56 .....		1-18
16.0 ENTRY PROGRAMS .....		(1+ 90)
FC- 2760-P60's Entry Programs .....	total	1-35
FC- 2770-Reentry Control .....		1-31
FC- 2780-CM Entry Digital Autopilot .....		1-24
17.0 INDEX .....		1-28

FRESH START AND RESTART		
ENTRIES	SHEET	DESCRIPTION
SLAPI	2	ASTRONAUT INITIATED FRESH START
STARTSW	2	SIMULATION PURPOSES ONLY
POFSTART	3	SOFTWARE FRESH START
MR KLEAN	7	SUBROUTINE FOR MAKING ALL GROUPS INACTIVE
POOKLEAN	7	SUBROUTINE FOR MAKING GROUPS 1, 3, 4, 5, 6 INACTIVE
V37KLRAN	7	SUBROUTINE FOR MAKING GROUPS 3, 5, 6 INACTIVE USED BY V37
STARTSUB	8	SUBROUTINE FOR INITIALIZATION OF REGISTERS, USED BY BOTH FRESH START AND RESTART
STARTSB2	8	SUBROUTINE FOR INITIALIZATION OF REGISTERS USED BY SOFTWARE RESTART VIA GOPROG2
GOPROG	13	HARDWARE RESTART
TSIDLOC	17	IDLING ROUTINE FOR T5RUPRT
GOPROG2	20	USED BY SOFTWARE RESTART
GOTOPOOH	24	FLASH V37 ON DSKY REQUESTING ASTRONAUT TO SELECT NEW MAJOR MODE.
INITSUB	25	SUBROUTINE FOR SETTING DEADBAND, CLEAR IS FLAGS, ZERO INPUTS TO AUTOPILOTS
VAC5STOR	27	SUBROUTINE FOR STORING CONTENTS OF CERTAIN LOCATIONS IN E MEMORY FOR DEBUGGING
V37	30	CHANGE MAJOR MODE
V37XEQ	40	PREPARE FINDVAC CALLING SEQUENCE TO SCHEDULE MAJOR MODE
RESTARTS	43	INITIATES THE EXECUTION OF RESTART ADDRESSES AS A JOB OR A TASK. SETS L <sup>F</sup> TASK OR JOB INDICATED BY PHASE SETTING OF CURRENT GROUP. RESTARTS IS A SUBROUTINE.

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1	LIST OF ENTRIES
2	FLOW CHART OF FRESH START LOGIC
13	FLOW CHART OF RESTART LOGIC
30	FLOW CHART OF LOGIC FOR CHANGING MAJOR MODES
48	LIST OF SUBROUTINES WHICH ARE FLOWED ON OTHER FLOW CHARTS
49	INDEX OF REGISTERS AND CHANNELS WHICH ARE INITIALIZED. TEST LOGIC

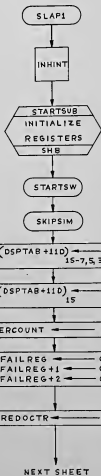
LIST OF REVISIONS

REV. NO.	REVISION
1	UPDATED COLOSSUS 237 TO COLOSSUS II-A (21 SHEETS REVISED AND ALL SHEETS 1-41 RENUMBERED - ARE NOW SHEETS 1-46)
2	UPDATED COLOSSUS II-A TO COLOSSUS II-C (SHEETS 5, 7 AND 25 REVISED AND ALL SHEETS 1-46 RENUMBERED - ARE NOW SHEETS 2-47) AND ADDED NEW SHEETS 1, 48, 49 AND 50.
3	UPDATED COLOSSUS II-C TO COLOSSUS II-D (SHEET 26 REVISED).

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRWING	<i>P. Allen</i>	FRESH START & RESTART	
AWRGT	<i>P. Allen</i>	COLOSSUS	DOCUMENT NO.
NOCAN	<i>C. J. Hinkle</i>	II-D	17-2020
APPROV	<i>C. J. Hinkle</i>	7-9-67	REV 3
APPROV			SHEET 1 OF 50

VIA VERB 36

FRESH START



ASTRONAUT INITIATED FRESH START

REGISTERS COMMON TO BOTH FRESH START AND RESTART

THIS LOCATION IS USED TO PATCH FOR SIMULATION PURPOSES ONLY

TURN OFF ALL C RELAYS AND LIGHTS EXCEPT THAT BIT 6 (SIMBAL LOCK LAMP) AND BIT 4 (NO-ATTITUDE LAMP) REMAIN INTACT.

THIS IS A SIGN TO PROGRAM T4RUPT TO TRANSMIT THE CURRENT CONTENTS (JUST SET) OF DSPTAB+11D TO CHANNEL 10 — THAT A CHANGE HAS OCCURRED IN BIT-POSITIONS 11-1 SINCE THE LAST TIME DSPTAB+11D WAS PROCESSED BY T4RUPT.

INDICATES NO MALFUNCTIONS

REMOVES INDICATIONS OF PREVIOUS ALARMS. PROGRAM ALARM WILL PROCESS THE NEXT ALARM AS THE FIRST ALARM

RESTART COUNTER INDICATES NO RESTARTS. SINCE THIS IS A FRESH START, THE COUNTING OF RESTARTS BEGINS WITH 0

FRESH START AND RESTART

APPROVED <i>C. J. [Signature]</i> 26 NOV 68 1-23-68 3	COLLOSSUS II-D FC-2020 2 50
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FROM  
PRECEDING SHEET

DSRPTSW ← OCT65777

CAUSES PROGRAM T4RPT TO CYCLE THROUGH ITS DISPLAY PROCEDURES IN ORDER TO BLANK THE DSKY WINDOWS BEFORE PERFORMING ITS NORMAL T4 FUNCTIONS

ENTERED FROM RESTART PROGRAM (GOPROG) ON SHEETS 13, 14, 15 TWICE AND 20 (TWICE), IF FRESH START IS REQUIRED

DOFSTART

ERESTORE ← 0

INDICATES THAT THE CHECKING OF ERASABLE MEMORY IN ROUTINE ERASCHK WAS NOT INTERRUPTED BY A RESTART. A ZERO ENABLES A RESTART TO CONTINUE IN GOPROG

SMODE ← 0

CAUSES EXECUTION OF THE IDLE LOOP (NO CHECKING) IN PROGRAM SELF CHECK

CLEAR  
UPSVFLAG

ZERO UPDATE STATE VECTOR  
REQUEST FLAGWORD

CLEAR ALL  
BITS OF  
CHANS

TURN OFF  
RCS JETS

CLEAR ALL  
BITS OF  
CHAN G

TURN OFF  
RCS JETS

NEXT SHEET

SEARCHED  
SERIALIZED  
INDEXED  
FILED  
OCT 1965  
C. H. Beck  
John A. Moran

FRESH START AND RESTART

COLOSSUS  
II-D

FC-2020

3

3

50

FROM  
PRECEDING SHEET

CLEAR ALL  
BITS OF  
CHAN 11

TURNS ENGINE OFF. ALL INDIVIDUAL  
INDICATORS OF THE DISPLAY  
SYSTEM ARE TURNED OFF

CLEAR ALL  
BITS OF  
CHAN 12

TERMINATES THE DRIVING OF  
MISCELLANEOUS NAVIGATION  
AND SPACECRAFT HARDWARE

CLEAR ALL  
BITS OF  
CHAN 13

TERMINATES THE CONTROL OF  
MISCELLANEOUS NAVIGATION  
SYSTEM FUNCTIONS

CLEAR ALL  
BITS OF  
CHAN 14

TERMINATES THE TRANSMISSION OF  
OUTPUT PULSES FROM THE VARIOUS COUNTERS.  
(CDU, OPTICS, PIPA, UPLINK, ETC)

WTOPTION ← +0

INDICATES THAT ZOPTICS  
MUST BEGIN OVER AGAIN

DNLSTGOD ← +0

SELECT COAST AND  
ALIGNMENT DOWNLIST

NVSAVE ← +0  
EBANKTEM ← +0

CLEAR  
DISPLAY-INTERFACE-ROUTINES  
SAVE REGISTERS

RATEINDX ← +0

INITIALIZE MANEUVER RATE  
TO 0.5 DEG/SEC

TRKMKCNT ← +0

INITIALIZE NUMBER OF  
OPTICS MARKS

VHFCNT ← +0

INITIALIZE NUMBER OF  
VHF MARKS

EXTVBACT ← +0

RELEASES EXTENDED VERB  
AND MARK ACTIVITY

ARE  
BOTH BIT 6  
AND 4 OF (OSPTAB  
+110) = 1  
?  
NO  
YES

ARE BOTH GIMBAL LOCK (BIT 6) AND  
NO-ATTITUDE (BIT 4) LAMPS ON?

SET BOTH  
BIT 6  
AND 4 OF  
CHAN 11

ENABLE IMU CDU  
ERROR COUNTERS (BIT 6)  
AND ENABLE COARSE  
ALIGN OF IMU (BIT 4)

MAKE ALL GROUPS  
INACTIVE VIA  
SUBROUTINE  
MR. KLEAN

ALLGROUPS  
KILL ALL  
GROUP  
RESTARTS

NEXT SHEET

FRESH START AND RESTART

COLLOSSUS

FC-2020

3

50



FROM  
PRECEDING SHEET

CLEAR  
FLAGWR00

CLEAR BITS  
15-13 AND 11-1  
OF FLAGWR01

CLEAR  
FLAGWR02

CLEAR BITS  
15, 14 AND 12-1  
OF FLAGWR03

CLEAR  
FLAGWR04

CLEAR BITS  
15-9 AND 7-1  
OF FLAGWR05

SET  
BIT 8 OF  
FLAGWR05

SET  
BIT 3 OF  
FLAGWR06

CLEAR BITS  
15-4 6 AND 1  
OF FLAGWR06

CLEAR  
FLAGWR07

CLEAR BITS  
15-13, 10, 9 AND  
7-1 OF FLAGWR08

CLEAR  
FLAGWR09

CLEAR  
FLAGWR10

CLEAR  
FLAGWR11

ENDRSTRY

END OF  
FRESH START

VIA POSTJUMP

DUMMYJOB+2

STATUS OF NODOP01 FLAG (BIT 12)  
REMAINS INTACT

STATUS OF REFSMFLG (BIT 13)  
REMAINS INTACT

INITIALIZE ALL FLAGWRDS BY SETTING APPROPRIATE  
SWINIT VALUES INTO EACH FLAG.  
SWINIT VALUES ARE SUCH AS TO ZERO ALL BITS  
EXCEPT BIT 8 (COMPUTER) OF FLAGWR05 WHICH IS  
SET TO ONE. ALSO BIT 12 (NODOP01) OF FLAGWR01,  
BIT 13 (REFSMAT FLAG) OF FLAGWR03, BITS 12  
(CMOONFLG), 11 (LMOONFLG) AND 8 (SURFFLAG) OF  
FLAGWR08 WHICH REMAIN INTACT

INDICATES THAT COMPUTER  
IS CMC (A "0" IS LGC)  
APSESW FLAG

DRAG OVER 0.05G  
.05G SW FLAG

STATUS OF CMOONFLG (BIT 12),  
LMOONFLG (BIT 11), AND SURFFLAG (BIT 8)  
REMAIN INTACT

FRESH START AND RESTART

*A. J. Campbell* 27 NOV 68  
*R. H. Beck* 12549  
*John D. Moore* 27 NOV 68

COLOSSUS  
II-D  
FC-2020  
3  
6 60



FROM  
SLAP1 AND GOPROG

START SUB

SUBROUTINE  
USED BY BOTH FRESH START AND RESTART.  
FOR INITIALIZATION OF REGISTERS COMMON TO BOTH

DNTMGOTO ← TC DNPHASE1

INITIALIZES PROGRAM DOWN TELEMETRY

TIME 5 ← 37774

WILL CAUSE TIME COUNTER TIME5 TO OVERFLOW  
IN 40 MILLISECONDS FROM NOW TO IN TURN INITIATE  
THE EXECUTION OF T5RUPT INTERRUPT

TIME 4 ← 37775

WILL CAUSE TIME COUNTER TIME4 TO OVERFLOW  
IN 30 MILLISECONDS FROM NOW TO IN TURN INITIATE  
THE EXECUTION OF INTERRUPT PROGRAM T4RUPT  
ENTERED BY "SOFTWARE" RESTART, I.E., EXECUTION  
OF RESTART PROCEDURE UNDER PROGRAM CONTROL.  
FROM ROUTINE GOPROG2 (ENEMA)

STARTS B2

CLEAR BITS  
7-3 OF  
CHAN11

TURN OFF UPLINK ACTIVITY (3), TEMPERATURE CAUTION  
(4), KEY RELEASE (5), FLASH (6), AND OPERATOR  
ERROR (7) INDICATORS. LEAVE OTHER INDIVIDUAL  
INDICATORS INTACT. ALSO, LEAVE ENGINE CONTROL  
INDICATORS INTACT.

TIME 3 ← 37777

WILL CAUSE TIME COUNTER TIME3 TO OVERFLOW  
IN 10 MILLISECONDS FROM NOW TO IN TURN INITIATE  
THE EXECUTION OF INTERRUPT PROGRAM T3RUPT

CLEAR BITS  
11 AND  
10 OF  
CHAN13

WILL TERMINATE STANDBY OPERATION AND TESTING OF  
DSKY LIGHTS AND RELAYS. LEAVE INPUTS TO 8MAG  
COUNTERS, ENABLE T6RUPT FLAG, RESET TRAP  
FLAG, TELEMETRY WORD ORDER FLAG, BLOCK INLINK  
FLAG AND INHIBIT UPLINK FLAG REMAIN INTACT. THE  
8MAG COUNTERS ACCUMULATE INCREMENTAL ANGULAR  
DATA FROM THE GYRO DISPLAY COUPLER OF THE SC5  
BODY-MOUNTED ATTITUDE GYROS

CLEAR  
BIT 14 OF  
FLAGWRD2

OPTION TWO FOR MARKRUPT  
FLAG R2IMARK

CLEAR  
BIT 12 OF  
FLAGWRD2

CALCULATE BASE VECTOR DURING 1ST PASS THROUGH P21  
STEERING OMITTED  
P21FLAG

SET  
BIT 10 OF  
FLAGWRD2

DISREGARD RADAR READ BECAUSE OF SOFTWARE OR  
HARDWARE RESTART  
FLAG SKIPVHF

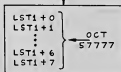
EBANK ← ECAOR LST1

LST1 AND LST2 ARE IN EBANK 3

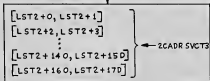
NEXT SHEET

FORM 1	REVISED EDITION, JAN 1964 (NO. 1) WASS.	FIELD NO. RANGE AND NAVIGAT
OPERATOR <i>A. J. Campbell</i> 30 DEC 64		FRESH START AND RESTART
PROGRAM	<i>FC-2020</i>	
ANALYST	<i>J. B. Becke</i> 1-23-69	COLOSSUS II-D FC-2020
DATE	<i>John A. Moore</i> 23 JAN 69	REV 3
APPROVED		REV 3

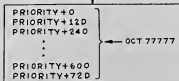
FROM  
PRECEDING SHEET



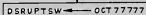
SCHEDULE TASK SVCT3 IN WAITLIST TO BE EXECUTED 81.93 SECONDS FROM NOW AND EVERY 81.93 SECONDS THEREAFTER UNTIL A REGULAR TASK HAS BEEN SCHEDULED. T3RUPRT WILL PLACE OCT 17777 (OCT 57777 PLUS OCT 37777) INTO COUNTER TIME3 WHICH WILL RESULT IN 81.93 SECONDS



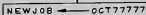
T3RUPRT WILL CAUSE THE EXECUTION OF TASK SVCT3 WHOSE COMPLETE ADDRESS IS IN THE ADDRESS LIST LST2. TASK SVCT3 CHECKS GYRO DRIFT AND COMPENSATES IF NECESSARY AND RESUMES INTERRUPTED ROUTINE VIA TASKOVER



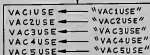
A MINUS ZERO IN THE PRIORITY REGISTER OF EACH JOB REGISTER SET INDICATES EACH JOB REGISTER SET IS AVAILABLE TO NEW JOBS



INITIALIZES T4RUPRT. SEQUENCE OF T4RUPRT FUNCTIONS WILL START OVER AGAIN. FRESH START CHANGES THIS; RESTART DOES NOT



A MINUS ZERO CAUSES THE EXECUTIVE TO INITIATE IDLING - THE EXECUTION OF PROGRAM SELF CHECK IN THE ABSENCE OF AN ACTIVE JOB. A MINUS ZERO INDICATES NO ACTIVE JOBS WAITING EXECUTION



THE ADDRESS OF THE FIRST LOCATION OF EACH VAC AREA IS STORED IN THE SAME LOCATION (CONTROL CELL) TO INDICATE THAT EACH VAC AREA IS AVAILABLE TO NEW JOBS

NEXT SHEET

3 DEC 64

SEARCHED  
SERIAL  
INDEXED  
FILED

DEC 15 1964

ANALYST  
OPERATOR  
APPROVER

*C. J. [unclear]*  
*P. H. [unclear]*  
*J. A. [unclear]*

3 DEC 64  
1-23 64  
23-11-14

FRESH START AND RESTART

COLOSSUS II-D

FC-2020

REV 3

9 1 50

FROM  
PRECEDING SHEET

DSPOFF

DSPTAB+10D  
DSPTAB+9D  
DSPTAB+8D  
⋮  
DSPTAB+1  
DSPTAB+0

← OCT73777

DELAYLOC+D  
DELAYLOC+1  
DELAYLOC+2  
DELAYLOC+3

← 0

RISAVE ← 0

INLINK ← 0

DSPCNT ← D

CADRSTOR ← 0

REQRET ← 0

CLPASS ← 0

DSPLDCK ← 0

MONSAVE ← 0

MONSAVE1 ← 0

VERBREG ← 0

NEXT SHEET

BLANKS DSKY WINDOWS (PROGRAM NUMBER, VERB NOUN AND R1, R2 AND R3 CHARACTERS). THE ONE IN BIT-POSITION 15 INDICATES TO PROGRAM T4RUPT THAT THERE HAS BEEN A CHANGE IN BIT-POSITIONS 11 THROUGH 1 SINCE THE LAST TIME PROGRAM T4RUPT PROCESSED THAT DSPTAB REGISTER. A ZERO IN BIT POSITION 12 PREVENTS UNWANTED CGS BRANCH IN THE T4RUPT PROGRAM

ANY JOBS THAT HAVE BEEN MADE DORMANT FOR A SPECIFIED TIME INTERVAL BEFORE REACTIVATING ARE REMOVED. A ZERO SIGNIFIES THAT NO JOBS ARE WAITING (SLEEPING) NOW

CLEAR MARK AND EXTENDED VERB DISPLAYS. CLEAR REPEAT AND RETURN REQUEST

CLEARs THE INLINK COUNTER OF ALL UPLINK DATA

CAUSES T4RUPT TO SCAN THE DSPTAB TABLE AT DSPTAB+D FOLLOWED BY DSPTAB+10, +9, ETC

INDICATES THAT NO JOB IS USING ENDLIE (NO INTERNAL ROUTINE ASLEEP WAITING OPERATOR'S RESPONSE)

GIVES THE ENTER BUTTON THE MEANING OF EXECUTING A VERB-NOUN COMBINATION RATHER THAN THE ENTERING OF DATA

INDICATES TO THE DISPLAY SYSTEM THAT THE CLEAR BUTTON MAY BE USED TO CLEAR THE DISPLAY REGISTERS CONSECUTIVELY

INDICATES THAT THE DISPLAY SYSTEM HAS BEEN RELEASED BY THE OPERATOR AND IS AVAILABLE FOR INTERNAL USE

TERMINATES THE DISPLAY MONITOR ACTIVITY

TERMINATES THE DISPLAY MONITOR ACTIVITY

INDICATES TO PINBALL THAT THE VERB DISPLAY WINDOW IS BLANK

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		FIELD TO SCANT AND NAVIGATION	
SEARCHED <i>[Signature]</i> INDEXED		FRESH START AND RESTART	
PRINTED <i>[Signature]</i> RECORDED		CDLOSSUS DIVISION	
APPROVED <i>[Signature]</i> 7-23-62		II-D FC-2020	
APPROVED <i>[Signature]</i> 7-23-62		SHEET 10 OF 60	



FROM  
PRECEDING SHEET

NOUNREG ← 0

INDICATES TO PINBALL THAT THE  
NOUN DISPLAY WINDOW IS BLANK

DSPLIST ← 0

INDICATES THAT NO JOB IS USING  
ROUTINE NVSUBUSY (NO INTERNAL  
ROUTINE IS ASLEEP WAITING FOR THE  
OPERATOR TO RELEASE THE DISPLAY SYSTEM)

MARKSTAT ← 0

INDICATES THAT NO OPTICS MARK OPERATIONS  
HAVE BEEN REQUESTED AND LEAVES THE MARK  
SYSTEM FREE TO IMMEDIATELY RECOGNIZE  
A MARK REQUEST (MARK SYSTEM NOW AVAILABLE)

IMUCADR ← 0

INDICATES TO PROGRAM IMU MODE SWITCHING  
ROUTINES THAT NO JOB IS IN THE DORMANT  
STATE AWAITING THE COMPLETION OF AN  
IMU MODE SWITCH. THE SYSTEM IS PREPARED  
TO PUT A JOB REQUESTING A MODE CHANGE  
INTO A DORMANT STATE UNTIL THE SWITCH  
HAS BEEN COMPLETED. SEE NOTE BELOW

OPTCADR ← 0

INDICATES TO PROGRAM MODE SWITCHING  
ROUTINES THAT NO JOB IS IN THE DORMANT  
STATE AWAITING THE COMPLETION OF AN  
OPTICS MODE SWITCH. THE SYSTEM IS  
PREPARED TO PUT A JOB REQUESTING A MODE  
CHANGE INTO A DORMANT STATE UNTIL THE SWITCH  
HAS BEEN COMPLETED. SEE NOTE BELOW

RADCADR ← 0

INDICATES TO PROGRAM MODE SWITCHING  
ROUTINES THAT NO JOB IS IN THE DORMANT  
STATE AWAITING THE COMPLETION OF A  
RADAR MODE SWITCH. THE SYSTEM IS  
PREPARED TO PUT A JOB REQUESTING A  
MODE CHANGE INTO A DORMANT STATE  
UNTIL THE SWITCH HAS BEEN COMPLETED.  
SEE NOTE BELOW

ATTCADR ← 0

INDICATES THAT PROGRAM KALCMANU  
IS AVAILABLE (FREE). SEE NOTE BELOW

NEXT SHEET

NOTE:

THESE FOUR "CADR" REGISTERS ARE  
USED TO STORE RETURN ADDRESSES  
OF JOBS USING THE VARIOUS MODE  
CHANGE AND MANEUVER ROUTINES

MIT INSTRUMENTATION LAB CAMBRIDGE MASS		APR 19 1964 RESEARCH AND DEVELOPMENT DIV.	
DRAWN <i>[Signature]</i>	2DEC64	FRESH START AND RESTART	
PROGRAM <i>[Signature]</i>	253018		
ANALYST		COLOSSUS	
ISSUED <i>[Signature]</i>	1-25-67	II-D	
APPROVED <i>[Signature]</i>	27-11-67	FC-2020	
		SHEET 11 OF 50	

FRDM  
PRECEDING SHEET

LGYRO ← 0

INDICATES THE GYROS ARE  
AVAILABLE TO BE PULSED

CLEAR  
FLAGWRD4

URNS OFF INTERFACE DISPLAYS

NOUT ← DEC11

INDICATES TO PROGRAM T4RPT  
THAT THERE ARE ELEVEN CHANGES  
IN THE DSPTAB REGISTER TABLE  
(ELEVEN RELAY CODES TO BE  
TRANSMITTED VIA CHANNEL 10, I.E. OUT 0)

CLEAR  
BITS 15 AND  
13-1 OF  
EXTVBACT

CLEAR EXTENDED VERB AND MARK  
ACTIVITY. LEAVE EXTENDED VERB  
RESTART FLAG (BIT 14) INTACT.  
IT INHIBITS OTHER EXTENDED VERB  
ACTIVITY AFTER AN R62 OR R63 RESTART

SELFRET ← "SELFCHK"

CAUSES CONTROL TO BE TRANSFERRED  
FROM ROUTINE ADVAN (DUMMY JOB+6)  
IN THE EXECUTIVE TO ROUTINE SELFCHK  
IN PROGRAM SELF CHECK. THIS IS THE  
IDLING ACTIVITY

DSPCOUNT ← DCT-23

A NEGATIVE VALUE PREVENTS THE  
ACCEPTANCE OF NUMERICAL CHARACTERS  
BY PROGRAM PINBALL

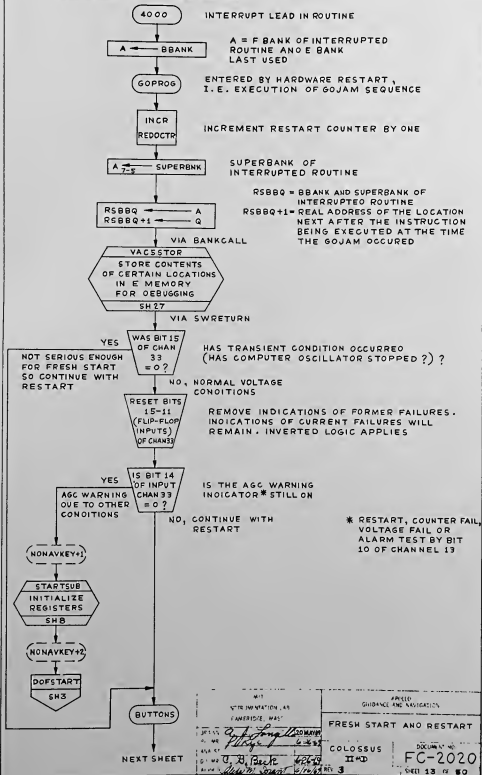
RETURN VIA  
Q

END OF SUBROUTINE STARTSUB

WET	REVISED
INSTRUMENTATION DEPT	COMPTON AND ASSOCIATES
"AMBRIDGE WAY"	
FRESH START AND RESTART	
DRAWN <i>J. J. Smith</i>	3 DEC 64
CHECKED <i>V. P. Rye</i>	20 JAN 65
ANALYST	COLOSSUS
DESIGNED <i>C. B. Beck</i>	II-D
APPROVED <i>John A. Moore</i>	FC-2020
	8
	12 20 50

CONTROL COMES HERE  
AS THE RESULT OF A GOJAM  
FROM THE INTERRUPTED ROUTINE

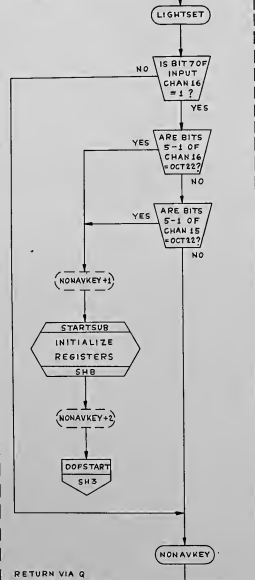
RESTART



MIT "REINVENTION AS CANDIDATE WAS"	FIELD GUIDANCE AND NAVIGATION
APPROVED <i>[Signature]</i> DATE <i>[Date]</i>	FRESH START AND RESTART
COLOSSUS II-AD	DOCUMENT NO. FC-2020
REV. 3	DEED 13 OF 80

FROM  
PRECEDING SHEET

SUBROUTINE LIGHTSET



SIMULTANEOUS DEPRESSION OF THE MARK REJECT AND THE ERROR RESET KEYS WILL CAUSE A FRESH START. THIS IS TO ALLOW THE ASTRONAUT TO TERMINATE A RESTART LOOP

IS THE OPTICS MARK REJECT SIGNAL PRESENT ?

HAS THE NAVIGATION PANEL DSKY ERROR LIGHT RESET BUTTON BEEN DEPRESSED ?

HAS THE MAIN PANEL DSKY ERROR LIGHT RESET BUTTON BEEN DEPRESSED ?

RETURN VIA Q

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPROD GUIDANCE AND NAVIGATION
PLANNED DESIGNED ANALYST CHECKED APPROVED	FRESH START AND RESTART COLOSSUS II-D DOCUMENT NO. FC-2020 REV 3 SHEET 14 OF 50

FROM  
PRECEDING SHEET

IS THE ADDRESS LAST CHECKED BY ROUTINE  
ERASCHK (IN PROGRAM SELF CHECK)  
SITUATED IN E MEMORY (LESS THAN  
OCTAL 2000) ?

NO  
IS  
ERESTORE  
< OCT2000  
?

DOUBT  
E MEMORY  
DO FRESH  
START

NONAVKEYH

STARTSUB  
INITIALIZE  
REGISTERS  
SHB

NONAVKEYH2

DOFSTART  
SH3

NO  
IS  
ERESTORE  
≠ 0  
?

WAS CHECKING E MEMORY IN ROUTINE  
ERASCHK INTERRUPTED BY A RESTART?

NOTE:  
REGISTER ERESTORE IS SET TO +0  
BY ROUTINE ERASCHK AFTER THE  
CHECKING OF E MEMORY IS COM-  
PLETED

NO  
INTERRUPT,  
CONTINUE  
WITH RESTART

ELRSKIP-1  
SH16

NO  
IS  
ERESTORE  
= SKEEP?  
?

IS E MEMORY SATISFACTORY ?

NOTE:  
THE E MEMORY ADDRESS TO BE CHECKED  
WAS STORED IN BOTH REGISTERS BY  
ROUTINE ERASCHK PRIOR TO THE  
CHECKING

ERESTORE  
≠ SKEEP?  
DOUBT  
E MEMORY, DO  
FRESH START

ERESTORE = SKEEP?

NONAVKEYH1

STARTSUB  
INITIALIZE  
REGISTERS  
SHB

NONAVKEYH2

DOFSTART  
SH3

NEXTSHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIC SCHEDULE AND SPECIFICATIONS
<i>[Handwritten Signature]</i> ANALYST DATE <i>[Handwritten]</i> BY <i>[Handwritten]</i>	FRESH START AND RESTART
COLOSSUS II-D REV 3	DOCUMENT NO. FC-2020 SHEET 15 OF 50

FROM  
PRECEDING SHEET

PRIOR TO CHECKING E MEMDRY LOCATIONS E AND E+1, THE ORIGINAL CONTENTS OF E AND E+1 WERE TEMPORARILY STORED INTO REGISTERS SKEEP5 AND SKEEP6, RESPECTIVELY. ALSO, ADDRESS E WAS STORED INTO REGISTERS SKEEP7 AND ERESTORE

RESTORE ORIGINAL CONTENTS. SINCE ROUTINE ERASCHK WAS INTERRUPTED BY A RESTART, THE LAST TWO CONSECUTIVE E MEMDRY LOCATIONS DID NOT HAVE THEIR ORIGINAL CONTENTS RESTORED. THEREFORE, THE ORIGINAL CONTENTS ARE RESTORED TO LOCATIONS E AND E+1 WHERE E IS AN E MEMORY LOCATION WHOSE ADDRESS IS DEFINED AS:

OCT 1461  $\leq$  E  $\leq$  OCT 1776  
IN E BANK 0

OR OCT 1400  $\leq$  E  $\leq$  OCT 1776  
IN E BANK 1, 3, 4, 5, 6 OR 7

OR OCT 1400  $\leq$  E  $\leq$  OCT 1772  
IN E BANK 2

INDICATES THAT THE CHECKING OF ERASCHK WAS NOT INTERRUPTED BY A RESTART. A ZERO ENABLES THE NEXT RESTART TO CONTINUE IN GOPROG

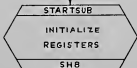
E ← SKEEP5  
E+1 ← SKEEP6

NOTE:  
E AND E+1 SIGNIFY THE ADDRESSES OF THE LAST TWO CONSECUTIVE E MEMORY LOCATIONS WHICH WERE CHECKED

ERESTORE ← +0

ENTER HERE FROM PRECEDING SHEET

ELRSKIP-1



REGISTERS COMMON TO BOTH FRESH START AND RESTART

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS		APPLIC GORDON AND KERRY STUBS	
DRAWN <i>A. J. ...</i>		FRESH START AND RESTART	
CHKD <i>[Signature]</i>		COLOSSUS	
ANK ST		II-D	
DATE <i>1-23-59</i>		FC-2020	
APPROV <i>[Signature]</i>		MAY 16 1950	

FROM  
PRECEDING SHEET

ELRSKIP

TSLOC IS SET TO APPROPRIATE RESTART ADDRESS, DEPENDING UPON WHICH DAP (DIGITAL AUTO PILOT) IS OPERATING. NORMALLY (NO RESTART) TSLOC IS SET BY PROGRAMS USING THE DAP OR BY THE DAP ROUTINES

SEE TSIDLER TABLE  
SPECIFIED FOR  
NEXT TSRUPT  
SEE FLOW CHART TABLE

TIMES WAS SET IN STARTSUB TO INITIATE EXECUTION OF TSTRUPT ROUTINE IN 40 MS

TSIDLER TABLE

TSTRUPT ROUTINE (DETERMINED BY BITS 15 AND 14 OF FLAGWRD6)

BITS	BIT	
15	14	
0	0	2CADR TSIDLOC (ON THIS SHEET—EXECUTED WITHIN 40 MS AND EVERY 163.84 SECONDS THEREAFTER IF NO OTHER ROUTINE IS USING TSTRUPT)
0	1	2CADR REDORGS (REESTABLISH RGS DAP ROUTINE)
1	0	2CADR REDOTVC (REESTABLISH TVG DAP ROUTINE)
1	1	2CADR REDOSAT (REESTABLISH SATURN CONTROL FUNCTION ROUTINE)

NEXT SHEET

FLOW CHART TABLE

ROUTINE	FLOW CHART
REDORGS	FC - 2380
REDOTVC	FC - 2430
REDOSAT	FC - 2540
TSIDLOC	THIS SHEET

FROM  
INTERRUPTED  
ROUTINE  
VIA TSTRUPT

TSIDLOC

IDLING ROUTINE  
(DAP ROUTINES INACTIVE)

A ← L

BANK OF  
INTERRUPTED  
ROUTINE

RETURN VIA  
RESUME

TO  
INTERRUPTED  
ROUTINE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ARL ORDINANCE AND RESEARCH
31 APR 68 2058P R. H. G. 1-3-68 300 WAC 8000'S	FRESH START AND RESTART COLOSSUS II-2D RE 3
	DOCUMENT NO. FC-2020 SHEET 17 OF 50

FROM  
PRECEDING SHEET

CLEAR  
BIT 14  
OF RASFLAG

INTEGRATION NOT IN PROGRESS  
INTFLAG

OPTMODES  $\leftarrow$  0  
10, 3-1

OPTMODES  $\leftarrow$  1  
7

INITIALIZE OPTICS STATUS BITS.  
REMOVE ANY OPTICS FAILURE DETECTED  
(BIT 7). LEAVE INTACT COARSE OPTICS,  
ZERO OPTICS AND GMC CONTROL  
(BITS 9, 5, 4)

IMODES33  $\leftarrow$  0  
15-7, 5-1

LEAVE DAPENABLE  
SWITCH INTACT (BIT 6)

IMODES33  $\leftarrow$  7  
13-11

NO ACCELEROMETER FAIL.  
DOWN TELEMETRY AND UPLINK  
RATES ARE NORMAL

(DSPTAB+11D)  $\leftarrow$  0  
8

NO OPTICS COU MALFUNCTION.  
PROGRAM ALARM, GIMBAL LOCK AND  
NO-ATTITUDE LAMPS REMAIN INTACT  
(BITS 9, 6, 4)

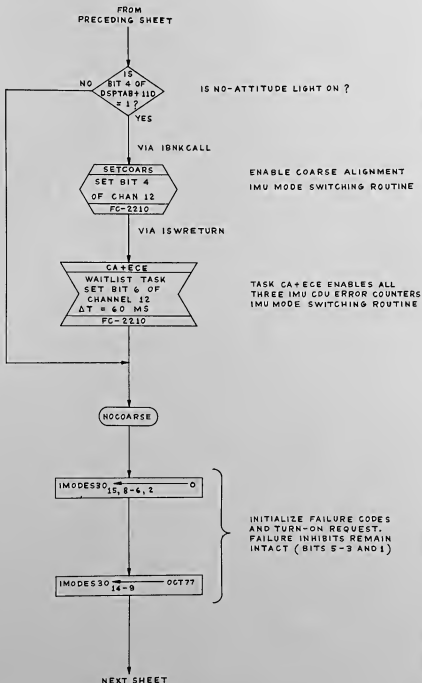
(DSPTAB+11D)  $\leftarrow$  1  
15

THIS IS A SIGN TO PROGRAM T4RPT  
TO TRANSMIT THE CURRENT CONTENTS  
(JUST SET) OF DSPTAB+11D TO  
CHANNEL 10 TO FORCE AGREEMENT  
BETWEEN DSPTAB+11D AND THE  
DSKY RELAY SETTINGS. CHANNEL 10  
WAS CLEARED BY RESTART HARDWARE  
ACTION

NEXT SHEET

NO. 1	FILE NO.
EXPERIMENTATION LAB	DESIGN AND VAL. DATA
AMBRIDGE WAYS	
DATE	FRESH START AND RESTART
BY <i>J. A. Moore</i>	COLOSSUS
ANALYST <i>J. A. Moore</i>	II * D
APPROVED <i>J. A. Moore</i>	DOCUMENT NO. FC-2020
A. D. <i>J. A. Moore</i>	REV. 18 * 80



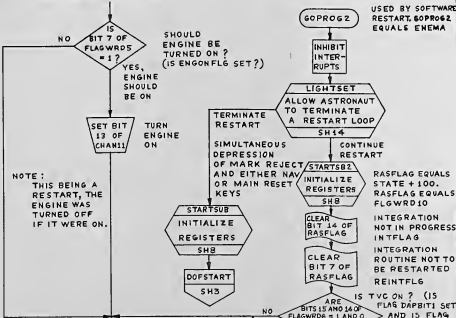


MIT TELECOMMUNICATIONS LAB CAMBRIDGE, MASS.	REPORT NO. COLOSSUS 20, NAVIGATION
DRAWN: <i>[Signature]</i> 5 DEC 67 PROGRAM: <i>[Signature]</i> ANALYST: <i>[Signature]</i> DEX NR: <i>[Signature]</i> APPROVED: <i>[Signature]</i>	FRESH START AND RESTART COLOSSUS II-D DOCUMENT NO. <b>FC-2020</b> REV 3 19 0 30

FROM PRECEDING SHEET

FROM SHEET 38

USED BY SOFTWARE  
RESTART. &OPROG2  
EQUALS ENEMA



NOTE:  
THIS BEING A  
RESTART, THE  
ENGINE WAS  
TURNED OFF  
IF IT WERE ON.

CHECK FOR  
PHASE TABLE  
AGREEMENT.  
INDEX FOR  
SIX GROUPS

GOPROG3

A ← S

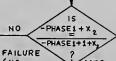
A ← (MPAC+5)  
DECREMENT A

PCLOOP

MPAC+5 ← A

X<sub>2</sub> IS AN INDEX  
X<sub>2</sub> = CONTENTS  
OF A

A ← TWICE A



FAILURE  
(NO  
AGREEMENT)

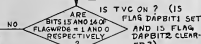
PTBAD

ALARM  
SETS A FAILURE  
REGISTER WITH  
CODE OCT1107  
FC-2140

DOFSTART  
SH3

SET PROGRAM ALARM LIGHT  
AND ALARM CODE TO INDICATE  
PHASE TABLE FAILURE

NEXT SHEET



INITIALIZE TVC  
PITCH AND YAW  
DAP VARIABLES  
FC-2430

PHASE TABLE REGISTERS

- PHASE 1 EQUALS - PHASE1 +1
- PHASE 2 " " +2
- PHASE 3 " " +3
- PHASE 4 " " +4
- PHASE 5 " " +5
- PHASE 6 " " +6
- PHASE 7 " " +7
- PHASE 8 " " +8D
- PHASE 9 " " +9D
- PHASE 10 " " +10D
- PHASE 11 " " +11D

IS EACH PHASE IN THE PHASE  
TABLE IN AGREEMENT?

DOES THE PHASE (IN COMPLEMENT  
FORM) IN THE 11TH (-PHASE 6), 9TH  
(-PHASE 5), ... 1ST (-PHASE 1) LINES  
OF THE PHASE TABLE AGREE WITH  
THE PHASE (IN TRUE FORM) IN THE  
12TH (PHASE 6), 10TH (PHASE 5), ...  
2ND (PHASE 1) LINES, RESPECTIVELY,  
OF THE PHASE TABLE?

MPAC+5	A	IS
5	10	-PHASE 6 = PHASE 6?
4	8	-PHASE 5 = PHASE 5?
3	6	-PHASE 4 = PHASE 4?
2	4	-PHASE 3 = PHASE 3?
1	2	-PHASE 2 = PHASE 2?
0	0	-PHASE 1 = PHASE 1?

FRESH START AND RESTART

APPROVED BY: *[Signature]* 11DEC68  
 AUTHORITY: *[Signature]* 21DEC68  
 BY: *[Signature]* 1-23-69  
 FOR: *[Signature]* 23/11/69

COLOSSUS II-D FC-2020  
 20 50

FROM  
PRECEDING SHEET

CLEAR  
MPAC+4

RESET PHASE ACTIVITY FLAG  
TO INDICATE INACTIVE STATUS

MMDSPY  
DISPLAY MAJOR  
MODE VIA  
DSPMMJOB  
FC-2030

IN PHASE TABLE MAINTENANCE  
PROGRAM

INHIBIT  
INTER-  
RUPTS

ARE  
BITS 15 AND  
14 OF FLAGWRD6  
= 0 AND 1 RESPEC-  
TIVELY?  
YES  
NO

IS RCS DAP  
IN PROGRESS?  
(IS FLAG DAPBIT1 CLEARED  
AND IS FLAG DAPBIT2 SET?)

STOPRATE  
ZERO INPUTS TO  
AUTOPILOT  
FC-2350

STOP ALL AUTOMATIC  
MANEUVERING  
IN KALCMANU STEERING  
PROGRAM

(NXTRST -1)

A ← S

INITIALIZE INDEX  
FOR SIX GROUPS

NEXT SHEET

REF	ADVIC
INSTRUMENTATION LAB	GUIDANCE AND NAVIGATION
CAMBRIDGE, MASS.	
FRESH START AND RESTART	
DRAMAN <i>C. J. Smith</i>	11 DEC 68
PPCMM <i>R. J. ...</i>	22 MAR 69
ANALYST	
DATE <i>8/23/68</i>	
APPROV <i>W. A. ...</i>	
	REV 3
GOLOSSUS	DOCUMENT NO.
II+D	FC-2020
	SHEET 24 OF 50

FROM PRECEDING SHEET

NXTRST

SEARCH FOR ACTIVE GROUP

MPAC+5 ← A  
A ← 2-A

X3 IS A NOTATION FOR THE INDEX AND IS EQUAL TO CONTENTS OF A

A ← (PHASE1+X3)

GROUP 6 5 4 3 2 1  
X3 10 8 6 4 2 0  
MPAC+5 5 4 3 2 1 0

IS A > 0 ?  
NO YES

IS NEXT GROUP ACTIVE? GROUP 6 IS TESTED FIRST. IN SUCCEEDING LOOPS GROUP 5, THEN 4, 3, 2 AND LAST 1 ARE TESTED FOR ACTIVE STATUS

PACTIVE

MPAC ← (PHASE1+X3)

TEMPORARILY STORE PHASE NUMBER OF GROUP JUST TESTED AND FOUND TO BE ACTIVE

INCREMENT MPAC+6

SET PHASE ACTIVITY FLAG BY INCREMENTING MPAC+6

VIA SWCALL

RESTARTS  
SET UP TASK OR JOB INDICATED BY PHASE SETTING OF CURRENT GROUP  
SH43

ENTER ROUTINE RESTARTS WITH THE NUMBER OF THE ACTIVE GROUP MINUS ONE IN MPAC+5, ITS PHASE NUMBER IN MPAC AND THE PHASE ACTIVITY FLAG MPAC+6 = 1

VIA SWRETURN

PINACT

IS MPAC+5 = 0 ?  
NO YES

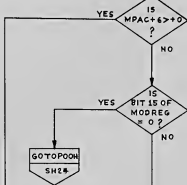
HAVE ALL GROUPS BEEN TESTED FOR ACTIVE STATUS?

A ← (MPAC+5)  
DECREMENT A

NEXT SHEET

13 DEC 64 13 JAN 65 13 FEB 65 13 MAR 65 13 APR 65 13 MAY 65 13 JUN 65 13 JUL 65 13 AUG 65 13 SEP 65 13 OCT 65 13 NOV 65 13 DEC 65	13 DEC 64 13 JAN 65 13 FEB 65 13 MAR 65 13 APR 65 13 MAY 65 13 JUN 65 13 JUL 65 13 AUG 65 13 SEP 65 13 OCT 65 13 NOV 65 13 DEC 65	FRESH START AND RESTART COLOSSUS II-D FC-2020 22 OF 50
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FROM  
PRECEDING SHEET



ARE ANY  
GROUPS ACTIVE ?

WAS A MAJOR MOOE  
IN PROGRESS ?

MOOREG SET TO -0 BY FRESH START  
AND GOJAM OCCURRED BEFORE A  
REQUEST FOR A MAJOR MOOE

ENDRSTRY

END OF RESTART  
(GOPROG AND GOPROG2)

VIA  
POSTJUMP

DUMMYJOB+2

IN THE  
EXECUTIVE  
PROGRAM  
FC-2050

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPROX GUIDANCE AND NAVIGATION
FRESH START AND RESTART	
DRAWN <i>G. J. ...</i>	COLOSSUS
PREPARED <i>G. J. ...</i>	II-D
DATE <i>1/23/57</i>	DOCUMENT NO. FC-2020
APPROVED <i>J. A. ...</i>	SHEET 23 OF 60

FROM  
71  
LOCATIONS

GOTOPOOH

FUNCTION:  
FLASH V37 ON DSKY  
REQUESTING ASTRONAUT  
TO SELECT NEW MAJOR  
MODE

GROUP4.1  
SET UP RESTARTS  
TO RETURN TO  
THE LAST  
DISPLAY

VIA POSTJUMP

GOPOOFIX

INITSV8  
SET DEADBAND,  
CLEAR 15 FLAGS AND  
ZERO INPUTS TO  
AUTOPILOT  
SH26

SUBROUTINE ON FC-2130

CLEARMRK+2

IN INTERFACE  
DISPLAY ROUTINE

INHIBIT  
INTER-  
RUPTS

CLEAR  
BIT 1 OF  
FLAGWRD4

NO SPECIAL MARK  
INFORMATION  
XD5PFLAG

RELEASE  
INTERRUPT  
INHIBIT

VIA BANKCALL

GOFFLASH  
FLASH V37 ON DSKY  
WAIT FOR RESPONSE  
FROM OPERATOR  
FC-2130

IN DISPLAY  
INTERFACE ROUTINE

RECYCLE

W1  
100 INDEPENDENT LAB  
"AMAR" DCE MASS  
A. J. [Signature] 13MAY 68  
C. B. [Signature] 13MAY 68  
REV 3

ARGO  
GUIDANCE AND NAVIGATION

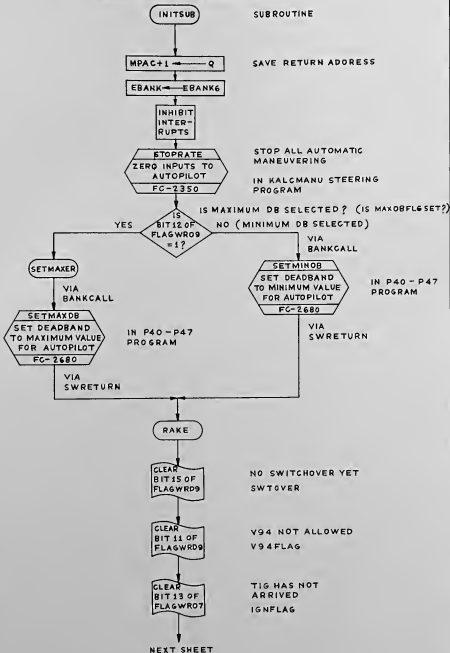
FRESH START AND RESTART

COLOSSUS  
II-D

FC-2020

REV 24 C 30

ENTERED FROM ROUTINE GOPOOFIX  
ON SHEET 24 AND FROM PROGRAM V37  
(ROUTINE DUMMYAD) ON SHEET 35.



FRESH START AND RESTART

COLOSSUS II-D FC-2020

3

25 of 59

1706648

1-23-62

0.4

FROM  
PRECEDING SHEET

CLEAR  
BIT 12 OF  
FLAGWRD7

ASTRONAUT HAS NOT  
APPROVED IGNITION  
ASTNFLAG

CLEAR  
BIT 14 OF  
FLAGWR07

CLOCKTASK  
INOPERATIVE  
TIMRFLAG

CLEAR  
BIT 13 OF  
FLAGWRD6

DO ULAGEOFF ONLY  
STRULLEW FLAG

CLEAR  
BIT 12 OF  
FLAGWRD5

NORMAL MARKING  
FOR P23  
V59FLAG

CLEAR  
BIT 7 OF  
FLAGWRD5

ENGINE TURNED  
OFF  
ENGNONFLG

CLEAR  
BIT 6 OF  
FLAGWRD5

MANEUVER SPECIFIED  
BY ONE AXIS  
3AXISFLG

CLEAR  
BIT 14 OF  
FLAGWRD3

NOT IN  
GIMBAL LOCK  
GLOKFAIL FLAG

CLEAR  
BIT 9 OF  
FLAGWRD3

ALLOW BACKWARDS  
INTEGRATION  
POOFFLAG

CLEAR  
BIT 12 OF  
FLAGWRD2

1ST PASS THROUGH P21, CALCULATE BASE  
VECTOR, STEERING OMITTED  
P21FLAG

CLEAR  
BIT 11 OF  
FLAGWRD2

NO STEERING  
STEERSW

CLEAR  
BIT 6 OF  
FLAGWRD1

ENABLE R41 (ENGFAL)  
IDLEFAIL

RELEASE  
INTER-  
RUPT  
INHIBIT

VIA SUBROUTINE UPFLAG  
(SERVICE ROUTINE)  
FLAG IMPULSW

SET  
BIT 9 OF  
FLAGWRD2

NO OPTICS IN PROGRESS.  
CAUSES PROGRAM T4RUPT TO  
BYPASS THE OPTICS CDU  
DRIVING FUNCTION

OPTIND ← -1

RETURN VIA  
Q

END OF SUBROUTINE INITSUB

A-101 GUIDANCE AND NAVIGATION	
FRESH START AND RESTART	
COLOSSUS II-D	FC-2020
3	NET 26 0 50

*P. R. Boyd*  
*P. N. Beck*  
*Property Signature*



SUBROUTINE VACSSTOR  
 ENTERED FROM 4 LOCATIONS  
 (3 IN PROGRAM ALARM AND ABORT  
 AND 1 ON SHEET 13 OF THIS PROGRAM)

ENTERED VIA BANKCALL

CALLING  
SEQUENCE:

$\mathcal{L}+0$  TO BANKCALL  
 $\mathcal{L}+1$  CADR VACSSTOR  
 $\mathcal{L}+2$  RETURN HERE

VACSSTOR

SUBROUTINE VACSSTOR STORES  
 CONTENTS OF CERTAIN LOCATIONS  
 IN E MEMORY FOR DEBUGGING

ITEMP1 ← 0  
 ITEMP2 ← 0

INITIALIZE INDEXES

X5 AND X6 ARE NOTATIONS FOR  
 INDEXES AND ARE EQUAL TO THE  
 CONTENTS OF ITEMP1 AND  
 ITEMP2, RESPECTIVELY

BEGIN NEXT PASS

V5LOOP1

ROUTINE V5LOOP1 STORES THE  
 2CADR, PRIORITY AND VAC AREA  
 ADDRESS OF EACH JOB (PRESENTLY  
 SCHEDULED) INTO VACS+0 THROUGH  
 VACS+20

VACS+X6 ← (LOC+X5)  
 VACS+1+X6 ← (LOC+1+X5)

PASS OPERATION

1ST	{	VACS ←	LOC
		VACS+1 ←	(LOC+1)
		VACS+2 ←	PRIORITY
2ND	{	VACS+3 ←	(LOC+12)
		VACS+4 ←	(LOC+13)
		VACS+5 ←	(PRIORITY+12)
3RD	{	VACS+6 ←	(LOC+24)
		VACS+7 ←	(LOC+25)
		VACS+8 ←	(PRIORITY+24)
4TH	{	VACS+9 ←	(LOC+36)
		VACS+10 ←	(LOC+37)
		VACS+11 ←	(PRIORITY+36)
5TH	{	VACS+12 ←	(LOC+48)
		VACS+13 ←	(LOC+49)
		VACS+14 ←	(PRIORITY+48)
6TH	{	VACS+15 ←	(LOC+60)
		VACS+16 ←	(LOC+61)
		VACS+17 ←	(PRIORITY+60)
7TH (LAST)	{	VACS+18 ←	(LOC+72)
		VACS+19 ←	(LOC+73)
		VACS+20 ←	(PRIORITY+72)

VACS+2+X6 ← (PRIORITY+X5)

HAVE ALL PASSES  
BEEN COMPLETED?

NO  
 IS  
 ITEMP2  
 = 18  
 ?  
 YES

INCREMENT  
 ITEMP1  
 BY 12

SET  
 INDEXES  
 FOR  
 NEXT  
 PASS

INCREMENT  
 ITEMP2  
 BY 3

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ARFLO GUIDANCE AND NAVIGATION
DESIGNER: <i>C. H. Beck</i> ANALYST: <i>C. H. Beck</i> APPROVER: <i>C. H. Beck</i>	FRESH START AND RESTART COLLOSSUS II-D DOCUMENT NO. FC-2020 SHEET 27 OF 50

FROM  
PRECEDING SHEET

VSOUT1

ROUTINE VSOUT1 STORES  
THE 2CADR OF RESTART  
ADDRESS OF EACH RESTART  
GROUP INTO VAC5+210  
THROUGH VAC5+320

EBANK ← EBANK3

PHSNAME AND PHSBB REGISTERS  
ARE IN E BANK 3

GENTRAN

COPY AND STORE  
2CADR OF RESTART  
ADDRESS PER  
,NOTE A

FC-2070

NOTE A :

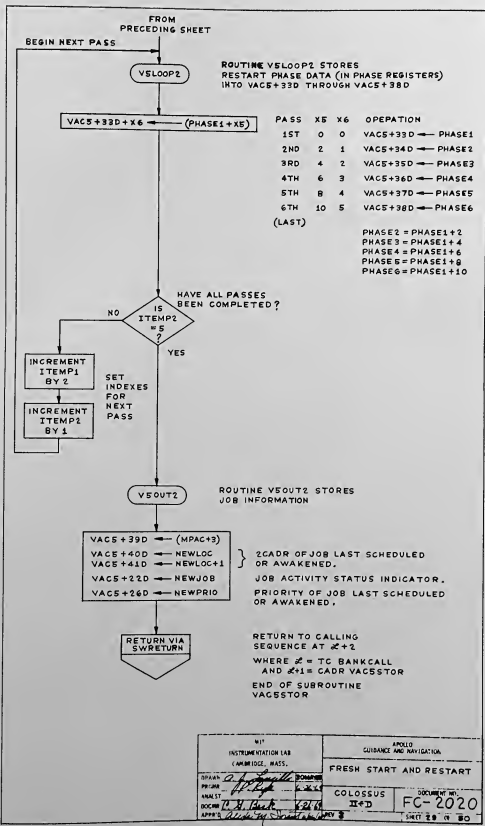
VAC5 + 320	←	PHSBB6
VAC5 + 310	←	PHSNAME 6
VAC5 + 300	←	PHSBB5
VAC5 + 290	←	PHSNAME5
VAC5 + 280	←	PHSBB 4
VAC5 + 270	←	PHSNAME4
VAC5 + 260	←	PHSBB3
VAC5 + 250	←	PHSNAME3
VAC5 + 240	←	PHSBB2
VAC5 + 230	←	PHSNAME 2
VAC5 + 220	←	PHSBB1
VAC5 + 210	←	PHSNAME1

ITEMP1 ← 0  
ITEMP2 ← 0

INITIALIZE INDEXES  
FOR ROUTINE VSLOOP2

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC. COVERAGE AND NAVIGATION	
DRAWN: <i>A. J. ...</i> BOWMAN		FRESH START AND RESTART	
PROGRAM: <i>...</i> 6-26-65		COLOSSUS II-D	
ANALYST: <i>...</i>		DOCUMENT NO. FC-2020	
DESIGN: <i>...</i> 5-26-65		SHEET 28 OF 80	
APPROVED: <i>...</i>		REV 3	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARPOLO GUIDANCE AND NAVIGATION	
PROJECT: <i>A. J. ...</i>		FRESH START AND RESTART	
ANALYST: <i>H. ...</i>	DATE: <i>6-21-68</i>	COLOSSUS II+D	DOCUMENT NO. FC-2020
APPROVED: <i>H. ...</i>	DATE: <i>6-21-68</i>	PAGE 2 OF 20	

CONTROL COMES HERE  
FROM MMCHANG OF THE  
PINBALL PROGRAM VIA POST-  
JUMP AS THE RESULT OF  
VERB 37

CHANGE MAJOR MODE

ACCUMULATOR CONTAINS KEYED-IN  
MAJOR MODE WHICH WILL REPLACE  
THE CURRENT MODE

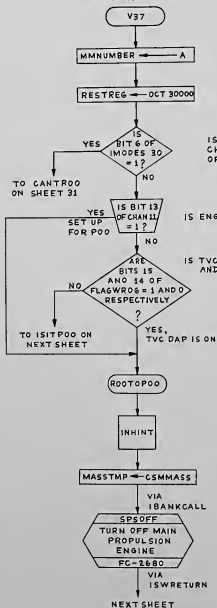
STORE MAJOR MODE

SUPER BANK AND PRIORITY FOR  
DISPLAY INTERFACE ROUTINES.  
SUPER BANK 15 0 IN BIT-POSITIONS 7-5  
AND PRIORITY IS 30 IN BIT-POSITIONS  
14-10

IS IMU BEING INITIALIZED?  
CHECK TO PREVENT WIPE OUT  
OF TASK BY RESTART LOGIC

IS ENGINE ON ?

IS TVC DAP ON? (IS FLAG DAPBIT1 SET  
AND IS FLAG DAPBIT2 CLEARED?)

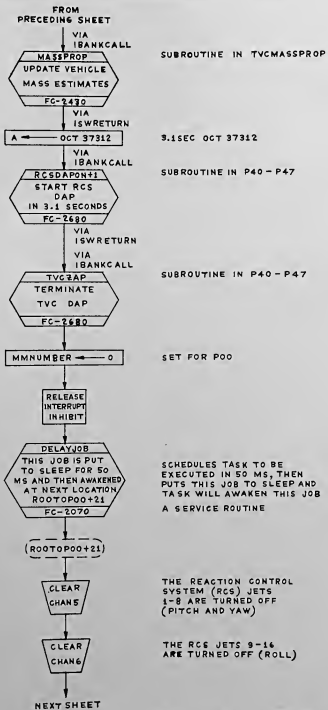


CSM MASS STORED TEMPORARILY (COPY  
CYCLE) FOR SUBROUTINE SPSOFF  
FOR RESTART PROTECTION

SUBROUTINE IN P40-P47

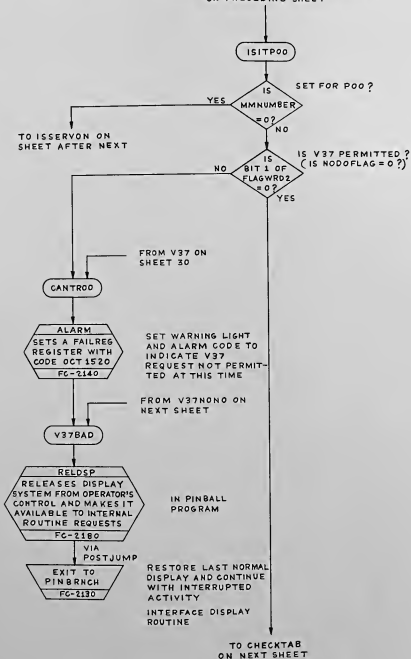
NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		FRESH START AND RESTART	
DESIGN <i>A. J. ...</i>	CHECKED <i>A. J. ...</i>	COLOSSUS II-D	DOCUMENT # FC-2020
ANALYST <i>C. H. ...</i>	DATE 12-2-69		REV. 30 TO 50
APPROVED <i>John A. Morse</i>	3		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN: <i>[Signature]</i> CHECKED: <i>[Signature]</i> DOC NO: <i>[Signature]</i> APPROV: <i>[Signature]</i>	<b>FRESH START AND RESTART</b>  COLOSSUS II-D DOCUMENT NO. FC-2020 SHEET 39 OF 80

FROM V37 ON SHEET 26 OR ROOTPOO  
ON PRECEDING SHEET



1010	10
INSTRUMENTATION LAB CAMBRIDGE, MASS.	DISPATCH AND NAVIGATION
DESIGNER <i>P. J. [unclear]</i>	FRESH START AND RESTART
DRAWN <i>P. J. [unclear]</i>	COLOSSUS II-D
CHKD <i>C. J. [unclear]</i>	DOCUMENT NO. FC-2020
BY ENG <i>C. J. [unclear]</i>	SHEET 32 OF 50
APPROV <i>John A. [unclear]</i>	3

FROM ISITPOO ON  
PRECEDING SHEET

CHECKTAB

A ← DEC 28

NUMBER OF MAJOR MODES

AGAINMM

DETERMINE LOCATION IN PREMM1 TABLE  
WHICH CONTAINS THE KEYED-IN  
MAJOR MODE IN BIT-POSITIONS 7-1

MPAC+1 ← A

CONTENTS OF MPAC+1 WILL BE  
USED AS AN INDEX AND IS  
DESIGNATED AS X4

IS  
(PREMM1+X4)  
= MMNUMBER  
7-1 ?

IS THE KEYED-IN MAJOR MODE  
SAME AS MAJOR MODE IN THE  
ENTRY OF THE PREMM1 TABLE  
INDICATED BY X4 ?

IS  
MMNUMBER  
> (PREMM1+X4)  
7-1 ?

IS THE KEYED-IN MAJOR MODE LARGER  
THAN THE SAME MAJOR MODE OF  
THE PREMM1 TABLE ?

IS  
MPAC+1  
= 0 ?

HAS THE MAJOR MODE OF EACH  
ENTRY OF THE PREMM1 TABLE  
BEEN COMPARED WITH THE KEYED-IN  
MAJOR MODE ?

CHECK  
NEXT ENTRY

DECREMENT  
A BY 1

V37N0NO

FALTON  
TURN ON  
OPERATOR  
ERROR LIGHT  
FC-2180

UNABLE TO FIND THE  
KEYED-IN MAJOR MODE  
NUMBER IN THE PREMM1 TABLE  
IN PINBALL PROGRAM

TO V37BAD ON  
PRECEDING SHEET

MINDEX ← (MPAC+1)

SAVE INDEX FOR FURTHER USE

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ARCLO GUIDANCE AND NAVIGATION
DRAWN <i>C. B. Rye</i> PROGRAM <i>C. B. Rye</i> ANALYST OPERATOR <i>C. B. Rye</i> APPROVED <i>C. B. Rye</i>	FRESH START AND RESTART COLOSSUS II-ED SOLUTION NO. FC-2020 DATE 33 7 50

FROM  
PRECEDING SHEET AND SHEET 32

ISSERVON

IS  
BIT 6 OF  
FLAGWRD7  
= 1?

YES

IS AVERAGE6 (SERVICER) RUNNING?  
(IS V37FLAG SET?)

INHINT

INHIBIT INTERRUPT PROGRAMS

CLEAR  
BIT 1 OF  
FLAGWRD1

DISCONTINUE THE  
AVERAGE ROUTINE  
(CLEAR AVEGFLAG)

ENDOFJOB

IN EXECUTIVE PROGRAM  
FC-2050

AVERAGE6 ROUTINE WILL TRANSFER  
CONTROL TO CANV37 WHEN IT TERMINATES

CANV37

SELECT DOWNLIST ADDRESS  
CORRESPONDING TO THE MAJOR MODE

TEMPFLSH ← CADR DUMMYAD

TEMPFLSH IS SET SO THAT CONTROL  
WILL RETURN TO ROUTINE R00 IN CASE  
THERE IS A RESTART (PROVIDED A ONE  
IS SET INTO ANY OF THE PHASE REGISTERS)

GROUP 4.1  
SET UP RESTARTS  
TO RETURN TO  
THE LAST DISPLAY

WILL CAUSE RESTARTS TO IMPLEMENT  
ROUTINE INITDSP, THUS RESTARTING A  
JOB INDICATED BY THE CONTENTS OF  
REGISTER TEMPFLSH. THIS IS A SPECIAL  
CASE—NORMALLY RESTARTS ARE SET UP  
TO RETURN TO THE LAST DISPLAY

FROM INITDSP OF INTERFACE  
DISPLAY ROUTINES VIA TEMPFLSH  
WHICH WAS SET ABOVE (IN THIS  
ROUTINE — CANV37)

NEXT SHEET

UNIT	AMPLIFIER
OPERATOR	OPERATOR AND CALL AT
DATE	
TIME	
TEST	
REMARKS	
APPROVED	

FRESH START AND RESTART

COLOSSUS II-D FC-2020

12345

3

25 JAN 65

25 JAN 65

25 JAN 65



FROM  
PRECEDING SHEET

ROO

VIA  
INTPRET

INSTALL  
WAIT FOR  
COMPLETION OF  
INTEGRATION  
FC-2290

DETERMINE IF STALL AREA IS AVAILABLE.  
IF SO, STALL AREA IS GRABBED. IF NOT,  
WAIT (THIS JOB IS PUT TO SLEEP).  
INSTALL IS A ROUTINE IN THE INTEGRATION  
INITIALIZATION PROGRAM

VIA  
EXIT

DUMMYAD

CLEAR  
BIT 10 OF  
CHAN11

CLEAR CAUTION  
RESET SIGNAL

CLEAR  
BIT 9 OF  
CHAN11

AVERAGE - G IS  
NOT RUNNING

CLEAR  
BIT 14 OF  
CHAN12

TERMINATE  
S4B CUTOFF

CLEAR  
BIT 13 OF  
CHAN12

TERMINATE S4B  
INJECTION SEQUENCE

CLEAR  
BIT 11 OF  
CHAN12

ENGAGE OPTICS DIGITAL TO  
ANALOG CONVERTER (DAC)

CLEAR  
BIT 10 OF  
CHAN12

ZERO OPTICS  
TERMINATED

CLEAR  
BIT 8 OF  
CHAN12

TERMINATE TVC (THRUST  
VECTOR CONTROL) ENABLE

CLEAR  
BIT 3 OF  
CHAN12

TERMINATE  
STAR TRACKER

CLEAR  
BIT 2 OF  
CHAN12

ENABLE OPTICS CDU  
ERROR COUNTERS ARE  
CLEARED TO ZERO

CLEAR  
BIT 0 OF  
CHAN13

NOT ASSIGNED

NEXT SHEET

W11 INSTRUMENTATION LAB CAMBRIDGE, MASS	APPLIED ELECTRICAL AND SYSTEMS
BY: <i>A. J. ...</i> DATE: <i>12/15/50</i>	FRESH START AND RESTART
BY: <i>C. H. Beck</i> DATE: <i>12/15/50</i>	COLOSSUS II-D
	DOCUMENT NO. FC-2020 PAGE 35 OF 50

FROM  
PRECEDING SHEET

CLEAR  
BIT 8 OF  
CHAN11

TERMINATE INPUTS TO  
BMAG X, BMAGY AND  
BMAGZ

INITSUB  
SET DEADBAND,  
CLEAR IS FLAGS AND  
ZERO INPUTS TO  
AUTOPILOTS  
SH28

FC-2130

SUBROUTINE CLEARMRK IS IN  
INTERFACE DISPLAY ROUTINE

CLEARMRK

RELEASES EXTENOE VEB  
AND MARK ACTIVITY

CLEAR  
EXTVACT

INHIBIT  
INTER-  
RUPTS

NO SPECIAL MARK  
INFORMATION  
XDSPFLAG

CLEAR  
BIT 1 OF  
FLAGWRD4

RELEASE  
INTERRUPT  
INHIBIT

SUBROUTINE DOWNFLAG

CMC CONTROL  
STIKFLAG

CLEAR  
BIT 14 OF  
FLAGWRD1

SUBROUTINE UPACTOFF

TURN OFF UPLINK  
ACTIVITY LIGHT

CLEAR  
BIT 3 OF  
CHAN11

SUBROUTINE DOWNFLAG

STOP ACCEPTANCE  
OF RANGE DATA

CLEAR  
BIT 9 OF  
FLAGWRD9

VHFRFLAG

SUBROUTINE DOWNFLAG

OPTION TWO FOR MARKRUPT

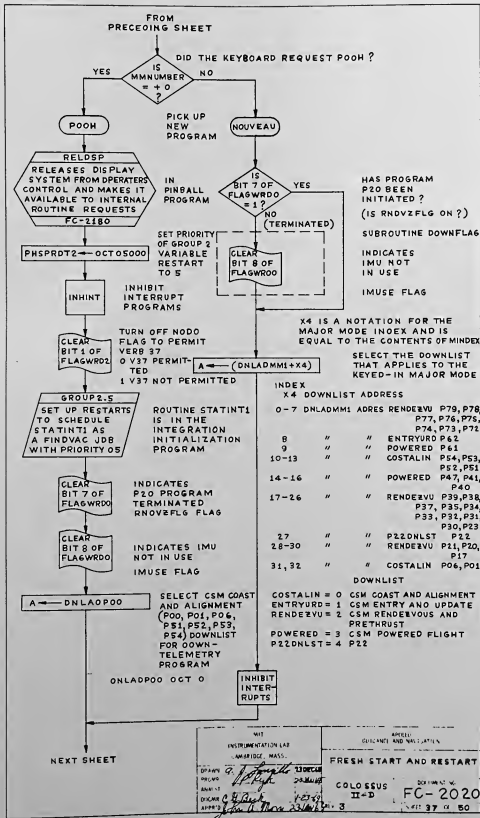
CLEAR  
BIT 14 OF  
FLAGWRD2

R21MARK FLAG

NEXT SHEET

UNIT	ARIEL
INSTRUMENTATION	COLOSSUS AND ASSOCIATION
OPERATION	FRESH START AND RESTART
DATE	24 69
BY	COLOSSUS IIAD
FILE NO.	FC-2020
REV	36 50

*W. J. [Signature]*  
*C. H. Beck*  
*11/24/69*



FROM  
PRECEDING SHEET

SEU00PO0

DNLSTG00 ← A

SET UP APPROPRIATE DOWNLIST ADDRESS.  
CONTAINS 0, 1, 2, 3 OR 4 WHICH WILL  
BE USED AS AN INDEX IN  
DOWN-TELEMETRY PROGRAM TO  
SELECT DOWNLIST ADDRESS

EBANKTEM ← OCT76657

INITIALIZED TO PREVENT THE  
OLD DISPLAY DURING SUBSEQUENT  
RESTARTS (DUE TO BIT 4). ASSURES  
THAT BIT 4 = 1

CLEAR  
BIT 5 OF  
FLAGWRD1

INDICATES TRACKING  
NOT ALLOWED  
TRACKFLG

CLEAR  
BIT 7 OF  
FLAGWRD1

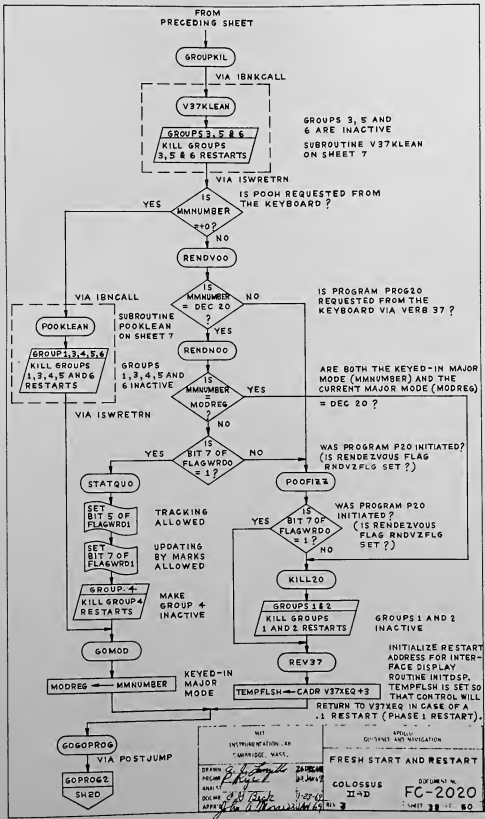
INDICATES UPDATING BY  
MARKS NOT ALLOWED  
UPDATFLG

CLEAR  
BIT 10 OF  
FLAGWRD1

INDICATES NOT  
SIGHTING LEM  
TARGIFLG

NEXT SHEET

MIT REPLICATION LAB CAMBRIDGE, MASS		ANALYTICAL GUIDANCE AND RELATIONS	
DRAWN: <i>[Signature]</i> 23 DEC 68		FRESH START AND RESTART	
PROGRAM: <i>[Signature]</i> 22 JUL 68		COLOSSUS II ED	
ANALYST: <i>[Signature]</i> 123 45		DOCUMENT NO. FC-2020	
DESIGN: <i>[Signature]</i> 23 JUL 68		REV 2	
APPROV: <i>[Signature]</i>		REV 2	



MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

DESIGN: *[Signature]* 24 DEC 68  
PROGRAM: *[Signature]* 24 DEC 68  
ANALYST: *[Signature]*  
DOC NO: *[Signature]*  
APPROVED: *[Signature]* 11-27-69

APPLIC: GUNNET AND NAVIGATION

FRESH START AND RESTART

COLOSSUS IIAD

DOCUMENT NO. FC-2020

SHEET 38 OF 60

(INITDSP+6)

PART OF INTERFACE DISPLAY  
ROUTINES.  
A = CADR V37XEQ

A ← TEMPFLSH-3  
VIA  
BANKJUMP

TEMPFLSH WAS SET TO CADR  
V37XEQ+3 IN ROUTINE REV37 OF  
PROGRAM V37 ON SHEET 39

V37XEQ

PREPARE THE CALLING SEQUENCE (SEE BOTTOM)  
FOR ROUTINE FINDVAC IN LOCATIONS GOLOC-1 TO  
GOLOC+2 AND THE ACCUMULATOR. FINDVAC WILL  
REQUEST THE EXECUTIVE TO INITIATE THE  
EXECUTION OF THE KEYED-IN MAJOR MODE  
ACCORDING TO THE PRIORITY IN THE ACCUMULA-  
TOR

INHIBIT  
INTER-  
RUPTS

INHIBIT INTERRUPT PROGRAMS

(PHSPRT4)<sub>14-10</sub> ← (PREMM1+X4)<sub>15-11</sub>

X4 IS A NOTATION FOR INDEX AND IS EQUAL  
TO THE CONTENTS OF MINDEX.

PRIORITY FOR GROUP 4 RESTART

REGISTER PHSPRT4 IS IN  
VARIABLE PHASE TABLE.

(NEWPRIO)<sub>14-10</sub> ← (PREMM1+X4)<sub>15-11</sub>

PRIORITY OF KEYED-IN MAJOR MODE.

PRIORITY FOR SPVAC  
ENTRY TO THE EXECUTIVE PROGRAM

L ← (PREMM1+X4)<sub>10-8</sub>  
L ← (FCADRMM1+X4)<sub>15-11</sub>

EBANK } BBCON OF KEYED-IN  
FBANK } MAJOR MODE  
FORMED IN L

A ← (FCADRMM1+X4)<sub>10-1</sub>  
A ← A + OCT 02000

GENADR FORMED IN A

VIA SPVAC  
WITH:

A = GENADR } 2CADR }  
L = BBCON } OF KEYED-IN  
NEWPRIO = PRIORITY } MAJOR MODE

NEXT SHEET

U.S. GOVERNMENT PRINTING OFFICE: 1964 O 348-000

24 DEC 1964  
28 JAN 1965  
1-27-65  
11-27-64

FRESH START AND RESTART

COLOSSUS II-D

FC-2020

40 50

FROM  
PRECEDING SHEET

VIA SPVAC  
WITH :

A = GENAOR } 2CADR } OF KEYED-IN  
L = BBCON } MAJOR MODE  
NEWPRIO = PRIORITY }

SEE FCAORMM1 TABLE  
FINDVAC JOB  
PRIORITY IS IN  
THE PREMM1 TABLE

REQUEST THE EXECUTIVE PROGRAM TO  
INITIATE THE EXECUTION OF THE KEYED-IN  
MAJOR MODE ACCORDING TO THE PRIORITY  
IN NEWPRIO. THE 2CADR AND PRIORITY OF  
THE KEYED-IN MAJOR MODE WERE DERIVED  
ABOVE FROM THE FCAORMM1 AND PREMM1  
TABLES AS FOLLOWS :

PREMM1 15-11 = PRIORITY

PREMM1 10-8 = E BANK NUMBER

PREMM1 7-1 = MAJOR MODE NUMBER

FCAORMM1 = FCAOR OF THE MAJOR MODE

PREMM1 TABLE (OCT)	PRIORITY (OCT)	E BANK NO.	MAJOR MODE NO. (DEC)	FCAORMM1 TABLE FCAOR OF
27117	13	4	79	P79
27116	13	4	78	P78
27115	13	4	77	P77
27714	13	7	76	P76
27113	13	4	75	P75
27112	13	4	74	P74
27111	13	4	73	P73
27110	13	4	72	P72
27476	13	6	62	P62
27475	13	6	61	P61
27266	13	5	54	P54
27265	13	5	53	P53
27264	13	5	52	PROG52
27263	13	5	51	P51
27262	13	7	47	P47CSM
27451	13	6	41	P41CSM
27450	13	6	40	P40CSM
27047	13	4	39	P39
27046	13	4	38	P38
27645	13	7	37	P37
27043	13	4	35	P35
27042	13	4	34	P34
27041	13	4	33	P33
27040	13	4	32	P32
27637	13	7	31	P31
27636	13	7	30	P30
27227	13	5	23	P23
27226	13	5	22	PROG22
27025	13	4	21	PROG21
27424	13	6	20	PROG20
27021	13	4	17	P17
27006	13	4	06	P06
41201	13	5	01	6T5CP551

TO  
V37XEQC  
ON NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		APPRO-0 DISK AND NAVIGATION	
DESIGN FROM ANALYST D-CNR APPRO	<i>A. J. Smith</i> <i>A. J. Smith</i> <i>P. H. Beck</i> <i>John A. ...</i>	FRESH START AND RESTART COLOSSUS II+D	REVISED BY FC-2020 MAY 23 1965

FROM  
PRECEDING SHEET

V37XEQC

$A_{7-1} \leftarrow (\text{PREMM1} + X4)_{7-1}$

NEW (KEYED-IN) MAJOR MODE  
NUMBER.

$A_{15-8} = 0$

NEWMODEA  
UPDATE MODREG  
WITH NEW MAJOR  
MODE NUMBER AND  
DISPLAY IT  
FC-2030

IF THERE IS A CHANGE IN THE MAJOR  
MODE, REGISTER MODREG IS UPDATED  
TO CONTAIN THE NEW MAJOR MODE  
NUMBER, AND ROUTINE NOVAC OF THE  
EXECUTIVE PROGRAM IS REQUESTED TO  
INITIATE THE EXECUTION OF ROUTINE  
DSPMMJOB AS A JOB ACCORDING TO  
PRIORITY 30. ROUTINE DSPMMJOB WILL  
CAUSE THE NEW (KEYED-IN) MAJOR MODE  
NUMBER IN MODREG TO BE DISPLAYED  
IN PHASE TABLE MAINTENANCE PROGRAM

RELDSP  
RELEASES DISPLAY  
SYSTEM FROM OPERATOR'S  
CONTROL AND MAKES IT  
AVAILABLE TO INTERNAL  
ROUTINE REQUESTS  
FC-2100

IN PINBALL PROGRAM

ENDOFJOB

MIT DUMMINT 15, 1968 CAMBRIDGE MASS	FRESH START AND RESTART
FORM NO. 1 REV. 10-67 C. H. ... APPROV. ...	COLLOSSUS II-D FC-2020 REV 3 42 50













SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	WHERE CALLED	DESCRIPTION
SETCOARS	FC-2210	SH. 19	ENABLE COARSE ALIGNMENT
ALARM	FC-2140	SH. 20, 32	SETS A FAILREG REGISTER WITH ALARM CODE AND TURNS ON PROGRAM ALARM LIGHT
MMDSP	FC-2030	SH. 21	DISPLAY MAJOR MODE VIA DSPMMJOB
STOPRATE	FC-2350	SH. 21, 25	ZERO INPUTS TO AUTOPILOT
CLEARMRK+2	FC-2130	SH. 24	CLEAR XDSPFLAG (NO SPECIAL MARK INFORMATION)
SETMAXDB	FC-2680	SH. 25	SET DEADBAND TO MAXIMUM VALUE FOR AUTOPILOT
SETMINDB	FC-2680	SH. 25	SET DEADBAND TO MINIMUM VALUE FOR AUTOPILOT
GENTRAN	FC-2070	SH. 28	COPY AND STORE 2CADR OF ALL VARIABLE RESTART ADDRESSES
SPSOFF	FC-2680	SH. 30	TURN OFF MAIN PROPULSION ENGINE
MASSPROP	FC-2430	SH. 31	UPDATE VEHICLE MASS ESTIMATES
RCS DAPON+1	FC-2680	SH. 31	START RCS DAP IN 3.1 SECONDS
TVCZAP	FC-2680	SH. 31	TERMINATE TVC DAP
DELAYJOB	FC-2070	SH. 31	THIS JOB IS PUT TO SLEEP FOR 30 MS AND THEN AWAKENED AT NEXT LOCATION ROOTPOO+21
RELDSP	FC-2180	SH. 32, 37, 42	RELEASES DISPLAY SYSTEM FROM OPERATOR'S CONTROL AND MAKES IT AVAILABLE TO INTERNAL ROUTINE REQUESTS
FALTON	FC-2180	SH. 32	TURN ON OPERATOR ERROR LIGHT
INTSTALL	FC-2290	SH. 35	WAIT FOR COMPLETION OF INTEGRATION
CLEARMRK	FC-2130	SH. 36	CLEAR XDSPFLAG (NO SPECIAL MARK INFORMATION)
UPACTOFF	FC-2120	SH. 36	TURN OFF UPLINK ACTIVITY LIGHT
NEWMODEA	FC-2030	SH. 42	UPDATE MODREG WITH NEW MAJOR MODE NUMBER AND DISPLAY IT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		FRESH START & RESTART	
PRGRM		COLOSSUS	DOCUMENT NO.
ANALYST <i>[Signature]</i>	7-8-51	II-D	FC-2020
DOCTR <i>[Signature]</i>	7-8-51	REV 3	SHEET 48 OF 80

INDEX OF REGISTERS AND CHANNELS  
which are initialized, tested, etc.

REGISTER	SHEET	ROUTINE	REGISTER	SHEET	ROUTINE	REGISTER	SHEET	ROUTINE
ATTCADR	11	DSPOFF	EXTVBACT	4	DOFSTART	GROUP 1. 4.0	7	POOKLEAN
CADRSTOR	10	DSPOFF	EXTVBACT	12	DSPOFF	GROUP 2.0	7	MR. KLEAN
CADRTAB	44	CONTEL2	EXTVBACT	36	DUMMYAD	GROUP 2.5	37	POOH
CHAN 5	3	DOFSTART	FAILREG	2	SKIPSIM	GROUP	7	V37KLEAN
CHAN 5	31	ROOTOPOO	FLAGWRD0	6	DOFSTART	3. 5. 6.0	36	GROUPKIL
CHAN 6	3	DOFSTART	FLAGWRD0	37	POOH	GROUP 4.0	39	STAUQU
CHAN 6	31	ROOTOPOO	FLAGWRD0	37	NOUVEAU	GROUP 4.1	24	GOTOPOOH
CHAN 11	14	DOFSTART	FLAGWRD0	39	RENDNOO	GROUP 4.1	34	CANV37
CHAN 11	8	STARTSB2	FLAGWRD0	39	POOFIZZ	IMODES30	5	DOFSTART
CHAN 11	30	V37	FLAGWRD1	6	DOFSTART	IMODES30	19	NOCOARSE
CHAN 11	20	NOCOARSE	FLAGWRD1	26	RAKE	IMODES30	30	V37
CHAN 11	35	DUMMYAD	FLAGWRD1	34	ISSERVON	IMODES33	5	DOFSTART
CHAN 11	36	DUMMYAD	FLAGWRD1	36	DUMMYAD	IMODES33	18	ELRSKIP
CHAN 12	4	DOFSTART	FLAGWRD1	38	SEUDOPOO	IMUCADR	11	DSPOFF
CHAN 12	35	DUMMYAD	FLAGWRD1	39	STATQUO	INLNK	10	DSPOFF
CHAN 13	4	DOFSTART	FLAGWRD2	6	DOFSTART	LGYRO	12	DSPOFF
CHAN 13	8	STARTSB2	FLAGWRD2	8	STARTSB2	LOC	27	V5LOOPI
CHAN 13	35	DUMMYAD	FLAGWRD2	26	RAKE	LONGBASE	45	ITSLGCL2
CHAN 13	36	DUMMYAD	FLAGWRD2	32	ISITPOO	LONGTIME	45	ITSLGCL2
CHAN 14	4	DOFSTART	FLAGWRD2	36	DUMMYAD	LONGTIME	46	ITSLGCL2
CHAN 15	14	LIGHTSET	FLAGWRD2	37	POOH	LONGTIME	47	LONGCLCL
CHAN 16	14	LIGHTSET	FLAGWRD3	6	DOFSTART	LST1	9	STARTSB2
CHAN 33	13	GOPROG	FLAGWRD3	26	RAKE	LST2	9	STARTSB2
CLPASS	10	DSPOFF	FLAGWRD4	6	DOFSTART	MARKSTAT	11	DSPOFF
CSMMASS	30	ROOTOPOO	FLAGWRD4	12	DSPOFF	MASSTMP	30	ROOTOPOO
DELAYLOC	10	DSPOFF	FLAGWRD4	24	GOPROFIX	MMNUMBER	30	V37
DNLADMMI	37	NOUVEAU	FLAGWRD4	36	DUMMYAD	MMNUMBER	31	ROOTOPOO
DNLADPMO	37	POO	FLAGWRD5	6	DOFSTART	MMNUMBER	32	ISITPOO
DNLSTCOD	4	DOFSTART	FLAGWRD5	20	NOCOARSE	MMNUMBER	33	AGAINMM
DNLSTCOD	38	SEUDOPOO	FLAGWRD5	26	RAKE	MMNUMBER	37	DUMMYAD
DNTMGOTO	8	STARTSUB	FLAGWRD6	6	DOFSTART	MMNUMBER	39	GROUPKIL
DSPCNT	10	DSPOFF	FLAGWRD6	20	GOPROG2	MMNUMBER	39	RENDNOO
DSPCOUNT	12	DSPOFF	FLAGWRD6	21	PCLoop	MMNUMBER	39	RENDVOO
DSPLIST	11	DSPOFF	FLAGWRD6	26	RAKE	MMNUMBER	39	GOMOD
DSPLOCK	10	DSPOFF	FLAGWRD6	30	V37	MINDEX	33	AGAINMM
DSPTAB#1D	2	SKIPSIM	FLAGWRD7	6	DOFSTART	MODREG	5	DOFSTART
DSPTAB#11D	4	DOFSTART	FLAGWRD7	26	RAKE	MODREG	23	PINACT
DSPTAB#11D	18	ELRSKIP	FLAGWRD7	34	ISSERVON	MODREG	39	RENDNOO
DSPTAB#11D	19	ELRSKIP	FLAGWRD8	6	DOFSTART	MODREG	39	GOMOD
DSPTAB#10D through DSPTAB#0	10	DSPOFF	FLAGWRD9	6	DOFSTART	MONSAVE	10	DSPOFF
DSRUPTSW	3	SKIPSIM	FLAGWRD9	25	INITSUB	MONSAVE1	10	DSPOFF
DSRUPTSW	9	STARTSB2	FLAGWRD9	25	RAKE	NEWJOB	4	STARTSB2
DUMMYAD	34	CANV37	FLGWRD10	6	DUMMYAD	NEWJOB	26	V5OUT2
EBANKTEM	4	DOFSTART	FLGWRD11	6	DOFSTART	NEWLOC	29	V5OUT2
EBANKTEM	38	SEUDOPOO	FCADRM1	40	V37XEQ	NEWPRIO	29	V5OUT2
ERCOUNT	2	SKIPSIM	FCADRM1	41	V37XEQ	NOUNREG	40	V37XEQ
ERESTORE	3	DOFSTART	GROUP 1-6.0	4	DOFSTART	NOUT	11	DSPOFF
ERESTORE	15	BUTTONS	GROUP 1. 2.0	39	KILL20	NVSAVE	4	DOFSTART
ERESTORE	16	BUTTONS	GROUP 1. 3. 4. 5. 6.0	39	GROUPKIL	OPTCADR	11	DSPOFF
						OPTIND	5	DOFSTART

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. White</i> 1-5-67		FRESH START & RESTART	
FIGURE		COLOSSUS	DOCUMENT NO.
ANALYST <i>P. H. G.</i> 1-5-67		11-D	FC-2020
DOC# <i>C. H. G. 1-5-67</i>			
APPROVED <i>R. White</i> 1-5-67 REV 3			SHEET 49 OF 80

INDEX OF REGISTERS AND CHANNELS (cont'd)

REGISTER	SHEET	ROUTINE	REGISTER	SHEET	ROUTINE	REGISTER	SHEET	ROUTINE
OPTIND	26	RAKE	PRIORITY	9	STARTSB2	TEMPFLSH	34	CANV37
OPTMODES	5	DOFSTART	PRIORITY	27	V5LOOP1	TEMPFLSH	39	REV37
OPTMODES	18	ELRSKIP	RADCADR	11	DSPOFF	TEMPFLSH	40	INITDSP
PHASE1-6	20	PCLLOOP	RASFLAG	18	ELRSKIP	TIME1	45	FINDTIME
PHASE1-6	29	V5LOOP2	RASFLAG	20	GOPROG2	TIME1	45	ITSLGCL2
PHSBB1-6	28	V5OUT1	RATEINDX	4	DOFSTART	TIME2	45	ITSLGCL2
PHSNAME1-6	28	V5OUT1	REDOCTR	2	SKIPSIM	TIME3	8	STARTSB2
PHSNAME1-6	43	ITSAVAR	REDOCTR	13	GOPROG	TIME4	8	STARTSUB
PHSNAME1-6	43	ITSLKEB	REDORCS	17	ELRSKIP	TIME5	8	STARTSUB
PHSPRDT1	44	ITSAJOB	REDOGAT	17	ELRSKIP	TRKMICNT	4	DOFSTART
PHSPRDT1	44	ITSAWAIT	REDOTVC	17	ELRSKIP	T5IDLOC	5	DOFSTART
PHSPRDT1	44	ITSLNGCL	REQRET	10	DSPOFF	T5IDLOC	17	ELRSKIP
PHSPRDT2	37	POOH	RESTREG	5	DOFSTART	UPSVFLAG	3	DOFSTART
PHSPRDT4	40	V37XEQ	RESTREG	30	V37	VAC5	27	V5LOOP1
POINTER	43	ITSATBL	RSBQ	13	GOPROG	VAC5	29	V5LOOP2
POINTER	43	ITSEVEN	RISAVE	10	DSPOFF	VAC5	29	V5OUT2
POINTER	44	PHSPART2	SELFRET	12	DSPOFF	VAC1USE through VAC5USE	9	STARTSB2
PRDTTAB	44	CONTLB2	SIZETAB	43	ITSATBL	VERBREG	10	DSPOFF
PRDTTAB	44	ITSAJOB2	SIZETAB	43	ITSEVEN	VHFNT	4	DOFSTART
PRDTTAB	44	ITSWTLST	SKEEP5	16	BUTTONS	V37XEQ	39	REV37
PREMM1	33	AGAINMM	SKEEP6	16	BUTTONS	WTOPTION	4	DOFSTART
PREMM1	40	V37XEQ	SKEEP7	15	BUTTONS			
PREMM1	41	V37XEQ	SMODE	3	DOFSTART			
PREMM1	42	V37XEQC	TBASE1-6	45	FINDTIME			

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. White</i>	<i>2-2-67</i>	FRESH START & RESTART	
PROB#		COLOSSUS	DOCUMENT NO.
ANALYST <i>FLC</i>	<i>2-9-67</i>	II-D	FC-2020
DOCHR <i>J. Van Hook</i>	<i>2-8-67</i>		
APP'D <i>K. B. ...</i>	<i>2-2-67</i>	REV 3	SHEET 50 OF 50



# PHASE TABLE MAINTENANCE

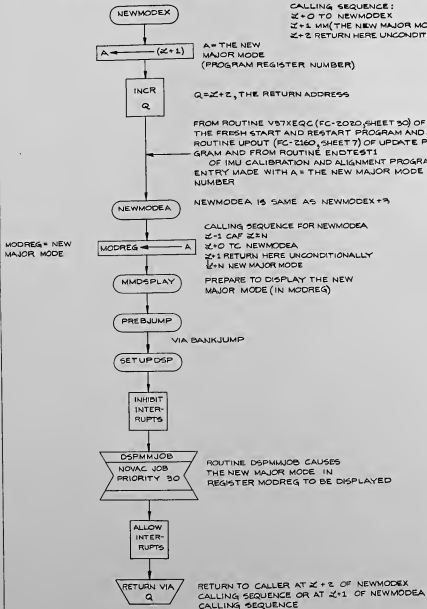
THERE HAVE BEEN NO CHANGES (EXCEPT PAGE NUMBERING)  
FROM THE COLOSSUS 237 FLOWCHART, FC-2030, REV. 0, TO  
THE COLOSSUS II FLOWCHART, FC-2030, REV. 1.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		SUNSHINE	
DESIGNER A.C. WILLIAMS	DATE 3/17/68	PHASE TABLE MAINTENANCE	
REVISOR P. Rye	DATE 3/17/68	REV. 1	
ANALYST C. J. Beck	DATE 3-6-69	COLOSSUS II	FC-2030
APPROVED John A. Moran	DATE 6/24/69	REV. 1	1-1-16

CONTROL ARRIVES HERE FROM ANY OF 12 LOCATIONS (Z) WITH Q = Z+1, THE ADDRESS OF THE LOCATION CONTAINING THE NEW MAJOR MODE NUMBER

SUBROUTINE FOR UPDATING THE MAJOR MODE REGISTER MODREG AND THE MAJOR MODE DISPLAY ON THE DSKY WITH THE NEW MAJOR MODE

CALLING SEQUENCE:  
 Z+0 TO NEWMODEX  
 Z+1 MM (THE NEW MAJOR MODE)  
 Z+2 RETURN HERE UNCONDITIONALLY

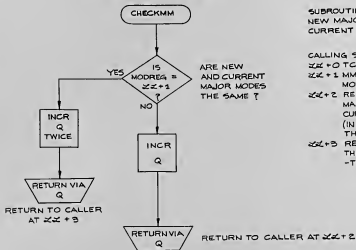


PHASE TABLE  
 MAINTENANCE

COLLOSSUS II FC-2030

2 16

CONTROL ARRIVES HERE FROM  
ANY OF 12 LOCATIONS



SUBROUTINE FOR COMPARING  
NEW MAJOR MODE WITH  
CURRENT MAJOR MODE

CALLING SEQUENCE :

ZZ+0 TO CHECKMM

ZZ+1 MM (THE NEW MAJOR  
MODE)

ZZ+2 RETURN HERE IF NEW  
MAJOR MODE AND  
CURRENT MAJOR MODE

(IN MODREG) ARE NOT  
THE SAME

ZZ+3 RETURN HERE IF  
THEY ARE THE SAME  
-THEY MATCH

WIT	
INSTRUMENTS & LAB	
AMBRIDGE 1945	
DATE	13 MAY 1953
BY	<i>Phy</i>
CHKD BY	<i>Phy</i>
APPROV	<i>for A. Howard</i>

PHASE TABLE MAINTENANCE	COLOSSUS II
FC-2030	REV 1
REV 3	16

CONTROL ARRIVES HERE FROM ANY OF 9 LOCATIONS (Z) WITH THE PHASE NUMBER IN A AND ADDRESS Z+1 IN Q

NEWPHASE

INHIBIT INTERRUPTS

L ← A

INCR Q

TEMPG ← Z (Z+1)

IS L ≤ -0 ?

NO

YES

NUFAZ+10

L ← L

TBASE 1-2 \* X1 ← TIME I

-PHASE 1-2 \* X1 ← L

-PHASE 1-1 \* X1 ← L

ALLOW INTERRUPTS

RETURN VIA Q

RETURN TO CALLER AT Z+2 WITH THE TRUE AND COMPLEMENT FORMS OF THE OLD PHASE IN A AND L, RESPECTIVELY

SUBROUTINE NEWPHASE IS USED TO MAKE A QUICK NON-VARIABLE PHASE CHANGE. IT ALSO PERMITS THE STORING OF TIME I INTO TBASE IN COMPLEMENT FORM

CALLING SEQUENCE:

Z-1 CA (OR CS) ZIN  
Z=0 TO NEWPHASE  
Z=1 OCT XXXX (GROUP)  
Z=2 RETURN HERE UNCONDITIONALLY

...  
ZIN OCT YYYYY (PHASE)  
\* CA IF TBASE IS NOT TO BE SET  
CS IF TBASE IS TO BE SET  
OCT XXXX = BINARY 000 000 000 000 GGG  
OCT YYYYY = BINARY 000 000 000 PPP PPP  
WHERE G IS THE GROUP NUMBER AND P IS THE PHASE NUMBER

INHIBIT INTERRUPT PROGRAMS

L = PHASE NUMBER

Q = Z-2, THE RETURN ADDRESS

DOUBLE THE GROUP NUMBER IN LOCATION Z+1 OF THE CALLING SEQUENCE AND STORE IT IN TEMPG FOR LATER USE AS AN INDEX. IT WILL BE REFERRED TO AS X1

SHOULD TBASE BE SET ?  
(IS THE PHASE NUMBER NEGATIVE ?)

X1 IS AN INDEX AND IS EQUAL TO TWICE THE GROUP NUMBER SITUATED IN BIT-POSITIONS 3-1 OF Z+1 OF THE CALLING SEQUENCE

STORE THE COMPLEMENT OF THE CONTENTS OF TIME COUNTER TIME I INTO THE LOCATION OF THE TBASE TABLE ASSOCIATED WITH THE GROUP NUMBER

STORE THE COMPLEMENT AND THE TRUE FORM OF THE PHASE NUMBER INTO THE LOCATIONS OF THE PHASE TABLE ASSOCIATED WITH THE GROUP NUMBER

RELEASE INTERRUPT PROGRAM INHIBIT

PHASE, TBASE AND PHSPROT1 TABLES

- PHASE 1
- PHASE 2
- PHASE 3
- PHASE 9
- PHASE 3
- PHASE 4
- PHASE 4
- PHASE 5
- PHASE 5
- PHASE 6
- PHASE 6
- TBASE 1
- PHSPROT1
- TBASE 2
- PHSPROT2
- TBASE 3
- PHSPROT3
- TBASE 4
- PHSPROT4
- TBASE 5
- PHSPROT5
- TBASE 6
- PHSPROT6

PHASE TABLE MAINTENANCE

COLOSSUS II FC-2030

28  
3/21/64  
123 67  
33 10/16/64

CONTROL ARRIVES HERE FROM  
ANY ONE OF 114 LOCATIONS WITH

Q = \* + 1

A = IRRELEVANT CONTENTS

PHASCHNG

SUBROUTINE FOR MAKING ANY  
OF SEVERAL TYPE PHASE CHANGES  
FOR RESTARTS. A PHASE IDENTIFIES  
ONE OF SEVERAL PLACES WITHIN A  
ROUTINE TO RESTART THAT ROUTINE  
WHEN THAT ROUTINE HAS BEEN  
INTERRUPTED BY A HARDWARE FAILURE

TYPES OF PHASE CHANGE INFORMATION  
CONTAINED IN OCT XXXXX OF THE CALLING  
SEQUENCE (NEXT SHEET) ARE:

TYPE A FIXED PHASE CHANGES  
STORED IN PERMANENT FORM  
TYPE B COMBINATION OF FIXED AND  
VARIABLE PHASE CHANGES  
TYPE C VARIABLE PHASE CHANGE INFORMATION  
STORED IN ERASABLE LOCATION

THE BINARY REPRESENTATION OF OCT XXXXX IS:

TYPE A TL0 00P PPP PPP GGG  
TYPE B TL1 DAP PPP PPP GGG  
TYPE C TL0 1AD XXX C JW GGG

WHERE IF  
T=0 TBASE WILL NOT BE SET  
T=1 TBASE WILL BE SET WITH TIME1  
L=0 LONGBASE WILL NOT BE SET  
L=1 LONGBASE WILL BE SET WITH TIME2 &  
TIME1  
D=0 USE OLD PRIORITY (OR DELTA TIME)  
WHICH IS IN THE FHSPTD TABLE  
D=1 USE NEW PRIORITY (OR DELTA TIME)  
WHICH IS IN NEXT LOCATION OF THE  
CALLING SEQUENCE  
A=0 NEXT LOCATION (EITHER  $\mathcal{L} + 2$  AND  $\mathcal{L} + 3$ )  
IN THE CALLING SEQUENCE IS THE  
RESTART ADDRESS  
A=1 THE 2CADR OF THE RESTART ADDRESS  
IS IN THE NEXT 2 LOCATIONS (EITHER  
 $\mathcal{L} + 2$  AND  $\mathcal{L} + 3$  OR  $\mathcal{L} + 3$  AND  $\mathcal{L} + 4$ ) OF  
THE CALLING SEQUENCE  
C=0 RESTART IS NOT A LONGCALL TASK  
C=1 RESTART IS A LONGCALL TASK (J=0,  
W=0)  
J=0 RESTART IS NOT A JOB  
J=1 RESTART IS A JOB (C=0, W=0)  
W=0 RESTART IS NOT A WAITLIST TASK  
W=1 RESTART IS A WAITLIST TASK  
G GROUP NUMBER, OCTAL 1-7  
P=0 INACTIVE, WILL NOT PERMIT GROUP G  
TO RESTART  
P=1 WILL CAUSE LAST DISPLAY TO BE  
REACTIVATED MAINLY IN MANNED  
FLIGHTS)  
P=2, 4, 6, .. (EVEN) A DOUBLE TABLE RESTART.  
CAN CAUSE ANY COMBINATION OF 2  
JOBS, TASKS AND/OR LONGCALL TASKS  
TO BE RESTARTED  
P=3, 5, 7, .. (ODD) A SINGLE TABLE RESTART.  
CAN CAUSE EITHER A JOB, TASK OR  
LONGCALL TASK TO BE RESTARTED

NEXT PAGE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	
DRAWN <i>J. J. Christman</i>	DOCNO 23 JAN 65
PRINR <i>P. J. ...</i>	
ANAL ST	
DOCNR <i>P. H. ...</i>	123 69
APPRV <i>J. B. ...</i>	27 JAN 65

PHASE TABLE MAINTENANCE	
COLOSSUS II	FC-2030
REV 1	SHEET 5 OF 16

FROM PRECEDING SHEET

GENERAL  
CALLING SEQUENCE  
Z+0 FC PHASCHNG  
Z+1 OCT XXXXX (TYPE A, B OR C)

IF Z+1 IS	TYPE A	TYPE B OR C	
AND PRIORITY (OR QT) IS		OLD (IN PHSPRODT1 TABLE)	NEW (IN Z+2)
AND THE VARIABLE (IF ANY) RESTART ADDRESS IS		ZCADR IN Z+2	ZCADR IN Z+3, Z+4

Z+2 RETURN HERE IF	X	X	
(A=0, D=0) *			
Z+3 RETURN HERE IF			X
(A=0, D=1)			
Z+4 RETURN HERE IF		X	
(A=1, D=0)			
Z+5 RETURN HERE IF			X
(A=1, D=1)			

\*NOTE:

A IS BIT-POSITION 11 OF Z+1 (TYPE B OR C) AND D IS 10 (IF TYPE C) OR 12 (IF TYPE B). SEE BINARY REPRESENTATION OF OCT XXXXX ON PRECEDING SHEET

INHIBIT  
INTER-  
RUPTS

INHIBIT INTERRUPT PROGRAMS

TEMPSW ← 1

INDICATES THAT ENTRY WAS  
MADE VIA PHASCHNG

PHASCHNG+3

ENTRY FROM ROUTINE 2 PHASCHNG

TEMPSW ← (Z+1)

STORE OCTAL CODE IN LOCATION  
Z+1 OF THE CALLING SEQUENCE

INCR  
Q

SET RETURN ADDRESS  
TO Z+2

TEMPBBCN ← BANK

STORE BANK OF CALLER

NEXT SHEET

PHASE TABLE  
MAINTENANCE

COLOSSUS II FC-2030

6 16

APPROVED: *J. Chalkish* 21 JAN 67  
 CHECKED: *CH Beck* 123 67  
 DATE: *12 JAN 67*

FROM PRECEDING SHEET

PHSCHNGZ

TEMPG ← Z · TEMP5W 3-1

DOUBLE THE GROUP NUMBER IN BIT-POSITIONS 3-1 AND STORE IT FOR LATER USE AS AN INDEX. (HEREAFTER THE INDEXING WORD "TEMPG" WILL BE REFERRED TO AS X2)

HENCEFORTH WHEN TEMPG OR TEMP5W ARE USED IN THE PROGRAM, THIS DIAGRAM WILL REFER INSTEAD TO THE BITS OF THE ORIGINAL OCTAL WORD IN Z+1 WHICH WILL LESSEN CONFUSION

TEMP5W ← 10-1 TEMP5W 13-4

GET THE RESTART TYPE AND/OR PHASE NUMBER

TEMP5W ← 13-1 0

CLEAR ALL TEMP5W EXCEPT TBASE AND LONGBASE BITS (13;14)

ARE BITS 13 & 12 OF Z+1 = 0?

DOES Z+1 CONTAIN TYPE A PHASE INFORMATION?

NO (TYPE B OR C)

YES (TYPE A)

ONE OR TWO DETERMINE PRIORITY AND RE-START ADDRESS SH9

(PHASE 1-2+X2) ← (Z+1) 13-4

STORE THE PHASE NUMBER INTO THE PHASE TABLE IN TRUE FROM

BELOW1

WAS ENTRY VIA PHSCHNGZ?

IS TEMP5WE +1?

CONTROL CANNOT COME HERE SINCE THIS DIAGRAM APPLIES TO PHSCHNGZ

YES (VIA PHSCHNGZ)

NEXT SHEET

REV 1

100 WASHINGTON LANE  
ANDOVER, MASS.

DESIGNER *J. J. ...*

PROGRAMMER *R. J. ...*

ANALYST *E. J. ...*

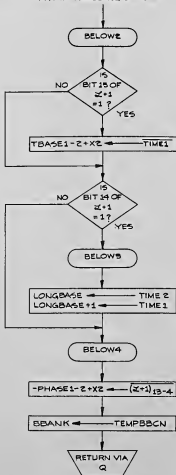
DATE *1/23/61*

APPROVED *John H. ...*

PHASE TABLE MAINTENANCE

COLOSSUS II FC-2030 SHEET 7 OF 16

FROM PRECEDING SHEET



SHOULD TBASE BE SET ?

SET TBASE ASSOCIATED WITH GROUP NUMBER

SHOULD LONGBASE BE SET ?

SET LONGBASE

STORE THE COMPLEMENT FROM OF THE PHASE NUMBER INTO THE PHASE TABLE IN THE LOCATION ASSOCIATED WITH THE GROUP NUMBER IN  $(Z+1)_{B-1}$  BBANK = FBANK OF CALLER AND E BANK LAST USED

RETURN TO CALLING SEQUENCE AT EITHER  $Z+2$ ,  $Z+3$ ,  $Z+4$  OR  $Z+5$ , SEE TABLE BELOW:

TYPE A	IF TYPE B OR C				THEN THE RETURN TO THE CALLING SEQUENCE IS AT LOCATION
	RESTART ADDRESS IS ONE OF LOCATIONS IN THE CALLING SEQUENCE (A=0)		RESTART ADDRESS IS 2CADR IN TWO LOCATIONS OF THE CALLING SEQUENCE (A=1)		
	PRIORITY (OR DELTA TIME) TO BE USED IS:		PRIORITY (OR DELTA TIME) TO BE USED IS:		
	OLD (D=0)	NEW (D=1)	OLD (D=0)	NEW (D=1)	
X	X	X	X	X	Z+2
					Z+3
					Z+4
					Z+5

### PHASE TABLE MAINTENANCE

*28*  
*P. Ege*  
*8/4/67*  
*12369*  
*John R. Mason 23 Mar 67*

COLOSSUS II FC-2030



FROM SHEET 7

DETERMINE APPLICABLE PRIORITY OR DELTA TIME AND STORE IT

ONEORTWO

BANK ←→ TEMPBCH

TEMPORARILY RESTORE BBANK OF THE CALLER OF PHASCHNG

IS BIT 13 OF Z+1 = 1 ?

DOES Z+1 CONTAIN TYPE B PHASE INFORMATION ?

CHECKB

WILL A NEW PRIORITY (OR NEW DELTA TIME) BE USED ? (IS THE PRIORITY OR DELTA TIME BIT 'D' IN Z+1 = 1 ?)

IS BIT 12 OF Z+1 = 1 ?  
YES (USE NEW PRIORITY)  
NO (USE OLD PRIORITY)

IS BIT 10 OF Z+1 = 1 ?  
YES (USE NEW PRIORITY)  
NO (USE OLD PRIORITY)

THE NEW PRIORITY (OR DELTA TIME) IS SITUATED IN LOCATION Z+2 AND THE OLD PRIORITY (OR DELTA TIME) IS SITUATED IN THE PHSPRT1 TABLE

GETPRIO

OLDPRIO

TEMPPR ← (Z+2)

TEMPPR ← (PHSPRT1-Z+X2)

TEMPORARILY STORE NEW OR OLD PRIORITY (OR DELTA TIME)

INCR Q

Q = Z+3

Q = Z+2

CON1

DETERMINE RESTART ADDRESS AND STORE ITS ZCADR

IS THE ZCADR OF THE RESTART ADDRESS SITUATED IN THE NEXT TWO LOCATIONS OF THE CALLING SEQUENCE ? (IS THE RESTART ADDRESS BIT 11 OF Z+1 DESIGNATED AS 'A' EQUAL TO 1 ?)

IS BIT 11 OF Z+1 = 1 ?

NO, RESTART ADDRESS IS THE LOCATION WHERE PHASCHNG RETURNS TO THE CALLER

GETNEWNM

TEMPNM ← Q  
SAVE THE RETURN LOCATION TO THE CALLER (THIS IS ALSO THE RESTART ADDRESS)

TEMPNM ← (Z+3)  
TEMPBB ← (Z+4)

TEMPNM ← (Z+2)  
TEMPBB ← (Z+3)

STORE THE ZCADR OF THE RESTART ADDRESS PROVIDED BY CALLER

TEMPBB 15-11, 3-1  
TEMPBB 7-3  
SUPERBANK+3

SAVE THE CALLER'S BBANK AND SUPERBANK

INCRQ BY 2

INCRQ BY 2

Q = Z+5

Q = Z+4

Q = Z+2 OR Z+3

NEXT SHEET

PHASE TABLE MAINTENANCE

RECALL: *J.J. Chisholm*

REMARK: *1/23/69*

APPROVED: *J.P. Beck*

DATE: *1/23/69*

BY: *John W. Howe*

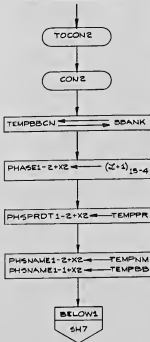
PHASE TABLE MAINTENANCE

COLOSSUS II FC-2030

REV 1

10/13/68

FROM PRECEDING SHEET



STORE THE PHASE NUMBER, PRIORITY (OR DELTA TIME) AND ZCADR OF THE RESTART ADDRESS INTO TABLES FOR USE BY THE RESTART ROUTINES

SAVE CALLER'S BBANK

STORE THE TRUE FORM OF THE PHASE NUMBER INTO THE PHASE TABLE IN THE LOCATION ASSOCIATED WITH THE GROUP NUMBER IN  $(Z+1)_{3-1}$

STORE THE PRIORITY OR DELTA TIME INTO THE PRIORITY-DELTA TIME TABLE IN THE LOCATION ASSOCIATED WITH THE GROUP NUMBER

STORE THE ZCADR OF THE RESTART ADDRESS INTO THE ADDRESS TABLE IN THE LOCATIONS ASSOCIATED WITH THE GROUP NUMBER

THE PHASE-CHANGE TABLES ARE AS FOLLOWS:

PHASES	TBASE AND PRIORITY (OR DELTA TIME)	ZCADR OF RESTART ADDRESS
-PHASE 1	TBASE 1	PH5NAME 1
PHASE 1	PHSPRDT 1	PH5BB 1
-PHASE 2	TBASE 2	PH5NAME 2
PHASE 2	PHSPRDT 2	PH5BB 2
-PHASE 3	TBASE 3	PH5NAME 3
PHASE 3	PHSPRDT 3	PH5BB 3
-PHASE 4	TBASE 4	PH5NAME 4
PHASE 4	PHSPRDT 4	PH5BB 4
-PHASE 5	TBASE 5	PH5NAME 5
PHASE 5	PHSPRDT 5	PH5BB 5
-PHASE 6	TBASE 6	PH5NAME 6
PHASE 6	PHSPRDT 6	PH5BB 6

PHASE TABLE  
MAINTENANCE

COLOSSUS II FC-2030

10 16

2PHSCHNG

SUBROUTINE FOR CHANGING  
TWO GROUPS AT ONCE  
IN FIXED-FIXED MEMORY

THE CALLING SEQUENCE IS:

Z=0 OCT 2PHSCHNG  
Z=1 OCT XXXX (TYPE A)  
Z=2 OCT YYYY (TYPE A, B OR C)  
IF Z=2 IS

AND PRIORITY (OR  
ΔT) IS

TYPE A	TYPE B OR C	
	OLD (IN PHSPROT1 TABLE)	NEW (IN Z=3)
	ZCADR IN Z=3	ZCADR IN Z=4
	Z=3	Z=4
	Z=4	Z=5

AND THE VARIABLE  
(FANY) RESTART  
ADDRESS IS

Z=3 RETURN HERE (A=0, D=0) IF X X  
 Z=4 RETURN HERE (A=0, D=1) IF X X  
 Z=5 RETURN HERE (A=1, D=0) IF X X  
 Z=6 RETURN HERE (A=1, D=1) IF X X

\* NOTE 1 IS BIT-POSITION 11 OF Z=2 (TYPE B OR C) AND  
 D IS 10 (IF TYPE C) OR 12 (IF TYPE B). SEE PAGE 4 FOR  
 BINARY REPRESENTATION OF OCT XXXXX AND  
 OCT YYYY

INHIBIT  
INTER-  
RUPTS

TEMPPZ ← (Z+1)

STORE OCTAL CODE WHICH IS IN LOCATION  
Z+1 OF THE CALLING SEQUENCE (ALWAYS  
TYPE A)

INCR  
Q

Q=Z+2

FORM THE INDEX.

DOUBLE THE GROUP NUMBER IN BIT-POSITIONS  
3-1 AND STORE IT FOR LATER USE AS AN INDEX.  
(HEREAFTER THE INDEXING WORD "TEMPQ2"  
WILL BE REFERRED TO AS X3)

TEMPQ2 ← 2·(TEMPPZ)<sub>3-1</sub>

TEMPPZ<sub>10-1</sub> ← TEMPQ2<sub>13-4</sub>

GET THE PHASE NUMBER

HENCEFORTH WHEN TEMPPZ OR TEMPSW2  
ARE USED IN THE PROGRAM, THIS DIAGRAM  
WILL REFER INSTEAD TO THE BITS OF THE  
ORIGINAL OCTAL WORD IN Z+1 WHICH WILL  
LESSEN CONFUSION. AN EXCEPTION IS  
TEMPSW2 USED IN ROUTINE BELOW 1 TO  
INDICATE THE ENTRY

TEMPSW2<sub>15</sub> ← TEMPQ2<sub>15</sub>  
TEMPSW2<sub>14-1</sub> ← 0

SAVE TBASE INDICATOR (BIT 15)  
1- TBASE SHOULD BE SET  
0- TBASE SHOULD NOT BE SET

NEXT SHEET

PHASE TABLE  
MAINTENANCE

COLOSSUS II FC-2030

11 16

*John L. Rose 23 Jul 1967*



FROM PRECEDING SHEET

BELOW 1

SET PHASE TABLE AND TBASE TABLE (IF REQUESTED) FOR THE GROUP INDICATED IN Z+1 OF CALLING SEQUENCE

IS TEMPORARY # 1 ?

WAS ENTRY MADE VIA ZPHSCHNG ?

NO (VIA PHASCHNG) (=1)

YES (VIA ZPHSCHNG) (= 00000 OR OCT 40000)

CONTROL CANNOT COME HERE SINCE THIS DIAGRAM APPLIES TO ZPHSCHNG

$[-\text{PHASE1}-Z+X_3, -\text{PHASE1}-1+X_3] \leftarrow [Z+1]_{13-4}, [Z+1]_{13-4}$

STORE PHASE INFORMATION WHICH IS IN LOCATION Z+1 OF THE CALLING SEQUENCE INTO THE PHASE TABLE IN BOTH COMPLEMENT AND TRUE FORM

IS BIT 15 OF Z+1 = 1 ?

SHOULD TBASE FOR THE GROUP IN Z+1 BE SET ?

$(\text{TBASE1}-Z+X_3) \leftarrow \text{TIME1}$

STORE THE COMPLEMENT OF THE COMPUTER TIME (LOW ORDER) INTO THE PROPER TBASE REGISTER

BELOW 2

SET TBASE AND/OR LONGBASE TABLES (IF REQUESTED) FOR THE GROUP INDICATED IN Z+2 OF CALLING SEQUENCE

IS BIT 15 OF Z+2 = 1 ?

SHOULD TBASE FOR THE GROUP IN Z+2 BE SET ?

$(\text{TBASE1}-Z+X_4) \leftarrow \text{TIME1}$

STORE THE COMPLEMENT OF THE COMPUTER TIME (LOW ORDER) INTO THE PROPER TBASE REGISTER

IS BIT 14 OF Z+2 = 1 ?

SHOULD LONGBASE BE SET ?

BELOW 3

STORE THE COMPUTER TIME READINGS (BOTH HIGH AND LOW ORDER) INTO LONGBASE REGISTERS

$\text{LONGBASE} \leftarrow \text{TIME2}$   
 $\text{LONGBASE}+1 \leftarrow \text{TIME1}$

NEXT SHEET

MIT INSTRUMENTATION LAB (CAMBRIDGE, MASS.)		PHASE TABLE MAINTENANCE	
DRAWN <i>J. J. Chiswick</i>	DESIGNED <i>J. J. Chiswick</i>	COLLOSSUS II	FC-2030
AMPLIFIED <i>C. H. Beck</i>	APPROVED <i>John A. M... 1/20/49</i>	REV 1	MAY 13 1946

FROM PRECEDING SHEET

BELOW

GET REMAINING PART OF PHASE TABLE AND RESTORE BBANK

$(-PHASE1 - Z + X) \leftarrow (Z + E)_{13-4}$

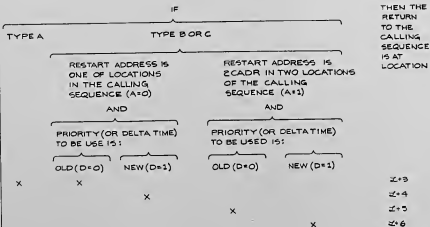
STORE THE COMPLEMENT FORM OF PHASE INFORMATION WHICH IS IN LOCATION  $Z + E$  OF THE CALLING SEQUENCE INTO THE PHASE TABLE

BBANK  $\leftarrow$  TEMPBBCN

RESTORE ORIGINAL CONTENTS TO BBANK. BBANK = FBANK OF CALLING SEQUENCE AND E BANK LAST USED

RETURN VIA Q

RETURN TO CALLING SEQUENCE AT EITHER  $Z + 3$ ,  $Z + 4$ ,  $Z + 5$  OR  $Z + 6$ . SEE TABLE BELOW



PHASE TABLE MAINTENANCE

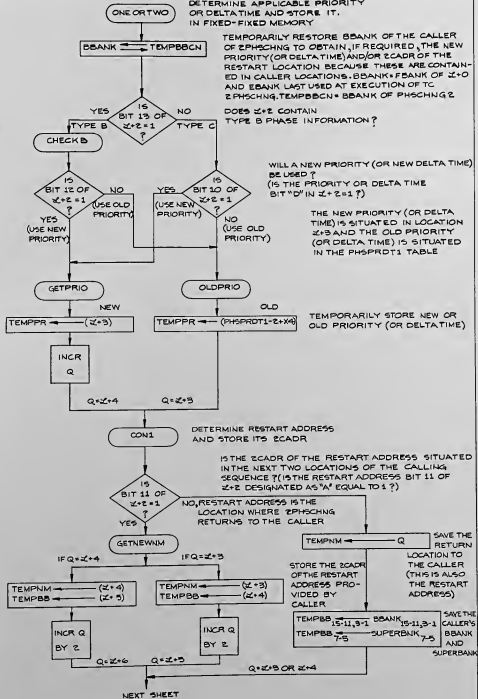
COLOSSUS II FC-2030

14 36

J. Christensen  
 F. Eyr  
 G. R. B...  
 1-29-49  
 1

FROM SHEET 12

DETERMINE APPLICABLE PRIORITY OR DELTA TIME AND STORE IT IN FIXED-FIXED MEMORY



TEMPORARILY RESTORE BBANK OF THE CALLER OF ZPHSCHNG TO OBTAIN, IF REQUIRED, THE NEW PRIORITY (OR DELTA TIME) AND/OR ECADR OF THE RESTART LOCATION BECAUSE THESE ARE CONTAINED IN CALLER LOCATIONS. BBANK = FBANK OF Z+0 AND EBANK LAST USED AT EXECUTION OF TC ZPHSCHNG. TEMPBBN = BBANK OF PHSCHNGZ

DOES Z+2 CONTAIN TYPE B PHASE INFORMATION?

WILL A NEW PRIORITY (OR NEW DELTA TIME) BE USED? (IS THE PRIORITY OR DELTA TIME BIT "D" IN Z+2 = 1?)

THE NEW PRIORITY (OR DELTA TIME) IS SITUATED IN LOCATION Z+3 AND THE OLD PRIORITY (OR DELTA TIME) IS SITUATED IN THE PHSPRDT1 TABLE

TEMPORARILY STORE NEW OR OLD PRIORITY (OR DELTA TIME)

DETERMINE RESTART ADDRESS AND STORE ITS ECADR

IS THE ECADR OF THE RESTART ADDRESS SITUATED IN THE NEXT TWO LOCATIONS OF THE CALLING SEQUENCE? (IS THE RESTART ADDRESS BIT 11 OF Z+2 DESIGNATED AS "A" EQUAL TO 1?)

NO, RESTART ADDRESS IS THE LOCATION WHERE ZPHSCHNG RETURNS TO THE CALLER

SAVE THE RETURN LOCATION TO THE CALLER (THIS IS ALSO THE RESTART ADDRESS)

SAVE THE CALLER'S BBANK AND SUPERBANK

NEXT SHEET

PHASE TABLE MAINTENANCE

15-11, 3-1

7-5

15-11, 3-1

7-5

COLOSSUS II FC-2030

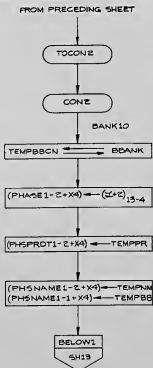
15 16

CLASSIFIED BY: 23/01/2006

DECLASSIFIED BY: 1/1/2007

DATE: 1/23/07

APPROVED BY: John A. M...



FIXED-FIXED MEMORY

STORE THE PHASE NUMBER, PRIORITY (OR DELTA TIME) AND ZCADR OF THE RESTART ADDRESS INTO TABLES FOR USE BY THE RESTART ROUTINES

SAVE CALLER'S BBANK  
 $BBANK = BBANK$  OF PHSCHNGZ  
 $TEMPBBCN = B$  BANK OF CALLER (Z)

STORE THE TRUE FORM OF THE PHASE INFORMATION INTO THE PHASE TABLE IN THE LOCATION ASSOCIATED WITH THE GROUP NUMBER IN  $(Z+2)_{13-4}$

STORE THE PRIORITY OR DELTA TIME INTO THE PRIORITY-DELTA TIME TABLE IN THE LOCATION ASSOCIATED WITH THE GROUP NUMBER

STORE THE ZCADR OF THE RESTART ADDRESS INTO THE ADDRESS TABLE IN THE LOCATIONS ASSOCIATED WITH THE GROUP NUMBER

THE PHASE-CHANGE TABLES ARE AS FOLLOWS:

PHASES	TBASE AND PRIORITY (OR DELTATIME)	ZCADR OF RESTART ADDRESSES
- PHASE 1	TBASE 1	PHSNAME 1
PHASE 1	PHSPRT 1	PHSDB 1
- PHASE 2	TBASE 2	PHSNAME 2
PHASE 2	PHSPRT 2	PHSDB 2
- PHASE 3	TBASE 3	PHSNAME 3
PHASE 3	PHSPRT 3	PHSDB 3
- PHASE 4	TBASE 4	PHSNAME 4
PHASE 4	PHSPRT 4	PHSDB 4
- PHASE 5	TBASE 5	PHSNAME 5
PHASE 5	PHSPRT 5	PHSDB 5
- PHASE 6	TBASE 6	PHSNAME 6
PHASE 6	PHSPRT 6	PHSDB 6

PHASE TABLE  
MAINTENANCE

COLLOSSUS II FC-2030

*2nd Annual Meeting 11/18/69*  
*P. R. G. 2*  
*11/18/69*  
*John J. Moran*



THE EXECUTIVE

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

FINDVAC:	USED TO SCHEDULE A JOB NEEDING A SET OF ERASABLE LOCATIONS, CALLED THE VAC AREA.	SH. 3
SPVAC:	SAME AS FINDVAC, EXCEPT THAT NEWPRIO IS ALREADY LOADED, A, L = 2CADR OF JOB TO BE SCHEDULED, AND INTERRUPTS ALREADY INHIBITED.	SH. 3
NOVAC:	USED TO SCHEDULE A JOB NOT NEEDING A VAC AREA.	SH. 4
ENDOFJOB:	USED TO TERMINATE A JOB. FREES CORESET AND VAC AREA, IF ANY, AND SCANS FOR ACTIVE JOB OF HIGHEST PRIORITY. IF IT FINDS ONE, IT PASSES CONTROL TO IT; OTHERWISE, CONTROL IS TRANSFERRED TO DUMMYJOB.	SH. 6
PRIORCHG:	USED TO CHANGE A JOB'S PRIORITY. IF CHANGED PRIORITY IS STILL HIGHEST, CONTROL IS RETURNED TO CALLER, OTHERWISE, JOB WITH HIGHEST ACTIVE PRIORITY IS GIVEN CONTROL.	SH. 10
JOBSLEEP:	USED TO MAKE THE CALLING JOB TEMPORARILY INACTIVE UNTIL SOME EVENT (LIKE I/O) HAS OCCURRED. CONTROL IS TRANSFERRED TO JOB WITH HIGHEST ACTIVE PRIORITY, OR TO DUMMYJOB, IF THERE ARE NO ACTIVE JOBS.	SH. 10
JOBWAKE:	USED TO WAKE UP A SLEEPING JOB. IF JOB IS NOT FOUND, -1 IS LOADED INTO LOCCTR.	SH. 11
CHANG1:	USED BY A BASIC JOB TO GIVE CONTROL TO JOB POINTED TO BY NEWJOB.	SH. 13
CHANG2:	USED BY THE INTERPRETER TO GIVE CONTROL TO JOB POINTED TO BY NEWJOB.	SH. 13
ADVAN:	CHECK ON NEWJOB CALLED BY SELF CHECKING ROUTINE	SH. 16

SPECIAL CONVENTION: DOUBLE ARROW MEANS EXCHANGE OPERATION

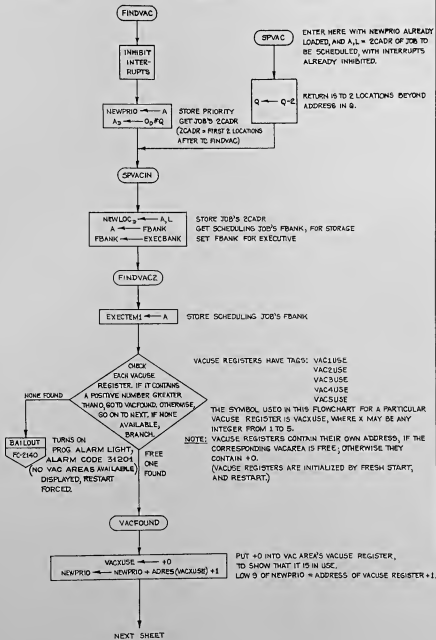
ENCLOSED ARE REPLACEMENT SHEETS NEEDED TO UPDATE THE COLOSSUS IIA FLOWCHART FC-2050, REV. 0, TO THE COLOSSUS IIC FLOWCHART FC-2050, REV. 1.

EFFECTIVE SHEETS NOW ARE:

SH. 1 - 2	REV. 0
SH. 3 - 4	REV. 1
SH. 5 - 20	REV. 0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
THE EXECUTIVE			
DRAWN A.C. WILLIAMS	DESIGNED	DOCUMENT NO.	
PCWDR <i>P. Roper</i>	6-25-67	FC-2050	
ANALYST		SHEET 1 OF 80	
DOCKED <i>D. Roper</i>	6-27-68	COLOSSUS IIC	
APPROVED <i>Alfred M. Schmitt</i>	REV 1		





MIT  
 ELECTRONICS LAB  
 CAMBRIDGE, MASS.

APPROVED: J. A. WILLIAMS  
 DATE: 6-26-68  
 BY: P. R. [Signature]

THE EXECUTIVE  
 COLLOSSUS II C  
 FC-2050  
 4

FROM PRECEDING SHEET

NOVAC

INHIBIT  
INTER-  
RUPTS

NEWPRIO ← A + 110<sub>6</sub>

NEWLOC ← 07Q  
EXECTEM1 ← FBANK  
FBANK ← EXECBANK

FAKEPRIET = OCTAL 110 (TAKES PLACE OF VAC ADRES) SEEMS TO ALLOW QPRIET TO BE SET TO WPAC + 6, PERMITTING A NOVAC JOB TO DO AN INTERPRETIVE "CALL" ORDER, FOR EXAMPLE.  
STORE 2CADR OF NEW JOB.  
STORE SCHEDULING JOB'S FBANK FOR RETURN.  
SET FBANK FOR EXECUTIVE.

NOVAC2

LOOCTR ← 0  
A ← G

INITIALIZE LOOCTR, THE STORAGE FOR CORE SET INDEX.  
PREPARE TO INITIALIZE EXECTEM2.

NOVAC3

START OF CORE SEARCH LOOP

EXECTEM2 ← A

A ← EXECTEM2 - 1

IS CORE SET POINTED TO BY LOOCTR AVAILABLE?

IS  
PRIORITY# LOOCTR  
= -0?

A PRIORITY REGISTER CONTAINS A NEGATIVE NUMBER IF IT INDICATES A DORMANT JOB OCCUPIES THE CORRESPONDING CORE SET. A POSITIVE NUMBER MEANS ACTIVE JOB, AND MINUS 0 MEANS CORESET IS FREE.

NO  
DO OR DO  
TRY NEXT  
ONE

NEXTCORE

ADD 122 TO LOOCTR

LOOCTR ← LOOCTR + COREINC

CORFOUND

PRIORITY# LOOCTR ← NEWPRIO  
PUSHLOC# LOOCTR ← BITS 1-9 OF NEWPRIO

INSERT PRIORITY & VAC ADDRESS + 1  
OR FAKE PRIET.  
GIVE PUSHLOC ITS STARTING VALUE.

WAS THAT THE  
LAST CORE SET?

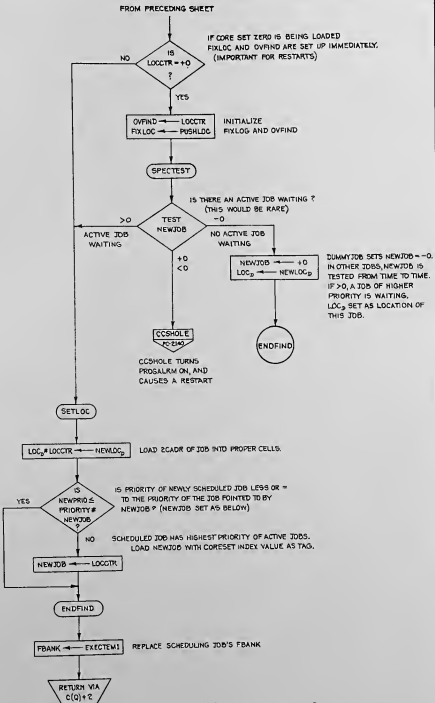
IS  
EXECTEM2 = +0?

BALLOUT  
FC=140

BALLOUT TURNS ON  
PRGM ALARM LIGHT, DISPLAYS  
ALARM CODE 31202  
(NO CORE SETS AVAILABLE),  
FORCES RESTART.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		THE EXECUTIVE	
DRAWN A. C. WILLIAMS	DESIGNED J. W. GALT	COLOSSUS IIC	
PREPARED P. B. GALT	6-26-57	FC-2050	
ANALYST		4 20	
OPERATOR			
APPROVED			



SEARCHED INDEXED  
SERIALIZED FILED  
FBI - DENVER  
MAY 1964

SMARS-9  
6-26-69

THE EXECUTIVE

FC-2050

6-27-69

COLLOSUS IIC

1

20

THIS ROUTINE IS CALLED TO TERMINATE A JOB. IT FREES ITS CORE SET AND VAC AREA, IF ANY, AND SEARCHES FOR HIGHEST PRIORITY AMONG THE ACTIVE JOBS. IF IT FINDS NO ACTIVE JOBS, IT TRANSFERS CONTROL TO DUMMY JOB.

ENDOFJOB

FBANK ← EXECBANK FBANK MUST BE SET

ENDJOB1

INHIBIT  
INTER-  
RUPTS

A ← -ZERO  
BUF +1 → A  
L ← BITS 9:10 OF PRIORITY  
PRIORITY ← A

MINUS ZERO INITIALIZES BUF +1 FOR ETSKAN TEST FOR ACTIVE JOBS. IF IT REMAINS UNCHANGED, THERE ARE NO ACTIVE JOBS. PRIORITY = -ZERO FREES CORESET 0. JOB WITH HIGHEST PRIORITY (ACTIVE) WILL TAKE OVER CORESET 0, AND -0 WILL BE EXCHANGED TO FREE ITS OLD CORESET.

IF L (THE LOW 9 BITS OF THE PRIORITY WORD) = FAKEPRET (110<sub>2</sub>), THEN THE JOB TO BE ENDED WAS A NOVAC JOB. OTHERWISE, L = ADDRESS OF VAC AREA + 1.

IS  
L = FAKEPRET ?

YES  
NOVAC

NO: FINDVAC JOB,  
VAC AREA MUST  
BE RELEASED.

0 ← (L-1) ← L-1

LOAD ADDRESS OF VAC AREA (LOW 9 OF PRIORITY - 1) INTO THE CORRESPONDING VACUSE REGISTER. (THE VACUSE REGISTER OF A FREE VAC AREA CONTAINS ITS OWN ADDRESS, IT CONTAINS +0 IF THE VAC AREA IS IN USE)

ETSKAN

ENTRY FROM JOBSLEEP AND PRIORCHG (VIA JOBSL2)

TEST  
PRIORITY + 12D

EJ1: FIRST TIME ENTERED

INPUT:

A = (PRIORITY + 12D) - 1  
BUF + 1 = -0, IF ENTERED FROM  
ENDOFJOB OR JOBSLEEP  
= -NEW PRIORITY IF ENTERED  
VIA PRIORCHG.

BUF = +ZERO, IF PRIORCHG, INDETER-  
MINATE, OTHERWISE.

OUTPUT: IF A PRIORCHG, EJ1 COMPARES  
CHANGED PRIORITY WITH (PRIORITY + 12D)  
- 1. IF CHANGED PRIORITY IS STILL  
HIGH, RETURN. IF NOT, OR IF ENTERED  
FROM ENDOFJOB OR JOBSLEEP,  
BUF + 2 = [(PRIORITY + 12D) - 1]  
BUF = Q

A ← (PRIORITY + 12D) - 1

CSHOLE  
FC-2140

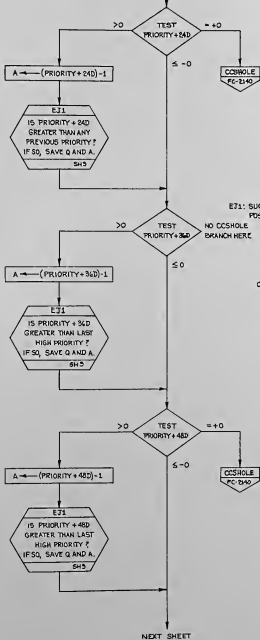
EJ1  
IS PRIORITY + 12D  
GREATER THAN ANY  
PREVIOUS PRIORITY  
(AS IN PRIORCHG)?  
IF SO, SAVE A AND Q.  
SMS

NEXT SHEET

ENVIRONMENTAL DIVISION  
CAMBRIDGE MASS.  
30 ANN A.C. WILLIAMS  
FOLIO 1  
P. Rye  
APPROV  
DATE 11/17/68

THE EXECUTIVE  
COLOSSUS II C  
FC-2050  
1 C 20

FROM PRECEDING SHEET



E11: SUCCEEDING ENTRANCES (CONSIDER 12X TO BE POSITIVE, NON-ZERO MULTIPLE OF 12D)

INPUT:

$A_p = (PRIORITY + 12X) - 1$   
 $BUF+1 =$  -HIGHEST PRIORITY YET FOUND.  
 $BUF =$  + ZERO IF ENTERED VIA PRIORITYING,  
 & CHANGED PRIORITY STILL HIGH,  
 $=$  Q OF HIGHEST YET FOUND, OTHERWISE

OUTPUT:

IF  $|A|$  IS STRICTLY LARGER THAN  $|BUF+1|$   
 $BUF+1 = -A$ ,  $BUF = Q$   
 NO CHANGE OTHERWISE.

NEXT SHEET

THE EXECUTIVE

COLLOSSUS III C FC-2050

DATE: 6-27-65

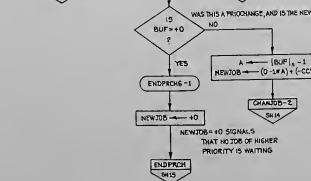
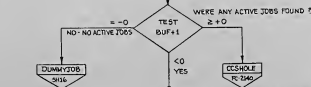
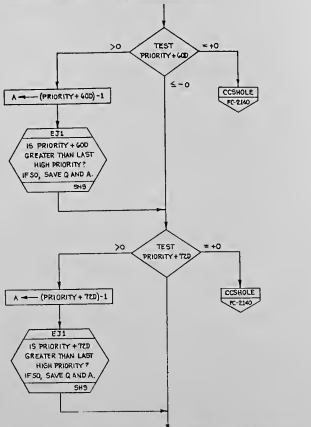
APPROVED: *[Signature]*

BY: *[Signature]*

FOR: *[Signature]*

REVISION: 1

FROM PRECEDING SHEET

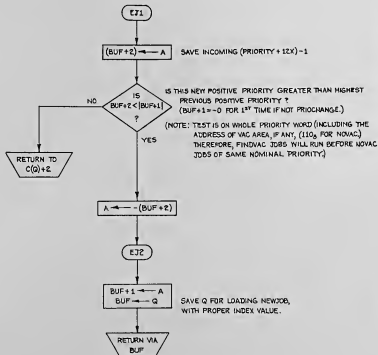


THIS OPERATION HAS THE EFFECT OF LOADING THE CORE SET NUMBER OF THE HIGHEST PRIORITY JOB INTO NEWJOB. NEWJOB IS USED BY CHANJOB FOR INDEXING. -CCSPR = COMPLEMENT OF A CELL CONTAINING INSTRUCTION; CCS = PRIORITY.

APPROVED: *[Signature]*  
 SPECIAL AGENT IN CHARGE  
 SECURITY DIVISION  
 FEDERAL BUREAU OF INVESTIGATION  
 WASHINGTON, D. C. 20535

THE EXECUTIVE  
 JOURNAL  
 COLDESSUP IIC  
 FC-2050  
 8 20





DATE: 6-27-64 DRAWN: A.C. WILLIAMS CHECKED: P. R. [Signature] APPROVED: [Signature] TITLE: [Signature]	THE EXECUTIVE COLLOSSUS II C FC-2050 REV. 1
--	--

PRI0CHNG

INHIBIT  
INTER-  
RUPTS

NEWPRIO ← A  
BANKSET ← B BANK  
EBANK ← EXECBANK  
LOC ← Q

PREPARE FOR PRIORITY CHANGE.  
SET BANKSET TO PREPARE EADR OF RETURN LOCATION.  
SET EBANK TO EXECBANK.  
SET 5 - REGISTER OF ECADR

PRI0CHZ

BUF ← ZERO  
PRIORITY ← (BITS 5-1 OF PRIORITY) + NEWPRIO  
A ← - PRIORITY

SET BUF + 40 FOR TAG TO EJSCAN: INDICATES  
ENTRY VIA PRI0CHNG  
SET UP NEW PRIORITY WITH ADDRESS OF VAC AREA (X LOC)  
- PRIORITY PUT INTO BUF + 1 FOR COMPARISON WITH  
OTHER PRIORITY WORDS.

J0BSLEEP

LOC ← A  
FBANK ← EXECBANK

A = CADR OF FIRST INSTRUCTION TO BE  
PERFORMED UPON AWAKENING.  
SET FBANK

J0BSLP1

INHIBIT  
INTER-  
RUPTS

PRIORITY ← - PRIORITY  
A ← LOW # OF EBANK

NEGATIVE PRIORITY INDICATES A DORMANT JOB.  
GET EBANK

SUPERBANK  
INTO  
A 7-5

GET SUPERBANK BITS

BANKSET ← A  
A ← - ZERO

MINUS ZERO, SUBSEQUENTLY LOADED INTO BUF + 1,  
WILL INDICATE TO EJSCAN THAT NO JOBS ARE AWAKE,  
IF IT REMAINS UNTOUCHED.

J0BSLP2

ENTRY FOR PRI0CHNG.

BUF + 1 ← A

INITIALIZE FOR EJSCAN.

EJSCAN  
SH6

FIND HIGHEST JOB PRIORITY,  
AND PUT IT ON. (OR GO TO  
DUMMYJOB)

TITLE INFORMATION EXPENSE, MAIL	FILED AND NUMBERED
DIRECTOR A.C. WILLIAMS SPECIAL AGENT <i>P. Rye</i>	DATE 6-24-68
DIVISION <i>S.A. Williams</i>	COLLOSSUS IIC
APPROVED <i>Alvin P. Vincent</i>	DOCUMENT # <b>FC-2050</b> PAGE 10 OF 20

JOBWAKE

INHIBIT  
INTER-  
RUPTS

Q ← Q-2

RETURN IS TO TWO  
LOCATIONS BEYOND ADDRESS IN Q.

NEWLOC ← A  
A ← FBANK  
FBANK ← EXECBANK

A CONTAINS ADDR OF JOB TO BE AWAKENED.  
SAVE FBANK  
SET EXEC FBANK

JOBWAKE2

EXECITEM ← A  
LOGCTR ← 0  
A ← 6

STORE CALLING FBANK  
INITIALIZE  
SEARCH LOOP

NEXT SHEET

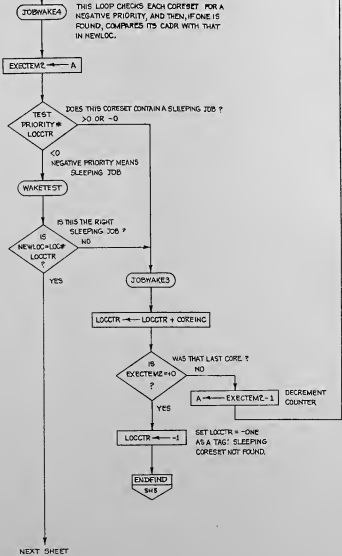
SEARCHED  
SERIALIZED  
INDEXED  
FILED  
A.C. WILLIAMS  
P. Rye  
D. J. Lamb  
AUG 27 1951  
AUG 27 1951

THE EXECUTIVE

COLOSSUS II C

FC-2050

FROM PRECEDING SHEET



W-1  
 NEW STATE  
 2000 11 15  
 A.C. WILLIAMS  
 P.K.G.  
 6-27-62  
 21074

THE EXECUTIVE

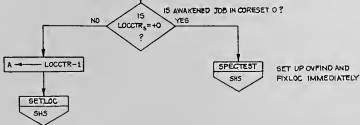
COLOSSUS IIC

FC-2050

FROM PRECEDING SHEET

NEWPRIO ← - PRIORITY # LOCCTR  
 PRIORITY # LOCCTR ← - PRIORITY # LOCCTR  
 NEWLOC + 1 ← BANKSET # LOCCTR + BITS 15-11 OF NEWLOC  
 NEWLOC ← BIT 11 + BITS 10-1 OF NEWLOC

- 1) SET POSITIVE PRIORITY INTO NEWPRIO (AWAKENED JOBS USE FINDVAC-NOWAC ROUTINE)
- 2) MAKE AWAKENED PRIORITY POSITIVE.
- 3) FORM ZCADR OF AWAKENING LOCATION.



CHANG1 SUSPENDS A BASIC LANGUAGE JOB SO THAT A HIGHER PRIORITY JOB (POINTED TO BY NEWJOB) CAN BE EXECUTED.

L ← Q  
 A ← B\$BANK  
 B\$BANK ← EXECBANK

SAVE RETURN ADDRESS CADR  
SAVE B\$BANK

CHANGJOB SH34

CHANG2 SUSPENDS A JOB CURRENTLY UNDER CONTROL OF INTERPRETER SO THAT A HIGHER PRIORITY JOB, POINTED TO BY NEWJOB, CAN BE EXECUTED.

L ← -LOC

NEGATIVE LOC IN L INDICATES THIS WAS AN INTERPRETIVE JOB.

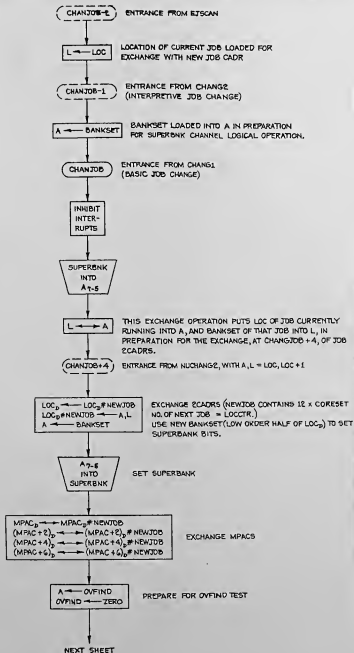
CHANG2+2

B\$BANK ← EXECBANK

SET EXECUTIVE B\$BANK.

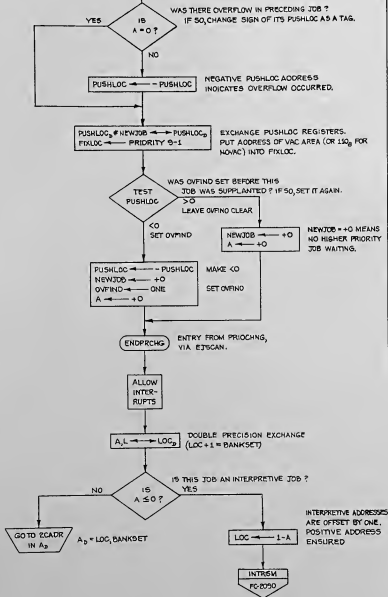
CHANGJOB-1 SH34

A.C. WILLIAMS <i>P. Rye</i> <i>Ed. Rye</i> <i>11/15/60</i>	THE EXECUTIVE COLOSSUS IIC DOCUMENT # <b>FC-2050</b> NOV 15 1960
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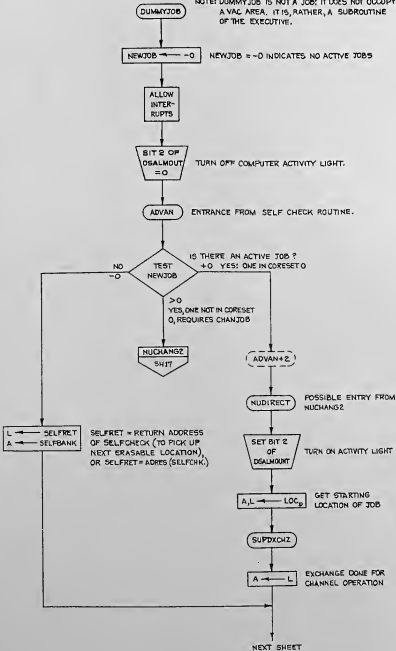
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		THE EXECUTIVE	
PREPARED <i>S. R. King</i>	DATE <i>1-1-62</i>	COLLOSSUS II C	DOCUMENT NO. <b>FC-2050</b>
ANALYST <i>B. J. P. ...</i>	REV <i>1</i>		5-111 24 OF 20
DOCTOR <i>B. J. P. ...</i>	REV <i>1</i>		
APPROVED <i>Alvin ...</i>	REV <i>1</i>		

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AP-410 DESIGN AND NAVIGATION	
THE EXECUTIVE			
DRAWN A.C. WILLIAMS	DATE 6-26-62	COLDSPRUS II C	DOCUMENT NO. FC-2050
PREPARED P. Rye	REV 1		
ANALYST J. Rye	6-28-62	SHEET 15 OF 20	
APPROVED C. Rye			

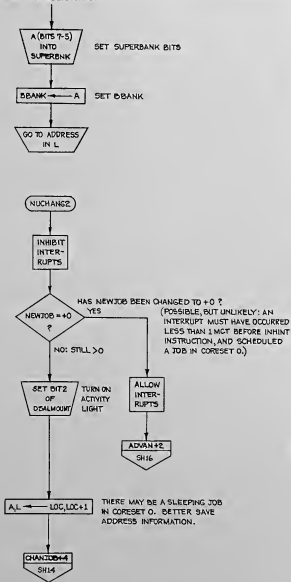
NOTE: DUMMYJOB IS NOT A JOB; IT DOES NOT OCCUPY A VAC AREA. IT IS, RATHER, A SUBROUTINE OF THE EXECUTIVE.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		THE EXECUTIVE	
FR: MR P. Rye	DATE 5-24-67	DOCUMENT NO. FC-2050	
ANALYST J. J. Rye	REV 4	COLLOSSUS IIC	
APPROVED: [Signature]		REV 4	
		DOCUMENT NO. FC-2050	
		REV 4	



FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIG* CO	
DRAWN A.C. WILLIAMS		THE EXECUTIVE	
FORM	P. 105	DOCUMENT NO.	FC-2050
ANALYST		COLOSSUS IIC	
DESIGNER		REV 1	5-6-62
APPROVED			5-6-62

DIAGRAM OF CORESETS:

MPAC: 7 REGISTERS
MODE
LOC
BANKSET
PUSHLOC
PRIORITY

THE ACTIVE JOB, IF ANY, OCCUPIES FIRST CORESET. THERE ARE SIX OTHER CORESETS, OCCUPYING THE NEXT 72 LOC TIONS, FOR NON-ACTIVE JOBS, ALL IDENTICAL, AND ACCESSIBLE BY INDEXING.

4811 INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		THE EXECUTIVE	
DESIGNER <u>A.C. WILLIAMS</u> DRAWN BY <u>P.R.G.</u> ANALYST <u>J.P. [unclear]</u> CHECKED <u>[unclear]</u> APPROVED <u>[unclear]</u>	TAPR&S 6-26-67 6-27-67	COLLOSSUS IIC	DOCUMENT # FC-2050 PAGE 15 OF 20

## ERASABLE LOCATIONS USED

AGC  
TAG

MEANING

NOTE: IF A REGISTER IN CORESET 0 IS LISTED, IT SHOULD BE ASSUMED THAT CORRESPONDING REGISTERS IN OTHER CORESETS ARE ALSO USED. "ACTIVE" AND "NOT ACTIVE" REFER TO THE SIGNIFICANCE OF A CELL WHEN ITS JOB IS ACTIVE, AND THAT WHEN THE JOB IS NOT ACTIVE, RESPECTIVELY.

BANKSET ACTIVE: BBANK ASSOCIATED WITH LOC IN INTERPRETER. OTHERWISE, UNSAVED STORAGE CELL.  
NOT ACTIVE: BBANK (AND SUPERBNK) ASSOCIATED WITH LOC; EBANK AND SUPERBNK IF FROM JOBSLEEP.

BBANK

BUF BUFFER IN EJSCAN

BUF +1 BUFFER IN EJSCAN

BUF +2 BUFFER IN EJSCAN

LSALNOUT CHANNEL 11; WRITTEN INTO BY DUMMYJOB TO TURN ON AND OFF THE ACTIVITY LIGHT.

EXECTEM1 TEMPORARY STORAGE, USUALLY HOLDS Q

EXECTEM2 TEMPORARY STORAGE.

FBANK

FIXLOC CONTAINS ABSOLUTE ADDRESS OF START OF VAC AREA

LOC ACTIVE: ADDRESS INFORMATION FOR OPERAND IN INTERPRETER; UNSAVED OTHERWISE.  
NOT ACTIVE: (1) - ACTIVE CONTENTS, IF JOB WAS RUNNING IN INTERPRETER;  
(2) - STARTING LOCATION OF BASIC LANGUAGE JOB; OR (3) - CADR OF WAKING ADDRESS FOR SLEEPING JOB.

LOCCR

MPAC } MULTIPURPOSE ACCUMULATOR FOR INTERPRETER, OTHERWISE STORAGE.

MPAC +2, }  
ETC. }

NEWJOB -0 IF IN DUMMYJOB, AND NO NON-DORMANT JOB SCHEDULED  
+0 IF CURRENTLY ACTIVE JOB HAS HIGHEST PRIORITY. POSITIVE INDEX VALUE OF THE CORESET OF HIGHEST PRIORITY NON-SLEEPING JOB, OTHERWISE.

NEWLOC STARTING LOCATION OF JOB BEING SCHEDULED

NEWPRIO PRIORITY OF JOB BEING SCHEDULED (OR NEW PRIORITY IN PRIORITY)

OVFPND OVERFLOW REGISTER (INTERPRETER)

PRIORITY PRIORITY OF JOB (IN HIGH ORDER BITS) AND IN LOW ORDER BITS: ADDRESS OF THE VAC AREA (OR 110<sub>8</sub> IF A NOVAC JOB).

PUSHLOC ACTIVE: CURRENT ADDRESS OF NEXT CELL TO BE LOADED IN PUSHLIST, IF INTERPRETER.  
NOT ACTIVE: IF OVFPND +0, SET TO -PUSHLOC, SAME AS ACTIVE, OTHERWISE.

SELFRET RETURN ADDRESS TO SELF CHECK ROUTINE

VAC1USE }  
VAC2USE }  
VAC3USE } CONTAIN OWN ADDRESS IF VAC AREA NOT IN USE. OTHERWISE, CONTAIN +0.  
VAC4USE }  
VAC5USE }

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AROLD GUIDANCE AND NAVIGATION	
		THE EXECUTIVE	
DRAWN <i>[Signature]</i>	<i>[Signature]</i>	COLOSSUS IIC	DOCUMENT NO.
PHONE <i>[Signature]</i>	<i>[Signature]</i>		FC-2050
ANALYST			
DOCNO <i>[Signature]</i>	<i>[Signature]</i>		
APPROV <i>[Signature]</i>	<i>[Signature]</i>	REV 1	SHEET 19 OF 20

PROGRAM CONSTANTS

AGC TAG	MEANING
-CCSPR	COMPLEMENT OF A CCS PRIORITY INSTRUCTION, TO OBTAIN THE CORRECT INDEX VALUE IN EJSCAN
CORINC	DEC. 12, THE SIZE OF A CORESET
EXECBANK	BANK SETTING FOR THE EXECUTIVE
FAKEPRET	OCT. 110, TO BE LOADED INTO PRIORITY, IN LIEU OF A VAC AREA ADDRESS
NO.CORES	DEC. 6, FOR INDEXING CORESETS.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARTICLE GUIDANCE AND NAVIGATION	
		THE EXECUTIVE	
BY <u>FRANK A. WILLIAMS</u>	DATE <u>7/27/58</u>		
CHKD <u>P. Rye</u>	DATE <u>6-26-58</u>		
ANAL <u>P. Rye</u>		COLLOSSUS II C	DOCUMENT NO. <b>FC-2050</b>
DOCTR <u>P. Rye</u>	DATE <u>6-25-58</u>		
APPR <u>FRANK A. WILLIAMS</u>	DATE <u>7/27/58</u>	REV 1	SHEET 20 OF 20

WAITLIST PROGRAM SECTION

ENTRIES	SHEET	DESCRIPTION
TWIDDLE	9	SCHEDULES TASK IN SAME BANK. GENADR OF TASK IS GIVEN IN LOCATION $\mathcal{L}+1$ , WHERE $\mathcal{L} = TC$ TWIDDLE. DELTA TIME IS IN A. RETURNS TO LOCATION $\mathcal{L}+2$ OF CALLING SEQUENCE. SINGLE-PRECISION DELTA TIME.
WAITLIST	9	SCHEDULES TASK IN ANOTHER BANK. 2CADR OF TASK IS GIVEN IN LOCATIONS $\mathcal{L}+1$ AND $\mathcal{L}+2$ , WHERE $\mathcal{L} = TC$ WAITLIST. DELTA TIME IS IN A. RETURNS TO LOCATION $\mathcal{L}+3$ OF CALLING SEQUENCE.
DLY2-1	10	SCHEDULES TASK WITH 2CADR OF TASK GIVEN IN A AND L. DELTA TIME IS IN Q. RETURN ADDRESS IS IN WAITEXIT.
FIXDELAY	10	DELAYS EXECUTION OF LOCATION $\mathcal{L}+2$ BY SCHEDULING LOCATION $\mathcal{L}+2$ OF CALLING SEQUENCE AS A TASK WHERE $\mathcal{L} = TC$ FIXDELAY. DELTA TIME IS GIVEN IN $\mathcal{L}+1$ . CALLING SEQUENCE IS A TASK WHICH CONTINUES INTO FIXDELAY, WHERE THIS TASK IS TERMINATED WITH A TRANSFER TO TASKOVER, UNTIL RESUMED AT $\mathcal{L}+2$ .
VARDELAY	10	DELAYS EXECUTION OF LOCATION $\mathcal{L}+1$ BY SCHEDULING LOCATION $\mathcal{L}+1$ OF CALLING SEQUENCE AS A TASK WHERE $\mathcal{L} = TC$ VARDELAY. DELTA TIME IS GIVEN IN A. LIKE FIXDELAY, THE CALLING SEQUENCE IS A TASK WHICH CONTINUES INTO VARDELAY, WHERE THIS TASK IS TERMINATED WITH A TRANSFER TO TASKOVER UNTIL RESUMED AT $\mathcal{L}+1$ .
T3RUPT	16	TRANSFERS CONTROL TO TASK WHOSE 2CADR IS IN LOCATION LST2+0 AND LST2+1. BEFORE EXECUTION OF TASK, TIMES IS SET FOR NEXT TASK. TABLES LST1 AND LST2 SHIFTED UPWARD, DUMMY JOB TIME INTERVAL AND 2CADR ADDED TO BOTTOM OF BOTH TABLES. AFTER EXECUTION OF TASK, CONTROL GOES TO TASKOVER. EITHER RETURN TO T3RUPT FOR NEXT TASK OR TO RESUME INTERRUPTED ROUTINE.
TASKOVER	18	ALL TASKS TERMINATE BY TRANSFERRING CONTROL TO TASKOVER, WHICH RETURNS CONTROL TO T3RUPT TO EXECUTE ANY TASK WHICH MAY HAVE BEEN WAITING TO BE PERFORMED DURING THE SAME INTERRUPT. IF NO OTHER TASK IS TO BE PERFORMED AT THIS TIME, CONTROL IS RETURNED TO THE INTERRUPTED ROUTINE AFTER RESTORING ORIGINAL CONTENTS TO CERTAIN REGISTERS.
LONGCALL	21	SCHEDULES TASK WITH DOUBLE-PRECISION DELTA TIME GIVEN IN A AND L AND ITS 2CADR IN LOCATIONS $\mathcal{L}+1$ AND $\mathcal{L}+2$ , WHERE $\mathcal{L} = TC$ LONGCALL. RETURNS TO LOCATION $\mathcal{L}+3$ OF CALLING SEQUENCE.

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2	DESCRIPTION
9	MAIN FLOW CHART
23	OUTLINE FLOW CHART
24	SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS
24	ERASABLE LOCATIONS USED

REV  
 1. update col II A to col II-C (Sh. 9, 13.)  
 2. Sh. 7 20 23

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLS GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> 9/16/68		WAITLIST	
PROGRAM	7-7-68	DOCUMENT NO.	FC-2060
ANALYST <i>[Signature]</i>	7-7-68	REV	2
APPROVED <i>[Signature]</i>	7/16/68	SHEET	1 of 24

WAITLIST PROGRAM SECTION

THIS WAITLIST PROGRAM SECTION IS USED FOR SCHEDULING AND EXECUTION OF TASKS. TASKS ARE ROUTINES WHICH ARE EXECUTED AFTER A GIVEN TIME PERIOD HAS ELAPSED FROM THE TIME THE TASK WAS SCHEDULED. THE TIME PERIOD IS REFERRED TO AS DELTA TIME (OR  $\Delta T$ ) AND IS EQUAL TO  $T_N - T$ , WHERE  $T_N$  IS THE TIME FOR TASK N TO BE EXECUTED AND T IS CURRENT TIME.

SCHEDULING USES ANY OF THE FOLLOWING SIX ENTRIES: FIXDELAY, VARDELAY, TWIDDLE, WAITLIST, DLY2-1, AND LONGCALL. THE ENTRY USED DEPENDS UPON WHERE THE INPUT DATA (DELTA TIME, ADDRESS OF THE TASK, AND RETURN ADDRESS TO THE CALLING SEQUENCE) IS SITUATED UPON ARRIVAL, AND ALSO DEPENDS UPON THE SIZE OF THE DELTA TIME.

LONGCALL IS INTENDED FOR HANDLING DOUBLE-PRECISION DELTA TIMES, THOUGH IT CAN ALSO HANDLE SINGLE-PRECISION DELTA TIMES. THE OTHER ENTRIES MENTIONED CAN HANDLE ONLY SINGLE-PRECISION DELTA TIMES. WAITLIST AND TWIDDLE WILL NOT ACCEPT ZERO OR NEGATIVE DELTA TIMES (RESULTS IN RESTART VIA POODOO). FIXDELAY, VARDELAY, AND DLY2-1 WILL ACCEPT ZERO OR NEGATIVE DELTA TIMES, BUT WILL SCHEDULE THE TASK FOR A DELTA TIME OF 163.84 SECONDS MINUS THE ABSOLUTE VALUE OF THE DELTA TIME. DELTA TIME IS IN A FOR VARDELAY, TWIDDLE AND WAITLIST. DELTA TIME IS IN Q FOR DLY2-1. DELTA TIME IS IN THE CALLING SEQUENCE FOR FIXDELAY ( $\alpha + 1$ ). DELTA TIME IS IN A AND L FOR LONGCALL. THE 2CADR OF THE TASK TO BE SCHEDULED IS FOUND IN THE CALLING SEQUENCE ( $\alpha + 1$  AND  $\alpha + 2$ ) FOR TWIDDLE (GENADR ONLY BECAUSE TASK IS IN SAME BANK), WAITLIST, AND LONGCALL, AND IN A AND L FOR DLY2-1, AND IS (not in but actually is) THE CALLING SEQUENCE FOR FIXDELAY ( $\alpha + 2$ ) AND VARDELAY ( $\alpha + 1$ ). THE RETURN ADDRESS IS THE NEXT LOCATION AFTER THOSE CONTAINING THE ADDRESS OF THE TASK IN THE CALLING SEQUENCE OF TWIDDLE, WAITLIST, AND LONGCALL. THE RETURN ADDRESS IS IN WAITEXIT FOR DLY2-1. THE USUAL RETURN ADDRESS DOES NOT EXIST FOR FIXDELAY AND VARDELAY UNLESS THE LOCATIONS IN THEIR CALLING SEQUENCES WHICH ARE SCHEDULED AS TASKS WERE REFERRED TO AS RETURN ADDRESSES WITH RETURN DELAYED BY DELTA TIME SECONDS.

SCHEDULING CONSISTS OF COMPARING THE EXECUTION TIME  $T_N$  OF THE NEW TASK TO BE SCHEDULED WITH THE EXECUTION TIME  $T_1$  OF TASK 1 (SO NUMBERED BECAUSE IT IS THE FIRST TO BE EXECUTED OF THOSE TASKS THAT WERE SCHEDULED AND NOT EXECUTED YET). TASKS 1, 2, 3, ..., 8 AND 9 WILL BE EXECUTED AT TIMES  $T_1, T_2, T_3, \dots, T_8$  AND  $T_9$ . ASSUME  $T_9 > T_8 > T_7$ , etc. UNTIL TASK N IS SCHEDULED, TIMES COUNTER WILL HAVE BEEN SET TO OVERFLOW AT TIME  $T_1$  FOR EXECUTION OF TASK 1 [TIME3 - OCT 40000 - ( $T_1 - T$ )]. THE TIME INTERVAL BETWEEN THE EXECUTION TIME OF EACH TASK AND THE NEXT TASK WILL HAVE BEEN PLACED INTO THE LST1 TABLE AND THE 2CADR OF EACH TASK INTO THE LST2 TABLE AS FOLLOWS:

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
WAITLIST		
DEFIN	<i>G. J. Campbell</i>	3 APR 68
PRIME		
ANALYST	<i>D. J. ...</i>	7-11-67
OWNER	<i>C. J. ...</i>	7-11-67
APPROD	<i>...</i>	7/12/67
COLOSSUS II, FC-2060		DOCUMENT NO.
		SHEET 2 OF 24

TASK	LST1 TABLE	LST2 TABLE
1	$TIMES = OCT\ 40000 - (T_1 - T)$	LST2+0 - GENADR OF TASK 1 LST2+1 - BCCON OF TASK 1
2	$LST1+0 = -(T_2 - T_1) + 1$	LST2+2 } 2CADR OF TASK 2 LST2+3 }
3	$LST1+1 = -(T_3 - T_2) + 1$	LST2+4 } 2CADR OF TASK 3 LST2+5 }
4	$LST1+2 = -(T_4 - T_3) + 1$	LST2+6 } 2CADR OF TASK 4 LST2+7 }
5	$LST1+3 = -(T_5 - T_4) + 1$	LST2+8 } 2CADR OF TASK 5 LST2+9 }
6	$LST1+4 = -(T_6 - T_5) + 1$	LST2+10 } 2CADR OF TASK 6 LST2+11 }
7	$LST1+5 = -(T_7 - T_6) + 1$	LST2+12 } 2CADR OF TASK 7 LST2+13 }
8	$LST1+6 = -(T_8 - T_7) + 1$	LST2+14 } 2CADR OF TASK 8 LST2+15 }
9	$LST1+7 = -(T_9 - T_8) + 1$	LST2+16 } 2CADR OF TASK 9 LST2+17 }
$\alpha$	$LST1+\alpha - 2 = -(T_\alpha - T_{\alpha-1}) + 1$	LST2 + 2 $\alpha$ - 2 } 2CADR OF TASK $\alpha$ LST2 + 2 $\alpha$ - 1 }

A SEARCH IS MADE OF THE LST1 TABLE TO FIND WHERE THE NEW TASK SHOULD BE PLACED SUCH THAT  $T_\alpha > T_N \geq T_{\alpha-1}$ .

IF THE NEW TASK (TASK N) SHOULD BE EXECUTED BEFORE TASK I ( $T_1 > T_N$ ), THEN

- (1) OCT 40000 -  $(T_N - T)$  IS SET INTO TIMES.
- (2)  $-(T_1 - T_N) + 1$  IS SET INTO LST1+0;  $-(T_2 - T_1) + 1$  IS SHIFTED FROM LST1+0 TO LST1+1;  $-(T_3 - T_2) + 1$  IS SHIFTED FROM LST1+1 TO LST1+2 ETC; AND  $-(T_9 - T_8) + 1$  IS DISCARDED.
- (3) THE 2CADR OF THE NEW TASK IS PLACED INTO LST2+0 AND LST2+1; THE 2CADR OF TASK I IS SHIFTED FROM LST2+0 AND LST2+1 TO LST2+2 AND LST2+3, ETC; THE 2CADR OF TASK 9 IS DISCARDED.
- (4) IF THE 2CADR OF TASK 9 WAS A 2CADR OF A REGULAR TASK (NOT A DUMMY TASK), A RESTART IS INITIATED VIA BAILOUT (AN ABORT), OTHERWISE RETURN TO THE CALLER.

ASSUMING THAT  $T_\alpha > T_N > T_\alpha$ , THEN THE TIME INTERVAL  $-(T_N - T_\alpha) + 1$  WOULD BE COMPUTED AND PLACED INTO LST1+4. ALSO, THE TIME INTERVAL  $-(T_6 - T_5) + 1$  WOULD BE COMPUTED AND PLACED INTO LST1+5 REPLACING  $-(T_7 - T_6) + 1$ , WHICH WOULD BE SHIFTED INTO LST1+6, AND THE TIME INTERVALS OF THE SUCCEEDING TASKS WOULD BE LIKEWISE SHIFTED DOWN UNTIL THE LAST ONE,  $-(T_9 - T_8) + 1$  WOULD BE DISCARDED. ALSO, THE 2CADR OF THE NEW TASK WOULD BE INSERTED INTO LST2+10 AND LST2+11, REPLACING THE 2CADR OF TASK 6, WHICH WOULD BE SHIFTED DOWN INTO LST2+12 AND LST2+13, AND THE 2CADR'S OF THE SUCCEEDING TASKS WOULD BE LIKEWISE SHIFTED DOWN UNTIL THE LAST ONE. IF THE LAST ONE IS THE 2CADR OF REGULAR TASK (NOT A DUMMY TASK), A RESTART IS INITIATED VIA BAILOUT (AN ABORT); OTHERWISE RETURN TO THE CALLER. THE TIME INTERVALS AND 2CADR'S FOR TASKS 1 THROUGH 5 WILL REMAIN INTACT IN THEIR LST1 AND LST2 REGISTERS.

ASSUMING THAT  $T_N = T_5$ , THEN TASK 5 WOULD BE EXECUTED BEFORE THE NEW TASK. TASKS WHOSE TIMES OF EXECUTION ARE THE SAME ARE EXECUTED IN THE SAME ORDER THAT THEY WERE SCHEDULED - THE FIRST ONE SCHEDULED IS THE FIRST ONE TO BE EXECUTED AND SO FORTH.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AROLD GUIDANCE AND NAVIGATION	
DRAWN <i>W. B. West</i> 2/1/62		WAITLIST	
PROGRAM	ANALYST <i>W. B. West</i>	COLOSSUS IIC	DOCUMENT NO. FC-2060
DOCNO <i>W. B. West</i>	DATE <i>2-1-62</i>		
APPROV <i>William M. Stewart</i>	DATE <i>2/1/62</i>	REV E	SHEET 3 OF 24

ASSUMING THAT  $T_N > T_9$ , THE SEARCH IN THE LST1 TABLE WILL REVEAL THAT THERE IS NO ROOM IN THE TABLE FOR THE NEW TASK, AND A RESTART IS INITIATED VIA BAILOUT.

THE LONGCALL TASK IS USED TO SCHEDULE TASKS WHOSE DELTA TIME IS IN DOUBLE PRECISION, WHICH CANNOT BE HANDLED BY THE WAITLIST (SINGLE-PRECISION) ENTRY. LONGCALL WILL HANDLE DELTA TIMES FROM OCT 00001 (0, 01 SECOND) TO [OCT 37777, OCT 37777] (2, 684, 354.55 SECONDS OR 745 HOURS, 39 MINUTES, AND 14.55 SECONDS). THE LONGCALL ROUTINE SCHEDULES ROUTINE LONGCYCL AS A WAITLIST TASK EVERY 81.92 SECONDS ( $\Delta T = 81.92$  SECONDS) IN A LOOP UNTIL THE UNUSED (REMAINING OR UNEXPIRED) PORTION OF THE DELTA TIME IS LESS THAN OR EQUAL TO 81.92 SECONDS. THEN ROUTINE GETCADR IS SCHEDULED AS A WAITLIST TASK TO BE EXECUTED AT THE END OF A TIME PERIOD EQUAL TO THE UNUSED LONGCALL DELTA TIME. THIS USING UP THE ENTIRE LONGCALL DELTA TIME. ROUTINE GETCADR WILL TRANSFER CONTROL DIRECTLY TO THE LONGCALL TASK, WHICH WILL TERMINATE WITH ROUTINE TASKOVER.

EXECUTION OF THE TASKS USES THE T3RUPRT ENTRY. ASSUME TASKS 1 THROUGH 9 ARE SCHEDULED AND THEIR TIME DATA AND 2CADR'S ARE IN THE TIMES (TASK 1) COUNTER AND LST1 AND LST2 TABLES. THEN CONTROL IS TRANSFERRED TO ENTRY T3RUPRT VIA THE LEAD-IN INTERRUPT ROUTINE AFTER INTERRUPTING SOME ROUTINE ELSEWHERE. WHEN  $T > T_1$ , THEN OCT 40000 - ( $T_1 - T$ ) IN TIME COUNTER TIMES WILL EQUAL OCT 40000, THE OVERFLOW CONDITION. ACTUALLY, TIMES WILL CHANGE FROM OCT 37777 TO OCT 00000 WITH THE LAST (BEFORE  $T > T_1$ ) INCREMENT OF THE TIME COUNTER. UPON OVERFLOW, INTERRUPT CONDITION IS STARTED. THIS CAUSES (1) THE INSTRUCTION AFTER THE INSTRUCTION BEING EXECUTED AT THE MOMENT THE INTERRUPT TOOK PLACE TO BE SAVED IN REGISTER BRUPT, AND (2) THE ADDRESS OF THE LOCATION AFTER THE LOCATION CONTAINING THE INSTRUCTION IN BRUPT TO BE SAVED IN REGISTER ZRUPRT (THIS INSTRUCTION AND THIS ADDRESS ARE LATER RESTORED BY INSTRUCTION RESUME WHEN THE INTERRUPTED ROUTINE IS RESUMED). THEN INTERRUPT CAUSES CONTROL TO BE TRANSFERRED TO THE T3RUPRT LEAD-IN ROUTINE FOR SAVING CONTENTS OF CERTAIN REGISTERS. CONTROL IS THEN TRANSFERRED TO ROUTINE T3RUPRT. BEFORE TASK 1 IS EXECUTED, TIMES WILL BE SET FOR TASK 2. THE TIME INTERVALS FOR EACH TASK WILL BE SHIFTED UPWARD ONE REGISTER, AND THE TIME INTERVAL (81.92 SECONDS) BETWEEN TASK 9 AND A DUMMY TASK WILL BE PLACED INTO THE LAST REGISTER LST1+7. IN ORDER TO SET TIMES FOR TASK 2, THE CONTENTS ( $T - T_1$ ) OF TIMES, OCT 37777, AND THE TIME INTERVAL  $-(T_2 - T_1) - 1$  FOR TASK 2 ARE ALL ADDED TOGETHER TO OBTAIN OCT 40000 - ( $T_2 - T$ ) WHICH IS PLACED INTO TIMES. IF TASK 2 WAS SCHEDULED FOR THE SAME TIME AS TASK 1 ( $T_1 = T_2$ ) OR THE T3RUPRT WAS DELAYED BY AN INHIBIT OR ANOTHER INTERRUPT ( $T > T_2$ ), THEN ROUTINE TASKOVER IS NOTIFIED THAT TASK 2 SHOULD BE EXECUTED IMMEDIATELY AFTER TASK 1 INSTEAD OF RESUMING THE INTERRUPTED ROUTINE. THE 2CADR'S IN THE LST2 ADDRESS TABLE ARE SHIFTED UPWARD, AND THE 2CADR OF A DUMMY TASK IS PLACED INTO THE LAST TWO REGISTERS LST2+16D AND LST2+17D. CONTROL IS THEN TRANSFERRED TO TASK 1 AT THE LOCATION WHOSE 2CADR WAS IN REGISTERS LST2+0 AND LST2+1 (THE TOP OF THE LIST). THEN THE TASK IS EXECUTED.

ALL TASKS TERMINATE IN A TRANSFER OF CONTROL TO ROUTINE TASKOVER. IF  $T > T_2$  WHEN CONTROL ARRIVED AT T3RUPRT TO EXECUTE TASK 1, THEN CONTROL WILL PASS FROM ROUTINE TASKOVER TO T3RUPRT2 LOCATION OF T3RUPRT TO INITIATE THE EXECUTION OF TASK 2. SET TIMES FOR TASK 3, AND SHIFT THE LST1 AND LST2 TABLES UPWARD. OTHERWISE, ROUTINE TASKOVER WILL TRANSFER CONTROL TO ROUTINE RESUME TO RESTORE ORIGINAL CONTENTS OF CERTAIN REGISTERS FOR RESUMING THE EXECUTION OF THE INTERRUPTED ROUTINE. LAST, CONTROL IS TRANSFERRED TO THE INTERRUPTED ROUTINE.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		WAITLIST	
DRAWN <i>P. Rys</i>	<i>7-8-62</i>	COLOSSUS IIC	DOCUMENT NO.
ANALYST <i>P. Rys</i>	<i>7-11-62</i>		FC-2060
DOCNO <i>P. H. Rys</i>	<i>7-11-62</i>		
APPROV <i>W. H. Rys</i>	<i>7/11/62</i>		
		REV 2	SHEET 4 OF 24



IF THE TASK TO BE EXECUTED WERE NOT A REGULAR TASK, BUT INSTEAD A DUMMY TASK, THEN DUMMY TASK SVCT3 WOULD BE EXECUTED. IF NO GYRO COMPENSATION IS REQUIRED, CONTROL IS TRANSFERRED TO ROUTINE TASKOVER. OTHERWISE, SVCT3 SCHEDULES (VIA TC NOVAC) ROUTINE NBDONLY AS A JOB (PRIORITY 35) TO COMPENSATE FOR NBD COEFFICIENTS ONLY. IF IMUSTALL IS NOT AVAILABLE, THEN A REGULAR TASK WILL BE SET UP VIA FIXDELAY WITH A DELTA TIME OF FIVE SECONDS TO COME BACK AND AGAIN ATTEMPT TO SCHEDULE JOB NBDONLY. IF IMUSTALL IS STILL NOT AVAILABLE, ANOTHER TASK WITH FIVE-SECOND DELAY IS SCHEDULED. AFTER THE DELAY IS SET UP OR AFTER THE JOB NBDONLY IS SCHEDULED, CONTROL IS TRANSFERRED TO TASKOVER.

SUMMARY OF THE TWO SALIENT OPERATIONS

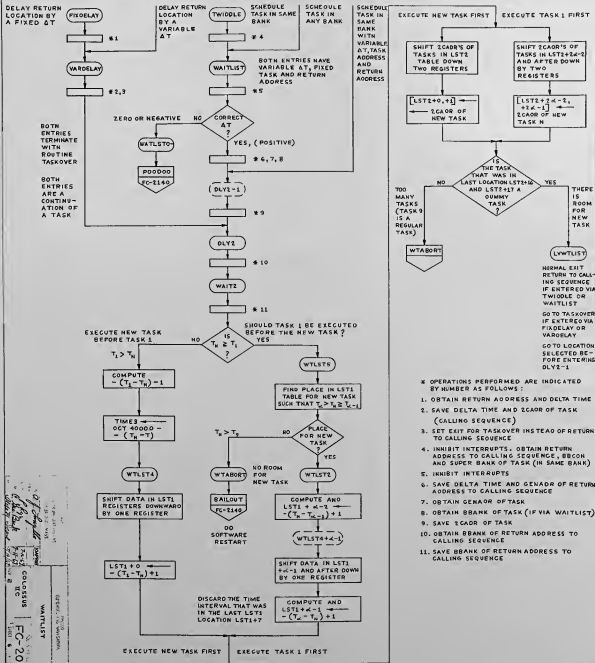
SCHEDULING A NEW TASK THE DELTA TIME OF THE NEW TASK IS  $T_N - T + \Delta T_N$ .  
 IF  $T_{\sigma-1} \leq T_N < T_{\sigma}$ , THE TIME INTERVAL  $-(T_N - T_{\sigma-1})+1$  REPLACES  $-(T_{\sigma} - T_{\sigma-1})+1$  AND  $-(T_{\sigma} - T_N)+1$  REPLACES  $-(T_{\sigma+1} - T_{\sigma})+1$ , WHICH IN TURN REPLACES  $-(T_{\sigma+2} - T_{\sigma+1})+1$ , ETC. IN THE LST1 TABLE. IF  $T_1 > T_N$ , THE TIME INTERVAL COUNTER VALUE OCT 40000  $-(T_N - T)$  REPLACES OCT 40000  $-(T_1 - T)$  IN TIME COUNTER TIMES AND  $-(T_1 - T_N)+1$  REPLACES  $-(T_2 - T_1)+1$ , WHICH IN TURN REPLACES  $-(T_3 - T_2)+1$ , ETC. IN THE LST1 TABLE. IF  $T_2 > T_3$ , THERE IS NO ROOM IN THE LST TABLES FOR THE NEW TASK, AND A RESTART IS INITIATED.

INITIATING THE EXECUTION OF A TASK (TASK1): THE  $-(T_2 - T_1)+1$  IN THE TOP OF THE LST1 TABLE, THE  $(T - T_1)$  IN TIMES  $(T > T_1)$  AND OCT 37777 ARE ADDED TOGETHER TO OBTAIN OCT 40000  $-(T_2 - T)$  TO BE SET INTO TIMES FOR TASK 2 AND ALL OTHER TIME INTERVALS IN THE LST1 TABLE ARE MOVED UP.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ANPLS GUIDANCE AND NAVIGATION	
		WAITLIST	
DRAWN PRGRM	<i>J. B. [unclear]</i>	DATE	DEC 16 62
ANALYST	<i>P. R. [unclear]</i>	7-16-62	
DOCTR	<i>C. H. [unclear]</i>	7-11-62	
APPRO'D	<i>[unclear]</i>	7/11/62	REV 2
		DOCUMENT NO.	FC-2060
		SHEET 5 OF 24	

FUNCTIONAL FLOW CHART OF WAITLIST TASK SCHEDULING

NOTE: THE TASK TO BE SCHEDULED IS REFERRED TO AS THE NEW TASK (TASK N). TASK 1 IS SO NUMBERED BECAUSE IT IS THE FIRST TASK TO BE EXECUTED AMONG THOSE TASKS, (TASKS 1, 2, 3, ..., B AND D) THAT HAVE BEEN SCHEDULED, BUT NOT EXECUTED YET. T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>, ..., T<sub>B</sub>, T<sub>D</sub> AND T<sub>N</sub> ARE THE EXECUTION TIMES OF TASKS 1, 2, 3, ..., B, D AND N, RESPECTIVELY. ASSUME T<sub>1</sub> < T<sub>2</sub> < ... < T<sub>B</sub> < T<sub>D</sub>. T IS CURRENT TIME.

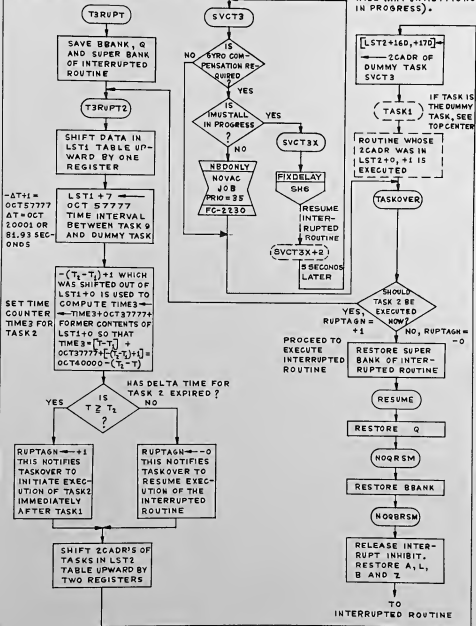


FC-2060  
 COLONISUS  
 FC-2060  
 FC-2060

FUNCTIONAL FLOW CHART FOR EXECUTION OF TASK

PREPARE TO EXECUTE TASK (ASSUME TASK1) WHOSE  $\Delta T$  EXPIRED ( $T = T_1$ ) BECAUSE TIME3 OVERFLOWED. ENTERS FROM INTERRUPTED ROUTINE VIA LEAD-IN INTERRUPT ROUTINE WHICH SAVES CONTENTS OF CERTAIN REGISTERS

SVCT3 IS THE DUMMY TASK. IT COMPENSATES FOR NBD COEFFICIENTS ONLY IF REQUIRED AND IMUSTALL IS NOT IN PROGRESS (IF IT IS IT WILL WAIT UNTIL IT IS NOT IN PROGRESS).



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CAMBRIDGE, MASS.

PROJECT: *Colossus*  
AUTH: *Ray*  
DIVER: *Jack & Rev*  
APP'D: *Jack & Rev*

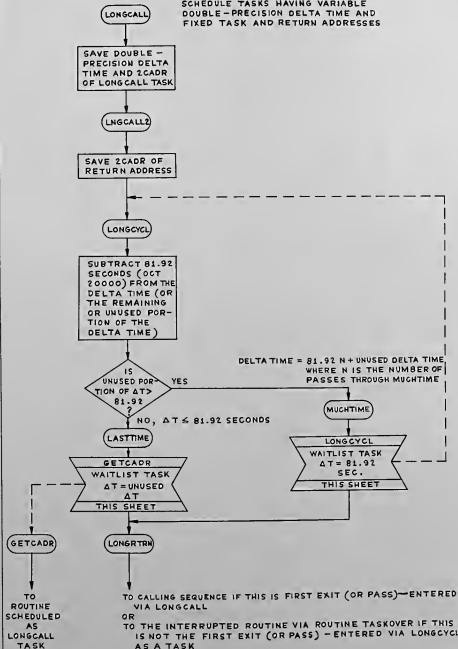
AFTR. C.  
GUIDANCE AND NAVIGATION

WAITLIST

COLLOSSUS IIC DOCUMENT NO. FC-2060  
REV 2 SHEET 7 OF 24

FUNCTIONAL FLOW CHART OF LONGCALL

SCHEDULE TASKS HAVING VARIABLE DOUBLE-PRECISION DELTA TIME AND FIXED TASK AND RETURN ADDRESSES



DELTA TIME = 81.92 N + UNUSED DELTA TIME WHERE N IS THE NUMBER OF PASSES THROUGH MUGHTIME

TO ROUTINE SCHEDULED AS LONGCALL TASK

TO CALLING SEQUENCE IF THIS IS FIRST EXIT (OR PASS) - ENTERED VIA LONGCALL  
OR  
TO THE INTERRUPTED ROUTINE VIA ROUTINE TASKOVER IF THIS IS NOT THE FIRST EXIT (OR PASS) - ENTERED VIA LONGCYCL AS A TASK

WAITLIST  
 COLLOSSUS IIC  
 FC-2060  
 SHEET 8 OF 24

*Handwritten notes:*  
 J. Longello  
 7/16/63  
 P. J. Beck  
 7-11-63  
 4378

MAIN (DETAILED) FLOW CHART

ENTRIES TWIDDLE AND WAITLIST ON THIS SHEET AND DLYZ-1, FIXDELAY AND VARDELAY ON NEXT SHEET ARE USED FOR SCHEDULING TASKS

ENTERED FROM 5 LOCATIONS WITH A = DELTA TIME

WAITLIST ENTRY ENTERED FROM 58 LOCATIONS WITH A = DELTA TIME

CALLING SEQUENCE:

- 2-1 CA 2-N
- 2+0 TC TWIDDLE
- 2+1 ADRES OF TASK
- 2+2 RELINT(RETURN HERE UNCONDITIONALLY)
- ...
- 2-N OCT XXXXX CENTI-SECONDS (DELTA TIME)

TWIDDLE

NOTE:

IF THE TASK IS IN THE SAME E BANK AND F BANK AS THE ROUTINE THAT INITIATED THE SCHEDULING OF IT, USE TWIDDLE ENTRY. IF EITHER BANK IS DIFFERENT, USE WAITLIST ENTRY.

CALLING SEQUENCE:

- 2-1 CA 2-N
- 2+0 TC WAITLIST
- 2+1 GENADR OF TASK
- 2+2 BBCON OF TASK
- 2+3 RELINT(RETURN HERE UNCONDITIONALLY)
- ...
- 2-N OCT XXXXX CENTI-SECONDS (DELTA TIME)

INHIBIT INTER-RUPTS

DECREMENT QBY1

Q = 2+0

L 15-11, 3-1 BBANK 15-11, 3-1  
L 7-5 SUPERBNK 7-5

L = BBCON AND SUPER BANK OF CALLER

WAITLIST

INHIBIT INTER-RUPTS

IS DELTA TIME CORRECTLY GIVEN?  
(IS  $\Delta T > +0$ ?)

NO

YES

WATLSTO-

PODDOO  
FC-2140

RESULTS IN RESTART WITH ALL GROUPS INACTIVE

WAITEXIT ← 0

WAITEXIT CONTAINS 2+0 WHERE 2- CONTAINS TC TWIDDLE  
OR  
WAITEXIT CONTAINS 2+1 WHERE 2- CONTAINS TC WAITLIST

TURN ON PROGRAM ALARM LIGHT AND SET ALARM CODE OCT 21200 INTO ONE OF THE FAILREG REGISTERS SO IT IS AVAILABLE FOR DISPLAY. IT INDICATES NEGATIVE OR ZERO DELTA TIME WAITLIST (OR TWIDDLE) CALL.

Q ← A

Q = DELTA TIME IN CENTISECONDS

VIA TWIDDLE VIA WAITLIST

A ← (2+1)

GENADR OF TASK

A ← (2+1)  
L ← (2+2)

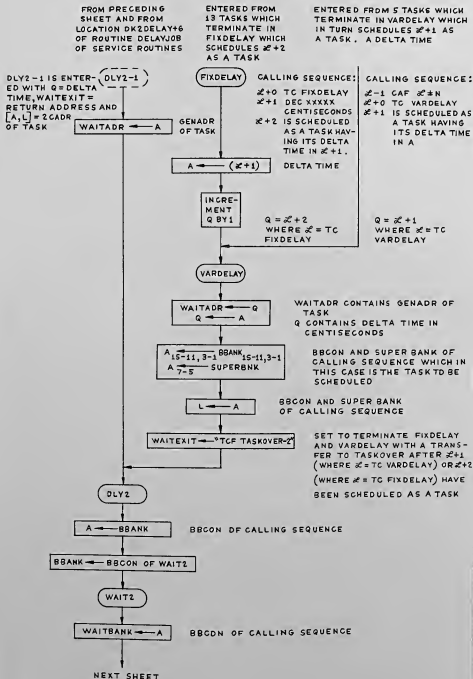
GENADR  
BBCON

2CADR OF TASK

NEXT SHEET

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DATE: <i>10/16/63</i> BY: <i>J. J. [Signature]</i> APPROVED: <i>[Signature]</i>		WAITLIST COLOSSUS IIC SEC. NO. FC-2060 DATE: 9/10/63	

MAIN (DETAILED) FLOW CHART



WAITLIST

*u. J. Sample* 151000  
*Pls* 7-16-69  
*C. W. Beck* 7-14-69

COLDESSUS  
 IIC

FC-2060

10 24

FROM  
PRECEDING SHEET

$A \leftarrow \text{OCT } 200 - \text{TIME3}$

$\text{TIME3} = \text{OCT } 40000 - (T_1 - T)$  IF  $\text{TIME3}$  DID NOT  
OVERFLOW DURING CURRENT INHINT.  
 $T_1 > T_N$

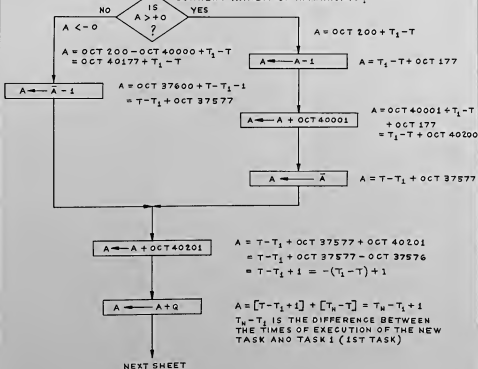
$\text{TIME3} = T - T_1$  IF  $\text{TIME3}$  OVERFLOWED DURING  
CURRENT INHINT.  $T_N > T_1$

WHERE  $T =$  CURRENT (NOW) TIME  
 $T_N, T_1, T_2, T_3,$  ETC. = TIME FOR NEXT (NEXT),  
2ND, 3RD, ECT. TASK  
TO BE EXECUTED.

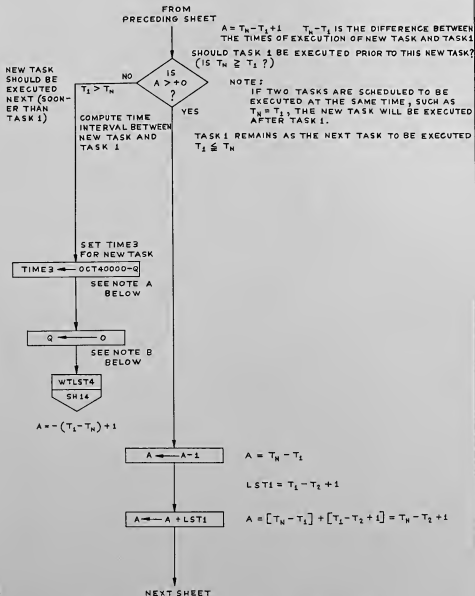
$\text{OCT } 200$  (OEC 128) IS A VALUE GREATER THAN THE HIGHEST  
POSSIBLE VALUE  $\text{TIME3}$  COULD HAVE NOW IF OVERFLOW  
OCCURRED SINCE CURRENT INHIBIT OF INTERRUPTS WAS  
STARTED. IF THE NEXT TASK HAD THE LARGEST ALLOW-  
ABLE DELTA TIME, 162.5 SECONOS,  $\text{TIME3}$  WOULD CON-  
TAIN  $\text{OCT } 206$ . THEREFORE,  $\text{OCT } 200$  IS A VALUE LESS  
THAN THE SMALLEST VALUE  $\text{TIME3}$  COULD HAVE IF OVER-  
FLOW DID NOT OCCUR. THUS  $\text{OCT } 200$  IS ACCEPTABLE  
TO USE AS A BREAK POINT.

PROCEED TO COMPUTE  $-(T_1 - T) + 1$  FOR EITHER  
OVERFLOW OR NO OVERFLOW CONOITION.

OCT  $\text{TIME3}$  OVERFLOW DURING  
CURRENT INHIBIT OF INTERRUPTS?



MIT ASTRONOMICAL OBSERVATORY CAMBRIDGE MASS.		APOLLO DISTANCE AND NAVIGATION	
DRAWN <i>A. J. S. Smith</i>		WAITLIST	
DATE <i>1/2/69</i>	SCALE <i>1/4" = 1"</i>	COLOSSUS IIC	DOCUMENT NO. FC-2060
BY <i>R. M. Beck</i>	DATE <i>1/2/69</i>	REV #	SHEET 11 OF 24



NOTE A : SET TIME COUNTER TIME3 TO OVERFLOW DELTA TIME CENTISECONDS FROM NOW (AT TIME  $T_N$ )

TIME3 = OCT 40000 - DELTA TIME = OCT 40000 - ( $T_N - T$ )

TIME3 IS NOW SET FOR THE NEW TASK

NOTE B : SET INDEX HEREAFTER REFERRED TO AS X1.

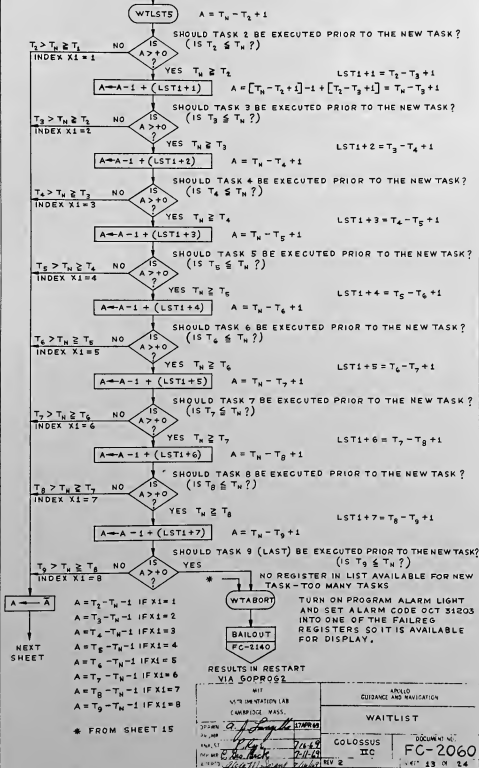
X1 = 0

MIT DOCUMENTATION LAB CAMBRIDGE, MASS.	AP-1-0 GLORIE AND NAVIGATION
APPROV. <i>A. J. Sanyal</i>	WAITLIST
DATE <i>7-1-57</i>	COLLOSSUS IIC
BY <i>P. G. Beck</i>	DOCUMENT NO. FC-2060
APPROV. <i>Beck</i>	SHEET 12 OF 24



FROM  
PRECEDING SHEET

FIND PLACE IN LST1 TABLE OF TIME  
INTERVALS FOR THE NEW TASK



MIT  
VLSI INVENTATION LAB  
CAMBRIDGE MASS.

*A. J. Sengupta* 3/27/69

DATE: 7/16/69  
BY: C. Ho, B. K. 7/16/69

FC-2140

ARLCO  
GUIDANCE AND NAVIGATION

WAITLIST

GOLOSSUS  
FC-2060

DOCUMENT NO.  
FC-2060

REV 2

1967 13 OF 24

FROM PRECEDING SHEET

WTLST2

$A = T_{\alpha} - T_{\alpha-1}$  WHERE  $\alpha = X1 + 1$  AND  $X1$  IS AN INDEX DETERMINED IN WTLST5 AND IS EITHER 1, 2, 3, 4, 5, 6, 7, OR 8 (SEE TABLE BELOW):

NOTE:  
Q WILL BE USED AS AN INDEX AND IS HEREAFTER REFERRED TO AS X1. SEE TABLE AT RIGHT FOR ITS VALUE.

Q ← (SEE NOTE)

(LST1-1 + X1) ←  
A + 1 + (LST1-1 + X1)

A ←  $\bar{A}$

X1 (BEFORE)	LST1-1+X1 (NOW)
1	$-(T_1 - T_1) + 1$ $-(T_{\alpha} - T_1) + 1$ IF $T_1 > T_{\alpha} \geq T_1$ , LST1+0
2	$-(T_2 - T_2) + 1$ $-(T_{\alpha} - T_2) + 1$ IF $T_2 > T_{\alpha} \geq T_2$ , LST1+1
3	$-(T_3 - T_3) + 1$ $-(T_{\alpha} - T_3) + 1$ IF $T_3 > T_{\alpha} \geq T_3$ , LST1+2
4	$-(T_4 - T_4) + 1$ $-(T_{\alpha} - T_4) + 1$ IF $T_4 > T_{\alpha} \geq T_4$ , LST1+3
5	$-(T_5 - T_5) + 1$ $-(T_{\alpha} - T_5) + 1$ IF $T_5 > T_{\alpha} \geq T_5$ , LST1+4
6	$-(T_6 - T_6) + 1$ $-(T_{\alpha} - T_6) + 1$ IF $T_6 > T_{\alpha} \geq T_6$ , LST1+5
7	$-(T_7 - T_7) + 1$ $-(T_{\alpha} - T_7) + 1$ IF $T_7 > T_{\alpha} \geq T_7$ , LST1+6
8	$-(T_8 - T_8) + 1$ $-(T_{\alpha} - T_8) + 1$ IF $T_8 > T_{\alpha} \geq T_8$ , LST1+7

NOW:

$A = - (T_2 - T_{\alpha}) + 1$	IF X1 = 1
$A = - (T_3 - T_{\alpha}) + 1$	IF X1 = 2
$A = - (T_4 - T_{\alpha}) + 1$	IF X1 = 3
$A = - (T_5 - T_{\alpha}) + 1$	IF X1 = 4
$A = - (T_6 - T_{\alpha}) + 1$	IF X1 = 5
$A = - (T_7 - T_{\alpha}) + 1$	IF X1 = 6
$A = - (T_8 - T_{\alpha}) + 1$	IF X1 = 7
$A = - (T_9 - T_{\alpha}) + 1$	IF X1 = 8

$A = T_{\alpha} - T_{\alpha-1} + 1$

X1 = 0

FROM WAIT5 ON SHEET 12 WITH  $A = T_{\alpha} - T_1 + 1$ ,  $T_1 > T_{\alpha}$

NEW TASK WAITING EXECUTION

WTLST4

SHIFT THE CONTENTS OF EACH OF SOME OR ALL LST1 REGISTERS TO THE NEXT LST1 REGISTER TO ACCOMMODATE THE VALUE FOR THE NEW TASK.

IF X1 = 1

LST1 ↔ A

IF X1 = 2

LST1+1 ↔ A

IF X1 = 3

LST1+2 ↔ A

IF X1 = 4

LST1+3 ↔ A

IF X1 = 5

LST1+4 ↔ A

IF X1 = 6

LST1+5 ↔ A

IF X1 = 7

LST1+6 ↔ A

IF X1 = 8

LST1+7 ↔ A

THE VALUE FOR THE NEW TASK IS  $T_{\alpha} - T_{\alpha-1} + 1$  IN A.  $\alpha$  IS DETERMINED BY THE CONDITION  $T_{\alpha} > T_{\alpha-1} \geq T_{\alpha-2}$ . THE VALUE  $T_{\alpha} - T_{\alpha-1} + 1$  IS PLACED INTO REGISTER LST1+ $\alpha-1$  SO THAT TASK N WILL BE EXECUTED  $T_{\alpha} - T_{\alpha-1}$  CENTISECONDS AFTER TASK  $\alpha-1$  AND  $T_{\alpha} - T_{\alpha-1}$  CENTISECONDS BEFORE TASK  $\alpha$ . THE FORMER CONTENTS OF LST1+ $\alpha-1$  WILL BE SHIFTED TO LST1+ $\alpha+0$ , THE FORMER CONTENTS OF LST1+ $\alpha+0$  TO LST1+ $\alpha+1$ , LST1+ $\alpha+1$  TO LST1+ $\alpha+2$ , ETC. TO THE END WHERE THE FORMER CONTENT OF LST1+7 IS LEFT IN A AND LOST THEREAFTER.  $\alpha$  IS EITHER 1, 2, 3, ..., 7, 8 OR 9. LST1 REGISTERS, IF ANY, PRECEDING LST1+ $\alpha-1$  REMAIN UNCHANGED.

LST1+ $\alpha-1$  ←  $-(T_{\alpha} - T_{\alpha}) + 1$ , IF X1 =  $\alpha-1$  UPON ARRIVAL

NEXT SHEET

REF. INFORMATION 12  
UNIT, DIV. 7471

QUALITY AND RELIABILITY

WAITLIST

APPROVED: *[Signature]*  
DATE: 7-16-59  
BY: *[Signature]*  
DATE: 7-16-59

COLOSSUS  
IIC

FC-2060

REV 2

16 8 24

FROM  
PRECEDING SHEET

SHIFT THE ADDRESS OF TASKS IN SOME OR ALL  
LST2 REGISTERS TO THE NEXT LST2 REGISTER  
TO ACCOMMODATE THE ADDRESS OF THE NEW TASK

A = GENADR OF THE NEW TASK (TASK N.)  
L = BBGON OF THE NEW TASK (L WAS SET  
ON SHEET 9)

A ← WAITAOR

IF X1 = 1, 2, 3, ... 8 OR 9

IF X1 = 0, T<sub>1</sub> > T<sub>N</sub> NEW TASK IS WAITING EXECUTION

[LST2, LST2+1] ⇌ [A, L]

IF X1 = 1

T<sub>2</sub> > T<sub>N</sub> ≥ T<sub>1</sub>

[LST2+2, LST2+3] ⇌ [A, L]

IF X1 = 2

T<sub>3</sub> > T<sub>N</sub> ≥ T<sub>2</sub>

[LST2+4, LST2+5] ⇌ [A, L]

IF X1 = 3

T<sub>4</sub> > T<sub>N</sub> ≥ T<sub>3</sub>

[LST2+6, LST2+7] ⇌ [A, L]

IF X1 = 4

T<sub>5</sub> > T<sub>N</sub> ≥ T<sub>4</sub>

[LST2+8, LST2+9] ⇌ [A, L]

IF X1 = 5

T<sub>6</sub> > T<sub>N</sub> ≥ T<sub>5</sub>

[LST2+10, LST2+11] ⇌ [A, L]

IF X1 = 6

T<sub>7</sub> > T<sub>N</sub> ≥ T<sub>6</sub>

[LST2+12, LST2+13] ⇌ [A, L]

IF X1 = 7

T<sub>8</sub> > T<sub>N</sub> ≥ T<sub>7</sub>

[LST2+14, LST2+15] ⇌ [A, L]

IF X1 = 8

T<sub>9</sub> > T<sub>N</sub> ≥ T<sub>8</sub>

[LST2+16, LST2+17] ⇌ [A, L]

SHIFTING OF ADDRESSES OF THE TASKS  
IN THE LST2 LIST IS DONE IN THE SAME  
MANNER AS THE TIME DATA WAS SHIFTED  
IN THE LST1 LIST.

THE 2CADR OF EACH TASK IS  
STORED IN THE LST2 LIST.

IS LST TABLE AVAILABLE TO ALL TASKS ?  
(WAS TASK IN LAST REGISTER A DUMMY TASK ?)

TOO  
MANY  
TASKS

NO

IS  
A = GENADR  
OF SVCT3  
?

YES

LST2+16 PREVIOUSLY CONTAINED GENADR  
SVCT3, THE DUMMY TASK

LVWTLIST

RETURN VIA  
WAITEXIT

WTABORT

SH13

RETURN TO CALLING SEQUENCE  
Z+2 WHERE Z = TC TWIDOLE,  
Z+3 WHERE Z = TC WAITLIST  
OR GO TO TASKOVER ON SHEET 18  
IF ENTERED VIA FIXDELAY OR VARDELAY  
OR GO TO LOCATION SET IN WAITEXIT  
BEFORE DLY2-1 WAS ENTERED

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DRAWN <i>A. J. Long</i>		WAITLIST	
PROGNO	<i>P. R. R.</i>	COLOSSUS	DOCUMENT NO.
ANALYST	<i>P. R. R.</i>	IIC	FC-2060
DRAWN	<i>P. R. R.</i>	REV 2	SHEET 15 OF 24
APPROV	<i>P. R. R.</i>		

NOT PART OF WAITLIST PROGRAM

SAVE A AND L FOR INTERRUPTED ROUTINE

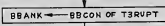
SAVE BBCON OF INTERRUPTED ROUTINE

FROM INTERRUPTED ROUTINE WHEN TIME COUNTER TIMES OVERFLOWS. DELTA TIME EXPIRED.

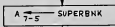
$$T \geq T_1$$



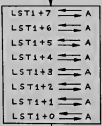
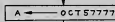
4014



T3RUPT



T3RUPT2



NEXT SHEET

\* - (T<sub>0</sub> - T<sub>9</sub>) + 1 = OCT 57777  
 OR (T<sub>0</sub> - T<sub>9</sub>) = - OCT 57776 =  
 OCT 20001 OR 81.93 SECONDS  
 WHERE T<sub>0</sub> IS EXECUTION TIME  
 OF DUMMY TASK SVCT3 (WILL BE  
 EXECUTED 81.93 SECONDS  
 AFTER TASK 9)

INTERRUPTED ROUTINE SEQUENCE

Z+0 ← (← IS INSTRUCTION BEING EXECUTED WHEN INTERRUPT BEGAN)  
 Z+1 ← (← IS INSTRUCTION TO BE EXECUTED FIRST UPON RESUMING INTERRUPTED ROUTINE)  
 Z+2

SAVE NEXT INSTRUCTION β AND ADDRESS Z+2 IN BRUPT AND ZRUPT, RESPECTIVELY.  
 HARDWARE ACTION AUTOMATICALLY PERFORMED AT BEGINNING OF INTERRUPT. SEE NOTE AT BOTTOM RIGHT OF SHEET 19.

NOTE:

IF, WHEN TIME COUNTER TIMES OVERFLOWS, INTERRUPTS ARE INHIBITED BY AN INHINT OR ANOTHER INTERRUPT IS IN PROGRESS AND/OR WAITING (T<sub>6</sub>, T<sub>5</sub>), TRANSFER OF PROGRAM CONTROL TO LOCATION 4014 WILL BE DELAYED UNTIL THE INHIBIT IS RELEASED (RELINT) OR INTERRUPT IN PROGRESS IS TERMINATED AND/OR T<sub>6</sub> OR T<sub>5</sub> INTERRUPT IS ALSO COMPLETED IF WAITING

INTERRUPT LEAD IN ROUTINE

ROUTINE T3RUPT CAUSES PROGRAM CONTROL TO BE TRANSFERRED TO TASK 1. ALSO, IT MOVES THE TIME INTERVAL DATA AND ZCADR FOR THE REMAINING SCHEDULED TASKS UPWARD ONE PLACE IN THE LST1 AND LST2 LISTS SO TASK 2 WILL BE READY NEXT TIME TIMES OVERFLOWS.

SUPER BANK AND BBCON OF INTERRUPTED ROUTINE COMBINED TOGETHER AND SAVED IN BANKRUPT.

SAVE Q

FROM ROUTINE TASKOVER ON SHEET 18

SCHEDULE TASK SVCT3 (SH 20) TO BE EXECUTED 81.93 SECONDS AFTER THE EXECUTION TIME OF THE TASK WHOSE GENADR IS IN LOCATION LST2 + 14

MOVE TIME DATA UPWARD ONE REGISTER IN LST1 TABLE

LST1+7	←	A	LST1+7 #	DUMMY TASK SVCT3
LST1+6	←	A	LST1+6 = - (T <sub>9</sub> - T <sub>8</sub> ) + 1	TASK 9
LST1+5	←	A	LST1+5 = - (T <sub>8</sub> - T <sub>7</sub> ) + 1	TASK 8
LST1+4	←	A	LST1+4 = - (T <sub>7</sub> - T <sub>6</sub> ) + 1	TASK 7
LST1+3	←	A	LST1+3 = - (T <sub>6</sub> - T <sub>5</sub> ) + 1	TASK 6
LST1+2	←	A	LST1+2 = - (T <sub>5</sub> - T <sub>4</sub> ) + 1	TASK 5
LST1+1	←	A	LST1+1 = - (T <sub>4</sub> - T <sub>3</sub> ) + 1	TASK 4
LST1+0	←	A	LST1+0 = - (T <sub>3</sub> - T <sub>2</sub> ) + 1	TASK 3
			A = - (T <sub>2</sub> - T <sub>1</sub> ) + 1	TASK 2

MIT COMMUNICATIONS LAB CAMBRIDGE, MASS.	APPROVED SUBMIT AND NAVIGATION
MIT COMMUNICATIONS LAB CAMBRIDGE, MASS.	WAITLIST
RESEARCH 2-11-63 2-11-63 2-11-63	COLOSSUS IIC DOCUMENT NO <b>FC-2060</b> SHEET 16 OF 24

FROM  
PRECEDING SHEET

THE FOLLOWING OPERATIONS WILL REVEAL WHETHER TASK 2 SHOULD BE EXECUTED IMMEDIATELY AFTER TASK 1 OR WHETHER THE INTERRUPTED ROUTINE SHOULD BE RESUMED AFTER TASK 1

TIME3 = TIME (CENTISECONDS) ELAPSED SINCE OVERFLOW  
 $T - T_1 = \text{OCT } 00000$  IF NO DELAY (INHINTOR OTHER INTERRUPTS) AND PROBABLY NO MORE THAN  $\text{OCT } 00002$  IF THERE IS A DELAY.

A =  $-(T_2 - T_1) + 1$   
T = CURRENT TIME (NOW)  
 $T_1$  = EXECUTION TIME OF TASK 1  
 $T_2$  = EXECUTION TIME OF TASK 2

A ← OCT 37777 + A

THIS OPERATION WILL PRODUCE AN OVERFLOW CONDITION IN A ONLY IF  $T_2 = T_1$

A ← TIME3 + A

OVERFLOW WOULD OCCUR IN A IF THE ELAPSED TIME (COUNTED UP BY TIME 3) IS EQUAL TO OR GREATER THAN  $T_2 - T_1$

SHOULD TASK 2 BE EXECUTED IMMEDIATELY AFTER TASK 1?  
(HAS DELTA TIME FOR TASK 2 EXPIRED? - HAS DELAY EXCEEDED TIME INTERVAL BETWEEN TASK 1 AND TASK 2?)

YES  
DOES A CONTAIN OVERFLOW?

$(T - T_1) \geq (T_2 - T_1)$   
 $T \geq T_2$

NO  $(T_2 - T_1) > (T - T_1)$   
 $T_2 > T$

RUPTAGN ← +1

INDICATES TO ROUTINE TASKOVER THAT TASK 2 SHOULD BE EXECUTED IMMEDIATELY AFTER EXECUTION OF TASK 1 WITHOUT RETURNING CONTROL TO THE INTERRUPTED ROUTINE BETWEEN THE TWO TASKS

RUPTAGN ← -0

INDICATES TO ROUTINE TASKOVER (SHEET 18) THAT PROGRAM CONTROL SHOULD BE RETURNED TO THE INTERRUPTED ROUTINE IMMEDIATELY AFTER EXECUTION OF TASK 1 RATHER THAN RETURNING TO EXECUTE TASK 2

NEXT SHEET

SPANN	<i>A. J. Smith</i>	3 JUL 68	WAITLIST	
DOCNO				
ANALYT	<i>P. R.</i>	71-43	COLOSSUS	FORM 16
DT. MR	<i>B. H. Beck</i>	7-1-68	IC	FC-2060
APPROV	<i>B. H. Beck</i>	7/1/68	2	17 24

FROM PRECEDING SHEET

[A, L] ← 2CADR SVCT3

SET UP ADDRESS (2CADR) OF DUMMY TASK SVCT3 FOR LAST (BOTTOM) REGISTER OF LST2 TABLE (TABLE OF ADDRESSES OF TASKS WAITING FOR EXECUTION - WAITING FOR THEIR DELTA TIMES TO EXPIRE)

[LST2+16D, +17D] ⇒ [A, L]  
 [LST2+14D, +15D] ⇒ [A, L]  
 [LST2+12D, +13D] ⇒ [A, L]  
 [LST2+10D, +11D] ⇒ [A, L]  
 [LST2+8D, +9D] ⇒ [A, L]  
 [LST2+6, +7] ⇒ [A, L]  
 [LST2+4, +5] ⇒ [A, L]  
 [LST2+2, +3] ⇒ [A, L]  
 [LST2+0, +1] ⇒ [A, L]

MOVE ADDRESSES OF TASKS UPWARD IN LST2 TABLE

[LST2+16D, +17D] = 2CADR OF SVCT3 (DUMMY TASK)  
 [LST2+14D, +15D] = 2CADR OF TASK 9  
 [LST2+12D, +13D] = 2CADR OF TASK 8  
 [LST2+10D, +11D] = 2CADR OF TASK 7  
 [LST2+8D, +9D] = 2CADR OF TASK 6  
 [LST2+6, +7] = 2CADR OF TASK 5  
 [LST2+4, +5] = 2CADR OF TASK 4  
 [LST2+2, +3] = 2CADR OF TASK 3  
 [LST2+0, +1] = 2CADR OF TASK 2

[A, L] = 2CADR OF TASK 1 WHICH WILL BE EXECUTED NOW

SUPERBNK ← L 7-5

SET SUPERBNK WITH SUPER BANK OF TASK 1.

NOT PART OF PROGRAM WAITLIST. TASK 1 IS A TASK SO NUMBERED BECAUSE IT IS THE FIRST TO BE EXECUTED OF THOSE TASKS THAT WERE SCHEDULED AND NOT EXECUTED YET.

IF TASK 1 IS DUMMY TASK

EXECUTE TASK WHOSE 2CADR IS IN A AND L.

TO SVCT3 (DUMMY TASK) ON SHEET 20.

(TASK 1)

NOTE: PROGRAM CONTROL IS TRANSFERRED TO THE LOCATION WHOSE 2CADR IS IN A (GENADR) AND L (8BCON).

EXECUTE INSTRUCTIONS CONTAINED IN CODING FOR THIS ROUTINE

THUS TASK 1 IS NOW EXECUTED. TASK 1 IS ANY ROUTINE THAT WAS SCHEDULED AT CENTISECONDS AGO BY WAITLIST. THE TIME NOW  $T \geq T_1$ , THE EXECUTION TIME OF TASK 1.

TASKOVER

FROM LONGTRN ON SHEET 22 OR SVCT3 (DUMMY TASK) ON SHEET 20.

ALL TASKS TERMINATE WITH A TRANSFER (TC TASKOVER) OF PROGRAM CONTROL TO ROUTINE TASKOVER. \*

SHOULD TASK 2 BE EXECUTED NOW BEFORE RETURN TO INTERRUPTED ROUTINE? (DID DELTA TIME FOR TASK 2 EXPIRE WHEN RUPTAGN WAS SET IN ROUTINE T3RUPT2 ON PRECEDING SHEET?)

EXECUTE TASK 2 NOW

IS RUPTAGN = +1 ?

RETURN TO INTERRUPTED ROUTINE

BBANK ← WAITBB

SET BBANK FOR ROUTINE T3RUPT2

SUPERBNK ← BANKRUPT 7-5

RESTORE SUPER BANK OF INTERRUPTED ROUTINE

T3RUPT2 SH16

PRECEED TO EXECUTE TASK 2.

NEXT SHEET

NOTE: TASK 2 SHOULD NOW BE REFERRED TO AS TASK 1 BECAUSE IT IS THE FIRST TO BE EXECUTED OF THOSE TASKS THAT WERE SCHEDULED AND NOT EXECUTED YET. LIKEWISE, TASK 3 BECOMES TASK 2, AND SO FORTH.

\* ROUTINE TASKOVER IS ENTERED FROM 73 LOCATIONS DIRECTLY.

WIT 4 TO INSTRUCTION 83 LAMBERT, WASH. APPROV: <i>[Signature]</i> DATE: <i>7-16-62</i> BY: <i>[Signature]</i> 2-11-62 2-11-62 2-11-62	APPLICABLE GUIDANCE AND NAVIGATION WAITLIST COLLOSSUS IIC FC-2060 18 24
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FROM  
PRECEDING SHEET

RESUME

PREPARE TO RESUME EXECUTION OF INTERRUPTED ROUTINE BY RESTORING TO REGISTERS Q, BBANK, A AND L THE CONTENTS THEY HAD AT THE TIME THE INTERRUPTION OCCURRED. THESE CONTENTS WERE SAVED BY THE INTERRUPT LEAD-IN ROUTINE AND THE INTERRUPT ROUTINE.

Q ← QRUPT

RESTORE Q

NOQRSM

BBANK ←<sub>15-11, 3-1</sub> BANKRUPT<sub>15-11, 3-1</sub>

RESTORE BBANK

NOQBRSM

A ← ARUPT  
L ← LRUPT

RESTORE A AND L

RELEASE  
INTER-  
RUPT

NOW LEAVING  
INTERRUPT MODE

SET UP TO EXECUTE NEXT INSTRUCTION  
OF INTERRUPTED ROUTINE

B ← BRUPT  
Z ← ZRUPT

} INSTRUCTION RESUME (COMPRISES THESE  
TWO OPERATIONS)

THE RESUME INSTRUCTION TAKES THE INSTRUCTION IN BRUPT AND PLACES IT INTO B TO BE EXECUTED NEXT THUS RESUMING THE INTERRUPTED ROUTINE. ALSO, THE ADDRESS OF THE LOCATION NEXT AFTER THE LOCATION CONTAINING THE INSTRUCTION (IN B) TO BE EXECUTED FIRST UPON RESUMING THE INTERRUPTED ROUTINE IS TAKEN FROM ZRUPT AND PLACED INTO Z.

NOTE:

REGISTERS BRUPT AND ZRUPT WERE LOADED WITH THE CONTENTS OF B AND Z, RESPECTIVELY, BY HARDWARE ACTION IMMEDIATELY AFTER THE INTERRUPTION OF THE INTERRUPTED ROUTINE BEGAN AND BEFORE CONTROL WAS TRANSFERRED TO THE INTERRUPT LEAD-IN ROUTINE. THUS,

BRUPT = \* NEXT INSTRUCTION (THE ONE AFTER THE INSTRUCTION BEING EXECUTED AT TIME OF INTERRUPTION).

ZRUPT = GENADR OF LOCATION AFTER THE LOCATION CONTAINING THE INSTRUCTION IN BRUPT.

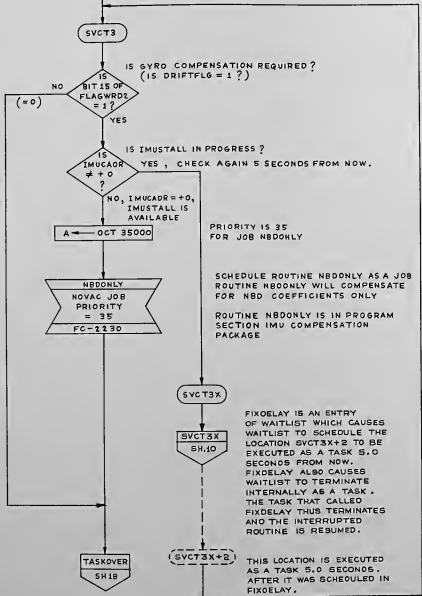
\* IF NEXT INSTRUCTION IS AN EXTEND INSTRUCTION, THE INTERRUPT IS DELAYED UNTIL THE NEXT INSTRUCTION IS NOT AN EXTEND INSTRUCTION.

RESUME EXECUTION  
OF THE INTERRUPTED  
ROUTINE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
FORM <i>2.1</i>		WAITLIST	
INSTR <i>2.1</i>	ANALYST <i>2.1</i>	COLOSSUS	DOCUMENT #
DATE <i>2-8-69</i>	APPROV <i>2-8-69</i>	IIIC	FC-2060
APPROV <i>2-8-69</i>		REV 2	SHEET 19 OF 24

FROM  
TRUPT2 ON  
SHEET 18

ROUTINE SVCT3 IS THE DUMMY TASK. IT  
IT IS SCHEDULED IN TRUPT

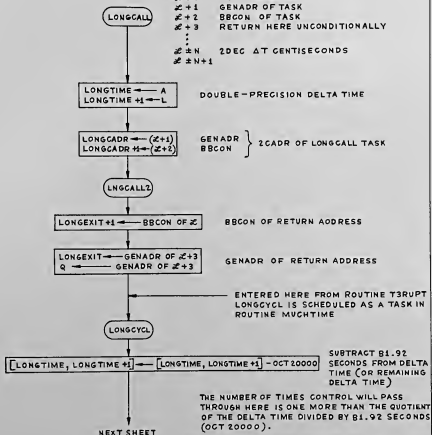


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		MIT SURFACING AND METASTATION  WAITLIST	
SEARCHED <i>[Signature]</i>	INDEXED <i>[Signature]</i>	COLOSSUS IIC	DOCUMENT NO FC-2060
ANALYST <i>[Signature]</i>	APPROVED <i>[Signature]</i>	REV 2	SHEET 20 OF 24



LONGCALL IS USED TO SCHEDULE TASKS WHOSE DELTA TIME IS IN DOUBLE PRECISION WHICH CANNOT BE HANDLED BY WAITLIST (SINGLE PRECISION) ROUTINE. LONGCALL WILL HANDLE DELTA TIMES FROM OCT0000 (0.01 SECOND) TO [OCT 37777, OCT 37777] (2,484,354.85 SECONDS OR 745 HOURS 39 MINUTES AND 14.85 SECONDS OR APPROXIMATELY ONE MONTH). [OCT 37777, OCT 37777] = OCT 1,777,777,777 = DEG 268,438,455

CALLING SEQUENCE :  
 $Z \pm 2$  EXTEND  
 $Z \pm 1$  DCA  $Z \pm N$   
 $Z \pm 0$  TC LONGCALL  
 $Z \pm 1$  GENADR OF TASK  
 $Z \pm 2$  BBCON OF TASK  
 $Z \pm 3$  RETURN HERE UNCONDITIONALLY  
 ...  
 $Z \pm N$  2DEG  $\Delta T$  CENTISECONDS  
 $Z \pm N+1$



THE NUMBER OF TIMES CONTROL WILL PASS THROUGH HERE IS ONE MORE THAN THE QUOTIENT OF THE DELTA TIME DIVIDED BY 81.92 SECONDS (OCT 20000).

THIS DOUBLE-PRECISION SUBTRACTION OPERATION PERFORMED EACH PASS RESULTS IN THE HIGH-ORDER MAGNITUDE IN LONGTIME BEING DECREMENTED BY ONE WHEN AN OVERFLOW OCCURRED IN THE LOW-ORDER MAGNITUDE SUBTRACTION. ALSO, THE LOW-ORDER MAGNITUDE IS INCREASED BY OCT 40000 AT THE SAME TIME. THIS DOES NOT OCCUR WHEN SUBTRACTION RESULTS IN A NEGATIVE LOW-ORDER MAGNITUDE — ONLY ON OVERFLOW. APPLICATION OF THIS RULE WILL GIVE CORRECT RESULTS IN THE FOLLOWING TESTS OF LONGTIME AND LONGTIME+1 ON THE NEXT SHEET.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN PFC/MP ANALYST DOY MR B. Van Dyke APPROV'd 7-14-67 7-14-67		WAITLIST COLLOSSUS IIC DOCUMENT NO. FC-2060 SHEET 21 OF 24	

FROM PRECEDING SHEET

IS DELTA TIME (OR REMAINING PORTION) GREATER THAN 81.92 SECONDS?  
(THIS IS DETERMINED BY TESTING LOW-ORDER MAGNITUDE OF UNUSED DP AT FIRST, AND THEN THE HIGH IF NECESSARY)

IS LONGTIME > +0 ?

YES, ( $\Delta T > 81.92$  SECONDS)

(LONGTIME+1 CONTAINS LOW-ORDER MAGNITUDE)

CHECK FURTHER (LONGTIME+1  $\leq$  -0)

(TEST HIGH-ORDER MAGNITUDE - IS IT > +0 ?)

IS LONGTIME > +0 ?

YES,  $\Delta T \geq 163.84$  SECONDS

NO, (LONGTIME = -0)

THE UNUSED (REMAINING) PORTION OF  $\Delta T$  IS LESS THAN 81.93 SECONDS

THE NUMBER (N) OF PASSES THROUGH ROUTINE MUGHTIME IS SUCH THAT  $81.92 \times N + \Delta T = \Delta T$  TIME FOR THE LONGCALL TASK WHERE  $\Delta T$  IS THE UNUSED PORTION (CONTENTS OF A WHEN TASK GETCADR IS SCHEDULED AT LOWER LEFT) OF THE DELTA TIME.  $\Delta T_i \leq 81.92$

DELAY EXECUTION OF LONGCALL TASK 81.92 SECONDS (OR ANOTHER 81.92 SECONDS)

SET  $\Delta T = 81.92$  SECONDS FOR TASK LONGCYCL

MUGHTIME

A ← OCT 20000

LASTTIME

A ← (LONGTIME + 1) + OCT 20000

RESTORE OCT 20000 WHICH WAS SUBTRACTED IN LONGCYCL ON PRECEDING SHEET.

A = UNUSED (REMAINING OR UNEXPIRED) PORTION OF DELTA TIME FOR THE

GETCADR WAITLIST TASK  $\Delta T$  IS IN A THIS SHEET

LONGCYCL WAITLIST TASK  $\Delta T = 81.92$  SEC. PRECEDING SHEET

LONGCALL TASK.

LONGRTRN

A ← GENADR OF TASKOVER

SET FOR ALL EXITS EXCEPT THE FIRST EXIT

GETCADR

SETCADR IS A TASK WHICH WILL BE EXECUTED DELTA TIME CENTISECONDS FROM THE TIME INSTRUCTION "TC LONGCALL" WAS EXECUTED.

A ← LONGEXIT GENADR }  
L ← (LONGEXIT + 1) BBCON

ZCDAR OF THE RETURN LOCATION  $\neq$  +3 (WHERE  $\neq$  = TC LONGCALL) FOR 1ST EXIT. TASKOVER FOR SUCCEEDING EXITS.

A ← LONGCADR GENADR }  
L ← LONGCADR + 1 BBCON } ZCADR OF LONGCALL TASK

RETURN VIA A AND L

RETURN TO  $\neq$  +3 (WHERE  $\neq$  = TC LONGCALL) IF THIS IS FIRST EXIT.

OR

RETURN TO INTERRUPTED ROUTINE VIA ROUTINE TASKOVER IF THIS IS NOT THE FIRST EXIT.

EXIT VIA A AND L

TO ROUTINE SCHEDULED AS A LONGCALL TASK

LONGCALL TASK WILL NOW BEGIN.

THE LONGCALL TASK THUS APPEARS TO BE THE CONTINUATION OF TASK GETCADR

UNIT INSTRUMENTATION LAB "AMBRIDGE" Bldg. 30-AN 9-11-62 7-11-62 9-11-62 9-11-62		ARTIFICIAL GUIDANCE AND NAVIGATION WAITLIST COLLOSSUS IIC 0001 W/11/62 FC-2060 Feb. 22 of 24	
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SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
RAILOUT	FC-2140	URNS ON PROGRAM ALARM LIGHT AND SETS ALARM CODE OCT 1203 INTO ONE OF THE FAILREG REGISTERS SO IT IS AVAILABLE FOR DISPLAY. EXITS TO DO SOFTWARE RESTART VIA GOPROG.	SH. 13
POODOO	FC-2140	URNS ON PROGRAM ALARM LIGHT AND SET ALARM CODE OCT 1204 INTO ONE OF THE FAILREG REGISTERS SO IT IS AVAILABLE FOR DISPLAY. EXITS TO DO SOFTWARE RESTART VIA GOPROG. IF SERVICER IS NOT RUNNING, ALL RESTART GROUPS ARE MADE INACTIVE.	SH. 9
NBDONLY (JOB)	FC-2230	COMPENSATES FOR NBD COEFFICIENTS ONLY.	SH. 20

ERASABLE LOCATIONS USED

AGC TAG	MEANING
WAITEXIT	GENADR OF CALLING SEQUENCE OR EXIT ADDRESS
WAITBANK (WAITEXIT*1)	BBCON OF CALLING SEQUENCE
WAITADR	GENADR OF TASK
WAITADR+1	BBCON OF TASK
WAITTEMP	TIME INTERVAL BETWEEN TASKS
LST1*0 TO +7	TIME INTERVAL TABLE
LST2*0 TO +17D	2CADR-OF-TASKS TABLE
HANKRUPT	SAVE BBCON AND SUPER BANK OF ROUTINE INTERRUPTED BY T3RUPT
QRUPT	SAVE Q OF ROUTINE INTERRUPTED BY T3RUPT
RUPTAGN	INDICATES TO TASKOVER WHETHER (*1) THE NEXT TASK SHOULD BE EXECUTED IMMEDIATELY AFTER THE CURRENT TASK OR WHETHER (-0) THE INTERRUPTED ROUTINE SHOULD BE EXECUTED IMMEDIATELY AFTER THE CURRENT TASK
ARUPT	SAVE A OF ROUTINE INTERRUPTED BY T3RUPT
LIRUPT	SAVE L OF ROUTINE INTERRUPTED BY T3RUPT
LONGCADR+0, +1	2CADR OF LONGCALL TASK
LONGTIME+0, -1	DP DELTA TIME FOR LONGCALL TASK
LONGEXIT+0, -1	2CADR OF RETURN ADDRESS TO CALLING SEQUENCE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
WAITLIST			
DRAWN <i>A. J. Long</i>	DATE <i>7/26/68</i>	DOCUMENT NO.	
INSTR. ST. <i>114</i>		COLOSSUS ID:	<b>FC-2060</b>
ENTR BY <i>B. J. Clark</i>	<i>7-2-68</i>		
APPROV. <i>John J. Clark</i>	REV. 2		NET 2.4 OF 2.0

## SERVICE ROUTINES

ENTRY	TABLE OF CONTENTS BRIEF DESCRIPTION	SHEET
SUBROUTINE UPENT2	SETS SELECTED BIT POSITIONS OF A SELECTED FLAG WORD (LIMITED SELECTION BY CODE)	2
SUBROUTINE DOWNENT2	CLEAR SELECTED BIT POSITIONS OF A SELECTED FLAG WORD (LIMITED SELECTION BY CODE)	3
SUBROUTINE UPFLAG	SETS A BIT POSITION OF A FLAG WORD (BOTH DETERMINED BY THE FLAG NAME)	4
SUBROUTINE DOWNFLAG	CLEAR A BIT POSITION OF A FLAG WORD (BOTH DETERMINED BY THE FLAG NAME)	4
LIST OF FLAG CODES VERSUS BIT-POSITION OF FLAG WORD		7
LIST OF FLAG NAMES VERSUS FLAG CODES		7
SUBROUTINE DELAYJOB	PLACES CURRENT JOB TO SLEEP FOR M CENTISECONDS AND IS AWAKENED AT LOCATION ←2 (←CONTAINS TC DELAYJOB)	8
SUBROUTINE GENTRAN	COPIES CONTENTS OF N CONSECUTIVE LOCATIONS INTO ANY N CONSECUTIVE LOCATIONS	11
ROUTINE B5OFF	CLEAR BIT-POSITION 5 OF REGISTER EXTVBACK AND TERMINATES AS A JOB. INDICATES THAT THE DISPLAY HAS BEEN ANSWERED	12
SUBROUTINE TRFAILON	URNS TRACKER FAIL LIGHT (OPTICS CDU FAIL) ON	13
SUBROUTINE TRFAILOFF	URNS TRACKER FAIL LIGHT (OPTICS CDU FAIL) OFF	13

## LIST OF REVISIONS

REV NO.	REVISION
1	UPDATED COLOSSUS I TO COLOSSUS II-C (SHEET 9 REVISED)
2	UPDATED COLOSSUS IIC TO COLOSSUS IID (SHEET 7 REVISED)

MIT OFFICE OF INSTRUMENTATION CAMBRIDGE MASS	APRIL 1954 U. S. AIR FORCE
DEPT. OF DEFENSE DIRECTORATE OF RESEARCH AND ENGINEERING ANAL. DIV. ATTN: C. W. Beck AF-03 2000 2000 2000 2000	SERVICE ROUTINES COLOSSUS IID FC-2070 Sheet 1 of 14

SERVICE ROUTINES (UPENT2)

ENTERED FROM 4 LOCATIONS IN THE DISPLAY INTERFACE ROUTINES WITH A = THE CODE FOR SELECTING A FLAG WORD (FLAGWRD0, 1, 2, ..., 6 OR 7) AND ALSO FOR SELECTING THE BIT POSITION (15, 14, 13, ..., 5 OR 4) IN THE FLAG WORD TO BE SET.



RETURN TO  $\alpha+2$  OF CALLING SEQUENCE

EXAMPLE OF CALLING SEQUENCE:

RESTSLEP	CA	GENMASK
	MSK	ASTROMSK
	TC	UPENT2
OCT24100	OCT	24100
	NDX	COPINDEX
	CAF	NYCADR
	.	.
	.	.

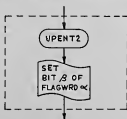
SUBROUTINE FOR SETTING SELECTED BIT POSITIONS OF A SELECTED FLAG WORD.

THE BIT POSITIONS SELECTED TO BE SET ARE THE SAME AS THOSE BIT POSITIONS OF  $A_{15-4}$  WHICH CONTAIN A ONE.

THE FLAG WORD SELECTED IS DETERMINED BY THE CONTENTS OF  $A_{3-1}$ . THE CONTENTS ARE USED AS AN INDEX TO SELECT FLAG WORDS AS SHOWN IN THE FOLLOWING TABLE:

$A_{3-1}$	FLAG WORD SELECTED
0	FLAGWRD0 + 0 OR FLAGWRD0
1	" + 1 OR FLAGWRD1
2	" + 2 OR FLAGWRD2
3	" + 3 OR FLAGWRD3
4	" + 4 OR FLAGWRD4
5	" + 5 OR FLAGWRD5
6	" + 6 OR FLAGWRD6
7	" + 7 OR FLAGWRD7

THIS SUBROUTINE WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING IT:



$Q = \alpha+2$  OF CALLING SEQUENCE

CALLING SEQUENCE:

$\alpha+0$  TC UPENT2  
 $\alpha+1$  OCT ANY DATA  
 $\alpha+2$  RETURN HERE UNCONDITIONALLY

NOTE:

UPON EXECUTION OF INSTRUCTION "TC UPENT2", THE ACCUMULATOR CONTAINS THE FLAG AND BIT CODE.

NOTE:

THIS SUBROUTINE IS APPLICABLE TO ONLY THE FIRST EIGHT FLAG WORDS (BIT-POSITIONS 15 THROUGH 4). BIT-POSITIONS 3 THROUGH 1 OF THE FIRST EIGHT FLAG WORDS AND ALL BIT POSITIONS OF FLAGWRD8, 9, 10 AND 11 CANNOT BE SET BY UPENT2.

REVISION DRAWN ANALYST DESIGNER APPROVED	DATE 3-12-67 BY J. G. M...	TITLE SERVICE ROUTINES COLOSSUS II-D FC-2070	SHEET 2 OF 14
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SERVICE ROUTINES (DOWNENT2)

ENTERED FROM 3 LOCATIONS  
IN DISPLAY INTERFACE ROUTINES  
WITH A= THE CODE FOR SELECTING  
A FLAG WORD (FLAGWRD0, 1, 2, ...,  
6 OR 7) AND ALSO FOR SELECTING  
THE BIT POSITION (15, 14, 13, ...,  
5 OR 4) IN THE FLAG WORD TO BE CLEARED.

SUBROUTINE FOR CLEARING SELECTED  
BIT POSITIONS OF A SELECTED FLAG  
WORD.

CALLING SEQUENCE:  
Z+0 TC DOWNENT2  
Z+1 OCT ANY DATA  
Z+2 RETURN HERE UNCONDITIONALLY

NOTE:  
UPON EXECUTION OF INSTRUCTION  
"TC DOWNENT2", THE ACCUMULATOR  
CONTAINS THE FLAG AND BIT CODE.

THE BIT POSITIONS SELECTED  
TO BE CLEARED ARE THE SAME  
AS THOSE BIT POSITIONS OF A 15-4  
WHICH CONTAINS A ONE.

THE FLAG WORD SELECTED IS  
DETERMINED BY THE CONTENTS OF  
A 3-1. THE CONTENTS ARE USED AS AN  
INDEX TO SELECT FLAG WORDS AS  
SHOWN IN THE FOLLOWING TABLE:

A <sub>3-1</sub>	FLAG WORD SELECTED
0	FLAGWRD0 OR FLAGWRD0
1	" +1 OR FLAGWRD1
2	" +2 OR FLAGWRD2
3	" +3 OR FLAGWRD3
4	" +4 OR FLAGWRD4
5	" +5 OR FLAGWRD5
6	" +6 OR FLAGWRD6
7	" +7 OR FLAGWRD7

Q=Z+2 OF CALLING SEQUENCE WHERE  
Z IS THE LOCATION CONTAINING  
INSTRUCTION "TC DOWNENT2"

NOTE:  
THIS SUBROUTINE IS APPLICABLE  
TO ONLY THE FIRST EIGHT FLAG  
WORDS (BIT-POSITIONS 15 THROUGH  
4). BIT-POSITIONS 3 THROUGH 1 OF  
THE FIRST EIGHT FLAG WORDS  
AND ALL BIT POSITIONS OF  
FLAGWRD8, 9, 10 AND 11 CANNOT  
BE CLEARED BY DOWNENT2.

THIS SUBROUTINE WILL BE SHOWN AS  
FOLLOWS IN PROGRAMS USING IT:



RETURN TO Z+2  
OF CALLING SEQUENCE

EXAMPLE OF CALLING  
SEQUENCE:

```

ENDRET+7 CA GENMASK
          MSK PINIDMSK
          TC DOWNENT2

PINIDMSK OCT 74044
          CS THREE
          TS NVSUB
          *
          *
          *
  
```

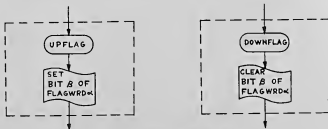
SERVICE ROUTINES

22 JUNE 1969  
 R. B. Breda  
 COLLOSSUS II-D  
 FC-2070  
 3 14

SERVICE ROUTINES (UPFLAG AND DOWNFLAG)

THESE SUBROUTINES, UPFLAG AND DOWNFLAG, ARE USED FOR SETTING AND CLEARING, RESPECTIVELY, ANY FLAG. A FLAG IS ANY BIT POSITION THAT HAS A NAME SUCH AS "MIDAVFLG" FOR EXAMPLE. THESE BIT POSITIONS ARE BIT-POSITIONS 15-1 OF CONSECUTIVE FLAG WORDS FLAGWRD0, FLAGWRD1, FLAGWRD2, . . . , FLAGWRD10 AND FLAGWRD11. A FEW OF THE LATTER DO NOT YET HAVE NAMES. EACH FLAG HAS A CODE NUMBER WHICH DETERMINES THE FLAG WORD AND THE BIT POSITION IN THAT FLAG WORD TO BE SET OR CLEARED. THE FLAG WORD (FLAGWRD $\kappa$  WHERE  $\kappa$  IS 0, 1, 2, . . . , 10 OR 11) AND THE BIT POSITION  $\beta$  (WHERE  $\beta$  IS 15, 14, 13, . . . , 2 OR 1) ARE OBTAINED BY DIVIDING THE CODE BY 15 SO THAT THE FLAG WORD WILL BE FLAGWRD0 + THE QUOTIENT (THE QUOTIENT IS  $\kappa$ ) AND THE BIT POSITION OF THAT FLAG WORD WILL BE  $\beta$  ( $\beta$  IS 15 MINUS  $Q$ , THE REMAINDER). THUS, THE CODE NUMBER IS  $15\kappa + Q$  OR  $15\kappa + 15 - \beta$ . AS AN EXAMPLE, THE CODE NUMBER FOR MIDAVFLG IS DEC 148. THE QUOTIENT OF  $148 \div 15$  IS 9 AND THE REMAINDER IS 13 ( $\kappa = 9$ ,  $Q = 13$ ,  $\beta = 15 - Q = 2$ ). THUS, THE FLAG MIDAVFLG IS IN FLAG WORD FLAGWRD0 + 9 WHICH IS FLAGWRD9. FLAG MIDAVFLG IS BIT-POSITION2 OF FLAGWRD9.

THESE SUBROUTINES WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING IT.

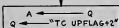


CALLING SEQUENCE:

- |  |  |
|--|--|
| $\kappa + 0$ TC UPFLAG                   | $\kappa + 0$ TC DOWNFLAG                 |
| $\kappa + 1$ ADRES FLAG NAME             | $\kappa + 1$ ADRES FLAG NAME             |
| $\kappa + 2$ RETURN HERE UNCONDITIONALLY | $\kappa + 2$ RETURN HERE UNCONDITIONALLY |

ENTERED HERE FROM  
55 LOCATIONS

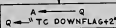
UPFLAG



A =  $\kappa + 1$  OF  
CALLING  
SEQUENCE

ENTERED HERE FROM  
60 LOCATIONS

DOWNFLAG



A =  $\kappa + 1$  OF  
CALLING  
SEQUENCE

DEBIT

INCRE-  
MENT A  
BY 1

A =  $\kappa + 2$  OF  
CALLING SEQUENCE

INHIBIT  
INTER-  
RUPTS

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
SERVICE ROUTINES	
DRAWN <i>A. J. ...</i> 27 JAN 68 CHECKED <i>R. ...</i> 31 JAN 68 ANALYST <i>D. B. ...</i> APPROVED <i>John G. ...</i> 29 APR 68	COLOSSUS II-D DOCUMENT OF FC-2070 SHEET 4 OF 14



FROM  
PRECEDING SHEET

SERVICE ROUTINES  
(UPFLAG AND DOWNFLAG)

ITEMP3 ← A

ITEMP3 =  $\mathcal{X} + 2$  (THE RETURN ADDRESS) IN  
THE CALLING SEQUENCE.

ITEMP1 ← QUOTIENT OF  $(\mathcal{X} + 1) \div \text{DEC } 15$

ITEMP1 =  $\mathcal{Q}$  (THE QUOTIENT)  
THE QUOTIENT WILL BE USED AS  
AN INDEX FOR SELECTING THE  
FLAG WORD AND WILL BE  
REFERRED TO AS " $\mathcal{X}1$ "

ITEMP2 ← REMAINDER OF  $(\mathcal{X} + 1) \div \text{DEC } 15$

ITEMP2 =  $\mathcal{R}$  (THE REMAINDER)  
THE REMAINDER WILL BE USED  
AS AN INDEX FOR SELECTING  
THE BIT POSITION IN THE  
SELECTED FLAG WORD AND  
WILL BE REFERRED TO AS " $\mathcal{X}2$ "

L ← (FLAGWRD0 +  $\mathcal{X}1$ )

L = CONTENTS OF FLAG WORD ASSOCIATED  
WITH THE FLAG NAME IN LOCATION  $\mathcal{X} + 1$   
OF THE CALLING SEQUENCE.

INDEX $\mathcal{X}1$	FLAG WORD
FLAGWRD0 + 0	FLAGWRD0
" + 1	FLAGWRD1
" + 2	FLAGWRD2
" + 3	FLAGWRD3
" + 4	FLAGWRD4
" + 5	FLAGWRD5
" + 6	FLAGWRD6
" + 7	FLAGWRD7
" + 8	FLAGWRD8
" + 9	FLAGWRD9
" + 10	FLAGWRD10
" + 11	FLAGWRD11

A ← (BIT15 +  $\mathcal{X}2$ )

A = ONES IN ALL BIT POSITIONS EXCEPT  
THE BIT POSITION ASSOCIATED WITH  
THE FLAG NAME IN LOCATION  $\mathcal{X} + 1$  OF  
THE CALLING SEQUENCE.

INDEX $\mathcal{X}2$	REGISTER	CONTENTS	BIT POSITION SET OR Cleared
BIT15 + 0	BIT15	OCT 40000	15
" + 1	BIT14	OCT 20000	14
" + 2	BIT13	OCT 10000	13
" + 3	BIT12	OCT 04000	12
" + 4	BIT11	OCT 02000	11
" + 5	BIT10	OCT 01000	10
" + 6	BIT9	OCT 00400	9
" + 7	BIT8	OCT 00200	8
" + 8	BIT7	OCT 00100	7
" + 9	BIT6	OCT 00040	6
" + 10	BIT5	OCT 00020	5
" + 11	BIT4	OCT 00010	4
" + 12	BIT3	OCT 00004	3
" + 13	BIT2	OCT 00002	2
" + 14	BIT1	OCT 00001	1

NEXT SHEET

MIT SUPERINTENDENT (AN AMBRIDGE, MASS.	SERIAL NO. 100-10000 SERVICE ROUTINES
SEARCHED <i>R. J. [unclear]</i> 27, 1949 INDEXED <i>W. [unclear]</i> 27, 1949 SERIALIZED <i>[unclear]</i> FILED <i>[unclear]</i> APR 2 1949 APPROVED <i>[unclear]</i>	COLOSSUS II-D FC-2070 5 14

SERVICE ROUTINES  
(UPFLAG AND DOWNFLAG)

FROM  
PRECEDING SHEET

L = COMPLETE ORIGINAL FLAG WORD (CONTENTS OF FLAG WORD ASSOCIATED WITH THE FLAG NAME IN LOCATION  $\mathcal{Z}+1$  OF THE CALLING SEQUENCE).  
Q = DOWNFLAG+2

Q = UPFLAG+2

UPFLAG+2

DOWNFLAG+2

A ←  $\bar{A}$

A = ALL ZEROES EXCEPT A ONE IN THE BIT POSITION ASSOCIATED WITH THE FLAG NAME IN LOCATION  $\mathcal{Z}+1$  OF THE CALLING SEQUENCE

A = ALL ONES EXCEPT A ZERO IN THE BIT POSITION ASSOCIATED WITH THE FLAG NAME IN LOCATION  $\mathcal{Z}+1$  OF THE CALLING SEQUENCE.

A ← A  $\wedge$  L

NOTE: " $\wedge$ " IS A SYMBOL FOR THE "AND" OPERATION WHICH CAUSES A ONE TO REMAIN IN EACH BIT POSITION OF A IF THE SAME BIT POSITION FORMERLY CONTAINED A ONE AND IF THE SAME BIT POSITION OF L CONTAINS A ONE. A ZERO IN EITHER WILL RESULT IN A ZERO IN A.

A ← A  $\vee$  L

NOTE: " $\vee$ " IS A SYMBOL FOR THE "OR" OPERATION WHICH CAUSES A ONE TO BE PLACED INTO EACH BIT POSITION OF A IF THE FORMER CONTENT WERE ONE OR IF THE SAME BIT POSITION OF L CONTAINED A ONE. A ZERO IN BOTH WILL CAUSE A ZERO TO BE PLACED INTO THE SAME BIT POSITION OF A.

A = SAME AS CONTENTS OF FLAG WORD ASSOCIATED WITH THE FLAG NAME IN  $\mathcal{Z}+1$  EXCEPT A ZERO IN THAT BIT POSITION HAVING ITS FLAG NAME IN  $\mathcal{Z}+1$ .

L CONTAINS COMPLETE ORIGINAL FLAG WORD.  
A = SAME AS CONTENTS OF FLAG WORD ASSOCIATED WITH THE FLAG NAME IN  $\mathcal{Z}+1$  EXCEPT THAT A ONE IS IN THE BIT POSITION WHOSE FLAG NAME IS IN  $\mathcal{Z}+1$ .

COMFLAG

(FLAGWRD0 + X1) ← A

RESTORE THE ORIGINAL CONTENTS OF THE FLAG WORD CONTAINING THE BIT POSITION WHOSE FLAG NAME IS IN  $\mathcal{Z}+1$  EXCEPT FOR THAT SAME BIT POSITION WHICH IS NOW SET IF ENTRY WAS VIA UPFLAG AND CLEARED IF ENTRY WAS VIA DOWNFLAG.

RELEASE  
INTER-  
RUPT  
INHIBIT

RETURN VIA  
ITEMPS

RETURN TO CALLER  
AT  $\mathcal{Z}+2$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED GUIDANCE AND NAVIGATION	
DESIGN <i>A. J. Smith</i> 12/19/68 PROGRAM <i>W. D. ...</i> ANALYST OPERATOR <i>J. A. ...</i> 3-15-69 APPROVED <i>John A. ...</i> 2/24/69		SERVICE ROUTINES COLOSSUS II-D DOCUMENT NO. FC-2070 REV 2 6-11-68	

SERVICE ROUTINES  
(UPFLAG AND DOWNFLAG)

CODES FOR EACH FLAG (DECIMAL)

BIT-POSITION #	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
FLAGWORD	α														
FLAGWRD0	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FLAGWRD1	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
FLAGWRD2	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
FLAGWRD3	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
FLAGWRD4	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74
FLAGWRD5	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89
FLAGWRD6	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104
FLAGWRD7	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119
FLAGWRD8	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134
FLAGWRD9	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149
FLAGWRD10	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164
FLAGWRD11	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179

CODE	FLAG NAME	CODE	FLAG NAME	CODE	FLAG NAME	CODE	FLAG NAME
45	VSONIFL	90	DAPBIT1	135	SWDVI		
46	GLONFAL	91	DAPBIT2	136			
47	REPSIFL	92	STRULLSW	137	VR2LFL		
48	LUNAFAL	93	CDAPARM	138	MAXIFL		
49	P22MFL	94	GAMDFSW	139	V94LFL		
50	VFLAG	95	GONEPAST	140	SRFL		
51	POOFIL	96	RVLVFL	141	VHFIFL		
52	PRECIFL	97	INSW	142	SOURFL		
53	CULTIFL	98	COMSWICH	143	FACML		
54	OROWFL	99	HIND	144	SRORFL		
55	STATEFL	100	INFLSW	145	CULTIFL		
56	INTYFFL	101	LATSW	146	R31FL		
57	VINTFL	102		147	VIDIFL		
58	D6ORFL	103	CM/DSTBY	148	IDA		
59	DIYOFL	104	GVMDFSW	149	AF		
60	VRIDFL	105	TERMFL	150			
61	PRIDFL	106	ITSWICH	151	INTFL		
62	NRIDFL	107	IGNFL	152			
63	DSIFL	108	ASTYFL	153			
64	NWATFL	109	TIMEFL	154			
65	NWATFL	110	NORISW	155			
66	NRKVF	111	RWSW	156			
67	RENVFL	112	NOBEY	157			
68	PROVFL	113		158	RINTFL		
69	DINRFL	114	V3FL	159			
70	NRUPFL	115		160			
71	NRUPFL	116	UPLOCKFL	161			
72	MKOVFL	117	VRIFL	162			
73		118	ATCHEL	163			
74	NDFL	119	TFSSW	164			
75	DSKYFL	120	RPOFL	165	S2FL		
76	RETROFL	121		166	S2FL		
77	SLDMFL	122		167	S2FL		
78	VSOFL	123	NMIFL	168	S2FL		
79	INCOFL	124	COONFL	169	S2FL		
80	RMSCL	125	ADVTSK	170			
81	D'ENFL	126	P3P79SW	171			
82	COMPUTER	127	SUFL	172			
83	ENCOFL	128	ISCNFL	173			
84	JAXISFL	129	ORDEPSW	174			
85	GRSRFL	130	APSESW	175			
86	R6OFL	131	COALFL	176			
87	SOLNSW	132	V94LFL	177			
88	NCLVFL	133		178			
89	RENDVFL	134	360SW	179			

\*ALSO CODE FLAG NAME 21 R23FLG 39 FIRSTFL OPTNSW 80 PRTPKAT 92 ENTRYDSP 97 RKNWNFLG R57FLG

SERVICE ROUTINES

COLOSSUS  
II

FC-2070

2

14

*Handwritten notes:*  
 31 MAR 69  
 3-12-69  
 24 MAR 69

SERVICE ROUTINES (DELAYJOB)

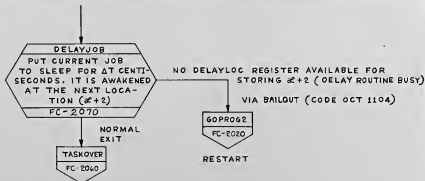
SUBROUTINE DELAYJOB IS USED TO PUT THE CURRENT JOB TO SLEEP FOR  $\Delta T$  CENTISECONDS. AT THE END OF THIS TIME PERIOD THIS JOB IS AWAKENED AT THE NEXT LOCATION ( $\mathcal{Z}+2$  OF THE CALLING SEQUENCE).

THIS IS ACCOMPLISHED BY FIRST SEARCHING THE TABLE OF DELAYLOC REGISTERS WHICH CONTAIN THE CADR OF THOSE JOBS NOW BEING DELAYED. IF NO REGISTER IS AVAILABLE, AN ABORT IS EXECUTED. IF ONE IS AVAILABLE FOR THE CURRENT JOB, ROUTINE WAKER IS SCHEDULED TO BE EXECUTED AS A TASK AT CENTISECONDS FROM NOW. THE CADR OF  $\mathcal{Z}+2$  IS FORMED AND STORED INTO THE AVAILABLE DELAYLOC REGISTER. THEN THIS CURRENT JOB IS PUT TO SLEEP. AFTER  $\Delta T$  CENTISECONDS HAVE ELAPSED, TASK WAKER IS EXECUTED AND CAUSES THE LOCATION  $\mathcal{Z}+2$  OF THE CALLING SEQUENCE TO BE AWAKENED. TASK WAKER IS THEN TERMINATED.

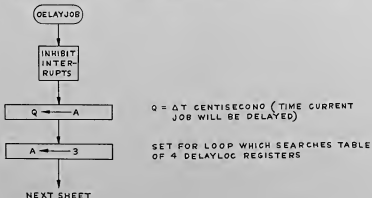
CALLING SEQUENCE :

$\mathcal{Z}-1$	CAF	$\mathcal{Z} \pm N$	
$\mathcal{Z}+0$	TC	BANKCALL	
$\mathcal{Z}+1$	CADR	DELAYJOB	
$\mathcal{Z}+2$	RETURN HERE AFTER A DELAY OF $\Delta T$ CENTISECONDS		
.	.	.	.
.	.	.	.
$\mathcal{Z} \pm N$	OEC	$\Delta T$ CENTISECONDS	

THIS SUBROUTINE WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING IT :

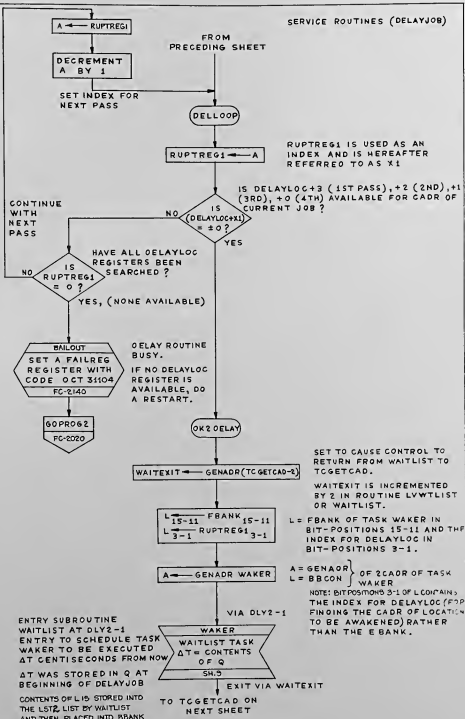


ENTERED FROM 13 LOCATIONS VIA BANKCALL WITH  $A = \Delta T$  AND  $2CADR$  OF LOCATION  $\mathcal{Z}+2$ , THE RETURN TO THE CALLING SEQUENCE, IN  $BUF2$  AND  $BUF2+1$ .  $BUF2$  AND  $BUF2+1$  WERE SET BY BANKCALL.



MIT DOCUMENTATION CENTER CAMBRIDGE MASS.	RESEARCH ALIGNED BY ANALYST
TITLE: <i>Delay Job</i> PROJECT: <i>W. S. Burdick</i> ANALYST: <i>J. D. Rife</i> OPERATOR: <i>John A. Ross</i> APPROVED: <i>24 JAN 61</i>	SERVICE ROUTINES COLOSSUS II-D DOCUMENT NO. FC-2070 REV 2 PAGE 8 OF 14

SERVICE ROUTINES (DELAYJOB)



RUPTRREG1 IS USED AS AN INDEX AND IS HEREAFTER REFERRED TO AS X1

IS DELAYLOC+3 (1ST PASS), +2 (2ND), +1 (3RD), +0 (4TH) AVAILABLE FOR CADR OF CURRENT JOB?

CONTINUE WITH NEXT PASS

HAVE ALL DELAYLOC REGISTERS BEEN SEARCHED?  
YES, (NONE AVAILABLE)

IS RUPTRREG1 = 0?

BAILOUT  
SET A FAILREG REGISTER WITH CODE OCT 31104  
FC-2140

60PROG2  
FC-2020

DELAY ROUTINE BUSY.  
IF NO DELAYLOC REGISTER IS AVAILABLE, DO A RESTART.

OK2 DELAY

WAITEXIT ← GENADR(TCGETCAD-2)

SET TO CAUSE CONTROL TO RETURN FROM WAITLIST TO TCGETCAD.

WAITEXIT IS INCREMENTED BY 2 IN ROUTINE LVWTLIST OR WAITLIST.

L ← FBANK 15-11  
L ← RUPTRREG1 3-1

L = FBANK OF TASK WAKER IN BIT-POSITIONS 15-11 AND THE INDEX FOR DELAYLOC IN BIT-POSITIONS 3-1.

A ← GENADR WAKER

A = GENADR } OF CADR OF TASK WAKER  
L = BBCON }

NOTE: BIT POSITIONS 3-1 OF L CONTAINS THE INDEX FOR DELAYLOC (FOR FINDING THE CADR OF LOCATION TO BE AWAKENED) RATHER THAN THE EBANK.

ENTRY SUBROUTINE WAITLIST AT DLY2-1  
ENTRY TO SCHEDULE TASK WAKER TO BE EXECUTED AT CENTISECONDS FROM NOW  
ΔT WAS STORED IN Q AT BEGINNING OF DELAYJOB  
CONTENTS OF L IS STORED INTO THE LIST LIST BY WAITLIST AND THEN PLACED INTO FBANK BY TRUPT.

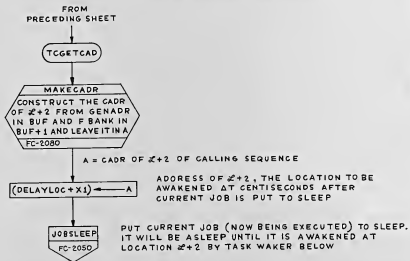
WAKER  
WAITLIST TASK  
ΔT = CONTENTS OF Q  
SH.5

EXIT VIA WAITEXIT TO TCGETCAD ON NEXT SHEET

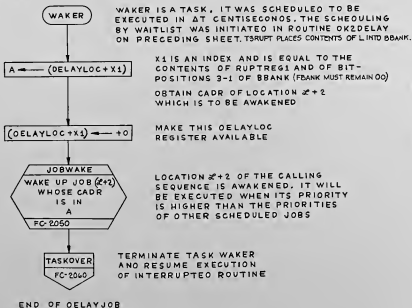
378188  
3-12-67  
FC-2070

SERVICE ROUTINES  
COLOSSUS II-D  
FC-2070  
9 19

SERVICE ROUTINES (DELAYJOB)



DURING THIS PERIOD OF  $\Delta T$  CENTISECONDS, OTHER JOBS ARE EXECUTED AS THEIR PRIORITIES BECOME HIGHEST INTERRUPTED BY TASKS AS THEIR DELTA TIMES EXPIRE



MIT INSTRUMENTAL LAB CAMBRIDGE, MASS.		SERVICE ROUTINES	
FORM 3 FEB 68	3 FEB 68	COLLOSSUS	DOCUMENT NO.
BY: <i>Robert Moore</i>	<i>sk</i>	II-D	FC-2070
CHKD BY: <i>C. J. Beck</i>	3-12-69	REV 2	SHEET 10 OF 14
APPRO: <i>John A. Moore</i>	23 MAR 69		

SERVICE ROUTINES (GENTRAN)

THIS SUBROUTINE IS USED FOR COPYING CONTENTS OF N CONSECUTIVE LOCATIONS WHOSE INITIAL ADDRESS IS M INTO N CONSECUTIVE LOCATIONS WHOSE INITIAL ADDRESS IS X.

THE CALLING SEQUENCE IS:

X ← -1 CAF X ← M  
 X ← 0 TC GENTRAN  
 X ← 1 ADRES M  
 X ← 2 ADRES X  
 X ← 3 RETURN HERE UNCONDITIONALLY  
 :  
 :  
 X ← N OCT N ← 1

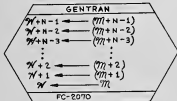
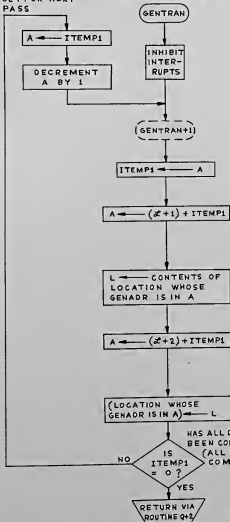
EXAMPLE OF CALLING SEQUENCE:

MARKIT1 CAF SIX  
 TC GENTRAN  
 ADRES MRKBUF1  
 ADRES MRKBUF2

ENTERED FROM 13 LOCATIONS WITH A = OCT N-1

THIS SUBROUTINE WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING IT:

SET FOR NEXT PASS



ITEMPL = (N-1) FOR 1ST PASS, (N-2) FOR 2ND PASS, (N-3) FOR 3RD, ..., AND 0 FOR LAST PASS

X ← 1 = ADRES M  
 A = ADRES (M+N-1) FOR 1ST PASS,  
 ADRES (M+N-2) FOR 2ND PASS,  
 ADRES (M+N-3) FOR 3RD PASS, ...  
 :  
 ADRES M FOR LAST PASS

L = CONTENTS OF LOCATION (M+N-1) FOR THE 1ST PASS, (M+N-2) FOR 2ND, (M+N-3) FOR 3RD, ..., AND M FOR THE LAST PASS

X ← 2 = ADRES X  
 A = ADRES (X+N-1) FOR 1ST PASS,  
 ADRES (X+N-2) FOR 2ND PASS,  
 ADRES (X+N-3) FOR 3RD PASS, ...  
 :  
 ADRES X FOR LAST PASS

M+N-1 ← M+N-1 FOR 1ST PASS,  
 M+N-2 ← M+N-2 FOR 2ND PASS,  
 M+N-3 ← M+N-3 FOR 3RD PASS, ...  
 :  
 M FOR LAST PASS

HAS ALL DATA BEEN COPIED? YES  
 (ALL PASSES COMPLETED)

RETURN TO CALLER AT X+3

RETURNS TO Q+3 OF CALLER

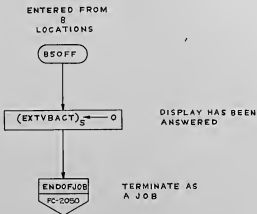
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	SERVICE ROUTINES
APPROVED DATE: 3-2-59 BY: J. H. B. / J. H. B.	COLLOSSUS II-D FC-2070
APPROVED DATE: 3-2-59 BY: J. H. B. / J. H. B.	REV 2

SERVICE ROUTINES (B5OFF)

ROUTINE B5OFF CLEARS BIT-POSITION 5 OF REGISTER EXTVBACT AND TERMINATES AS A JOB. A ZERO IN BIT-POSITION 5 INDICATES THAT THE DISPLAY HAS BEEN ANSWERED

CALLING SEQUENCE:

∞+0 TO B5OFF



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APRILLO LIBRARY AND VALIDATION	
		SERVICE ROUTINES	
DRAWN: <i>A. J. Smith</i> TITLE: <i>REVISIONS</i> ANNOT: <i>C. J. Beck</i> AP'D: <i>John A. Moran</i>	14 FEB 69 2-21-69 3-13-69 2-1-69	COLOSEUS II-D REV B	DOCUMENT NO. <b>FC-2070</b> SHEET 12 OF 14



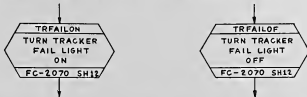
SERVICE ROUTINES  
(TRFAILON AND TRFAILOF)

SUBROUTINES TRFAILON AND TRFAILOF ARE USED TO TURN THE TRACKER FAIL LIGHT (OPTICS CDU FAIL) ON AND OFF, RESPECTIVELY

THE CALLING SEQUENCES ARE:

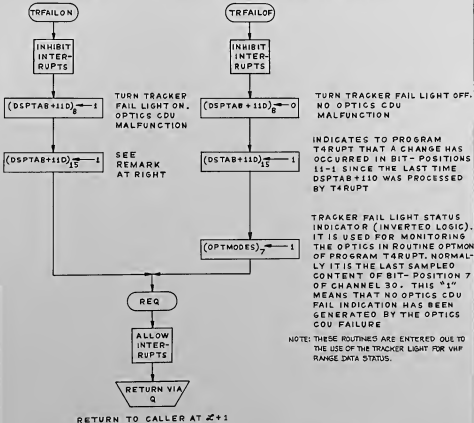
$Z+0$ TO TRFAILON	$Z+0$ TO TRFAILOF
$Z+1$ RETURN HERE UNCONDITIONALLY	$Z+1$ RETURN HERE UNCONDITIONALLY

THESE SUBROUTINES WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING THEM:



ENTERED FROM ROUTINE LIGHTON OF PROGRAM P20-P25

ENTERED FROM ROUTINE RANGED OF PROGRAM P20-P25 AND FROM ROUTINE RESETVHF OF EXTENDED VERBS (VERB 88)



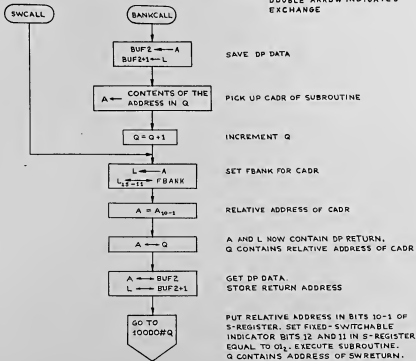
NOTE: THESE ROUTINES ARE ENTERED DUE TO THE USE OF THE TRACKER LIGHT FOR VHF RANGE DATA STATUS.

INSTRUMENTATION LAB CAMBRIDGE, MASS.		SERVICE ROUTINES	
OPER: <i>A. J. Beck</i> PROGRAM: <i>TRFAILON</i> ANALYST: <i>C. J. Beck</i> DOCNR: <i>FC-2070</i> APP'D: <i>John A. Moore</i>	16 FEB 68 3-10-68 REV 2	COLOSSUS II-D	FC-2070 13 14



THE FOLLOWING ROUTINE CAN BE USED TO CALL A SUBROUTINE IN A BANK DIFFERENT FROM THE CALLER'S. THE BANKCALL VERSION PRESERVES THE DP CONTENTS OF THE ACCUMULATOR; THE CADR OF THE SUBROUTINE IMMEDIATELY FOLLOWS THE TC BANKCALL INSTRUCTION. IN THE SWCALL VERSION THE CADR OF THE SUBROUTINE IMMEDIATELY PRECEDES THE TC SWCALL INSTRUCTION; THE CONTENTS OF THE ACCUMULATOR ARE NOT PROTECTED.

NOTE:  
DOUBLE ARROW INDICATES EXCHANGE



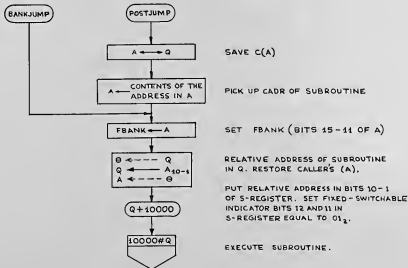
IT IS POSSIBLE TO RETURN FROM THE SUBROUTINE CALLED BY BANKCALL OR SWCALL BY TERMINATING SUBROUTINE WITH TC SWRETURN OR TC Q.



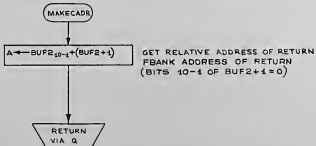
INTERBANK COMMUNICATION

COLOSSUS II FC-2080

THE POSTJUMP AND BANKJUMP ROUTINES PERMIT UNIDIRECTIONAL JUMPS TO ANOTHER BANK. POSTJUMP PROTECTS C(A) WITH THE CADR IMMEDIATELY FOLLOWING THE TC POSTJUMP INSTRUCTION. BANKJUMP DOES NOT PROTECT C(A), ENTERS WITH CADR OF SUBROUTINE IN A.



MAKECADR PUTS THE RETURN CADR SAVED BY BANKCALL OR SWCALL INTO THE ACCUMULATOR.



SUPERSW MAY BE CALLED BY ANY PROGRAM IN BANKS 00-27, BUT NEVER BY ANY PROGRAM IN SUPERBANK. ENTER WITH SUPERBITS IN THE ACCUMULATOR.



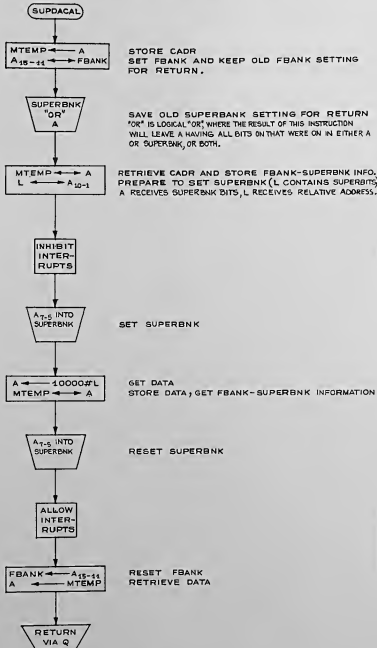
INTERBANK COMMUNICATION

COLOSSUS II FC-2080

2 5

4 Pages  
 E. W. Zimmerman 6-15-58  
 Jack A. Manning 6/16/58  
 J. Hays 6-18-58

THE FOLLOWING ROUTINE OBTAINS DATA FROM AN ADDRESS IN FIXED-SWITCHABLE MEMORY. ENTER WITH SUPERBANK BITS FOR DATA IN L, AND CADR OF ADDRESS IN A.

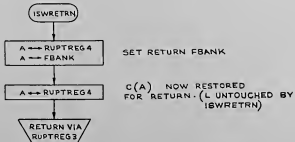
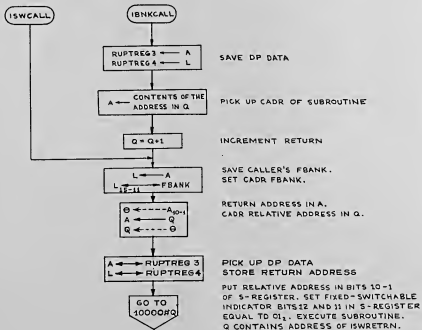


RECEIVED 22 JUN 58  
 CAMBRIDGE, MASS.  
 DEPT. OF DEFENSE  
 HEADQUARTERS  
 AIR FORCE  
 OFFICE OF THE  
 CHIEF OF STAFF  
 AIR FORCE  
 WASHINGTON, D.C.

*Wintersmore*  
*25 Feb 58*  
*John A. Moore*

INTERBANK COMMUNICATION  
 COLOSSUS II FC-2080  
 3 5

IBKCALL, ISWCALL, AND ISWRETRN, USED IN INTERRUPT,  
PERFORM THE SAME FUNCTIONS AS BANKCALL, SWCALL, SWRETURN.



INTERBANK COMMUNICATION

7. Reason 3. ENOVS

L. W. Stankovic 6/15/55

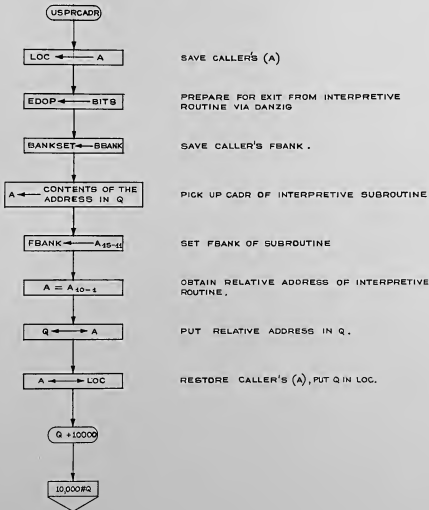
Joseph P. Blumhagen 4/16/56

J. King 6-11-51

COLOSSUS II FC-2080

4 5

USPRCADR PROVIDES ACCESS FROM BASIC CODING TO INTERPRETIVE CODING WHICH DOES NOT USE THE ENTERING CONTENTS OF Q AND WHICH EXITS VIA DANZIG. THE CALLER'S (A) IS SAVED. U&PRCADR CHANGES FBANK, ENTER WITH CADR INTPRETX IMMEDIATELY FOLLOWING THE TC USPRCADR INSTRUCTION.



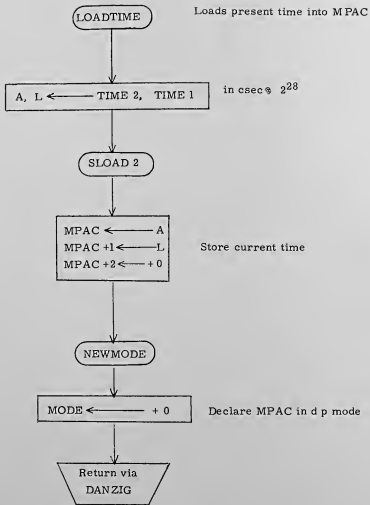
WE INSTRUMENTATION, INC. CAMBRIDGE, MASS.	SPILL CIVIL ENGINEERING
DRAWN <i>W. B. Smith</i> CHECKED <i>W. B. Smith</i> ANALYST DESIGNER <i>W. B. Smith</i> APPROVED <i>John A. Moore</i>	INTERBANK COMMUNICATION COLLOSSUS II FC-2080 27761 5 5

RTB OP CODES

LOADTIME	Sh. 2
CDULOGIC	Sh. 3
READPIPS	Sh. 4
SGNAGREE	Sh. 5
1STO2S	Sh. 5
VISTO2S	Sh. 6
2VISTO2S	Sh. 7
1TO2SUB	Sh. 8
INCRCDUS	Sh. 9
CDUINC	Sh. 10
PULSEIMU	Sh. 12
VECSGNAG	Sh. 12
TRANSP1	Sh. 13
TRANSP2	Sh. 13
SIGNMPAC	Sh. 14
NORMUNXI	Sh. 15
NORMUNIT	Sh. 15

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Peizer</i>	<i>1/22/67</i>	RTB Op Codes	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2100
DOCMR <i>Roberta M. Ester</i>	<i>12/1/67</i>	REV	SHEET 1 OF 17
APPR'D <i>Roberta M. Ester</i>			

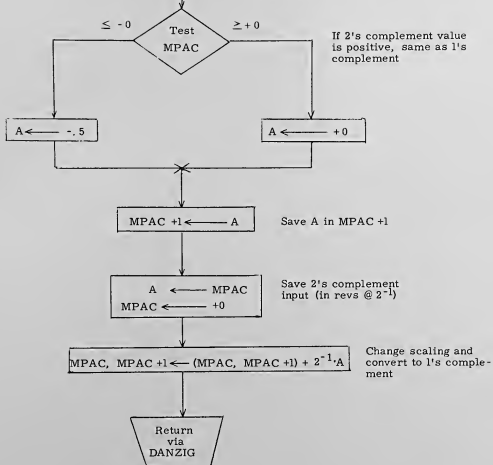




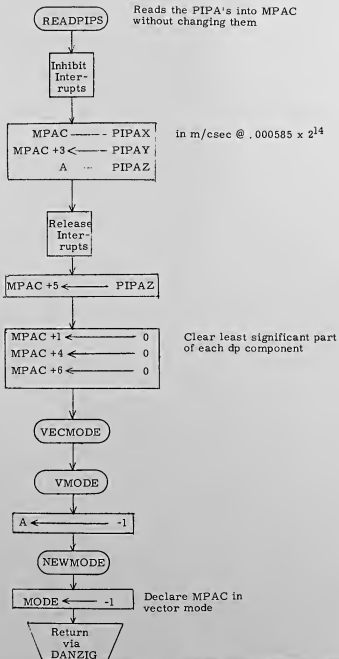
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Newitz</i>	<i>11/22/69</i>	RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2100
ANALST			
DOCMR <i>R.M. Euter</i>	<i>12/3/69</i>	REV	SHEET 2 OF 17
APPR'D <i>R.M. Euter</i>			

CDULOGIC

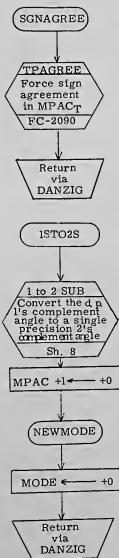
Converts the single precision 2's complement number arriving in MPAC in revs @  $2^{-1}$  to a dp 1's complement number in revs @  $2^0$



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Reder</i>		RTB Op Codes	
PRGMR	<i>11/22/69</i>	DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2100
DOCMR <i>R.M. E. J.</i>	<i>12/1/69</i>	REV	SHEET 3 OF 17
APPR'D <i>R.M. E. J.</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>S. River</i>	<i>11/21/67</i>	RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2100
ANALST			
DOCMR <i>R.M. Euter</i>	<i>12/13/67</i>	REV	SHEET 4 OF 17
APPR'D <i>R.M. Euter</i>			



Forces sign agreement  
in MPAC<sub>T</sub>

Converts the d.p. 1's complement  
angle in revs @ 2° to a single pre-  
cision 2's complement angle in  
revs 2<sup>-1</sup>

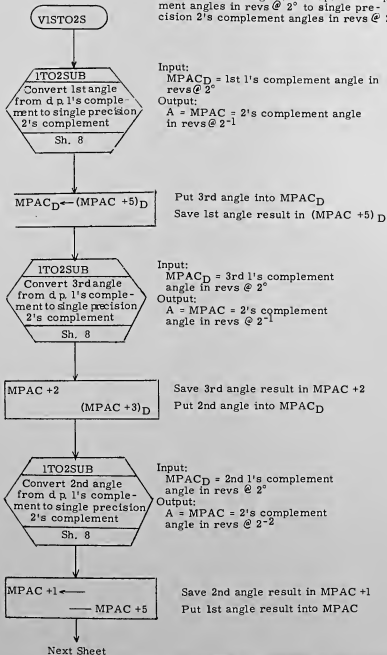
Input:  
MPAC<sub>D</sub> = 1's complement angle  
in revs 2°

Output:  
A = MPAC = 2's complement  
angle in revs @ 2<sup>-1</sup>

Declare MPAC in d.p. mode

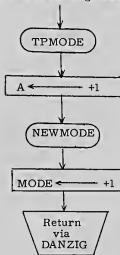
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. M. E. 11/21/69</i>		RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2100
ANALST			
DOCNR <i>R. M. E. 12/2/69</i>		REV	SHEET 5 OF 17
APPR'D <i>R. M. E.</i>			

Converts (on 3 angles) the d. p. 1's complement angles in revs @  $2^0$  to single precision 2's complement angles in revs @  $2^{-1}$

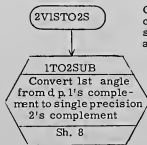


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Reiser</i> 1/24/69		RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2100
DOCMR <i>R.M. Suter</i>	12/3/69	REV	SHEET 6 OF 17
APPR'D <i>R.M. Suter</i>			

From Preceding Sheet



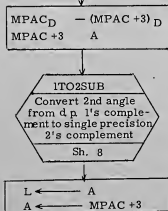
Declare MPAC in t. p. mode



Converts (on 2 angles) the d. p. 1's complement angles in revs @  $2^\circ$  to single precision 2's complement angles in revs @  $2^{-1}$

Input:  
 $MPAC_D = 1st\ 1's\ complement\ angle\ in\ revs\ @\ 2^\circ$   
 Output:  
 $A = MPAC = 2's\ complement\ angle\ in\ revs\ @\ 2^{-1}$

Load 2nd angle for input.  
 Save 1st angle result in MPAC + 3.



Input:  
 $MPAC_D = 2nd\ 1's\ complement\ angle\ in\ revs\ @\ 2^\circ$   
 Output:  
 $A = MPAC = 2's\ complement\ angle\ in\ revs\ @\ 2^{-1}$

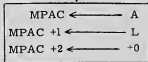
Save 2nd angle results in L  
 Put 1st angle result into A

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Reyer</i> 1/22/69		RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2100
DOCMR <i>R. M. Fester</i> 1/23/69		REV	
APPR'D <i>R. M. Fester</i>			SHEET 7 OF 17

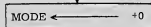
From Preceding Sheet

SLOAD2



Store 1st angle result in MPAC and store 2nd angle result in MPAC +1

NEWMODE



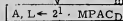
Declare MPAC in d. p. mode

Return via DANZIG

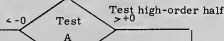
I/O2SUB

Input:  
 $MPAC_D = \text{angle in 1's complement in revs } 2^7$

Output:  
 $A = MPAC = \text{angle in 2's complement in revs } 2^{-1}$



Change scaling to  $2^{-1}$



Add 1 low-order bit to negative value in 1's complement to form 2's complement



0 angle must be +0 in 2's complement

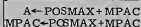


For positive value 1's complement = 2's complement

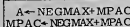
Should bit 15 = 0 ?



Should bit 15 = 1 ?



POSMAX=37777g



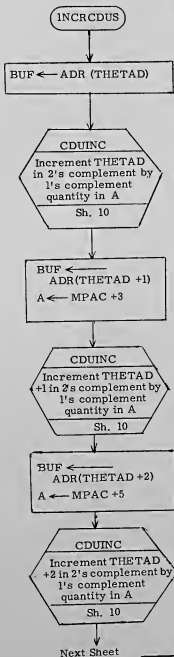
Restore 1 to bit 15  
 Lost if overflow  
 NEGMAX=40000g

Fix "overflow corrected" result

Return via Q

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Reider</i>	<i>4/22/67</i>	RTB Op Codes	
PRGRM		COLOSSUS 2D	DOCUMENT NO. FC-2100
ANALST		REV	SHEET 8 OF 17
DOCMR <i>R.M. Euter</i>	<i>12/14/67</i>		
APPR'D <i>R.M. Euter</i>			

Increments CDU's  
 Input: angles in MPAC, +3, +5 in revs  
 $2^{-1}$  in 1's complement  
 THETAD, +1, +2 in 2's complement



Input: A = MPAC  
 BUF = Address of quantity to be incremented  
 (here = address of THETAD)  
 Result:  $ADR^{-1}(BUF) = THETAD$  incremented  
 in 2's complement by 1's complement quantity  
 in MPAC

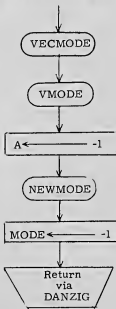
Input: A = MPAC +3  
 BUF = address of quantity to be incremented  
 (here address of THETAD +1)  
 Result:  $ADR^{-1}(BUF) = THETAD +1$  incremented  
 in 2's complement by 1's complement quantity  
 in MPAC +3

Input: A = MPAC +5  
 BUF = address of quantity to be incremented  
 (here = address of THETAD +2)  
 Result:  $ADR^{-1}(BUF) = THETAD +2$  incremented  
 in 2's complement by 1's complement quantity  
 in MPAC +5

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R.M. Euter</i> 11/22/69		RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2100
DOCMR <i>R.M. Euter</i>	12/3/69	REV	SHEET 9 OF 17
APPR'D <i>R.M. Euter</i>			



From Preceding Sheet



Declare THETAD in vector mode

CDUINC

Increments in 2's complement the register whose address is in BUF by the 1's complement quantity which arrives in A

TEM2 ← A

1's complement increment value arrives in A and is stored in TEM2

Test  $ADR^{-1}(BUF)$

Change 2's complement angle whose address is stored in BUF to 1's complement by subtracting 1 low-order bit if negative ( $\leq -0$ )

A ← +0

A ←  $ADR^{-1}(BUF)$

A ←  $ADR^{-1}(BUF) - 1$

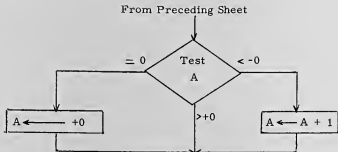
A ← A + TEM2

Increment by input value

Next Sheet

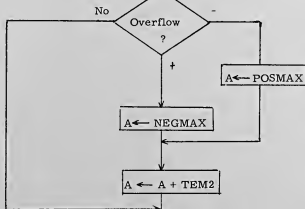
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Reiter</i>	<i>11/22/69</i>	RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2100
ANALST			
DOCMR <i>R.M. Fanta</i>	<i>12/2/69</i>	REV	SHEET 10 OF 17
APPR'D <i>R.M. Fanta</i>			

0 must be  
+0 in 2's  
complement



Add 1 low-order  
bit to negative  
value in 1's comple-  
ment to form 2's  
complement

Store incremented  
2's complement value

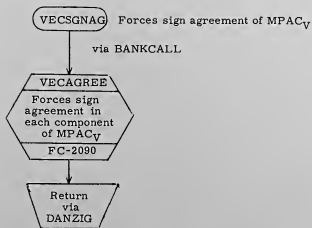
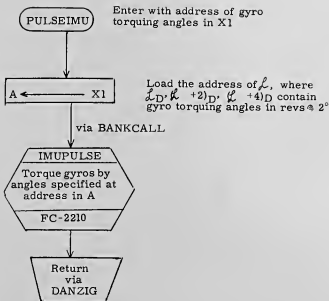


If overflow, fix  
bit 15 by adding  
POSMAX (37777<sub>8</sub>)  
or NEGMAX  
(40000<sub>8</sub>)  
(quantity  $\times 2^{-1}$ )

Store new angle  
in 2's complement

Return  
via  
Q

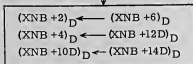
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Reiser</i>	<i>9/12/69</i>	RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2100
DOCNR <i>R. M. Euter</i>	<i>12/13/69</i>	REV	SHEET 11 OF 17
APPR'D <i>R. M. Euter</i>			



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DRAWN <i>E. Reiser</i>	<i>11/21/69</i>	RTB Op Codes	
PRGMR		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2100
DOCMR <i>R.M. Estra</i>	<i>12/3/69</i>	REV	SHEET 12 OF 17
APPR'D <i>R.M. Estra</i>			

TRANSP1

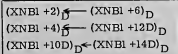
Replaces a 3 x 3 matrix in  
d. p. with the transpose matrix



Return  
via  
DANZIG

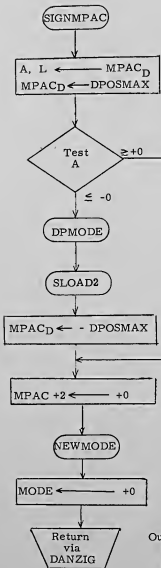
TRANSP2

Replaces a 3 x 3 matrix in  
d. p. with the transpose matrix



Return  
via  
DANZIG

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Reiser</i>	<i>4/21/69</i>	RTB Op Codes	
PRGMR _____	_____	COLOSSUS 2D	DOCUMENT NO.
ANALST _____	_____		FC-2100
DOCMR <i>R. M. Euter</i>	<i>12/2/69</i>	REV _____	SHEET 13 OF 17
APPR'D <i>R. M. Euter</i>	_____	_____	_____



Sets contents of  $MPAC_D$  to  $DPOSMAX$  if  $MPAC$  is positive and to  $-DPOSMAX$  if  $MPAC$  is negative.  
 Input:  $MPAC_D$

$DPOSMAX = 37777_8, 37777_8$

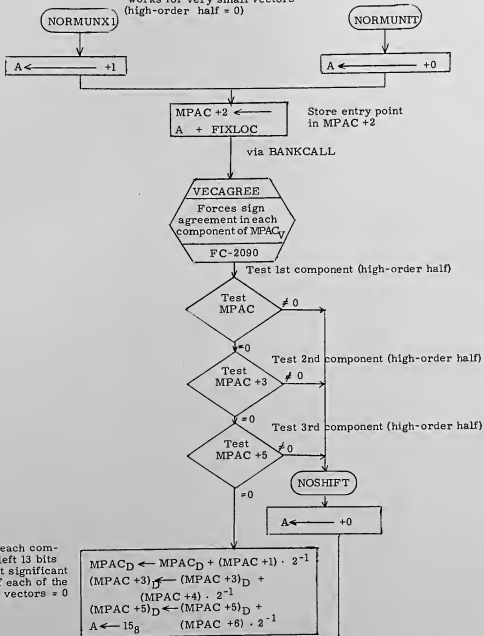
For positive  $MPAC$ , set  $MPAC_D = DPOSMAX$ .  
 For negative  $MPAC$ , set  $MPAC_D = -DPOSMAX$   
 ■ maximum d. p.  
 Negative magnitude.

Declare  $MPAC$  in d. p. mode

Output:  
 $MPAC_D$  containing  
 $DPOSMAX$  or  $-DPOSMAX$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Reiner</i> 1/23/68		RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2100
DOCMR <i>R. M. E. S. S.</i>	12/2/67	REV	SHEET 14 OF 17
APPR'D <i>R. M. E. S. S.</i>			

Performs unit operation but also works for very small vectors (high-order half = 0)



Shifts each component left 13 bits if most significant part of each of the 3 d.p. vectors = 0

$$MPAC_D \leftarrow MPAC_D + (MPAC + 1) \cdot 2^{-1}$$

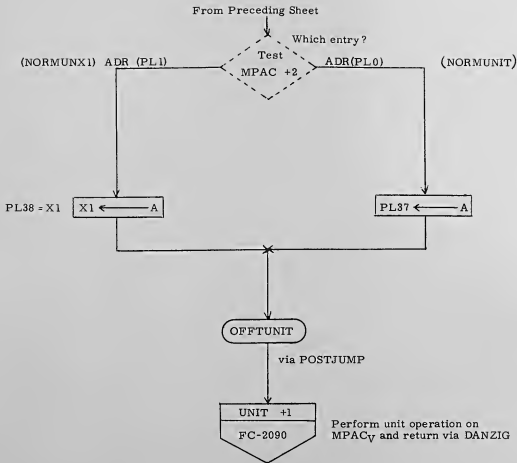
$$(MPAC + 3)_D \leftarrow (MPAC + 3)_D + (MPAC + 4) \cdot 2^{-1}$$

$$(MPAC + 5)_D \leftarrow (MPAC + 5)_D + (MPAC + 6) \cdot 2^{-1}$$

$$A \leftarrow 15_8$$

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>E. REVER</i>	RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2100
DOCMR	<i>R. M. EISEN</i>	REV	
APPR'D	<i>R. M. EISEN</i>		SHEET 15 OF 17



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>E. PEIDEN</i>	RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2100
DOCMR	<i>R. M. EATON</i>	REV	SHEET 16 OF 17
APPR'D	<i>R. M. EATON</i>		

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
IMUPULSE	FC-2210	Torques gyros	Sh. 12
TPAGREE	FC-2090	Forces sign agreement in MPAC <sub>T</sub>	Sh. 5
UNIT	FC-2080	Performs unit operation	Sh. 16
VECAGREE	FC-2090	Forces sign agreement in each component of MPAC <sub>V</sub>	Sh. 12, 15

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN _____		RTB Op Codes	
PRGMR _____			DOCUMENT NO.
ANALST _____		COLOSSUS 2D	FC-2100
DCMR <i>R.M. Smith</i>	<i>12/1/69</i>	REV	SHEET 17 OF 17
APPR'D <i>R.M. Smith</i>			

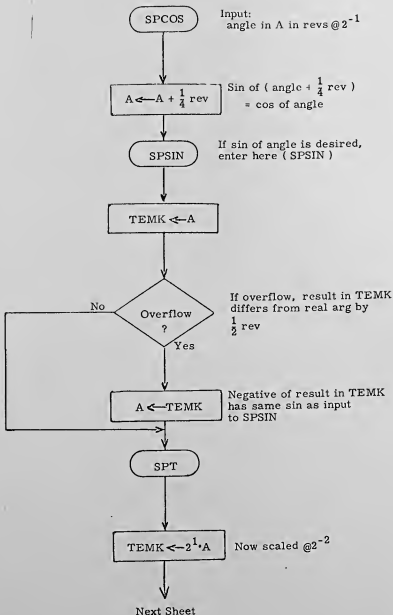


Single Precision Subroutines

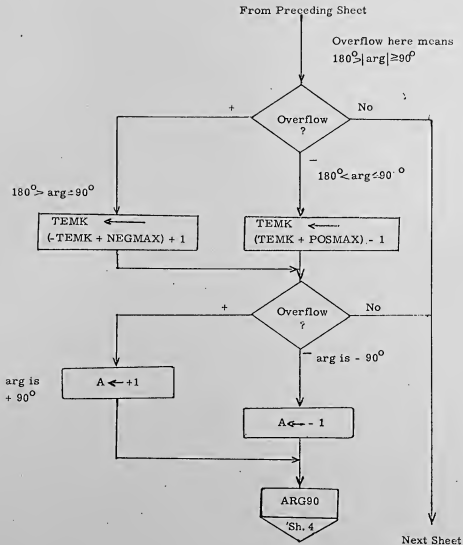
SPCOS Sh. 2

SPSIN Sh. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Single Precision Subroutines	
DRAWN	<i>[Handwritten Signature]</i>	COLOSSUS	DOCUMENT NO.
PRGMR	<i>[Handwritten Signature]</i>	2D	FC-2110
ANALST	<i>[Handwritten Signature]</i>		
DOCMR	<i>[Handwritten Signature]</i>		
APPR'D	<i>[Handwritten Signature]</i>		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Collins</i>		Single Precision Subroutines	
PRGRM	<i>A</i>	COLLOSSUS 2D	DOCUMENT NO. FC-2110
ANALST	<i>D. S. 12-20-67</i>		
DOCMR	<i>Edwards, J. F. 12/20/67</i>		
APPR'D <i>J. Collins</i>	<i>E. J. 12/20/67</i>	REV	SHEET 2 OF 4



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>P.C.T.</i>	Single Precision Subroutine	
PRCMR	<i>D.S.T.</i>	COLOSSUS 2D	DOCUMENT NO. FC-2110
ANALST	<i>D.S.T.</i>		
DOCMR	<i>P.C.T.</i>		
APPR'D	<i>P.C.T.</i>	REV	SHEET 3 OF 3

From Preceding Sheet

POLLEY

A = TEMK  
arg = angle in revs @  $2^{-2}$   
 $|\arg| < 90^\circ$

$$A \leftarrow 2(C5/2 \cdot TEMK^5 + C3/2 \cdot TEMK^3 + C1/2 \cdot TEMK)$$

$$C5/2 = \frac{1}{5!} (2\pi)^5 @ 2^{11}$$

$$C3/2 = \frac{1}{3!} (2\pi)^3 @ 2^7$$

$$C1/2 = 1 \cdot 2 \pi @ 2^3$$

$2\pi$  is conversion factor to convert from revs to radians. A is in radians @  $2^0$

No  
Overflow  
?

Yes

Return  
via  
Q

ARG90

Test  
angle

= -90°

= +90°

$$A \leftarrow - POSMAX$$

$$A \leftarrow -NEGMAX$$

Sin = -1  
- POSMAX  
= NEGMAX  
= 40000<sub>8</sub> is

as close as can  
get to -1 @  $2^0$

Sin = +1  
- NEGMAX = POSMAX  
= 37777<sub>8</sub>

is as close as can get to  
+1 @  $2^0$

Return  
via  
Q

Output:

A = sin of input to SPSIN  
( = cos of input to SPCOS ) @  $2^0$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>[Signature]</i>	Single Precision Subroutines	
PROGR	<i>[Signature]</i>	COLOSSUS 2D	DOCUMENT NO. FC-2110
ANALYST	<i>[Signature]</i>		
APPR'D	<i>[Signature]</i>	REV	SHEET 1 OF 1

AGC COMPUTER SELF CHECK ROUTINE

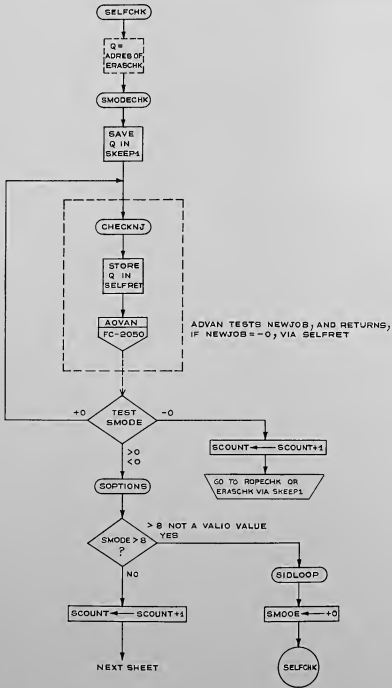
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

SELFRET:	ERASABLE LOCATION CONTAINING RETURN ADDRESSES TO SELF CHECK	
SELFCHK:		SH. 2
STSHOSUM:	ENTRY FROM SHOWSUM ROUTINE	SH. 7

SELF CHECK ROUTINE

*P.M. Bishop* 2/11/66  
*Frank Smith* 5-27-69  
*Donald R. Bond* 5-27-69  
*Robert W. Smith* 5/28/69

COLOSSUS II FC-2120

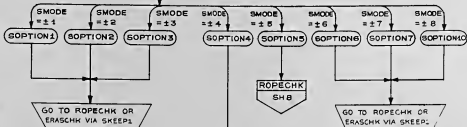


27 JAN 68  
 5-28-68  
 Donald H. [unclear]  
 [unclear]

SELF CHECK ROUTINE

COLOSSUS II FC-2120

FROM PRECEDING SHEET



ERASCHK

SKEEP2 ← + 1

SKEEP2 CONTROLS CHECKING OF NON-SWITCHABLE ERASABLE WITH BANK NUMBERS IN EBANK

OEBANK

EBANK ← + 0  
SKEEP7 ← 01461<sub>8</sub>  
SKEEP3 ← 01777<sub>8</sub>

EBANK 0  
STARTING ADDRESS  
ENDING ADDRESS

ERASLOOP

START OF ERASABLE CHECK LOOP

INHIBIT  
INTER-  
RUPTS

SKEEP4 ← EBANK  
SKEEP5<sub>0</sub> ← 0000<sub>8</sub> # SKEEP7  
ERESTORE ← SKEEP7  
0 # SKEEP7 ← SKEEP7  
1 # SKEEP7 ← (SKEEP7 + 1)

SAVE EBANK SETTING

SAVE CONTENTS OF DP REGISTER POINTED TO BY SKEEP7

MAKE ERESTORE NON-ZERO, TO INDICATE ERASABLE MUST BE RESTORED  
PUT INTO REGISTER POINTED TO BY SKEEP7 OWN ADDRESS  
LIKEWISE WITH NEXT REGISTER

A ← D# SKEEP7 - 1 # SKEEP7

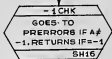
SHOULD BE -1 (THE ADDRESS OF ONE REGISTER - ADDRESS OF NEXT REGISTER + 1)

NEXT SHEET

SELF CHECK ROUTINE

27 JAN 69  
5 2849  
FC-2120

FROM PRECEDING SHEET

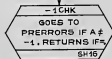


IS  
ERESTORE = 0 ?

HAS ERASABLE  
BEEN RESTORED ? (MIGHT HAPPEN IN -1CHK)

Q1# SKEEP7 ← -Q1# SKEEP7  
A ← -Q2# SKEEP7 + 1# SKEEP7

CHANGE SIGNS AND CHECK AGAIN



IS  
ERESTORE = 0 ?

HAS ERASABLE  
BEEN RESTORED ? (MIGHT HAPPEN IN -1CK)

Q1# SKEEP7 ← SKEEPB\_D  
ERESTORE ← +0

RETURN CONTENTS OF ERASABLE CELLS  
INDICATE CONTENTS RETURNED.

ELOOPFIN

ALLOW  
INTER-  
RUPTS

CHECKN.J

STORED  
IN  
SELFRET

ADVAN  
FC-2050

NEXT SHEET

SELF CHECK ROUTINE

COLOSSUS IIA FC-2120



FROM PRECEDING SHEET

EBANK ← SKEEP4  
SKEEP7 ← SKEEP7+1

RESET EBANK CORRECTLY (ADVAN MIGHT HAVE FOUND A JOB AND RETURNED)  
CHECK NEXT REGISTER

IS WAS EBANK FINISHED ?  
SKEEP7 = SKEEP3 ?

ERASLOOP  
SH3

IS SKEEP2 = 0 ?  
HAS NONSWITCHABLE ERASABLE WITH BANK NUMBERS IN EBANK BEEN CHECKED ?

A ← + 0

NOEBANK  
SH6

SKEEP2 ← + 1  
EBANK ← EBANK + 400<sub>8</sub>

ENSURE NEXT-ROUND CHECK OF UNSWITCHED ERASABLE  
TAKE NEXT EBANK

IS THIS NEXT THE SECOND EBANK ?  
IS EBANK = 1000<sub>8</sub> ?

2EBANK  
SH6

HAVE ALL EBANKS BEEN CHECKED ?

E134567B  
SH6

EBANK ← 1400<sub>8</sub>

CNTRCHK  
SH7

4-10-64  
COMPL BY  
*W. D. Rouse*  
CHECKED BY  
*Frank Stewart*  
AND  
*W. D. Rouse*  
DATE  
*10/1/67*

SELF CHECK ROUTINE

COLOSSUS II A FC-2120

NOEBANK

CHECKS UNSWITCHEO ERASBLE

SKEEP2 ← A  
SKEEP7 ← 0064<sub>8</sub>  
SKEEP3 ← 0177<sub>8</sub>

+0 TO SKEEP2 FOR NEXT-ROUND CHECK OF SWITCHED ERASBLE  
STARTING ADDRESS  
ENDING ADDRESS

ERASLOOP  
SH3

REBANK

CHECKS SECONO EBANK

SKEEP7 ← 01400<sub>8</sub>  
SKEEP3 ← 01773<sub>8</sub>

STARTING ADDRESS  
ENDING ADDRESS

ERASLOOP  
SH3

E134567<sub>8</sub>

SKEEP7 ← 01400<sub>8</sub>  
SKEEP3 ← 01777<sub>8</sub>

STARTING ADDRESS  
ENDING ADDRESS

ERASLOOP  
SH3

UNIT ADDRESS NAME PHONE CITY STATE ZIP	SELF CHECK ROUTINE COLOSSUS IIA FC-2120 6 18
--	--

*Handwritten:* 28 JAN 69  
 15-28-69  
 15-28-69  
 15-28-69

CNTRCHK

PERFORMS "C5" ON ALL REGISTERS FROM 60<sub>8</sub> TO 10<sub>8</sub>  
A PARITY FAILURE WILL CAUSE A HARDWARE RESTART

A ← 00050<sub>8</sub> ADDRESS OF FIRST COUNTER

CNTRLOOP

SKEEP2 ← A  
A ← -(10<sub>8</sub>#A)

IS SKEEP2 = +0 ?

NO

YES

A ← SKEEP2-1

CYCLSHFT

A ← 25252<sub>8</sub>  
CYR ← A  
CYL ← A  
SR ← A  
EDOP ← A  
A ← CYR + CYL + SR + EDOP + 52400

C(CYR) = 12525<sub>8</sub>  
C(CYL) = 52524<sub>8</sub>  
C(SR) = 12525  
+C(EDOP) = 00125  
TOTAL = -52400-1

SENSING OPERATIONS LEAVE THESE VALUES IN THE REGISTERS:

C(CYR) = 45252  
C(CYL) = 25254  
C(SR) = 05252  
C(EDOP) = +00000

TOTAL = -2

-1CHK

A ← -1 IF SO,  
RETURN. IF  
NOT BRANCH TO  
PRERORS

SH16

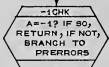
A ← CYR + CYL + SR + EDOP + 1 SHOULD = -1

NEXT SHEET

SELF CHECK ROUTINE

COLOSBUS IIA FC-2120

FROM PRECEDING SHEET



SCOUNT+1 ← (SCOUNT+1)+1      INCREMENT SCOUNT+1

SMODECHK  
SH2

Q=  
 ADRES  
 ROPECHK      CHECK NEWJOB FOR ANY JOB SCHEDULED.

RETURN IF  
 NEWJOB = -1, AND SMODE = -0, ± 10, OR ± (1, 2, 3, 5, OR 7)

ROPECHK

SKEEP6 ← -0      INDICATES THIS IS ROPECHK, NOT SHOWSUM

STSHOSUM

SKEEP4 ← +0      0 BANK  
 A ← +1            POSITIVE NUMBER IN A  
                      FOR SWITCHED FIXED  
                      (LOADED INTO SKEEP7 AT COMMX)

COMMX

SKEEP7 ← A      SKEEP7 MUST BE >0 TO RETURN TO HERE  
 SKEEP4 ← +0      SKEEP4 WILL HOLD SUM  
 SKEEP3 ← +0      FIRST ADDRESS TO BE SENSED  
 SKEEP5 ← +1      INITIALIZE FOR "TC SELF" COUNTDOWN

NEXT SHEET

WITH  
 INFORMATION  
 CHANGE  
 5/28/64  
 COLUSSUS IIA  
 3/18/64

SELF CHECK ROUTINE

COLUSSUS IIA FC-2120

8 18

FROM PRECEDING SHEET

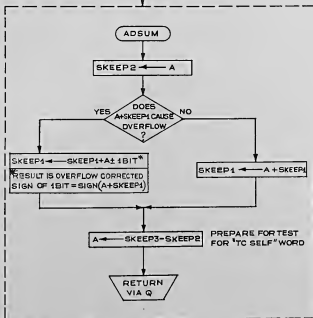
COMADDR

L ← SKEEP4  
A ← (BITS 15-11 OF SKEEP4) + SKEEP3

L CONTAINS FBANK SETTING (INCLUDING SUPERBNK)  
A CONTAINS CADR OF CELL TO BE SENSED

SUPDACAL  
GET DATA FROM  
CELL WHOSE  
FBANK IN L, CADR  
IN A  
FC-2080

INPUT: A = CADR  
L = FBANK + SUPERBNK  
OUTPUT: A = CONTENTS OF THE CELL THE CADR OF  
WHICH WAS IN A.



A "TC SELF" WORD CONTAINS ITS OWN ADDRESS. ABANK THAT DOES NOT HAVE ALL ITS LOCATIONS WIRED ENDS WITH 2 CONSECUTIVE LOCATIONS CONTAINING THEIR OWN ADDRESS, FOLLOWED BY BANKSUM.

A ← 0200<sub>B</sub> + A

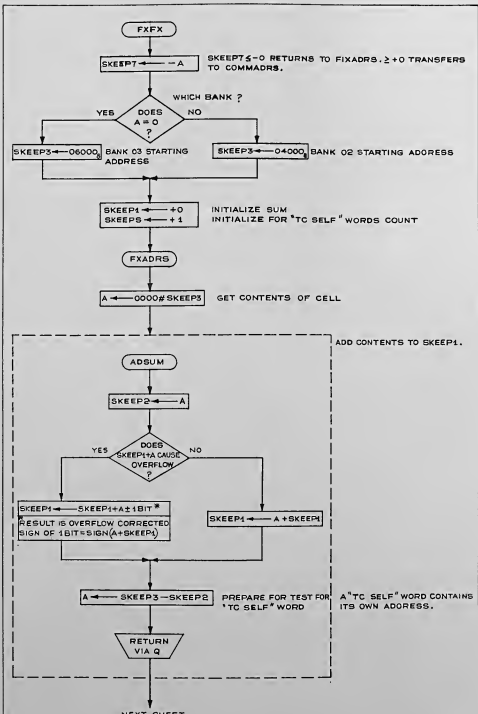
SWITCHED FIXED MEMORY ADDRESSES START WITH 2000<sub>B</sub>

ADRSCHK  
SH44

IN IS...  
 30 JAN 68  
 5-28-68  
 2172  
 7/26/68

SELF CHECK ROUTINE

COLOSSUS II A FC-2120



FROM PRECEDING SHEET

ADRSCHK

L ← A

PREPARE FOR "TC SELF" CHECK

IS SKEEPS<sub>3</sub> = (MAXADRS) ?

END OF THE BANK ?

YES

NO

IS SKEEPS < 0 ?

HAVE 2 "TC SELF" WORDS BEEN ENCOUNTERED (THIS CONDITION IS NOT SATISFIED UNTIL THE CELL IMMEDIATELY AFTER THE SECOND "TC SELF" WORD HAS BEEN SENSED)

YES

NO

SOPTION SH43

IS L = -D ?

WAS SENSED CELL A "TC SELF" WORD? (ONLY TWO CONSECUTIVE "TC SELF" WORDS WILL RESULT IN THE SUCCEEDING "TC SELF" WORDS BEING PROCESSED AS BANKSUM.)

YES

NO

FIRST OR SECOND

TEST SKEEPS

SECOND

+0

>0 FIRST

A ← -1

CONTINU

A ← +0

A ← +1

CONTINU+1

SKEEPS ← A

SET SKEEPS ACCORDINGLY:  
+1: TWO CONSECUTIVE "TC SELF" WORDS NOT YET SENSED.  
+0: 1ST "TC SELF" SENSED ON THIS ROUND.  
-1: 2 CONSECUTIVE "TC SELF" WORDS SENSED, NEXT LOCATION CONTAINS BANKSUM

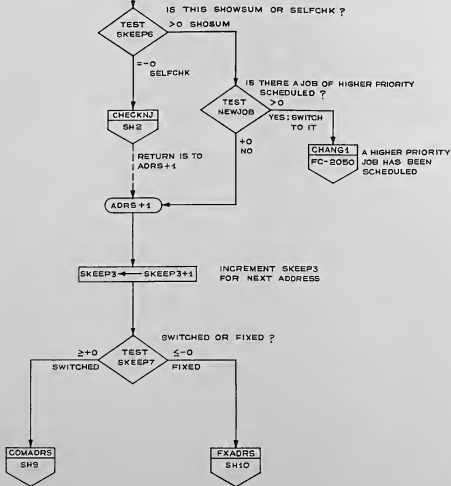
NEXT SHEET

*Handwritten notes:*  
312AM00  
5-28-61  
COLOSSUS IIA FC-2120  
11 18

SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

FROM PRECEDING SHEET

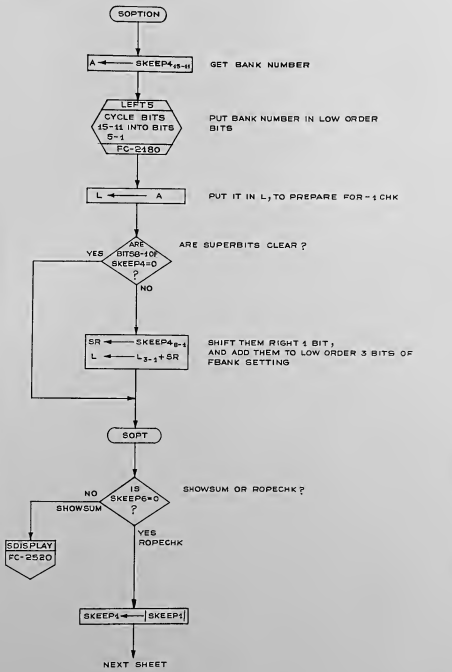


APPROVED BY  
DATE  
*P.M. Dick*  
*Frank E. Stewart*  
5-28-64  
21 2/63  
APR 6 1964

SELF CHECK ROUTINE

COLOSSUS IIA FC-2120





SELF CHECK ROUTINE  
 FC-2120  
 15 18

*Handwritten:* OK, 3/28/64  
 3/28/64  
 3/28/64

FROM PRECEDING SHEET

BNKCHK

A ← SKEEP4-1-L

SHOULD = -1

--1CHK  
A CHECKED  
TO = -1  
SH16

NXTBNK

IS SKEEP4 = 66100 ?  
WAS THAT LAST BANK ?

YES

NO

ENOSUMS

IS THIS SELFCHK ?

YES

NO

SELFCHK

SH 2

SHOWSUM

STSHOSUM

FC-2620

DOES SKEEP4 + 2000<sub>8</sub> OVERFLOW ?

YES

NO

17 TO 20

SKEEP4 ← SKEEP4 + 2000<sub>8</sub>

NEXT BANK

SKEEP4 ← SKEEP4 + 40000<sub>8</sub>

NEXT SHEET

GONXTBNK

GO SUM BANK

SH15

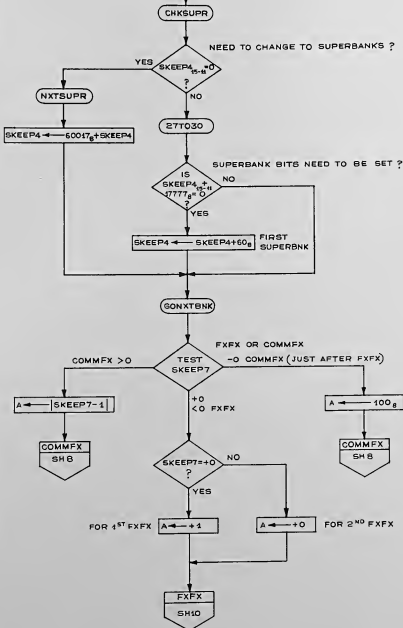
20

*PH. Outer*  
*Handwritten notes and signatures*

SELF CHECK ROUTINE

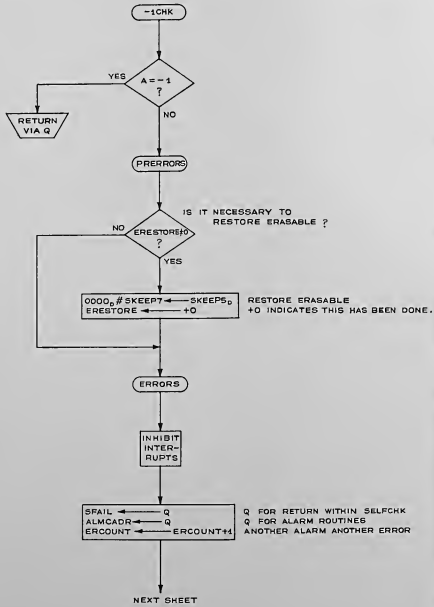
COLOSSUS II FC-2120

FROM PRECEDING SHEET



SELF CHECK ROUTINE

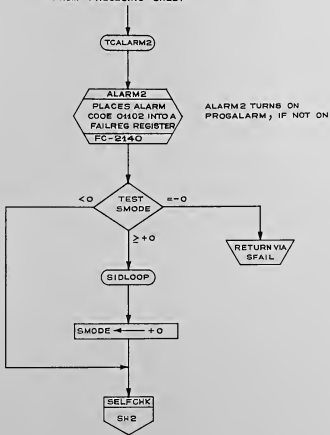
COLOSSUS IIA FC-2120



SELF CHECK ROUTINE  
 COLLOSSUS IIA FC-2120  
 16 18

*PH. D. ...*  
*...*  
*...*

FROM PRECEING SHEET



ALARM2 TURNS ON  
PROGALARM, IF NOT ON

SELF CHECK ROUTINE

4 FEB 68

5-28-69

COLOSSUS IIA FC-2120

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUPDACAL:

FC-2080

OBTAINS DATA FROM ANY BANK

SH.

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
CYR					
CYL					
SR					
EDOP					
SKEEP1		Pointer for Starting ROPECHK or ERASCHK (Depending also on SMODE), DE-SUM-LOCATE			
SKEEP2		CONTROLS CHECKING OF NON-SWITCHABLE ERASABLE, WITH EBANK SET; STORES FBANK CELL DATA			
SKEEP3		HOLDS ADDRESS FOR ROPECHK; ENDING ADDRESS FOR EBANK CHECK			
SKEEP4		HOLDS FBANK AND FBANK SETTINGS			
SKEEP5		HOLDS HIGH ORDER HALF OF ERASABLE LOCATIONS BEING CHECKED; COUNTS DOWN TWO "TC SELF WORDS"			
SKEEP6		HOLDS LOW ORDER HALF OF ERASABLE LOCATIONS BEING CHECKED; SHOWSUM-ROPECHK INDICATOR			
SKEEP7		FXFX-COMMFX INDICATOR; ADDRESS POINTER FOR ERASCHK			
SMODE		SELF CHECK MODE INDICATOR			
SELFRET		RETURN ADDRESS OF STORAGE (ALSO LOADED BY FRESH START AND SHOWSUM)			
SCOUNT		COUNTS NUMBER OF TIMES THROUGH SELFCHECK			
SCOUNT+1		INTERNAL COUNTER			
SFAIL		HOLDS RETURN ADDRESS FOR ALARM			
ERCOUNT		COUNTS ERRORS			

SELF CHECK ROUTINE

*DMW*  
*Frank*  
*23/10/67*  
*Binary System*

4FEB60

5-22-69

COLOSSUS IIA FC-2120

## ALARM AND ABORT

The alarm routine and its associated entries are used for setting the alarm code into one of the FAILREG registers. It turns on the program alarm light (by setting bit-position 9 of register DSPTAB+11D to one). The alarm code (or codes) is then available for display. Also, the 2CADR of the location where the alarm condition occurred is set into the ALMCADR registers so it is available for display.

There are three FAILREG registers for storing alarm codes. The first alarm code is set into registers FAILREG and FAILREG+2. The second alarm code is set into registers FAILREG+1 and FAILREG+2. The last (3rd or more) is set into register FAILREG+2. Subsequent alarm codes (3rd or more) will replace the existing alarm code in register FAILREG+2. This will continue as additional alarm conditions are encountered until the operator depresses the error light reset key. Before depressing this key, the operator will normally key in verb 05 and noun 09, which will cause the contents of all three of the FAILREG registers to be displayed so that the operator can determine the type of alarm condition from the alarm code (see Table of Alarm Codes versus Alarm Conditions, etc. on sheet 6) and can respond with appropriate action. If further information is necessary, the operator will also key in verb 05 and noun 08, which will cause the contents of registers ALMCADR, ALMCADR+1 and ERCOUNT to be displayed. The operator can then determine the location of the alarm condition from the 2CADR in registers ALMCADR and ALMCADR+1 and determine the number of errors detected in the self check program (since fresh start) from the count in register ERCOUNT. These errors are identified by alarm code OCT 1102. Depressing the error light reset key will clear registers FAILREG and FAILREG+1 and turn off the program alarm light. A fresh start will also do this and clear FAILREG+2 in addition. Registers ALMCADR and ALMCADR+1 are never cleared to zero. Their contents are replaced each time an alarm condition occurs. Register ERCOUNT is cleared to zero only during fresh start. Each time an error is detected by self check, register ERCOUNT is incremented by one.

Alarm conditions are due to program failures (not hardware failures). If the failure is not serious, control returns to the calling sequence. If the failure is serious, no return is made, and an abort is made resulting in a software restart. Failures which are not serious use the following entries: PRIOLARM, VARALARM, CURTAINS, ALARM and ALARM2. Failures which are serious use the following entries: BAILOUT, POODOO, and CSHOLE.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Lichtenberg</i> 2-12-69		Alarm and Abort	
PROGRAM <i>J. Rosenberg</i> 11-6-69		DOCUMENT NO.	
ANALYST		FC-2140	
DOCWR <i>C. Hoar, Becke</i> 11-6-69		COLOSSUS II-D	
APPR'D <i>Robert M. Egan</i> 11/6/69		REV 2	SHEET 1 OF 18

Each entry will make the alarm code available for display and turn on the program alarm light (if off). Only entry PRIOLARM will display the alarm codes in the three FAILREG registers. The return location and the location containing the alarm code is given in the calling sequence for each entry shown below.

Besides turning on the program alarm light (if off) and making the alarm code available for display, other functions of each entry are:

PRIOLARM	Displays the alarm codes via PRIODSPR (V05N09) and returns. Used by the "target out of view" alarm condition.
VARALARM	Calling sequence obtains a variable alarm code from an applicable register. Returns to calling sequence.
CURTAINS	Alarm code OCT 217 is only one used. Used for bad returns from stall routines. Returns to calling sequence.
ALARM	Used for alarm conditions such as improper input data, etc. Returns to calling sequence.
BAILOUT	Terminates in a software restart. Used by alarm conditions such as no vac areas available, too many tasks, etc.
POODOO	Clears AVEGFLAG and V37FLAG. Inactivates all restart groups and terminates in a software restart, and GOTOPOOH and flash verb 37 for operator to select new major mode. Used by alarm conditions such as an attempt to take the square root of a negative number, illegal flashing display, etc.
CCSHOLE	Alarm code OCT 21103 is only code used. Clears AVEGFLAG and V37FLAG, inactivates all restart groups and terminates in a software restart, and GOTOPOOH and flash verb 37 for operator to select new major mode. Used when unused CCS branch is executed.
ALARM2	Alarm code OCT 1102 is only code used. Used only by self check program when an error is detected.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Luthersich 8-12-67</i>		Alarm and Abort	
PRGMR <i>S. Rosenberg</i>	<i>11-6-67</i>	DOCUMENT NO.	
ANALST		COLOSSUS IID	FC-2140
DOCMR <i>C. Van Hook</i>	<i>11-6-69</i>	REV <i>2</i>	SHEET 2 OF 18
APPR'D <i>Robert J. M. Estlin</i>	<i>11/1/69</i>		



Two Of The Five  
Non-Abortive Entries with Return

Displays Alarm Code

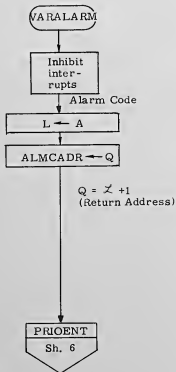
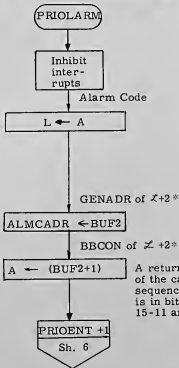
From location R52L+5 of P51-P53  
via BANKCALL with A = ALARM  
code, [BUF2, BUF2+1] = 2CADR  
of  $\lambda+2$

From 3 locations with A = alarm code

Calling sequence  
 $\lambda+0$  TC VARALARM  
 $\lambda+1$  Return

Calling sequence

$\lambda+0$  TC BANKCALL  
 $\lambda+1$  CADR PRIOLARM  
 $\lambda+2$  TERMINATE  
 $\lambda+3$  PROCEED  
 $\lambda+4$  ENTER  
 $\lambda+5$  IMMEDIATE RETURN

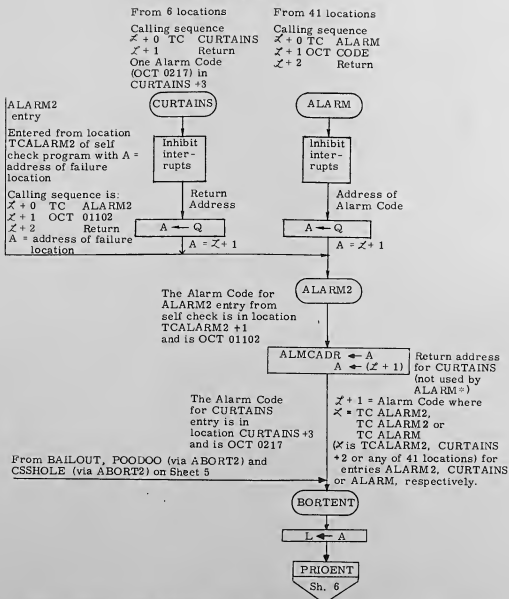


Note: Symbol " = " means "contains" in this flow chart.

\* The address stored in register ALMCADR is not used as a return address for these entries (PRIOLARM, ALARM, ALARM2 via self check, BAILOUT, POODOO and CSHOLE) while the other two entries (VARALARM and CURTAINS) do use the address as a return address. However, the address associated with each entry in register ALMCADR and its BBCON in register ALMCADR+1 and the contents of register ERCOUNT are available for display by verb 05 and noun 08.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>B. Luthra</i> 9-13-69		Alarm and Abort	
PRGMR <i>S. Rosenberg</i> 11-5-69			DOCUMENT NO.
ANALST		COLOSSUS II-D	FC-2140
DOCMR <i>C. Neo, Beck</i> 11-6-69		APPR'D <i>R. ...</i> 11/16/69	REV 2
			SHEET 3 OF 18

Three of the five  
Non-Abortive Entries with Return



\* The address stored in register ALMCADR is not used as a return address for these entries (PRIORIT, ALARM, ALARM2 via self check, BAILOUT, POODOO and CSHOLE) while the other two entries (VARALARM and CURTAINS) do use the address as a return address. However, the address associated with each entry in register ALMCADR and its BECON in register ALMCADR + 1 and the contents of register ERCOUNT are available for display by VERB 05 and NOUN 08.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. L. ...</i> 8-12-67		Alarm and Abort	
PRGRM <i>S. ...</i> 11-6-69			DOCUMENT NO.
ANALST		COLOSSUS 11-D	FC-2140
DOCNR <i>U. ...</i> 4-6-67		REV 2	SHEET 4 OF 16
APPR'D <i>Robert M. ...</i> 11/16/68			

Abortive Entries Ending in Restart

From 7 locations

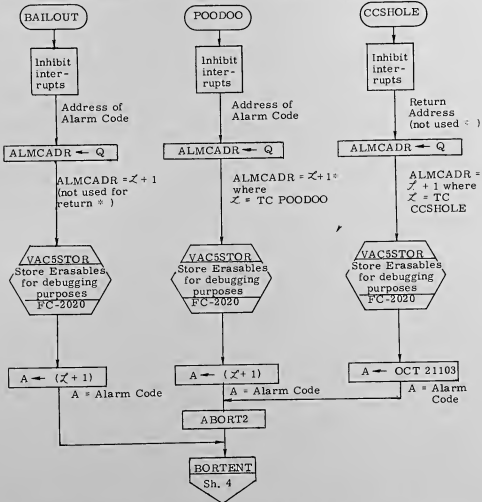
Calling sequence  
 $Z+0$  TC BAILOUT  
 $Z+1$  OCT CODE  
 No Return

From 7 locations

Calling sequence  
 $Z+0$  TC POODOO  
 $Z+1$  OCT CODE  
 No Return

From 18 locations

Calling sequence  
 $Z+0$  TC CSHOLE  
 No Return  
 One Alarm Code (OCT 21103) in CSHOLE+3



\* The address stored in register ALMCADR is not used as a return address for these entries (PRIOLARM, ALARM, ALARM2 via self check, BAILOUT, POODOO and CSHOLE) while the other two entries (VARALARM and CURTAINS) do use the address as a return address. However, the address associated with each entry in register ALMCADR and its BBCON in register ALMCADR+1 and the contents of register ERCOUNT are available for display by verb 05 and noun 08.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>S. L. ...</i> 8-19-68		Alarm and Abort	
PRGMR <i>S. L. ...</i> 11-6-69		DOCUMENT NO.	
ANALST		COLOSSUS II-D	
DOCMR <i>C. ...</i> 11-6-69		FC-2140	
APPRD <i>R. ...</i> 11-16-69		REV 2	
		SHEET 5 OF 18	

From Sheets 3 and 4

PRIOENT

A<sub>15-11, 3-1</sub> ← BBANK<sub>15-11, 3-1</sub>

BBCON of the Return Address of the calling sequence

From Sheet 3

(PRIOENT + 1)

A<sub>7-5</sub> ← SUPERBNK<sub>7-5</sub>

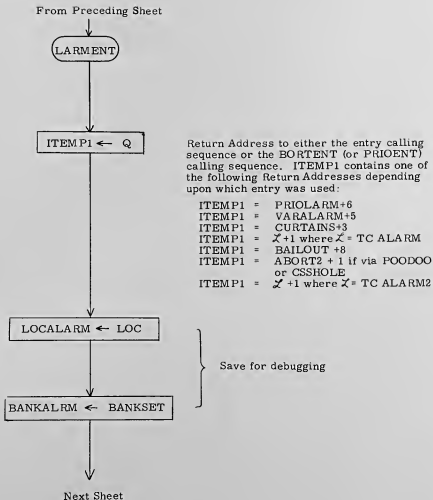
SUPER BANK of the Return Address of the calling sequence included with the BBCON

ALMCADR+1 ← A

Store BBCON and SUPER BANK

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. Sullivan</i>	<i>8-12-69</i>	Alarm and Abort	
PRGMR <i>J. Loomis</i>	<i>11-6-69</i>	DOCUMENT NO.	
ANALST		COLOSSUS II-D	FC-2140
DOCMR <i>C. Lee Bank</i>	<i>11-6-69</i>	REV 2	SHEET 6 OF 16
APPR'D <i>Robert D. Evans</i>	<i>11/1/69</i>		



NOTE: Symbol " ← " means "contains" in this flowchart

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. S. Rosenberg</i> 8-12-69		Alarm and Abort	
PRGMR <i>S. Rosenberg</i> 11-6-69			DOCUMENT NO.
ANALST		COLOSSUS II-D	FC-2140
DOCMR <i>D. S. Rosenberg</i> 11-6-69		REV 2	SHEET 7 OF 16
APPR'D <i>Robert M. Eastman</i> 11-6-69			

CHKFAIL1

Update Table of Alarm conditions. Registers FAILREG and FAILREG+1 are set with the first and second ALARM CODES, respectively, since these registers were last cleared. FAILREG+2 is set with each ALARM CODE, thus it will contain the last ALARM CODE.

Is FAILREG = +0? Is this the first ALARM since the FAILREG registers were last cleared?

Note: The first two FAILREG registers are cleared by depressing the error light reset key. A fresh start clears all three FAILREG registers.

FAILREG ← L

Alarm Code (1st)

CHKFAIL2

Is (FAILREG +1) = +0? Is this the second alarm?

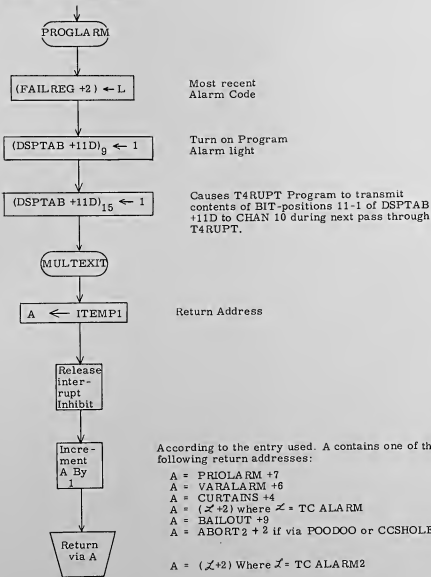
(FAILREG +1) ← L

Alarm Code (2nd)

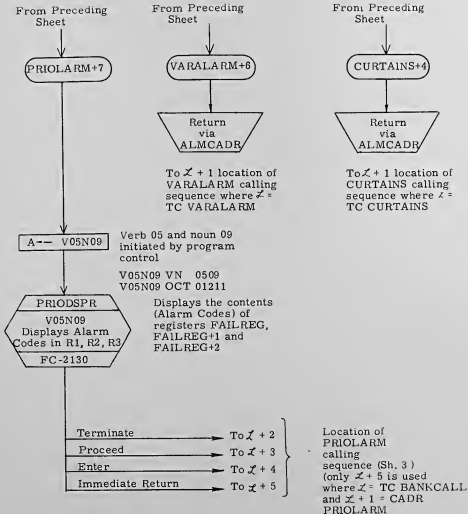
Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Alarm and Abort	
DRAWN <i>S. Lathrop</i>	8-2-69		
PRGMR <i>S. Rosenberg</i>	11-6-69		
ANALST			
DOCMR <i>C. Lee Becht</i>	11-6-69	COLOSSUS II-D	DOCUMENT NO. FC-2140
APPR'D <i>A. S. ...</i>		REV 2	SHEET 8 OF 18

From Preceding Sheet

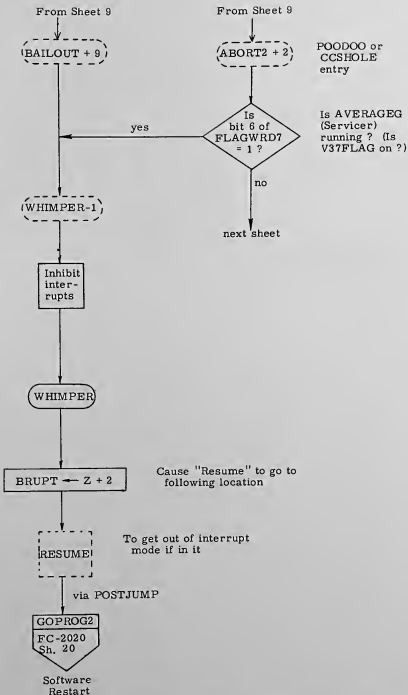


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Alarm and Abort	
DRAWN <i>L. L. L.</i>	<i>11-6-69</i>	COLOSSUS II-II	DOCUMENT NO.
PRGMR <i>S. L. L.</i>	<i>11-6-69</i>		FC-2140
ANALST		REV 2	SHEET 0 OF 18
DOCMR <i>C. H. L.</i>	<i>11-6-69</i>		
APPR'D <i>R. M. L.</i>	<i>11/6/69</i>		



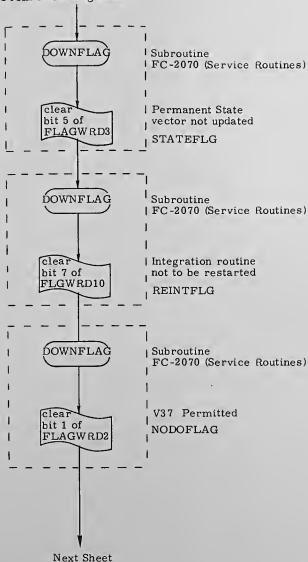
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Luthke</i> 11-2-69		Alarm and Abort	
PRGMR <i>S. Rosenberg</i> 11-6-69			DOCUMENT NO.
ANALST		COLOSSUS II-D	FC-2140
DOCMR <i>C. Van Beek</i> 11-6-69		REV 2	SHEET 10 OF 18
APPR'D <i>Roberta M. Ent...</i> 11-11-69			



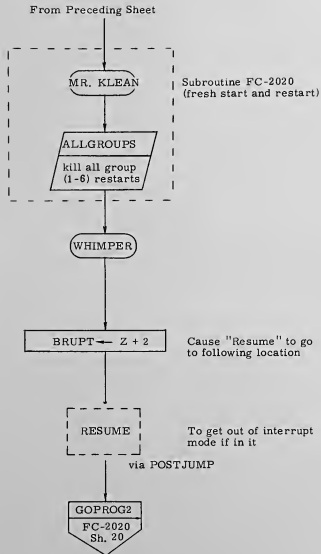


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Sutherland</i> 8/2/69		Alarm and Abort	
PRGRM <i>L. Rosenberg</i> 11-6-69		DOCUMENT NO.	
ANALST		COLOSSUS II-D	FC-2140
DOCMR <i>C. Hoar, Beak</i> 11-6-69		REV 2	SHEET 11 OF 16
APPR'D <i>R. ...</i>			

From Preceding Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Alarm and Abort	
DRAWN	<i>J. L. ...</i> 11-2-67		
PRGMR	<i>E. Rosenberg</i> 11-6-67		
ANALST		COLOSSUS II-D	DOCUMENT NO. FC-2140
DOCWR	<i>C. ...</i> 11-6-67	REV 2	SHEET 12 OF 16
APPR'D	<i>Robert M. ...</i> 11/1/67		



See Note A

Note A Go to routine GOTOPOOH and display flashing verb 37 unless no major mode was active in which case control goes to DUMMYJOB +2 (see restart, Sheet 23 of FC-2020).

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. Luttarich</i> 2-12-67		Alarm and Abort	
PRGMR <i>J. Rosenberg</i> 11-6-67		DOCUMENT NO.	
ANALST		COLOSSUS II-D	FC-2140
DOCMR <i>C. Hao, Brock</i> 11-6-67		REV 2	SHEET 13 OF 16
APPR'D <i>Robert M. Easton</i> 11/6/67			

ALARM AND ABORT  
TABLE OF ALARM CODES

ALARM CODE	ALARM CONDITION	SET BY	ALARM ENTRY USED
00110	No mark since last mark reject	SXTMARK	ALARM
00112	Mark not being accepted	SXTMARK	ALARM
00113	No inbits	SXTMARK	ALARM
00114	Mark made, but not desired	SXTMARK	ALARM
00115	Optics torque request with switch not at CMG	EXT VERB OPTICS CDU	ALARM
00116	Optics switch altered before 15 sec zero time elapsed	T4RUPT	ALARM
00117	Optics torque request with optics not available (OPTIND = - 0)	EXT VERB OPTICS CDU	ALARM
00120	Optics torque request with optics not zeroed	T4RUPT	ALARM
00121	CDUS no good at time of mark	SXTMARK	ALARM
00122	Marking not called for	SXTMARK	ALARM
00124	TPI search - no safe perictr here	P17, P77	ALARM
00205	Bad PIPA reading	SERVICER	ALARM
00206	Zero encode not allowed with coarse align +gimbal lock	IMU MODE SWITCH IMU-2	ALARM
00207	ISS turn-on request not present for 90 sec	T4RUPT	ALARM
00210	IMU not operating	IMU MODE SWITCH, IMU-2, R02, P51	ALARM VARALARM
00211	Coarse align error - drive >2 degrees	IMU MODE SWITCH	ALARM
00212	PIPA fail but PIPA is not being used	IMU MODE SWITCH, T4RUPT	ALARM
00213	IMU not operating with turn-on request	T4RUPT	ALARM
00214	Program using IMU when turned off	T4RUPT	ALARM
00215	Preferred orientation selected but not specified	P52, P54	ALARM
00217	Bad return from stall routines	CURTAINS	ALARM2
00220	IMU not aligned - no REFSSMMAT	R02, P51	VARALARM
00401	Desired gimbal angles yield gimbal lock	INF ALIGN, IMU-2	ALARM

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Alarm and Abort	
DRAWN <i>S. Rosenberg</i>	<i>8/2/69</i>		DOCUMENT NO.
PRGMR <i>S. Rosenberg</i>	<i>11-6-69</i>		FC-2140
ANALST		COLOSSUS II-D	
DOCMR <i>C. Neo. Beck</i>	<i>11-6-69</i>		
APPR'D <i>Robert M. Egan</i>	<i>11/4/69</i>	REV 2	SHEET 14 OF 16

ALARM CODE	ALARM CONDITION	SET BY	ALARM ENTRY USED
00404	Target out of view - trunnion angle > 90 deg	R52	PRIOLARM
00405	Two stars not available	P52, P54	ALARM
00406	Rend navigation not operating	R21, R23	ALARM
00407	Auto optics request trunnion angle $\geq 50$ deg (target out of view)	R52	ALARM
00421	W-matrix overflow	INTEGRV	ALARM
00600	Imaginary roots on first iteration	P32, P72	VARALARM
00601	Perigee altitude LT PMIN1	P32, P72	VARALARM
00602	Perigee altitude LT PMIN2	P32, P72	VARALARM
00603	CSI to CDH time LT PMIN22	P32, P33, P72, P73	VARALARM
00604	CDH to TPI time LT PMIN23	P32, P72	VARALARM
00605	Number of iterations exceeds loop maximum	P32, P37, P72	VARALARM
00606	DV exceeds maximum	P32, P72	VARALARM
00611	No TIG for given elev angle	P34, P74	ALARM
00612	State vector in wrong sphere of influence	P37	VARALARM
00613	Reentry angle out of limits	P37	VARALARM
00777	PIPA fail caused the ISS warning	T4RUPT	VARALARM
01102	CMC self test error	SELF CHECK	ALARM2
01105	Downlink too fast	T4RUPT	ALARM
01106	Uplink too fast	T4RUPT	ALARM
01107	Phase table failure. Assume erasable memory is destroyed	RESTART	ALARM
01301	ARCSIN-ARCCOS input angle too large	INTERPRETER S40.8	ALARM
01407	VG increasing		ALARM
01426	IMU unsatisfactory	P61, P62	ALARM
01427	IMU reversed	P61, P62	ALARM
01520	V37 request not permitted at this time	V37	ALARM
01600	Overflow in drift test	OPT PRE ALIGN CALIB	ALARM
01601	Bad IMU torque	OPT PRE ALIGN CALIB	ALARM
01602	Bad optics during verification	OPTALGN CALIB (CSM)	ALARM
01703	Insuf. time for integ., TIG has slipped	R41	ALARM
03777	ICDU fail caused the ISS warning	T4RUPT	VARALARM
04777	ICDU, PIPA fails caused the ISS warning	T4RUPT	VARALARM

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. Lickesuch</i> 12/2/68		Alarm and Abort	
PRGRM <i>S. Lomborg</i>	11-6-69	DOCUMENT NO.	
ANALST		COLOSSUS II-D	FC-2140
DOCMR <i>C. Ho, G. G. G.</i>	11-6-69	REV 2	SHEET 15 OF 16
APPR'D <i>R. ...</i>			

ALARM CODE	ALARM CONDITION	SET BY	ALARM ENTRY USED
07777	IMU fail caused the ISS warning	T4RUPT	VARALARM
10777	IMU, PIPA fails caused the ISS warning	T4RUPT	VARALARM
13777	IMU, ICDU fails caused the ISS warning	T4RUPT	VARALARM
14777	IMU, ICDU, PIPA fails caused the ISS warning	T4RUPT	VARALARM
20430*	Integ. abort due to subsurface s. v.	ALL CALLS TO INTEGRATION	POODOO
20607*	No solution from time theta or time radius routine	TIMETHET, TIMERAD	POODOO
20610*	Lamda less than unity	P37	POODOO
21103*	Unused CCS branch executed	CCSHOLE	ABORT2
21204*	Negative or zero delta time - waitlist call	WAITLIST	POODOO
21206*	Second job attempts to go to sleep via keyboard and display program	PINBALL	POODOO
21210*	Two programs using device at same time	IMU MODE SWITCH	POODOO
21302*	SQRT called with negative argument. Abort	INTER-PRETER	POODOO
21501*	Keyboard and display alarm during internal use (NVSUB). Abort	PINBALL	POODOO
21502*	Illegal flashing display	GOPLAY	POODOO
21521*	P01 or P07 illegally selected	P01, P07	POODOO
31104*	Delay routine busy	SERVICE ROUTINES	BAILOUT
31201*	Executive overflow - no vac areas	EXEC	BAILOUT
31202*	Executive overflow - no core sets	EXEC	BAILOUT
31203*	Waitlist overflow - too many tasks	WAITLIST	BAILOUT
31207*	No vac area for marks	SXTMARK	BAILOUT
31211*	Illegal interrupt of extended verb	SXTMARK	BAILOUT

\* Indicates abort type. All others are non-abortive.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Alarm and Abort	
DRAWN <i>R. Luthardt</i>	<i>P-2-69</i>		
PRGMR <i>S. Rosenberg</i>	<i>11-6-69</i>		
ANALST			DOCUMENT NO.
DOCMR <i>C. Neo. Finkle</i>	<i>11-6-69</i>	COLOSSUS II-D	FC-2140
APPR'D <i>R. E. ...</i>	<i>11/6/69</i>	REV 2	SHEET 16 OF 18

## KEYRUPT AND UPRUPT

When the operator or the ground communicates with the computer, the information being transmitted is first received by this program KEYRUPT and UPRUPT.

Several ways are available to communicate with the computer. A command may be keyed in (Verb-Noun combination) by depressing keys VERB, V1, V2, NOUN, N1, N2, and ENTER, where V1, V2, N1, and N2 represent numerical keys (0, 1, 2, . . . , 8 or 9). Data may be entered on request from the computer by depressing several numerical keys (and a sign key) and key ENTER. Keys CLEAR, ERROR RESET, KEY RLSE may also be depressed. Each time a key is depressed, routine KEYRUPT which requests the execution of job CHARIN (in Pinball program, FC-2180), is executed. Each time job CHARIN is executed, it performs an operation determined by the key that was depressed. When key ENTER is depressed, the command (which has been keyed in as a Verb-Noun combination) is executed or the data (which has been keyed in) is accepted. Routine UPRUPT is executed each time an uplink word has been received from the ground; it also requests the execution of job CHARIN. Each uplink word contains information similar to that generated by depressing a key on a Dsky.

Routine KEYRUPT processes the key code of each character transmitted from the keyboard of the Dsky via Channel 15 (Bit positions 5-1). Routine UPRUPT processes the key code of each character transmitted from the ground via uplink counter INLINK.

When a key on the keyboard is depressed, the routine being executed is interrupted by interrupt program No. 5. A key code (5-bit configuration) representing the character selected will be placed into bit positions 5-1 of channel 15 by hardware action. Control will arrive at routine KEYRUPT via its lead-in interrupt routine.

When uplink counter INLINK overflows, the routine being executed is interrupted by interrupt program No. 7. A key code word (uplink word) representing the character transmitted from the ground is serially loaded from the uplink receiver into INLINK. The key code word is a 16-bit word consisting of a one in bit-position 16 and the key code (5-bit configuration) is in bit position 15-11 and 5-1 and its complement in 10-6. When the one in bit-position 16 of the 16-bit word reaches

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		KEYRUPT AND UPRUPT	
DRAWN	<i>AT Conwell</i>	<i>8/29/68</i>	DOCUMENT NO. FC-2150
PRGMR	<i>John Keller</i>	<i>8/28/68</i>	
ANALST			COLOSSUS II-C
DOCMR	<i>C. Van Beck</i>	<i>8-28-68</i>	
APPR'D	<i>John Keller</i>	<i>8/29/68</i>	REV
			SHEET 1 OF 9

bit-position 16 of INLINK during the serial loading (shifting left in INLINK one bit-position at a time), overflow occurs causing interrupt No. 7. Control will arrive at routine UPRUPT via its lead-in interrupt routine.

The characters are represented by the following key codes:

Character (or action)	Key Code (binary)	Character (or action)	Key Code (binary)
0	10 000	VERB	10 001
1	00 001	ERROR RESET	10 010
2	00 010	KEY RELEASE	11 001
3	00 011	+	11 010
4	00 100	-	11 011
5	00 101	ENTER	11 100
6	00 110	CLEAR	11 110
7	00 111	NOUN	11 111
8	01 000		
9	01 001		

Both routines preserve the banks, Q register and the current time (double precision) and make the key code available for routine CHARIN of program Pinball.

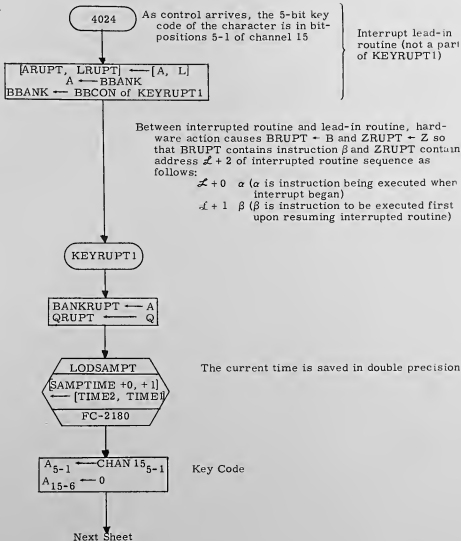
KEYRUPT also sets DSKYFLAG (indicates that displays are to be sent to the Dsky) and schedules routine CHARIN of program Pinball as a job at priority 30.

UPRUPT also clears INLINK for the next key code, turns on uplink activity light and tests the key code for triple character redundancy. The key code is satisfactory if the original contents of bit-positions 15-11 of INLINK are the same as the original contents of bit-positions 5-1 and the complement of the original contents of bit-positions 10-6. If the key code is not satisfactory, UPLOCKFL flag is set and the interrupted routine is resumed. If the key code is satisfactory, and it is the error reset code, then the UPLOCKFL flag is cleared and routine CHARIN of program Pinball is scheduled as a job at priority 30 and the interrupted routine is resumed. If the key code is not the error reset code and the UPLOCKFL flag is cleared, then routine CHARIN is scheduled as a job. If the UPLOCKFL flag was not cleared, CHARIN will not be scheduled and the interrupted routine will be resumed because an error reset code must be sent since the last unsatisfactory key code before subsequent key codes can be accepted.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A.C. Cornell</i> 5/14/68		KEYRUPT AND UPRUPT	
PRGMR <i>John Vella</i> 4/24/68		COLOSSUS II-C	DOCUMENT NO.
ANALST			FC-2150
DOCMR <i>Ken Buck</i> 8-28-68		APPR'D <i>Allen M. Smith</i> 2/28/69	REV
			SHEET 2 OF 3



Control arrives here from the interrupted routine when a key on the keyboard of the DSKY is depressed to transmit a character.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. H. ...</i> 8/17/69		KEYRUPT AND UPRUPT	
PRCHAR <i>John ...</i> 8/19/69		DOCUMENT NO.	
ANALST <i>C. ...</i> 8-28-69		COLOSSUS II-C	FC-2150
APPR'D <i>C. ...</i> 8/28/69		REV	SHEET 3 OF 9

From Preceding Sheet

KEYCOM

RUPTREG4 ← A

Key Code (0-0-K)

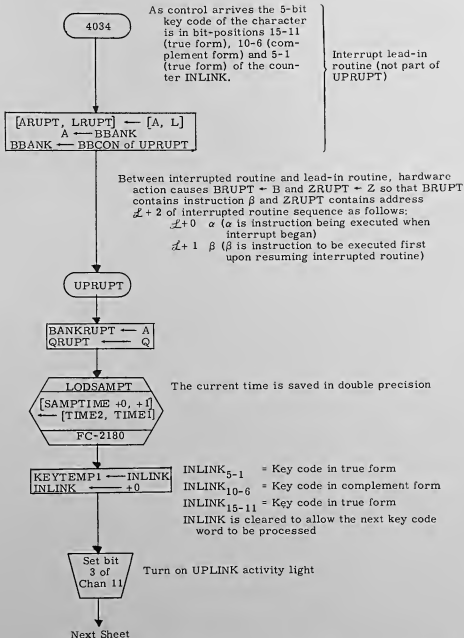
Set  
bit 15 of  
FLAGWRD5

Set DSKYFLAG  
Indicates that displays were sent to the DSKY.

ACCEPTUP  
Sh. 9

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>PA Connell</i>	<i>2/16/69</i>	KEYRUPT AND UPRUPT	
PRGMR <i>John Pella</i>	<i>2/28/69</i>	COLOSSUS II-C	DOCUMENT NO.
ANALST			FC-2150
DOCMR <i>C. Van Brock</i>	<i>8-28-69</i>	REV	SHEET 4 OF 9
APPR'D <i>Robert J. Wood</i>	<i>8/28/69</i>		

Control arrives here from the interrupted routine each time a character is transmitted from the ground.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>PA Donald</i> 8/18/69		KEYRUPT AND UPRUPT	
PRGMR <i>John Keller</i> 9/29/69		COLOSSUS	
ANALST		DOCUMENT NO.	
DOCMR <i>C. Leo Buck B-28-69</i>		II-C	
APPR'D <i>PA Donald</i>		FC-2150	
		REV	
		SHEET 5 OF 9	

From Preceding Sheet

UPRPT1

Test for triple character redundancy. If the key codes in bit-positions 5-1 and 15-11 agree and if the key code in bit-positions 10-6 is the complement of the key code in bit positions 5-1, then the key code is accepted.

A ← KEYTEMP1

Key code (three in K-K-K arrangement)

KEYTEMP1<sub>15-6</sub> ← 0

KEYTEMP1<sub>5-1</sub> = Key code in true form  
KEYTEMP1<sub>15-6</sub> = 0

A<sub>10-1</sub> ← A<sub>15-6</sub>  
A<sub>15-11</sub> ← 0

Shift key code arrangement to the right 5 bit positions so that A contains the 0-K-K arrangement

KEYTEMP2 ← A

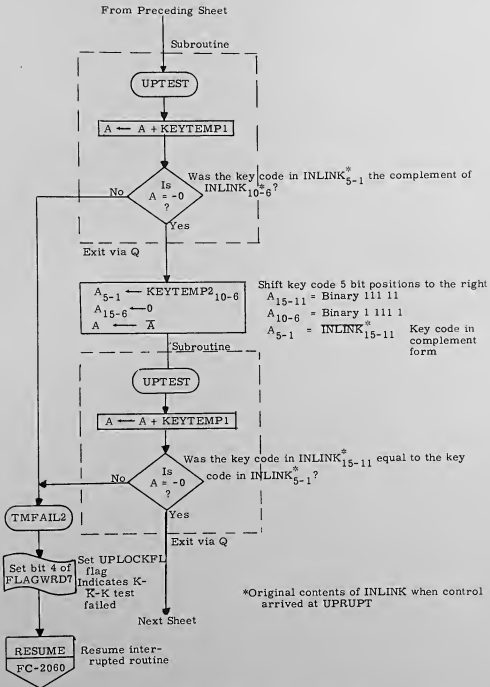
Key code arranged 0-K-K will be used for second part of redundancy test.

A<sub>15-6</sub> ← All 1's

A<sub>5-1</sub> = Key code in complement form  
A<sub>15-6</sub> = Binary 111 111 111 1

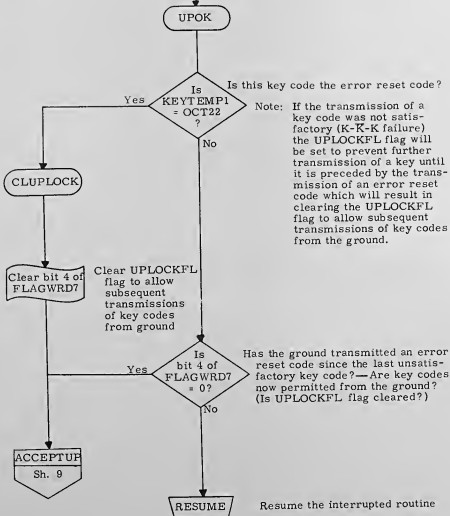
Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>Ed. Brownell</i> 8/26/69		KEYRUPT AND UPRUPT	
PRGRM <i>John Vella</i> 8/26/69		COLOSSUS	DOCUMENT NO.
ANALST		II-C	FC-2150
DOCMR <i>C. Lee, Brook 8-28-69</i>			
APPR'D <i>Ed. Brownell</i>		REV	SHEET 6 OF 9



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>P. W. Smith</i> 8/16/69		KEYRUPT AND UPRUPT	
PROGRAM <i>John P. Keller</i> 8/16/69		DOCUMENT NO.	
ANALYST		COLOSSUS II-C	FC-2150
DOCUM <i>C. Hea. Back 8-28-69</i>		REV	SHEET 7 OF 9
APPR'D <i>C. Hea. Back 8-28-69</i>			

From Preceding Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		KEYRUPT AND UPRUPT	
DRAWN <i>[Signature]</i>	<i>[Date]</i>		
PRGMR <i>[Signature]</i>	<i>[Date]</i>	COLOSSUS	DOCUMENT NO.
ANALYS <i>[Signature]</i>		II-C	FC-2150
DOCNR <i>[Signature]</i>	<i>[Date]</i>		
APPR'D <i>[Signature]</i>	<i>[Date]</i>	REV	SHEET 8 OF 9

From Sheets 4 and 8

ACCEPTUP

CHARIN

NOVAC job  
priority = 30

FC-2180

Location CHARIN is the beginning of program PINBALL (its entry point)

Program PINBALL executes the requests for displays from the operator (key board) and the ground

(MPAC # LOCCTR) ← RUPTREG4

RUPTREG4 = KEYTEMP1 and contains the key code in the 0-0-K arrangement

RESUME

Resume the interrupted routine

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. J. Connolly</i> 8/12/67		KEYRUPT AND UPRUPT	
PRGRM <i>John P. Della</i> 8/22/67		COLOSSUS	DOCUMENT NO.
ANALST		II-C	FC-2150
DOCNR <i>C. Leo Hack R-28-67</i>		REV.	SHEET 9 of 9
APPR'D <i>John P. Della</i>			

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

T4RUPT	SERVICE ROUTINE WHICH PROCESSES DISPLAY REQUESTS AND MONITORS VARIOUS HARDWARE SYSTEMS	SH, 3
CDRVE	BRANCH OF T4RUPT ENTERED EVERY 120 MS; EXECUTES CYCLICALLY FUNCTIONS LISTED ABOVE FOR T4RUPT	SH, 4
OPTTEST	BRANCH OF CDRVE ENTERED EVERY 480 MS, DOES COARSE ALIGNMENT OF OPTICS SHAFT AND TRUNNION	SH, 6
OPTMON	BRANCH OF CDRVE ENTERED EVERY 480 MS, MONITORS CHANGES IN OPTICS CDU FAILURE STATUS, OPTICS SWITCH POSITION	SH, 11
IMUMON	BRANCH OF CDRVE ENTERED EVERY 480 MS; MONITOR IMU STATUS CHANGES	SH, 25
TLIM	MONITORS CHANGE IN IMU TEMPERATURE STATUS	SH, 28
ITURNON	MONITORS CHANGE IN ISS TURN-ON REQUEST STATUS	SH, 29
SETISSW	SETS ISS WARNING LAMP AS APPROPRIATE	SH, 30
IMUCAGE	MONITORS CHANGE IN IMU CAGE SWITCH STATUS	SH, 31
IMUOP	MONITORS CHANGE IN IMU OPERATE STATUS	SH, 32
TNONTST	ENTERED FROM IMUMON EVERY 480 MS, DOES ISS INITIALIZATION IF APPROPRIATE	SH, 33
ENDTNO	ENDS ISS TURN-ON SEQUENCE	SH, 35
C33TEST	ENTERED FROM TNONTST EVERY 480 MS, MONITORS CHANNEL 33 BITS 11 - 13	SH, 38
PIPFAL	MONITORS CHANGE IN PIPA FAILURE STATUS	SH, 41
DNTMFAST	MONITORS CHANGE IN DOWN TELEMETRY SPEED STATUS	SH, 42
UPTMFAST	MONITORS CHANGE IN UP TELEMETRY SPEED STATUS	SH, 42
GLOCKMON	ENTERED FROM C33TEST EVERY 480 MS; MONITORS MIDDLE IMU GIMBAL ANGLE FOR POSSIBLE GIMBAL LOCK	SH, 43
QUKDSP	BRANCH OF T4RUPT ENTERED BETWEEN 120 MS PASSES. EXECUTES DISPLAY FUNCTIONS ONLY	SH, 46
DSPUTSB	FINDS AND PROCESSES ONE DISPLAY REQUEST	SH, 47

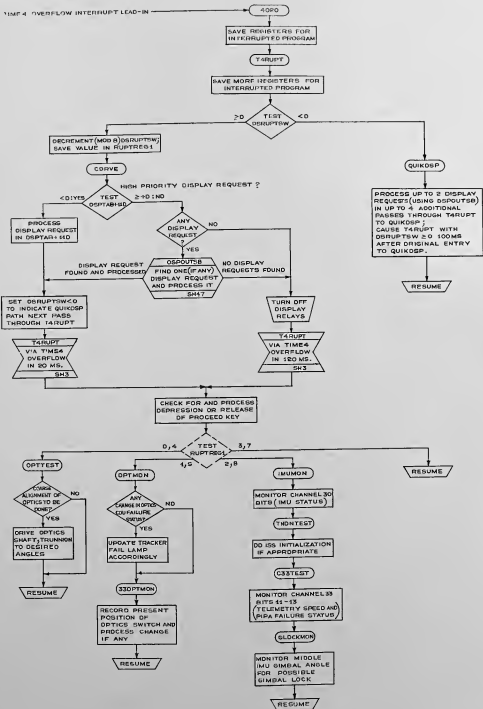
SPECIAL CONVENTIONS:

- ⊖ MODULAR SUBTRACTION
- + LOGICAL "EXCLUSIVE OR"
- $\bar{\phantom{x}}$  LOGICAL COMPLEMENT OF  $\phantom{x}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT CELESTIAL AND NAVIGATION	
SPARK <i>J.P. Hunt</i> 17 MAR 68		T4RUPT	
POLAR <i>J.P. Hunt</i> 13 MAR 68		DOCUMENT NO.	
ANALYST		COLDSSUS IIA FC-2200	
DOLME <i>J.P. Hunt</i> 13 MAR 68		SHEET 4 OF 55	
APPROV <i>J.P. Hunt</i> 13 MAR 68		REV	



TIME 4 OVERFLOW INTERRUPT LEAD-IN



FC-2200  
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 11-A  
 COLONEL  
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T4TRUPT

4020

SERVICE ROUTINE WHICH PROCESSES  
DISPLAY COMMANDS AND MONITORS  
VARIOUS SYSTEMS

ENTERED VIA HARDWARE WHENEVER  
TIME4 COUNTER OVERFLOWS  
(AT LEAST EVERY 120 MS -  
OFTENER WHEN DISPLAY COMMANDS  
ARE PROCESSED)

SAVE REGISTERS FOR INTERRUPTED PROGRAM

ARUPT ← A  
LRUPT ← L

A ← BBANK

T4RUPT

BANKRUPT ← A

QRUPT ← Q

DETERMINE PATH FOR THIS PASS THROUGH T4RUPT

> 0  
TEST  
DSRUPTSW

< 0

NORMAL  
(SYSTEM  
MONITOR)  
120 MS PASS

INTERMEDIATE DISPLAY - ONLY  
PASS  
(DISPLAY COMMAND WAS  
PROCESSED DURING LAST  
PASS THROUGH CDRVE BRANCH)

NORMT4

QUIKDSP  
SH46

A ← (DSRUPTSW) - 1

A ← 7

RUPTREG1 ← A  
DSRUPTSW ← A

FOR NORMAL (MONITOR) PASSES,  
DSRUPTSW AND RUPTREG1  
INDICATE PRESENT POINT IN  
AN EIGHT-PASS CYCLE;  
BY A VALUE OF 0-7  
VALUE IS UPDATED HERE -  
UPON ENTRY TO THIS BRANCH

CDRVE  
SH4

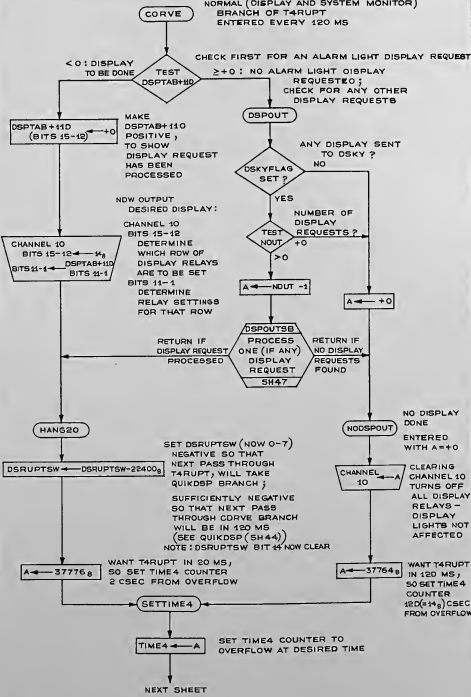
17 MAR 68  
J. G. Gordon  
COLOSSUS  
II-A

T4RUPT

COLOSSUS  
II-A

FC-2200

NORMAL (DISPLAY AND SYSTEM MONITOR)  
BRANCH OF T4RUPRT  
ENTERED EVERY 120 MS

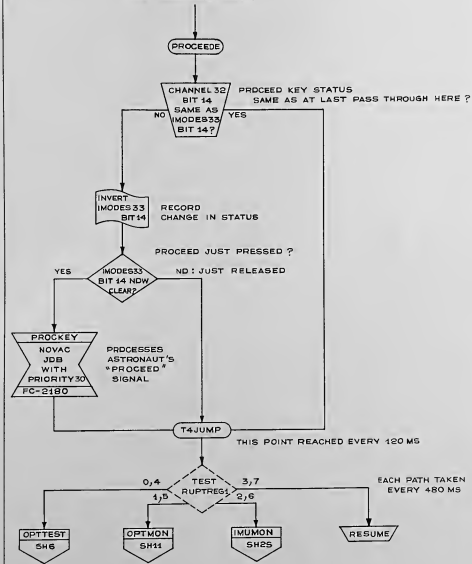


T4RUPRT

CDLOSSUS  
II-A

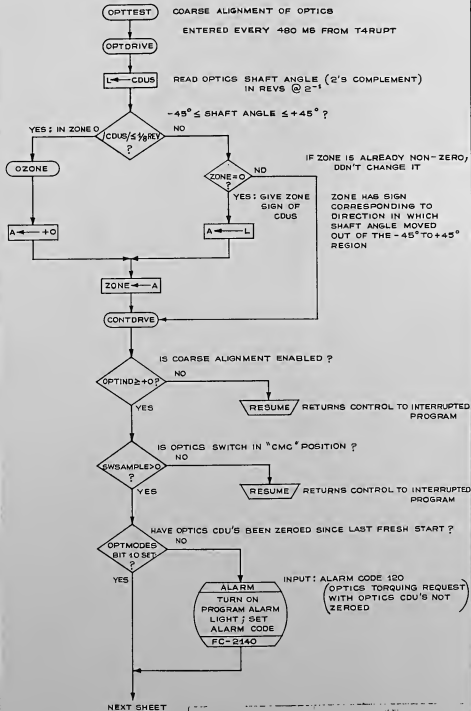
FC-2200

FROM PRECEDING SHEET



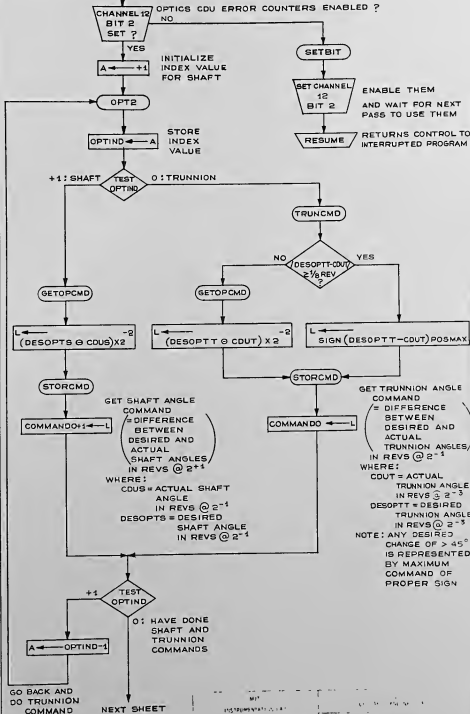
APPROVED: *[Signature]* 20MR69  
BY: E. W. ...  
DATE: 11/11/69

T4RUPT  
COLOSSUS II-A FC-2200  
5 55



MIC INFORMATION LAB WRIGHT PAT. 2000 11-18-64 11-18-64 11-18-64	T4RUPT COLLOSSUS II-A FC-2200 6 55
---	---

FROM PRECEDING SHEET



*J.C. Weller*  
*J.C. Weller*  
*J.C. Weller*

FROM PRECEDING SHEET

ITEMP1 ← 0

INITIALIZE NUMBER OF COMMANDS TO BE SENT

SEE IF DESIRED COMMAND FOR SHAFT ANGLE MIGHT RUN INTO STOPS:  
(MAGNITUDE OF SHAFT ANGLE MAY NOT BE DRIVEN TO GREATER THAN ABOUT 270°)

YES  
|CDUS| ≤ 1/4 + 2<sup>-15</sup> REV ?

IS PRESENT SHAFT ANGLE IN 1ST OR 4TH QUADRANT?  
(IF SO, COMMAND COULD NOT BE LARGE ENOUGH TO DRIVE ANGLE INTO STOP)

NO

YES  
ZONE = 0 ?

ZONE CANNOT BE ZERO IF SHAFT ANGLE IS IN 2ND OR 3RD QUADRANT

NO

NO  
DO ZONE AND COMMANDO+1 HAVE SAME SIGN ?

IF SHAFT ANGLE CONTINUES TO INCREASE IN THE SAME DIRECTION IN WHICH IT HAS BEEN GOING, MAGNITUDE MIGHT BE APPROACHING 270°

YES

NO  
|DESOPTS| ≤ 1/4 + 2<sup>-15</sup> REV ?

IS DESIRED SHAFT ANGLE IN 1ST OR 4TH QUADRANT?  
IF SO, DESIRED COMMAND WOULD RUN INTO A STOP -

YES

IN THIS CASE, MUST DRIVE ANGLE IN OPPOSITE DIRECTION SO THAT CAN EVENTUALLY (GENERALLY IN A LATER PASS) REACH DESIRED ANGLE WITHOUT RUNNING INTO STOPS

COMMANDO+1 ← -(COMMANDO+1)

SO REPLACE SHAFT ANGLE COMMAND WITH ITS NEGATIVE

CMOSETUP

A ← +1

INITIALIZE INDEX VALUE TO PROCESS SHAFT ANGLE COMMAND FIRST

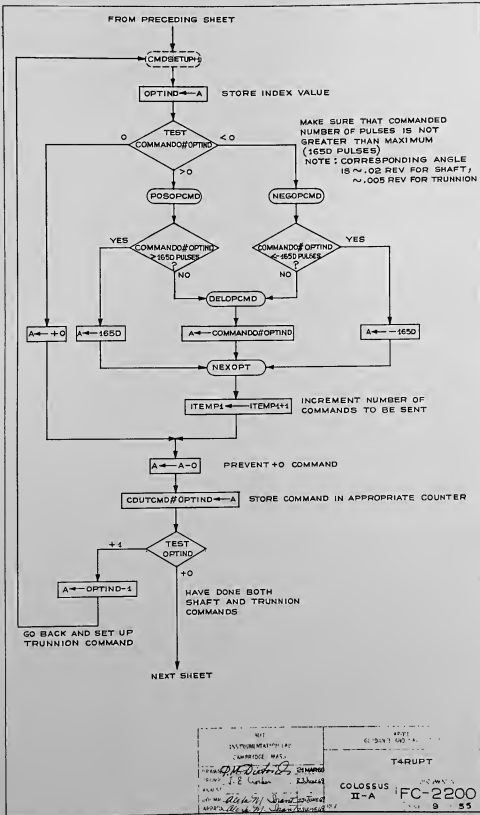
NEXT SHEET

T4RUPT

COLLOSSUS II-A

FC-2200

8 55



MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

*P.M. Distefano* SHAWMUT  
SERIAL - J. B. Larkin E33682  
APPROX. 11/16/71

MIT  
GLD 317 440 - A

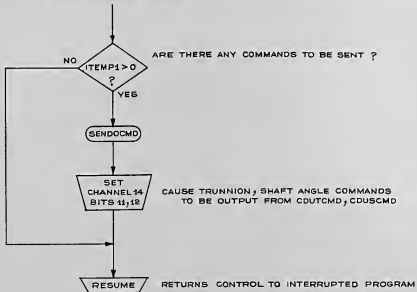
T4RUPT

COLOSSUS  
II-A

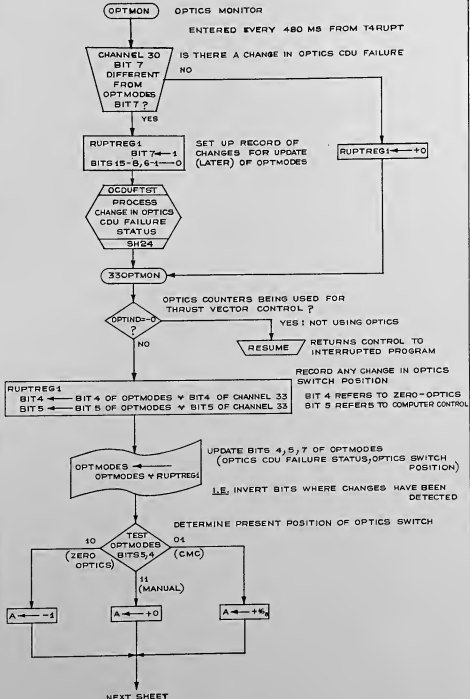
FC-2200  
8 55



FROM PRECEDING SHEET



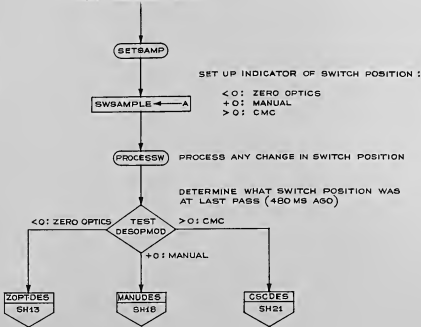
MIT INSTRUMENTATION & FIELD ENG. SECTS	REPORT CLASSIFICATION
<i>P.H. ...</i> <i>J.C. ...</i>	T4RUPT
<i>...</i>	GOLOSSUS II-A
<i>...</i>	FC-2200
<i>...</i>	40 55



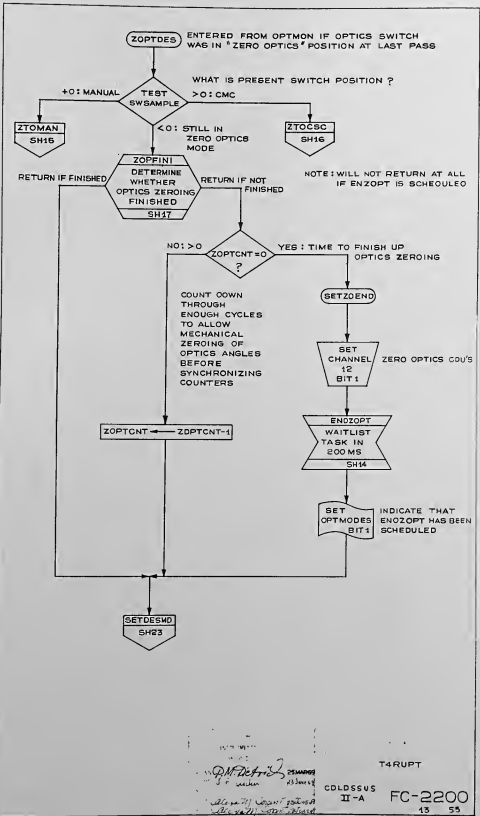
MIT  
INSTRUMENTATION # 2  
APPROX DATE  
APPROX DATE  
APPROX DATE  
APPROX DATE  
APPROX DATE

T4RUPT  
COLOSSUS II-A FC-2200  
11 55

FROM PRECEDING SHEET



EXAMINE  
I. E. Quinn  
23 Nov 57  
COLOSSUS II-A  
T4RUPT  
FC-2200  
12 55



*P.M. DeFries*  
 25 MAR 68  
 13 55

T4RUPT

COLDSSUS  
 II-A

FC-2200

13 55

ENDZOPT

FINISH UP OPTICS ZEROING

SCHEDULED AS A TASK WHEN HAVE BEEN IN 'ZERO OPTICS' MODE FOR SUFFICIENT TIME ( $\approx 15$  SEC) TO ALLOW MECHANICAL ZEROING OF OPTICS ANGLES

ZEROPCDU

INITIALIZE VARIABLES FOR ZERO ANGLE CONDITIONS

COUS ← +0

ZERO SHAFT ANGLE (IN REVS @  $2^{-1}$ )

ZONE ← +0

HENCE SHAFT ANGLE ZONE MUST BE ZERO

CDUT ← -20DEGS

$\approx 20^\circ$  OFFSET BETWEEN VALUE MEASURED AND THAT USED IN COMPUTATIONS FOR TRUNNION ANGLE

$20\text{DEGS} = 7199 \times 2^{-17} \text{ REVS}$   
( $\approx 20^\circ$ ) @  $2^{-3}$

RETURN VIA Q

CLEAR BIT 4 OF CHANNEL 42

ALLOW COUS, CDUT TO RECEIVE ACTUAL OPTICS SHAFT, TRUNNION ANGLE DATA

VARDELAY  
WAIT  
200 MS  
FC-2060

WAIT FOR RESYNCHRONIZATION OF COUNTERS (CDUS, COUT) AND OPTICS CDU'S (COUNTERS COUNT UP TO TRUE VALUES) OF ANGLES

SET OPTMODES BIT 10  
CLEAR OPTMODES BIT 3  
BIT 2  
BIT 1

OPTICS HAVE BEEN ZEROED SINCE LAST FRESH START

OPTICS ZEROING FINISHED  
ALLOW OPTICS CDU FAILURE SIGNAL  
ENZOPT NO LONGER SCHEDULED

OCDFIST

CHECK ON OPTICS CDU FAILURE STATUS  
SH24

FAILURE SIGNAL INHIBIT (OPTMODES BIT 2) MAY HAVE PREVENTED SIGNAL WHEN CHECKED PREVIOUSLY; SO CHECK AGAIN.

TASKOVER

1550 WINTER 1964

*[Handwritten signature]* 28 MAR 64

*[Handwritten signature]* 23 MAR 64

*[Handwritten signature]* 23 MAR 64

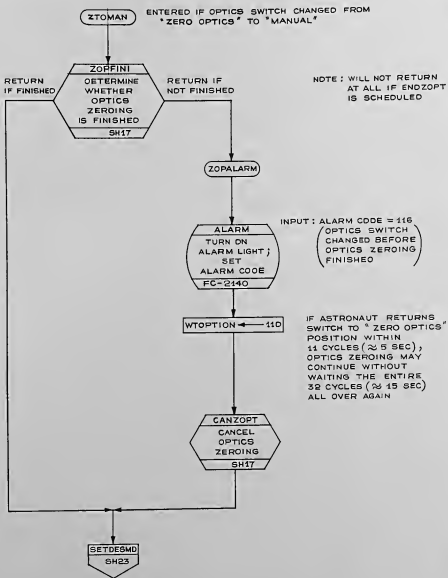
1742 AND 1743/1745

T4RUPT

COLOSSUS II-A

FC-2200

14 55



T4RUPT

COLDSSUS II-A FC-2200

15 55

ZTOCSC

ENTERED IF OPTICS SWITCH CHANGED FROM  
'ZERO OPTICS' TO 'COMPUTER' POSITION

ZOPFINI

DETERMINE  
WHETHER  
OPTICS ZEROING  
IS FINISHED  
SH17

RETURN IF FINISHED

RETURN IF NOT FINISHED

NOTE: WILL NOT RETURN  
AT ALL IF ENDOZPT  
IS SCHEDULED

MANTOCSC  
SH20

SET UP FOR  
COMPUTER MODE

ALARM  
TURN ON  
ALARM LIGHT;  
SET  
ALARM CODE  
FC-2140

INPUT: ALARM CODE 116  
(OPTICS SWITCH CHANGED  
BEFORE OPTICS ZEROING  
FINISHED)

CANZOPT  
CANCEL  
OPTICS  
ZEROING  
SH17

MANTOCSC  
SH20

ZERO WTOPTION  
(SO THAT RETURN TO 'ZERO OPTICS'  
MODE MUST INCLUDE THE WHOLE  
32 CYCLE WAIT - AS OPTICS  
MAY BE DRIVEN WHILE IN  
'COMPUTER' MODE)

THEN SET UP COMPUTER MODE

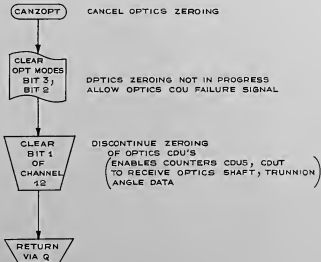
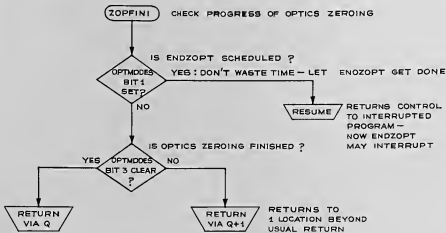
*P. M. ...*  
28 June 69

T4RUPT

COLOSSUS  
II-A

FC-2200

16 55



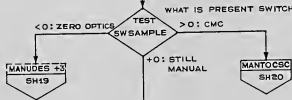
27MAR68  
 23 June 68  
 1 C. W. ...  
 COLOSSUS II-A  
 FC-2200  
 17 55

T4RUPT

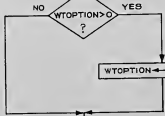


MANUDES

ENTERED FROM OPTMON IF OPTICS SWITCH WAS IN 'MANUAL' POSITION AT LAST PASS



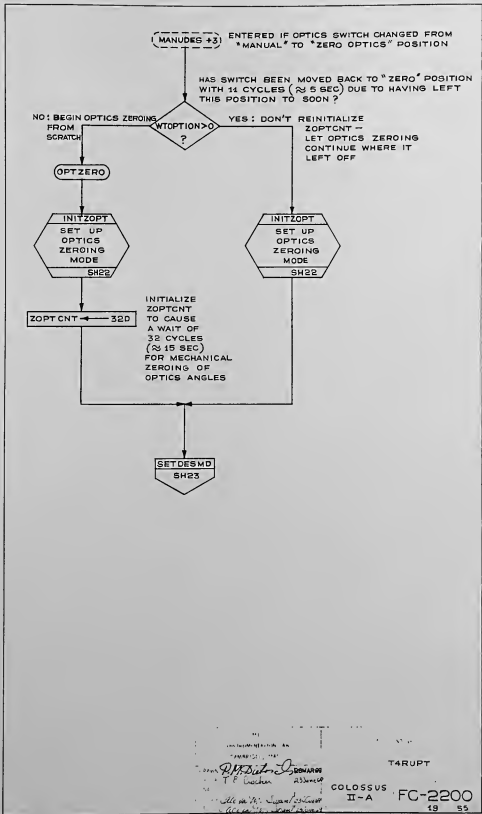
MANTOMAN



COUNT DOWN THROUGH DESIRED NUMBER OF CYCLES TO INDICATE, IF HAVE SWITCHED TO 'MANUAL' FROM 'ZERO OPTICS' MODE TOO SOON, HOW LONG HAVE BEEN IN MANUAL MODE (ELEVEN) SET IN WTOPTION WHEN ABOVE SITUATION OCCURS

(i.e. WHETHER MORE OR LESS THAN NUMBER OF CYCLES (ELEVEN) SET IN WTOPTION WHEN ABOVE SITUATION OCCURS)

SETDESMD SH23



T4RUPT  
 T. F. Wacker  
 COLLOSSUS II-A  
 FC-2200  
 19 55

MANTOCSC

ENTERED WHEN OPTICS SWITCH CHANGED FROM "MANUAL" TO "CMC" POSITION OR FROM ZTOCSC (5H16)

WTOPTION ← +0

IN CASE WTOPTION WAS SET >0 TO ALLOW RETURN TO "ZERO OPTICS" MODE WITHOUT FULL DELAY ; CANCEL THIS OPTION

ZOPTCNT ← +0

(MANTOCSC +3)

MAY ALSO BE ENTERED FROM ZTOCSC (5H16)

COARSLOK

HAS THERE BEEN COARSE ALIGNMENT OF OPTICS SINCE LAST FRESH START ?

OPTMODES BIT 9 SET?

NO

YES: COARSE ALIGNMENT WAS ENABLED WHEN LAST IN "COMPUTER" MODE

RETURN VIA Q

RETURN VIA Q +1

OPTINO ← +1

INDICATE COARSE ALIGNMENT ALLOWED

SET BIT 2 OF CHANNEL 12

ENABLE OPTICS COU ERROR COUNTERS

SETDESMD

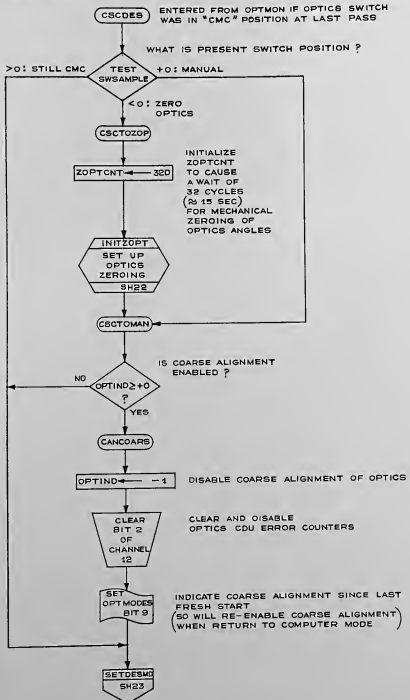
5H23

*PH*  
18  
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25

TARUPT

COLOSSUS II - A

FC-2200



MIT INFORMATION LAB CAMBRIDGE, MASS.	6 SEP 1954
DR: <i>P.H. Dyer</i>	T4RUPT
DE: <i>J.P. Laska</i>	COLOSSUS II-A
AN: <i>...</i>	FC-2200
AP: <i>...</i>	21 55

(INITZOPT)

SET UP "ZERO OPTICS" MODE

WTOPTION ← +0

UNLESS WTOPTION IS RESET >0,  
MUST BEGIN WITH FULL DELAY  
IF SWITCH LEAVES AND RETURNS  
TO "ZERO OPTICS" POSITION

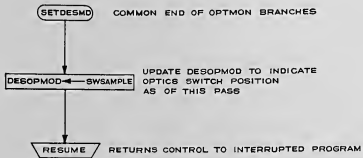
SET  
OPTMODES  
BIT 3,  
BIT 2

OPTICS ZEROING IN PROGRESS  
INHIBIT OPTICS CDU FAILURE SIGNAL

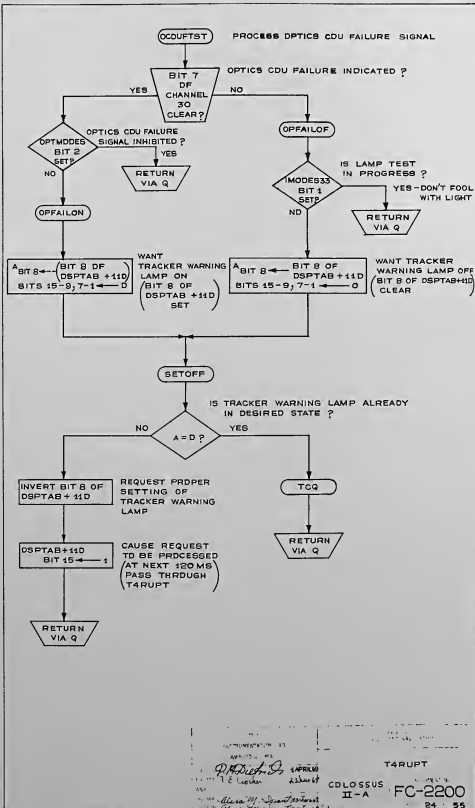
RETURN  
VIA Q

W. I. SYNCHRONIZATION DATE 01 1957	A. B. 1 THE SYSTEM DATA
<i>P. M. D. J.</i> P. M. D. J. E. C. L. W. H.	T4RUPT
31 MAR 57 23 MAR 57	FC-2200
COLOSSUS II-A	22 53

*See also of Special Interest  
clearly marked*



SET INSTRUMENTATION LEAD (ANALYTICAL) W/AS		REV. 1 1. 10/17/54 AND 10/24/54	
DRAWN BY: <i>P. H. DeWitt</i> CHECKED BY: <i>E. Walker</i> DATE: <i>11/18/54</i> APPROVED BY: <i>Allen H. Walker</i>		T4RUPT COLOSSUS II-A FC-2200 23 55	



T4RUPT

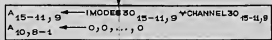
*P. Dietrich*  
 1 APR 1968  
 18 Wochen  
 28.4.68  
 1 APR 1968  
 28.4.68

CDLOSSUS II-A  
 FC-2200  
 24 55

IMUMON

IMU MONITOR  
ENTERED EVERY 480 MS. FROM T4RUPT

DETERMINE BITS (OF 15-11,9) WHERE  
CHANNEL 30 AND IMODES30  
(RECORD OF CHANNEL 30 AT LAST PMS)  
ARE DIFFERENT; THE BITS WHERE  
CHANGES OCCURRED NOW CONTAIN 1'S



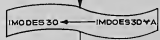
A ≠ 0?

HAVE ANY CHANGES OCCURRED?  
NO: NONE TO PROCESS -  
GO TO NEXT STEP

TNONTST  
SH33

RUPTREG1 ← A

SAVE RECORD OF CHANGED BITS



UPDATE RECORD OF IMU STATUS  
BY INVERTING BITS WHERE CHANGES OCCURRED

A ← RUPTREG1

RUPTREG1 ← -1

INITIALIZE INDEX VALUE

BIT 45  
OF A  
SET?

HAS THERE BEEN A CHANGE IN IMU TEMPERATURE STATUS?

TLIM  
SH28

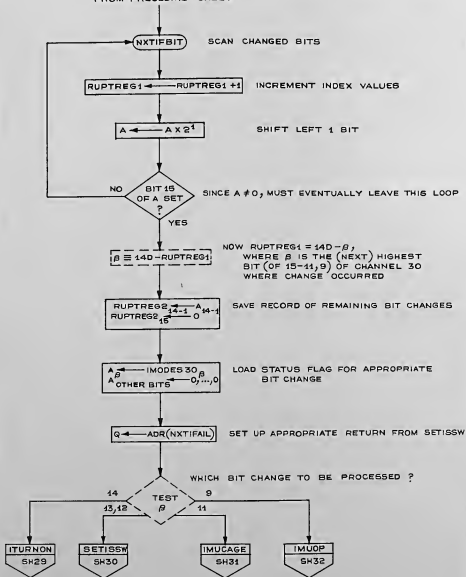
NEXT SHEET

REV  
INSTRUMENTATION-43  
CAMBRIIDGE, MASS  
APPROVED: *[Signature]*  
DATE: 11/6/68  
ANALYST  
DO, MR. *[Signature]*  
APPROVED: *[Signature]*

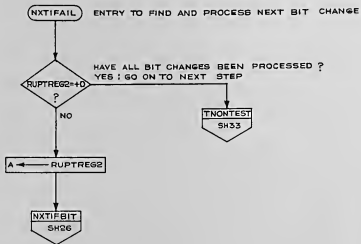
FC 2447 AND DER. 4-1  
T4RUPT  
COLOSSUS  
II-A  
FC-2200  
25 59



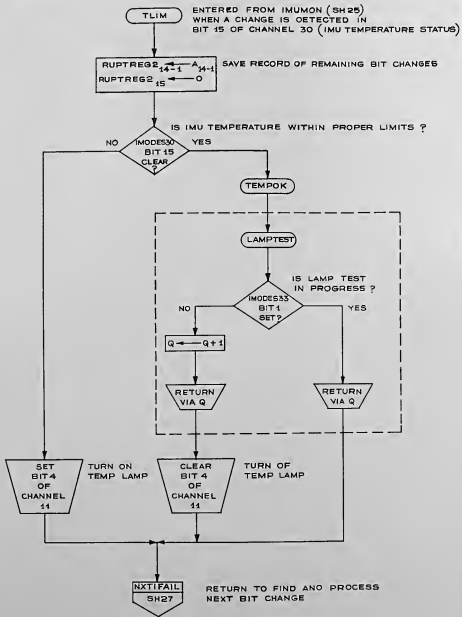
FROM PRECEDING SHEET

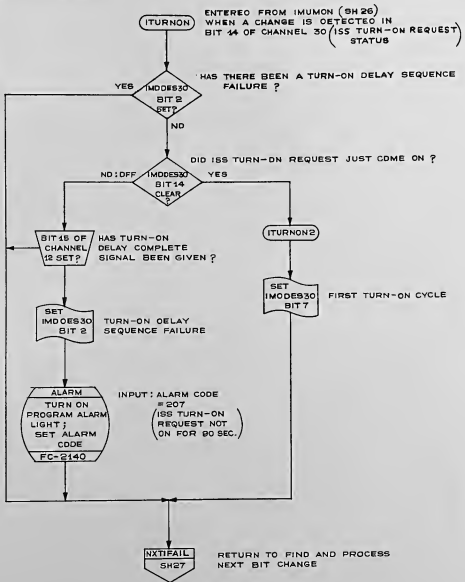


COLOSSUS II-A FC-2200  
T4RUPT  
26 55



WRT INSTRUMENTATION LAB ANALYSIS BRANCH ANALYST: <i>T. E. Cooper</i> APPROVED: <i>[Signature]</i> DATE: <i>23 June 67</i>	G. 2486 (REV. 1-6-67) T4RUPT COLOSSUS II-A FC-2200 27 55
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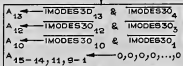




MIT INSTRUMENTATION LAB "BRIDGE" HAS	APR 10 LEONARD AND MATHIAS
20-1440 <i>[Signature]</i> <i>[Signature]</i> 19-1440 <i>[Signature]</i> ANALYST DOC NO. APPROV.	T4RUPT DOCUMENT NO. <b>COLOSSUS II-A</b> <b>FC-2200</b> 29 N 55

SETISSW

ENTERED FROM IMUMON (SH 26)  
WHEN A CHANGE IS DETECTED IN  
BIT 12 OR 13 OF CHANNEL 30  
ALSO CALLED BY ENDTON (SH 37)  
AND BY PIPFAIL (SH 41) WHEN A  
CHANGE IS DETECTED IN BIT 13  
OF CHANNEL 33



- 1 IFF IMU FAILURE DETECTED AND FAILURE SIGNAL ALLOWED
- 1 IFF ICPU FAILURE DETECTED AND FAILURE SIGNAL ALLOWED
- 1 IFF PIPA FAILURE DETECTED AND ISS WARNING FAILURE SIGNAL ALLOWED

HAVE ANY OF THESE FAILURES BEEN DETECTED,  
WITH ISS WARNING SIGNAL ALLOWED?

YES

NO

A ← A - 1

SET UP ALARM CODE

ISSWON

SAVE  
Q  
IN  
ITEMP6

INPUT: A = APPROPRIATE  
ALARM CODE:

00777 PIPA FAILURE  
 03777 ICPU FAILURE  
 04777 ICPU, PIPA FAILURES  
 07777 IMU FAILURE  
 10777 IMU, PIPA FAILURES  
 13777 IMU, ICPU FAILURES  
 14777 IMU, ICPU, PIPA  
 FAILURES

VARALARM  
 TURN ON  
 PROGRAM ALARM  
 LIGHT; SET  
 ALARM CODE  
 FC-2140

SET BIT 1  
OF  
CHANNEL  
11

TURN ON  
ISS WARNING LIGHT

RETURN VIA  
ITEMP6

ISSWOFF

LAMP TEST IN PROGRESS?

YES

NO

IMODES33  
BIT 1  
SET?

CLEAR  
BIT 1  
OF  
CHANNEL  
11

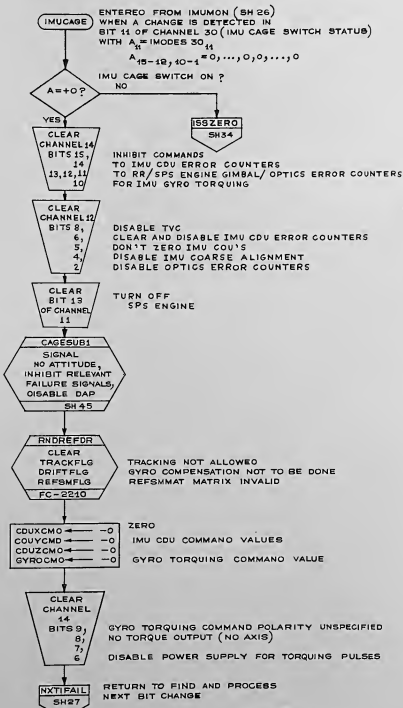
TURN OFF  
ISS WARNING LIGHT

RETURN  
VIA Q

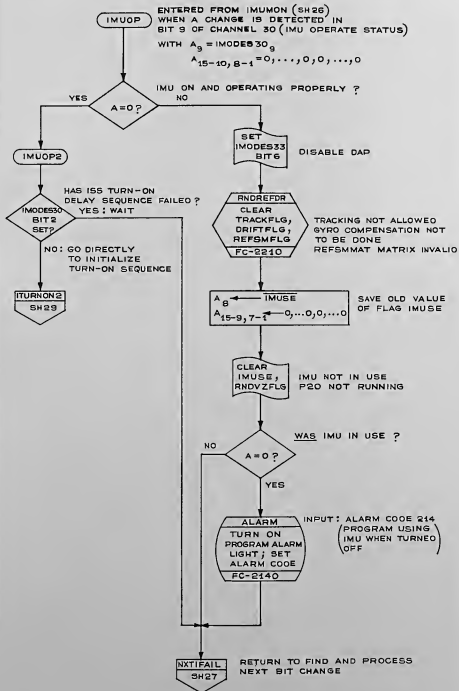
T4RUPT

COLOSSUS II-A FC-2200

30 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	APPROVED DI DANT AND KATHY HIL
DRAWN <i>[Signature]</i> BY J. E. Weston ANALYST CHECKED <i>[Signature]</i> APPROVED <i>[Signature]</i>	<b>T4RUPT</b>  <b>COLOSSUS II-A</b> DOCUMENT NO. <b>FC-2200</b> SHEET 31 OF 53



RECEIVED  
18 JUN 68  
P. H. [Signature]  
23 JUN 68

T4RUPT

COLOSSUS  
II-A  
FC-2200  
32 53

TNONTEST

ISS INITIALIZATION ROUTINE  
ENTERED EVERY 480 MS FROM T4RUPT  
(VIA IMUMON)  
(ENTERED AT A LOWER POINT IF  
IMU CAGE SWITCH TURNED OFF)

IMODES30  
BIT 7  
SET?

HAS FIRST TURN-ON CYCLE ARRIVED?  
NO

YES

IMODES30  
BIT 8  
SET?

HAS SECOND TURN-ON  
CYCLE ARRIVED?  
NO: NOT YET - SET IT UP NOW

YES:  
PROCEED WITH  
TURN-ON

SET  
IMODES30  
BIT 8

PROCTNON

C33TEST  
SH3B

CLEAR  
IMODES30  
BIT 7, 8

REINITIALIZE  
TURN-ON CYCLE FLAGS

IMODES30  
BIT 14  
CLEAR?

HAS ISS TURN-ON BEEN REQUESTED?  
NO: IMU OPERATING ONLY

YES

OPONLY  
SH34

IMODES30  
BIT 9  
CLEAR?

IMU ON AND  
OPERATING PROPERLY?  
NO

YES

ALARM  
TURN ON  
PROGRAM ALARM  
LIGHT; SET  
ALARM CODE  
FC-2140

INPUT: ALARM CODE 213  
(ISS TURN-ON REQUEST  
WHEN IMU NOT OPERATING)

CAGESUB  
INITIALIZE  
IMU AND  
CORRESPONDING  
SIGNALS  
SH45

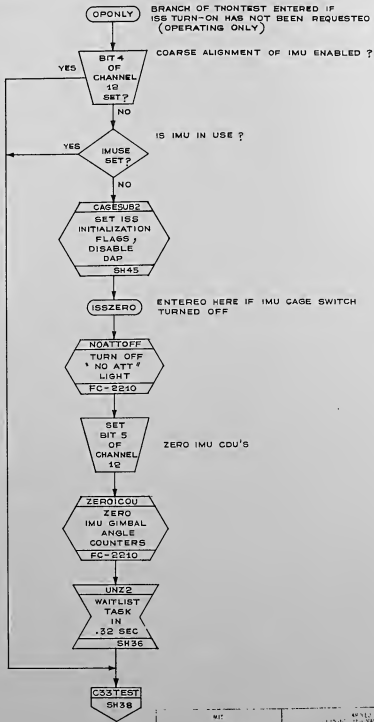
ENDTNON  
WAITLIST  
TASK  
IN  
90 SECONDS  
SH35

AFTER 90 SECONDS, END TURN-ON SEQUENCE

C33TEST  
SH3B

MIT INSTRUMENTATION LAB AMHERST, MASS. DRAWN BY: <i>P. M. ...</i> PROGRAM: T.C. ... ANALYST: ... INSTRUMENTATION: ... APPROVED: ...	AFOLLO CONTROL AND NAVIGATION  T4RUPT  COLOSSUS II-A DOCUMENT NO: <b>FC-2200</b> DATE: 33 3 55
--	---





MIT  
ASTRONOMICAL LAB  
COMM. USE MAIL

770 *P.H. ...*  
-4-48 TE (check) 23805  
11-11-54  
11-11-54

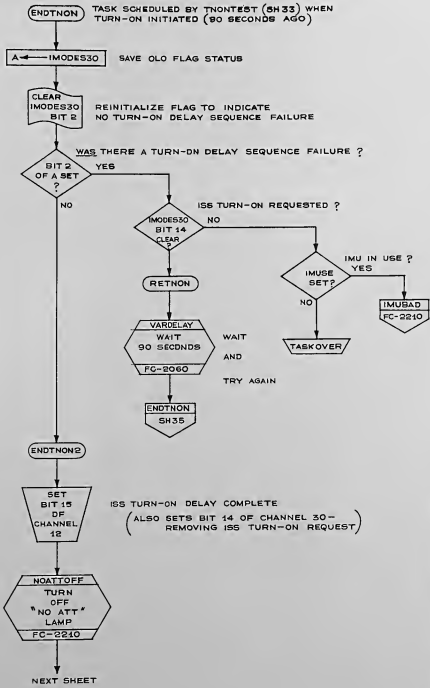
40912  
-11-20-54 2ND NEW 2475

T4RUPT

COLOSSUS  
II-A

FC-2200

34 55



FROM PRECEDING SHEET

UNZ2 THIS POINT ALSO SCHEDULED BY OPONLY (SH34)

ZEROICDU  
ZERO IMU  
GIMBAL ANGLE  
COUNTERS  
FC-2210

CLEAR  
CHANNEL  
12  
BITS 4,  
5

DISABLE COARSE ALIGNMENT OF IMU  
ALLOW IMU GIMBAL ANGLE COUNTERS  
TO RECEIVE TRUE DATA

VARDELAY  
WAIT  
10.24  
SECONDS  
FC-2060

WAIT FOR COUNTERS TO COUNT UP

ISSUP

CLEAR  
IMODES30  
BITS 3,  
4,  
6

ALLOW ICDU FAILURE SIGNAL  
ALLOW IMU FAILURE SIGNAL  
IMU NOT BEING INITIALIZED

CLEAR  
IMODES33  
BIT 6

ENABLE DAP

NEXT SHEET

UNIT INSTRUMENTATION LAB FAIRHURST, MASS.	APPROVED S. STANLEY AND N. DUTTON
PREPARED BY <i>[Signature]</i>	T4RUPT
APPROVED BY T. E. Crocker	COLOSSUS II-A
ANALYST <i>[Signature]</i>	DOCUMENT NO. FC-2200
DO NOT WRITE IN THESE SPACES	36 - 55

FROM PRECEDING SHEET



ISS WARNING SIGNAL MAY HAVE BEEN  
INHIBITED BEFORE - NOW ALLOWED



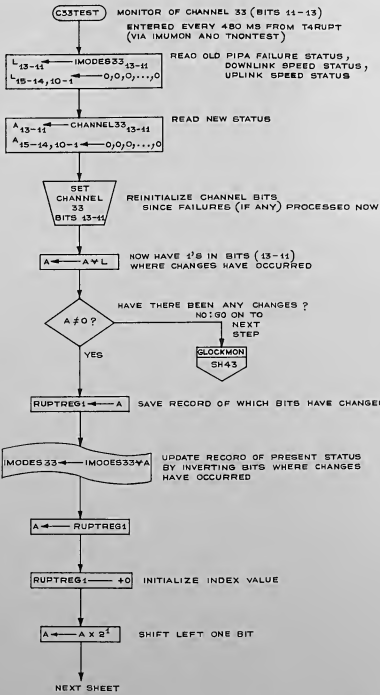
REINITIALIZE SITUATION :  
ISS TURN-ON DELAY SEQUENCE NOT COMPLETE



AFTER 4 SECONDS, PIPA FAILURE PROGRAM ALARM  
SIGNAL WILL BE ALLOWED.

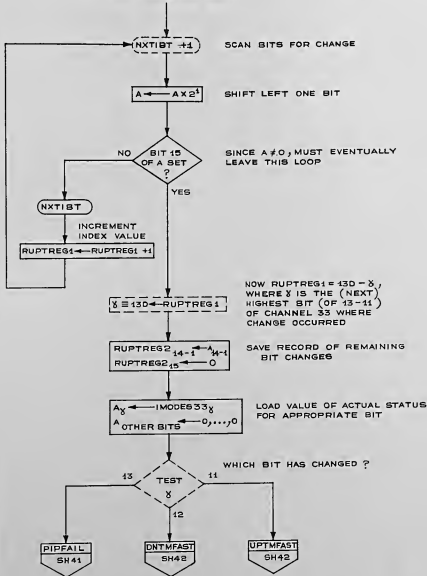


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	APPROX CALIBRATION AND QUALIFICATION
CHARGE: <i>[Signature]</i> DATE: <i>1-1-68</i> ANALYST: <i>T.E. Cochran</i> DISTRIBUTION: <i>Alberici</i> APPROVED: <i>[Signature]</i>	T4RUPT COLOSSUS II-A FC-2200 37 55

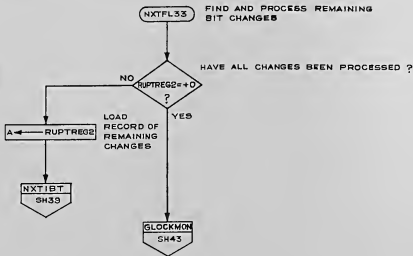


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIC CONTROL AND NAVIGATION
DRAWN: <i>[Signature]</i> REVISED: <i>[Signature]</i> CHECKED: <i>[Signature]</i> APPROVED: <i>[Signature]</i>	T4RUPT COLOSSUS II-A FC-2200 SHEET 38 of 55

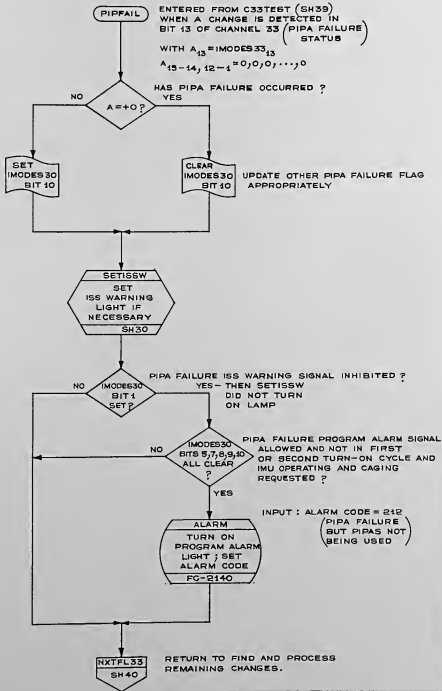
FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	44-2110 C. DANC. ENG. TANKER 44-101
TO: <i>John G. ...</i> FROM: <i>E. ...</i> ANALYST: DATE: <i>12/14/55</i> APPROVED: <i>...</i>	T4RUPT COLOSSUS II - A FC-2200 DOCUMENT NO. 39 - 55

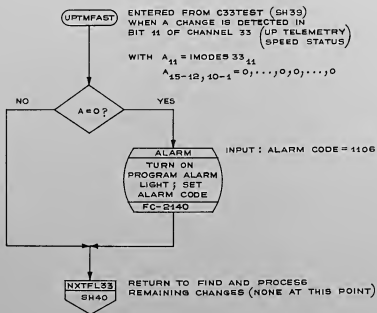
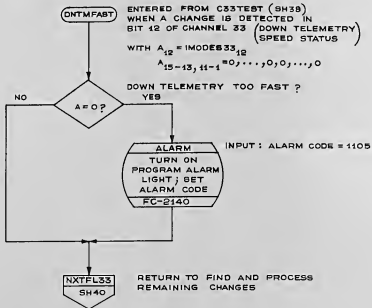


WFO INSTRUMENTATION LAB FARM BRIDGE, MASS DRAWN BY <i>[Signature]</i> REVISION BY <i>[Signature]</i> ANA ST IN THE SECURITY DOCUMENTS APPROVED BY <i>[Signature]</i>	AFULL GUIDANCE AND FACILITATION  T4RUPT  COLOSSUS II-A DOCUMENT NO. FC-2200 REV. 40 - 53
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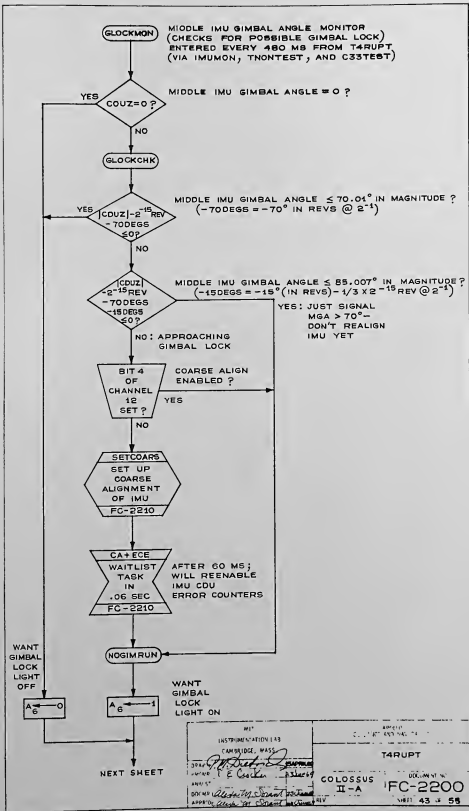
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	PROJECT GUIDANCE AND NAVIGATION
DRAWN BY <i>P.M. Dwyer</i>	T4RUPT
DESIGNED BY <i>E. Corbett</i>	COLOSSUS
ANALYST	II-A
TECHNICAL SUPERVISOR	DOC. NO. FC-2200
APPROVED BY <i>[Signature]</i>	PAGE 41 OF 55





MIL INSTRUMENTATION LAB CAMBRIDGE MASS 120-44 150-44 151-44	48310 ELECTRIC AND NAVIGATION T4RUPT BY: M-1-W COLOSSUS II-A FC-2200 42 X 55
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APPROVED: *D.M. [Signature]*  
 T. E. [Signature]  
 APPROVED: *[Signature]*



REP  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS

DATE: *10/1/68*  
BY: *E. Coakley*

APPROVED: *[Signature]*

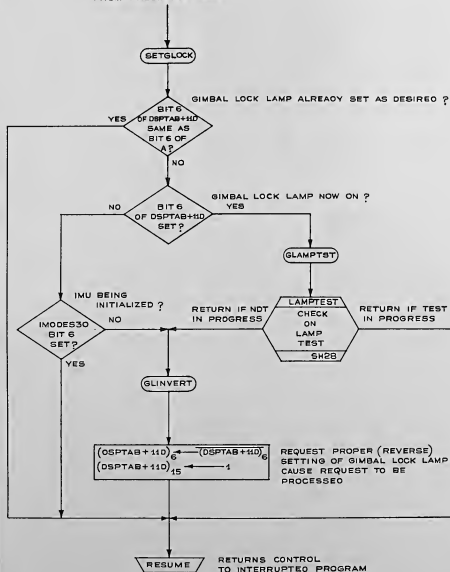
COLOSSUS II-A

DOCUMENT NO. FC-2200

T4RUPT

REV 43-55

FROM PRECEDING SHEET



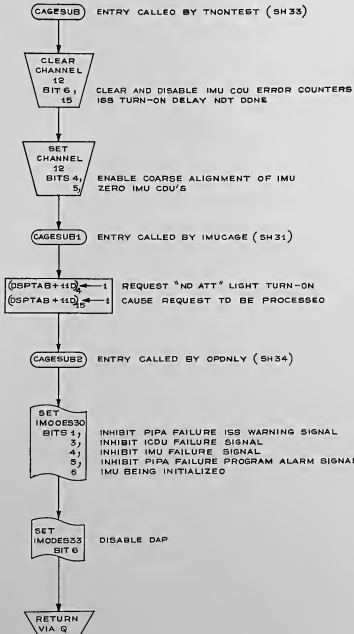
412  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

DESIGNED BY *[Signature]*  
TO AIR *[Signature]*  
ANNEX *[Signature]*  
REV. NO. *[Signature]*  
APPROVED BY *[Signature]*

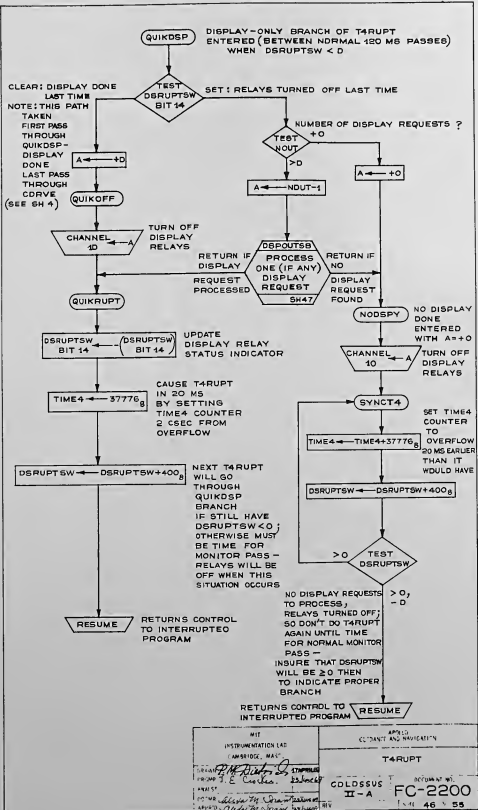
APPLIC  
EL. CANTS AND NAVIGATION

T4RUPT

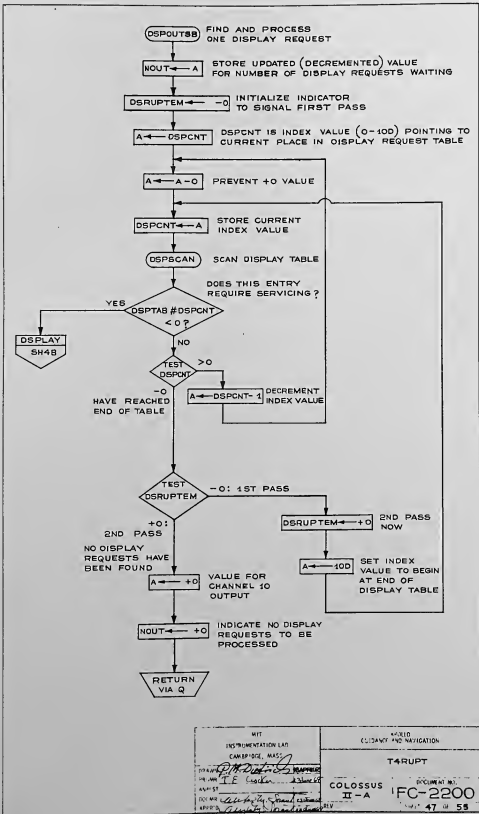
DOCUMENT #  
COLOSSUS II-A FC-2200  
44 2 55



WFO INSTRUMENTATION LAB CAMP-DIE, MASS. BY: <i>J.E. Crutcher</i> FOR: <i>J.E. Crutcher</i> ANALYST: <i>J.E. Crutcher</i> DATE: <i>1/24/68</i> APPROVED BY: <i>J.E. Crutcher</i>	ANALYST: <i>J.E. Crutcher</i> COLOSSUS II-A DOCUMENT NO. <b>FC-2200</b> SHEET 45 OF 59
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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS		APPLIC CLOCKING AND NAVIGATION	
PREPARED BY: <i>F.M. ...</i> PROJECT: <i>J. E. ...</i> ANALYST: <i>...</i> APPROVED: <i>...</i>		<b>T4RUPT</b>	
COLDSSUS II - A		FORM NO. 1 <b>FC-2200</b>	
		DATE: 46 5 55	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	FILED CLASSIFY AND NAVIGATION
DRAWN BY: <i>P.M. Dutton</i> CHECKED BY: <i>T.E. Caskey</i> DATE: <i>2/23/67</i> DESIGNED BY: <i>...</i> APPROVED BY: <i>...</i>	T4RUPT COLOSSUS II - A DOCUMENT NO. FC-2200 47 of 55

DISPLAY

PROCESS DISPLAY REQUEST  
FOUND BY DSP6CAN

DSPTAB # DSPCNT ← DSPTAB # DSPCNT

MAKE TABLE ENTRY NONNEGATIVE  
TO SHOW REQUEST HAS BEEN PROCESSED

DSRUPTEM

BITS 15-12 ← 0

DSPTAB # DSPCNT  
BITS 11-1 ← BITS 11-1

MASK OUT BITS 11-1, WHICH GIVE  
DESIRED DISPLAY RELAY SETTINGS  
FOR ONE ROW (OF RELAYS)

CHANNEL 10  
BITS 15-12 ← RELTAB # DSPCNT  
BITS 15-12  
DSRUPTEM  
BITS 11-1 ← BITS 11-1

OUTPUT DISPLAY COMMAND  
VIA CHANNEL 10

BITS 15-12 SPECIFY RELAY ROW  
BITS 11-1 SPECIFY SETTINGS FOR  
RELAY IN THAT ROW

RETURN  
VIA Q+1

RETURNS TO 2 LOCATIONS BEYOND  
SUBROUTINE CALL

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS PROJECT: <i>DSRUPT</i> DES. BY: <i>J. E. Cuckey</i> DRAWN BY: <i>[Signature]</i> CHECKED BY: <i>[Signature]</i> APPROVED BY: <i>[Signature]</i> DATE: <i>[Signature]</i>	ARCADIA ELECTRONIC AND INVESTIGATION T4RUPT COLOSSUS II-A DOCUMENT NO. FC-2200 FEB 48 1955
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SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
ALARM	FC-2140	TURN ON PROGRAM ALARM LIGHTS; SET ALARM CODE	SH, 6, 15, 16, 29, 32, 33, 41, 42
CA+ECE	FC-2210	ENABLE IMU CDU ERROR COUNTERS	SH, 43
IMUBAD	FC-2210	ERROR END OF IMU TASK	SH, 35
NOATTOFF	FC-2210	TURN OFF "NO ATT" LAMP	SH, 34, 35
PFALOK	FC-2210	ALLOW PROGRAM ALARM IN CASE OF PIPA FAILURE	SH, 37
PROCKEY	FC-2180	PROCESS ASTRONAUT'S "PROCEED" SIGNAL	SH, 5
RNDREFDR	FC-2210	CLEAR TRACKFLG (NO TRACKING), DRIFTFLG (NO GYRO COMPENSATION), REFSMFLG (REFSMMAT MATRIX INVALID)	SH, 31, 32
SETCOARS	FC-2210	SET UP COARSE ALIGNMENT OF IMU	SH, 43
VARALARM	FC-2140	TURN ON PROGRAM ALARM LIGHT; SET ALARM CODE	SH, 30
ZEROICDU	FC-2210	ZERO IMU GIMBAL ANGLE COUNTERS	SH, 34, 36

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DRIFTFLG FLAGWRD2 BIT 15	TRUPT CALLS GYRO COMPENSATION	TRUPT DOES NO GYRO COMPENSATION		SH, 11, 32	
DSKYFLAG FLAGWRD5 BIT 15	DISPLAY SENT TO DSKY	NO DISPLAY SENT TO DSKY			SH, 4
DSRUPTSW BIT 14	DISPLAY RELAYS TURNED OFF LAST PASS THROUGH T4RUPT	DISPLAY DONE AT LAST PASS - TURN OFF RELAYS	SH, 45	SH, 4, 46	SH, 46
IMODES30 BIT 1	PIPA FAILURE NOT TO CAUSE ISS WARNING	PIPA FAILURE SIGNAL ALLOWED	SH, 45		SH, 30, 41
IMODES30 BIT 2	ISS DELAY-SEQUENCE FAILURE	NO ISS DELAY-SEQUENCE FAILURE	SH, 28	SH, 35	SH, 28, 32, 35
IMODES30 BIT 3	ICDU FAILURE SIGNAL INHIBITED	ICDU FAILURE SIGNAL ALLOWED	SH, 45	SH, 36	SH, 30
IMODES30 BIT 4	IMU FAILURE SIGNAL INHIBITED	IMU FAILURE SIGNAL ALLOWED	SH, 45	SH, 36	SH, 30
IMODES30 BIT 5	PIPA FAILURE NOT TO CAUSE PROG ALARM	PIPA FAILURE SIGNAL ALLOWED	SH, 45		SH, 31
IMODES30 BIT 6	IMU BEING INITIALIZED	IMU NOT BEING INITIALIZED	SH, 45	SH, 36	SH, 44
IMODES30 BIT 7	FIRST ISS TURN-ON CYCLE HAS ARRIVED	FIRST ISS TURN-ON CYCLE HAS NOT ARRIVED	SH, 29	SH, 33	SH, 33, 41
IMODES30 BIT 8	SECOND ISS TURN-ON CYCLE HAS ARRIVED	SECOND ISS TURN-ON CYCLE HAS NOT ARRIVED	SH, 33	SH, 33	SH, 33, 41

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	G-1041-100-1A & 100-1B
DRAWN: <i>[Signature]</i> CHECKED: <i>[Signature]</i> ANALYST: <i>[Signature]</i> DATE: <i>[Signature]</i> APPROVED: <i>[Signature]</i>	T4RUPT
	COLOSSUS II-A FC-2200
	49 56



FLAGS (CONTINUED)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
IMODES30 BIT 9	ISS NOT OPERATING	ISS OPERATING	SH. 25	SH. 25	SH. 32, 33, 41
IMODES30 BIT 10	NO PIPA FAILURE	PIPA FAILURE	SH. 41	SH. 41	SH. 30, 41
IMODES30 BIT 11	IMU CAGE NOT REQUESTED	IMU CAGE REQUESTED	SH. 25	SH. 25	SH. 31
IMODES30 BIT 12	NO ICDU FAILURE	ICDU FAILURE	SH. 25	SH. 25	SH. 30
IMODES30 BIT 13	NO IMU FAILURE	IMU FAILURE	SH. 25	SH. 25	SH. 30
IMODES30 BIT 14	ISS TURN-ON NOT REQUESTED	ISS TURN-ON REQUESTED	SH. 25	SH. 25	SH. 29, 33
IMODES30 BIT 15	ISS TEMPERATURE NOT WITHIN LIMITS	ISS TEMPERATURE WITHIN LIMITS	SH. 25	SH. 25	SH. 28
IMODES33 BIT 1	LAMP TEST IN PROGRESS	LAMP TEST NOT IN PROGRESS			SH. 24, 28
IMODES33 BIT 5	AUTOPILOT DISABLED	AUTOPILOT ENABLED	SH. 32, 45	SH. 36	
IMODES33 BIT 11	UPLINK NOT TOO FAST	UPLINK TOO FAST	SH. 38	SH. 38	SH. 42
IMODES33 BIT 12	DOWNLINK NOT TOO FAST	DOWNLINK TOO FAST	SH. 38	SH. 38	SH. 42
IMODES33 BIT 13	NO PIPA FAILURE	PIPA FAILURE	SH. 38	SH. 38	SH. 41
IMODES33 BIT 14	PROCEED KEY NOT DEPRESSED	PROCEED KEY DEPRESSED	SH. 5	SH. 5	SH. 5
IMUSE FLAGWRDD BIT 8	IMU IN USE	IMU NOT IN USE		SH. 32	SH. 34, 35
OPTMODES BIT 1	ENDZOPT SCHEDULED	ENDZOPT NOT SCHEDULED	SH. 13	SH. 14	SH. 17
OPTMODES BIT 2	OPTICS CDU FAILURE SIGNAL INHIBITED	OPTICS CDU FAILURE SIGNAL ALLOWED	SH. 22	SH. 17, 17	SH. 17
OPTMODES BIT 3	OPTICS ZEROING IN PROGRESS	OPTICS ZEROING NOT IN PROGRESS	SH. 22	SH. 14, 17	SH. 17
OPTMODES BIT 4	OPTICS SWITCH NOT IN "CMC" POSITION	OPTICS SWITCH IN "CMC" POSITION	SH. 11	SH. 11	SH. 11
OPTMODES BIT 5	OPTICS SWITCH NOT IN "ZERO" POSITION	OPTICS SWITCH IN "ZERO" POSITION	SH. 11	SH. 11	SH. 11
OPTMODES BIT 7	NO OPTICS CDU FAILURE	OPTICS CDU FAILURE	SH. 11	SH. 11	
OPTMODES BIT 9	OPTICS HAVE BEEN COARSE ALIGNED SINCE LAST FRESH START	OPTICS HAVE NOT BEEN COARSE ALIGNED SINCE LAST FRESH START	SH. 21		SH. 30
OPTMODES BIT 10	OPTICS HAVE BEEN ZEROED SINCE LAST FRESH START	OPTICS HAVE NOT BEEN ZEROED SINCE LAST FRESH START	SH. 14		

MIT  
INS REGENERATION LAB  
AMRO CRT, MASS  
FROM *J.M. O'Neil*  
DATE *J.E. Cook* 23 Nov 49  
BY *J.E. Cook*  
CHECKED BY *John P. ...*  
APPROVED BY *John P. ...*

T4RUPT

COLOSSUS II-A FC-2200

FLAGS (CONTINUED)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
REFSMFLG FLAGWRD3 BIT 13	REFSMMAT MATRIX VALID	REFSMMAT MATRIX NOT VALID		SH. 32, 33	
RNDVZFLG FLAGWRD0 BIT 7	RADAR IN USE	RADAR NOT IN USE		SH. 33	
TRACKFLG FLAGWRD1 BIT 5	TRACKING ALLOWED	TRACKING NOT ALLOWED		SH. 32, 33	

DISPLAYS

VERB- NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
	ALARM	PROG ALARM LIGHT ON; R1, R2, R3 NOT AFFECTED	SH. 6, 15, 16, 29, 30, 32, 33, 41, 42

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
A		ACCUMULATOR REGISTER (IN AGC CENTRAL PROCESSOR)			
ARUPT		TEMPORARY STORAGE FOR A (ABOVE) DURING INTERRUPT			
BANKRUPT		TEMPORARY STORAGE FOR BANK (BELOW) DURING INTERRUPT			
BBANK		CENTRAL REGISTER CONTAINING ADDRESS INFORMATION (USED BY CENTRAL PROCESSOR)			
CDUS		OPTICS SHAFT ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-1</sup>
CDUSCMD (=CDUTCMD+1)		COMMANDED CHANGE IN SHAFT ANGLE (OUTPUT COUNTER)	DEGREES	REVS	2 <sup>+1</sup>
CDUT		OPTICS TRUNNION ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-3</sup>
CDUTCMD		COMMANDED CHANGE IN TRUNNION ANGLE (OUTPUT COUNTER)	DEGREES	REVS	2 <sup>-1</sup>
CDUXCMD		COMMANDED VALUE FOR OUTER IMU GIMBAL ANGLE	DEGREES	REVS	2 <sup>1</sup>
CDUYCMD		COMMANDED VALUE FOR INNER IMU GIMBAL ANGLE	DEGREES	REVS	2 <sup>1</sup>
CDUZ		MIDDLE IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-1</sup>

MIT INSTRUMENTATION LAB AMSTERDAM, MASS. DATE: <i>10/10/67</i> BY: <i>J.E. Coker</i> FOR: <i>Colossus II</i> APPROVED: <i>[Signature]</i>	RAND RAND CORP. SANTA MONICA, CALIF. T4RUPT COLLOSSUS II FC-2200 54 - 55
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## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
CDUZCMD		COMMANDED VALUE FOR MIDDLE IMU GIMBAL ANGLE	DEGREES	REVS	2 <sup>1</sup>
COMMANDO		PRELIMINARY COMMAND FOR CHANGE IN TRUNNION ANGLE	DEGREES	REVS	2 <sup>-1</sup>
COMMANDO+1		PRELIMINARY COMMAND FOR CHANGE IN SHAFT ANGLE	DEGREES	REVS	2 <sup>+1</sup>
DESOPMOD		INDICATES WHETHER OPTICS SWITCH WAS IN CMC, MANUAL, OR ZERO POSITION (BY POSITIVE, +0, OR NEGATIVE VALUE, RESPECTIVELY) AT LAST PASS THROUGH OPTMON			
DESOPTS (=DESOPTT+1)		DESIRED SHAFT ANGLE	DEGREES	REVS	2 <sup>+1</sup>
DESOPTT		DESIRED TRUNNION ANGLE	DEGREES	REVS	2 <sup>-1</sup>
DSFCNT		INDEX VALUE POINTING TO ENTRY IN DISPLAY REQUEST TABLE (SEE DSPTAB BELOW)			
DSPTAB, . . . .		TWELVE LOCATIONS CONTAINING CODES FOR DISPLAY RELAYS TO BE SET FOR EACH OF 12 ROWS OF RELAYS. EACH ENTRY MUST BE SET NEGATIVE IN ORDER TO BE PROCESSED.			
DSPTAB+11D					
DSRUPTSW		POINTER TO PATH THROUGH T4RUPT. IF NON-NEGATIVE, CYCLES (EVERY 960 MS) BETWEEN VALUES OF 0 - 7 TO INDICATE WHICH SERVICE ROUTINE IS TO BE DONE THIS PASS. IF NEGATIVE, AN INTERMEDIATE PASS (BETWEEN PASSES OF ABOVE TYPE, WHICH OCCUR EVERY 120 MS) WHICH DOES DISPLAY ROUTINE ONLY			
GYROCMD		IMU GYRO TORQUING COMMAND	DEGREES	REVS	2 <sup>7</sup>
ITEMP1		USED HERE TO INDICATE NUMBER OF OPTICS COMMANDS TO BE SENT			2 <sup>14</sup>
L		LOW-ORDER ACCUMULATOR REGISTER (IN AGC CENTRAL PROCESSOR)			
LRUPT		TEMPORARY STORAGE FOR L (ABOVE) DURING INTERRUPT			
NOUT		NUMBER OF OUTPUT DISPLAY REQUESTS TO BE PROCESSED			
OPTIND		INDICATES WHETHER COARSE ALIGNMENT OF OPTICS MAY BE PERFORMED OR NOT, BY VALUE $\geq +0$ OR $\leq -0$ , RESPECTIVELY. IF $\geq +0$ , +1 INDICATES SHAFT ANGLE IS UNDER CONSIDERATION, AND +0 INDICATES TRUNNION ANGLE IS UNDER CONSIDERATION. IF $\leq -0$ , -0 INDICATES OPTICS NOT BEING USED AS OPTICS ERROR COUNTERS ARE BEING USED FOR THRUST VECTOR CONTROL, AND $< -0$ MERELY DISABLES COARSE ALIGNMENT.			

T4RUPT

COLOSSUS II-A FC-2200

52 58

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
Q		CENTRAL PROCESSOR REGISTER USED FOR RETURNS FROM SUBROUTINES			
QRUPT		TEMPORARY STORAGE FOR Q (ABOVE) DURING INTERRUPT			
SWSAMPLE		INDICATES WHETHER OPTICS SWITCH IS IN CMC, MANUAL, OR ZERO POSITION (BY POSITIVE, +0, OR NEGATIVE VALUE, RESPECTIVELY) AT PRESENT PASS THROUGH OPTMON			
TIME <sub>D</sub> * (TIME <sub>2</sub> / TIME <sub>1</sub> )		PRESENT TIME FROM LIPTOFF	SECS	CSECS	2 <sup>28</sup>
TIME <sub>4</sub>		COUNTER WHICH CONTROLS TIMING OF T4RUPT			
WTOPTION		NUMBER OF 480 MS CYCLES WITH OPTICS IN MANUAL MODE BEFORE A CHANGE TO ZERO MODE WOULD REQUIRE THE FULL INITIALIZATION DELAY			2 <sup>14</sup>
ZONE		INDICATES WHETHER MAGNITUDE OF OPTICS SHAFT ANGLE IS $\pm 45^\circ$ (IF SO, ZONE = 0) AND IF NOT, IN WHICH DIRECTION SHAFT ANGLE LEFT THAT REGION (BY POSITIVE OR NEGATIVE VALUE).			
ZOPTCNT		NUMBER OF 480 MS CYCLES WITH OPTICS IN ZERO MODE BEFORE TIME TO FINISH OPTICS ZEROING PROCESS			2 <sup>14</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE MASS	APPLIC CONTRACT # 44-0197-10A
PREPARED BY: <i>P.H. ...</i> CHECKED BY: <i>E. ...</i> DATE: <i>...</i> APPROVED BY: <i>...</i>	T4RUPT DOCUMENT NO. <b>COLOSSUS II-A FC-2200</b> 53 55

## CHANNEL BITS

CHANNEL BITS	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
CHANNEL 33 BIT 13	NO PIPA FAILURE	PIPA FAILURE	SH. 38		SH. 38
BIT 12	DOWN TELEMETRY NOT TOO FAST	DOWN TELEMETRY TOO FAST	SH. 38		SH. 38
BIT 11	UP TELEMETRY NOT TOO FAST	UP TELEMETRY TOO FAST	SH. 38		SH. 38
BIT 5	OPTICS SWITCH NOT IN "CMC" POSITION	OPTICS SWITCH IN "CMC" POSITION			SH. 11
BIT 4	OPTICS SWITCH NOT IN "ZERO OPTICS" POSITION	OPTICS SWITCH IN "ZERO OPTICS" POSITION			SH. 11
CHANNEL 32 BIT 14	PROCEED KEY NOT DEPRESSED	PROCEED KEY DEPRESSED			SH. 5
CHANNEL 30 BIT 15	IMU TEMPERATURE OUT OF PROPER LIMITS	IMU TEMPERATURE WITHIN PROPER LIMITS			SH. 25, 28
BIT 14	ISS TURN-ON NOT REQUESTED	ISS TURN-ON HAS BEEN REQUESTED	SH. 35		SH. 25, 26, 29
BIT 13	NO IMU FAILURE	IMU FAILURE			SH. 25, 26, 30
BIT 12	NO IMU CDU FAILURE	IMU CDU FAILURE			SH. 25, 26, 30
BIT 11	NO IMU CAGE COMMAND	IMU CAGE COMMAND			SH. 25, 26, 31
BIT 9	IMU NOT OPERATING	IMU ON AND OPERATING			SH. 25, 26, 32
BIT 7	NO OPTICS CDU FAILURE	OPTICS CDU FAILURE			SH. 11, 24
CHANNEL 14 BITS 15-13	COMMANDS TO IMU ERROR COUNTERS TRANSMITTED	COMMANDS TO IMU ERROR COUNTERS INHIBITED		SH. 31	
BITS 12-11	COMMANDS TO OPTICS ERROR COUNTERS TRANSMITTED	COMMANDS TO OPTICS ERROR COUNTERS INHIBITED	SH. 10	SH. 31	
BIT 10	IMU GYRO TORQUING COMMAND TRANSMITTED	IMU GYRO TORQUING COMMAND INHIBITED		SH. 31	
BIT 9	GYRO TORQUING COMMAND HAS NEGATIVE POLARITY	POLARITY OF GYRO TORQUING COMMAND UNSPECIFIED		SH. 31	
BITS 8-7	SPECIFY AXIS FOR GYRO MEANS NO AXIS SPECIFIED.	TORQUING; BOTH CLEAR		SH. 31	
BIT 6	GYRO TORQUING POWER SUPPLY ENABLED	GYRO TORQUING POWER SUPPLY DISABLED		SH. 31	
CHANNEL 12 BIT 15	ISS TURN-ON DELAY COMPLETE	ISS TURN-ON DELAY NOT COMPLETE	SH. 35	SH. 37, 45	SH. 29
BIT 8	OPTICS ERROR COUNTERS CONNECTED TO SPS ENGINE GIMBALS (TVC ENABLED)	TVC DISABLED		SH. 31	
BIT 8	IMU CDU ERROR COUNTERS ENABLED	IMU CDU ERROR COUNTERS CLEARED AND DISABLED		SH. 31, 45	
BIT 5	ZERO IMU CDU'S	IMU GIMBAL ANGLE COUNTERS MAY RECEIVE DATA	SH. 34, 45	SH. 31, 36	
BIT 4	IMU COARSE ALIGNMENT ENABLED	IMU COARSE ALIGNMENT DISABLED	SH. 45	SH. 31, 36	SH. 34, 43

BIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

ARJLC  
GUIDANCE AND NAVIGATION

TARGET

DRAWN *R. H. Hart* L.MAYER  
 PROGRAM *J. C. Corbin* R. L. MAYER  
 ANALYST  
 CHECKED *William J. ...*  
 APPROVED *...*

COLOSSUS II-A

FC-2200

REV 54 OF 55

## CHANNEL BITS (CONTINUED)

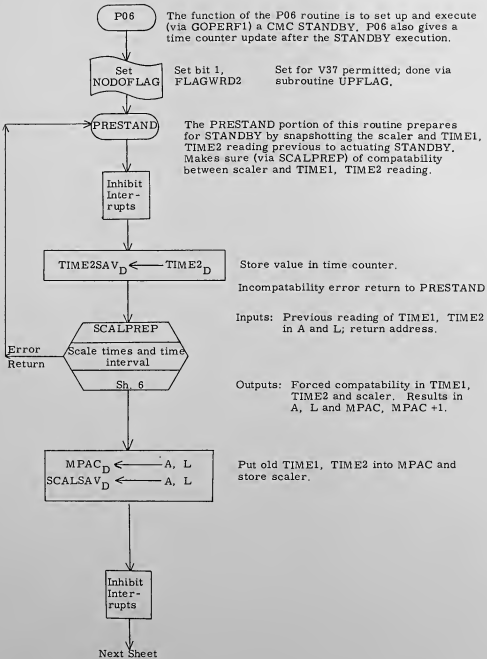
CHANNEL BITS	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
CHANNEL 12 BIT 2	OPTICS ERROR COUNTERS ENABLED	OPTICS ERROR COUNTERS DISABLED	SH. 7, 20	SH. 21, 31	SH. 7
BIT 1	ZERO OPTICS CDU'S	OPTICS ANGLE COUNTERS MAY RECEIVE DATA	SH. 13	SH. 14, 17	
CHANNEL 11 BIT 13	SPS ENGINE ON	SPS ENGINE OFF		SH. 31	
BIT 4	TEMP LIGHT ON	TEMP LIGHT OFF	SH. 28	SH. 28	
BIT 1	ISS WARNING LIGHT ON	ISS WARNING LIGHT OFF	SH. 30	SH. 30	
CHANNEL 10 BITS 15-12	SPECIFY RELAY ROW FOR DSKY LIGHTS		SH. 4, 48	SH. 4, 46, 48	
BITS 11-1	SPECIFY SETTING OF RELAYS OF ROW DETERMINED BY BITS 15-12		SH. 4, 48	SH. 4, 46, 48	
	NOTE: IF CHANNEL 10 BITS 15-12 ALL CLEARED, ALL DISPLAY RELAYS TURNED OFF (THIS DOES NOT TURN OFF THE LIGHTS)				

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	WOLFE CD JAVCI AND NAVICAT C
DESIGN <i>J. E. Cole</i> <i>RMYS2</i>	TARUPT
INSTR <i>J. E. Cole</i> <i>4/26/62</i>	
DOC NO <i>Relay Diagrams</i>	COLOSSUS II-A
APPROV <i>George S. ...</i>	REV
	FORM NO. 55 0 55

P06 GNCS POWER DOWN

SCALPREP Sh. 7  
 POSTAND Sh. 4

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. F. Adams</i>		P06 GNCS Power Down	
PRGMR <i>Wensmode</i>	<i>12-3-66</i>	DOCUMENT NO.	
ANALST		COLOSSUS 2D	
DOCMR <i>G. S. Swift</i>	<i>12/1/66</i>	FC-2220	
APPR'D <i>Robert M. Cantel</i>	<i>12/1/66</i>	REV	SHEET 1 OF 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>G. Flaherty</i> <i>10/6/68</i>		P06 GNCS Power Down	
PRGMR <i>Wensmate</i>	<i>11/1/68</i>	COLOSSUS 2D	DOCUMENT NO. FC-2220
ANALST			
DOCMR <i>OH Smith</i>	<i>12/9/69</i>		
APPR'D <i>R. M. S. ...</i>	REV		SHEET 2 OF 8



From Preceding Sheet

Clear TRACKFLG  
REFSMFLG  
DRIFTFLG

Bit 6, FLAGWRD1  
Bit 13, FLAGWRD3  
Bit 15, FLAGWRD2

Inhibit tracking.  
REFSMMAT is no good.  
Inhibit gyro compensation.  
Accomplished via  
BANKCALL to RNDREFDR

Clear IMUSE  
RNDVZFLG

Bit 8, FLAGWRD0  
Bit 7, FLAGWRD0

IMU not in use.  
P20 not running.  
Accomplished via subroutine  
DOWNFLAG.

Set bit 11  
of  
channel 13

STANDBY ENABLE DISCRETE

GROUP 4  
Set up  
POSTAND as  
Job with  
priority 20  
after restart

V32, V33, V34

GOPERF1  
V50 N25  
R1 = 00062<sub>8</sub>

Request performance of CMC Standby  
(Verbs 32, 33, 34 not relevant)

Proceed

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. Yurchak</i> 11-25-69		P06 GNCS Power Down	
PRGMR <i>W. S. Moore</i> 12-3-69	ANALST	COLOSSUS 2D	DOCUMENT NO.
DOCMR <i>D. S. Moore</i> 12/16/69	APPR'D <i>Robert M. ...</i> 12/16/69		FC-2220
REV			SHEET 3 OF 8

From Preceding Sheet

Turn on Standby Light

Blank DSKY

Go into standby (exit P06)

POSTAND

POSTAND recovers the time after STANDBY and snapshots the scaler while setting TIME1, TIME2; insures compatability between the scaler reading and the clearing of the time counter. POSTAND then computes the d. p. difference in scaler values and increments the previously snapshotted values TIME1, TIME2 by the difference. The updated result is then placed into the time counters.

Turn off Standby Light

Clear bit 11 of channel 13

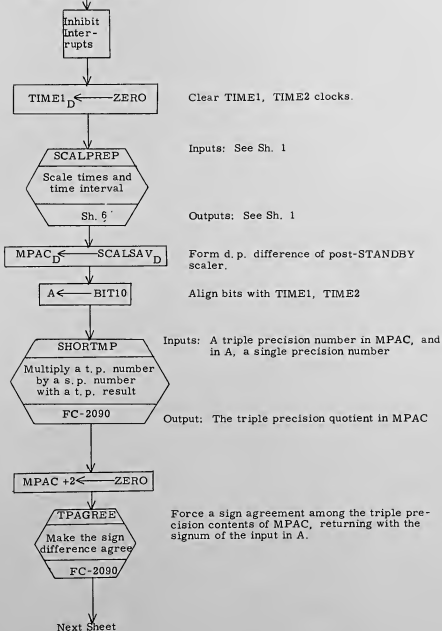
Clear STANDBY ENABLE bit

POSTAND+3

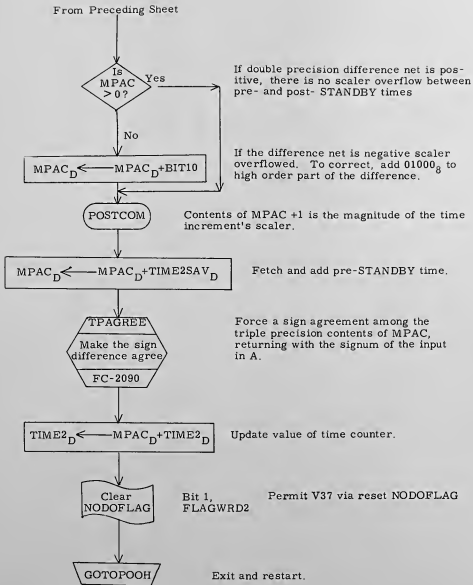
Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P06 GNCS Power Down	
DRAWN <i>D. Schallert</i>	<i>12/1/69</i>	COLOSSUS 2D	DOCUMENT NO.
PRGMR <i>Wensmore</i>	<i>12-3-69</i>		FC-2220
ANALST			
DOCMR <i>J. Smith</i>	<i>12/3/69</i>		
APPR'D <i>Robert M. Fitch</i>	<i>12/3/69</i>	REV	SHEET 4 OF 8

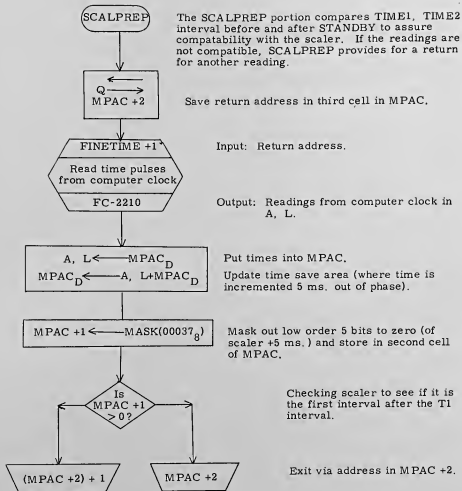
From Preceding Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. P. Labaree</i> 10/6/68		P06 GNCS Power Down	
PRGMR <i>Wensinger</i> 12-3-68		COLOSSUS 2D	DOCUMENT NO. FC-2220
ANALST			
DOCMR <i>G. Smith</i> 12/2/68			
APPR'D <i>R. St. M. Estrella</i> 1/2/69	REV		SHEET 5 OF 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Eberly</i> <i>12/2/68</i>		P06 GNCS Power Down	
PRGMR <i>Nensmore</i> <i>12-3-68</i>		COLOSSUS 2D	DOCUMENT NO. FC-2220
ANALST			
DOCMR <i>QJ S...</i> <i>12/2/68</i>			
APPR'D <i>Robert M. ...</i> <i>12/2/68</i>		REV	SHEET 6 OF 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	J. Flinders	P06 GNCS Power Down	
PRGMR	Nemsmole	COLOSSUS 2D	DOCUMENT NO. FC-2220
ANALST			
DOCMR	OBSM	REV	SHEET 7 OF 8
APPR'D	R. Smith		

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
NODOFLAG	V37 not permitted	V37 permitted	Sh. 2	Sh. 6	
TRACKFLG	Tracking allowed	Tracking not Allowed		Sh. 3	
REFSMFLG	REFSMMAT good	REFSMMAT no good		Sh. 3	
DRIFTFLG	T3RUPT calls gyro compensation	T3RUPT does no good		Sh. 3	
IMUSE	IMU in use	IMU not in use		Sh. 3	
RNDVZFLG	P20 running	P20 not running		Sh. 3	

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
GOPERF1	FC - 2130	Perform CMC Standby	Sh. 3
SHORTMP	FC-2090	Multiplies a triple precision number by a single precision number with a t. p. result.	Sh. 5
TPAGREE	FC-2090	Makes sign difference of two numbers agree.	Sh. 5. 6
FINETIME + 1	FC-2210	Read computer clock time pulses	Sh. 7

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Edwards</i> 11/23/67		P06 GNCS Power Down	
PRGRM <i>W. M. Sample</i> 2-2-67		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2220
DOCMR <i>J. Smith</i> 12/5/68		APPRO'D <i>W. M. Sample</i> 12/15/67	SHEET 8 OF 8

IMU EXTENDED VERBS

VBZERO	Sh. 2
VBCOARK	Sh. 4
IMUFINEK	Sh. 8

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <u>H. COANOR</u>	<u>11-24-69</u>	IMU Extended Verbs	
PRGMR <u>E. J. Hall</u>	<u>12-4-65</u>	COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2235
DOCMR <u>Robert M. Euter</u>	<u>12/4/69</u>	REV	SHEET 1 OF 10
APPR'D <u>Robert M. Euter</u>	<u>12/4/69</u>		

VBZERO

Extended verb 40

OP/INERT

A--24<sub>8</sub>+NOUNREGNOUN  
20  
?

Is A = 0?

No, NOUN 91; A = 71

Q -  
Q + 1Increment  
Q for  
return

Yes

via XACTOQ (FC-2520)

A=A + OPIMDIFF A now = 0

Test  
A

#0, illegal

= 0  
via XACTOQ

Yes

ALM/END  
FC-2190Turn on operator  
error light and  
go to PINBRNCH  
(FC-2130)

IMUZEROK

CKMODCAD

Is  
MODECADR  
in use?

Sh. 3

No

Next Sheet

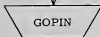
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		IMU Extended Verbs	
DRAWN <i>M. E. Carter</i>	<i>4/24/67</i>		
PRGRM <i>S. Gray</i>	<i>2-4-65</i>		
ANALST		DOCUMENT NO.	
DOCMR <i>Robert M. Carter</i>	<i>2/4/67</i>	COLOSSUS 2D	FC - 2235
APPR'D <i>Robert M. Carter</i>	<i>2/4/67</i>	REV	SHEET 2 OF 10



From Preceding Sheet  
via BANKCALL



via BANKCALL



CKMODCAD

A - MODECADR

CKMODCAD + 1

Is CADR in use?

Yes, exit

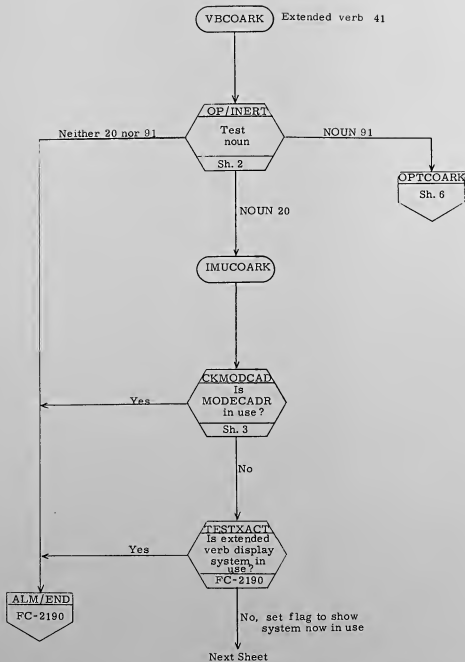
Is  
A  
≠ 0?

No, return

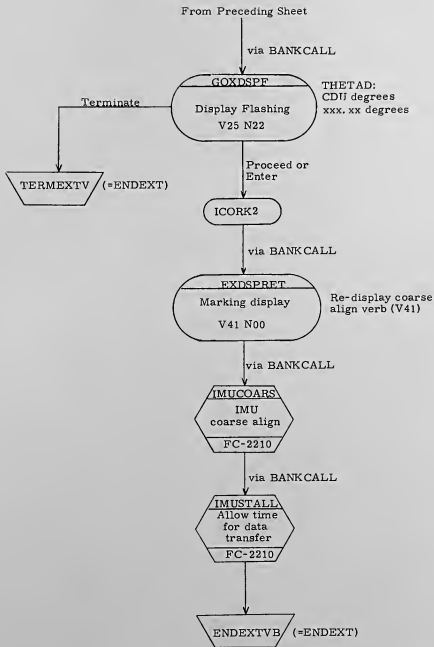
ALM/END  
FC-2190

Return  
via Q

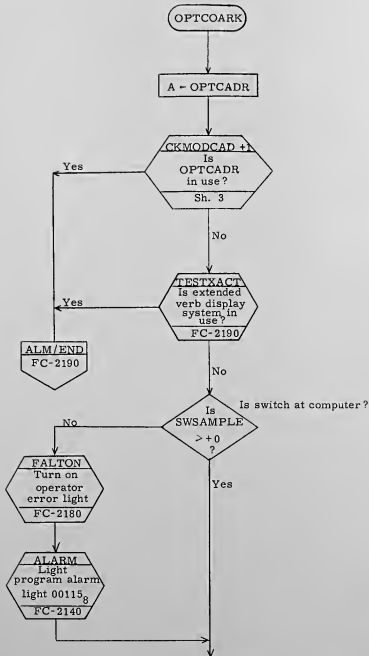
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Kanner</i> 11/24/69		IMU Extended Verbs	
PRGMR <i>E. Grace</i> 12-4-69		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2235
DOCMR <i>Robert M. Cutler</i> 12/1/69		REV	
APPR'D <i>Robert M. Cutler</i> 12/1/69			SHEET 3 OF 10



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>M. C. H. N. C. R.</i> 12/24/67		IMU Extended Verbs	
PRGMR <i>S. G. J. C. E.</i> 12-4-65		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2235
DOCMR <i>Robert M. C. S. J.</i> 12/14/67		REV	
APPR'D <i>Robert M. C. S. J.</i> 12/14/67		SHEET 4 OF 10	

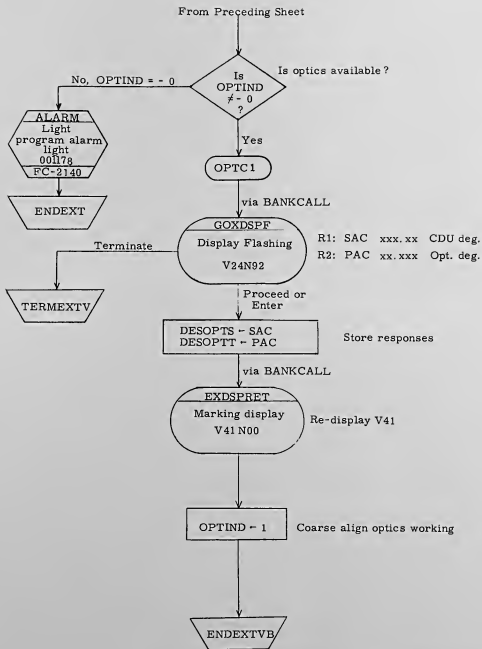


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>M. Foster</i> 11/24/67		IMU Extended Verbs	
PRGMR <i>S. G. 124</i> 11-4-69		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2235
DOCMR <i>M. Foster</i> 12/11/67		REV	SHEET 5 OF 10
APPR'D <i>M. Foster</i> 12/14/67			



Next Sheet

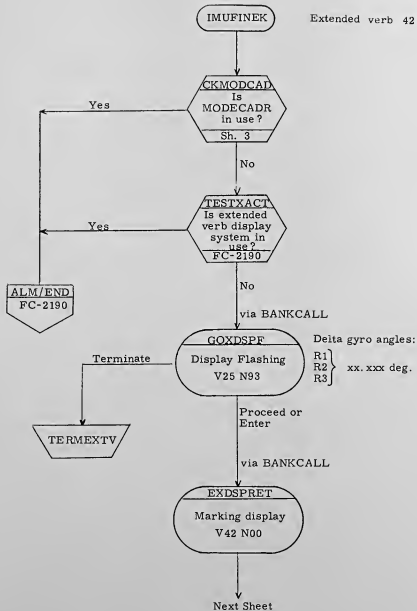
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Connor</i>	<i>11/26/67</i>	IMU Extended Verbs	
PRGMR <i>S. Gray</i>	<i>11-4-65</i>	COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2235
DOCMR <i>Robert M. Egan</i>	<i>12/4/67</i>	REV	SHEET 6 OF 10
APPR'D <i>Robert M. Egan</i>	<i>12/4/67</i>		



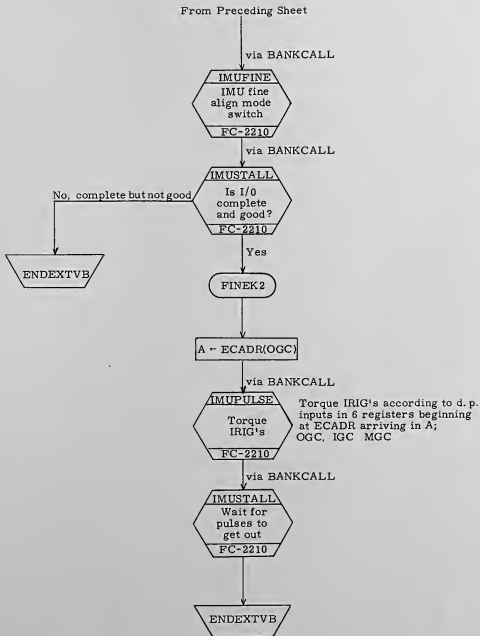
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Ganner</i> 11 26 67		IMU Extended Verbs	
PRGMR <i>S. Grace</i> 12 7 67		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2235
DOCMR <i>Robert M. S. ...</i> 2/4/69		REV	SHEET 7 OF 10
APPR'D <i>Robert M. S. ...</i> 2/4/69			

IMUFINEK

Extended verb 42



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	M. G. ...	IMU Extended Verbs	
PRGMR	S. G. ...	COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2235
DOCMR	R. S. ...	REV	SHEET 8 OF 10
APPR'D	R. S. ...		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>M. Connor</i> 11/26/67		IMU Extended Verbs	
PRGMR <i>S. Gma</i> 12-4-69		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2235
DOCMR <i>Robert M. Suter</i> 12/15/67		REV	
APPR'D <i>Robert M. Suter</i> 12/15/67		SHEET 9 OF 10	

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
ALARM	FC-2140	Light program alarm light	6, 7
ALM/END	FC-2190	Turn on operator error light and return via PINBRNCH (FC-2130)	2, 3, 4, 6, 8
FALTON	FC-2180	Turn on operator error light	6
IMUCOARS	FC-2210	IMU coarse align mode switch	5
IMUFINE	FC-2210	IMU fine align mode switch	9
IMUPULSE	FC-2210	Torque IRIG's	9
IMUSTALL	FC-2210	Delays further execution of the calling routine until its selected I/O function is complete	3, 5, 9
IMUZERO	FC-2210	Zero IMU CDU angles	3
TESTXACT	FC-2190	Test extended verb display system	4, 6, 8

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>M. Connor</i>	<i>11/26/67</i>	IMU Extended Verbs	
PRGMR <i>S. G. Jones</i>	<i>12/4/67</i>	COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2235
DOCMR <i>Robert M. Estes</i>	<i>12/4/67</i>	REV	SHEET 10 OF 10
APPR'D <i>Robert M. Estes</i>	<i>12/4/67</i>		



## SXTMARK

ENCLOSED IS A REPLACEMENT SHEET TO UPDATE THE COLOSSUS II FLOW-  
CHART FC-2240, REV. 0, TO THE COLOSSUS IIC FLOWCHART FC-2240, REV. 1

EFFECTIVE SHEETS FOR THE COLOSSUS IIC FLOWCHART FC-2240, REV. 1,  
ARE:

SH. 1

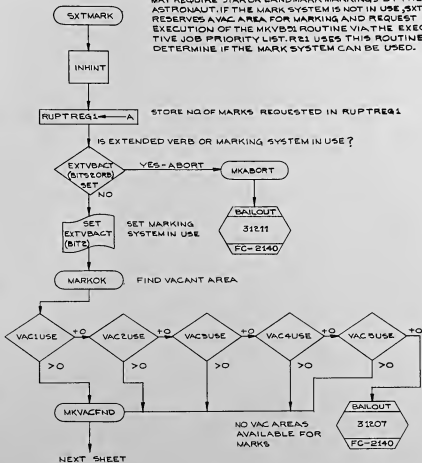
REV. 1

SH. 2-0

REV. 0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO C. RANGE AND NAVIGATION	
		SXTMARK	
DRAWN <i>D.H. Richards</i>	7 AUG 68	DOCUMENT NO.	
PREPARED <i>Ronald J. ...</i>	1-52	COLOSSUS IIC FC-2240	
ANALYST			
DESIGNER <i>G.S. NALEY</i>			
APPROVED <i>Abel ...</i>	1/17/69	REV. 1	SHEET 09

SXTMARK IS CALLED FROM INTERNAL ROUTINES WHICH MAY REQUIRE STAR OR LANDMARK MARKINGS BY THE ASTRONAUT. IF THE MARK SYSTEM IS NOT IN USE, SXTMARK RESERVES A VAC AREA FOR MARKING AND REQUEST EXECUTION OF THE MKVBSI ROUTINE VIA THE EXECUTIVE JOB PRIORITY LIST. REG1 USES THIS ROUTINE TO DETERMINE IF THE MARK SYSTEM CAN BE USED.



UNIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT GUIDANCE AND NAVIGATION	
DRAWN <i>J. Christensen</i>		SXTMARK	
DESIGNED <i>J. Christensen</i>	DOCTORED	COLOSSUS	DOCUMENT NO.
FORMER <i>J. Christensen</i>	ISSUED	IIIC	FC-2240
ANALYST			
DATE <i>G. S. NALLY</i>	DESIGNED		
APPROVED <i>John A. Riva</i>	ISSUED	REV 1	SHEET 1 OF 9

FROM PRECEDING SHEET

MARKSTAT ← A + 2  
QPRET (MARKSTAT) ← A + 2  
-1 (MARKSTAT) ← 0

VAC AREA ADDRESS  
VAC AREA POINTER VALVE  
1ST WORD SET TO +0  
(VAC AREA OCCUPIED)

CHECKMM  
MODREG = 53

IS BACKUP MARKING PROGRAM (P53)  
OPERATING ?

YES - BACKUP

CHECKMM  
MODREG = 54

IS BACKUP MARKING PROGRAM (P54)  
OPERATING ?

YES - BACKUP

MARKSTAT ← MARKSTAT + BIT 12 × RPT REG 1

ADD NO. OF MARKS REQUESTED  
(VAC AREA ADDR AND  
MARK VALUE)

MKVB51  
NOVAC  
PRIORITY  
52

REQUEST THAT MKVB51 BE PLACED  
ON PRIORITY LIST FOR JOB  
EXECUTION

RELINT

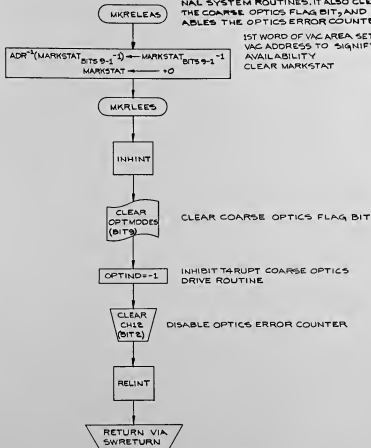
SWRETURN

DATE	
INSTRUMENTATION LAB	
AMUNDOZ, WA5	
PREPARED BY	<i>J. E. ...</i>
PROGRAM	<i>...</i>
ANALYST	
D. W. H.	<i>G. S. NALLY</i>
APPROVED	<i>John A. ...</i>

PROJECT	
COLOSSUS	
IC	
FC-2240	
REV 4	

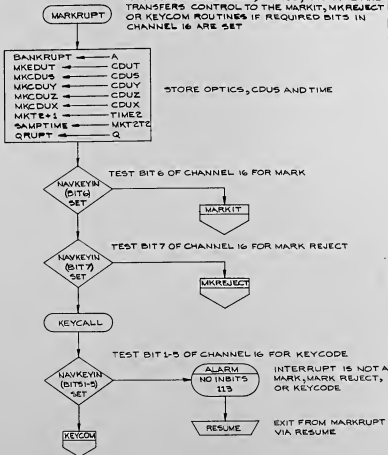
THIS ROUTINE IS EXECUTED BY INTERNAL ROUTINES TO RELEASE THE MARK SYSTEM TO MAKE IT AVAILABLE TO OTHER INTERNAL SYSTEM ROUTINES. IT ALSO CLEARS THE COARSE OPTICS FLAG BIT, AND DISABLES THE OPTICS ERROR COUNTER.

1ST WORD OF VAG AREA SET TO VAG ADDRESS TO SIGNIFY AVAILABILITY  
CLEAR MARKSTAT



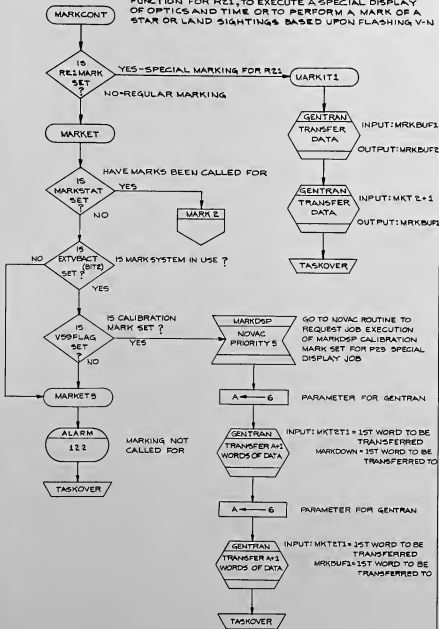
NIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		NAVY GUIDANCE AND NAVIGATION <b>SXTMARK</b>	
DRAWN BY CHECKED BY ANNO BY SKETCH BY APPROVED BY	<i>G. S. Nally</i> <i>J. A. Rose</i>	10 OCT 68 12 SEP 68 12 MAR 69 REV 1	COLOSSUS IIC DOCUMENT NO <b>FC-2240</b> SHEET 3 OF 9

MARKRUPT STORES CDUS, OPTICS, AND TIME AND TRANSFERS CONTROL TO THE MARKIT, MKREJECT OR KEYCOM ROUTINES IF REQUIRED BITS IN CHANNEL 16 ARE SET



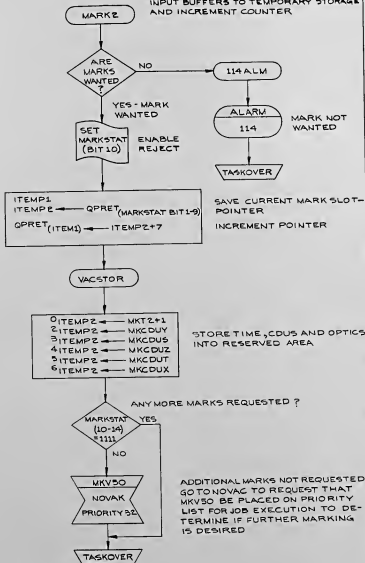
BIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFC-111 G. IDEAS AND NAVIGATION	
SPARR PROGRAM ANALYST SOLAR APPRO		PROJECTS DEPARTMENT REMARKS REV 1	
G. S. NALLY		SXT MARK	
John G. Nally		COLOSSUS IC	
		DOCUMENT NO. FC-2240 PAGE 4 OF 9	

MARKCONT IS USED TO PERFORM A SPECIAL MARK FUNCTION FOR R21, TO EXECUTE A SPECIAL DISPLAY OF OPTICS AND TIME OR TO PERFORM A MARK OF A STAR OR LAND SIGHTINGS BASED UPON FLASHING V-N



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARLDD GUIDANCE AND NAVIGATION	
		SXTMARK	
DRAWN <i>[Signature]</i> PROGRAM <i>[Signature]</i> ANALYST DOCNR APPR <i>[Signature]</i>	OCTOBER 1954 STORAGE G. S. NALLY, RMKGR REV 1	COLOSSUS IIC	DOCUMENT NO. <b>FC-2240</b> SHEET 5 OF 5

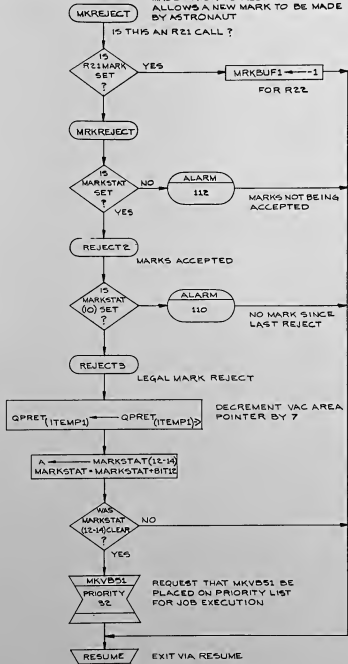
TRANSFER REQUESTED MARK DATA FROM INPUT BUFFERS TO TEMPORARY STORAGE AND INCREMENT COUNTER



INSTRUMENTATION LAB  
 APPROVED MARKS  
 DRAWN: *John A. Nally*  
 PRINTED: *John A. Nally*  
 ANALYST: *John A. Nally*  
 BY: *John A. Nally*  
 APPROVED: *John A. Nally*

SXTMARK  
 COLOSSUS IIC  
 FC-2240  
 REV 1  
 6 9

ALLOWS OPERATOR TO REJECT MARK MADE PRIOR TO ACCEPTANCE AND ALLOWS A NEW MARK TO BE MADE BY ASTRONAUT



MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

ARTICLE  
CITIZENSHIP AND NATURALIZATION

SXTMARK

DESIGNER: *[Signature]*  
PFCMR: *[Signature]*  
ANALYST: *[Signature]*  
DOCMAN: G. S. NALLY  
APPROV: *[Signature]*

COLOSSUS  
IIC

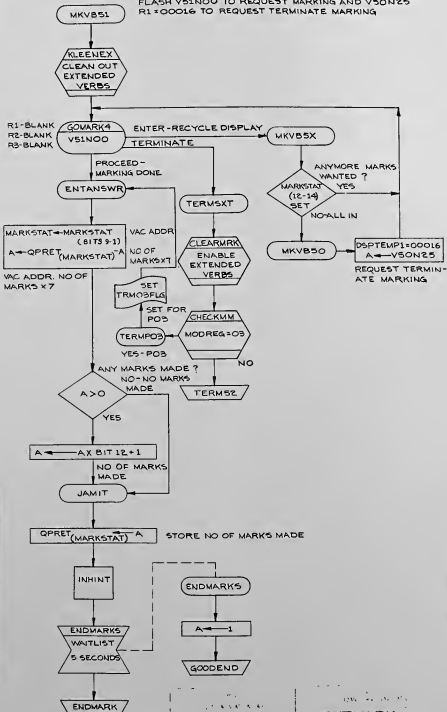
DOCUMENT NO.  
FC-2240

REV. 1

SHEET 7 OF 9

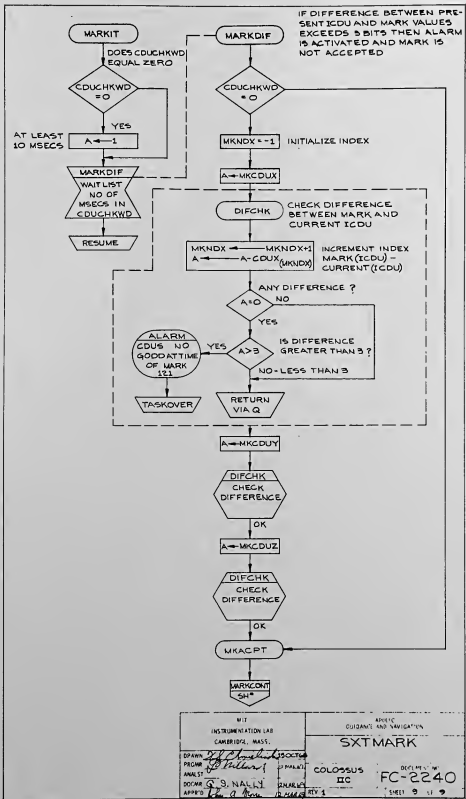


FLASH V51N00 TO REQUEST MARKING AND V50N25  
R1=00016 TO REQUEST TERMINATE MARKING



SXTMARK  
 COLLOSSUS IIC  
 FC-2240  
 B 1 9

*John Chaselsky*  
*D. J. Hillard*  
 Q. C. NALLY 12/24/65  
 John A. Moore 12/24/65



MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

DRAWN BY *J. Chalkley*  
FROM *J. Chalkley*  
ANALYST *J. Chalkley*  
DRAWN BY *J. Chalkley*  
APPROVED *J. Chalkley*

ARPAIC  
GUARDIAN AND NAVIGATOR

SXTMARK

COLOSSUS IIC

DEVELOPED BY  
FC-2240

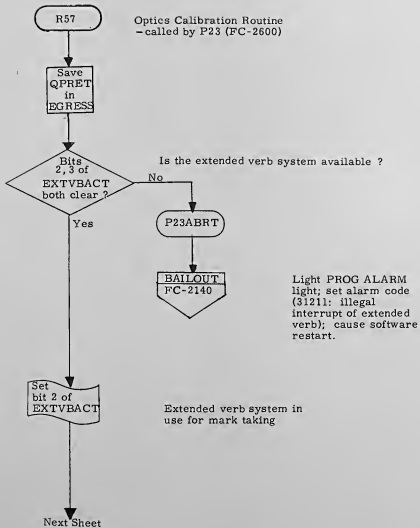
SHEET 9 OF 9

R57: OPTICS CALIBRATION ROUTINE

R57 Sh. 2

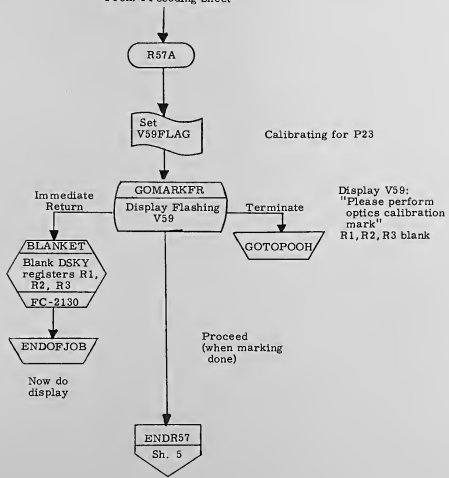
MARKDISP Sh. 4

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>W. S. ... 8/2/69</i>		R57: Optics Calibration Routine	
PRGMR <i>W. S. ... 9/8/69</i>		COLOSSUS IIC	DOCUMENT NO.
ANALST			FC-2242
DOCMR		REV 1	SHEET 1 OF 7
APPR'D <i>Robert M. ... 8-69</i>			

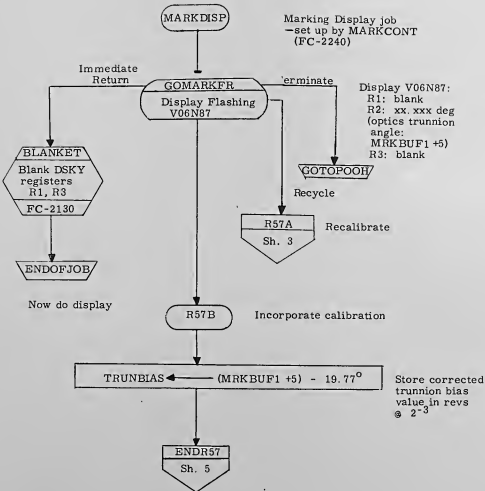


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>P. L. ...</i> 8-26-69		R57: Optics Calibration Routine	
PRGRM <i>R. W. ...</i> 7-9-69		COLOSSUS IIC	DOCUMENT NO. FC-2242
ANALST		REV 1	SHEET 2 OF 7
DOCMR			
APPR'D <i>Robert M. ...</i> 9-1-69			

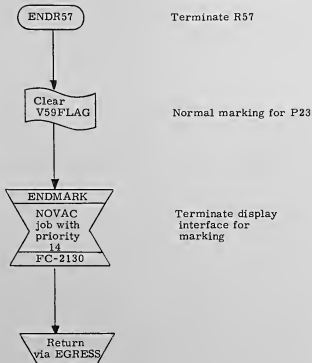
From Preceding Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. J. ...</i>		R57: Optics Calibration Routine	
PRGMR <i>A. J. ...</i>	ANALST	COLOSSUS IIC	DOCUMENT NO. FC-2242
DOCMR	APPR'D <i>...</i>	REV 1	SHEET 3 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. G. ...</i> 2-69		R57: Optics Calibration Routine	
PRGMR <i>R. ...</i> 7-69		COLOSSUS IIC	DOCUMENT NO. FC-2242
ANALST			
DOCMR			
APPR'D <i>Robert M. ...</i> 9-7-69		REV 1	SHEET 4 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. S. M. [unclear]</i> 8-28-69		R57: Optics Calibration Routine	
PRGMR <i>R. S. M. [unclear]</i> 9-8-69	ANALST	COLOSSUS IIC	DOCUMENT NO. FC-2242
DOCMR	APPR'D <i>R. S. M. [unclear]</i> 9-8-69	REV 1	SHEET 5 OF 7

Subroutines Called which are on Other Flow Charts

<u>Subroutine</u>	<u>Flow Chart</u>	<u>Description</u>	<u>Where Called</u>
BAILOUT	FC-2140	Light PROG ALARM light; set alarm code; cause software restart.	Sh. 2
BLANKET	FC-2130	Blank R1, R2, and/or R3	Sh. 3, 4
ENDMARK	FC-2130	Terminate marking display interface	Sh. 5

Displays

<u>Verb-Noun</u>	<u>Type of Display</u>	<u>Description of Registers</u>	<u>Where Called</u>
V59	Flashing	Please perform optics calibration mark. R1, R2, R3 blank.	Sh. 3
V06N87	Flashing	R1: blank R2: xx.xxx deg (optics trunnion angle MRKBUF1 +5) R3: blank	Sh. 4

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>B. J. ...</i>		R57: Optics Calibration Routine	
PRGMR <i>A. S. ...</i>		DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2242
DOCMR		REV 1	SHEET 6 OF 7
APPR'D <i>...</i>			



Flags

<u>Flag</u>	<u>Meaning When Set</u>	<u>Meaning When Clear</u>	<u>Where Set</u>	<u>Where Cleared</u>	<u>Where Tested</u>
EXTVBACT. bit 2	Extended verb system in use for marking	Extended verb system not in use for marking	Sh. 2		Sh. 2
EXTVBACT bit 3	Extended verb system in use for extended verb	Extended verb system not in use for extended verb			Sh. 2
V59FLAG (FLAGWRD5) bit 12	Calibrating for P23	Normal marking for P23	Sh. 3	Sh. 5	

Erasable Locations Used:

<u>AGC Tag</u>	<u>Meaning</u>	<u>Engineering Units</u>	<u>AGC Units</u>	<u>AGC Scale Factor</u>
MRKBUF1 +5	Optics trunnion angle displayed in noun 87	degrees	revs	2 -3
TRUNBIAS	Trunnion bias angle	degrees	revs	2 -3

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>S. Lippincott</i> 8-2-69		R57: Optics Calibration Routine	
PRGMR <i>S. Lippincott</i> 8-2-69	ANALST	COLOSSUS IIC	DOCUMENT NO.
DOCMR			FC-2242
APPR'D <i>Robert M. Fister</i> 9-2-69	REV 1	SHEET 7 OF 7	

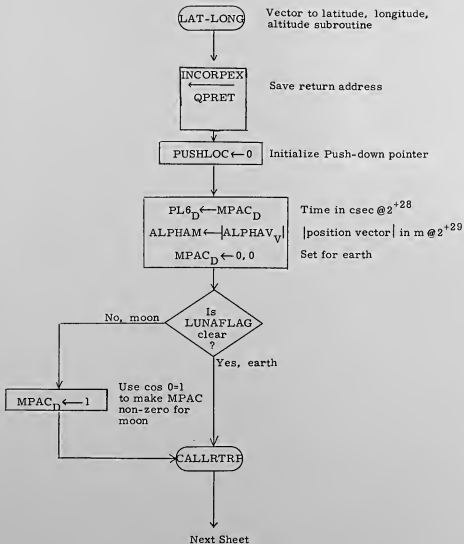
LATITUDE LONGITUDE SUBROUTINES

LAT-LONG Sh. 2

LALOTORV Sh. 7

GETERAD Sh. 9

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Right</i> <i>11/7/68</i>		Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALYST <i>A. M. Reber</i> <i>6.XII.68</i>			
DOCMR <i>Robert M. Evers</i> <i>12/4/69</i>			
APPR'D <i>Robert M. Evers</i> <i>12/4/69</i>		REV	SHEET 1 OF 13



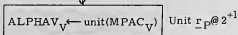
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Bright</i> 1/14/67		Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	
ANALST <i>J.M. Reber</i> 1/11/67		DOCUMENT NO. FC-2280	
DOCMR <i>Robert M. Euter</i> 12/14/67		SHEET 2 of 13	
APPR'D <i>Robert M. Euter</i> 1/14/67		REV	

From Preceding Sheet



Convert vector in reference  
coord. system to vector in  
planetary coord. system

Output: MPAC<sub>V</sub> = r<sub>P</sub> vector  
in m @ 2<sup>+29</sup> for earth  
in m @ 2<sup>+27</sup> for moon

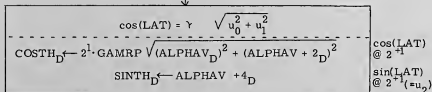


Input:  
LUNAF<sub>LAG</sub>:  
clear for earth  
set for moon

Output:  
GAMRP containing  
B2/A2 (earth γ) @ 2<sup>+1</sup>  
or 1B1 (=1, moon γ) @ 2<sup>+1</sup>



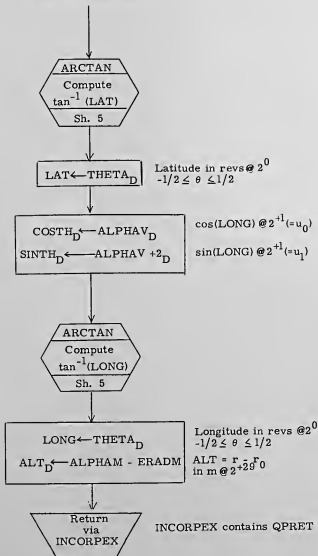
Output:  
ERADM<sub>D</sub> = earth or moon  
radius in m @ 2<sup>+29</sup>



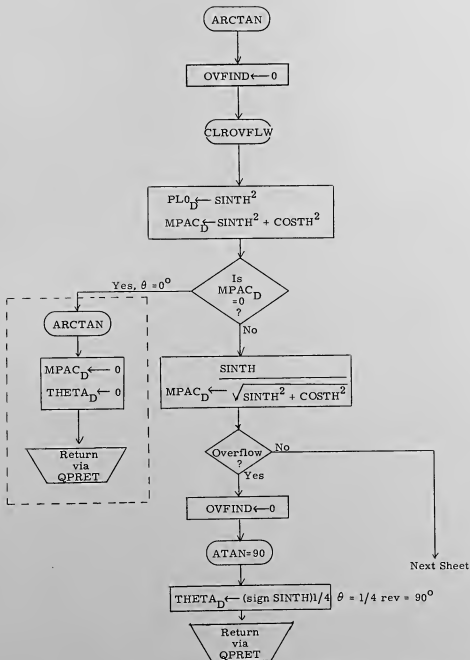
Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Bright</i>	<i>1/12/69</i>	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>J. M. Reber</i>	<i>4.11.69</i>		FC-2280
DOCMR <i>J. M. Reber</i>	<i>12/16/69</i>	REV	SHEET 3 OF 13
APPR'D <i>J. M. Reber</i>	<i>12/16/69</i>		

From Preceding Sheet

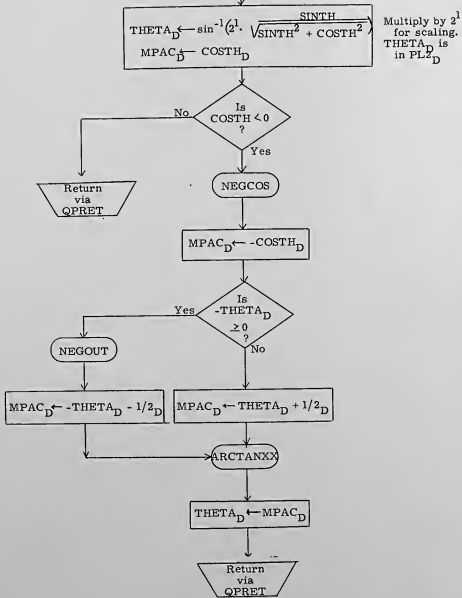


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Bright</i>	<i>11/7/69</i>	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>J. M. Roberts</i>	<i>4.11.69</i>		FC-2280
DOCMR <i>Robert M. Estlin</i>	<i>11/11/69</i>	REV	SHEET 4 OF 13
APPR'D <i>Robert M. Estlin</i>	<i>11/11/69</i>		

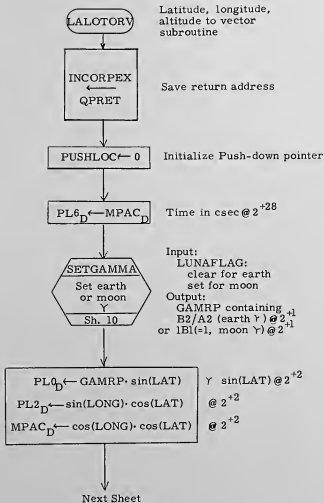


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>H. Bright</i> 11/7/69	Latitude Longitude Subroutines	
PRGMR			
ANALST	<i>J. M. Keller</i> 4-11-70	COLOSSUS 2D	DOCUMENT NO. FC-2280
DOCNR	<i>FC-2280-1-11-70</i>		
APPR'D	<i>R. S. ...</i> 11/4/69	REV	SHEET 5 OF 13

From Preceding Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Wright</i> <i>11/2/67</i>		Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALST <i>J. M. Riley</i> <i>11/11/67</i>			
DOCMR <i>Robert M. Estes</i> <i>11/16/67</i>		REV	SHEET 6 OF 13
APPR'D <i>Robert M. Estes</i> <i>12/11/67</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Bright</i>	<i>11/69</i>	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>A.M. Euter</i>	<i>11/69</i>		FC-2280
DOCMPR <i>Robert M. Euter</i>	<i>11/4/69</i>	REV	SHEET 7 OF 13



From Preceding Sheet

$$PL0_V \leftarrow \text{Unit}(MPAC_D, PL2_D, PL0_D)$$

$$ALPHA_V = \text{unit} \begin{bmatrix} \cos(\text{LONG})\cos(\text{LAT}) \\ \sin(\text{LONG})\cos(\text{LAT}) \\ \gamma \sin(\text{LAT}) \end{bmatrix}$$

$$ALPHA_V \leftarrow PL0_V$$

SETRE  
Set earth  
or moon  
radius  
Sh. 11

Output:  
ERADM<sub>D</sub> = earth or moon  
radius in m @ 2<sup>+29</sup>

MPAC<sub>D</sub> ← 0, 0

Set for earth

Is  
LUNAFLAG  
clear  
?  
No, moon  
Yes, earth

MPAC<sub>D</sub> ← 1  
Use cos 0=1  
to make  
MPAC  
non-zero  
for moon

CALLRPRT

RP-TO-R  
Convert  $r_p$   
vector to  
 $r$  vector  
FC-2283

Input:  
MPAC = 0 for earth  
= 1 for moon  
PL0<sub>V</sub> = unit  $r_p$  vector @ 2<sup>+2</sup>  
PL6<sub>D</sub> = time in csec @ 2<sup>+28</sup>  
OUTPUT:  
MPAC<sub>V</sub> = unit  $r$  vector  
@ 2<sup>+29</sup> for earth  
@ 2<sup>+27</sup> for moon

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATIOI	
DRAWN <i>A. Bright</i> 11/3/62		Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>A. M. Reiter</i> 4/11/63			FC-2280
DOCMR <i>Robert M. Estlin</i> 11/4/62		REV	SHEET 8 OF 13
APPR'D <i>Robert M. Estlin</i> 11/4/62			

From Preceding Sheet

$ALPHAV_V \leftarrow MPAC_V$  Unit  $r$  vector @  $2^{+2}$   
 $MPAC_D \leftarrow ERADM_D$  Earth or moon radius in m @  $2^{+29}$

$ALPHAV_V \leftarrow 2^1(ERADM + ALT)(ALPHAV_V)$  Shift left (multiply by  $2^1$ ) for scaling:  $r$  vector in m @  $2^{+29}$

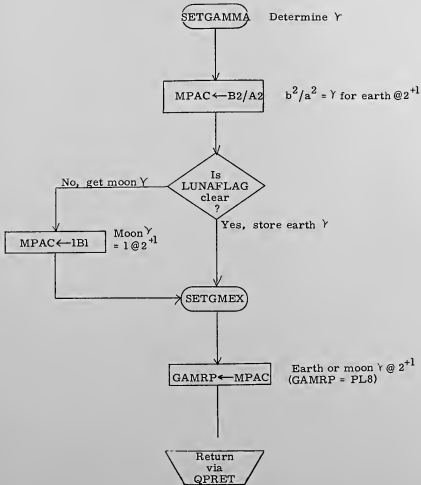
Return via INCORPEX  
INCORPEX contains QPRET

GETERAD

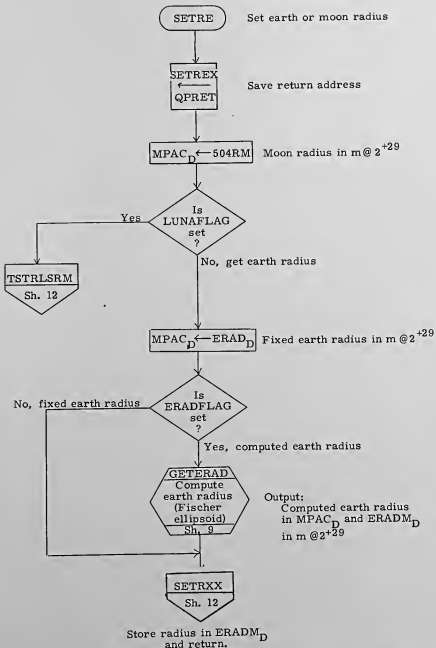
$r_F^2 = b^2/1 - (1 - \frac{b^2}{a^2})(1 - \sin L^2)$  Radius of Fischer ellipsoid.  
 $MPAC_D \leftarrow 2^{-4} \sqrt{B2XSC/1/2 - EE(1/2 - 2^1(ALPHAV + 4))^2}$  a: semi-major axis  
 $ERADM_D \leftarrow MPAC_D$  b: semi-minor axis  
 Earth radius in m @  $2^{+29}$

Return via QPRET

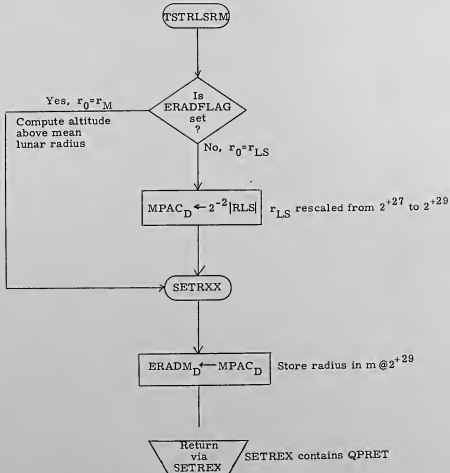
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Sargent</i>	<i>1/1/69</i>	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALST <i>J. M. Nelson</i>	<i>4.11.69</i>		
DOCMR <i>Robert M. Entel</i>	<i>12/1/69</i>		
APPR'D <i>Robert M. Entel</i>	<i>12/1/69</i>	REV	SHEET 9 OF 13



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Bright</i>	<i>1/11/69</i>	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>J. M. Peltan</i>	<i>1-11-69</i>		FC-2280
DOCMR <i>R. M. E. E. E.</i>	<i>12/16/69</i>	REV	SHEET 10 OF 13
APPR'D <i>R. M. E. E. E.</i>	<i>1/14/69</i>		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Bright</i>		Latitude Longitude Subroutines	
PRGMR <i>[Signature]</i>			
ANALST <i>J. M. Baker</i>		COLOSSUS 2D	DOCUMENT NO.
DOCMR <i>Robert M. Egan</i>			FC-2280
APPR'D <i>Robert M. Egan</i>		REV	SHEET 11 OF 13



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>H. Bright</i>	<i>11/7/69</i>	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>J. M. Parker</i>	<i>4/11/69</i>		FC-2280
DOCMR <i>R. J. M. Carter</i>	<i>12/14/69</i>	REV	SHEET 12 OF 13
APPR'D <i>R. J. M. Carter</i>	<i>12/14/69</i>		

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
R-TO-RP	FC-2283	Converts $\underline{r}$ vector to $\underline{r}_p$ vector	Sh. 3
RP-TO-R	FC-2283	Converts $\underline{r}_p$ vector to $\underline{r}$ vector	Sh. 8

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
ERADFLAG flag 1 bit 13	Earth: compute Fischer ellipsoid radius Moon: use fixed radius	Earth: use fixed radius Moon: use $r_{LS}$ for lunar radius			Sh. 11, 12
LUNAFLAG flag 3 bit 12	Lunar LAT-LONG	Earth LAT-LONG			Sh. 2, 8, 10, 11

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>K. Bright</i> <i>11/15/69</i>		Latitude Longitude Subroutines	
PRGMR		DOCUMENT NO.	
ANALYST <i>J. M. Peltz</i> <i>4.11.69</i>		COLOSSUS 2D	FC-2280
DOCMR <i>R. S. M. Egan</i> <i>12/16/69</i>		REV	
APPR'D <i>R. S. M. Egan</i> <i>12/14/69</i>		SHEET 13 OF 13	

PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)  
 MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

RP-TO-R	SH. 2
R-TO-RP	SH. 3
EARTHMX	SH. 4
MOONMX	SH. 5

1. GUIDANCE SYSTEM OPERATIONS PLAN USING PROGRAM COLOSSUS 2C,  
 (GSOP), R-557, SECTION 5, GUIDANCE EQUATIONS, (REV. 8), JULY 1968

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Robinson</i>		PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PROGRAM		COLOSSUS	DOCUMENT NO.
ANALYST		2D	FC-2283
DCOMR		REV	SHEET 1 OF 9
APPR'D			

RP-TO-P CONVERTS  $I_p$ , A VECTOR EXPRESSED IN THE PLANETARY (EARTH FIXED OR MOON FIXED) COORDINATE SYSTEM TO  $I$ , THE SAME VECTOR EXPRESSED IN THE BASIC REFERENCE COORDINATE SYSTEM

INPUT:

1. MPAC =  $\begin{cases} = 0 & \text{FOR EARTH} \\ \neq 0 & \text{FOR MOON} \end{cases}$

2.  $PL0_v = I_p$  @  $2^n$

3.  $PL6_0 = t$ , TIME OF  $I_p$ , IN GSEC AT  $2^{24}$

OUTPUT

1.  $MPAC_v = I$  IN M @  $2^{20}$  FOR EARTH  
@  $2^{27}$  FOR MOON

SAVE RETURN ADDRESS

RP-TO-R  
RPREXIT ← QPRET

SET UP FOR EARTH

= 0

≠ 0

SET UP FOR MOON

RPTORA

EARTHMX  
COMPUTE  $M^*(t)$   
FOR EARTH  
SH4

INPUT

1.  $PL6_0 = t$   
2.  $AZ0_0 = A_z$   
3.  $WEARTH_0 = W_w$

OUTPUT  
1.  $MMATRIX_M (= PL20_M)$   
 $= M^*(t) @ 2^1$

INPUT

1.  $AX0_0 = A_x$   
2.  $AY0_0 = -A_y$  } PAD LOADED AND  
CONSIDERED  
CONSTANT

OUTPUT  
1.  $MPAC_v = \underline{\underline{\alpha}} = (-A_x, -A_y, 0) @ 2^0$

MOONMX  
COMPUTE  $M^*(t)$   
FOR MOON  
SH5

INPUT

1.  $PL6_0 = T$   
2.  $BSUB0_0 = B_0$   
3.  $RODT_0 = \delta$   
4.  $NODI0_0 = \Omega_{I0}$   
5.  $NODD0_0 = \dot{\Omega}_{I0}$   
6.  $FSUB0_0 = F_0$   
7.  $FDDT_0 = \dot{F}$

OUTPUT

1.  $MMATRIX_M (= PL20_M)$   
 $= M^*(t) @ 2^1$

$\underline{\underline{\alpha}}_p = M^*(t) \underline{\underline{\alpha}}$   
 $MPAC_v = MMATRIX_M \cdot MPAC_v$   
SHIFTED @  $2^0$

CONVERT VECTOR FROM  
BASIC REFERENCE TO  
PLANETARY SYSTEM.  
EQ 5.2.3

$\underline{\underline{\alpha}}_p = \underline{\underline{\alpha}}_M$   
 $MPAC_v = 504LM_v$   
@  $2^0$

EQ 5.2.6

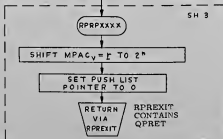
RPTORB

FORM  $I_p + \underline{\underline{\alpha}}_p \times I_p$   
 $MPAC_v \leftarrow 504RPR_v + MPAC_v \times 504RPR_v$   
@  $2^n$

504RPR = PL0

$I = (I_p + \underline{\underline{\alpha}}_p \times I_p)^T M^*(t)$   
 $MPAC_v \leftarrow MPAC_v \cdot MMATRIX_M$   
@  $2^{n+1}$

THIS IS EQUIVALENT TO  
 $M^*(t)^T (I_p + \underline{\underline{\alpha}}_p \times I_p)$   
EQ 5.2.2



$n = +70$  FOR EARTH  
 $= +71$  FOR MOON

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		PLANETARY INERTIAL ORIENTATION SUBROUTINE (176)	
DRAWN <i>[Signature]</i>	<i>[Signature]</i>	COLOSSUS	DOCUMENT NO. FC-2283
PROGRAM		2D	
ANALYST			
DOCNR		REV	SHEET 2 OF 3
APPROV			



R-TO-RP CONVERTS  $\underline{r}$ , A VECTOR EXPRESSED IN THE BASIC REFERENCE COORDINATE SYSTEM TO  $\underline{r}_p$ , THE SAME VECTOR EXPRESSED IN THE PLANETARY (EARTH FIXED OR MOON FIXED) COORDINATE SYSTEM.

INPUT

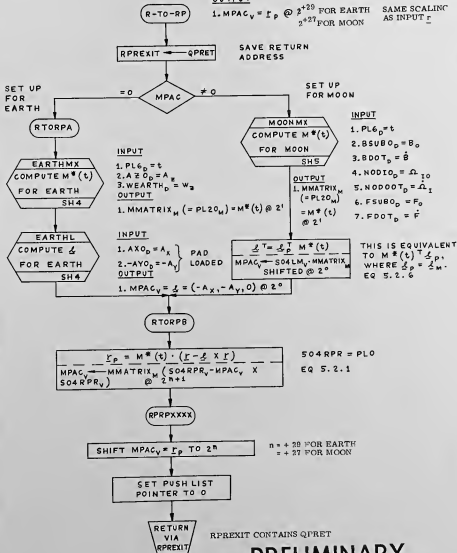
1. MPAC =  $\begin{cases} = 0 \text{ FOR EARTH} \\ \neq 0 \text{ FOR MOON} \end{cases}$

2.  $PL_0 = t$  @  $2^h$

3.  $PL_0 = t$ , TIME OF  $\underline{r}$ , IN CSEC, AT  $2^*$

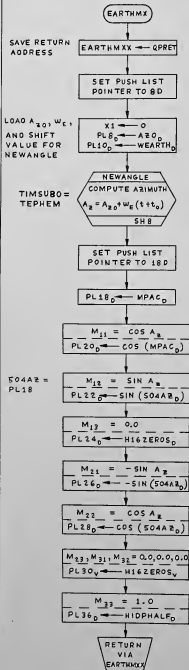
OUTPUT

1.  $MPAC_v = \underline{r}_p$  @  $2^{+20}$  FOR EARTH SAME SCALING AS INPUT  $\underline{r}$   
 $2^{+27}$  FOR MOON



**PRELIMINARY**

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>2/23/66</i>		PLANETARY INERTIAL ORIENTATION SUBROUTINE (PCS)	
PRGRM		COLOSSUS 2D	DOCUMENT NO.
ANALST			Fe-2283
DOCNR		REV	SHEET 3 OF 9
APPR'D			



EARTHMX  
CONTAINS Q'PRET

EARTHMX COMPUTES THE TRANSFORMATION MATRIX  $M^*(t)$  FOR THE EARTH, WHERE  $M^*(t)$  DESCRIBES A ROTATION OF THE COORDINATES SYSTEM ABOUT THE POLAR AXIS (Z-AXIS) OF THE EARTH.

INPUT

1.  $PL60 = t$ , TIME SINCE AGC CLOCK WAS ZEROED, IN CSEC AT 2<sup>10</sup>.
2.  $AZ00 = A_{20}$ , ANGLE BETWEEN X-AXIS OF BASIC SYSTEM AND X-AXIS OF EARTH SYSTEM AT JULY 1.0, 1968
3.  $WEARTH0 = w_e$ , ANGULAR VELOCITY OF EARTH IN REVS/CSEC AT 2<sup>-23</sup>
4.  $TIMSUBO = t_0$ , ELAPSED TIME FROM JULY 1.0, 1968 TO ZEROING OF AGC CLOCK, IN CSEC AT 2<sup>18</sup>

OUTPUT

1. MMATRIX  $M = M^*(t)$  AT 2<sup>1</sup> WHERE
- $$M^*(t) = \begin{bmatrix} \cos A_2 & \sin A_2 & 0 \\ -\sin A_2 & \cos A_2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

INPUT

1.  $PL80 = A_{20}$  IN REVS AT 2<sup>0</sup>
2.  $PL100 = w_e$  IN REVS/CSEC AT 2<sup>-23</sup>
3.  $x_1 = 0$ , SHIFT VALUE
4.  $PL60 = t$  IN CSEC AT 2<sup>18</sup>
5.  $TIMSUBO = t_0$  IN CSEC AT 2<sup>18</sup>

OUTPUT

1.  $MPAC0 = A_2$  IN REV AT 2<sup>0</sup> AT TIME  $t$

STORE  $A_2$  IN  
TEMPORARY STORAGE

$M_{11}$  THROUGH  $M_{33}$  ARE THE  
ELEMENTS OF MATRIX  $M^*(t)$

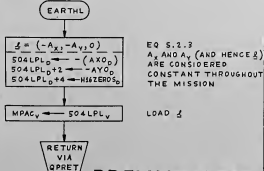
EARTHL COMPUTES THE ROTATION VECTOR  $\beta$   
FOR EARTH IN THE BASIC REFERENCE  
COORDINATE SYSTEM.

INPUT

1.  $AX00 = A_x$  IN REVS AT 2<sup>0</sup>
2.  $-AY00 = -A_y$  IN REVS AT 2<sup>0</sup>

OUTPUT

1.  $MPACV = \beta = (-A_x, A_y, 0)$  AT 2<sup>0</sup>



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. G. ...</i>		PLANETARY INERTIAL ORIENTATION SUBROUTINE (E-105)	
PROGRAM		COLOSSUS 2D	DOCUMENT NO. PC-2283
ANALYST			
DOCNR			
APPRO		REV	SHEET 4 OF 11

SAVE RETURN ADDRESS

LOAD  $B_0, \dot{B}$ , AND SHIFT VALUE FOR NEWANGLE

TIMSUBO = TEPHEM

MOONMX

EARTHMX ← QPRET

SET PUSH LIST POINTER TO BD

$X_1 \leftarrow 5$   
 $PLB_0 \leftarrow 8SUBO_0$   
 $PL10_0 \leftarrow BDT_0$

NEWANGLE

COMPUTE ANGLE OF OBLIQUITY  
 $B = B_0 + \dot{B}(t + t_0)$   
 SH 8

$PLB_0 \leftarrow MPAC_0$

$COS B, SIN B$   
 $COS B_0 \leftarrow COS(MPAC_0)$   
 $SIN B_0 \leftarrow SIN(PLB_0)$   
 @ 2<sup>1</sup>

$PLB_0 \leftarrow FSUBO_0$   
 $PL10_0 \leftarrow FDOT_0$   
 $X_1 \leftarrow 4$

NEWANGLE  
 COMPUTE ANGLE FROM ASCENDING NODE  
 $F = F_0 + \dot{F}(t + t_0)$   
 SH 8

$AVECTR_0 + 2 \leftarrow MPAC_0$

$PLB_0 \leftarrow NOD10_0$   
 $PL10_0 \leftarrow NODDOT_0$   
 $X_1 \leftarrow 5$

NEXT SHEET

MOONMX COMPUTES THE TRANSFORMATION MATRIX  $M^*(t)$  FOR THE MOON.  $M^*(t)$  ACCOUNTS FOR DIFFERENCE IN ORIENTATION OF BASIC SYSTEM AND MOON SYSTEM ACCORDING TO CASSINI'S LAWS

INPUT

- $PL6_0 = t$ , TIME SINCE AGC CLOCK WAS ZEROED, IN CSEC AT 2<sup>28</sup>
- $TIMSUBO_T = t_0$ , ELAPSED TIME FROM JULY 1.0, 1968 TO ZEROING OF AGC CLOCK, IN CSEC AT 2<sup>28</sup>
- $BSUBO_0 = \frac{B_0}{B}$  ANGLE AND IT'S DERIVATIVE BETWEEN EARTH'S EQUATORIAL PLANE AND THE ECLIPTIC AT JULY 1.0, 1968.
- $BDOT_0 = \dot{B}$
- $NOD10_0 = \frac{\Omega_1}{\Omega_2}$  LONGITUDE OF NODE OF MOONS ORBIT AND DERIVATIVE, IN BASIC SYSTEM AT JULY 1.0, 1968
- $NODDOT_0 = \dot{\Omega}_1$
- $FSUBO_0 = F_0$  ANGLE MEAN ASCENDING NODE OF MOON'S ORBIT AND DERIVATIVE AT JULY 1.0, 1968
- $FDOT_0 = \dot{F}$

OUTPUT

- MATRIX  $M (= PL20_M) = M^*(t)$  AT 2<sup>1</sup>

INPUT

- $PL8_0 = B_0$  IN REVS AT 2<sup>0</sup>
- $PL10_0 = \dot{B}$  IN REVS/CSEC AT 2<sup>-28</sup>
- $X_1 = 5$ , SHIFT VALUE
- $PL6_0 = t$  IN CSEC AT 2<sup>28</sup>
- $TIMSUBO_0 = t_0$  IN CSEC AT 2<sup>28</sup>

OUTPUT

- $MPAC_0 = B$  IN REVS AT 2<sup>0</sup> AT TIME  $t$   
 STORE B IN TEMPORARY STORAGE

STORE B IN TEMPORARY STORAGE

LOAD  $F_0, \dot{F}$ , AND SHIFT VALUE FOR NEWANGLE

INPUT

- $PL8_0 = F_0$  IN REVS AT 2<sup>0</sup>
- $PL10_0 = \dot{F}$  IN REVS/CSEC AT 2<sup>-27</sup>
- $X_1 = 4$ , SHIFT VALUE
- $PL6_0 = t$  IN CSEC AT 2<sup>28</sup>
- $TIMSUBO_0 = t_0$  IN CSEC AT 2<sup>28</sup>

OUTPUT

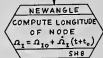
- $MPAC_0 = F$  IN REVS AT 2<sup>0</sup> AT TIME  $t$   
 SAVE F IN TEMPORARY STORAGE.  
 $AVECTR + 2 = PL22$

LOAD  $\Omega_1, \dot{\Omega}_2$ , AND SHIFT VALUE FOR NEWANGLE

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		PLANETARY INERTIAL ORIENTATION SUBROUTINE (PLCS)	
PROGRAM		COLOSSUS 2D	DOCUMENT NO.
ANALYST			FC-2383
DOC#		REV	SHEET 4 OF 4
APPROB			

FROM  
PRECEDING SHEET



INPUT

1.  $PLB_0 = \Omega_{10}$  IN REVS AT 2°
2.  $PL10_0 = \Delta\Omega_1$  IN REVS/CSEC AT 2°<sup>20</sup>
3.  $X1 = B$ , SHIFT VALUE
4.  $PL6_0 = t$  IN CSEC AT 2°<sup>20</sup>
5.  $TIMSUB0 = t_0$  IN CSEC AT 2°<sup>20</sup>

OUTPUT

1.  $MPAC_0 = \Omega_1$   
IN REVS AT  
2° AT TIME  
 $t$

$PLB_0 \leftarrow MPAC_0$

STORE  $\Omega_1$  IN  
TEMPORARY STORAGE

$$a_1 = \cos \Omega_1$$

$$PL10_0 \leftarrow MPAC_0 \rightarrow \cos(MPAC_0)$$

$$AVECTR_0 \leftarrow MPAC_0 @ 2'$$

$$b_2 = \cos B \cdot \cos \Omega_1$$

$$BVECTR_0 + 2 \leftarrow \cos B_0 \cdot MPAC_0$$

$$\text{SHIFTED @ } 2'$$

$$b_3 = \sin B \cdot \cos \Omega_1$$

$$BVECTR_0 + 4 \leftarrow \sin B_0 \cdot PL10_0$$

$$\text{SHIFTED @ } 2'$$

$$\sin \Omega_1$$

$$PLB_0 \leftarrow MPAC_0 \rightarrow \sin(PLB_0)$$

$$b_1 = -\sin \Omega_1$$

$$BVECTR_0 \leftarrow -(MPAC_0)$$

$$@ 2'$$

STORE F IN TEMPORARY STORAGE  
 $504F = PL6$

$$504F_0 \leftarrow AVECTR_0 + 2$$

$$a_2 = \cos B \cdot \sin \Omega_1$$

$$AVECTR_0 + 2 \leftarrow \cos B_0 \cdot PLB_0$$

$$\text{SHIFTED @ } 2'$$

SINNODI = PLB

$$a_3 = \sin B \cdot \sin \Omega_1$$

$$AVECTR_0 + 4 \leftarrow \sin B_0 \cdot SINNODI_0$$

$$\text{SHIFTED @ } 2'$$

CVECTR = PLB

$$c_1 = 0$$

$$PLB_0 \leftarrow HIGHZEROS_0$$

$$c_2 = -\sin B$$

$$PL10_0 \leftarrow -(S0B_0)$$

$$c_3 = \cos B$$

$$PL12_0 \leftarrow \cos B_0$$

# PRELIMINARY

$S_2 = \sin I, C_2 = \cos I$ , WHERE  $I = 1^\circ 32.1'$ , THE  
CONSTANT ANGLE BETWEEN THE LUNAR EQUATORIAL  
PLANE AND THE PLANE OF THE ECLIPTIC

$$b \cdot S_2$$

$$PL14_0 \leftarrow BVECTR_0 \cdot SINI_0$$

$$@ 2'$$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. J. ...</i>	<i>1/14/68</i>	PLANETARY INERTIAL (PIO) ORIENTATION SUBROUTINE 2	
PRGRM		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2283
BOCHN			
APPR'D		REV	SHEET # of #

FROM  
PRECEDING SHEET

$$\frac{m_3 = b \cdot S_T + \epsilon \cdot C_T}{\text{MMATRIX}_{M+12} \rightarrow \text{PL14} + \text{DVECTR}_V \cdot \text{COS I}_D} \\ \text{SHIFTED @ } 2'$$

ROW 3 OF M\* (t)  
EQ 5.2.6

$$\frac{\epsilon \cdot S_T}{\text{PLB}_V \rightarrow \text{PLB}_V \cdot \text{SIN I}_D} \\ \text{@ } 2'$$

$$\frac{d = b \cdot C_T - \epsilon \cdot S_T}{\text{PLB}_V \rightarrow \text{DVECTR}_V \cdot \text{COS I}_D - \text{PLB}_V} \\ \text{SHIFTED @ } 2'$$

$$\frac{d \cdot \text{COS F}}{\text{PL14}_V \rightarrow \text{DVECTR}_V \cdot \text{COS (504F}_D)} \\ \text{@ } 2'$$

DVECTR = PLB

$$\frac{m_2 = a \cdot \text{SIN F} - d \cdot \text{COS F}}{\text{MMATRIX}_{M+6} \rightarrow \text{AVECTR}_V \cdot \text{SIN (504F}_D) - \text{PL14}_V} \\ \text{SHIFTED @ } 2'$$

ROW 2 OF M\* (t)  
EQ 5.2.6

$$\frac{d \cdot \text{SIN F}}{\text{PLB}_V \rightarrow \text{PLB}_V \cdot \text{SIN (504F}_D)} \\ \text{@ } 2'$$

$$\frac{m_0 = - (a \cdot \text{COS F} + d \cdot \text{SIN F})}{\text{MMATRIX}_M \rightarrow \text{-(AVECTR}_V \cdot \text{COS (504F}_D) + \text{PLB}_V)} \\ \text{SHIFTED @ } 2'$$

ROW 1 OF M\* (t)  
EQ 5.2.6

RETURN  
VIA  
EARTHXX

EARTHXX CONTAINS QPRET

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Gilbert</i> <i>4/1/62</i>		PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIC)	
DESIGN		COLOSSUS 2D	DOCUMENT NO.
ANALST			PC-2283
DCNR		REV	SHEET 7 OF 9
APPRO			

NEWANGLE IS A GENERAL PURPOSE SUBROUTINE  
FOR EVALUATING THE FUNCTION:

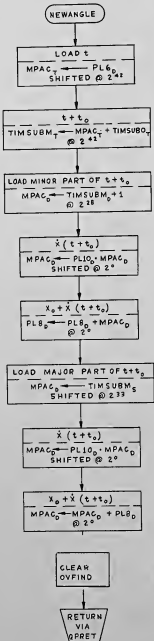
$$x = x_0 + \dot{x}(t+t_0)$$

INPUT

1.  $PL8_0 = x_0$  IN REVS AT  $2^0$
2.  $PL10_0 = \dot{x}$  IN REVS/CSEC AT  $2^{-12}/1^{-18}/2^{-27}$
3.  $X1 =$  SHIFT VALUE OF  $0/5/4$  CORRESPONDING TO  $\dot{x}$  SCALING
4.  $PL6_0 = t$ , TIME IN CSEC AT  $2^{28}$
5.  $TIMSUB0_T = t_0$ , TIME IN CSEC AT  $2^{42}$

OUTPUT

1.  $MPAC_0 = x$  IN REVS AT  $2^0$



TIMSUBM = PL 14

MINOR PART OF  $\dot{x}(t+t_0)$

FROM  $x_0$  PLUS MINOR  
PART OF  $\dot{x}(t+t_0)$

MAJOR PART OF  $\dot{x}(t+t_0)$

FORM  $x_0$  PLUS MAJOR  
AND MINOR PARTS OF  
 $\dot{x}(t+t_0)$

TURN OFF THE  
OVERFLOW INDICATOR

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>	30/43	PLANETARY INERTIAL ORIENTATION SUBROUTINE	
PROGRAM		COLOSSUS 2D	DOCUMENT NO. PC-2283
ANALYST			
DOCOR			
APP'D		REV	SHEET <i>[ ]</i> OF <i>[ ]</i>

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
HIZEROS <sub>V</sub>		THE VECTOR (0, 0, 0)	(0, 0, 0)	(0, 0, 0)	2 <sup>0</sup>
HIDPHALF <sub>D</sub>		THE NUMBER 1	1. 0	0. 5	2 <sup>1</sup>
NODIO <sub>D</sub>	$\Omega_{IO}$	LONGITUDE OF NODE OF LUNAR ORBIT IN BASIC REFERENCE SYSTEM, AT JULY 1.0, 1968	-6.03249419 RADS	-.960101269 REVS	2 <sup>0</sup>
NODDOT <sub>D</sub>	$\dot{\Omega}_I$	DERIVATIVE OF LONGITUDE OF NODE	-1.07047016 E-8 RAD/SEC	-.457335143 E-2 REV/CSEC	2 <sup>-28</sup>
FSUBO <sub>D</sub>	$F_O$	ANGLE FROM MEAN ASCENDING NODE OF LUNAR ORBIT TO THE MOON, AT JULY 1.0, 1968	2.61379488 RADS	.415998375 REVS	2 <sup>0</sup>
FDOT <sub>D</sub>	$\dot{F}$	DERIVATIVE OF ANGLE F	2.67240019 E-6 RAD/SEC	.570862491 REV/CSEC	2 <sup>-27</sup>
BSUBO <sub>D</sub>	$B_O$	OBLIQUITY, ANGLE BETWEEN MEAN EARTH EQUATORIAL PLANE AND ECLIPTIC, AT JULY 1.0, 1968	.409164173 RADS	.0651205006 REVS	2 <sup>0</sup>
BDOT <sub>D</sub>	$\dot{B}$	DERIVATIVE OF OBLIQUITY B	-7.19756866 E-14 RAD/SEC	-3.07500412 E-8 REV/CSEC	2 <sup>-28</sup>
WEARTH <sub>D</sub>	$\omega_E$	ANGULAR VELOCITY OF THE EARTH	7.29211515 E-5 RAD/SEC	.973561855 REV/CSEC	2 <sup>-23</sup>
COSE <sub>D</sub>	$C_I$	COS I } WHERE I IS ANGLE BETWEEN MEAN LUNAR EQUATORIAL PLANE AND ECLIPTIC (1°32.1')	.99964115	SAME	2 <sup>1</sup>
SINI	$S_I$		.02678760	SAME	2 <sup>1</sup>

## PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
504LM <sub>V</sub>	$I_M$	VECTOR LIBRATION IN MOON SYSTEM		RADS	2 <sup>0</sup>	
AXO <sub>D</sub>	$A_X$	ANGLES ABOUT X- AND Y- AXES OF BASIC SYSTEM DESCRIBING PRECESSION AND NUTATION	4.652459 x 10 <sup>-5</sup> RADS	RADS	2 <sup>0</sup>	
-AYO <sub>D</sub>	$-A_Y$		2.147535 x 10 <sup>-5</sup> RADS	RADS	2 <sup>0</sup>	
AZO <sub>D</sub>	$A_Z$	ANGLE BETWEEN X- AXIS OF BASIC SYSTEM AND EARTH SYSTEM, JULY 1.0, 1968	.7753206164 REVS	REVS	2 <sup>0</sup>	

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. G. Galt</i>		PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
FROM		COLOSSUS 2D	DOCUMENT NO. FC-2283
ANALYST			
DCMR			
APPROD		REV	SHEET 0 OF 0

LUNAR AND SOLAR EPHEMERIDES SUBROUTINE

THESE SUBROUTINES ARE USED TO DETERMINE THE POSITION AND VELOCITY VECTORS OF THE SUN AND MOON RELATIVE TO THE EARTH AT THE SPECIFIED GROUND ELAPSED TIME INPUT BY THE USER.

INPUT: GET-GROUND ELAPSED TIME

TEPHEM - ELAPSED TIME BETWEEN JULY 1.0, 1968 UNIVERSAL TIME AND THE TIME THAT THE COMPUTER CLOCK WAS ZEROED

TIMEMO - ELAPSED TIME BETWEEN JULY 1.0, 1968 UNIVERSAL TIME AND THE TIME AT THE CENTER OF THE RANGE OVER WHICH THE LUNAR-POSITION POLYNOMIAL IS VALID

VECOEM - VECTOR COEFFICIENTS OF THE LUNAR POSITION POLYNOMIAL LOADED IN DESCENDING SEQUENCE

RESO - POSITION VECTOR OF THE SUN RELATIVE TO THE EARTH AT TIMEMO

VEVO - VELOCITY VECTOR OF THE SUN RELATIVE TO THE EARTH AT TIMEMO

OMEGAES - ANGULAR VELOCITY OF THE VECTOR RESO AT TIMEMO

OUTPUT: LSPOS

VAC02D - POSITION VECTOR OF THE SUN RELATIVE TO THE EARTH AT INPUT BY USER

MPAC - POSITION VECTOR OF THE MOON RELATIVE TO THE EARTH AT TIME INPUT BY USER

LUNPOS

MPAC - POSITION VECTOR OF THE MOON RELATIVE TO THE EARTH AT TIME INPUT BY USER

LUNVEL

MPAC - VELOCITY VECTOR OF THE MOON RELATIVE TO THE EARTH AT TIME INPUT

SOLPOS

MPAC - POSITION VECTOR OF THE SUN RELATIVE TO THE EARTH AT TIME INPUT BY USER

NOTE: ALL INPUT EXCEPT GET IS INCLUDED IN THE PRE-LAUNCH ERASABLE DATA LOAD.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ASTRO GUIDANCE AND NAVIGATION	
DRWING	<i>R. A. Pinsky</i>	DATE	10/19/68
PROJ	<i>Project</i>	NO.	10/19/68
ANALYST			
DOC#	<i>R. A. Pinsky</i>		
APPROV	<i>John A. ...</i>		
		LSPOS, LUNPOS, LUNVEL, SOLPOS LUNAR AND SOLAR EPHEMERIDES SUBROUTINES	
		COLOSSUS II	
		DOCUMENT NO. FC-2286	
		SHEET 1 OF 3	



COMPUTES THE POSITION VECTORS OF THE SUN AND MOON

LSPDS

X2 ← CAOR(RESA)  
X1 ← CAOR(REB)

RES EXIT  
LSTIME  
EXIT

COMPUTES THE POSITION VECTOR OF THE MOON

LUNPOS

X1 ← CAOR(REM)

LSTIME  
EXIT

COMPUTES THE VELOCITY VECTOR OF THE MOON

LUNVEL

X1 ← CAOR(VEM)

LSTIME  
EXIT

COMPUTES THE POSITION VECTOR OF THE SUN

SOLPOS

X2 ← QPRET  
X1 ← CADR(RES)

RES EXIT  
LSTIME  
EXIT

LSTIME

MPAC<sub>v</sub> ← GET+TEPHEM-TIMEMO

DELTA TIME

$$t_M = t + t_0 - t_{M0}$$

GO TO CAOR(X1)

EXIT LSTIME

RES

POSITION VECTOR OF THE SUN RELATIVE TO THE EARTH AT DELTA TIME

MPAC<sub>v</sub> ← UNIT (RESO X VES0) X RES0 / SIN ((GET+TEPHEM-TIMEMO) X OMEGAS) + RESO X COS ((GET+TEPHEM-TIMEMO) X OMEGAS)

$$Y_{ES} = I_{ES0} \cos(W_{ES} t_M) + [I_{ES0} X UNIT (V_{ES0} X I_{ES0})] \sin(W_{ES} t_M)$$

GO TO CADR(X2)

EXIT RES

RESA

PLDZ<sub>v</sub> ← MPAC<sub>v</sub>

SAVE POSITION VECTOR IN PUSH LIST

REM

THE POSITION OF THE MOON IS STORED IN THE FORM OF A NINTH-DEGREE POLYNOMIAL APPROXIMATION WHICH IS VALID OVER A 14.5 DAY INTERVAL BEGINNING AT NOON EPHEMERIS TIME ON THE DAY OF THE LAUNCH

MPAC<sub>v</sub> ← VECOEN<sub>v</sub>

REMA

THIS AREA LOOPS TO OBTAIN 9TH DEGREE POLYNOMIAL

1ST PASS

2ND PASS

9TH PASS

MPAC<sub>v</sub> ← [VECOEN<sub>0</sub> + VECOEN<sub>1</sub> X (GET+TEPHEM-TIMEMO)] + [VECOEN<sub>2</sub> X (GET+TEPHEM-TIMEMO)<sup>2</sup>] + ... + VECOEN<sub>9</sub> (GET+TEPHEM-TIMEMO)<sup>9</sup>

$$Y_{EM} = \sum_{i=0}^9 C_i t_M^i$$

POSITION VECTOR OF THE MOON RELATIVE TO THE EARTH AT DELTA TIME

NO

9TH PASS

YES

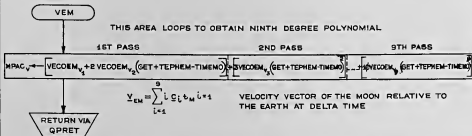
RETURN VIA QPRET

12 MPAC<sub>v</sub> INIT

*Handwritten signature*

LSPDS, LUNPOS, LUNVEL,  
SOLPOS LUNAR AND SOLAR  
EPHEMERIDES SUBROUTINES

COLOSSUS II FC-2286



THIS DIAGRAM ILLUSTRATES HOW THE POSITION OF THE SUN IS ARRIVED AT

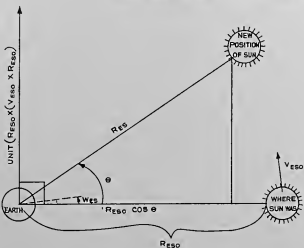
$R_{ES0_V}$  = POSITION VECTOR OF SUN AT  $T_0$   
 $V_{ES0_V}$  = VELOCITY VECTOR OF SUN AT  $T_0$

$\theta = W_{ES} \cdot \Delta t$

$RES = R_{ES0} \cos \theta + [UNIT R_{ES0}] + RESO \sin \theta (K)$

WHERE  $K = UNIT [R_{ES0} \times (V_{ES0} \times R_{ES0})]$

$= R_{ES0} \cos \theta + [R_{ES0} \times UNIT (V_{ES0} \times R_{ES0})] \sin \theta$



DRAWN <i>P.M. Dicks</i> CHECKED <i>P. B. White</i> ANALYST BY <i>J. J. Kelly</i> APPROVED <i>John A. Brown</i>	DESIGNED 21 FEB 67 COLLOSSUS II	LSPOS, LUNPOS, LUNVEL, SOLPOS LUNAR AND SOLAR EPHEMERIDES SUBROUTINES FC-2286
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3 3

INTEGRATION INITIALIZATION

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS		
STATINTI	POO: PRECISION INTEGRATES BOTH STATE VECTORS TO WITHIN 10 MINUTES OF CURRENT TIME	SH. 3
STATINT	SCHEDULES STATINTI	SH. 3
ATOPCSM	UPDATE PERMANENT CSM STATE VECTOR	SH. 5
ATOPELM	UPDATE PERMANENT LM STATE VECTOR	SH. 5
PTOACSM	MOVE PERMANENT CSM STATE VECTOR TO WORKING STORAGE	SH. 5
PTOALEM	MOVE PERMANENT LM STATE VECTOR TO WORKING STORAGE	SH. 5
CSMPREC	ENTRY FOR CSM STATE VECTOR PRECISION INTEGRATION	SH. 6
LEMPREC	ENTRY FOR LM STATE VECTOR PRECISION INTEGRATION	SH. 6
CSMCONIC	ENTRY FOR CSM STATE VECTOR CONIC INTEGRATION	SH. 7
LEMCONIC	ENTRY FOR LM STATE VECTOR CONIC INTEGRATION	SH. 7
INTEGRV5	INTEGRATE STATE VECTOR PROVIDED BY CALLER	SH. 8
INTEGRV	INTEGRATE CSM/LM STATE VECTOR AND W-MATRIX	SH. 8
INTEGRV2	ENTRY POINT FROM ORBITAL INTEGRATION PACKAGE, PC#2305 FOR NEXT PASS THROUGH INTEGRATION LOOP	SH. 8
RVCON	ENTRY FOR PERFORMING A CONIC INTEGRATION	SH. 9
INTSTALL	INTEGRATION STALL ROUTINE THAT PREVENTS AN ACTIVE JOB FROM CALLING THE INTEGRATION ROUTINE IF IT IS BUSY	SH.10
INTWAKEO	INTERPRETIVE ENTRY TO INTEGRATION WAKE ROUTINE TO WAKE UP ALL JOBS PUT TO SLEEP BY INTSTALL	SH.12
INTWAKE	BASIC CODE ENTRY TO INTEGRATION WAKE ROUTINE	SH.12
INTWAKEU	CALLED BY THE UPDATE PROGRAM P27 TO RELEASE ITS GRAB OF THE INTEGRATION ROUTINE	SH.14
AVETOMID	TRANSITION ROUTINE FROM THRUSTING PHASE TO COASTING PHASE	SH.16
MIDTOAV1	PRECISION INTEGRATES CSM PERMANENT STATE VECTOR TO SPECIFIED TIME	SH.19
MIDTOAV2	PRECISION INTEGRATES CSM PERMANENT STATE VECTOR TO CURRENT TIME PLUS 10 SECONDS	SH.19
USEPIOS	CALCULATES THE LM STATE VECTOR USING THE PLANETARY INERTIAL ORIENTATION SUBROUTINE WHEN LM ON LUNAR SURFACE	SH.21

REFERENCES FOR INTEGRATION INITIALIZATION

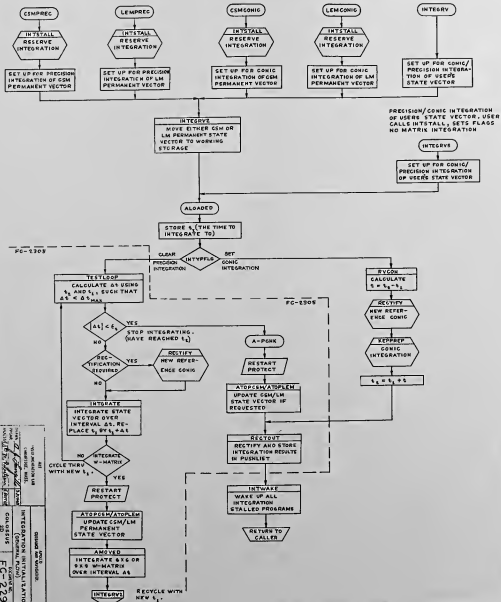
1. GUIDANCE SYSTEM OPERATIONS PLAN USING PROGRAM COLOSSUS (GSOP), R-577, SECTION 5, GUIDANCE EQUATIONS, MAY, 1968.
2. OSTANEK, W. F. USER'S GUIDE FOR ORBITAL INTEGRATION ROUTINE FOR FLIGHT 504, FLIGHT 504 MEMO 5, REV 1, JUNE, 1967.
3. OSTANEK AND KEFAUVER, LEVEL II TEST PACKAGE FOR COASTING INTEGRATION SUBROUTINE, MIT/IL, NOVEMBER, 1967.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. S. S. S.</i> 10/1/67		INTEGRATION INITIALIZATION	
PROGRAM	ANALYST <i>W. F. Ostaneck</i> 10/1/67	COLOSSUS 2D	DOCUMENT NO. FC-2280
DOCMR <i>R. S. S. S.</i> 10/1/67	APPROV <i>W. F. Ostaneck</i> 10/1/67	REV 1	SHEET 1 OF 26

PRECISION INTEGRATION OF PERMANENT CSM/LM STATE VECTOR. NO W-MATRIX INTEGRATION. FINAL UPDATE IS OPTIONAL

CONIC INTEGRATION OF PERMANENT CSM/LM STATE VECTOR. NO W-MATRIX INTEGRATION. FINAL UPDATE OPTIONAL

PRECISION/CONIC INTEGRATION OF CSM/LM PERMANENT VECTOR. USER CALLS INSTALL. SETS FLAG NO MATRIX INTEGRATION OPTIONAL



PRECISION/CONIC INTEGRATION OF CSM/LM PERMANENT VECTOR. USER CALLS INSTALL. SETS FLAG NO MATRIX INTEGRATION OPTIONAL

INSTALL  
RESERVE  
INTEGRATION

INSTALL  
RESERVE  
INTEGRATION

INSTALL  
RESERVE  
INTEGRATION

INSTALL  
RESERVE  
INTEGRATION

INSTALL  
RESERVE  
INTEGRATION

SET UP FOR PRECISION  
INTEGRATION OF CSM  
PERMANENT VECTOR

SET UP FOR PRECISION  
INTEGRATION OF LM  
PERMANENT VECTOR

SET UP FOR CONIC  
INTEGRATION OF CSM  
PERMANENT VECTOR

SET UP FOR CONIC  
INTEGRATION OF LM  
PERMANENT VECTOR

SET UP FOR CONIC/  
PRECISION INTEGRATION  
OF USER'S  
STATE VECTOR

INTRGVE  
MOVE EITHER CSM OR  
LM PERMANENT STATE  
VECTOR TO WORKING  
STORAGE

ALDGED

STORE  $t_0$  (THE TIME TO  
INTEGRATE TO)

INTVPFLG

CLEAR  
PRECISION  
INTEGRATION

SET  
CONIC  
INTEGRATION

TESTLOOP  
CALCULATE  $\Delta t$  USING  
 $t_0$  AND  $t_1$ , SUCH THAT  
 $\Delta t \leq \Delta t_{MAX}$

$A_1 \leq \epsilon_1$

STOP INTEGRATING.  
(HAVE REACHED  $t_1$ )

RE-  
CALCIFICATION  
REQUIRED

RECALIFY  
NEW REFER-  
ENCE CONIC

A-PENK  
RESTART  
PROTECT

RESTART  
PROTECT

ATOPCSM/LM  
UPDATE CSM/LM  
STATE VECTOR IF  
REQUESTED

RECALIFY  
NEW REFER-  
ENCE CONIC

REPPREP  
CONIC  
INTEGRATION

$t_0 = t_1 + \Delta t$

NO INTEGRATE  
W-MATRIX

CYCLE THRU  
WITH NEW  $t_1$

RESTART PROTECT

MOVED  
INTEGRATE  $\Delta t_0$  OR  
 $\Delta t_0$  W-MATRIX  
OVER INTERVAL  $\Delta t$

INTGRV

RECYCLE WITH  
NEW  $t_1$

INTWAKE  
WAKE UP ALL  
INTEGRATION  
STALLED PROGRAMS

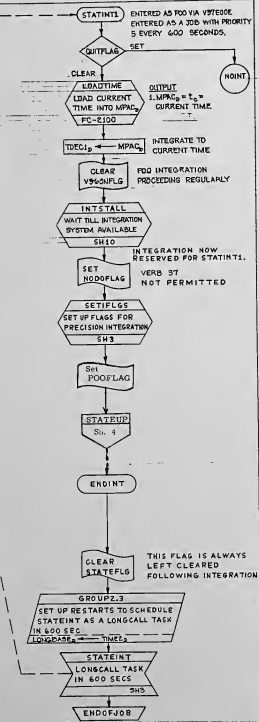
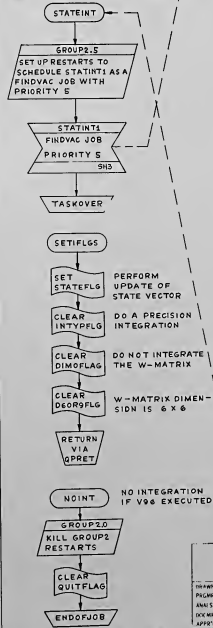
RETURN TO  
CALLED

FC-5303

FC-5305

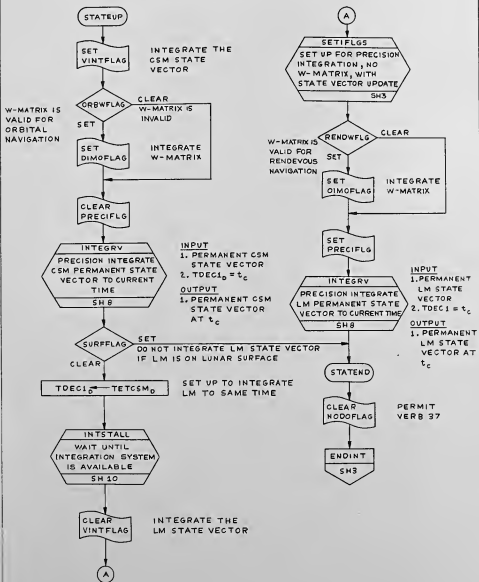
FC-5305

STATEINT IS SCHEDULED TO BE EXECUTED EVERY 600 SECONDS DURING THE IDLING PROGRAM P00. THUS BOTH STATE VECTORS ARE PRECISION INTEGRATED AND UPDATED TO WITHIN 600 SECONDS OF CURRENT TIME

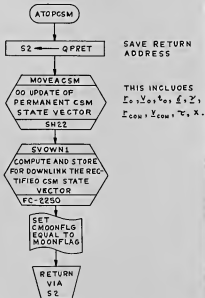


MIT IV. ILLUMINATION LAB CAMBRIDGE, MASS.		APPLIED D'ARCY AND NAVIGATION	
DRAWN <i>G. J. Sponholz</i> 5/NOV/68		INTEGRATION INITIALIZATION	
PROGRAM <i>M. Robertson</i> 5/SEP/68		COLOSSUS 2D	
ANALYST <i>M. Robertson</i> 5/SEP/68		DOCUMENT NO. FC-2290	
APPROVED <i>G. J. Sponholz</i> 5/SEP/68		SHEET 3 OF 26	

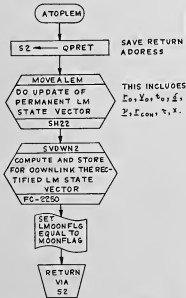
STATEUP DOES THE POO INTEGRATION, IT PRECISION INTEGRATES BOTH CSM AND LM STATE VECTORS TO CURRENT TIME WITH A PERMANENT UPDATE OF BOTH VECTORS. IT INTEGRATES THE W-MATRIX IF IT IS VALID.



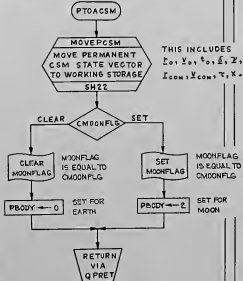
PERFORM AN UPDATE OF PERMANENT  
CSM STATE VECTOR AND FLAG  
CMOONFLG



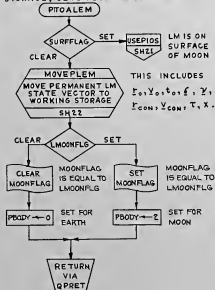
PERFORMS AN UPDATE OF PERMANENT  
LM STATE VECTOR AND FLAG  
LMOONFLG



MOVES PERMANENT CSM STATE VECTOR  
AND FLAG CMOONFLG TO WORKING  
STORAGE, SETS PBODY INDICATOR



MOVES PERMANENT LM STATE VECTOR  
AND FLAG LMOONFLG TO WORKING  
STORAGE, SETS PBODY INDICATOR



MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

DESIGN *A. J. Langille* SMOYNE  
FROM *A. J. Langille* SMOYNE  
ANAL. *A. J. Langille* SMOYNE  
DOC# *A. J. Langille* SMOYNE  
APPRO. *A. J. Langille* SMOYNE

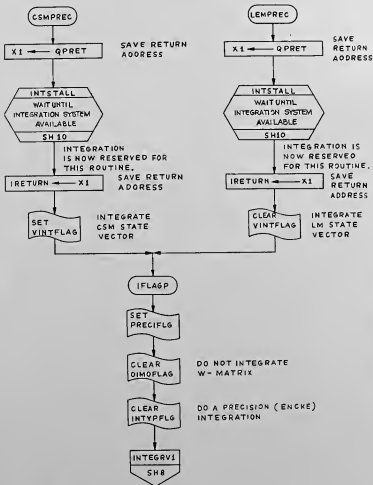
AFULLO  
GUIDANCE AND NAVIGATION

INTEGRATION INITIALIZATION

COLOSSUS  
2D

DOC# FC-2290  
SHEET 3 OF 24

CSMPREC AND LEMPREC ARE ENTRIES TO THE INTEGRATION ROUTINE FOR PERFORMING ORBIT INTEGRATION BY THE PRECISION (ENCKE) METHOD OF THE PERMANENT STATE VECTOR OF THE CSM AND LM RESPECTIVELY. ACCELERATIONS DUE TO OBLATENESS ARE INCLUDED. NO W-MATRIX INTEGRATION IS PERFORMED. A FINAL STATE VECTOR UPDATE IS OPTIONAL. THE CALLER MUST STORE THE TIME TO INTEGRATE TO IN  $TOECL_0 = t_2$ . THE ENTRIES AUTOMATICALLY LOAD THE APPROPRIATE STATE VECTOR AND TIME OF VALIDITY FROM PERMANENT STORAGE INTO  $RCV_V$ ,  $VCV_V$  AND  $TET_P$ . THESE ENTRIES SET UP ALL THE FLAGS REQUIRED BY THE INTEGRATION ROUTINE AND PERFORM THE CALL TO INTSTALL. OUTPUT INCLUDES THE INTEGRATED STATE VECTOR STORED IN THE PUSH LIST IN LOCATIONS  $RATT_V$ ,  $VATT_V$  AND THE TIME ACTUALLY INTEGRATED TO IN PUSH LIST LOCATION  $TAT_P$ .



INTEGRATION INITIALIZATION

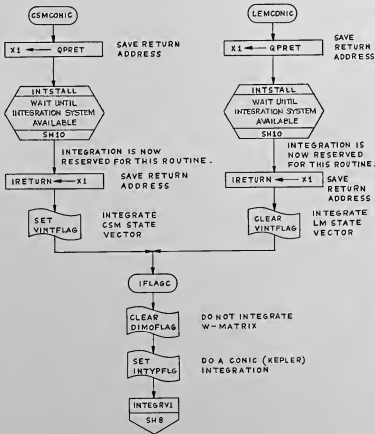
COLOSSUS  
21D

FC-2290

6-26



CSMCONIC AND LEMCONIC ARE ENTRIES TO THE INTEGRATION ROUTINE FOR PERFORMING DRBIT INTEGRATION BY THE CONIC (KEPLER) METHOD OF THE PERMANENT STATE VECTOR OF THE CSM AND LM RESPECTIVELY. NO DISTURBING ACCELERATIONS ARE INCLUDED. THE STATE VECTOR IS RECTIFIED IMMEDIATELY PRIOR TO THE KEPLER SOLUTION. THE CALLER MUST STORE THE TIME TO INTEGRATE TO IN TDECI =  $t_2$ . THE ENTRIES AUTOMATICALLY LOAD THE APPROPRIATE STATE VECTOR AND TIME OF VALIDITY FROM PERMANENT STORAGE INTO RCV<sub>V</sub>, VCV<sub>V</sub>, AND TET<sub>V</sub>. THESE ENTRIES SET UP ALL THE FLAGS REQUIRED BY THE INTEGRATION ROUTINE AND PERFORM THE CALL TO INTSTALL. OUTPUT INCLUDES THE INTEGRATED STATE VECTOR STORED IN THE PUSH LIST IN LOCATIONS RATT<sub>V</sub>, VATT<sub>V</sub> AND THE TIME ACTUALLY INTEGRATED TO IN PUSH LIST LOCATION TAT<sub>0</sub>.



WIT	
INTEGMENTATION, SP	
ANBR (DCI, MA)	
NAME	6 NOV 68
DESIGN	
ANALYST	
QUALITY	
APPROVED	

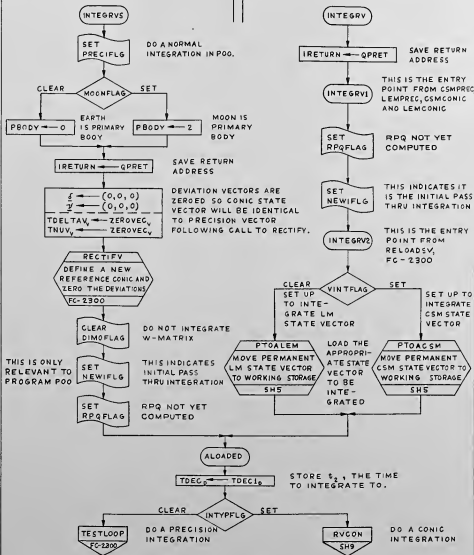
INTEGRATION INITIALIZATION

COLOSSUS  
2D

FC-2290

INTEGRVS IS AN ENTRY TO THE INTEGRATION ROUTINE FOR PERFORMING INTEGRATION (PRECISION OR CONIC) OF A STATE VECTOR PROVIDED BY THE CALLER. THE CALLER MUST CALL ROUTINE INTSTALL, SET UP THE FLAGS INTYPFLG, MOONFLAG AND LOAD THE STATE VECTOR TO BE INTEGRATED AND TIME INTO LOCATIONS RCV<sub>1</sub>, VCV<sub>1</sub> AND TET<sub>1</sub>. THE TIME TO INTEGRATE TO MUST BE LOADED IN TDEC<sub>1</sub> = t<sub>2</sub>.

INTEGRV IS AN ENTRY TO THE INTEGRATION ROUTINE FOR PERFORMING INTEGRATION (PRECISION OR CONIC) OF THE CSM OR LM PERMANENT STATE VECTOR. THE CALLER MUST CALL ROUTINE INTSTALL AND SET UP THE FLAGS INTYPFLG, VINTFLAG, DIMOFLAG, DSOR9FLG AND STATEFLG. THE TIME TO INTEGRATE TO MUST BE LOADED IN TOEC<sub>1</sub> = t<sub>2</sub>. THIS ENTRY LOADS THE APPROPRIATE STATE VECTOR AND TIME FROM PERMANENT STORAGE INTO RCV<sub>1</sub>, VCV<sub>1</sub> AND TET<sub>1</sub>. THIS IS THE ONLY ENTRY THAT PERMITS W-MATRIX INTEGRATION AS AN OPTION. THIS ENTRY IS USED GENERALLY BY THE NAVIGATION PROGRAMS.



INTEGRATION INITIALIZATION

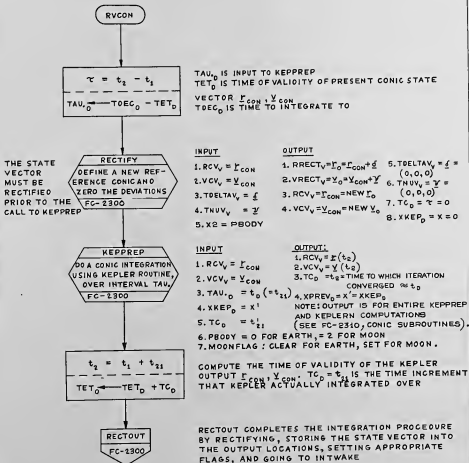
7 NOV 68

COLLOSS 2D

FC-2290

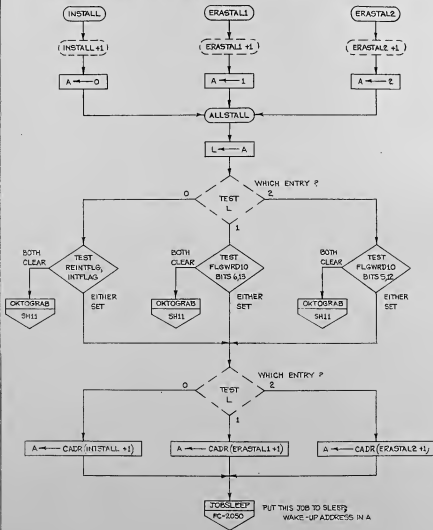
26

RVCON SETS UP ORBIT INTEGRATION TO DO A CONIC SOLUTION FOR POSITION AND VELOCITY OVER THE TIME INTERVAL FROM TET TO TDEC. IT CALLS THE KEPPREP SUBROUTINE WHICH IN TURN CALLS THE KEPLER SUBROUTINE. RVCON IS ENTERED IF G5MCONIC OR LEMCONIC WAS CALLED OR IF INTEGRVS OR INTEGRV WAS CALLED WITH INTYPLG6.

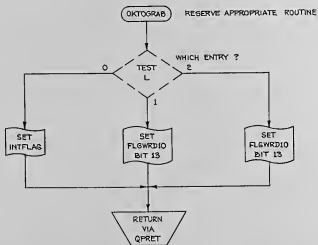


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	AIRS-D GUIDANCE AND NAVIGATION
DRAWN <i>A. J. Sipple</i> 7 NOV 68 PPLNR ANALYST <i>W. M. Robertson</i> 6 SEP 68 DOCNR APPROV <i>Ch. J. F. P. ...</i> 17 OCT 68	<b>INTEGRATION INITIALIZATION</b>  COLOSSUS 2D DRAWING # <b>FC-2290</b> SHEET 9 OF 26

THE INTEGRATION STALL ROUTINE PREVENTS AN ACTIVE JOB FROM CALLING THE INTEGRATION SUBROUTINE IF (1) IT HAS BEEN CALLED BY ANOTHER PROGRAM (WHICH IS PRESENTLY INACTIVE) AND (2) IT HAS NOT COMPLETED ITS CALCULATIONS AND RETURNED CONTROL TO THE CALLING PROGRAM. IF THE INTEGRATION SUBROUTINE IS AVAILABLE, THEN IT IS RESERVED FOR THE CALLING PROGRAM. IF THE INTEGRATION SUBROUTINE IS IN USE OR ALREADY RESERVED, THE CALLING PROGRAM IS PUT TO SLEEP.

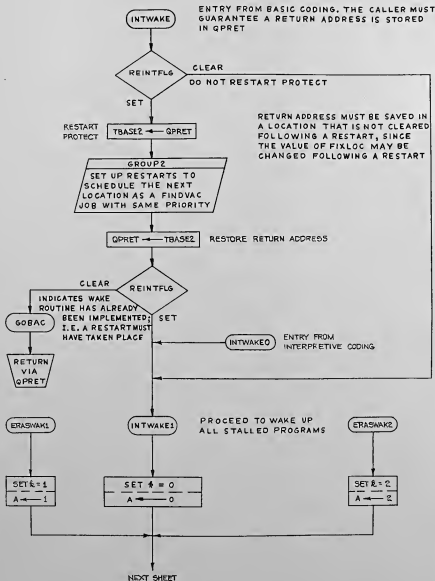


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		INTEGRATION INITIALIZATION	
DRAWN A. C. WILLIAMS CHECKED ANAL. BY <i>John Robinson</i> DATE 10/10/54	220103 STARTED 2-1-54	COLLOSSUS 2D FC-2200	REV 1 10 26



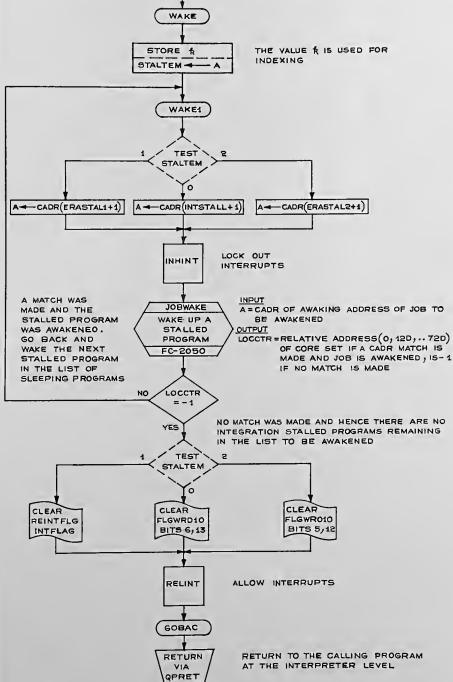
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		INTEGRATION INITIALIZATION	
DRAWN A.C.WILLIAMS	202JUN68		
PROGR			
ANALYS	<i>M. Robertson</i>	5 APR 68	DOCUMENT #
DEV MR		COLOSSUS 2D	FC-2290
APP'D	<i>Robert D. Carter</i>	11-5-68	REV 1
			SHEET 11 OF 26

THE INTEGRATION WAKE ROUTINE WAKES UP ALL PROGRAMS THAT HAVE BEEN PUT TO SLEEP (I.E. STALLED) BY THE INTEGRATION STALL ROUTINE INSTSTALL.



MIT INTEGRATION CENTER CAMBRIDGE, MASS	INTEGRATION INITIALIZATION
DESIGNED BY: <i>J. S. ...</i> DRAWN BY: <i>M. ...</i> ANALYZED BY: <i>M. ...</i> CHECKED BY: <i>M. ...</i> APPROVED BY: <i>M. ...</i>	COLOSSUS 2D FC-2290 12 26

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPROVED CLEMENS AND SAPIRAT.
DRAWN BY <i>P. M. DeLoach</i> CHECKED BY <i>P. M. DeLoach</i> ANALYST <i>W. M. Robertson</i> DOC. NO. <i>FC-2290</i> APPROVED BY <i>Robert M. Cutler</i>	INTEGRATION INITIALIZATION DRAWING NO. <b>FC-2290</b> REV. <b>1</b> DATE <b>11 13 66</b> OF <b>26</b>

THIS ROUTINE IS CALLED ONCE BY P27 (THE UPDATE PROGRAM) TO RELEASE ITS GRAB (MADE VIA INSTALL) OF THE INTEGRATION ROUTINE

ALLOW INTERRUPTS

SAVE RETURN ADDRESS

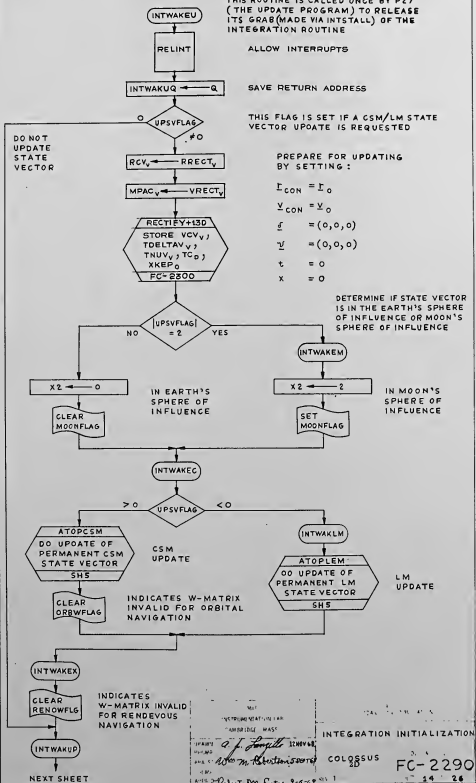
THIS FLAG IS SET IF A CSM/LM STATE VECTOR UPDATE IS REQUESTED

PREPARE FOR UPDATING BY SETTING :

$I_{CON} = I_0$   
 $V_{CON} = V_0$   
 $\underline{f} = (0, 0, 0)$   
 $\underline{v} = (0, 0, 0)$   
 $t = 0$   
 $x = 0$

DETERMINE IF STATE VECTOR IS IN THE EARTH'S SPHERE OF INFLUENCE OR MOON'S SPHERE OF INFLUENCE

DO NOT UPDATE STATE VECTOR



INTEGRATION INITIALIZATION

COLOSSUS

FC-2290

14 26



FROM  
PRECEDING SHEET

UPSVFLAG ← 0

CLEAR THE WORD TO ZERO  
TO INDICATE AN UPDATING  
IS NOT REQUESTED

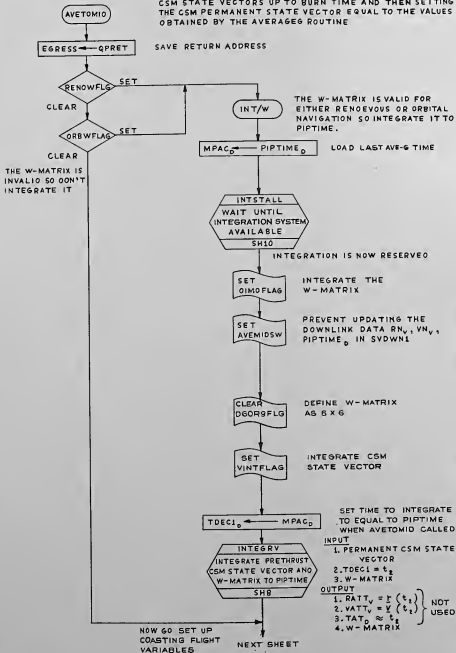
INTWAKED  
WAKE UP ALL  
STALLED  
PROGRAMS  
SHIE

GROUP 6  
SET UP RESTARTS  
TO SCHEDULE THE  
NEXT LOCATION AS  
A JOB WITH THE  
SAME PRIORITY

RETURN  
VIA  
INTWAKQ

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		CHANDLER AND ENCLAVE
DRAWN <i>C. J. Temple</i> D110006		INTEGRATION INITIALIZATION
DESIGNED <i>M. B. Weston</i> 5 SEP 66	ANALYST <i>M. B. Weston</i> 5 SEP 66	COLOSSUS 2D
APPROVED <i>Robert M. Dixon</i> 3 SEP 66	REL. NO. FC-2290	REV. 15 79 26

AVETOMID PERFORMS THE TRANSITION FROM A THRUSTING PHASE TO A COASTING PHASE BY INTEGRATING THE LM AND CSM STATE VECTORS UP TO BURN TIME AND THEN SETTING THE CSM PERMANENT STATE VECTOR EQUAL TO THE VALUES OBTAINED BY THE AVERAGES ROUTINE



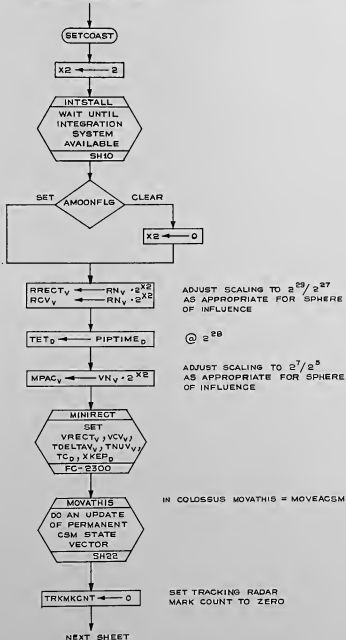
INTEGRATION INITIALIZATION

COLOSSUS  
2D

FC-2290

16 26

FROM PRECEDING SHEET



ADJUST SCALING TO  $2^{29} / 2^{27}$   
AS APPROPRIATE FOR SPHERE  
OF INFLUENCE

@  $2^{20}$

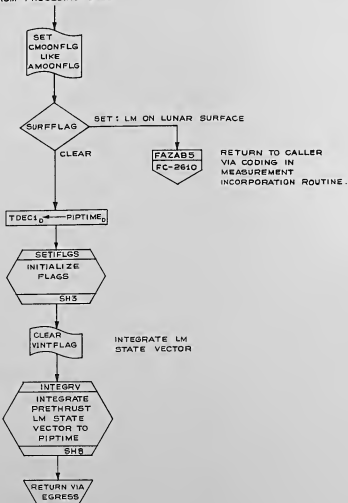
ADJUST SCALING TO  $2^7 / 2^5$   
AS APPROPRIATE FOR SPHERE  
OF INFLUENCE

IN COLOSSUS MOVATHIS = MOVEACSM

SET TRACKING RADAR  
MARK COUNT TO ZERO

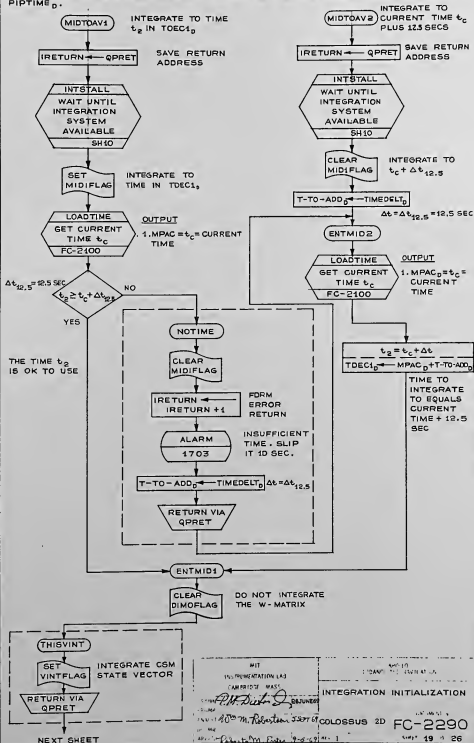
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED COSMANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		INTEGRATION INITIALIZATION	
PROGRAM	ANALYST <i>[Signature]</i>	COLLOSSUS 2D	DOCUMENT NO. FC-2290
DATE	APPROVED <i>[Signature]</i>	REV 1	SHEET 17 OF 26

FROM PRECEDING SHEET



MIT ASTRONOMICAL OBSERVATORY CAMBRIDGE, MASS.	PROJECT COLOSSUS 2D
<i>P.H. ...</i>	INTEGRATION INITIALIZATION
400 ...	REVISION 1
...	FC-2290
...	18 26

MIDTOAV1 DOES PRECISION INTEGRATION OF THE CSM PERMANENT STATE VECTOR TO THE TIME  $t_2$  SPECIFIED IN TDEC1<sub>0</sub>. IF THIS TIME IS LESS THAN CURRENT TIME PLUS 10 SECONDS IT IS AUTOMATICALLY SET TO THIS VALUE, ALARM 1703 IS SET AND FOLLOWING THE INTEGRATION RETURN IS TO THE RETURN ADDRESS PLUS ONE. MIDTOAV2 DOES PRECISION INTEGRATION OF CSM PERMANENT STATE VECTOR TO CURRENT TIME PLUS 12.5 SECONDS. IN EITHER CASE THE INTEGRATED STATE VECTOR AND TIME ARE STORED IN RN<sub>Vj</sub> VN<sub>Vj</sub> PIPTIME<sub>0</sub>.



MIT  
INTEGRATION LAB  
CAMBRIDGE MASS  
RESEARCH CENTER  
COLOSSUS 2D  
FC-2290  
19 4 26

FROM PRECEDING SHEET

CLEAR  
INTYPFLG

DO PRECISION  
INTEGRATION

SET  
MIDAVFLG

INDICATE TO INTEGRATION THAT IT  
WAS CALLED BY THE MIDTOAVE ROUTINE

INTEGRV  
INTEGRATE CSM  
STATE VECTOR TO  
TIME  $t_2$   
SHB

INPUT

1. PERMANENT CSM STATE VECTOR
2.  $TOEC1_0 = t_2$
3. INTERPRETIVE FLAGS

OUTPUT

1.  $RATT_v = \Gamma(t_2)$
2.  $VATT_v = \dot{V}(t_2)$
3.  $TAT_0 \approx \frac{1}{2} t_2$

RTX2 ← XP  
RTX1 ← X1

CLEAR  
AMODNFLG

2

0

RTX2

SET  
AMCONFLG

SET  
FLAG  
ACCORDING  
TO  
SPHERE OF  
INFLUENCE  
(FOR  
SCALING OF  
STATE VECTOR)

RN1\_v ← RATT\_v  
VN1\_v ← VATT\_v  
PIPTIME\_0 ← TAT\_0

STORE THE OUTPUT  
OF INTEGRV

INHINT

INHIBIT INTERRUPTS

$\Delta t = t_2 - t_0$   
MPAC\_0 ← TAT\_0 - TIME2\_0

COMPUTE A DELTA TIME EQUAL TO  
TIME ACTUALLY INTEGRATED TO  
MINUS THE CURRENT TIME IN TIME 2, TIME 1

TRAGREE  
FORCE SIGN  
AGREEMENT IN  
MPAC\_v  
FC-2090

RETURN VIA  
IRETURN1

RETURN IS MADE VIA SUBROUTINE BANK JUMP.  
IRETURN1 CONTAINS EITHER NORMAL RETURN  
ADDRESS OR ERROR RETURN ADDRESS

INTEGRATION INITIALIZATION

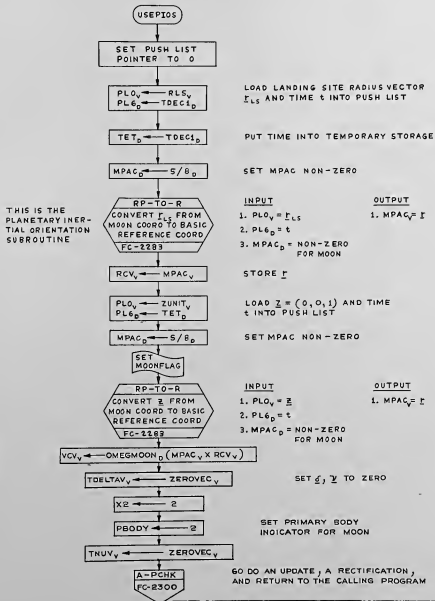
100% M. Richardson's work

COLOSSUS 2D

FC-2290

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USEPIOS IS EXECUTED INSTEAD OF THE NORMAL CODING IN PTOALEM IF THE LM IS ON THE SURFACE OF THE MOON. THE LM POSITION AND VELOCITY VECTORS ARE CALCULATED USING THE PLANETARY INERTIAL ORIENTATION SUBROUTINE INSTEAD OF USING THE NORMAL INTEGRATION ROUTINES. SINCE THE LANDING SITE MOVES RELATIVE TO THE BASIC REFERENCE SYSTEM BECAUSE OF LUNAR ROTATION IT IS MORE CONVENIENT TO STORE THE LM STATE VECTOR IN THE MOON FIXED COORDINATE SYSTEM WHERE IT DOES NOT CHANGE IN TIME. THIS ROUTINE CONVERTS THE RLS TO THE BASIC REFERENCE COORDINATE SYSTEM.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AP-110 GUIDANO INV. CALCULATION	
DRAWN <i>O. J. Smith</i> 1/28/64		INTEGRATION INITIALIZATION	
PROG: <i>USEPIOS</i>		COLOSSUS	
ANAL: <i>M. Robinson</i> 5/28/64		2D	
DESCR: <i>USEPIOS</i>		FC-2290	
APPRO: <i>Robert M. C. ...</i> 7-2-67		REV 1	
		DRAWING NO. FC-2290	
		SHEET 24 OF 26	

IN COLOSSUS  
MOVATHIS =  
MOVEACSM

MOVEACSM

SET BBANK REGISTER FOR  
INTEGRY ROUTINE AND DATA

RRECT <sub>V</sub> ← RRECT <sub>V</sub>	MOVE GCM
VRECT <sub>V</sub> ← VRECT <sub>V</sub>	STATE VECTOR
TET <sub>D</sub> ← TET <sub>D</sub>	$I_0, Y_0, t_0,$
DELTA <sub>V</sub> ← DELTA <sub>V</sub>	$f, \gamma, I_{CON},$
NUCSM <sub>V</sub> ← TNUV <sub>V</sub>	$Y_{CON}, T, X$
RCVCSM <sub>V</sub> ← RCV <sub>V</sub>	FROM WORKING
VCVCSM <sub>V</sub> ← VCV <sub>V</sub>	STORAGE TO
TCCSM <sub>D</sub> ← TC <sub>D</sub>	PERMANENT
XKEPCSM <sub>D</sub> ← XKEP <sub>D</sub>	STORAGE

RETURN  
VIA  
DANZIG

MOVEALEM

SET BBANK REGISTER FOR  
INTEGRY ROUTINE AND DATA

RRECT <sub>V</sub> ← RRECT <sub>V</sub>	MOVE LM
VRECT <sub>V</sub> ← VRECT <sub>V</sub>	STATE VECTOR
TET <sub>D</sub> ← TET <sub>D</sub>	$I_0, Y_0, t_0,$
DELTA <sub>V</sub> ← DELTA <sub>V</sub>	$f, \gamma, I_{CON},$
NULEM <sub>V</sub> ← TNUV <sub>V</sub>	$Y_{CON}, T, X$
RCV <sub>V</sub> ← RCV <sub>V</sub>	FROM WORKING
VCV <sub>V</sub> ← VCV <sub>V</sub>	STORAGE TO
TC <sub>D</sub> ← TC <sub>D</sub>	PERMANENT
XKEP <sub>D</sub> ← XKEP <sub>D</sub>	STORAGE

RETURN  
VIA  
DANZIG

MOVEPCSM

SET BBANK REGISTER FOR  
INTEGRY ROUTINE AND DATA

RRECT <sub>V</sub> ← RRECTCSM <sub>V</sub>	MOVE GCM
VRECT <sub>V</sub> ← VRECTCSM <sub>V</sub>	STATE VECTOR
TET <sub>D</sub> ← TETCSM <sub>D</sub>	$I_0, Y_0, t_0,$
DELTA <sub>V</sub> ← DELTACS <sub>V</sub>	$f, \gamma, I_{CON},$
TNUV <sub>V</sub> ← NUCSM <sub>V</sub>	$Y_{CON}, T, X$
RCV <sub>V</sub> ← RCVCSM <sub>V</sub>	FROM
VCV <sub>V</sub> ← VCVCSM <sub>V</sub>	PERMANENT
TC <sub>D</sub> ← TCCSM <sub>D</sub>	STORAGE TO
XKEP <sub>D</sub> ← XKEPCSM <sub>D</sub>	WDKING
	STORAGE

RETURN  
VIA  
DANZIG

MOVEPLEM

SET BBANK REGISTER FOR  
INTEGRY ROUTINE AND DATA

RRECT <sub>V</sub> ← RRECTLEM <sub>V</sub>	MOVE LM
VRECT <sub>V</sub> ← VRECTLEM <sub>V</sub>	STATE VECTOR
TET <sub>D</sub> ← TETLEM <sub>D</sub>	$I_0, Y_0, t_0,$
DELTA <sub>V</sub> ← DELTALEM <sub>V</sub>	$f, \gamma, I_{CON},$
TNUV <sub>V</sub> ← NULEM <sub>V</sub>	$Y_{CON}, T, X$
RCV <sub>V</sub> ← RCVLEM <sub>V</sub>	FROM
VCV <sub>V</sub> ← VCVLEM <sub>V</sub>	PERMANENT
TC <sub>D</sub> ← TCLEM <sub>D</sub>	STORAGE TO
XKEP <sub>D</sub> ← XKEPLEM <sub>D</sub>	WORKING
	STORAGE

RETURN  
VIA  
DANZIG

MIT  
INSTRUMENTATION LAB  
CAMBRIDGE MASS.

APPROVED BY  
A. J. Long  
M. Robertson  
DATE 5/26/66

DATE OF  
TEST AND NAVIGATION

INTEGRATION INITIALIZATION

COLOSSUS  
2D

FC-2290

REV 22 26



SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
LOADTIME	2100	LOAD TIME1 AND TIME2 (CURRENT TIME) INTO MPAC	SH. 3, 19
JOBSLEEP	2050	PUT CALLING PROGRAM TO SLEEP	SH. 10
SVDWN1	2250	GET RECTIFIED CSM STATE VECTOR FOR DOWNLINK	SH. 5
SVDWN2	2250	GET RECTIFIED LM STATE VECTOR FOR DOWNLINK	SH. 5
RECTIFY	2300	DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS	SH. 8, 9
RECTIFY +13D	2300	SPECIAL ENTRY TO RECTIFY (ABOVE)	SH. 14
TESTLOOP	2300	ENTRY POINT FOR PRECISION INTEGRATION	SH. 8
MINIRECT	2300	SPECIAL ENTRY TO RECTIFY (ABOVE)	SH. 17
KEPPREP	2300	ENTRY POINT FOR CONIC (KEPLER) INTEGRATION	SH. 9
RECTOUT	2300	ENTRY POINT FOR COMPLETING AN INTEGRATION	SH. 9
JOBWAKE	2050	WAKE UP A SLEEPING JOB	SH. 13
FAZAB5	2610	ENTRY POINT IN INCORP ROUTINE FOR ENDING AVETOMID ROUTINE	SH. 18
RP-TO-P	2283	CONVERT A VECTOR FROM MOON COORDINATES TO BASIC REFERENCE COORDINATES	SH. 21
A-PCHK	2300	ENTRY POINT FOR PERFORMING AN UPDATE AND RECTIFICATION	SH. 21

FLAGS

NAME (BIT, FLAGWRD)	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
INTYPLG (4, 3)	DO CONIC (KEPLER) INTEGRATION	DO PRECISION (ENCKE) INTEGRATION	SH. 7	SH. 3, 6, 20	SH. 8
INTFLAG (3, 3)	INTEGRATE THE CSM STATE VECTOR	INTEGRATE THE LM STATE VECTOR	SH. 4, 6, 7, 16, 19	SH. 4, 6, 7, 18	SH. 8
DIMOFLAG (1, 3)	INTEGRATE THE W-MATRIX	DO NOT INTEGRATE THE W-MATRIX	SH. 4, 18	SH. 3, 6, 7, 8, 19	
DSORSFLG (2, 3)	W-MATRIX IS 9x9	W-MATRIX IS 6x6		SH. 3, 16	
STATEFLG (5, 3)	UPDATE PERMANENT CSM/LM STATE VECTOR	DO NOT UPDATE PERMANENT CSM/LM STATE VECTOR	SH. 3	SH. 3	
NODOFLAG (1, 2)	VERB 37 IS NOT PERMITTED	VERB 37 IS PERMITTED	SH. 3	SH. 4	
QUITFLAG (5, 0)	DISCONTINUE INTEGRATION AT START OF NEXT TIMESTEP	CONTINUE INTEGRATION		SH. 3	SH. 3
SURFFLAG (8, 8)	LM IS ON LUNAR SURFACE	LM IS NOT ON LUNAR SURFACE			SH. 4, 5, 18
RENDFWFLG (1, 5)	W-MATRIX IS VALID FOR RENDEZVOUS NAVIGATION	W-MATRIX IS INVALID FOR RENDEZVOUS NAVIGATION		SH. 14	SH. 4, 16

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
INTEGRATION INITIALIZATION			
DRAWN <i>[Signature]</i>	DATE 12 NOV 64	COLOSSUS 2D	DOCUMENT NO. FC-2290
APPROVED <i>[Signature]</i>	DATE 7-2-57	REV 1	SHEET 23 OF 26

FLAGS (CONTINUED)

NAME (BIT, FLAGWRD)	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
PRECIFLG (8, 3)	CSMPREC OR LEMPREC WAS CALLED	INTEGRV OR INTEGRVS WAS CALLED	SH, 4, 6, 8	SH, 4	
MOONFLAG (12, 0)	INSIDE LUNAR SPHERE OF INFLUENCE	OUTSIDE LUNAR SPHERE OF INFLUENCE	SH, 5, 14, 21	SH, 5, 14	SH, 5, 8
CMOONFLG (12, 8)	(PERMANENT CSM REPRESENTATION OF MOONFLAG)		SH, 5, 18	SH, 5, 18	SH, 5
LMOONFLG (11, 8)	(PERMANENT LM REPRESENTATION OF MOONFLAG)		SH, 5	SH, 5	SH, 5
NEWIFLG (13, 8)	INITIAL PASS THROUGH INTEGRATION LOOP	SUBSEQUENT PASS THROUGH INTEGRA- TION LOOP	SH, 8		
RPQFLAG (15, 9)	RPQ NOT COMPUTED	RPQ COMPUTED	SH, 8		
INTFLAG	INTEGRATION IS IN PROGRESS	INTEGRATION IS NOT IN PROGRESS	SH, 11	SH, 13	SH, 10
REINTFLG (7, 10)	RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS	DO NOT RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS		SH, 13	SH, 10, 12
MIDAVFLG (2, 9)	INTEGRATION WAS CALLED BY THE MIDTOAV ROUTINE	INTEGRATION WAS NOT CALLED BY THE MIDTOAV ROUTINE	SH, 20		
MIDIFLAG (3, 9)	INTEGRATE TO TIME IN TOEC1	INTEGRATE TO CURRENT TIME PLUS 10 SECONDS	SH, 19	SH, 19	
V96ONFLG (3, 8)	POO INTEGRATION INHIBITED BY V96	POO INTEGRATION PROCEEDING REGULARLY		SH, 3	
AVEMIDSW (1, 9)	PREVENT UPDATING THE CSM DOWNLINK DATA RN, VN, PIPTIME	ALLOW UPDATING THE CSM DOWNLINK DATA RN, VN, PIPTIME	SH, 18		
UPSVFLAG	CSM/LM STATE VECTOR UPDATE IS REQUESTED	CSM/LM STATE VECTOR UPDATE NOT REQUESTED		SH, 15	SH, 14
ORBWFLAG (6, 3)	W-MATRIX IS VALID FOR ORBITAL NAVIGATION	W-MATRIX IS INVALID FOR ORBITAL NAVIGATION		SH, 14	SH, 4, 16
AMOONFLG (2, 0)	STATE VECTOR IN LUNAR SPHERE AT MIDTOAVE	STATE VECTOR IN EARTH SPHERE AT MIDTOAVE	SH, 20	SH, 20	SH, 17, 18
POOFLAG (5, 3)	*N PROGRAM POO	NOT IN PROGRAM POO	SH, 3		
VERB- NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER			WHERE EXECUTED
	ALARM	ALARM CODE = 1703 INSUFFICIENT TIME FOR INTEGRATION, TIG WAS SLIPPED			SH, 19

BIT  
 INSTRUMENTATION LAB  
 INTEGRATION INITIALIZATION  
 DATE: 10/20/68  
 BY: S. E. Shaw  
 COLOSSUS 2D  
 FC-2290  
 P. 1  
 24 26

## ERASABLE LOCATIONS USED

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TDECI <sub>D</sub>	t	TIME TO INTEGRATE TO	CSEC	CSEC	2 <sup>28</sup>
TETCSM <sub>D</sub>	t	TIME TO INTEGRATE TO IN P00	CSEC	CSEC	2 <sup>28</sup>
RCV <sub>V</sub>	$\underline{r}_{con}$	CONIC POSITION VECTOR	M	M	2 <sup>20</sup> /2 <sup>27</sup>
VCV <sub>V</sub>	$\underline{v}_{con}$	CONIC VELOCITY VECTOR	M/CSEC	M/CSEC	2 <sup>7</sup> /2 <sup>5</sup>
TET <sub>D</sub>	t	TIME OF VALIDITY OF STATE VECTOR	CSEC	CSEC	2 <sup>28</sup>
RRECT <sub>V</sub>	$\underline{r}_o$	POSITION VECTOR AT RECTIFICATION	M	M	2 <sup>20</sup> /2 <sup>27</sup>
VRECT <sub>V</sub>	$\underline{v}_o$	VELOCITY VECTOR AT RECTIFICATION	M/CSEC	M/CSEC	2 <sup>7</sup> /2 <sup>5</sup>
TDELTA <sub>V</sub> <sub>V</sub>	$\underline{\delta}$	POSITION DEVIATION VECTOR	M	M	2 <sup>22</sup> /2 <sup>18</sup>
TNUV <sub>V</sub>	$\underline{u}$	VELOCITY DEVIATION VECTOR	M/CSEC	M/CSEC	2 <sup>3</sup> /2 <sup>-1</sup>
TC <sub>D</sub>	t <sub>21</sub>	TIME SINCE RECTIFICATION	CSEC	CSEC	2 <sup>28</sup>
XKEP <sub>D</sub>	x	UNIVERSAL VARIABLE	M <sup>1/2</sup>	M <sup>1/2</sup>	2 <sup>17</sup> /2 <sup>16</sup>
TDEC <sub>D</sub>	t	TIME TO INTEGRATE TO	CSEC	CSEC	2 <sup>28</sup>
PBODY	P	PRIMARY BODY INDICATOR	INTEGER	INTEGER	
IRETURN		LOCATION FOR STORING RETURN ADDRESS	INTEGER	INTEGER	
TAU <sub>D</sub>	$\tau$	TIME INTERVAL FOR CONIC INTEGRATION	CSEC	CSEC	2 <sup>28</sup>
TBASE2		TEMPORARY STORAGE FOR RETURN ADDRESS	INTEGER	INTEGER	
STALTEM		TEMPORARY STORAGE FOR SUBSCRIPT k	INTEGER	INTEGER	
EGRESS		LOCATION FOR STORING RETURN ADDRESS	INTEGER	INTEGER	
PIPTIME <sub>D</sub>	t	BURN TIME	CSEC	CSEC	2 <sup>28</sup>
TAT <sub>D</sub>	t	TIME ACTUALLY INTEGRATED TO	CSEC	CSEC	2 <sup>28</sup>
TRMKCNT		TRACKING RADAR MARK COUNT	INTEGER	INTEGER	
RN <sub>V</sub>	$\underline{r}_{con}$	POSITION VECTOR OF CSM FOR DOWNLINK	M	M	2 <sup>20</sup> /2 <sup>27</sup>
VN <sub>V</sub>	$\underline{v}_{con}$	VELOCITY VECTOR OF CSM FOR DOWNLINK	M/CSEC	M/CSEC	2 <sup>7</sup> /2 <sup>5</sup>
R-OTHER <sub>V</sub>	$\underline{r}_{con}$	POSITION VECTOR OF LM FOR DOWNLINK	M	M	2 <sup>20</sup> /2 <sup>27</sup>
V-OTHER <sub>V</sub>	$\underline{v}_{con}$	VELOCITY VECTOR OF LM FOR DOWNLINK	M/CSEC	M/CSEC	2 <sup>7</sup> /2 <sup>5</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	INTEGRATION INITIALIZATION
FORM 30 REV. 10-69 APPROX. 10-69	COLOSSUS 2D REV. 1 MAY 25 26

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
OMEGMOON <sub>D</sub>			$2.66169947 \times 10^{-8}$	$2.66169947 \times 10^{-8}$	$2^{-23}$
ZEROVEC <sub>V</sub>	(0, 0, 0)	THE ZERO VECTOR	(0.0, 0.0, 0.0)	(0, 0, 0)	ANY
UPMNSVCD <sub>D</sub>		INTEGER 2	2	2	$2^{14}$
TIMDELTD <sub>D</sub>	$\Delta t_{12.5}$	USED IN TEST TO DETERMINE IF TIME TO INTEGRATE TO MUST BE SLIPPED	12.5 SEC	1250 CSEC	$2^{28}$
5/8 <sub>D</sub>		A NON-ZERO CONSTANT	5/8	5/8	$2^3$

## PAD LOADS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
RLS <sub>V</sub>	$\underline{r}_{LS}$	LUNAR LANDING SIGHT VECTOR				

WIT  
 INSTRUMENTATION AP  
 FORM 012 Rev. 1  
 444 *H. E. Hall* JORDYBS  
 444 *Wm. M. Roberts, 52095* COLLOSSUS 2D FC-2290  
 444 *Roberts, M. Date 7-5-58* 1

INTEGRATION INITIALIZATION

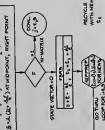
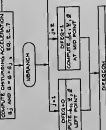
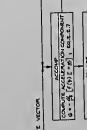
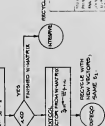
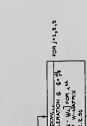
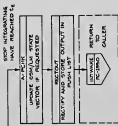
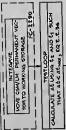
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## ORBITAL INTEGRATION

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS		
TESTLOOP	ENTRY TO ACTUAL INTEGRATION LOOP	SH. 3
TIMESTEP	INTERMEDIATE ENTRY POINT IN INTEGRATION LOOP	SH. 6
INTGRATE	INTERMEDIATE ENTRY POINT IN INTEGRATION LOOP THAT INITIALIZES LOCATIONS FOR FIRST PASS THROUGH LOOP	SH. 8
ACCOMP	COMPUTES THE ACCELERATION COMPONENTS FOR EARTH AND MOON	SH. 9
GAMCOMP	SUBROUTINE THAT COMPUTES ACCELERATION $a_p$ DUE TO THE ATTRACTION OF THE PRIMARY BODY	SH. 23
DIFEQ*0	EVALUATE $\dot{x}$ AND $\dot{y}$ AT THE LEFT HAND POINT	SH. 27
DIFEQ*1	EVALUATE $\dot{x}$ AND $\dot{y}$ AT THE MID-POINT	SH. 27
FBR3	CALCULATE TIME AND CONIC STATE VECTOR AT MIDPOINT AND RIGHT HAND POINT	SH. 28
KEPPREP	SUBROUTINE COMPUTES ESTIMATE OF $x$ AND THEN CALLS KEPLER SUBROUTINE TO CALCULATE CONIC STATE VECTOR	SH. 29
DIFEQ*2	EVALUATE $\dot{x}$ AND $\dot{y}$ AT THE RIGHT HAND POINT AND THEN CALCULATE THE FUNCTION $y$ AND ITS DERIVATIVE $\dot{y}$ AT RIGHT HAND POINT	SH. 32
NEXTCOL	INTERMEDIATE ENTRY POINT FOR INTEGRATING A COLUMN OF THE W-MATRIX	SH. 35
CKMID2	ROUTINE ENTERED BY INTEGRATION IF CALLED BY MIDTOAV	SH. 36
A-PCHK	WRAPS UP THE INTEGRATION ROUTINE WITH A STATE VECTOR UPDATE IF REQUESTED AND A RECTIFICATION	SH. 38
RECTOUT	DOES RECTIFICATION AND STORES OUTPUT IN PUSHLIST	SH. 40
DOW..	ROUTINE THAT CONTROLS THE CALCULATION OF THE ACCELERATION TERMS USED FOR INTEGRATING THE W-MATRIX	SH. 41
DOW..1	SUBROUTINE THAT CALCULATES THE ACCELERATIONS $a_p$ AND $a_q$	SH. 42
RECTIFY	DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS	SH. 43
MINIRECT	ENTRY POINT IN RECTIFY IF $\dot{x}$ , $\dot{y}$ MUST BE INITIALLY ZERO	SH. 43
RECTIFY *13D	ENTRY POINT IN MINIRECT IF VRECT <sub>v</sub> ALREADY STORED	SH. 43
ORIGCHNG	CHANGE ORIGIN OF COORDINATE SYSTEM	SH. 44
REFERENCES FOR ORBITAL INTEGRATION		
1. GUIDANCE SYSTEM OPERATIONS PLAN USING PROGRAM COLOSSUS (GSOE), R-577, SECTION 5, GUIDANCE EQUATIONS, MAY, 1968.		
2. OSTANEK, W. F., USER'S GUIDE FOR ORBITAL INTEGRATION ROUTINE FOR FLIGHT 504, FLIGHT 504 MEMO 5, REV. 1, JUNE, 1967.		
3. OSTANEK AND KEFAUVER, LEVEL II TEST PACKAGE FOR COASTING INTEGRATION SUBROUTINE, MIT/IL, NOVEMBER, 1967.		

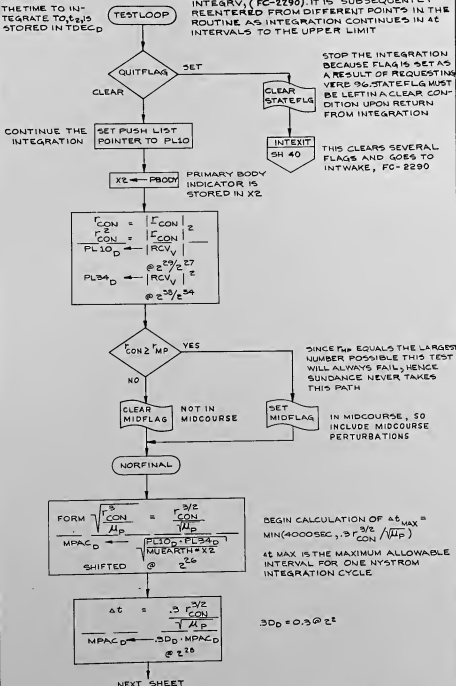
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. White</i> 1/18/68		ORBITAL INTEGRATION	
PROGR	ANALYST <i>R. M. Johnston</i> 1/14/68	DOCUMENT NO.	
DOCNR <i>Repts. to M. E. ...</i> 1/14/68	COLOSSUS 2D	FC-23100	
APPR <i>Repts. to M. E. ...</i> 1/14/68	REV 1		SHEET 1 OF 50

ENTRY TO INTEGRATION IS FROM THE INITIAL STATE VECTOR. THE INITIAL INTEGRATION IS PERFORMED ON VECTOR IN WORKING STORAGE FROM TIME  $t_0$  TO TIME  $t_1$ .



THE TIME TO INTEGRATE TO  $t_2$  IS STORED IN TDEC

THE INITIAL ENTRY INTO TESTLOOP IS FROM INTEGRV, (FC-2290). IT IS SUBSEQUENTLY REENTERED FROM DIFFERENT POINTS IN THE ROUTINE AS INTEGRATION CONTINUES IN  $\Delta t$  INTERVALS TO THE UPPER LIMIT



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARLEY GUIDANCE AND NAVIGATION	
DRAWN <i>D. J. Chouhach</i>		ORBITAL INTEGRATION	
PROGRAM <i>W. M. Robertson</i>		COLOSSUS, DIVISION 4 21D FC-2300	
ANALYSIS <i>W. M. Robertson</i>		REV 1	
CHECKED <i>W. M. Robertson</i>		REV 1	
APPROVED <i>W. M. Robertson</i>		REV 1	

FROM PRECEDING SHEET

SHIFT AND LOAD MPAC SUCH THAT  $3r_{CON}^{3/2}/\sqrt{t_P}$  IS TRUNCATED TO A MULTIPLE OF 128 CSECS, SCALED AT  $z^{20}$

$$\frac{\Delta t_{MAX}}{PL12D} = \frac{3r_{CON}^{3/2}/\sqrt{t_P}}{MPAC_D} @ z^{20}$$

OVERFLOW  
NO

YES

$DT/2 \cdot MAX_D = 4000$   
SECS AT  $z^{20}$

$\Delta t_{MAX} > 4000$   
SECS

YES

NO

MAXOT

$$\frac{\Delta t_{MAX} = 4000 \text{ SEC}}{PL12D} = \frac{DT/2 \cdot MAX_D}{MPAC_D} @ z^{20}$$

LIMIT  $\Delta t_{MAX}$  TO THE MAXIMUM VALUE ALLOWED

AT THIS POINT  
 $\Delta t_{MAX} = \text{MIN}$   
 $(3r_{CON}^{3/2}/\sqrt{t_P}, 4000 \text{ SEC})$

DT/2 COMP

CALCULATE  $\Delta t$ , GUARANTEEING THAT  $\Delta t \leq \Delta t_{MAX}$

$$\frac{\Delta t}{MPAC_D} = \frac{t_2 - t_1}{TDEC_D - TET_D} @ z^{20}$$

$\Delta t$  IS THE TIME INTERVAL BETWEEN  $t_1$  THE CURRENT TIME AS USED IN INTEGRATION LOOP AND  $t_2$  THE UPPER LIMIT. THE VALUE  $t_1$  IN  $TET_D$  IS INCREMENTED BY  $\frac{\Delta t}{2}$  TWICE CORRESPONDING TO POINTS  $j = 2$  AND  $3$ . SEE SH. 24

SGNAGREE  
FORCE SIGN AGREEMENT  
FC-2100

THE SUBROUTINE TAKES THE DOUBLE PRECISION VALUE IN MPAC AND FORCES SIGN AGREEMENT

SHIFT MPAC LEFT 8 PLACES TO SCALE  $\Delta t$  AT  $z^{20}$  AND STORE IN  $DT/z_D$

STORE  $\Delta t$  AT  $z^{20}$ . THIS CAN ALSO BE CONSIDERED AS  $\Delta t/2$  AT  $z^{19}$

NEXT SHEET

ORBITAL  
INTEGRATION I

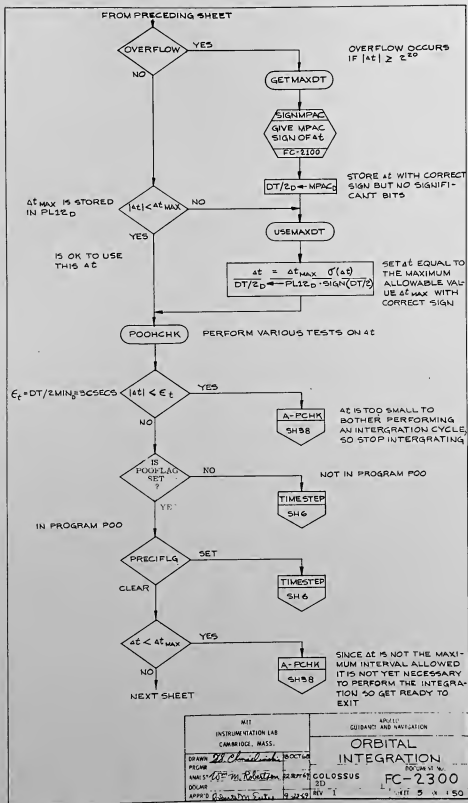
J. J. Clements  
W. M. Robertson

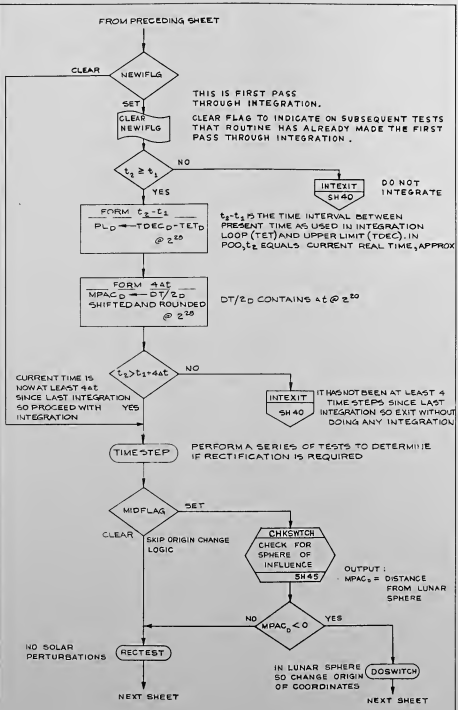
COLOSSUS  
21D

FC-2300

4 50







ORBITAL INTEGRATION

FC-2300

6 50

21

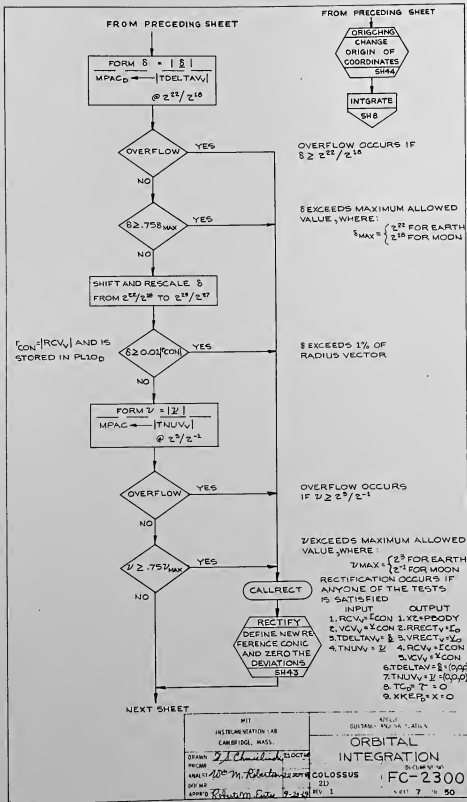
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9-25-67

COLOSSUS

RELATION

CHALMERS



FROM PRECEDING SHEET

INTEGRATE

THIS IS THE ENTRY SEQUENCE FOR INITIALIZING LOCATIONS FOR THE FIRST PASS THROUGH THE INTEGRATION LOOP, LOCATIONS ARE SET UP FOR INTEGRATING THE STATE VECTOR SINCE THE STATE VECTOR IS ALWAYS INTEGRATED FIRST

$ZV \leftarrow TNUV$   
@  $z^7/z^{-1}$   
 $YV \leftarrow TDELTA VV$   
@  $z^{22}/z^{18}$

STORE U, S IN WORKING STORAGE PRIOR TO INTEGRATING THE STATE VECTOR

CLEAR  
J SWITCH

INITIALIZE TO INDICATE THE STATE VECTOR AND NOT THE W-MATRIX IS BEING INTEGRATED

DIFEQO

THIS IS THE ENTRY POINT FOR INITIALIZING LOCATIONS PRIOR TO MAKING THREE PASSES THROUGH THE INTEGRATION LOOP (FOR  $j=1, 2, 3$ ) THE VECTOR BEING INTEGRATED OVER A TIME INTERVAL OF  $\Delta t$  IS EITHER A STATE VECTOR OR A VECTOR IN THE W-MATRIX

$j = 1$   
DIFEQCNT  $\leftarrow 0$

INITIALIZE  $j$ .  
 $j$  TAKES ON THE VALUES 1, 2, 3 CORRESPONDING TO THE LEFT POINT, MIDPOINT, AND RIGHT POINT OF AN INTERVAL OF LENGTH  $\Delta t$ . DIFEQCNT TAKES ON THE VALUES 0, 12D, -24D

$\alpha_j = \beta$   
ALPHAVV  $\leftarrow$  YVV  
@  $z^{22}/z^{26}$

INITIALIZE  $\alpha_j$ .  
 $\alpha_j$  IS THE ESTIMATE OF  $\beta$  USED ON EACH OF THE THREE PASSES THROUGH THE INTEGRATION LOOP

$\lambda = 0$   
HC  $\leftarrow$  DPZERO D

INITIALIZE  $\lambda$ .  
 $\lambda$  TAKES ON THE VALUES 0,  $\frac{\Delta t}{2}$ ,  $\Delta t$  CORRESPONDING TO THE LEFT POINT, MID POINT, AND RIGHT POINT VALUE OF THE INTERVAL  $\Delta t$ .

CLEAR  
J SWITCH

SET

ACCOMP  
SH9

INTEGRATE THE STATE VECTOR

DOW..  
SH41

INTEGRATE A VECTOR FROM THE W-MATRIX

ORBITAL  
INTEGRATION

FC-2300

8

90

D. J. Chudovskiy ELECTRO

W. M. Robertson ELECTRO COLLOSSUS

Robinson, C. S. 9-22-57

ACCOMP COMPUTES THE ACCELERATION COMPONENTS. IT IS ENTERED ON EACH OF THE THREE PASSES THROUGH THE INTEGRATION LOOP, CORRESPONDING TO  $j=1, 2, 3$

ACCOMP

$X1 \leftarrow PBODY$   
 $X2 \leftarrow PBODY$

$PBODY = \begin{cases} 0 & \text{FOR EARTH} \\ 2 & \text{FOR MOON} \end{cases}$

$f_j = 0$   
 $FV \leftarrow ZEROVECV$   
@  $2^{16}/2^{20}$

INITIALIZE  $f_j$   
 $f_j$  IS THE VALUE OF THE SECOND DERIVATIVE, AT POINT  $j$ .

SHIFT AND RESCALE  $\underline{\beta}_j =$   
ALPHAV FROM  $2^{22}/2^{18}$   
TO  $2^{29}/2^{27}$

$\underline{\beta}_j$  IS THE ESTIMATE OF  $\underline{\beta}$   
AT POINT  $j$ .

$\underline{\beta}_j = \underline{\beta}_j + I_{CON}$   
 $BETA_{Vj} \leftarrow ALPHAV_j + RC_{Vj}$   
@  $2^{29}/2^{27}$

$\underline{\beta}_j$  IS AN ESTIMATE OF THE PRECISION VECTOR  $\underline{\beta}$  BASED ON THE LATEST ESTIMATE OF  $\underline{\beta}$  (EQUAL TO  $\underline{\beta}_j$ ) AND THE LATEST VALUE OF  $I_{CON}$

DIMOF LAG

SET

THE W-MATRIX IS TO BE INTEGRATED SO STORE  $\underline{\beta}_j$  IN TEMPORARY STORAGE FOR LATER USE IN SUBROUTINE OOV..1.

THE W-MATRIX IS NOT TO BE INTEGRATED SO DON'T BOTHER TO STORE  $\underline{\beta}_j$ .

CLEAR

$X2 \leftarrow OI_{EQCNT}$

PUT VECTOR POINTER (CORRESPONDING TO A VALUE OF  $j$ ) INTO  $X2$

STORE  $\underline{\beta}_j$   
 $VECTAB_{Vj} \leftarrow X2 \leftarrow BETA_{Vj}$

STORE  $\underline{\beta}_j = \underline{\beta}$  INTO PROPER SPOT IN VECTOR TABLE

$OI_{EQCNT} \leftarrow X2$

RESTORE BOTH LOCATIONS

$\underline{y}_{jk} = (\underline{\beta}_j)$  UNIT  
 $\alpha_j = |\underline{\beta}_j|$   
ALPHAW  $\leftarrow$  UNIT (ALPHAW)  
@  $2^1$   
ALPHAM  $\leftarrow$  |ALPHAV|  
@  $2^9/2^{27}$

$\underline{y}_{jk} = \underline{\beta}$   
 $\alpha_j = \beta = |\underline{\beta}|$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ASTROPHYSICAL OBSERVATORY CAMBRIDGE, MASS.
APPROVED BY: <i>D. Chandrasekhar</i> 12 OCT 68	APPROVED BY: <i>W. M. Roberts</i> 22 NOV 68
PROJECT: <i>COLOSSUS</i>	PROJECT: <i>COLOSSUS</i>
APPROVED BY: <i>Robert M. Cutler</i> 12 OCT 68	APPROVED BY: <i>Robert M. Cutler</i> 12 OCT 68
REV 1	REV 1
	FC-2300
	4 9 50

FROM PRECEDING SHEET

$Q_p$  IS THAT PORTION OF THE SECOND DERIVATIVE  $f_j$  DUE TO THE ATTRACTION OF THE PRIMARY BODY, CONSIDERED AS A POINT MASS



INPUT  
1. BETAV<sub>0</sub> =  $\beta_j = \dot{r}(t)$   
2. ALPHAV<sub>0</sub> =  $\alpha_j = \dot{\alpha}_j$   
3. ALPHAM<sub>0</sub> =  $\alpha_j = \dot{\alpha}_j$

OUTPUT  
1. FV<sub>0</sub> =  $Q_p$   
2. BETAV<sub>0</sub> =  $\beta_j = (\beta_j)$  UNIT =  $\dot{r}$   
3. BETAM<sub>0</sub> =  $\beta_j = |\beta_j| = |\dot{r}|$

ALPHAV<sub>0</sub> ← MPAC<sub>0</sub> ← BETAV<sub>0</sub>

SAVE  $\beta_j = (\beta_j)$  UNIT =  $\dot{r}$

S2 ← X1

SAVE X1

ALPHAM<sub>0</sub> ← MPAC<sub>0</sub> ← BETAM<sub>0</sub>

SAVE  $\beta_j$

MIDFLAG

SET: INCLUDE SOLAR PERTURBATIONS

CLEAR

NO SOLAR  
PERTURBATIONS

OBLATE

SH14

NEXT SHEET

3511

INSTRUMENTATION LAB  
ASTRONOMICAL OBSERVATORY

10/10/68

10/10/68

10/10/68

10/10/68

ORBITAL INTEGRATION

COLOSSUS

FC-2300

FROM PRECEDING SHEET

CALCULATE THE DISTURBING ACCELERATIONS  
 $\underline{a}_{da} + \underline{a}_{ds}$

MPAC<sub>0</sub> ← TET<sub>0</sub>

LSPOS  
 CALCULATE  
 POSITION OF  
 SUN AND MOON  
 FC-2286

INPUT:

1. MPAC<sub>0</sub> = GROUND ELAPSED TIME

OUTPUT:

1. MPAC<sub>v</sub> =  $\Gamma_{EM}$ , POSITION OF MOON,  $z^{2D}$

2. PLZ<sub>v</sub> =  $\Gamma_{ES}$ , POSITION OF SUN,  $z^{18}$

X1 ← S2

CLEAR

MOONFLAG

SET

X2 ← 2

SET UP FOR  
 EARTH PRIMARY  
 $\Gamma_{ps} = \Gamma_{EM}$

$\Gamma_{ps} = -\Gamma_{EM}$

MPAC<sub>v</sub> ← -(MPAC<sub>v</sub>)

SET UP  
 FOR MOON  
 PRIMARY  
 EQ 2.2.19,  
 PAGE

X2 ← 0

STORE  $\Gamma_{ps}$

RPQV<sub>v</sub> ← BETAV<sub>v</sub> ← MPAC<sub>v</sub>  
 @  $z^{2D}$

NEXT SHEET

FILE IN-TELEGRAM LAB CAMBRIDGE, MASS.		APPROVED COMMANDER AND VALIDATED	
ORBITAL INTEGRATION		DOCUMENT NO.	
COLLOSSUS		FC-2300	
REV 1		SHEET 11 of 50	

APPROVED: *[Signature]* P-22-57  
 ANALYST: *[Signature]*  
 DATE: *[Date]*  
 TITLE: *[Title]*

FROM  
PRECEDING SHEET

STORE  $\underline{r}_{ES}$   
RPSV<sub>v</sub> ← PL 2<sub>v</sub>  
@ 2<sup>58</sup>

DIMOFLAG

CLEAR

NO W-MATRIX  
INTEGRATION

SET

$\underline{r}_{gc} = \underline{r} - \underline{r}_{pp}$   
MPAC<sub>v</sub> ← ALPHA<sub>v</sub> · ALPHA<sub>m</sub> - BETA<sub>v</sub>  
@ 2<sup>59</sup>

EQ 2.2.21,  
PAGE 5.2-19

X2 ↔ DIFEQNT

LOAD X2 WITH POINTER

STORE  $\underline{r}_{gc}$  IN TABLE  
(VECTAB + 6 # X2)<sub>v</sub> ← MPAC<sub>v</sub>

X2 = 0, -12D, -24D

X2 ↔ DIFEQNT

RESTORE VALUES

NEXT SHEET

MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS

RESEARCH CENTER

ORBITAL  
INTEGRATION

*G. J. Sposito*

APPROV

*Robert M. Carter*

RESEARCH CENTER

FC-2300

*Robert M. Carter*

12 50





FROM PRECEDING SHEET

OBLATE

$X2 \leftarrow P_{BODY}$

$P_{BODY} = \begin{cases} 0 & \text{FOR EARTH} \\ 2 & \text{FOR MOON} \end{cases}$

SET PUSH LIST  
POINTER TO ZERO

$r$  IS THE MAGNITUDE OF THE LATEST  
ESTIMATE OF THE PRECISION POSITION,  
IT EQUALS  $R$ ;  $r_{DP}$  IS THE RADIUS OF RELEVANCE  
OF THE PRIMARY BODY. IF THE SPACECRAFT  
IS OUTSIDE OF THIS SPHERE THEN THE  
ACCELERATION  $a_{dp}$  IS IGNORED.

$r \geq r_{DP}$

YES

SPACECRAFT IS  
OUTSIDE SPHERE  
OF RELEVANCE

NO

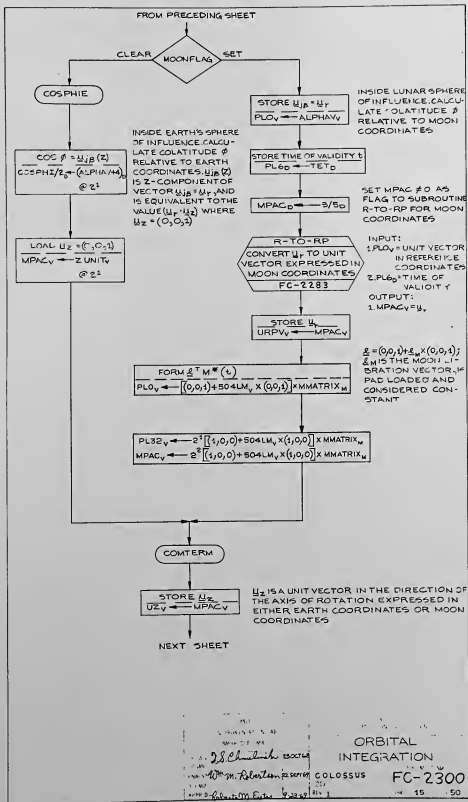
SPACECRAFT IS INSIDE  
SPHERE OF RELEVANCE  
SO CALCULATE  $a_{dp}$

NBRANCH  
SH21

DO NOT  
CALCULATE  $a_{dp}$

NEXT SHEET

MIT ASTRONOMICAL OBSERVATORY CAMBRIDGE, MASS.	SACD 75 GUSTAFSON, ANDERSON, LARSEN ORBITAL INTEGRATION
<i>John K. Anderson</i> 22 SEP 65 23	COLLOSSUS FC-2300 REV 7
	ANALYST # 50



FROM PRECEDING SHEET

$$\frac{P_2'}{P_{L0D}} = \frac{3 \cos \phi}{\cos \phi \cdot \frac{1}{2} \cdot \frac{3}{32} \cdot \frac{1}{2^6}}$$

$$3/32D = 3.0 @ 2^5$$

$$\frac{\text{FORM } 15 \cos^2 \phi}{MPACD} = \frac{15 \cos^2 \phi}{(\cos \phi \cdot \frac{1}{2} \cdot \frac{15}{64} \cdot \frac{1}{2^6})}$$

$$15/16D = 15.0 @ 2^4$$

$$\frac{P_3'}{PL2D} = \frac{1}{2} \frac{(15 \cos^2 \phi - 3)}{MPACD} = \frac{1}{2} \frac{(15 \cos^2 \phi - 3)}{(\cos \phi \cdot \frac{1}{2} \cdot \frac{15}{64} \cdot \frac{1}{2^6})}$$

3/64D = 3.0 @ 2^4  
DIVISION BY 2 IS ACCOMPLISHED BY A CHANGE IN THE SCALE FACTOR

$$\frac{\text{FORM } \frac{7}{2} \cos \phi P_3'}{PL4D} = \frac{7/2 \cos \phi P_3'}{7/12D \cdot \cos \phi \cdot \frac{1}{2} \cdot \frac{15}{64} \cdot \frac{1}{2^6}}$$

$$7/12D = \frac{7}{3} @ 2^2$$

$$\frac{\text{FORM } \frac{4}{3} P_2'}{MPACD} = \frac{4/3 P_2'}{2/3D \cdot \frac{1}{2} \cdot \frac{15}{64} \cdot \frac{1}{2^6}}$$

$$2/3D = \frac{4}{3} @ 2^1$$

$$\frac{P_4'}{PL4D} = \frac{4}{3} \cos \phi P_3' - \frac{4}{3} P_2'$$

$$\frac{\text{FORM } \frac{3}{2} \cos \phi P_4'}{PL6D} = \frac{3/2 \cos \phi P_4'}{3/16D \cdot \cos \phi \cdot \frac{1}{2} \cdot \frac{15}{64} \cdot \frac{1}{2^6}}$$

$$3/16D = \frac{3}{2} @ 2^3$$

$$\frac{P_5'}{MPACD} = \frac{3}{2} \cos \phi P_4' - \frac{5}{4} P_3'$$

$$5/128D = \frac{5}{4} @ 2^3$$

$$\frac{\text{FORM } \frac{J_{4P} P_D}{J_{3P}} P_5'}{MPACD} = \frac{J_{4P} P_D}{J_{3P}} \frac{P_5'}{(J_{4REG}/J_{3P}^2)D \cdot MPACD}$$

$$J_{4P} P_D / J_{3P} = \begin{cases} \frac{J_{4E} E}{J_{3E}} = 4991607.391 @ 2^{26} \\ \text{FOR EARTH} \\ \frac{J_{4M} M}{J_{3M}} = -176236.02 @ 2^{25} \\ \text{FOR MOON} \end{cases}$$

NEXT SHEET

ORBITAL  
INTEGRATION

FC-2300

28. Chandra 2000  
M. Robertson 2000  
Robert M. Foster 9-21-51

COLLUSUS  
2D

16 .5U

FROM PRECEDING SHEET

$$\text{FORM } \frac{J_{3P} P_3' / r + P_4'}{J_{3P}} = \frac{J_{3P} \left(\frac{r_P}{r}\right) P_3' + P_4'}{J_{3P}}$$

$$\text{MPAC}_D \rightarrow \text{MPAC}_D / \text{ALPHAM}_D + \text{PL} \text{ @ } 2^7$$

$$\text{FORM } \frac{J_{3P} \left(\frac{r_P}{r}\right) P_3' + P_4'}{J_{3P} \left(\frac{r_P}{r}\right)^2 P_3' + \frac{J_{3P} r_P}{J_{3P} \left(\frac{r_P}{r}\right)} P_4' / r}$$

$$= \frac{J_{3P} \left(\frac{r_P}{r}\right)^2 P_3' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_4'}{J_{3P} \left(\frac{r_P}{r}\right)}}{J_{3P} \left(\frac{r_P}{r}\right)^2 P_3' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_4'}{J_{3P} \left(\frac{r_P}{r}\right)}}$$

$$\text{MPAC}_D \rightarrow \text{MPAC}_D \cdot \frac{(2J_{3P} R E / J_{3P} X_2)_D}{\text{ALPHAM}_D} \text{ @ } 2^8$$

$$\frac{J_{3P} r_P}{J_{3P}} = \begin{cases} \frac{J_{3P} r_P}{J_{3P}} = 1.35542636 \times 10^{27} \\ \frac{J_{3P} r_P}{J_{3P}} = .3067493316 \times 10^{18} \end{cases}$$

FOR EARTH  
FOR MOON

$$\text{FORM } K_{2U} = \frac{J_{3P} \left(\frac{r_P}{r}\right)^2 P_3' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_4'}{J_{3P} \left(\frac{r_P}{r}\right)} + P_4'}{J_{3P} \left(\frac{r_P}{r}\right)^2 P_3' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_4'}{J_{3P} \left(\frac{r_P}{r}\right)}}$$

$$\text{TVEL}_V \rightarrow \left[ \text{MPAC}_D + \text{PL} \right]_D \text{ ALPHAV} \text{ @ } 2^6$$

$$\text{FORM } \frac{J_{3P} P_4'}{J_{3P}}$$

$$\text{MPAC}_D \rightarrow (4 \text{REQ})_D \text{ @ } 2^8 \text{ SHIFTED @ } 2^{34}$$

$$\text{FORM } \frac{J_{3P} P_4' / r + P_3'}{J_{3P}} = \frac{J_{3P} \left(\frac{r_P}{r}\right) P_4' + P_3'}{J_{3P}}$$

$$\text{MPAC}_D \rightarrow \text{MPAC}_D / \text{ALPHAM}_D + \text{PL} \text{ @ } 2^5$$

$$\text{FORM } \frac{J_{3P} \left(\frac{r_P}{r}\right) P_4' + P_3'}{J_{3P} \left(\frac{r_P}{r}\right)^2 P_4' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_3'}{J_{3P} \left(\frac{r_P}{r}\right)}}$$

$$= \frac{J_{3P} \left(\frac{r_P}{r}\right)^2 P_4' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_3'}{J_{3P} \left(\frac{r_P}{r}\right)}}{J_{3P} \left(\frac{r_P}{r}\right)^2 P_4' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_3'}{J_{3P} \left(\frac{r_P}{r}\right)}}$$

$$\text{MPAC}_D \rightarrow \text{MPAC}_D \cdot \frac{(2J_{3P} R E / J_{3P} X_2)_D}{\text{ALPHAM}_D} \text{ @ } 2^8$$

$$\text{FORM } K_{2U2} = \frac{J_{3P} \left(\frac{r_P}{r}\right)^2 P_4' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_3'}{J_{3P} \left(\frac{r_P}{r}\right)} + P_3'}{J_{3P} \left(\frac{r_P}{r}\right)^2 P_4' + \frac{J_{3P} \left(\frac{r_P}{r}\right) P_3'}{J_{3P} \left(\frac{r_P}{r}\right)}}$$

$$\text{MPAC}_V \rightarrow \left[ \text{MPAC}_D + \text{PL} \right]_D \text{ @ } 2^6 \text{ UZV}$$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ORBITAL INTEGRATION
DESIGNED BY: <i>J.S. Chivvis</i>	FC-2300
FOR USE BY: <i>W.D. Robertson</i>	REV 1
DATE: <i>11/20/59</i>	17 50

FROM PRECEDING SHEET

$$\text{FORM } K_2 \underline{U}_r - K_2 \underline{U}_z$$

$$\text{TVEC}_V \leftarrow \text{TVEC}_V - \text{MPAC}_V$$

@  $Z^6$

$$\text{NORMALIZE } r$$

$$\text{MPAC}_D \leftarrow \text{ALPHAM}_D$$

$$\text{NORMALIZE AT } \frac{Z^{20} \cdot \pi / 2 \cdot 21 \cdot \pi}{Z}$$

THE NORMALIZING VALUE - m  
IS STORED IN X1

$$\text{FORM } r^4$$

$$\text{MPAC}_D \leftarrow (\text{MPAC}_D)^4$$

@  $Z^{16} \cdot 4\pi / Z^{100} \cdot 4\pi$

$$\text{NORMALIZE AND STORE } r^4$$

$$\text{BLOC}_D \leftarrow \text{MPAC}_D$$

$$\text{NORMALIZED AT } \frac{Z^{136} \cdot 4\pi \cdot \pi}{Z^{100} \cdot 4\pi}$$

THE NORMALIZING VALUE - n  
IS STORED IN S1

$$\text{FORM } \frac{J_{22} r^2 \underline{U}_r^2 \underline{U}_p}{r^4}$$

$$\text{MPAC}_C \leftarrow (J_{22} \text{REQSQ} \cdot XZ)_D / \text{MPAC}_D$$

$J_{22} r^2 \underline{U}_p^2$

$J_{22} r^2 \underline{U}_p^2 = 2.75501139 \times 10^{22}$   
B-7Z FOR EARTH

$J_{22} r^2 \underline{U}_p^2 = 0.3067493316 \times 10^{28}$   
B-6O FOR MOON

$$\text{FORM } \left[ K_2 \underline{U}_r - K_2 \underline{U}_z \right] \frac{J_{22} r^2 \underline{U}_p^2}{r^4} = \frac{\text{MPAC}_C}{r^2 \cdot Z^2} \underline{U}_r \left( \frac{r \underline{U}_r}{r} \right) \left[ P_{11} \underline{U}_r - P_{12} \underline{U}_z \right]$$

$$\text{MPAC}_V \leftarrow \text{TVEC}_V \cdot \text{MPAC}_D$$

THIS IS  $B_{22}$  FOR THE  
EARTH OR THE MAJOR  
PART OF  $B_{21}$  FOR THE  
MOON!

CLEAR  
OVFFIND  
IF SET

$$\text{FORM } -3m - n$$

$$X1 \leftarrow 3 \cdot X1 + S1$$

NEXT SHEET

$$\left\{ K_2 \underline{U}_r - K_2 \underline{U}_z \right\} \frac{J_{22} r^2 \underline{U}_p^2}{r^4}$$

$$= \left\{ \frac{J_{22}}{J_{22}} \left( \frac{r \underline{U}_r}{r} \right)^2 P_2' - \frac{J_{22}}{J_{22}} \left( \frac{r \underline{U}_r}{r} \right) P_4' + P_5' \right\} \underline{U}_r - \left[ \frac{J_{22}}{J_{22}} \left( \frac{r \underline{U}_r}{r} \right)^2 P_4' + \frac{J_{22}}{J_{22}} \left( \frac{r \underline{U}_r}{r} \right) P_5' + P_2' \right] \underline{U}_z \left\} \frac{J_{22} r^2 \underline{U}_p^2}{r^4}$$

$$= \frac{J_{22}}{r^2} \left\{ \left[ \frac{r \underline{U}_r}{r} \right]^2 P_2' + \frac{r \underline{U}_r}{r} \left[ \frac{r \underline{U}_r}{r} \right] P_4' + \frac{r \underline{U}_r}{r} \left[ \frac{r \underline{U}_r}{r} \right] P_5' \right\} \underline{U}_r - \left[ \frac{r \underline{U}_r}{r} \left[ \frac{r \underline{U}_r}{r} \right]^2 P_4' + \frac{r \underline{U}_r}{r} \left[ \frac{r \underline{U}_r}{r} \right] P_5' + \left[ \frac{r \underline{U}_r}{r} \right]^2 P_2' \right] \underline{U}_z$$

$$= \frac{J_{22}}{r^2} \sum_{i=2}^5 \frac{r \underline{U}_r}{r} \left[ \frac{r \underline{U}_r}{r} \right]^i \left[ P_{i+1}' \underline{U}_r - P_i' \underline{U}_z \right]$$

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*S. Chelishvili*

10<sup>th</sup> M. Relevance 20079 COLOSSUS

FC-2300

18 90

FROM PRECEDING SHEET

$$\begin{aligned} \dot{f}_j &= f_j + \frac{3}{2} d_M \\ MPAC_V &\leftarrow FV_V + MPAC_V z^2 \text{EED} - X_1 \end{aligned}$$

$\alpha_{LDMR} + \text{ZONAL OBLATE}$

OVERFLOW

YES

IF OVERFLOW OCCURS DUE TO EXCESSIVELY LARGE ACCELERATIONS, GO BACK, DO A KEPLER UPDATE, RECTIFY, AND TRY AGAIN

GOBAQUE  
SH. 22

NO

$$FV_V \leftarrow MPAC_V$$

MOONFLAG

CLEAR

NBRANCH  
SH 21

THE FOLLOWING CALCULATIONS VALID FOR MOON ONLY

SET

$$\begin{aligned} \text{form } \frac{5(X_M^2 - Y_M^2)}{r^2} \frac{1}{r} \\ PL2_V \leftarrow \frac{5((URPV + 2)_0^2 - URPV_0^2)}{\text{SCALED } @ 2^3} \text{ALPHAV} \end{aligned}$$

$$\begin{aligned} \text{equivalent to } \frac{2X_M}{r} \frac{1}{r} + \frac{5(X_M^2 - Y_M^2)}{r^2} \frac{1}{r} \\ PL2_V \leftarrow PL2_V + URPV_0 \cdot PL32_V \\ \text{SCALED } @ 2^3 \end{aligned}$$

$$\begin{aligned} \text{equivalent to } \frac{5(X_M^2 - Y_M^2)}{r^2} \frac{1}{r} + \frac{2X_M}{r} \frac{1}{r} + \frac{2Y_M}{r} \frac{j}{r} \\ PL2_V \leftarrow PL2_V + z^4(URPV + 2)_0 (PL32_V \times UZ_V) \end{aligned}$$

$$MPAC_D \leftarrow \text{COSPH} / z_0$$

NEXT SHEET

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DRAWN: <i>P. M. ...</i> CHECKED: <i>W. M. ...</i> BY: <i>...</i> APPROVED: <i>Robert M. ...</i>	ORBITAL INTEGRATION DOCUMENT NO. <b>FC-2300</b> REV. 1 APR 1966

FROM PRECEDING SHEET

$$\begin{aligned} &\text{form } 5C\cos^2\phi \\ \text{PLB}_0 &\leftarrow \text{MPAC}_0^2 \\ &\text{SCALED @ } 2^5 \end{aligned}$$

$$\begin{aligned} &\text{form } 1 - 7C\cos^2\phi \\ \text{MPAC}_0 &\leftarrow 1 - (2\text{MPAC}_0^2 + \text{PLB}_0) \\ &\text{SCALED @ } 2^5 \end{aligned}$$

$$\begin{aligned} &\text{form } \frac{5X_M}{F} (1 - 7C\cos^2\phi) \underline{U}_r \\ \text{MPAC}_V &\leftarrow \text{MPAC}_0 \text{URPV}_0 \text{ALPHAV}_V \\ &\text{SCALED @ } 2^5 \\ \text{MPAC}_V &\leftarrow \text{PLB}_V \end{aligned}$$

VECTOR IN MPAC EXCHANGED WITH OP VALUE ( $5C\cos^2\phi$ ) IN PLB

$$\begin{aligned} &\frac{5X_M}{F} (1 - 7C\cos^2\phi) \underline{U}_r + (5C\cos^2\phi - 1) \underline{U}_M \\ \text{PLB}_V &\leftarrow \text{MPAC}_V + (\text{PLB}_0 - 1) \text{PLZ}_V \\ &\text{SCALED @ } 2^5 \end{aligned}$$

$$\begin{aligned} &\frac{5X_M}{F} (1 - 7C\cos^2\phi) \underline{U}_r + (5C\cos^2\phi - 1) \underline{U}_M + \frac{10X_M Z_M}{F^2} K_M \\ \text{PLB}_V &\leftarrow \text{PLB}_V + 10 \text{URPV}_0 (\text{URPV}_0 + 4) \cdot \text{UZ}_V \\ &\text{SCALED @ } 2^5 \end{aligned}$$

$$\begin{aligned} &3\mu_{122} \left( \frac{\Gamma_M}{F} \right)^2 \left[ -\frac{5(X_M^2 - V_M^2)}{F^2} \underline{U}_r + \frac{2X_M}{F} \underline{U}_M - \frac{2Y_M}{F} \underline{U}_N \right] \\ &+ \frac{3}{2} \mu_{12} C_{31} \left( \frac{\Gamma_M}{F} \right)^3 \left[ \frac{5X_M}{F} (1 - 7C\cos^2\phi) \underline{U}_r + (5C\cos^2\phi - 1) \underline{U}_M + \frac{10X_M Z_M}{F^2} K_M \right] \\ \text{MPAC}_V &\leftarrow 2 \cdot \left( \frac{-X_{127} \mu_{122} C_{31} \Gamma_M}{\text{ALPHAV}_0} \text{PLB}_V + \text{PLZ}_V \right) \text{SCALED @ } 2^{-20} \end{aligned}$$

$J_{22}$  TERM ADDED TO  $C_{31}$  TERM,  
STORED IN PLO

$$\text{MPAC}_V \leftarrow \text{MPAC}_V + \text{FV}_V$$

OVERFLOW

YES

GOBAQUE  
SH22

NO

$$\text{FV}_V \leftarrow \text{MPAC}_V$$

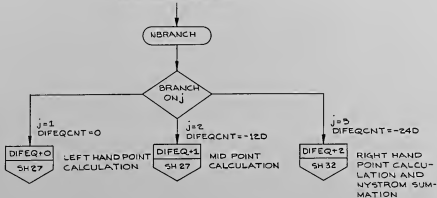
$$\text{X2} \leftarrow \text{PBODY}$$

NEXT SHEET

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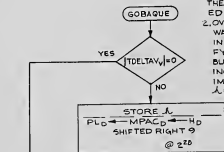


FROM PRECEDING SHEET



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DRAWN <i>J. Chubb</i>	SECTION	COLLOSSUS	FC-2300
FRONT		REV. I	21 * 50
ANALYST <i>M. Robertson</i>	DATE		
DESIGN			
APPROV. <i>G. J. ...</i>	DATE		

GOBAQUE IS ENTERED IF EITHER:  
 1. OVERFLOW OCCURRED IN GAMCOMP WHEN THE SECOND DERIVATIVE INCREMENT WAS ADDED TO  $f_j$ , OR,  
 2. OVERFLOW OCCURRED IN OBLATE WHEN  $Q_{dp}$  WAS ADDED TO  $q_p$ .  
 IN EITHER CASE DO A KEPLER UPDATE, RECTIFY, AND GO BACK AND INTEGRATE AGAIN, BUT NOW WITH A NEW REFERENCE CONIC. ELIMINATE THE PROBLEM OF OVERFLOW.  
 $\lambda = 0, \frac{\Delta t}{2}, \Delta t$



$$\lambda = 0, \frac{\Delta t}{2}, \Delta t$$

$$t_D = t_{21} - \lambda$$

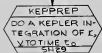
$$TAL_D \leftarrow TC_D - MPAC_D$$

$t_D$  = DESIRED TRANSFER TIME. IT MUST BE REDUCED BY  $\lambda$  TO MAKE TIME CORRESPOND TO THE PREVIOUS VALUE OF  $j$  SINCE RESULTS WERE VALID FOR THAT VALUE OF  $j$  (I.E. THERE WAS NO OVERFLOW)

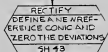
$$t_2 = t_2 - \lambda$$

$$TET_D \leftarrow TET_D - PL_D$$

$t_2$  IS REDUCED BY  $\lambda$  TO MAKE IT AGREE WITH TIME OF VALIDITY OF  $RCV_V, VCV_V$



INPUT	OUTPUT
1. BODY = 1 FOR EARTH 2 FOR MOON	1. $RCV_V = I(t_2)$
2. $RCV_V = I'(t_2)$	2. $VCV_V = V(t_2)$
3. $VCV_V = V'(t_2)$	3. $TC_D = t_2$ , TIME CONVERGED
4. $KPE_D = X'$	TO $\approx t_D$
5. $TAL_D = t_D$ , DESIRED TIME	4. $XPREV = X * XKEP_D$
6. $TC_D = t_{21}$	{ CLEAR FOR EARTH
7. MOONFLAG	{ SET FOR MOON



NOTE: OUTPUT IS FOR ENTIRE KEPPREP AND KEPLER COMPUTATIONS (SEE FC-2310: CONIC SUBROUTINES)

THE NEW REFERENCE CONIC IS BASED ON THE OUTPUT OF THE KEPLER UPDATE OF THE STATE VECTOR AND THE DEVIATIONS CALCULATED BY PRECISION INTEGRATION



THIS INDICATES THE VECTOR RPQ MUST BE CALCULATED



GO BACK AND INTEGRATE AGAIN USING THE NEW REFERENCE CONIC AND ZERO DEVIATIONS

INT-ABRT

POOD00  
FC-2140

POOD00 CLEANS OUT ALL RESTARTS (EXCEPT THOSE ASSOCIATED WITH SERVICER, IF RUNNING), DOES A RESTART, RESULTING IN POO. LIGHTS ALARM LIGHT, SETS ALARM CODE (OCT 20430; POSITION DEVIATION VECTOR = 0)

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22 50

THIS SUBROUTINE COMPUTES THE ACCELERATION TERM  $g_p$  DUE TO THE ATTRACTION OF THE PRIMARY BODY (EARTH OR MOON) CONSIDERED AS A POINT MASS

GAMCOMP

SET PUSH LIST  
POINTER TO ZERO

STORE  $\beta_j^2 = \beta_j \beta_j = |r|^{-2}$   
PL00 ← BETAVV · BETAVV  
SHIFTED AND NORMALIZED

THE VALUE  $\beta_j^2$  IS NORMALIZED AND ROUNDED BEFORE IT IS STORED. THE NORMALIZING VALUE -N IS STORED IN PL31

STORE  $\alpha_j = \delta = |\beta_j|$   
PL20 ← ALPHAM0  
NORMALIZED AND SHIFTED

THE NORMALIZING VALUE -M IS STORED IN PL32

$\mu_j = (\beta_j) \text{UNIT} = \beta_j r$   
 $\beta_j = |\beta_j| = r / \text{UNIT}(\text{BETAVV})$   
BETAM0 ← BETAVV

NORMALIZE  $\beta_j$   
MPAC0 ← BETAM0  
NORMALIZED

THE NORMALIZING VALUE -P IS STORED IN PL33

$\rho_j = \frac{\alpha_j}{\beta_j} = \frac{\delta}{r}$   
PL20 ← PL20 / MPAC0  
@  $2^{M+P+1}$

X1=0

S1 ← -7  
S2 ← -6

FOR EARTH

X1=2

S1 ← -9  
S2 ← -4

FOR MOON

EXCHANGE X2 AND S1 X2 = -7/-9

FORM SCALING VALUE -7/-9-MIP  
X2 ← X2 + PL32 - PL33

LOAD AND SHIFT  $\beta_j$   
MPAC0 ← PL20 · 2<sup>X2</sup>

NEXT SHEET

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FROM PRECEDING SHEET

EXCHANGE S1 AND X2

STORE  $P_j$   
 $PLA_0 \leftarrow MPAC_0$   
 @  $2^1$

STORE  $P_j$   
 $PL6_0 \leftarrow MPAC_0$   
 SHIFTED @  $2^2$

FORM  $2u_{jx} \cdot y_{j\beta}$   
 $MPAC_0 \leftarrow 2ALPHA_{Vj} \cdot BETA_{Vj}$   
 @  $2^2$

MULTIPLICATION BY 2 IS ACCOMPLISHED BY A LEFT SHIFT OF ONE PLACE

FORM  $P_j' - 2u_{jx} \cdot y_{j\beta} = \frac{P_j'}{P_j}$   
 $PL6_0 \leftarrow MPAC_0 \leftarrow PL6_0 \cdot MPAC_0$   
 @  $2^2$

$q_j = (P_j' - 2u_{jx} \cdot y_{j\beta}) / P_j$   
 $PL0_0 \leftarrow MPAC_0 \leftarrow MPAC_0 \cdot PLA_0$   
 SHIFTED @  $2^2$

FORM  $1 + q_j$   
 $PL10_0 \leftarrow MPAC_0 \leftarrow DQUARTER_0 + MPAC_0$   
 @  $2^2$

DQUARTER<sub>0</sub> = 1.0 @  $2^2$

FORM  $(1 + q_j)^{3/2}$   
 $PL12_0 \leftarrow MPAC_0 \leftarrow PL10_0 \cdot MPAC_0$   
 @  $2^3$

FORM  $1 + (1 + q_j)^{3/2}$   
 $PL14_0 \leftarrow DQUARTER_0 + MPAC_0$   
 @  $2^2$

MPAC IS FIRST SHIFTED LEFT 1 TO A SCALING OF  $2^2$

FORM  $\frac{(1 + q_j + 2)q_j + 3}{1 + (1 + q_j)^{3/2}} = \frac{3 + 3q_j + q_j^2}{1 + (1 + q_j)^{3/2}} = \frac{f(q_j)}{g_j}$   
 $MPAC_0 \leftarrow (PL10_0 + HALFOP_0) \cdot PL6_0 + THREE_{B_0}$   
 $PL14_0$  @  $2^1$

EQ 2.2.10, REF 1  
 HALFOP<sub>0</sub> = 2.0 @  $2^2$   
 THREE/B<sub>0</sub> = 3.0 @  $2^3$   
 THE NUMERATOR IS SHIFTED LEFT 1 PLACE PRIOR TO ADDING THREE/B<sub>0</sub>

NEXT SHEET

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 M. Robertson  
 Robert M. Eddy

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FROM PRECEDING SHEET

$$\text{FORM } \frac{f(\tau_j) \cdot \rho_j}{\rho_j} = \frac{f(\tau_j)}{\rho_j}$$

$$\text{MPAC}_D \leftarrow \text{MPAC}_D \cdot \text{PL6}_D$$

@Z<sup>3</sup>

$$\text{FORM } \frac{f(\tau_j)}{\rho_j} \Delta j_B + \Delta j_M$$

$$\text{PL16}_V \leftarrow \text{MPAC}_D \cdot \text{BETAV}_V + \text{ALPHAV}_V$$

@Z<sup>4</sup>

$$\text{FORM } \frac{\Delta_j^2 (1 + \rho_j)^{3/2}}{\text{MPAC}_D + \text{PL0}_D \cdot \text{PL30}_D}$$

NORMALIZING FACTOR - 5 IS STORED IN PL30  
NORMALIZED AND ROUNDED

$$\text{FORM } \frac{\rho_j}{\Delta_j^2 (1 + \rho_j)^{3/2}}$$

$$\text{MPAC}_D \leftarrow \frac{\text{PL2}_D}{\text{MPAC}_D}$$

$$\text{FORM } \Delta_j \frac{\rho_j}{\Delta_j^2 (1 + \rho_j)^{3/2}}$$

$$\text{MPAC}_D \leftarrow (\text{MUEARTH} + \text{XZ})_D \cdot \text{MPAC}_D$$

$$\text{FORM } \frac{\Delta_j \rho_j}{\Delta_j^2 (1 + \rho_j)^{3/2}} \left[ \frac{f(\tau_j)}{\rho_j} \Delta j_B + \Delta j_M \right]$$

$$\text{MPAC}_V \leftarrow \text{MPAC}_D \cdot \text{PL16}_V$$

EXCHANGE XZ AND S1

LOAD -7/-9 INTO XZ

$$\text{FORM } \frac{(-7/-9) + (-6/-4) - (-5) - (-1) = -13 + 5 + 11}{\text{XZ} \leftarrow \text{XZ} + 32 - \text{PL30} - \text{PL31}}$$

THIS IS THE UNNORMALIZING VALUE

CLEAR  
OVIND

TURN OFF OVERFLOW INDICATOR

NEXT SHEET

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AMHERST, MASS.  
LIBRARY *J. J. Chiriac*  
SERIALS  
NAME *M. M. Robertson*  
DATE MAR 23 1964  
APPROX *Robert M. Carter*

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FROM PRECEDING SHEET

SHIFT MPAC RIGHT -X2-1 PLACES  
TO A SCALING OF FV

EXCHANGE XE AND S1 RESTORE XE

$$f_j = \frac{f_j - \frac{H P \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[ \frac{f(q_j)}{\rho_j} \Delta_j \delta + \Delta_j \alpha \right]}{FV_j \leftarrow FV_j + MPACV}$$

THIS ADDS TO THE SECOND DERIVATIVE  $\frac{d^2}{dt^2} \underline{g}(t)$  THE

AMOUNT =  $-\frac{H P}{\Gamma_{CON}^2} \left[ f(q) I(t) + \underline{g}(t) \right]$   
EQ 2.2.7

OVERFLOW

YES

NO

RETURN  
VIA  
OPRET

GOBAQUE  
SH 22

GO BACK AND DO A KEPLER UPDATE, RECTIFY AND ATTEMPT INTEGRATING AGAIN.

THE DIFFERENTIAL EQUATION FOR THE ENCKE VARIABLE  $\underline{g}(t)$  CAN BE WRITTEN AS:

$$\frac{d^2}{dt^2} \underline{g}(t) = -\frac{H P}{\Gamma_{CON}^2} \left[ f(q) I(t) + \underline{g}(t) \right] + \underline{a}_{DP}(t) \quad (2.2.7)$$

THE FIRST TERM ON THE RIGHT, CALLED  $\gamma_j$ , IS EVALUATED IN GAMCOMP AS PART OF THE NYSTRON INTEGRATION SCHEME IN THE SUBSCRIBED FORM:

$$\gamma_j = -\frac{H P \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[ \frac{f(q_j)}{\rho_j} \Delta_j \delta + \Delta_j \alpha \right], \text{ FOR A GIVEN } j.$$

THE FOLLOWING SHOWS THAT  $\gamma_j$  IS EQUIVALENT TO THE FIRST TERM IN 2.2.7. LET  $\underline{g}(t) = \underline{g}_j = \alpha_j \Delta_j \alpha$  AND  $I(t) = \underline{g}_j = \beta_j \Delta_j \alpha$ , WHERE  $\alpha_j$  AND  $\beta_j$  ARE MAGNITUDES OF THE RESPECTIVE VECTORS. DEFINE  $\rho_j = \alpha_j / \Delta_j$ . THEN  $\gamma_j$  CAN BE WRITTEN AS

$$\gamma_j = -\frac{H P}{\Delta_j^2 (1+q_j)^{3/2}} \left[ f(q_j) \Delta_j + \beta_j \right], \text{ WHERE } \Gamma_{CON}^2 \text{ HAS BEEN REPLACED BY } \Delta_j^2 (1+q_j)^{3/2}. \text{ CONTINUING,}$$

$$\begin{aligned} \gamma_j &= -\frac{H P}{\Delta_j^2 (1+q_j)^{3/2}} \left[ f(q_j) \Delta_j \Delta_j \alpha + \alpha_j \Delta_j \alpha \right] \\ &= -\frac{H P}{\Delta_j^2 (1+q_j)^{3/2}} \left[ f(q_j) \Delta_j \alpha + \alpha_j \Delta_j \alpha \right] \\ &= -\frac{H P \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[ \frac{f(q_j)}{\rho_j} \Delta_j \alpha + \Delta_j \alpha \right] \end{aligned}$$

THE VARIABLE  $q$  IS EVALUATED AS,

$$\begin{aligned} q_j &= \frac{(\alpha_j - \beta_j) \cdot \alpha_j}{\Delta_j^2} = \frac{(\alpha_j \Delta_j \alpha - \beta_j \Delta_j \alpha) \cdot \alpha_j \Delta_j \alpha}{\Delta_j^2} \\ &= \left[ \frac{(\alpha_j}{\Delta_j} \right] \Delta_j \alpha \cdot \Delta_j \alpha - \beta_j \Delta_j \alpha \cdot \Delta_j \alpha = \rho_j \left[ \rho_j - \beta_j \Delta_j \alpha \cdot \Delta_j \alpha \right] \end{aligned}$$

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AMHERST, MASS.  
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26 50

EVALUATE THE RUNNING FUNCTIONS  $\psi$  AND  $\phi$  AT THE LEFT HAND POINT, FOR  $j=1$

DIFEQ=0

SET  $\psi = \phi = \lambda_1$   
 $PHIV \leftarrow FV$   
 SHIFTED @  $z^{19}/z^{17}$

$\psi$  AND  $\phi$  ARE INITIALLY EQUAL TO  $\lambda_1$   
 $\lambda_1 = f(\frac{1}{2}, t)$  OF  $(\lambda_1, t)$ , WHERE  $\frac{1}{2}$  IS ESTIMATE OF  $\psi$  AT THE LEFT POINT

EVALUATE THE RUNNING FUNCTIONS  $\psi$  AND  $\phi$  AT THE MID-POINT, FOR  $j=2$

DIFEQ=1

FORM  $4\lambda_2$   
 $PLV \leftarrow MPACV \rightarrow 4FV$   
 SHIFTED AT  $z^{19}/z^{17}$

MULTIPLICATION BY 4 IS ACCOMPLISHED BY A CHANGE IN SCALING FACTOR.  $\frac{1}{2}z_2 = f(\frac{1}{2} + z_2(\frac{z_2}{2}), t) = \frac{1}{2}\lambda_2 + z_2(\frac{z_2}{2})$ , WHERE  $z_2$  IS ESTIMATE OF  $\psi$  AT THE MIDPOINT

$\psi = \psi + 4\lambda_2$   
 $PHIV \leftarrow PHIV + MPACV$   
 @  $z^{19}/z^{17}$

CALCULATE RUNNING SUM IN PHIV  
 $\psi = \lambda_1 + 4\lambda_2$

$\phi = \phi + 2\lambda_2$   
 $PHIV \leftarrow PHIV + \frac{1}{2}PLV$   
 @  $z^{19}/z^{17}$

CALCULATE RUNNING SUM IN PHIV  
 $\phi = \lambda_1 + 2\lambda_2$ , WHERE  $2\lambda_2$  IS FORMED FROM  $4\lambda_2$  BY SHIFTING IT RIGHT ONE PLACE

DIFEQCOM

COMPUTE VALUES OF  $j, \lambda, z_j$  AT THE MID-POINT AND RIGHT HAND POINT IN PREPARATION FOR THE NEXT PASS THRU THE INTEGRATION LOOP

$\lambda = \lambda + \frac{\lambda F}{z}$   
 $MPAC \leftarrow H_0 + OT/z_0$   
 @  $z^{19}$

$\lambda$  TAKES ON THE VALUES  $\frac{\lambda F}{z}$ , AT

$j = j + 1$   
 $DIFEQCNT \leftarrow X1 - 12_0$

$j$  TAKES ON THE VALUES 2,3 CORRESPONDING TO DIFEQCNT = -12, -24

$H_0 \leftarrow MPAC$  STORE NEW  $\lambda$

$z_j = \psi + \lambda (\phi + \frac{\lambda F}{z})$   
 $ALPHA_V \leftarrow YV + H_0 (ZV + \frac{H_0 FV}{z})$   
 @  $z^{22}/z^{10}$

DIVISION BY 2 IS ACCOMPLISHED BY A RIGHT SHIFT OF ONE PLACE.  $z_j$  IS AN ESTIMATE OF  $\psi$  AT THE MIDPOINT AND RIGHT HAND POINT CALCULATED BY USING A TAYLOR EXPANSION ABOUT THE KNOWN VALUE OF  $\psi$  AT THE LEFT HAND POINT

TEST JSWITCH

FBR3  
 SH 2B

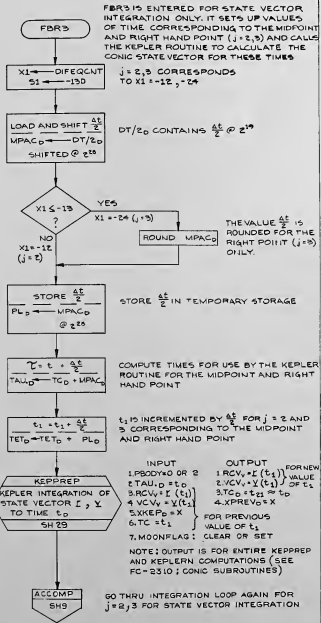
CONTINUE WITH STATE VECTOR INTEGRATION FOR  $j=2,3$

DOW.  
 SH 4R

CONTINUE WITH A VECTOR OF W-MATRIX INTEGRATION FOR  $j=2,3$

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 DRAWN BY *J.S. Chubbuck*  
 REGR. NO. *117*  
 AUTH. *M. Robertson*  
 DATE *10/10/68*  
 APPROV. *Robert M. Cutler*

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 27 50



FBR3 IS ENTERED FOR STATE VECTOR INTEGRATION ONLY. IT SETS UP VALUES OF TIME CORRESPONDING TO THE MIDPOINT AND RIGHT HAND POINT (j=2,3) AND CALLS THE KEPLER ROUTINE TO CALCULATE THE CONIC STATE VECTOR FOR THESE TIMES

j = 2,3 CORRESPONDS TO  $X1 = -12, -24$

$DT/20$  CONTAINS  $\frac{\Delta t}{2} @ 2^{19}$

THE VALUE  $\frac{\Delta t}{2}$  IS ROUNDED FOR THE RIGHT POINT (j=3) ONLY.

STORE  $\frac{\Delta t}{2}$  IN TEMPORARY STORAGE

COMPUTE TIMES FOR USE BY THE KEPLER ROUTINE FOR THE MIDPOINT AND RIGHT HAND POINT

$t_1$  IS INCREMENTED BY  $\frac{\Delta t}{2}$  FOR j = 2 AND 3 CORRESPONDING TO THE MIDPOINT AND RIGHT HAND POINT

CALCULATE CONIC STATE VECTOR AT MID POINT AND RIGHT HAND POINT

INPUT	OUTPUT	FOR NEW
1.PBODY=0 OR 2	1.RCV <sub>v</sub> =I (t <sub>1</sub> )	VALUE
2.TAU <sub>D</sub> =t <sub>0</sub>	2.VCV <sub>v</sub> =Y (t <sub>1</sub> )	VALUE
3.RCV <sub>v</sub> =I (t <sub>1</sub> )	3.TC <sub>0</sub> =T <sub>21</sub> ≈ t <sub>0</sub>	OF t <sub>1</sub>
4.VCV <sub>v</sub> =Y (t <sub>1</sub> )	4.XPREV <sub>0</sub> =X	
5.XKEP <sub>0</sub> =X		FOR PREVIOUS
6.TC=t <sub>1</sub>		VALUE OF t <sub>1</sub>
7.MOONFLAG: CLEAR OR SET		

NOTE: OUTPUT IS FOR ENTIRE KEPPREP AND KEPLERN COMPUTATIONS (SEE FC=2310; CONIC SUBROUTINES)

GO THRU INTEGRATION LOOP AGAIN FOR j=2,3 FOR STATE VECTOR INTEGRATION

ORBITAL  
INTEGRATION

FC-2300

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23. Chisholm  
23. Robertson  
Colossus



LOAD X2 WITH PRIMARY  
BODY INDICATOR

KEPPREP

X2 ← PBODY

SET PUSH LIST  
POINTER TO 0

STORE  $\sqrt{\mu}$   
PL0 ←  $\sqrt{\mu \text{EARTH} \# X2}$   
@  $2^{10}/2^{15}$

r' IS STORED IN  
NORMALIZED FORM  
THE VALUE -m IS  
STORED IN PL36

$\frac{U'}{r'} = \frac{r'}{\text{UNIT} (RCV)}$   
MPACV ←  $\frac{r'}{\text{UNIT} (RCV)}$   
@  $2^5$   
PL2 ←  $|RCV|$   
NORMALIZED @  $2^{20-m}/2^{27-m}$

THIS SUBROUTINE COMPUTES AN ESTIMATE OF THE VARIABLE X AT TIME  $t_D$  BASED ON THE VALUES  $X', I', V'$  AT TIME  $t_{E1}$  FROM THE PREVIOUS COMPUTATION CYCLE. THIS INITIAL ESTIMATE OF X IS USED AS INPUT TO KEPLER TO SPEED UP CONVERGENCE.

INPUT:

1. PBODY = 0 FOR EARTH PRIMARY, 2 FOR MOON
2. RCV =  $r' \cdot \cos(\tau - \frac{t}{\tau})$  THE STATE VECTOR COR-
3. VCV =  $v' \cdot \sin(\tau - \frac{t}{\tau})$  RESPONDING TO PREVIOUS
4. XKEP0 =  $X'(t_{E1})$  CYCLE
5.  $\tau_{D1} = t_D - t_{E1}$  DESIRED TRANSFER TIME
6.  $\tau_{E1} = t_{E1} - t_{E0}$  PREVIOUS TRANSFER TIME
7. MOONFLAG: CLEAR FOR EARTH, SET FOR MOON
8.  $t_{E0} = t_{E1} - \tau_{E1}$  PREVIOUS TRANSFER TIME
9. XCORNEW =  $X_c$  FIRST ESTIMATE OF X CORRESPONDING TO THE TRANSFER TIME  $\tau_D$
10. X1 = PL - TABLE POINTER, 2 FOR EARTH, 10 FOR MOON
11. PUSH LIST POINTER AT PL4

r' IS STORED IN NORMALIZED FORM AND THE NORMALIZING VALUE -m IS STORED IN X1. THE UNIT OPERATION ALSO STORES r' IN PL36 @  $2^{27}/2^{27}$

FORM  $\frac{U'}{r'} \cdot V'$   
PL4 ←  $MPACV + VCV$   
@  $2^7/2^5$

$\frac{\Delta t}{\tau} = t_D - t_{E1}$   
MPACD ←  $\tau_{D1} \tau_{E1} - \tau_{E1}^2$   
NORMALIZED @  $2^{25-m}$

A COMPLETE INTEGRATION STEP CORRESPONDS TO TWO  $\frac{\Delta t}{\tau}$  INCREMENTS. THE VALUE  $\frac{\Delta t}{\tau}$  IS NORMALIZED AND THE NORMALIZING VALUE -n IS STORED IN S1.

FORM  $\frac{\Delta t}{\tau} / r'$   
MPACD ←  $\frac{MPACD}{r' \tau_{E1}}$   
@  $2^{20-m}/2^{20-m-n}$

PL4 ←  $\frac{1}{r'} \left( \frac{\Delta t}{\tau} \right)$   
MPACD ←  $\frac{1}{r'} \cdot V'$

EXCHANGE MPAC AND PL4

$\gamma_s = \frac{U' r' \cdot V' \left( \frac{\Delta t}{\tau} \right)}{\tau_{E1}}$   
PL6D ←  $MPACD \cdot MPACD \cdot PL4$   
@  $2^{20-m-n}$

DIVISION BY  $\tau$  IS ACCOMPLISHED BY A CHANGE IN THE SCALING FACTOR

FORM  $\frac{\gamma_s}{\tau}$   
PL6D ←  $(MPACD)^2$   
@  $2^{15-m-n}$

MULTIPLICATION BY  $\tau$  IS ACCOMPLISHED BY A CHANGE IN THE SCALING FACTOR

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS. DRAWN <i>D. J. Chvalinski</i> PREPARED DATE 11/10/57 CHECKED <i>D. J. Chvalinski</i> APPROVED <i>D. J. Chvalinski</i>	MIT ORBITAL INTEGRATION COLLOSSUS DOCUMENT # FC-2300 29-50
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FROM PRECEDING SHEET

$$\text{FORM } \frac{1}{r^2} \left( \frac{\Delta t}{z} \right)^2$$

$$\text{PL10}_0 \leftarrow \frac{(PL4_0)^2}{z^{2(m-n)} / z^{4+2(m-n)}}$$

$$\text{STORE } \frac{H_p}{r^2}$$

$$\text{PL12}_0 \leftarrow (\text{MUEARTH} \times XZ)_0$$

SHIFTED @  $z^{10} / z^{27}$

$$\text{FORM } \frac{H_p \sqrt{y^2 r'}}{r^2}$$

$$\text{MPAC}_0 \leftarrow \frac{\text{PL12}_0 \cdot (\text{VCV}_y \cdot \text{VCV}_y) \cdot \text{PL36}_0}{\text{PL2}_0}$$

@  $z^{20+m} / z^{20+m}$

$$\text{FORM } -\frac{1}{2} \left( \frac{1}{r} - \alpha \right) S^2 = \frac{1}{2} \left( \frac{H_p \sqrt{y^2 r'}}{r^2} \right) \left( \frac{1}{r^2} \right) \left( \frac{\Delta t}{z} \right)^2$$

$$\text{MPAC}_0 \leftarrow \text{DPE/3}_0 \cdot \text{MPAC}_0 \cdot \text{PL10}_0$$

SHIFTED @  $z^{15+2(m-n)}$

$\text{DPE/3} = \frac{1}{2} @ z^2$

$$\text{FORM } (m) - (n) = n - m$$

$$X1 \leftarrow X1 - S1$$

$$\text{FORM } z(yS)^2 - \frac{1}{2} \left( \frac{1}{r} - \alpha \right) S^2$$

$$\text{MPAC}_0 \leftarrow \text{PLO}_0 + \text{MPAC}_0$$

SHIFTED @  $z^{7+m-n}$

$$\text{FORM } -YS + z(yS)^2 - \frac{1}{2} \left( \frac{1}{r} - \alpha \right) S^2$$

$$\text{MPAC}_0 \leftarrow -(\text{PL6}_0) + \text{MPAC}_0$$

@  $z^{7+m-n}$

$$\text{FORM } X' + S \left[ -YS + z(yS)^2 - \frac{1}{2} \left( \frac{1}{r} - \alpha \right) S^2 \right]$$

$$\text{MPAC}_0 \leftarrow \text{XKEP}_0 + \text{PLO}_0 \cdot \text{PL4}_0 \cdot \text{MPAC}_0$$

SHIFTED @  $z^{17} / z^{16}$

$\text{PLO}_0 \cdot \text{PL4}_0 = \sqrt{10} \cdot \frac{1}{r} \left( \frac{\Delta t}{z} \right) = 5$

EXCHANGE  $\text{MPAC}_0$  AND  $\text{PL4}_0$       STORE PRECEDING CALCULATION IN  $\text{P-4}$   
LOAD  $\text{MPAC}_0$  WITH  $\frac{1}{r} \left( \frac{\Delta t}{z} \right)$

NEXT SHEET

MIT AVIATION LAB BOSTON, MASS.	MIT COLLEGE AND NAVIGATION
DRAWN <i>J. S. Chubbuck</i> CHECKED <i>J. S. Chubbuck</i> APPROVED <i>R. B. ...</i>	ORBITAL INTEGRATION DOCUMENT NO. FC-2300 30 - 30

FROM PRECEDING SHEET

$$\theta = \frac{\sqrt{\mu p}}{r} \left( \frac{\Delta t}{z} \right)$$

MPACD ← PLOD · MPACD  
SHIFTED @  $z^{27}/z^{26}$

EQ. 2.2.5, PAGE 5.2-10

TURN OFF  
OVERFLOW INDICATOR

$$X_t = X' + S \left[ 1 - 7S + 2(7S)^2 - \frac{1}{6} \left( \frac{1}{r} - \alpha \right) S^3 \right]$$

XKEPNEWD ← MPACD + PL4D  
@  $z^{27}/z^{26}$

THIS ADDS S TO INTERMEDIATE CALCULATION IN PL4D.  $X_t$  IS AN ESTIMATE OF THE CORRECT VALUE OF X AT TIME  $t_0 = \tau$  BASED ON  $X', I', Y'$  AT TIME  $t_{21} = \tau - \frac{\Delta t}{2}$   
EQ. 2.2.4, PAGE 5.2-10

KEPRTN ← QPRET

THE RETURN ADDRESS IS STORED IN KEPRTN FOR USE BY KEPLER ROUTINE IN RETURNING TO CALLING ROUTINE.

CLEAR MOONFLAG

SET

X1 ← -2

EARTH IS  
PRIMARY BODY

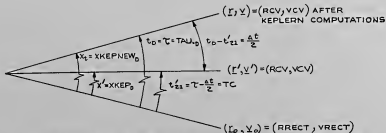
X1 ← -100

MOON IS  
PRIMARY BODY

KEPLERN  
FC-2310

CALCULATE  
CONIC STATE  
VECTOR AT  
TIME  $\tau_{0,0}$   
 $= t_0 = \tau$

THE KEPLER ROUTINE KEPLERN RETURNS CONTROL TO THE CALLING ROUTINE DIRECTLY VIA KEPRTN. SEE CONIC SUBROUTINES, FC-2310



$X', I', Y'$  CORRESPOND TO THE PREVIOUS TIME  $t_{21}$ . A VALUE OF X FOR TIME  $t_0$  IS CALCULATED BY A TAYLOR EXPANSION TYPE METHOD FOR AN INTERVAL OF TIME  $\frac{\Delta t}{2} = t_0 - t_{21}$  TO GET AN ESTIMATE  $X_t$  FOR TIME  $t_0$ .

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J. J. Chubbuck  
M. M. Robertson  
9-2-67

ORBITAL  
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31 50

DIFEQ+Z

EVALUATE THE RUNNING FUNCTIONS  $\Psi$  AND  $\Phi$  AT THE RIGHT HAND POINT, FOR  $j=3$ . THEN USE THEM TO EVALUATE THE FUNCTION  $\Psi_{n+1}$  AND ITS DERIVATIVE  $\dot{\Psi}_{n+1}$  AT THE RIGHT HAND POINT.

$$\text{FORM } \frac{1}{6} \Delta t = \frac{\Delta t}{6}$$

$$P_{L0} \rightarrow MPAC_0 \rightarrow DPZ/3_0 \cdot H_0 @ 2^3/z^{-1}$$

FOR  $j=0, \Delta t = \Delta t$   
 $DPZ/3_0 = \frac{1}{6} @ z^{-1}$

$$\Phi = \dot{\Psi}_n + \frac{\Delta t}{6} (\dot{\Psi}_1 + 2\dot{\Psi}_2)$$

$$MPAC_V \rightarrow ZV_V + MPAC_0 \cdot PHIV @ 2^3/z^{-1}$$

HAVE COMPLETED RUNNING SUM FOR  $\Phi$ .  
 EQ. 2.2.26, PAGE 5.2-19

$$\Psi_{n+1} = \Psi_n + \Phi \cdot \Delta t$$

$$YV_V \rightarrow YV_V + MPAC_V \cdot H_0$$

CALCULATE FUNCTION AT RIGHT HAND POINT  
 EQ. 2.2.26, PAGE 5.2-19

$$\Psi \cdot \Delta t = \frac{\Delta t}{6} (\dot{\Psi}_1 + 4\dot{\Psi}_2 + \dot{\Psi}_3)$$

$$MPAC_V \rightarrow P_{L0} \cdot (PSIV_V + FV_V)$$

SHIFTED @  $2^3/z^{-1}$

HAVE COMPLETED RUNNING SUM FOR  $\Psi$ .  
 PSIV\_V CONTAINS  $\dot{\Psi}_2 + 4\dot{\Psi}_3$ .  
 EQ. 2.2.26, PAGE 5.2-19

$$\dot{\Psi}_{n+1} = \dot{\Psi}_n + \Psi \cdot \Delta t$$

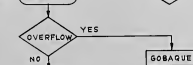
$$ZV_V \rightarrow ZV_V + MPAC_V$$

CALCULATE FIRST DERIVATIVE OF FUNCTION AT RIGHT HAND POINT  
 EQ. 2.2.26, PAGE 5.2-19



THIS INDICATES THE PRECEDING INTEGRATION PASS WAS FOR A STATE VECTOR

THIS INDICATES WE ARE IN THE PROCESS OF INTEGRATING THE W-MATRIX



GO BACK AND UPDATE, RECTIFY AND INTEGRATE AGAIN WITH NEW REFERENCE CONIC

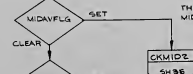
$$\dot{\Psi} \rightarrow \dot{\Psi}_{n+1}$$

$$\dot{\Psi} \rightarrow \dot{\Psi}_{n+1}$$

$$THUV_V \rightarrow ZV_V @ 2^3/z^{-1}$$

$$TDELTAV_V \rightarrow YV_V @ 2^{22}/z^{18}$$

STORE RESULTS OF INTEGRATION



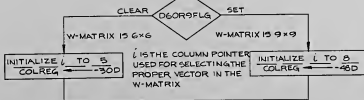
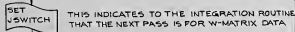
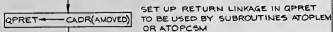
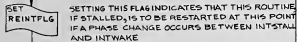
THIS FLAG IS SET BY THE MIDTAV ROUTINE ONLY

CKMIDZ TRANSFERS DIRECTLY TO TESTLOOP THUS PRECLUDING ANY W-MATRIX INTEGRATION



W-MATRIX IS NOT TO BE INTEGRATED SO CONTINUE IMMEDIATELY WITH STATE VECTOR INTEGRATION OVER NEXT TIME INTERVAL  $\Delta t$

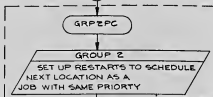
FROM PRECEDING SHEET



COME HERE FROM SHEET 32

(A)

CONTINUE WITH INTEGRATION OF THE W-MATRIX



LOAD  $\bar{l}$   
 $XZ \leftarrow COLREG$

$\bar{l}$  IS THE  $\bar{w}$  VECTOR POINTER FOR W-MATRIX OPERATIONS. IT TAKES ON THE VALUES 0, 7, ... 0 ( $XZ = -48, -42, \dots -6, 0$ ) FOR A  $9 \times 9$  MATRIX, OR 5, 9, ... 0 ( $XZ = -30, -24, \dots -6, 0$ ) FOR A  $6 \times 6$  MATRIX

$\bar{w}_0 + \bar{l} \leftarrow \bar{z}_{n+1}$   
 $(W \pm 48 \pm XZ)_V \leftarrow ZV$   
SHIFTED @  $2^0$

STORE THE NEW VELOCITY VECTOR INTO ITS PROPER SPOT IN EITHER SUBMATRIX  $W_3, W_4$ , OR  $W_5$  OF W-MATRIX

LOAD  $\bar{m}+1$   
 $MPACV \leftarrow YV_V$   
SHIFTED @  $2^{19}$

$\bar{m}+1$  IS SHIFTED FROM  $2^{22}$  TO  $2^{19}$

OVERFLOW

YES

NO

WMATEND  
SH37

IF OVERFLOW OCCURS AS A RESULT OF SHIFTING LEFT THEN AT LEAST ONE COMPONENT OF  $\bar{m}+1 \geq 2^{30}$

$\bar{w}_1 \leftarrow \bar{m}+1$   
 $(W \pm XZ)_V \leftarrow MPACV$   
@  $2^{19}$

STORE THE NEW POSITION VECTOR INTO ITS PROPER SPOT IN EITHER SUBMATRIX  $W_0, W_1$ , OR  $W_2$  OF W-MATRIX



LOAD  $\bar{l}$   
 $XZ \leftarrow COLREG$

$\bar{l}$  IS THE  $\bar{w}$  VECTOR POINTER FOR W-MATRIX OPERATIONS

$SZ \leftarrow 0$

SET  $SZ$  TO ZERO FOR SUBSEQUENT USE IN TEST FOR  $\bar{l} = 0$

$\bar{l} \leftarrow \bar{l} - 1$   
 $XZ \leftarrow XZ + 6$

CHANGE POINTER TO POINT AT NEXT VECTOR  $\bar{w}_{\bar{l}-1}$

NEXT SHEET

ORBITAL  
INTEGRATION

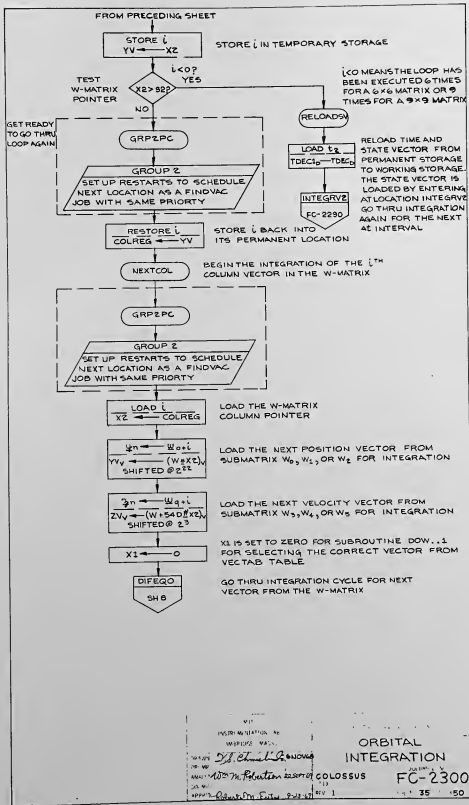
J.S. Chumak, 540160

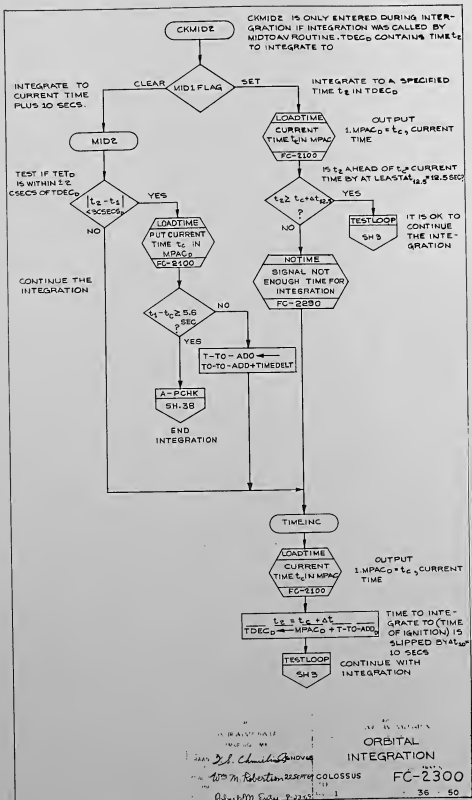
W.M. Robertson, 2220709 COLLOSSUS

FC-2300

Roberts/PM Series 9-2302

34 50





ORBITAL INTEGRATION

Dr. Charles J. ...

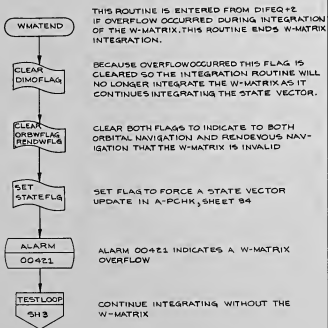
W. M. Robertson 22509 COLUSSUS

Adapted from ...

ORBITAL INTEGRATION

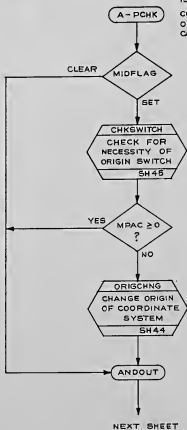
FC-2300





TITLE INSTRUMENTATION LAB AMES RESEARCH CENTER	GUIDANCE AND NAVIGATION <b>ORBITAL          INTEGRATION</b>
DRAWN <i>J. J. ...</i> DESIGNED ANALYST <i>W. M. ...</i> CHECKED APPROVED <i>P. J. ...</i>	COLLOSSUS FC-2300 REV. 1

A-PCHK CHECKS TO SEE IF AN UPDATE IS DESIRED AND, IF SO, PERFORMS IT. COME HERE FROM POOHCHK IF  $|\Delta t| \geq 2$  CBSEC OR IF  $\Delta t < \Delta t_{MAX}$  AND INTEGRATION WAS CALLED BY POO



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARLDO ORBITAL AND NAVIGATION	
DRAWN: <i>[Signature]</i> APPR: <i>[Signature]</i> ANAL: <i>[Signature]</i> TIME: <i>[Signature]</i> APPRO: <i>[Signature]</i>		ORBITAL INTEGRATION DOCUMENT NO. <b>FC-2300</b> REV 1 38 50	

FROM PRECEDING SHEET

STATE FLG

CLEAR

PERFORM A STATE VECTOR UPDATE

SET

CLEAR STATE FLG

FLAG IS CLEARED BECAUSE AN UPDATE IS ABOUT TO BE DONE AND A SUBSEQUENT UPDATE IS UNNECESSARY

DO NOT PERFORM AN UPDATE

GROUP 2  
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A JOB WITH SAME PRIORITY

SET REINTFLG

SETTING THIS BIT INDICATES THAT THIS ROUTINE, IF STALLED, IS TO BE RESTARTED AT THIS POINT IF A PHASE CHANGE OCCURRED BETWEEN INTSTALL AND INTWAKE

QPRET ← CADR(PHEXIT)

SET UP RETURN LINKAGE IN QPRET TO BE USED BY ATOPLEM OR ATOPCSM

CLEAR VINTFLAG

SET

ATOPLEM  
DO UPDATE  
OF LM STATE  
VECTOR  
FC-2290

LM STATE VECTOR WAS INTEGRATED

ATOPCSM  
DO UPDATE  
OF CSM STATE  
VECTOR  
FC-2290

CSM STATE VECTOR WAS INTEGRATED

PHEXIT

GRPEPC

GROUP 2  
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A JOB WITH SAME PRIORITY

NEXT SHEET

MIT  
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AMESDIE NAVY  
LIBRARY  
FC-2300  
SERIAL NO. 205  
DO NOT  
REMOVE

ORBITAL  
INTEGRATION  
COLLOSSUS  
FC-2300  
REV. 1  
39 50

FROM PRECEDING SHEET

RECTOUT

THIS ROUTINE DOES A RECTIFICATION AND STORES THE OUTPUT IN THE PUSH LIST

SET PUSH LIST  
POINTER TO ZERO

RECTIFY  
DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS  
SH 43

INPUT	OUTPUT
1. $RCV_v = I_{con}$	1. $LX = PBODY$
2. $ECV_v = Y_{con}$	2. $RRECT_v = I_{g} \cdot I_{con} + \frac{g}{2}$
3. $\Delta TAV_v = \frac{g}{2}$	3. $VRECT_v = Y_{g} = Y_{con} + \frac{g}{2}$
4. $TNUV_v = \frac{g}{2}$	4. $RCV_v = I_{con} = NEW Y_{g}$
	5. $RCV_v = Y_{con} = NEW Y_{g}$
	6. $\Delta TAV_v = \frac{g}{2} = (0, 0, 0)$
	7. $TNUV_v = \frac{g}{2} = (0, 0, 0)$
	8. $TC_0 = T = 0$
	9. $XKEP_0 = X = 0$

$PL0_v \leftarrow RRECT_v \text{ SHIFTED } @ Z^0$   
 $PL6_v \leftarrow VRECT_v \text{ SHIFTED } @ Z^1$   
 $PL12_0 \leftarrow TET_0 @ Z^0$   
 $PL18_v \leftarrow RRECT_v @ Z^2 / Z^1$   
 $PL24_v \leftarrow VRECT_v @ Z^2 / Z^1$   
 $PL30_0 \leftarrow (MUEARTH \# XE)_0$

STORE INTEGRATION OUTPUT IN PUSH LIST. THIS INCLUDES  $E_0, Y_0, t_0, \mu_p$



INTEXIT

COME HERE DIRECTLY FROM POOHCHK IF  $t_2 > t_1 + \Delta t$

SET PUSH LIST  
POINTER TO ZERO

TURN OFF OVERFLOW  
INDICATOR

CLEAR  
MIOAVFLG

CLEAR  
AVEMIOSW

CLEAR  
PRECI FLG

ALLOW UPDATE OF DOWNLINK CSM STATE VECTOR. SEE SHEET 20, FC-2300

QPRET  $\leftarrow$  IRETURN

STORE RETURN ADDRESS INTO QPRET SO INTWAKE CAN RETURN TO CALLING ROUTINE BY USING THE RVQ INSTRUCTION

INTWAKE  
FC-2290

RETURN TO CALLING ROUTINE VIA INTWAKE

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 CAMBRIDGE MASS  
 3745A  
 3745B  
 3745C  
 3745D  
 3745E  
 3745F  
 3745G  
 3745H  
 3745I  
 3745J  
 3745K  
 3745L  
 3745M  
 3745N  
 3745O  
 3745P  
 3745Q  
 3745R  
 3745S  
 3745T  
 3745U  
 3745V  
 3745W  
 3745X  
 3745Y  
 3745Z

ORBITAL  
INTEGRATION

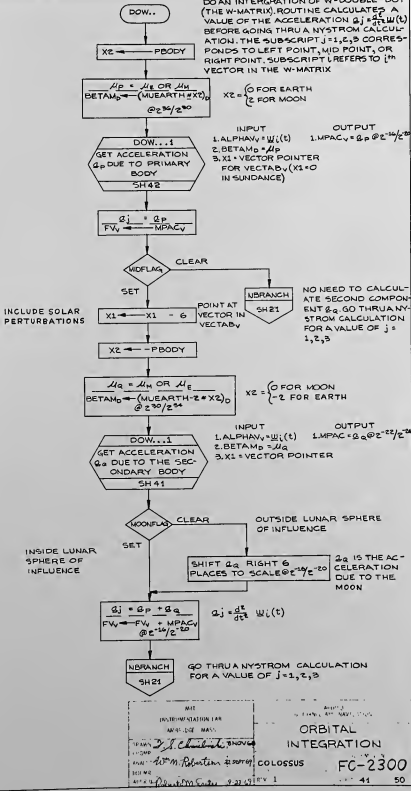
COLOSSUS

FC-2300

REV. 1

40 50

DO AN INTEGRATION OF W-DOUBLE-DOT (THE W-MATRIX). ROUTINE CALCULATES A VALUE OF THE ACCELERATION  $\ddot{a}_j = \frac{d^2}{dt^2} W(t)$  BEFORE GOING THRU A NYSTROM CALCULATION. THE SUBSCRIPT  $j=1,2,3$  CORRESPONDS TO LEFT POINT, MID POINT, OR RIGHT POINT. SUBSCRIPT  $l$  REFERS TO  $i^{th}$  VECTOR IN THE W-MATRIX



DOW..1

CALCULATE THE ACCELERATION COMPONENT  $a_p$  OR  $a_a$  FOR A GIVEN  $\omega_i$

STORE  $\omega_i$   
 $PLV \leftarrow \text{ALPHAV}_V$   
 SHIFTED @  $z^2/z^2$

FORM  $\omega = \int \text{UNIT}$   
 $r = |I|$   
 $(PL+6)_V \leftarrow \text{UNIT}(\text{VECTAB} @ X1)_V$   
 $PLD @ D @ z^2 \leftarrow \frac{1}{z^2} \left| \sqrt{\text{VECTAB} @ X1} \right|_V$

X1 IS A POINTER USED TO SELECT EITHER  $I(t)$  OR  $I_{ac}(t)$  FROM A TABLE. IN SUNDANCE X1=0.

FORM  $(\omega \cdot \omega_i) \omega$   
 $MPACV \leftarrow \frac{[(PL+6)_V \cdot \text{ALPHAV}_V] (PL+6)_V}{z^{2A}/z^{2B}}$

PROJECT  $\omega_i$  ONTO  $I$  WHERE  $\omega = \omega_i$  IS THE MAGNITUDE OF  $\omega_i$  IN THE DIRECTION OF  $I$ .

FORM  $B(\omega \cdot \omega_i) \omega - \omega_i$   
 $PLV \leftarrow B/D @ z^{2A}/z^{2E}$   
 $MPACV \leftarrow MPACV - PLV$

$B/4 = 3.0 @ z^2$

STORE  $r$  NORMALIZED  
 $(PL+6)_D \leftarrow MPACD @ PLD @ D$   
 NORMALIZED @  $z^{2E}/z^{2A-m}$

THE NORMALIZING COUNT - m IS STORED IN S2

STORE  $r^3$  NORMALIZED  
 $(PL+6)_D \leftarrow MPACD^3 \cdot (PL+6)_D$   
 NORMALIZED @  $z^{3(2E-m)}/z^{3(2A-m)-n}$

THE NORMALIZING COUNT - n IS STORED IN PL34.

FORM  $\frac{A}{r^3} [B(\omega \cdot \omega_i) \omega - \omega_i]$   
 $MPACV \leftarrow \frac{\text{BETAMD} \cdot PLV}{(PL+6)_D}$   
 $@ z^{-3A+3E+n}/z^{-2E+3m+n}$

THIS IS THE ACCELERATION COMPONENT  $a_p$  OR  $a_a$ . EQ 2.2.31, PAGE 5.2-23

FORM  $-3m-n$   
 $XZ \leftarrow -3Z+3Z+3Z+PL34$

-3m-n IS THE UNNORMALIZING COUNT

SHIFT MPACV TO UNNORMALIZE AND SCALE @  $z^{-10}/z^{-20}$

RETURN  
 VIA  
 QPRET

ORBITAL INTEGRATION

COLLOSSUS

FC-2300

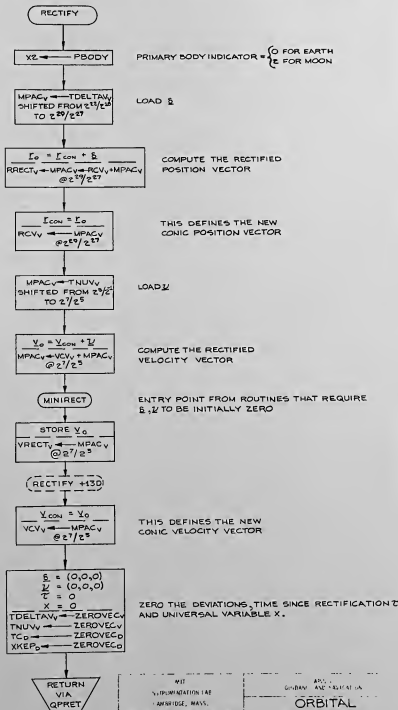
42 / 50

*D. S. Chelton*

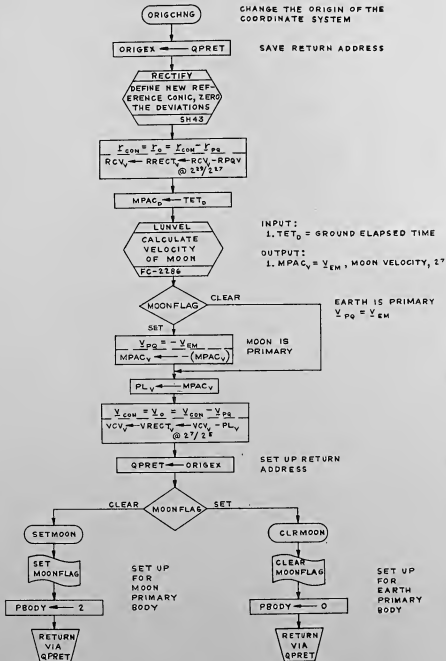
*W. M. Robertson*

*Robertson, Fort. 9-21-50*

THE RECTIFY SUBROUTINE IS CALLED BY THE INTEGRATION ROUTINE AND OCCASIONALLY BY THE MEASUREMENT INCORPORATION ROUTINES TO DEFINE A NEW REFERENCE CONIC.



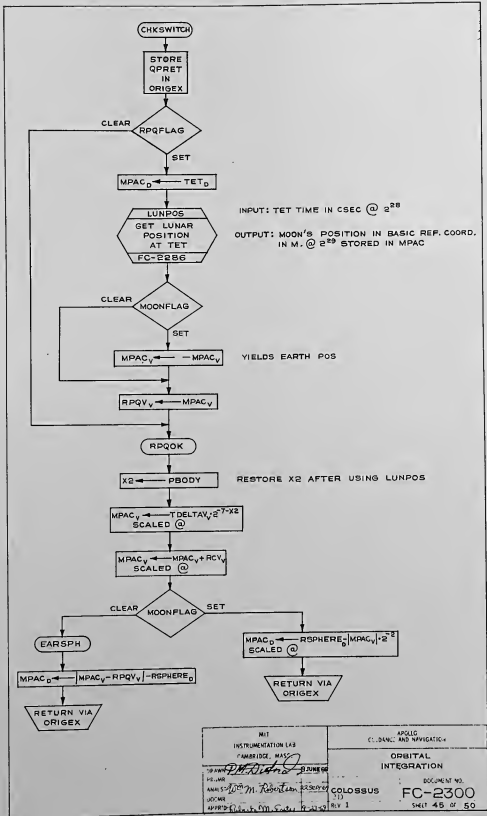
DRAWN <i>L. J. Christensen</i> 25 NOV 65 CHECKED <i>M. Robertson</i> 25 NOV 65 APPROVED <i>John H. Fisher</i> 2-22-67	FILE NO. 43-38-101 REV 1	PROJ. NO. 43-38-101 TITLE ORBITAL INTEGRATION FC-2300 FILE NO. 43-38-101 REV. 1
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MIT INSTRUMENTATION LAB WINDTUNNE WAYS, 77 MASSACHUSETTS AVENUE CAMBRIDGE, MASSACHUSETTS 02139	<b>ORBITAL INTEGRATION</b> <b>COLOSSUS</b> FC-2300 DOCUMENT 911 WENT 44 X 50
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APPROVED: *A. J. ...* MAPROV  
 APPROVED: *W. M. ...* 225075  
 APPROVED: *Robert M. ...* 9-27-59





SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
SGNAGREE	FC2100	FORCE SIGN AGREEMENT OF NUMBER IN MPAC	SH. 4
SIGNMPAC	FC2100	LOAD MPAC WITH SIGNUM (MPAC)	SH. 6
R-TO-RP	FC2283	CONVERT A VECTOR FROM BASIC REFERENCE COORDINATES TO MOON COORDINATES	SH. 15
RP-TO-R	FC2283	CONVERT VECTOR FROM MOON TO REFERENCE COORDINATES	SH. 20
KEPLERN	FC2310	KEPLER ROUTINE COMPUTES THE NEW CONIC STATE VECTOR	SH. 31
ATOPLEM	FC2290	DO UPDATE OF PERMANENT LM STATE VECTOR	SH. 33, 38
ATOPCSM	FC2290	DO UPDATE OF PERMANENT CSM STATE VECTOR	SH. 33, 38
INTEGRV2	FC2290	ENTRY POINT IN INTEGRATION INITIALIZATION FOR NEXT PASS THROUGH INTEGRATION WITH NEXT I VALUE	SH. 35
LOADTIME	FC2100	LOAD TIME1 AND TIME2 (CURRENT TIME) INTO MPAC	SH. 36
INTWAKE	FC2290	ENTRY POINT FOR WAKING UP ALL INTEGRATION STALLED PROGRAMS, WHEN PRESENT INTEGRATION IS COMPLETED	SH. 40
LSPOS	FC2286	CALCULATE POSITION OF SUN, MOON	SH. 41
LUNPOS	FC2286	CALCULATE POSITION OF MOON	SH. 45
LUNVEL	FC2286	CALCULATE VELOCITY OF MOON	SH. 44
POODOO	FC2140	TERMINATE MAJOR MODE IN RESTART	SH. 22

FLAGS

NAME (BIT FLAGWORD)	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
VINTFLAG (3, 3)	INTEGRATE THE CSM STATE VECTOR	INTEGRATE THE LM STATE VECTOR			SH. 33, 38
DIMOFMAG (1, 3)	INTEGRATE THE W-MATRIX	DO NOT INTEGRATE THE W-MATRIX		SH. 37	SH. 6, 12, 32
DGORSFLG (2, 3)	W-MATRIX IS 9X9	W-MATRIX IS 6X6			SH. 33
STATEFLG (5, 3)	UPDATE PERMANENT CSM/LM STATE VECTOR	DO NOT UPDATE PERMANENT CSM/LM STATE VECTOR	SH. 37	SH. 3, 38	SH. 38
QUITFLAG (5, 9)	DISCONTINUE INTEGRATION AT START OF NEXT TIMESTEP	CONTINUE INTEGRATION			SH. 3
MIDFLAG (13, 0)	INTEGRATE WITH SOLAR PERTURBATIONS	INTEGRATE WITHOUT SOLAR PERTURBATIONS	SH. 3	SH. 3	SH. 8, 10, 36, 41
PRECIPLG (8, 3)	CSMPREC OR LEMPREC CALLED	INTEGRY OR INTEGRVS CALLED		SH. 40	SH. 5
NEWIFLG (13, 8)	FIRST PASS THROUGH INTEGRATION LOOP	SUBSEQUENT PASS THROUGH INTEGRATION LOOP		SH. 6	SH. 6
JSWITCH (14, 0)	INTEGRATE A VECTOR FROM THE W-MATRIX	INTEGRATE THE STATE VECTOR	SH. 33	SH. 8	SH. 8, 27, 32
POOFLAG (9, 3)	IN PROGRAM POO	NOT IN PROGRAM POO			SH. 5

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		ORBITAL INTEGRATION	
PENGAR		DOCUMENT NO.	
ANALYST <i>[Signature]</i>		COLLUSUS 211 FC 2300	
DOOR		SHEET 4 OF 50	
APPROVED <i>[Signature]</i>		REV 1	

FLAGS (CONTINUED)

NAME (BIT, FLAGWORD)	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
MOONFLAG (12, 0)	INSIDE LUNAR SPHERE OF INFLUENCE	OUTSIDE LUNAR SPHERE OF INFLUENCE	SH. 44	SH. 44	SH. 11, 13, 15, 19, 31, 40, 41, 44, 45 SH. 44
RPQFLAG (15, 8)	CALCULATE THE VECTOR RPQ	DO NOT CALCULATE THE VECTOR RPQ	SH. 22		
MIDAVFLAG (2, 9)	INTEGRATION CALLED BY THE MIDTOAV ROUTINE	INTEGRATION NOT CALLED BY THE MIDTOAV ROUTINE		SH. 40	SH. 32
REINTFLG (7, 10)	RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS	DO NOT RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS	SH. 33, 38		
MIDIFLAG (5, 9)	INTEGRATE TO A SPECIFIED TIME $t_2$ STORED IN TDEC	INTEGRATE TO CURRENT TIME PLUS 10 SECONDS			SH. 36
ORBWFLAG (6, 3)	W-MATRIX IS VALID FOR ORBITAL NAVIGATION	W-MATRIX IS INVALID FOR ORBITAL NAVIGATION		SH. 37	
RENDWFLG (1, 5)	W-MATRIX IS VALID FOR RENDEZVOUS NAVIGATION	W-MATRIX IS INVALID FOR RENDEZVOUS NAVIGATION		SH. 37	
AVEMIDSW (1, 9)	PREVENT UPDATING THE CSM DOWNLINK DATA RN, VN, PIPTIME	ALLOW UPDATING THE CSM DOWNLINK DATA RN, VN, PIPTIME		SH. 40	

DISPLAYS

VERB- NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
	ALARM	PROG ALARM LIGHT ON; R1, R2, R3, NOT AFFECTED	SH. 37

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
DT/2 <sub>D</sub>	t	TIME INTERVAL FOR ONE INTEGRATION CYCLE	CSEC	CSEC	2 <sup>20</sup>
TDEC1 <sub>D</sub>	t <sub>2</sub>	TIME TO INTEGRATE TO	CSEC	CSEC	2 <sup>26</sup>
RCV <sub>V</sub>	$\underline{r}_{con}$	CONIC POSITION VECTOR	M	M	2 <sup>29</sup> /2 <sup>27</sup>
VCV <sub>V</sub>	$\underline{v}_{con}$	CONIC VELOCITY VECTOR	M/CSEC	M/CSEC	2 <sup>7</sup> /2 <sup>5</sup>
TET <sub>D</sub>	t	TIME OF VALIDITY OF STATE VECTOR	CSEC	CSEC	2 <sup>28</sup>
RRECT <sub>V</sub>	$\underline{r}_o$	POSITION VECTOR AT RECTIFICATION	M	M	2 <sup>29</sup> /2 <sup>27</sup>

W. J. INSTRUMENTATION LAB (AMARIZO, MEX.)		ORBITAL INTEGRATION	
NO. REV DATE DRAWN BY CHECKED BY APPROVED BY	<i>G. J. Long</i> <i>M. Robertson</i> <i>R. B. ...</i>	26 NOV 68 25 NOV 68 22 NOV 68	COLLOSSUS 2D REV 1
		FC-2300 47 50	

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
VRECT <sub>V</sub>	$v_0$	VELOCITY VECTOR AT RECTIFICATION	M/CSEC	M/CSEC	$2^7/2^5$
TDELTA <sub>V</sub>	$\delta$	POSITION DEVIATION VECTOR	M	M	$2^{22}/2^{18}$
TNUV <sub>V</sub>	$\underline{v}$	VELOCITY DEVIATION VECTOR	M/CSEC	M/CSEC	$2^3/2^{-4}$
TC <sub>D</sub>	$t_{21}$	TIME SINCE RECTIFICATION	CSEC	CSEC	$2^8$
XKEP <sub>D</sub>	x	UNIVERSAL VARIABLE	$M^{1/2}$	$M^{1/2}$	$2^{17}/2^{16}$
Y <sub>V</sub>	$\delta$	INTERMEDIATE VALUE OF $\delta$	M	M	$2^{22}/2^{18}$
ZV <sub>V</sub>	$\underline{v}$	INTERMEDIATE VALUE OF $\underline{v}$	M/CSEC	M/CSEC	$2^3/2^{-4}$
DIFQCNT	j	SUBSCRIPT FOR LEFT, MID, AND RIGHT POINTS	INTEGER	INTEGER	
ALPHA <sub>V</sub>	$\alpha_j$	INTERMEDIATE VALUE OF $\delta$	M	M	$2^{22}/2^{18}$
H <sub>D</sub>	h	RUNNING TIME INCREMENT EQUALS 0, $\Delta 1/2$ , $\Delta 1$	CSEC	CSEC	$2^{10}$
EV <sub>V</sub>	$f_j$	VALUE OF SECOND DERIVATIVE AT POINT j	$M/(CSEC)^2$	$M/(CSEC)^2$	$2^{-16} 2^{-20}$
BETA <sub>V</sub>	$\beta_j$	INTERMEDIATE VALUE OF $r_0$	M	M	$2^{29} 2^{27}$
VECTAB <sub>V</sub>	$\beta_j$	WORKING STORAGE FOR $\beta_j$	M	M	$2^{29} 2^{27}$
ALPHAM <sub>D</sub>	$\alpha_j$	$ \alpha_j $ , MAGNITUDE OF $\alpha_j$	M	M	$2^{29} 2^{27}$
BETAM <sub>D</sub>	$\beta_j$	$ \beta_j $ , MAGNITUDE OF $\beta_j$	M	M	$2^{29} 2^{27}$
UZ <sub>V</sub>	$\underline{u}_z$	UNIT VECTOR IN DIRECTION OF ROTATION AXIS			$2^1$
COSPHI/2 <sub>D</sub>	COS $\phi$	COSINE OF COALTITUDE $\phi$			$2^1$
URPV <sub>V</sub>	$\underline{u}_r$	UNIT VECTOR OF POSITION IN MOON COORDINATES			$2^1$
TVEC <sub>V</sub>	$\underline{a}_v$	THE DISTURBING ACCELERATION	$M/(CSEC)^2$	$M/(CSEC)^2$	
TAU <sub>D</sub>	$t_D$	DESIRED TRANSFER TIME	CSEC	CSEC	$2^{28}$
PIHV <sub>V</sub>	$\alpha$	RUNNING SUM OF $k_1 + 2k_2$	$M/(CSEC)^2$	$M/(CSEC)^2$	$2^{-13} 2^{-17}$
PSIV <sub>V</sub>	$\underline{e}$	RUNNING SUM OF $k_1 + k_2 + k_3$	$M/(CSEC)^2$	$M/(CSEC)^2$	$2^{-13} 2^{-17}$
PBODY	P	PRIMARY BODY INDICATOR	INTEGER	INTEGER	
XKEPNEW <sub>D</sub>	x	INITIAL ESTIMATE OF NEW VALUE OF x	$M^{1/2}$	$M^{1/2}$	$2^{17} 2^{16}$
W <sub>M</sub>	W	W-MATRIX	M, M/CSEC	M, M/CSEC	$2^{10} 2^0$

26 NOV 68  
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## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
.3D <sub>D</sub>			.3	.3	2 <sup>2</sup>
DT/2MAX <sub>D</sub>		LIMIT ON SIZE OF $t$	1000 SEC	100,000 CSEC	2 <sup>20</sup>
DT/2MIN <sub>D</sub>	$t$	MINIMUM VALUE OF $t$ ALLOWED	3 CSEC	3 CSEC	2 <sup>20</sup>
3/4 <sub>D</sub>			0.75	3	2 <sup>2</sup>
RECRATIO <sub>D</sub>			0.01	.01	2 <sup>0</sup>
ZEROVEC <sub>V</sub>		(0, 0, 0)	(0, 0, 0, 0, 0, 0)		
RDE <sub>D</sub>	$r_{DE}$	RADIUS OF RELEVANCE OF EARTH	60467200 M	SAME	2 <sup>29</sup>
RDM <sub>D</sub>	$r_{DM}$	RADIUS OF RELEVANCE OF MOON	16093440 M	SAME	2 <sup>27</sup>
3/5 <sub>D</sub>			3/5	.6	2 <sup>2</sup>
ZUNIT <sub>V</sub>		(0, 0, 1)	(0, 0, 0, 0, 1, 0)	(0, 0, 0, 0, 0, 5)	2 <sup>1</sup>
3/32 <sub>D</sub>			3.0	3.0	2 <sup>5</sup>
15/16 <sub>D</sub>			15.0	15.0	2 <sup>4</sup>
7/12 <sub>D</sub>			7/3	.5833...33	2 <sup>0</sup>
2/3 <sub>D</sub>			4/3	.666...67	2 <sup>0</sup>
9/16 <sub>D</sub>			9/4	9.0	2 <sup>4</sup>
5/128 <sub>D</sub>			5/4	5.0	2 <sup>7</sup>
J4REZ/J3 <sub>D</sub>	$J_4E/r_E$ $J_3E$	RATIO OF COEFFICIENTS OF FOURTH AND THIRD HARMONICS OF EARTH'S POTENTIAL FUNCTION	4991607.391	SAME	2 <sup>26</sup>
J3RE/J2 <sub>D</sub>	$J_3E/r_E$ $J_2E$	RATIO OF COEFFICIENTS OF THIRD AND SECOND HARMONICS OF EARTH'S POTENTIAL FUNCTION	13554.26363	SAME	2 <sup>27</sup>
J2REQSQ <sub>D</sub>	$J_2E/r_E^2$ $\mu_E$	SECOND HARMONIC, RADIUS AND MU OF EARTH	1.75501139 $\times 10^{21}$	SAME	2 <sup>72</sup>
J2REQSQ <sub>D</sub>	$J_2M/r_M^2$ $\mu_M$	SECOND HARMONIC, RADIUS AND MU OF MOON	.3067493316 $\times 10^{18}$	SAME	2 <sup>60</sup>
5/8 <sub>D</sub>			5.0	5.0	2 <sup>3</sup>
J22R3M <sub>D</sub>	$3.122M/r_M^2$ $\mu_M$		9.20479048 $\times 10^{-16}$	SAME	2 <sup>56</sup>
JQUARTER <sub>D</sub>			1.0	0.25	2 <sup>0</sup>
HALFDP <sub>D</sub>			2.0	0.5	2 <sup>0</sup>
THREE/8			3.0	0.375	2 <sup>0</sup>

INSTRUMENTATION AND  
ANALYSIS SECTION

ORBITAL  
INTEGRATION

FORMAN *A. J. Loyall* 26 NOV 68

ENG. *W. M. Peterson* 22 OCT 67

COLLOSSUS

FC-2300

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## PROGRAM CONSTANTS (CONTINUED)

AGC TAG	CSOP SYMBOL	MEANING	L. ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
MUEARTH <sub>D</sub>	"E	GRAVITATIONAL PARAMETER OF EARTH	$3.986032 \times 10^{10}$ M <sup>3</sup> /CSEC <sup>2</sup>	SAME	2 <sup>36</sup>
MUEARTH <sub>D</sub> -2	"M	GRAVITATIONAL PARAMETER OF MOON	$4.902778 \times 10^8$ M <sup>3</sup> /CSEC <sup>2</sup>	SAME	2 <sup>30</sup>
MUEARTH <sub>D</sub> -4	"S	GRAVITATIONAL PARAMETER OF SUN	$1.32715445 \times 10^{18}$ M <sup>3</sup> /CSEC <sup>2</sup>	SAME	2 <sup>54</sup>
DF2/3			1/6	.66...67	2 <sup>0</sup>
3CSECS			3 CSEC	3 CSEC	2 <sup>28</sup>
RME <sub>D</sub>	"ME	RADIUS OF INFLUENCE OF EARTH	7178165 M	SAME	2 <sup>29</sup>
RMM <sub>D</sub>	"MN	RADIUS OF INFLUENCE OF MOON	2538090 M	SAME	2 <sup>27</sup>

## PAD LOADS

AGC TAG	CSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
504LM <sub>v</sub>	M	MOON LIBRATION VECTOR				

MIT  
 77 PHOTODUPLICATIONS  
 CAMBRIDGE, MA  
 DATE 9/1/84 BY 240VLE  
 FOR M. Robertson 22 2071  
 8/2/84  
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TFFCONIC SUBROUTINES, AND DELASPL

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
SGNMPAC	2100	AFFIXES SIGN OF MPAC TO POSMAX	SH. 9
GETERAD	2280	COMPUTE RADIUS ON FISCHER ELLIPSOID, GIVEN A PARTICULAR LATITUDE	SH. 12
LALOTRV	2280	GIVEN ALTITUDE, LATITUDE, AND LONGITUDE & TIME COMPUTE RADIUS VECTOR FOR FIXED OR FISCHER	SH. 14
INTWAKE0	2300	PERMIT INTEGRATION TO BE USED AGAIN	SH. 14

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS			
TFFCONIC:		THIS SUBROUTINE IS CALLED TO COMPUTE THOSE CONIC PARAMETERS REQUIRED BY THE TFF CONICS, AND TO ESTABLISH THEM IN THE PUSHLIST AREA.	SH. 3
TFFCONMU:		SAME AS TFFCONIC, EXCEPT THAT TFF/RTMU IS ALREADY LOADED.	SH. 3
TFFRP/RA:		CALCULATE PERIGEE RADIUS AND ALSO APOGEE RADIUS FOR A GENERAL CONIC.	SH. 4
CALCTPER: CALCTFF:		PROGRAM CALCULATES THE FREE-FALL TIME OF FLIGHT FROM PRESENT POSITION RN AND VELOCITY VN TO A RADIUS LENGTH SPECIFIED BY RTERM, SUPPLIED BY THE USER IN MPAC. THE POSITION RN VECTOR MAY BE ON EITHER SIDE OF THE CONIC, BUT RTERM IS CONSIDERED ON THE INBOUND SIDE.	SH. 5
VGAMCALC:		EARTH CENTERED VIS VIVA CALCULATION OF TERMINAL VELOCITY AND GAMMA (REL TO HORIZONTAL), GIVEN THE SCALAR QUANTITIES: PRESENT RADIUS AND VELOCITY AND THE TERMINAL RADIUS. THE USER MUST APPEND PROPER SIGN TO GAMMA, SINCE IT IS CALCULATED AS A POSITIVE NUMBER.	SH. 11
PREVGAM:		SAME AS VGAMCALC, EXCEPT THAT IT IS ENTERED WITH NEW RTERM IN MPAC.	SH. 11
TFF/TRIG:		CALCULATE SINE, COSINE OF TRANSFER ANGLE FROM DATA LEFT IN THE PUSHLIST BY TFF SUBROUTINES.	SH. 11
FISHCALC:		GIVEN THE PRESENT POSITION, UNTR, CALCULATE A NEW UNTR THAT IS ROTATED THROUGH TRANSFER ANGLE, THETA, ALONG TRAJECTORY. THEN CALCULATE SIN(LAT) AND USE TO OBTAIN FISCHER RADIUS.	SH. 12
DELR5PL:		A SUBROUTINE OF EXTENDED VERB 82: CALCULATE (FOR DISPLAY ON CALL) AN APPROXIMATE MEASURE OF IN-PLANE SPLASHDOWN ERROR. IF THE FREE-FALL TRANSFER ANGLE TO 300K FT ABOVE PAD RADIUS IS POSITIVE: SPLASH ERROR = -RANGE TO TARGET + FREE-FALL TRANSFER ANGLE * ESTIMATED ENTRY ANGLE. THE TARGET LOCATION AT ESTIMATED TIME OF IMPACT IS USED. IF THE FREE-FALL TRANSFER ANGLE IS NEGATIVE: SPLASH ERROR = -RANGE TO TARGET. THE PRESENT TARGET LOCATION IS USED.	SH. 13
AUGEKUGL:		CALCULATES TIME FROM ENTRY AT 300K FT TO SPLASH, AND RANGE FROM 300K FT ENTRY TO SPLASH, GIVEN VELOCITY AND FLIGHT-PATH ANGLE AT 300K FT.	SH. 15

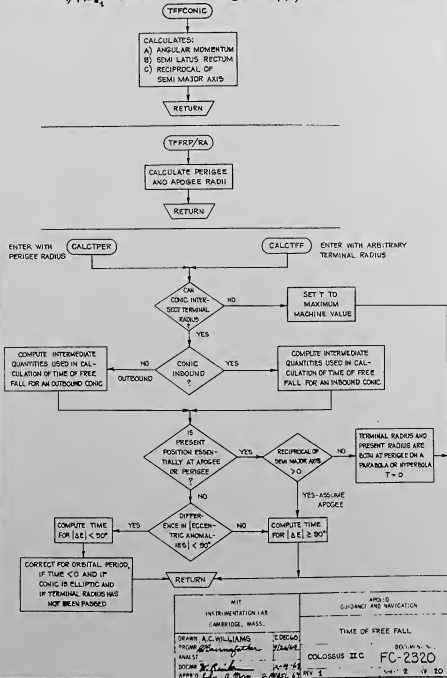
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGNER <i>Robert B. Smith</i>		TIME OF FREE FALL	
PROGRAMMER <i>Robert B. Smith</i>		COLOSSUS IIC	DOCUMENT NO. FC-2320
ANALYST		REV 1	SHEET 1 OF 20
ROOM			
APPROVED <i>Robert B. Smith</i>			

SINCE CONIC CALCULATIONS REQUIRED FLOATING POINT ARITHMETIC, THESE CHARTS ATTEMPT TO INDICATE WHERE SUCH OPERATIONS ARE EMPLOYED, LET REGISTER M BE NORMALIZED SO THAT  $1 > M \geq 0.5$ . LET THE NUMBER OF LEFT SHIFTS REQUIRED TO BRING THIS ABOUT BE -X1. THEN THE CONVENTION USED HEREIN IS THAT THE NORMALIZED CMC VARIABLE TFFM (G, S) IS RELATED TO THE UNNORMALIZED CMC VARIABLE IN M BY:  $TFFM = M \cdot 2^{-X1}$  AND  $M = NORM_{X1}(TFFM)$ .

R30 APPLICATION: THE SPHERICAL VALUES OF GRAVITATIONAL CONSTANT  $\mu$  ARE USED DEPENDING ON EARTH/MOON CENTERED COORDINATES:

EARTH:  $\sqrt{\mu_E} = .5007529 \times 10^{-5} @ 2^{-17} CS/(M)^{3/2}$   
 MOON:  $\sqrt{\mu_M} = .48162595 \times 10^{-4} @ 2^{-14} CS/(M)^{3/2}$

ENTRY APPLICATION: IN COLOSSUS P61 (FC-2760), A MODIFIED VALUE OF  $\mu$  ACCOUNTING FOR NEAR EARTH PERTURBATIONS MAY BE USED:  
 $\sqrt{\mu_{E1}} = .500750271 \times 10^{-5} @ 2^{-17} CS/(M)^{3/2}$

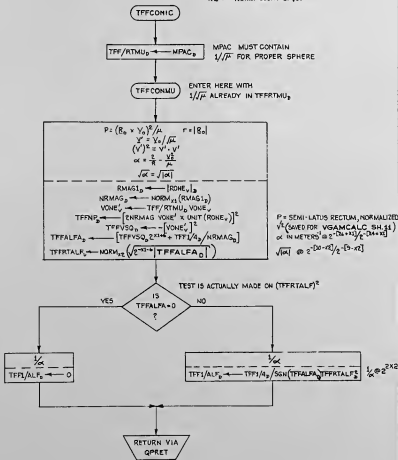




CALLED BY VB2 SEQUENCE (FC-2650) OR  
561.2 (FC-2760) TO COMPUTE THOSE CONIC  
PARAMETERS REQUIRED BY THE TFF SUBROUTINES  
AND ESTABLISH THEM IN THE PUSH LIST AREA

INPUTS:  $RONE_0 = B_0$  = PRESENT POSITION VECTOR IN METERS @  $2^2/2$   
 $VOVE_0 = V_0$  = PRESENT VELOCITY VECTOR IN METERS @  $2^2/2$   
 $TFFRTMU_0 = 1/\sqrt{\mu}$  FOR MOON OR EARTH

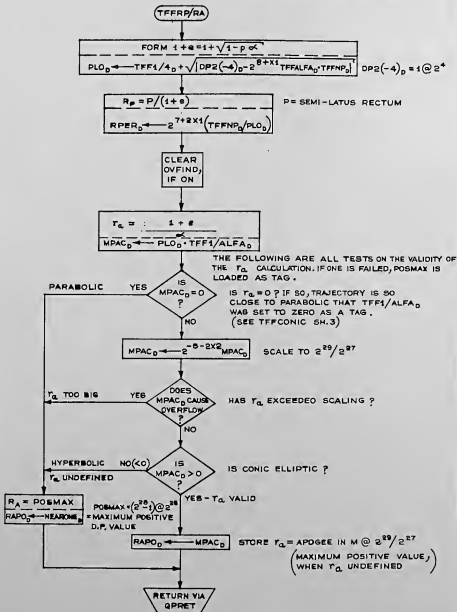
OUTPUTS:  $RMAG_0 = |B_0|$   
 $NRMAG_0 = (PL2D) * RMAG_0^{-2}$   
 $TFFNPR_0 = PL2D * P = \text{SEMI-LATUS RECTUM}$   
 $VOVE_0 = V_0/\sqrt{\mu}$   
 $TFFVSO_0 = \sqrt{V^2} = PL2D$   
 $TFFALFA = \alpha = (\text{SEMI-MAJOR AXIS})^{-1} = PL2D$   
 $TFFRALF = \sqrt{\alpha} = PL2D$   
 $TFFI/ALF = 1/\alpha = PL2D^2$   
 $X1 = -\text{NORM COUNT OF } RMAG_0$   
 $X2 = -\text{NORM COUNT OF } \sqrt{\alpha}$



UNIT  
 INSTRUMENTATION LAB  
 UNIVERSITY OF ARIZONA  
 DRAWN BY A.C. WILLIAMS      30DEC60  
 CHECKED BY *[Signature]*      3126/60  
 APPROVED BY *[Signature]*      207-60  
 APPROVED BY *[Signature]*      207-60

TIME OF FREE FALL  
 COLOSSUS IIC      FC-2320  
 5      20

CALLED BY VBE SEQUENCE (FC-2660).  
 CALCULATES APOGEE AND PERIGEE  
 FOR A GENERAL CONIC.  
 INPUT: TFFNP<sub>0</sub> = SEMI-LATUS RECTUM } FROM  
 TFFALFA<sub>0</sub> = RECIPROCAL SEMI-MAJOR AXIS } TFFCONIC  
 X1, X2  
 OUTPUT: RAPO<sub>0</sub> = APOGEE } IN METERS @ 2<sup>29</sup>/2<sup>27</sup>  
 RPER<sub>0</sub> = PERIGEE



NIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLID C'NANCE AND NAU. CATION
DRAWN BY <i>[Signature]</i> CHECKED BY <i>[Signature]</i> APPROVED BY <i>[Signature]</i>	TIME OF FREE FALL  COLOSSUS IIC FC-2320 5411 4 20
PERIOD: <i>[Signature]</i> ANALYST: <i>[Signature]</i> DATE: <i>[Signature]</i>	DOCUMENT NO. REV 1

CALLED BY V82 SEQUENCE (FC-2650) AND  
561.2 (FC-2760).  
CALCULATES THE TIME OF FREE FALL FLIGHT FROM PRESENT  
POSITION (RN) AND VELOCITY (VN) TO A RADIUS LENGTH  
SPECIFIED BY R<sub>h</sub>, SUPPLIED BY THE USER.

INPUT: MPAC = PERIGEE OR TERMINAL RADIUS (R<sub>h</sub>)

TFALFA, TFFNF, }  
R<sub>h</sub>AS, NR<sub>h</sub>AS, XLFC } FROM TFFCONIC  
TFF1/4, TFF1ALF }

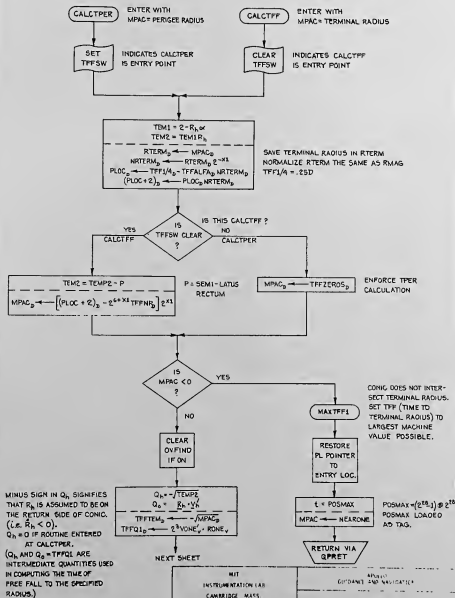
RONE<sub>1</sub>, VONE<sub>1</sub> = STATE VECTORS AT PRESENT

OUTPUT: MPAC = TIME OF FLIGHT TO PERIGEE OR TERMINAL RADIUS

NRTERM = NORMALIZED MAGNITUDE OF TERMINAL R.

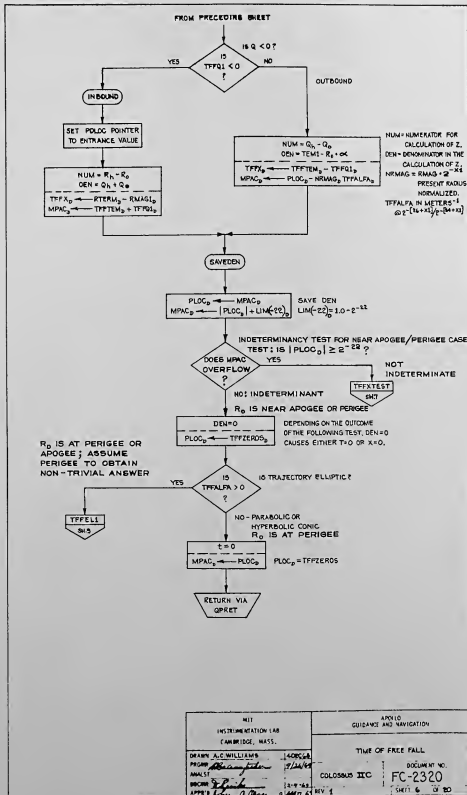
TFFTEM = Y = PZLZ OR P/6X SGH(Q<sub>0</sub> + R<sub>0</sub>/2)

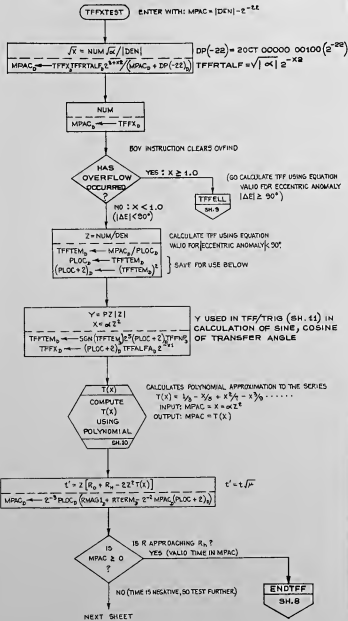
TFFX = αZ<sup>2</sup> OR 1/αZ<sup>2</sup>



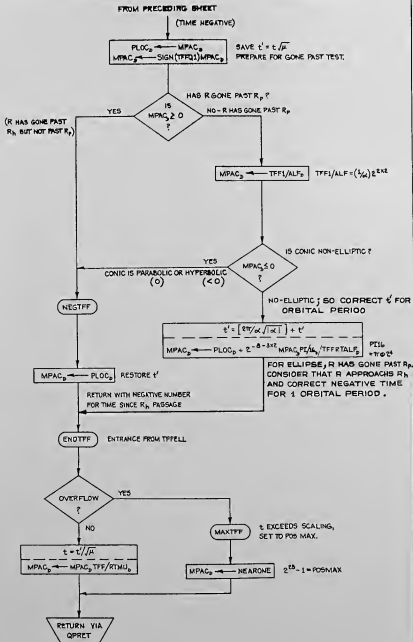
MINUS SIGN IN Q<sub>0</sub> SIGNIFIES THAT R<sub>h</sub> IS ASSUMED TO BE ON THE RETURN SIDE OF CONIC. (I.E. R<sub>h</sub> < 0).  
Q<sub>0</sub> = 0 IF ROUTINE ENTERED AT CALCTPER.  
(Q<sub>0</sub> AND Q<sub>0</sub> = TFFQ1 ARE INTERMEDIATE QUANTITIES USED IN COMPUTING THE TIME OF FREE FALL TO THE SPECIFIED RADIUS.)

MIT INSTRUMENTATION LAB CAMBRIDGE MASS		APPROVED GUIDANCE AND VALIDATED	
DRAWN A.C. WILLIAMS 1306145		TIME OF FREE FALL	
FROM <i>Williamson</i> 8/24/62		REV 001 V. 11	
ANALYST		COLLOSSUS IIC	
DESIGN <i>D. Rankin</i>		FC-2320	
APP'D <i>John A. Brown</i>		REV 1	
		3-11-65 10	





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		SH. 11 GUIDANCE AND NAVIGATION	
SPARR A.C. WILLIAMS    SDEC68 PRGMR <i>John Williams</i> 1/16/68 ANALCT DCRMR <i>John Williams</i> 1-4-68 APPRD <i>John Williams</i> 2-22-68	TIME OF FREE FALL COLOSSUS IIC    0000001 W. <span style="font-size: 1.5em;">FC-2320</span> REV 1    19417 7 = 10		



NIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		TIME OF FREE FALL	
PROGRAM	60850	DOCUMENT #	
ANALYST	9/26/60	COLOSSUS IIC	
DOC#	3-2-61	FC-2320	
APPROV	200011	SHEET 8 OF 10	

TFPELL TIME CALCULATION WHEN  $|\Delta E| \geq 90^\circ$  ( $X \geq 1.0$ )

ENTER FROM TFFTEST WITH NUM IN MPAC  
 $PLOC_0 = DEN$

$$\frac{1}{2} = DEN/NUM$$

$$PLOC_0 \leftarrow PLOC_0 / (MPAC_0^2)$$

TFPELL1 ENTER FROM SAVEDEN WITH  
 $PLOC_0 = TFFZEROS = 1/2$

$$\Delta O = Q_4 - Q_0$$

$$X = 1/\alpha z^2$$

$$TFFDELO_0 \leftarrow TFFTEM_0 - TFFQ_1$$

$$TFFTEM_0 \leftarrow PLOC_0$$

$$PLOC_0 \leftarrow TFFTEM_0 TFF1/ALF^2 - X^2$$

$$MPAC_0 \leftarrow PLOC_0 TFFTEM_0 z^{-2X}$$

TEMPORARY VARIABLE USED BELOW  
 $1/2$   
 $1/\alpha z$   
 $1/\alpha z^2 + X$

IF OVERFLOW ( $X=1$ ) CONTINUE (RATHER THAN BRANCHING  
 BACK — COULD COMPUTE EITHER  
 WAY FOR  $X=1$  CASE)

OVERFLOW?

YES

NO

CLEAR  
 OVFIND

SIGNMPAC  
 MPAC =  
 SIGN(MPAC)POS MAX  
 FC-100

POS MAX =  $2^{28} - 1 @ 2^{28}$

$TFFX_0 \leftarrow MPAC_0$  TFFX IS USED BY TFF/TRIG

T(X)  
 EVALUATE  
 POLYNOMIAL  
 T(X)  
 SH.10

CALCULATES POLYNOMIAL APPROXIMATION OF  
 THE SERIES

$$T(X) = 1/2 - X/5 + X^2/9 - X^3/9 \dots$$

INPUT: MPAC =  $X = 1/\alpha z^2$

OUTPUT: MPAC = T(X)

$$TEM_2 = \frac{1}{\alpha z} z [XT(X) - 1] = z \frac{XT(X) - 1}{\alpha z}$$

$$TEM = Q_0 + R_0/2$$

$$PLOC_0 \leftarrow PLOC_0 [z^{-3} MPAC_0 TFFX_0 - OPZ(-1/2)]$$

$$TFFTEM_0 \leftarrow TFFQ_1 + 4RANG_1 TFFTEM_0$$

TEM =  $SGN(SH(SF))$  WHERE SF = CONJ. TENSOR ANGLE

OPZ(-1) =  $1 @ 2^8$

$$Y = SGN(TEM) \frac{1}{\alpha z}$$

$$t = \frac{1}{\alpha z} \left[ \frac{Y}{\sqrt{|\alpha|}} - Q_0 + Q_0 + z \frac{XT(X) - 1}{\alpha z} \right]$$

$$TFFTEM_0 \leftarrow SGN(TFFTEM_0) z^{1-2X} TFF1/ALF_0 TFFTR$$

$$MPAC_0 \leftarrow z^{-1-2X} TFF1/ALF_0 (z^{-1+2X} (PLOC_0 + R_0/2) TFF1/ALF_0 - TFFDELO_0)$$

Y USED IN TFF/TRIG (SH.11)

TO CALCULATE SINE,

COSINE OF TRANSFER ANGLE

$$t = t \sqrt{|\alpha|}$$

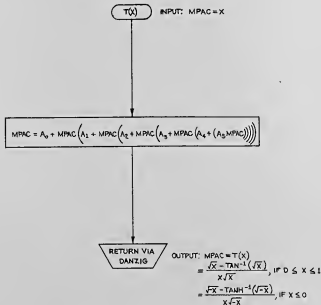
$$TFFTR = P - 2^{-2X+1}$$

$$TFF1/ALF = (1/\alpha) z^{2X}$$

$$TFFTEM = Y \cdot z^{-2X}$$

ENDTFF  
 SH.6

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ADULT ORDINANCE AND NAVIGATION
DRAWN A.C. WILLIAMS PRINTED <i>Basim Jaffer</i> ANALYST DOCMR <i>Dr. R. K. ...</i> APPROV <i>John Q. Thomas 2/11/62</i>	TIME OF FREE FALL DOCMR V. W. COLOSSUS IIC FC-2320 SH.11 B CA 20



$T(x)$  = POLYNOMIAL APPROXIMATION TO THE SERIES:  
 $1/3 - x/5 + x^2/7 - x^3/9 + \dots$

POLYNOMIAL IS OF 5<sup>TH</sup> ORDER, HAVING COEFFICIENTS

$A_0 = 1/3$   
 $A_1 = -1.099819135 \text{ E-1}$   
 $A_2 = 1.418148447 \text{ E-1}$   
 $A_3 = -1.01310997 \text{ E-1}$   
 $A_4 = 5.609004506 \text{ E-2}$   
 $A_5 = -1.536156925 \text{ E-2}$

RANGE OF POLYNOMIAL FIT  $x = (0, +1)$ . MAXIMUM DEVIATION OF FIT  $2\text{E-5}$ .  
 RANGE OF  $x$  SATISFYING ABOVE DEVIATION IS  $(-.08, +1)$ .

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS PROM <i>[Signature]</i> ANALYST <i>[Signature]</i> DOOR <i>[Signature]</i> APPROVED <i>[Signature]</i>	TIME OF FREE FALL COLLOSSUS IIC DOCUMENT NO. <span style="font-size: 1.2em; font-weight: bold;">FC-2320</span>
3306C6B 11/16/69 12-9-69 11/16/69	REV 1



USED BY P61 ENTRY DISPLAY (FC-2760)  
 CALCULATE  $\sin(\delta f)$ ,  $\cos(\delta f)$   
 FROM DATA LEFT IN PUSHLIST BY TFF SUBROUTINES.  
 ( $\delta f$  = TRANSFER ANGLE)

TFF/TRIG

$$\cos(\delta f) = 1 - \frac{Y}{R_0 R_h (1+X)}$$

$$CDEL F / Z_0 - 1 = \frac{TFFTEM_0}{NRMAG_0 NRTERM_0 (1 + TFFX_0)}$$

INPUT:  
 NRMAG<sub>0</sub> FROM TFFCONIC  
 NRTERM<sub>0</sub>  
 TFFX<sub>0</sub> FROM CALCTFF  
 TFFTEM<sub>0</sub>

OUTPUT:  
 CDEL F / Z<sub>0</sub> =  $\cos(\delta f)$  @  $\pm 1$   
 MPAC<sub>0</sub> =  $\sin(\delta f)$  @  $\pm 1$

$$\sin(\delta f) = \text{SGN}(Y) \sqrt{1 - \cos^2(\delta f)}$$

$$MPAC_0 = \text{SIGN}(TFFTEM_0) \sqrt{1 - (CDEL F / Z_0)^2}$$

TFFTEM =  $Y = PZ|Z|$ , IF  $\alpha Z^2 < 1$ .  
 =  $\left(\frac{P}{\alpha}\right) \text{SGN}\left(Q_0 + \frac{R_0}{Z}\right)$ ,  
 IF  $\alpha Z^2 \geq 1$ .

RETURN VIA  
 QPRET

USED BY P61 (FC-2760)  
 EARTH CENTERED VIS VNA CALCULATIONS OF TERMINAL  
 VELOCITY AND FLIGHT PATH ANGLE (RELATIVE TO  
 HORIZONTAL)

PREVGAM

NORMALIZE

$$NRTERM_0 \leftarrow \frac{1}{Z^{-X1}} MPAC_0 \quad (\text{MPAC}_0 \text{ CONTAINS } R_h \text{ @ } \pm 2^9 / \pm 2^7)$$

VGAMCALC

INPUT:  
 NRTERM<sub>0</sub> FROM CALCTFF  
 TFFM<sub>0</sub>  
 TFFVSO<sub>0</sub>  
 RMAG<sub>0</sub> FROM TFFCONIC  
 NRMAG<sub>0</sub>

$$V_h = \sqrt{\left(\frac{V_0}{Z}\right)^2 + 2 \frac{R_0 - R_h}{R_0 R_h}}$$

$$MPAC_0 \leftarrow \frac{NRMAG_0 NRTERM_0 2^{-9-X1}}{\sqrt{TFFVSO_0^2 + \frac{NRMAG_0 NRTERM_0 2^{-9-X1}}{FLOC_0}}}$$

$$FLOC_0 \leftarrow MPAC_0$$

CALCULATE MAGNITUDE OF  
 TERMINAL VELOCITY.

$$V_h = \sqrt{F} V_h'$$

$$MPAC_0 \leftarrow MPAC_0 / TFF / RTMU_0$$

$$MPAC_0 \leftarrow FLOC_0$$

MPAC EXCHANGED WITH FLOC<sub>0</sub>  
 SAVE UN-NORMALIZED VELOCITY FOR  
 OUTPUT

$$\gamma_0 = \cos^{-1} \left( \frac{R_h'}{R_h V_h} \right)$$

$$MPAC_0 \leftarrow \cos^{-1} \left( \frac{\frac{1}{2} TFFM_0^2}{NRTERM_0 MPAC_0} \right)$$

CALCULATE FLIGHT PATH ANGLE  
 RELATIVE TO LOCAL HORIZONTAL.

USER MUST SUPPLY CORRECT SIGN  
 FOR MPAC<sub>0</sub> ( $\gamma_0$ ) ON RETURNING.

RETURN VIA  
 QPRET

OUTPUT:  
 FLOC<sub>0</sub> = TERMINAL VELOCITY ( $V_h$ ) IN M/CSEC @  $\pm 2$   
 MPAC<sub>0</sub> = FLIGHT PATH ANGLE AT  
 EMS ALTITUDE ( $\gamma_0$ ) (IN REVS @  $\pm 2^\circ$ )

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		CALCULATED LIST NO. AND NAVIGATION	
BY: A.C. WILLIAMS	DATE: 3/16/69	TIME OF FREE FALL	
CHKD BY: <i>[Signature]</i>	BY: <i>[Signature]</i>	COLLOSSUS IIC	FC-2320
APPROV: <i>[Signature]</i>	BY: <i>[Signature]</i>	REV 1	REV 1

CALCULATE RADIUS OF FISCHER ELLIPSOID  
AT LATITUDE OF ESTIMATED TERMINAL RADIUS

USED BY P61 (FC-2760)

FISHCALC

INPUT:  
 $MPAC_0 = \sin(\delta f)_0$   
 $CDEL F / R_e = \cos(\delta f)_0$  } FROM TFF/TRIG  
 $UNIT R_h = UNIT (R_{h0})$  FROM AVERAGE  
 $UNIT V_x = UNIT (V_x \times R_{h0})$  FROM TARGETING  
 OUTPUT:  
 $MPAC_0 =$  RADIUS OF THE EARTH ( $R_e$ ) AT THE LATITUDE OF  $R_h$

$$UNIT(R_h) = UNIT(R_{h0}) \cos(\delta f) + [UNIT(R_{h0}) \times UNIT(V_x \times R_{h0}) \sin(\delta f)]$$

CALCULATE UNIT VECTOR ALONG  $R_h$  (TERMINAL RADIUS)

$$URH_v = URONE_v \cdot CDEL F / R_e + (URONE_v \times UNIT V_x) MPAC_0^2$$

$$\sin(LAT) = UNIT(W_e) \cdot UNIT(R_h)$$

$$ALPHA + 4 = 2 \cdot UNIT W_x \cdot URH_v$$

CALCULATE LATITUDE OF THE TERMINAL RADIUS.  
 $[UNIT W_x =$  UNIT VECTOR ALONG EARTH AXIS OF  
 ROTATION (PAD LOADED).]

GETERAD

CALCULATE RADIUS OF  
THE FISCHER ELLIPSOID AT  
THE GIVEN LATITUDE (EARTH  
RADIUS CORRECTED FOR  
FLATTENING AT THE POLES)  
FC-2260

INPUT:  
 $ALPHA + 4 = \sin(LAT) \odot 2^1$   
 OUTPUT:  
 $ERADM_0$   
 $= MPAC_0$  RADIUS OF THE EARTH AT THE  
 GIVEN LATITUDE ( $R_e$ ) IN M  $\odot 2^{29}$

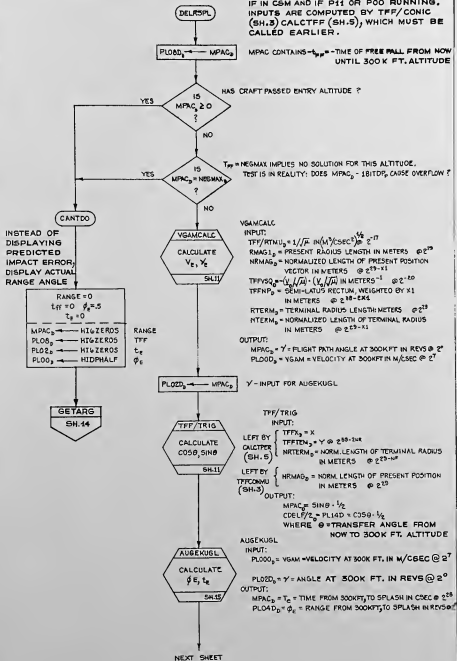
RETURN VIA  
QPRET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	
OFFICER A.C. WILLIAMS	30 DEC 68
PROGRAM A. Cairns	9/24/68
ANALYST J. R. ...	2-7-68
DESIGNER John A. ...	2/10/68
APPROVED	

TIME OF FREE FALL	
COLOSSUS IIC	FC-2320
	14 OCT 12 1970

CALLED AS PART OF V02 SEQUENCE (FC-2050) IF IN CSM AND IF P11 OR P00 RUNNING. INPUTS ARE COMPUTED BY TFF/CONIC (SH.3) CALCCTFF (SH.5), WHICH MUST BE CALLED EARLIER.

MPAC<sub>0</sub> CONTAINS  $-t_{pp}$  - TIME OF FREE FALL FROM NOW UNTIL 300K FT. ALTITUDE



DRAWN A.C. WILLIAMS PREPARED BY <i>[Signature]</i> ANALYST <i>[Signature]</i> DATE 12-9-53 APPROVED <i>[Signature]</i>		TIME OF FREE FALL COLLOSSUS IIC FC-2320 REV 1
--	--	---

FROM PRECEDING SHEET

$$\text{RANGE} = (\text{ARC COS}(\text{COS}\theta) + \beta_0)$$

$$\text{PLOW}_D \leftarrow \text{MPAC}_D$$

$$\text{MPAC}_D \leftarrow \text{ACOS}(\text{CDELF}/C) + \text{PLD}_D$$

STORE  $T_0$   
RANGE IN REVS @ 2°

GETARG

ALT=0

THETA<sub>10</sub> ← MPAC<sub>D</sub>  
LAT<sub>D</sub> ← LAT(SPL)<sub>D</sub>  
LONG<sub>D</sub> ← LNS(SPL)<sub>D</sub>  
ALT<sub>D</sub> ← HTGZEROS<sub>D</sub>

RANGE  
INPUT TO LALOTRY:  
(OBTAINED IN ORDER BY A "LOAD") REVS } @ 2°  
SPLASH HAS ZERO ALTITUDE.

SET VSTFLAG CLEAR COMPUTE  $T = (\text{STATE VECTOR TIME}) + t_{P2} + t_z$   
= PREDICTED IMPACT TIME

P41 RUNNING  
IN AVG. USE  
PIPTIME.

MPAC ← PIPTIME - PLBD + PLGD\*

POO RUNNING

MPAC ← TSTART02 - PLBD + PLGD\* TIME OF SPLASH

TSTART02 = STATE VECTOR TIME  
PIPTIME = STATE VECTOR TIME

\* NOTE: IF THIS CODING IS ACCESSED  
VIA CANTD, THEN PLGD IS  
IN REALITY PLOZD.

CLEAR  
ERAFLAG

COMPUTE FOR FIXED EARTH RADIUS

LALOTRY  
CALCULATE  
V SPL  
FC-2200

LALOTRY COMPUTES RADIUS VECTOR GIVEN TIME, LATITUDE  
LONGITUDE AND ALTITUDE

INPUT:

MPAC = PREDICTED IMPACT TIME  
LAT<sub>D</sub> = LATITUDE IN REVS @ 2°  
LONG<sub>D</sub> = LONGITUDE IN REVS @ 2°  
ALT<sub>D</sub> = ALTITUDE = 0  
ERAFLAG = CLEAR MEANS USE FIXED EARTH RADIUS.

OUTPUT:

MPAC = RADIUS VECTOR AT PREDICTED IMPACT POINT  
IN METERS @ 2<sup>53</sup>

$$\text{SPLEFFOR} = -(\text{ARCCOS}(\text{USR} \cdot \text{F}_1) - \text{RANGE})$$

$$\text{RSP-RREC}_D \leftarrow \text{THETA}_D - \text{ARCCOS}(2^\circ \text{UNIT}(\text{RONE}_D) \text{UNIT}(\text{MPAC}_D))$$

NOTE: NEGATIVE VALUE INDICATES  
THAT IMPACT POINT FALLS  
SHORT OF TARGET POINT

RANGE ERROR: REVS @ 2°

INTWAKO  
PERMIT  
INTEGRATION  
TO OCCUR  
FC-2200

(INTEGRATION IS STALLED TO HOLD  
COMPLETED STATE VECTOR IF V82  
CALLED IN POO)

SPLREY  
FC-2650

RETURN TO R30 (V82 SEQUENCE)

WIT  
INSTRUMENTATION LAB  
CAMBRIDGE MASS.

DRAWN A.C. WILLIAMS  
PREPARED BY *[Signature]*  
ANALYST  
CHKD BY *[Signature]*  
DATE 2-8-69  
BY *[Signature]*

DATE  
GOLDEN - 21000000

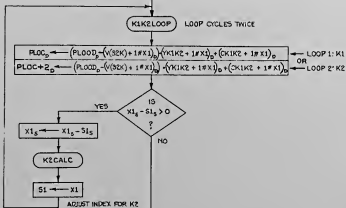
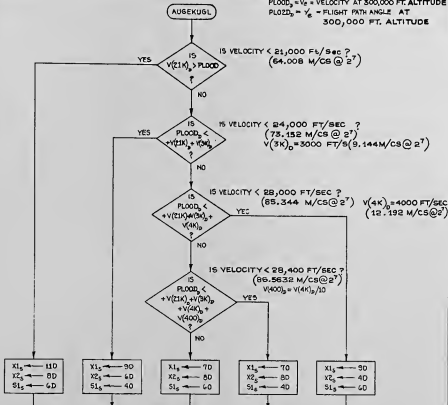
TIME OF FREE FALL

678669

COLORADO IIC  
REV 1

FC-2320  
REV 14 20

FLOOD<sub>0</sub> = V<sub>0</sub> = VELOCITY AT 500,000 FT. ALTITUDE  
 FLOOD<sub>0</sub> = V<sub>0</sub> = FLIGHT PATH ANGLE AT  
 300,000 FT. ALTITUDE



NEXT SHEET

INSTRUMENTATION LAB CAMBRIDGE, MASS.		DATE: 12/15/64	
DESIGN: A.C. WILLIAMS	DATE: 12/15/64	TIME OF FREE FALL	
PROGRAM: <i>Blairmof</i>	2/16/64	0 = 1000 FT	
ANALYST: <i>J. Williams</i>	2-1-68	COLOSSUS IIC	
PROGRAM: <i>J. Williams</i>	2-1-68	FC-2320	
APPROVED: <i>John A. Moore</i>	2/16/64	15 20	

FROM PRECEDING SHEET

$$\beta_0 = \frac{K1}{(\gamma_e - K4)}$$

$$PLOAD_0 \leftarrow MPAC \leftarrow PLOC_0 / (PLOC_0 - PLOC2_0) \quad \beta_e \text{ IN REVS @ } 2^7$$

IS THERE OVERFLOW ?

YES

NO

MPAC<sub>0</sub> < 0 ?

YES

NO

MPAC<sub>0</sub> ≥ MAXPHIC<sub>0</sub> ?

YES

NO

MAXPHI

$$PLOAD_0 \leftarrow MAXPHIC_0$$

MAXPHIC<sub>0</sub> = .08259258  
REVS @ 2<sup>6</sup>  
; 2000 NM  
FOR MAX  $\dot{q}_e$

PHICALC

IS  $V_e > 26,000$  FT/SEC ?  
(79.248 M/CS @ 2<sup>7</sup>)

YES

NO

TGR2<sub>0</sub>

$$MPAC_0 \leftarrow TGR26CON_0$$

TGR26CON =  $7.2 \times 10^5$   
@ 2<sup>28</sup>

$$\frac{\beta_0 \omega_0}{V_e}$$

$$MPAC_0 \leftarrow TLESS2_0 PLOAD_0 \quad TLESS2_0 = 5.70146686 \times 10^7 @ 2^{25}$$

TENT

$$T_e = \beta_0 / \beta \quad \text{OR} \quad T_e = \beta_e - \beta_0 \omega_0 / V_e$$

$$MPAC_0 \leftarrow MPAC_0 PLOAD_0 \quad T_e \text{ IN CSEC @ } 2^{28}$$

RETURN VIA QPRET

MIT INSTRUMENTATION LAB CAMBRIDGE, MA.		DATE: 11/24/68 TIME OF FREE FALL	
DESIGN: SPANN A. WILLIAMS	11/24/68	COLLOSSUS IIC	FC-2320
ANALYSIS: <i>[Signature]</i>			
DESIGN: <i>[Signature]</i>			
APPROVED: <i>[Signature]</i>	2/10/69		

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
GETERAD	2280	COMPUTE RADIUS OF FISCHER ELLIPSOID, GIVEN A PARTICULAR LATITUDE	SH. 12
SIGNMPAC	2100	PUT POSMAX INTO MPAC, USING CURRENT SIGN OF MPAC	SH. 9
INTWAKE0	2290	PERMIT INTEGRATION TO BE USED, AGAIN	SH. 14
LALOTORV	2280	GIVEN ALTITUDE, LATITUDE, LONGITUDE, AND TIME COMPUTE RADIUS VECTOR FOR FIXED OR FISCHER	SH. 14

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
ERADFLAG	COMPUTE FOR FISCHER ELLIPSOID	COMPUTE WITH FIXED RADIUS		SH. 14	
TFFSW	CALCTPER	CALCTFF	SH. 5	SH. 5	SH. 5
V37FLAG	AVERAGEG RUNNING	AVERAGEG OFF			SH. 14

ERASABLE LOCATIONS USED

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
ALPHAV <sup>4</sup> <sub>D</sub>	SIN(LAT)	SINE OF LATITUDE OF TERMINAL RADIUS	DEGREES	REVS	2 <sup>1</sup>
ALT <sub>D</sub>	ALT	ALTITUDE, FOR LALOTORV (EQUALS ZERO)	FEET	METERS	
CDEL <sup>2</sup> <sub>D</sub>	COS( $\theta$ )	COSINE OF TRANSFER ANGLE			2 <sup>1</sup>
LAT <sub>D</sub>	LAT <sub>SPL</sub>	INPUT FOR LALOTORV: LATITUDE	DEGREES	REVS	2 <sup>0</sup>
LATSPL <sub>D</sub>	LAT <sub>SPL</sub>	TARGET LOCATION, LOADED INTO LAT	DEGREES	REVS	2 <sup>0</sup>
LNGSPL <sub>D</sub>	LONG <sub>SPL</sub>	TARGET LOCATION, LOADED INTO LONG	DEGREES	REVS	2 <sup>0</sup>
LONG <sub>D</sub>	LONG <sub>SPL</sub>	INPUT FOR LALOTORV: LONGITUDE	DEGREES	REVS	2 <sup>0</sup>
NRMAG <sub>D</sub>		NORMALIZED MAGNITUDE OF $\underline{r}$	FEET	METERS	2 <sup>20</sup> -X1 / 2 <sup>27</sup> -X1
NRTERM <sub>D</sub>		NORMALIZED TERMINAL RADIUS	FEET	METERS	2 <sup>20</sup> -X1 / 2 <sup>27</sup> -X2
PIPTIME <sub>D</sub>	t	TIME OF STATE VECTOR COMPUTED BY AVERAGEG	SECONDS	CSEC	2 <sup>28</sup>
RMAG <sub>D</sub>	r	CURRENT RADIUS MAGNITUDE	FEET	METERS	2 <sup>20</sup> 2 <sup>27</sup>
RONE <sub>V</sub>	$\underline{r}$	CURRENT RADIUS STATE VECTOR	FEET	METERS	2 <sup>20</sup> 2 <sup>27</sup>
RPER <sub>D</sub>	r <sub>p</sub>	MAGNITUDE OF PERIGEE	FEET	METERS	2 <sup>20</sup> 2 <sup>27</sup>
RSP-RREC <sub>D</sub>	SPLERROR	RANGE ERROR	DEGREES	REVS	2 <sup>0</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		TIME OF FREE FALL	
DRAWN <i>A. J. ...</i> PREP'D <i>A. J. ...</i> ANALY <i>A. J. ...</i> CHECK'D <i>A. J. ...</i> APPROV'D <i>A. J. ...</i>	26 NOV 68 2/26/68 2-9-68 2 APR 69	COLOSSUS IIC FC-2320 17 20	

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
RTERM <sub>D</sub>	$r_h$	TERMINAL RADIUS	FEET	METERS	$2^{28}/2^{27}$
TFFALFA <sub>D</sub>	$a$	INVERSE OF SEMI-MAJOR AXIS OF CONIC	1/FEET	1/METERS	$2^{-26} \times X1$ $2^{-24} \times X1$
TFFDELQ <sub>D</sub>	$Q_h - Q_0$	TEMPORARY VARIABLE	FEET <sup>1/2</sup>	METERS <sup>1/2</sup>	$2^{16}/2^{15}$
TFFNP <sub>D</sub>	$p$	SEMI-LATUS RECTUM, WEIGHTED BY X1	FEET	METERS	$2^{38} \times X1$ $2^{36} \times X1$
TFFQ1 <sub>D</sub>	$Q_0$	$(x_0 + y_0)/\sqrt{\mu}$	FEET <sup>1/2</sup>	METERS <sup>1/2</sup>	$2^{16}/2^{15}$
TFFRTALF <sub>D</sub>	$\sqrt{a}$	SQUARE ROOT OF INVERSE OF SEMI-MAJOR AXIS	1/FEET <sup>1/2</sup>	1/METERS <sup>1/2</sup>	$2^{-10} \times X2$ $2^{-9} \times X2$
TFFTEM <sub>D</sub>	$-(\frac{v}{\mu})^2$	TEMPORARY VARIABLE LOCATION			
TFFVSO <sub>D</sub>	$-(v')^2 = (\frac{v}{\mu})^2$	MINUS SQUARE OF VELOCITY OVER MU	1/FEET	1/METERS	$2^{-20}/2^{-18}$
TFFX <sub>D</sub>	$x$	$1/aZ^2$ OR $az^2$			$2^0$
TFF1/ALF <sub>D</sub>	$1/a$	INVERSE OF ALPHA: SEMI-MAJOR AXIS	FEET	METERS	$2^{22} - 2X2$ $2^{20} - 2X2$
THETA1 <sub>D</sub>	$\theta$	TRANSFER ANGLE	DEGREES	REVS	$2^0$
UNI <sub>V</sub>	UNIT( $\underline{v}_0 \times \underline{r}_0$ )	UNIT NORMAL TO FLIGHT PATH PLANE			$2^1$
URH <sub>V</sub>	UNIT( $\underline{r}_h$ )	UNIT VECTOR OF TERMINAL			$2^1$
URONE <sub>V</sub>	UNIT( $\underline{r}_0$ )	UNIT VECTOR OF CURRENT POSITION			$2^1$
VONE <sub>V</sub>	$\underline{v}_0$	CURRENT VELOCITY VECTOR	FEET/SEC	METERS/CSEC	$2^7/2^5$
VONE' <sub>V</sub>	$\underline{v}'$	CURRENT VELOCITY VECTOR OVER MU <sup>1/2</sup>	FEET <sup>-1/2</sup>	METERS <sup>-1/2</sup>	$2^{-10}/2^{-9}$

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
NOTE: A SECOND SECTION OF PROGRAM CONSTANTS IS INCLUDED FOR DELRSP, AND ITS SUBROUTINE AUGKEUGL. THIS IS DONE TO PRESERVE THE TEST CONSTANT TABLE, WHICH IS INDEXED.					
DP1-22) <sub>D</sub>			$2^{-22}$	1	$2^{22}$
DP2-3) <sub>D</sub>	$1 @ 2^3$	ONE	$1 @ 2^3$	1	$2^3$
DP2-4) <sub>D</sub>	$1 @ 2^4$	ONE	$1 @ 2^4$	1	$2^4$
HDPHALF <sub>D</sub>	1/2		1/2	.5	$2^0$
HI6ZEROS <sub>D</sub>	0	ZERO	00000000.0	000000.0	$2^0$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TIME OF FREE FALL	
PROGRAM <i>[Signature]</i>		COLOSSUS	
ANALYST		11C	DOCUMENT NO. FC-2320
DOCNR		REV 1	SHEET 18 OF 20
APPROVAL <i>[Signature]</i> 1-7-70			



## PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSCP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
LIM(-22) <sub>D</sub>	1-2 <sup>22</sup>	TEST CONSTANT FOR  D	1-2 <sup>22</sup>	1-2 <sup>22</sup>	2 <sup>0</sup>
NEARONE <sub>D</sub>	2 <sup>28</sup> -1	MACHINE POSITIVE MAXIMUM	2 <sup>28</sup> -1	.999999999	2 <sup>0</sup>
PI/16 <sub>D</sub>	π	PI	π	π	2 <sup>4</sup>
TFPZEROS <sub>D</sub>	0	ZERO	0	0	
TFPI/4 <sub>D</sub>	2	TWO	2@2 <sup>3</sup>	2	2 <sup>3</sup>

## FOR DELRSPL AND AUGKUGL

NOTE: THIS TABLE IS INDEXED. ALL VALUES IN THE TABLE ARE EMPIRICALLY DERIVED CURVE-FITTING COEFFICIENTS, EXCEPT THAT SOME MAY ALSO BE TEST CONSTANTS, IN WHICH CASE THEY ARE SO LABELED.

(CK1K2 -10D) <sub>D</sub>			5500	7.07304526 × 10 <sup>-4</sup>	2 <sup>0</sup>
(CK1K2 -8) <sub>D</sub>			2400	3.08641975 × 10 <sup>-4</sup>	2 <sup>0</sup>
(CK1K2 -6) <sub>D</sub>			2400	3.08641975 × 10 <sup>-4</sup>	2 <sup>0</sup>
(CK1K2 -4) <sub>D</sub>			-3.2	-8.8888888 × 10 <sup>-3</sup>	2 <sup>0</sup>
(CK1K2 -2) <sub>D</sub>			1	2.7777777 × 10 <sup>-3</sup>	2 <sup>0</sup>
CK1K2			2.4	6.6666666 × 10 <sup>-3</sup>	2 <sup>0</sup>
(CK1K2 +2) <sub>D</sub>			0	0	2 <sup>0</sup>
(CK1K2 +4) <sub>D</sub>			-443	-1.86909989 × 10 <sup>-5</sup>	2 <sup>-7</sup>
(CK1K2 +6) <sub>D</sub>			0	0	2 <sup>0</sup>
(CK1K2 +8) <sub>D</sub>			.001225	1.11639691 × 10 <sup>-3</sup>	2 <sup>-7</sup>
(CK1K2 +10D) <sub>D</sub>			.00105	9.56911636 × 10 <sup>-4</sup>	2 <sup>-7</sup>
YK1K2			.000285	2.59733157 × 10 <sup>-4</sup>	2 <sup>-7</sup>
V(400)		TEST CONSTANT	400 FT/SEC	1.2182 M/CSEC	2 <sup>7</sup>
V(28K)			28000 FT/SEC	85.344 M/CSEC	2 <sup>7</sup>
V(3K)		TEST CONSTANT	3000 FT/SEC	9.144 M/CSEC	2 <sup>7</sup>

MET INSTRUMENTATION LAB CAMBRIDGE, MASS.		DATE: 12-1-68 TIME OF FREE FALL	
DRAWN: <i>J. R. Smith</i>	24 NOV 68	COLOSSUS IIC	
PROGRAM: <i>Smith</i>	3/24/68	FC-2320	
ANALYST:		SHEET 19 OF 20	
DOCUMENT: <i>J. R. Smith</i>	12-1-68		
APPROVED: <i>J. R. Smith</i>	24 NOV 68		

## PROGRAM CONSTANTS (CONTINUED)

## DELRPL-AUGEKUGL CONSTANTS, CONTINUED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
V(24K)			24000 FT/SEC	73.152 M/CSEC	2 <sup>7</sup>
			28000 FT/SEC	85.344 M/CSEC	2 <sup>7</sup>
V(32K)			32000 FT/SEC	97.536 M/CSEC	2 <sup>7</sup>
END OF THE INDEXED TABLE					
V(4K)		TEST CONSTANT	4000 FT/SEC	12.192 M/CSEC	2 <sup>7</sup>
V(21K)		TEST CONSTANT	20997.3 FT/SEC	64.008 M/CSEC	2 <sup>7</sup>
TLESS26		CURVE FIT CONSTANT	8660	5.70146688 × 10 <sup>7</sup>	2 <sup>35</sup>
TGR26CON		CURVE FIT CONSTANT	PHI/3	7.2 × 10 <sup>5</sup>	2 <sup>28</sup>
V(26K)		TEST CONSTANT	26000 FT/SEC	79.248 M/CSEC	2 <sup>7</sup>
X1CON		INDEX AND STEP REGISTER INITIAL VALUES	X1 X2 S1	10D 8D 8D	2 <sup>14</sup>
MAXPHIC		2000 NAUTICAL MILES FOR MAXIMUM PHI ENTRY	2000 N.M.	0.08258288 REVS	2 <sup>0</sup>

MIL INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFSC GUIDANCE AND NAV. CAT. N.	
		TIME OF FREE FALL	
DESIGN <i>D. J. Smith</i>	DATE <i>2/20/66</i>	COLOSSUS IIC FC-2320 SHEET 20 OF 20	
PROG <i>2/20/66</i>	DATE <i>2/20/66</i>		
ANALYST			
APPROV'D <i>D. J. Smith</i>	DATE <i>2/20/66</i>		
REV 4			

RENDEZVOUS PARAMETERS DISPLAYS

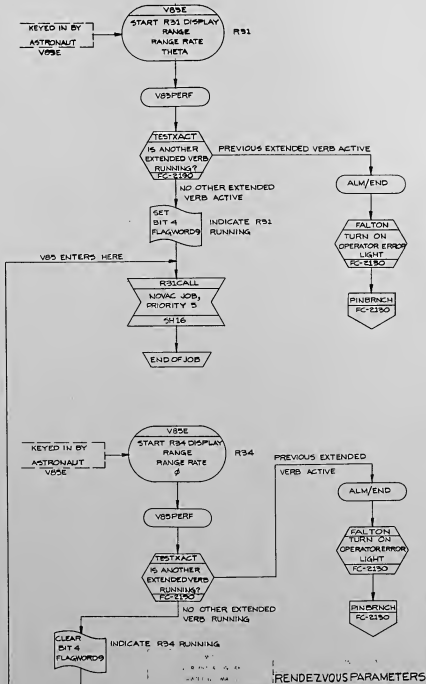
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

V83PERF: REQUEST FOR VERB 83, (R31), KEYED IN BY ASTRONAUT SH. 2  
V85PERF: REQUEST FOR VERB 85, (R34), KEYED IN BY ASTRONAUT SH. 2

THERE HAVE BEEN NO CHANGES FROM THE COLOSSUS II  
FLOWCHART FC-2325, REV. 0, TO THE COLOSSUS IIC FLOW-  
CHART FC-2325, REV. 1

HI			
INSTRUMENTATION LAB			
AMSTERDAM, N.A.S.			
REV. 3/21/61		RENDEZVOUS PARAMETERS DISPLAY	
DESIGNER: G. W. W. W.	23/2/61	COLOSSUS IIC FC-2325	
ANALYST: J. P. L.	23/2/61	INSTRUMENT NO.	
DESIGNER: J. P. L.	23/2/61	REV. 1	
ANALYST: J. P. L.	23/2/61	REV. 1	

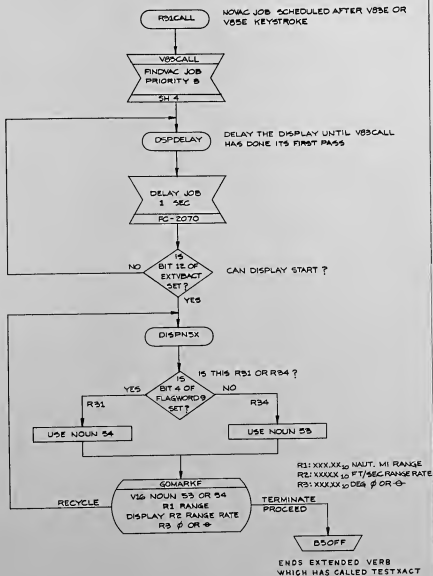
R31, R34 RENDEZVOUS PARAMETER DISPLAY



RENDEZVOUS PARAMETERS DISPLAY

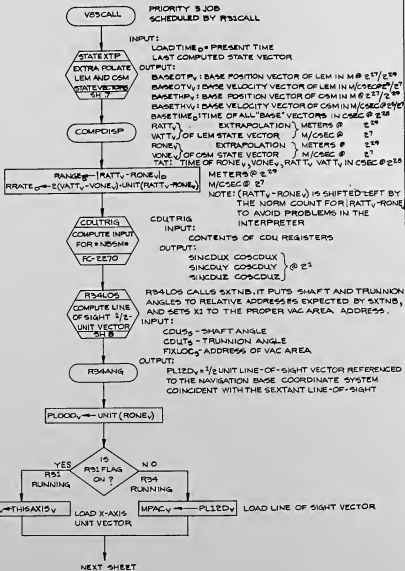
COLOSSUS IIC FC-2325

28. Chyalski  
J.B. Cohen  
J. R. ...  
John A. ...



11 1  
 VACATION 100  
 WEEK-LINE 100  
 FROM: J.E. Loken  
 TO: J.E. Loken  
 ANALYST: J.E. Loken  
 DATE: 2/7/45  
 BY: J.E. Loken  
 11/1/45

RENDEZVOUS PARAMETERS  
 DISPLAY  
 COLLOSSUS IIC FC-2325  
 14



WIT  
IMPLEMENTATION BY  
LAWRENCE, WALS.

DESIGNED BY *J. C. Cracker*  
PERFORMED BY *J. C. Cracker*  
ANALYZED BY *J. C. Cracker*  
APPROVED BY *J. C. Cracker*

DATE  
2/15/64  
2/16/64  
2/16/64

**RENDEZVOUS PARAMETERS  
DISPLAY**

**COLOSSUS IIC FC-2325**

REV 4

4 - 24

FROM PRECEDING SHEET



INPUT:  
 SINCDUX COSCDUX  
 SINCDCU COSDCU  
 SINCDUZ COSCDUZ  
 MPAC<sub>V</sub> IN N. B. COORDINATES  
 OUTPUT:  
 MPAC<sub>V</sub> IN S. M. COORDINATES

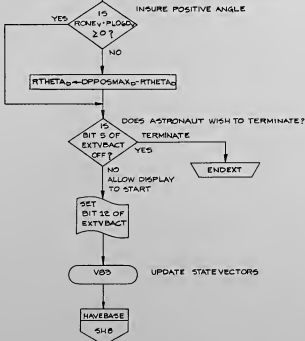
$$\theta = \cos^{-1} \left[ u_x \cdot u_p \cdot \text{SIGN}(u_p \cdot l_x \cdot r_c) \right] \text{ WHERE } l = \text{UNIT} \left[ r_c \times v_c \right], u_p = \text{UNIT} \left[ u_x - \left( \frac{u_x \cdot r_c}{r_c} \right) r_c \right]$$

$$\text{FLOOD}_D \leftarrow \text{MPAC}_V \times \text{REPOMAT}$$

$$\text{RTHETA}_D \leftarrow \text{ACOS} \left[ \text{SIGN} \left\{ 4 \left( \text{UNIT} \left( \text{FLOOD}_D - 4 \left( \text{FLOOD}_D \cdot \text{FLOOD}_D \right) \cdot \text{FLOOD}_D \right) \right) \right\} \right]$$

$$\text{WHERE } \left\{ = \left( \text{UNIT} \left( \text{RONE}_V \times \text{VONE}_V \right) \times \text{RONE}_V \right) \cdot \left( \text{UNIT} \left( \text{FLOOD}_D - 4 \left( \text{FLOOD}_D \cdot \text{FLOOD}_D \right) \cdot \text{FLOOD}_D \right) \right) \right\}$$

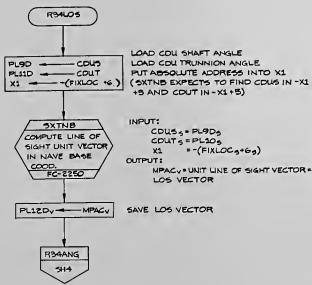
§ IS AN  
 INTERMEDIATE  
 VARIABLE §  
 NOT AN AGC  
 TAG



INFORMATION #1  
 281  
 I.E. Coker 28164  
 APPROV 6/21/68  
 6/21/68

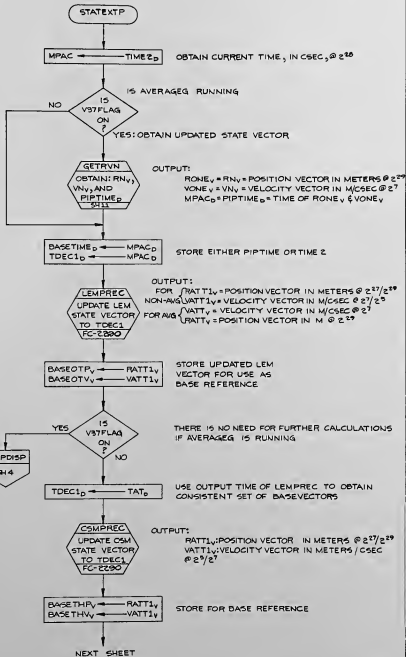
RENDEZVOUS PARAMETERS  
 DISPLAY

COLOSSUS II FC-2325

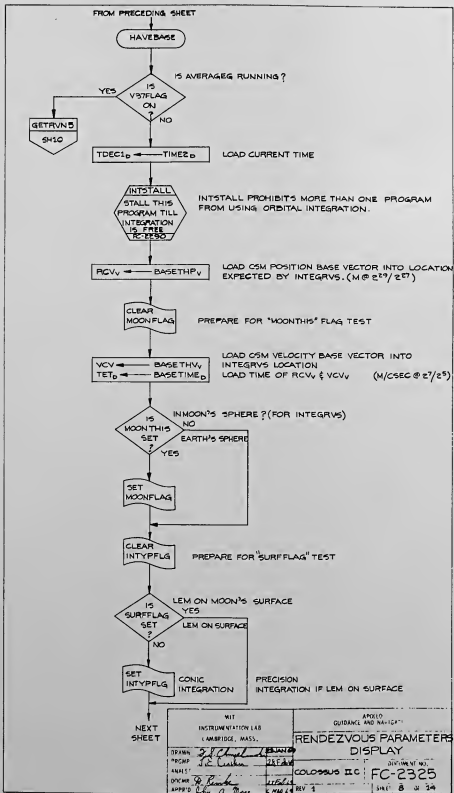


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AP 3 C PROGRAMS AND SPECIFICATIONS	
DPBAR: <i>J. G. Coker</i> PERFORM: <i>J. G. Coker</i> ANAL: <i>J. G. Coker</i> DESIGN: <i>J. G. Coker</i> APPROV: <i>John A. ...</i>		PROJECT: 22-1619 DATE: 11/26/61 REV 1	RENDEZVOUS PARAMETERS DISPLAY DOCUMENT NO. FC-2325 SHEET 6 OF 14





MII INSTRUMENTATION LAB CAMBRIDGE, MASS.		RENDEZVOUS PARAMETERS DISPLAY	
DRAWN PLOTTER ANALYST SYN. RE. APPROV.	<i>[Handwritten Signature]</i> 2/27/68 2/27/68 5:28 PM '68	COLOSSUS IIC FC-2325	REV 3 SHEET 7 of 14



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARLCO GUIDANCE AND NAVIGATION	
DRAWN: <i>S. J. Chisholm</i>		RENDEZVOUS PARAMETERS DISPLAY	
PROJ: <i>J. C. Cushman</i>	DATE: <i>1/27/68</i>	DOCUMENT NO.	
ANAL: <i>G. R. Rumble</i>	REV: <i>1/27/68</i>	COLOSSUS IIC	FC-2325
APP'D: <i>John A. Rose</i>	DATE: <i>1/27/68</i>	REV: <i>3</i>	SHEET 8 OF 24

FROM PRECEDING SHEET

INTEGRVS:

INPUT:

$TDEC1_D = BASETIME_D$  IN CSEC @  $2^9/2^0$   
 $RCV_V = BASEHP_V$  IN METERS @  $2^7/2^0$   
 $VCV_V = BASETV_V$  IN M/CSEC @  $2^7/2^0$   
MOONFLAG  
INTFLAG

OUTPUT:  $RAT_V, VAT_V, TAT_D$

INTEGRVS  
UPDATE  
OSM VECTOR  
TO TDEC1  
FC-2290

$RONE_V \leftarrow RAT_V$   
 $VONE_V \leftarrow VAT_V$   
 $MPAC_D \leftarrow TAT_D$

} STORE OUTPUT FOR COMDISP  
SAVE TIME OF  $RAT_V$  &  
 $VAT_V$

} POSITION VECTOR  
IN M @  $2^0$   
VELOCITY VECTOR  
IN M/CSEC @  $2^7$

IS LEM ON MOON'S SURFACE?  
IS SURFFLAG SET?

YES  
GETRVN6  
S430

INSTALL  
STALL THIS  
PROGRAM UNTIL  
INTEGRATION IS  
FREE  
FC-2290

SET  
INTYPFLG

CONIC INTEGRATION

OTHINT

$TDEC1_D \leftarrow MPAC_D$   
 $RCV_V \leftarrow BASEOTPV$

USE TIME OF  $RONE_V$  &  $VONE_V$  FOR LEM UPDATE  
BASE LEM POSITION VECTOR: M @  $2^0/2^7$

CLEAR  
MOONFLAG

PREPARE FOR "MOONTHIS" TEST

$VCV_V \leftarrow BASEOTV_V$   
 $TET_D \leftarrow BASETIME_D$

BASE LEM VELOCITY VECTOR: M/CSEC @  $2^7/2^0$   
BASE TIME: CSEC @  $2^0$

IS MOONTHIS SET?  
IN THE MOON'S SPHERE?  
NO  
EARTH

YES

SET  
MOONFLAG

MOON

INTEGRVS  
UPDATE LEM  
VECTOR  
FC-2290

INPUT:  $RCV_V, VCV_V, TET_D, MOONFLAG, INTYPFLG$   
OUTPUT:  $VAT_V @ 2^7, RAT_V @ 2^0$

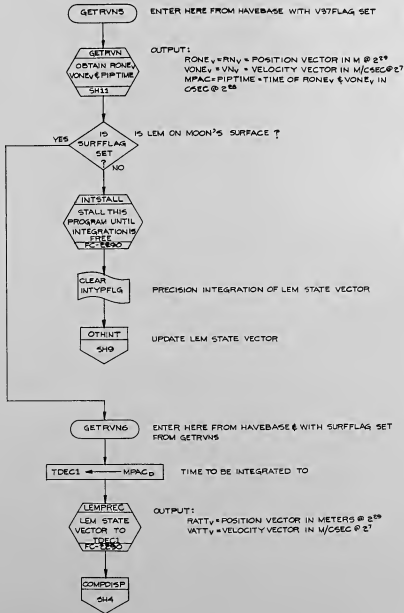
COMDISP  
S44

MEI  
MILITARY  
CAMBRIDGE MASS.  
DRAWN *J.C. Lusk*  
CHECKED *J.C. Lusk*  
ANALYST  
COPY ME  
APPROVED *John A. Rana*

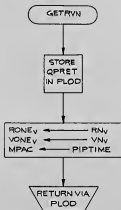
RENDEZVOUS PARAMETERS  
DISPLAY

COLLOSSUS IIC FC-2325

REV 9 10 64



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		RENDZVOUS PARAMETERS DISPLAY	
SPAWN <i>J.C. Lunden</i>	DESIGNED <i>J.C. Lunden</i>	PROGRAMMED <i>J.C. Lunden</i>	CONTINUED IN FC-2325
ANALYST	TESTED BY	COLLOSSUS IIC	FC-2325
DOCMGR <i>J.C. Lunden</i>	APPROVED <i>J.C. Lunden</i>	DATE 6/28/67	REV #
			SHEET 10 OF 14



THIS SELECTION IS CODED IN SUCH A WAY AS TO PERMIT A CONSISTENT SET OF RN, VN AND PIPTIME TO BE LOADED

RONE: 1M @ 2<sup>20</sup>  
 VONE: 1M/CSEC @ 2<sup>17</sup>  
 MPAC: CSEC @ 2<sup>20</sup>

402 117-70000-2 REV 11-54 WARRICK, MASS	41 CUBAN AIR OPERATION RENDEZVOUS PARAMETERS DISPLAY COLLOSSUS II C FC-2325 11-1-54
DESIGNED <i>J.P. Child</i> DRAWN <i>J.C. Gorman</i> CHECKED <i>J. Boudie</i> APPROVED <i>John A. Moran</i>	11-1-54 11-1-54



## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
BASETOP <sub>V</sub>	$\underline{r}_L$	POSITION VECTOR OF LEM AT BASETIME	FEET	METERS	$2^{27}/2^{29}$
BASEOTV <sub>V</sub>	$\underline{v}_L$	VELOCITY VECTOR OF LEM AT BASETIME	FEET/SEC	M/CSEC	$2^5/2^7$
BASETHP <sub>V</sub>	$\underline{r}_C$	POSITION VECTOR OF CSM AT BASETIME	FEET	METERS	$2^{27}/2^{28}$
BASETHV <sub>V</sub>	$\underline{v}_C$	VELOCITY VECTOR OF CSM AT BASETIME	FEET/SEC	M/CSEC	$2^5/2^7$
BASETIME <sub>D</sub>		REFERENCE TIME FOR ORIGINAL PRECISION STATE VECTORS	MIN/SEC	CSEC	$2^{28}$
CDUS		SHAFT ANGLE	DEGREES	REVS	$2^1$
CDUT		TRUNNION ANGLE	DEGREES	REVS	$2^1$
COSCDUX	}	OUTPUT OF CDUTRIG ROUTINE			$2^1$
COSCDUY					
COSCDUZ					
FIXLOC		ADDRESS OF VAC AREA			
PIPTIME <sub>D</sub>		TIME CORRESPONDING TO CURRENT STATE VECTOR (WHEN AVERAGE IS RUNNING)	SECONDS	CSEC	$2^{28}$
RANGE <sub>D</sub>	RANGE	DISTANCE BETWEEN THE TWO VEHICLES	FEET	METERS	$2^{29}$
RATT <sub>V</sub>		RADIUS VECTOR OUTPUT OF INTEGRATION	FEET	METERS	$2^{29}$
RATT1 <sub>V</sub>		SAME AS RATT, BUT VARIABLE SCALING	FEET	METERS	$2^{27}/2^{29}$
RCV <sub>V</sub>		POSITION VECTOR FROM WHICH TO START INTEGRATION	FEET	METERS	$2^{29}/2^{27}$
REFSMMAT <sub>M</sub>		TRANSFORMATION MATRIX FOR REFERENCE TO STABLE MEMBER CONVERSION			$2^1$
RN <sub>V</sub>	$\underline{r}$	RADIUS VECTOR AS GIVEN BY AVERAGED	FEET	METERS	$2^{29}$
RONE <sub>V</sub>	$\underline{r}$	RADIUS VECTOR INPUT TO INTEGRATION	FEET	METERS	$2^{29}/2^{27}$
RRATE <sub>D</sub>	RANGE RATE	RANGE RATE	FEET/SEC	M/CSEC	$2^7$
RTHETA <sub>D</sub>	$\theta$	THETA	DEGREES	REVS	$2^0$
SINCDUX	}	OUTPUT OF CDUTRIG			$2^1$
SINCDUY					
SINCDUZ					
TAT <sub>D</sub>		TIME OF THE OUTPUT OF ORBITAL INTEGRATION	SECONDS	CSEC	$2^{28}$
TDECI <sub>D</sub>		TIME TO BE INTEGRATED TO	SECONDS	CSEC	$2^{28}$
TET <sub>D</sub>		TIME TO BE INTEGRATED FROM	SECONDS	CSEC	$2^{28}$

MIL  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

RENDEZVOUS PARAMETERS  
DISPLAY

DATE: 2/11/68  
BY: J.E. Keenan  
APPROVED: J.E. Keenan  
REV: 1

COLOSSUS IIC FC-2325  
REV: 1

19 14





R62 CREW DEFINED MANEUVER

MAJOR SUBROUTINE ON THIS CHART

EXTENDED VER 49	: CREWMANU START AUTO ATTITUDE MANEUVER	SH2
	R62.DISP CREW DEFINED MANEUVER	SH3

THE ENCLOSED REPLACEMENT SHEETS WILL  
UPDATE THE COLOSSUS I (REV 237) FLOW CHART  
FC-2330, REV 0, TO COLOSSUS II  
FC-2330, REV 1.

THE EFFECTIVE SHEETS FOR COLOSSUS II ARE

1	REV 1
2	REV 1
3	REV 0
4	REV 0

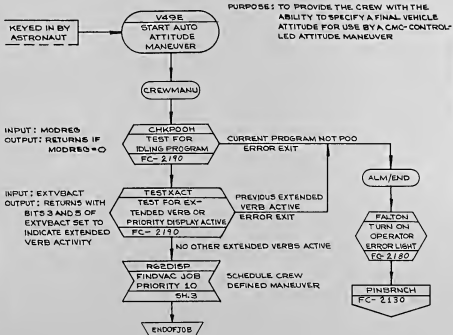
R62 CREW  
DEFINED MANEUVER

COLOSSUS II FC-2330

DATE: 9 SEP 68  
BY: J. J. Langille  
DATE: 17 DEC 68  
BY: Bob Kueh  
DATE: 24 SEP 68  
BY: J. C. Dwyer  
DATE: 30 DEC 68  
BY: Alan A. Morse

1 4

EXTENDED VERB 49: CREW DEFINED MANEUVER



RQ2 CREW  
DEFINED MANEUVER

*Handwritten:*  
 5557  
 11 DEC 68  
 COLGROSS II  
 20 11 11  
 20 11 11  
 20 11 11

FC-2330

2 4



1  
SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLDW CHARTS

SUBROUTINE NAME	FLDW CHART	DESCRIPTION	WHERE CALLED
CHKPOOH	FC-2190	TEST FOR IDLING PROGRAM	SH 2
FALTON	FC-2180	TURN ON OPERATOR ERROR LIGHT	SH 2
RGCCSM	FC-2340	PERFORM AUTO ATTITUDE MANEUVER	SH 3
TESTXACT	FC-2190	TEST FOR EXTENDED VERB OR PRIORITY DISPLAY ACTIVE	SH 2

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
3AXISFLG	MANEUVER SPECIFIED BY THREE AXES	MANEUVER SPECIFIED BY ONE AXIS	SH 3		

DISPLAYS

VERBNDUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
VO6N22	FLASHING	R1 - CPHI - XXX.XX DEG. - ROLL (DUTER) } DESIRED R2 - CT HETA - XXX.XX DEG. - PITCH (INNER) } GIMBAL R3 - CPSI - XXX.XX DEG. - YAW (MIDDLE) } ANGLES	SH 3

R62  
DEFINED MANEUVER

*DM Distill*, 12SEP68  
*D.W. Hearn*, 11 DEC 68

COLDSSUS II

FC-2330

*John A. ...*, 30 SEP 68  
*John A. ...*, 30 SEP 68

R60 ATTITUDE MANEUVER

MAJOR SUBROUTINE IN THIS FLOW CHART

R60CSM	ATTITUDE MANEUVER	SH2
VECPOINT	COMPUTE ONE AXIS MANEUVER ANGLES	SH5

THE ENCLOSED REPLACEMENT SHEETS WILL UPDATE THE COLOSSUS I (REV. 237) FLOWCHART, FC-2340, REV. 0, TO COLOSSUS II, FC-2340, REV. 1.

THE EFFECTIVE SHEETS FOR COLOSSUS II ARE:

1	REV.0
2-7	REV.1
8	REV.0
9	REV.1

REVISIONS

STAFF	<i>R. J. Angell</i>	10 SEAS	R60
REV. 0	<i>R. N. Kane</i>	19 DEC 68	ATTITUDE MANEUVER
REV. 1	<i>W. C. [unclear]</i>	25 SEP 69	COLOSSUS II
REV. 2	<i>John P. [unclear]</i>	31 DEC 69	FC-2340

REV. 1 9

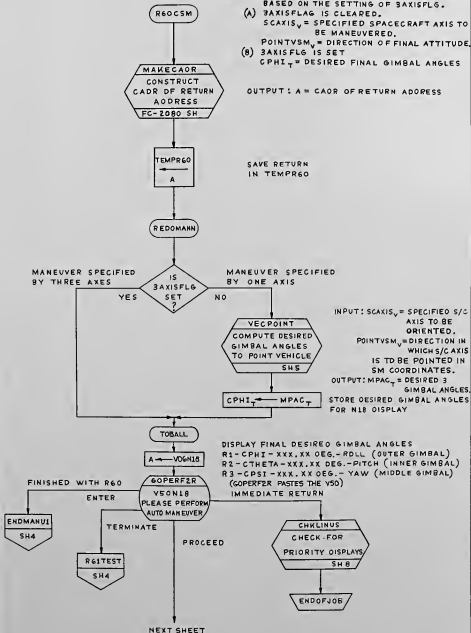
ATTITUDE MANEUVER

PURPOSE: TO MANEUVER THE LM/CSM OR CSM ALONE TO AN ATTITUDE SPECIFIED BY THE PROGRAM IN PROGRESS.

INPUT: THE FINAL ATTITUDE DESIRED IS SPECIFIED BASED ON THE SETTING OF 3AXISFLG.

- (A) 3AXISFLG IS CLEARED.  
SCAXIS<sub>v</sub> = SPECIFIED SPACECRAFT AXIS TO BE MANEUVERED.
- (B) POINTVSM<sub>v</sub> = DIRECTION OF FINAL ATTITUDE.  
3AXISFLG IS SET  
CPHI<sub>T</sub> = DESIRED FINAL GIMBAL ANGLES

OUTPUT: A = CAOR OF RETURN ADDRESS



PLANT DOCUMENTATION  
FORM ID: 104

R60

ATTITUDE MANEUVER

20 PAGES  
 10 SECS  
 170 SECS  
 25 SECS  
 31 SECS

COLOSSUS II

FC-2340



FROM  
PRECEDING SHEET

ATTCADR<sub>D</sub> ← BUF2<sub>D</sub>  
ATTCADR<sub>+1</sub> ← ATTCADR<sub>+1</sub> + EBANK  
ATTPRIO ← PRIORITY (BITS 14-10)

SAVE FINAL RETURN TO  
ENDMANUV FOR KALCMAN3

EBANK ← KALEBCDN

SET EBANK FOR KALCMAN3

KALCMAN3  
PERFORM MANEUVER  
CALCULATION AND  
STEERING  
FC-2350 SH2

INPUT : CPHI<sub>T</sub> = DESIRED FINAL GIMBAL  
ANGLES  
OUTPUT : SPACECRAFT MANEUVERED TO  
SPECIFIED ATTITUDE

NOTE : KALCMAN3 SETS UP A CALL TO  
ENDMANUV AS A JOB AT THE END  
OF THE MANEUVER

ENDMANUV

TOBALL

SH2

R61TEST

R60CSM WAS CALLED BY  
EXTENDED VERB49 OR VERB89

YES

ENDMANUV1

CLEAR  
3AXISFLG

RETURN VIA  
TEMPR60

MANEUVER SPECIFIED  
BY ONE AXIS

R60CSM WAS CALLED BY P40CSM (P40), P23(P23),  
R61CSM (P20) OR P41CSM (P41).

NO

R61CSM (P20)

YES

GO TOVS6

IS  
PDSFLAG  
SET ?

P40CSM (P40)

NO

GO TDP00H

R60  
ATTITUDE MANEUVER

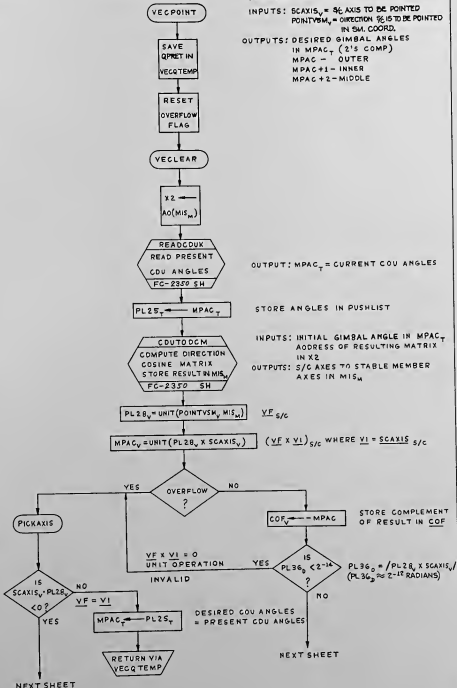
COLOSSUS II

FC-2340

4 9

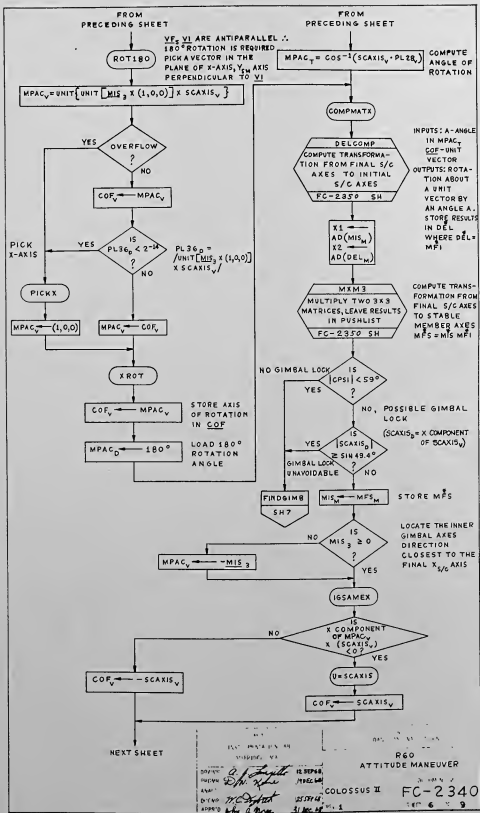


COMPUTE ONE AXIS MANEUVER ANGLES  
 INPUTS: SCAXIS<sub>v</sub> = %6 AXIS TO BE POINTED  
 POINTVSM<sub>v</sub> = DIRECTION %15 TO BE POINTED  
 IN SM. COORD.  
 OUTPUTS: DESIRED GIMBAL ANGLES  
 IN MPAC<sub>v</sub> (2'S COMP)  
 MPAC - OUTER  
 MPAC+1 - INNER  
 MPAC+2 - MIDDLE



R 60  
 ATTITUDE MANEUVER  
 COLOSSUS II  
 FC-2340  
 5 9

OPERATOR: J. J. Smith  
 ANALYST: J. C. Dwyer  
 APPROVED: J. A. Brown  
 11 SEP 68  
 19 DEC 68  
 25 OCT 68  
 31 MAR 68



FROM PRECEDING SHEET

CHEKAXIS

(SCAXIS<sub>0</sub> = X COMPONENT OF SCAXIS<sub>V</sub>)

1/SCAXIS<sub>V</sub> ≥ SIN 29.5° ?

NO

YES

PICKANG1

MPAC<sub>D</sub> ← 50°

LOAD 50° ROTATION ANGLE

MPAC<sub>D</sub> ← 35°

LOAD 35° ROTATION ANGLE

COMPMFSH

COMPUTE NEW ROTATION ABOUT SCAXIS S/C TO BRING MFS OUT OF GIMBAL LOCK

DELCOMP  
COMPUTE ROTATION ABOUT UNIT VECTOR  
STORE RESULTS IN DEL  
FC-2350 SH

INPUT: ANGLE IN MPAC, GOF=UNIT VECTOR  
OUTPUT: NEW TRANSFORMATION FROM FINAL S/C AXES TO INITIAL S/C AXES

X1 ← AD(MFS<sub>W</sub>)  
X2 ← AD(DEL<sub>W</sub>)

MRWS  
MULTIPLY TWO 3X3 MATRICES LEAVE RESULT IN PUSHLIST  
FC-2350 SH

COMPUTE NEW TRANSFORMATION FROM DESIRED S/C AXES TO STABLE MEMBER AXES WHICH WILL ALIGN V1 WITH V2 AND AVOID GIMBAL LOCK NEW MFS = OLD MFS DEL

FINDGIMB

SET X1 TO PLO

X1 ← AD(MFS<sub>W</sub>)

DCMTCDU  
EXTRACT DESIRED CDU ANGLES FROM MATRIX  
FC-2350 SH

INPUT: X1 = AD(MFS<sub>W</sub>)  
OUTPUT: MPAC<sub>V</sub> = DESIRED CDU ANGLES IN 1'S COMPLEMENT FORM

VISTO2S  
CONVERT ANGLES TO 2'S COMPLEMENT FORM  
FC-2100 SH

INPUT: MPAC<sub>V</sub> = CDU ANGLES<sub>D</sub>  
OUTPUT: MPAC<sub>V</sub> = CDU ANGLES<sub>S</sub>

SET PUSHLIST TO ZERO

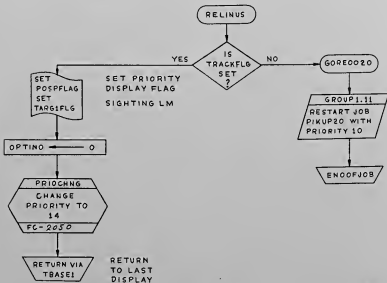
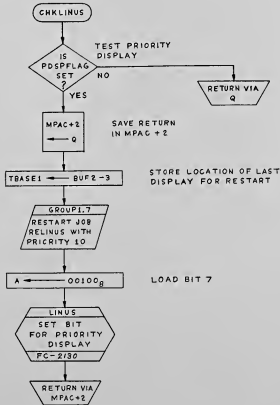
RETURN VIA VECQTEMP

APPROVED: *[Signature]*  
DATE: 25 SEP 68  
BY: *[Signature]*  
DATE: 25 SEP 68

R60 ATTITUDE MANEUVER

COLOSSUS II FC-2340

7 2 9



R 60  
ATTITUDE MANEUVER

COLOSSUS II

FC-2340

B 9

*Q. J. Langill* 13 SEP 68  
*Edith Kule* 14 SEP 68  
*McDonnell* 25 SEP 68  
*John A. Brown* 31 DEC 68

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
CDUTODCM	FC-2350	COMPUTE DIRECTION COSINE MATRIX	SH5
DCMTOCDU	FC-2350	EXTRACT DESIRED CDU ANGLES FROM MATRIX	SH7
DELCOMP	FC-2350	COMPUTE TRANSFORMATION MATRIX	SH4,7
KALCMAN3	FC-2350	MANEUVER CALCULATIONS AND STEERING	SH4
LINUS	FC-2130	SET BIT FOR PRIORITY DISPLAY	SH2
MAKESADR	FC-2080	LOAD RETURN CADR SAVED BY BANKCALL	SH2
MXM3	FC-2350	MULTIPLY TWO 3X3 MATRICES	SH6,7
PRIORCHNG	FC-2050	CHANGE PRIORITY OF JOB IN EXECUTION	SH8
READCDUK	FC-2350	READ PRESENT CDU ANGLES	SH5
VISTOZS	FC-2100	CONVERT 1'S COMPLEMENT ANGLES TO 2'S COMPLEMENT ANGLES	SH7

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
3AXISFLG	MANEUVER SPECIFIED BY THREE AXES	MANEUVER SPECIFIED BY ONE AXIS		SH4	SH2,3
POSPFLAG	CANNOT INTERRUPT PRIORITY DISPLAY	MAY INTERRUPT NO PRIORITY DISPLAY	SH8		SH4,8
TARG1FLG	SIGHTING LM	NOT SIGHTING LM			SH8
TRACKFLG	TRACKING ALLOWED	TRACKING NOT ALLOWED			SH8

DISPLAYS

VERB - NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V50N1B	FLASHING PLEASE PERFORM	R1 - CPHI - XXX.XX DEG. - ROLL (OUTER GIMBAL) FINAL DESIRED R2 - CTHETA - XXX.XX DEG. - PITCH (INNER GIMBAL) GIMBAL ANGLES R3 - CPSI - XXX.XX DEG. - YAW (MIDDLE GIMBAL)	SH2
V06N1B	NON FLASHING	R1 - CPHI - XXX.XX DEG. - ROLL (OUTER GIMBAL) FINAL DESIRED R2 - CTHETA - XXX.XX DEG. - PITCH (INNER GIMBAL) GIMBAL ANGLES R3 - CPSI - XXX.XX DEG. - YAW (MIDDLE GIMBAL)	SH3
PROGRAM ALARM	NON FLASHING ALARM	ALARM CODE = 1210 : TWO PROGRAMS USING DEVICE AT SAME TIME	SH3

ERASABLE LOCATIONS USED

AGC TAG	G50P SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
CPHI <sub>v</sub>		DESIRED FINAL GIMBAL ANGLES		REV UNIT - VECTOR	2 <sup>-1</sup>
SCAXIS <sub>v</sub>		SPECIFIED SPACECRAFT AXIS TO BE MANEUVERED *		UNIT - VECTOR	2 <sup>1</sup>
POINTVSM <sub>v</sub>		DIRECTION OF FINAL ATTITUDE IN STABLE MEMBER COORDINATES		UNIT - VECTOR	2 <sup>1</sup>

\* SEE DESCRIPTION ON SHEET 3

R60  
ATTITUDE MANEUVER

CDLOSSUS II FC-2340

9 9

*Handwritten notes and signatures:*  
13 SEP 68  
10 DEC 68  
25 SEP 68  
31 DEC 68

MANEUVER CALCULATIONS AND STEERING

MAJOR SUBROUTINES ON THIS CHART		
CDUTODCM	COMPUTE DIRECTION COSINE MATRIX	SH. 22
DCMTOCDU	DIRECTION COSINE MATRIX TO CDU ANGLES	SH. 20
DELCOMP	COMPUTE ROTATION MATRIX	SH. 16
KALCMAN3	MANEUVER CALCULATIONS AND STEERING	SH. 5
MXM3	MULTIPLY TWO 3 X 3 MATRICES	SH. 25
READCDUK	READ CURRENT CDU ANGLES	SH. 24
STOPRATE	ZERO INPUTS TO AUTOPILOT	SH. 26

THE ENCLOSED REPLACEMENT SHEETS WILL UPDATE THE COLOSSUS I (REV. 237) FLOW CHART FC-2350, REV. 0, TO COLOSSUS II FC-2350, REV. 2

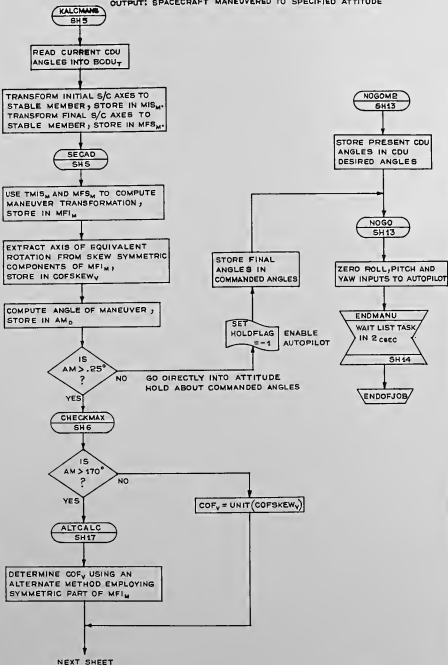
THE EFFECTIVE SHEETS FOR COLOSSUS II ARE:

1 - 2	REV 0
3	REV 1
4 - 5	REV 0
6	REV 2
7 - 11	REV 0
12	REV 2
13 - 14	REV 0
15	REV 1
16	REV 0
17	REV 1
18 - 26	REV 0
27	REV 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		MANEUVER CALCULATIONS AND STEERING	
PCBWR <i>[Signature]</i>	DATE <i>1/28/67</i>	COLOSSUS II	DOCUMENT NO.
ANALYST			FC-2350
DOCSR <i>[Signature]</i>	ISSUED <i>[Signature]</i>	REV 2	SHEET 1 OF 27
APPR'D <i>[Signature]</i>			

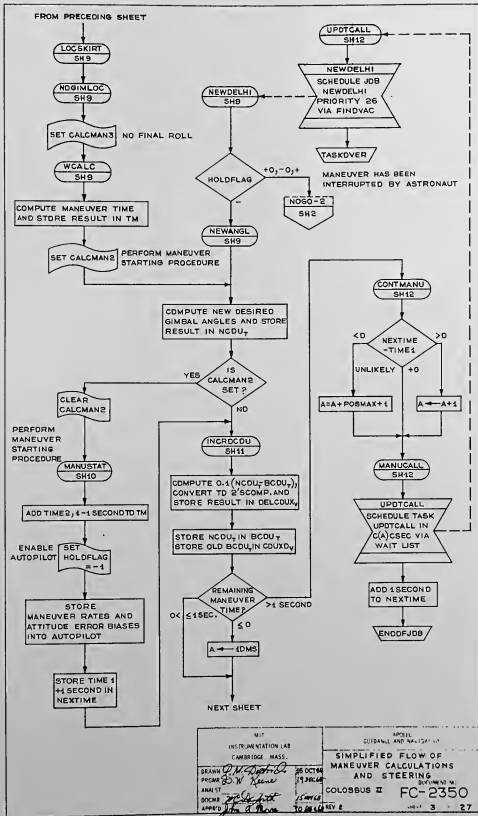
## SIMPLIFIED FLOW: MANEUVER CALCULATIONS AND STEERING

INPUT:  $C\Phi_{1v}$  = DESIRED FINAL GIMBAL ANGLES  
 OUTPUT: SPACECRAFT MANEUVERED TO SPECIFIED ATTITUDE



NEXT SHEET

WFI ENGINEERING DIVISION (AR) (AMBRIDGE, MASS)	AIRCRAFT COMPANY INVESTIGATIONS
DESIGNER <i>D. N. Kline</i> 24 OCT 68 PROGRAMMER <i>D. N. Kline</i> 25 OCT 68 ANALYST DOCUMENTER <i>M. J. ...</i> 25 OCT 68 APPROVER <i>J. A. ...</i> 20 NOV 68	SIMPLIFIED FLOW OF MANEUVER CALCULATIONS AND STEERING DOCUMENT # COLOSSUS II FC-2350 REV 2 WFI 2 4 27

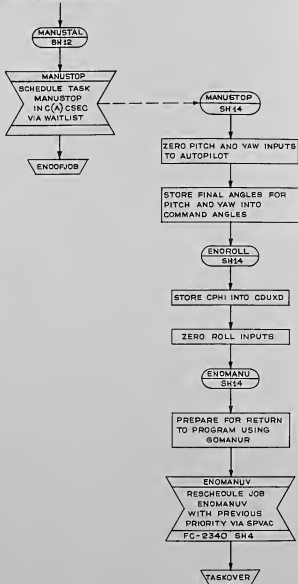


MIT  
 INSTRUMENTATION LAB  
 CAMBRIDGE, MASS.  
 DRAWN *[Signature]*  
 PROGRAM *[Signature]*  
 ANALYST *[Signature]*  
 DOC# *[Signature]*  
 APPRO'D *[Signature]*

APPROX  
 GUIDANCE AND MANEUVER  
 SIMPLIFIED FLOW OF  
 MANEUVER CALCULATIONS  
 AND STEERING  
 COLOSSUS II FC-2350  
 REV 2  
 26 OCT 66  
 19 DEC 66  
 15 MAR 68  
 3 = 27



FROM PRECEING SHEET



IN THE OBSERVATION AREA  
SERIAL NO. 1580078  
DATE: 11/20/64  
BY: [Signature]  
CHECKED: [Signature]  
APPROVED: [Signature]

SIMPLIFIED FLOW OF  
MANEUVER CALCULATIONS  
AND STEERING

COLOSSUS II FC-2350

REV. 4 27



MANEUVER CALCULATIONS AND STEERING  
 INPUT: CPHI<sub>T</sub> = DESIRED FINAL GIMBAL ANGLES  
 OUTPUT: SPACECRAFT MANEUVERED TO SPECIFIED  
 ATTITUDE

OUTPUT: MPAC<sub>T</sub> = CDU<sub>X</sub>, CDU<sub>Y</sub>, CDU<sub>Z</sub>

STORE INITIAL SPACECRAFT ANGLES

COMPUTE THE TRANSFORMATION FROM INITIAL  
 S/C AXES TO STABLE MEMBER AXES.

INPUT: MPAC<sub>T</sub> = CDU ANGLES  
 X2 = ADR (RESULTING MATRIX)  
 OUTPUT: MIS<sub>M</sub> = TRANSFORMATION MATRIX

LOAD DESIRED FINAL GIMBAL ANGLES

COMPUTE THE TRANSFORMATION FROM FINAL  
 S/C AXES TO STABLE MEMBER AXES.

INPUT: MPAC<sub>T</sub> = FINAL GIMBAL ANGLES  
 X2 = ADR (RESULTING MATRIX)  
 OUTPUT: MFS<sub>M</sub> = TRANSFORMATION MATRIX

INPUT: X1 = ADR (MATRIX)  
 OUTPUT: PLO<sub>M</sub> = TRANPOSED MATRIX

STORE MATRIX

INPUT: X1 = ADR (TMIS<sub>M</sub>)  
 X2 = ADR (MFS<sub>M</sub>)  
 OUTPUT: PLO<sub>M</sub> = TMIS<sub>M</sub> MFS<sub>M</sub>

MIT INSTRUMENTATION LAB		DATE: 24 OCT 62	
CAMBRIDGE, MASS.		PROJECT: 319 DEC 62	
TRAIN: <i>[Signature]</i>	PREPARED: <i>[Signature]</i>	COLLOSSUS II FC-2350	
ANALYST: <i>[Signature]</i>	DOING: <i>[Signature]</i>	REV: 5 - 27	
APPROVED: <i>[Signature]</i>			

FROM PRECEDING SHEET

$MFI_M \leftarrow PLO_M$

STORE MATRIX

SET  
PUSHLIST  
TO 18D

TRANSPOSE  
MATRIX IN  
PUSHLIST  
SH25

INPUT:  $PLO_M$  = INPUT MATRIX

OUTPUT:  $PLO_M$  = TRANSPOSED MATRIX

$TMFI_M \leftarrow PLO_M$

STORE MATRIX

$CDF_{SKEW}_V \leftarrow \begin{cases} (TMFI+10_0 - MFI + 10_0) \\ (MFI + 4_0 - TMFI + 4_0) \\ (TMFI + 20_0 - MFI + 20_0) \end{cases}$

USE  $TMFI_M$  TO EXTRACT AXIS OF SINGLE  
EQUIVALENT ROTATION FROM SKEW  
SYMMETRIC COMPONENTS OF  $MFI_M$

$CAM_0 \leftarrow MFI_0 + MFI + 8D_0 + MFI + 16D_0 - .2S$

COSINE OF ANGLE OF MANEUVER

$AM_0 \leftarrow \cos^{-1}(CAM_0)$

ANGLE OF MANEUVER

TEST MAGNITUDE OF  
MANEUVER ANGLE

IS  
 $AM > .25^\circ$   
?

ND GO DIRECTLY INTO ATTITUDE HOLD ABOUT  
COMMAND ANGLES

YES

CHECKMAX

IS  
 $AM > 17D^\circ$   
?

STORE MANEUVER AXIS

$CDF_V \leftarrow \text{UNIT}(CDF_{SKEW}_V)$

LOCKKIRT

SH9

NEXT SHEET

INHIBIT  
INTER-  
RUPTS

SET  
HOLOFLAG  
= -1

ENABLE AUTOPILOT

LOADCLOUD

SUBROUTINE TO  
STORE FINAL ANGLES  
IN COMMAND ANGLES

$COUXD \leftarrow CPHI$   
 $COUYD \leftarrow CTHETA$   
 $COUZD \leftarrow CPS1$

RETURN  
VIA Q

NOGO

SH13

REF	APP L
UNIT INFORMATION 148	FORM AND DATE 11/82
CAP (W/D) - 1885	
DATE BY <i>P.H. D... 22 OCT 68</i>	MANEUVER CALCULATIONS
PROGRAM <i>3078 K... 17 DEC 68</i>	AND STEERING
ANALYST	REV. NO. 1
CHK'D BY <i>P.H. D... 15 NOV 68</i>	COLDSSUS II FC-2350
APPROVED <i>J. A. M... 30 DEC 68</i>	REV. 6

FROM PRECEDING SHEET

ALTCALC

DETERMINE COF<sub>v</sub> USING AN ALTERNATE METHOD USING THE SYMMETRIC PART OF MFI<sub>w</sub>

$$MFISYM_M \leftarrow \frac{MFI_M + TMFI_M}{2}$$

$$PLO_D \leftarrow \frac{CAM_D}{2}$$

DOES  
1-CAM  
OVERFLOW?  
YES  
NO

SIGN MPAC  
LIMIT SIZE  
OF MPAC ON  
OVERFLOW  
FC-2100

OUTPUT: MPAC<sub>0</sub> = ± MAXIMUM  
BASED ON SIGN OF  
MPAC

$$MPAC_D \leftarrow 1 - CAM_D$$

$$PLQ_D \leftarrow MPAC_D$$

$$COFZ = \left( \frac{MFISYM_S - CAM}{1 - CAM} \right)^{1/2}$$

$$PLA_D \leftarrow \left( \frac{MFISYM + 16D_D - PLO_D}{PLQ_D} \right)^{1/2}$$

$$COFY = \left( \frac{MFISYM_A - CAM}{1 - CAM} \right)^{1/2}$$

$$PLB_D \leftarrow \left( \frac{MFISYM + 8D_D - PLO_D}{PLQ_D} \right)^{1/2}$$

$$COFX = \left( \frac{MFISYM_O - CAM}{1 - CAM} \right)^{1/2}$$

$$MPAC_D \leftarrow \left( \frac{MFISYM_O - PLO_D}{PLQ_D} \right)^{1/2}$$

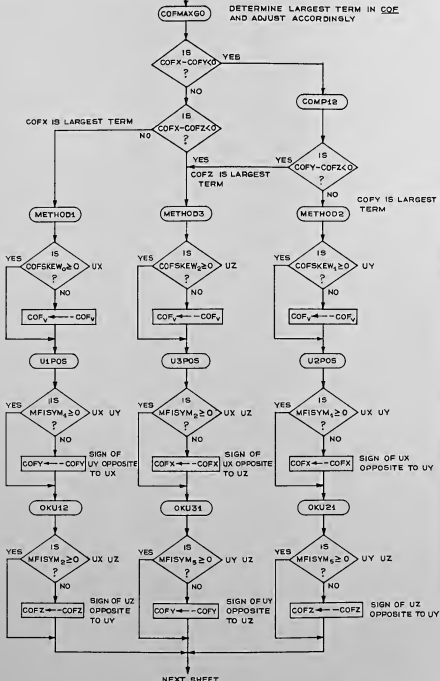
$$COF_v = (COFX, COFY, COFZ)$$

$$COF_v \leftarrow UNIT(MPAC_D, PLB_D, PLA_D)$$

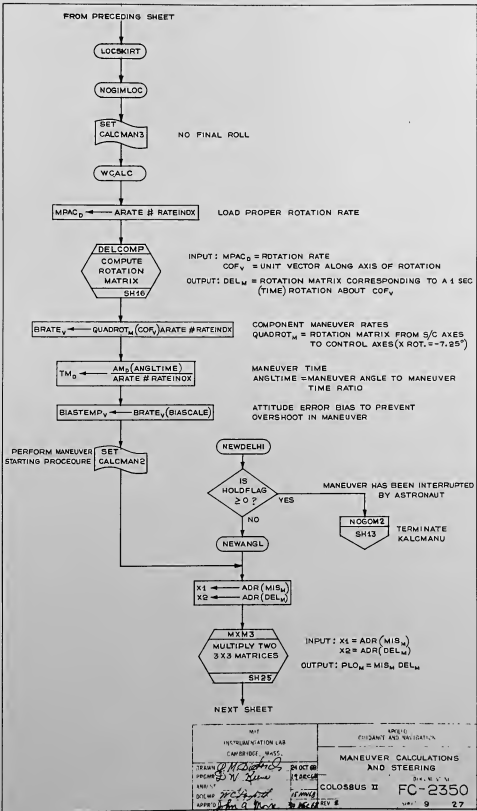
NEXT SHEET

MFI (MFI <sub>W</sub> + TMFI <sub>W</sub> ) / 2 CAM (FC-2100) REVISION: <i>20 OCT 68</i> PREPARED BY: <i>D. N. Kane</i> 19 DEC 68 ANALYST: <i>D. N. Kane</i> CHECKED: <i>W. C. [unclear]</i> 15 JAN 69 APPROVED: <i>John A. Moore</i> 20 DEC 68	MANEUVER CALCULATIONS AND STEERING COLOSSUS II FC-2350 7 27
--	--

FROM PRECEDING SHEET



<p style="text-align: center;">MIL INSTRUMENTATION LAB (CAMBRIDGE, MASS.)</p> <p>             DRAWN: <i>M. W. ...</i> 23 OCT 68              PREPARED: <i>W. N. ...</i> 23 DEC 68              ANALYST: <i>...</i>              CHECKED: <i>...</i>              APPROVED: <i>...</i> </p>	<p style="text-align: center;">APOLLO GUIDANCE AND NAVIGATION</p> <p style="text-align: center;">MANEUVER CALCULATIONS AND STEERING</p> <p style="text-align: center;">DEPARTMENT NO. COLOSSUS II FC-2350</p> <p style="text-align: right;">SHEET 8 OF 27</p>
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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AIR FORCE RESEARCH AND DEVELOPMENT	
DRAWN <i>[Signature]</i> 24 OCT 68 CHECKED <i>[Signature]</i> 19 DEC 68 REVISED <i>[Signature]</i> 11 MAR 69 APPROVED <i>[Signature]</i> 20 MAR 69		MANEUVER CALCULATIONS AND STEERING DR. W. C. W. COLOSSUS II FC-2350 UNIT 9 27	

FROM PRECEDING SHEET

MIS<sub>M</sub> ← PLO<sub>M</sub>  
X1 ← ADR(MIS<sub>M</sub>)

STORE MATRIX

DCMTCDDU  
DIRECTION  
COSINE MATRIX  
TO CDU ANGLES  
SH20

EXTRACT NEW DESIRED CDU ANGLES FROM MATRIX  
INPUT: X1 = ADR(MIS<sub>M</sub>)

OUTPUT: MPAC<sub>V</sub> = CDU ANGLES (1'S COMPLEMENT)

V45T02S  
CONVERT 1'S  
COMPLEMENT  
ANGLES TO 2'S  
COMPLEMENT  
FC-2100

INPUT: MPAC<sub>V</sub> = 1'S COMPLEMENT ANGLES

OUTPUT: MPAC<sub>T</sub> = 2'S COMPLEMENT ANGLES

NCDU<sub>T</sub> ← MPAC<sub>T</sub>

STORE NEW ANGLES

IS  
CALCMAN2  
SET?

NO → BYPASS STARTING MANEUVER

INCRDCDU4  
SH11

YES → CLEAR  
CALCMAN2

YES → BYPASS STARTING  
MANEUVER

MANUSTAT

TM<sub>0</sub> ← TM<sub>0</sub> + TIME2<sub>0</sub> - 1 SEC<sub>0</sub>

MANEUVER COMPLETION TIME - 1 SEC.

INHIBIT  
INTER-  
RUPTS

SET  
HOLDFLAG  
E=1

ENABLE AUTOPILOT

IS  
RATEINDX  
= 6?

YES → HIGHGAIN

HIGHGAIN

SET  
BIT 15 OF  
RCSFLAGS

HIGH RATE FLAG

NEXT SHEET

INSTRUMENTATION LAB  
CAMBRIDGE, MASS.  
SPANN: *DR. DePinto* 25 OCT 68  
POLAK: *D.W. James* 17 DEC 68  
AHLIC: *W.C. DePinto*  
DOWNS: *John & Moore* 30 SEPT 68

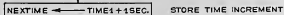
MANEUVER CALCULATIONS  
AND STEERING

COLOSSUS II

FC-2350

40 x 27

FROM PRECEDING SHEET



INCRDCDU-1

A ← 2

LOAD INDEX VALUE FOR THREE AXES

INCRDCDU

LOOP TO COMPUTE ANGLE INCREMENTS, DESIRED AND COMMANDED CDU ANGLES FOR THREE AXES  
 NCDU = NEW DESIRED CDU ANGLES  
 BCDU = INITIAL S/C ANGLES OR PREVIOUS DESIRED CDU ANGLES

A ← KSPNDX-1

KSPNDX ← A

SET K<sub>s</sub> INDEX FOR EACH AXIS

KDPNDX ← 2(A)

SET K<sub>D</sub> INDEX FOR EACH AXIS

DELCDX # KDPNDX ← D<sub>s</sub>(NCDU # KSPNDX - BCDU # KSPNDX)

ANGLE INCREMENTS TO BE ADDED TO DCU EVERY TENTH SECOND BY LM DAP.

COUXD # KDPNDX ← BCDU # KSPNDX  
 BCDU # KSPNDX ← NCDU # KSPNDX

UPDATE COMMANDED CDU ANGLES  
 UPDATE DESIRED CDU ANGLES

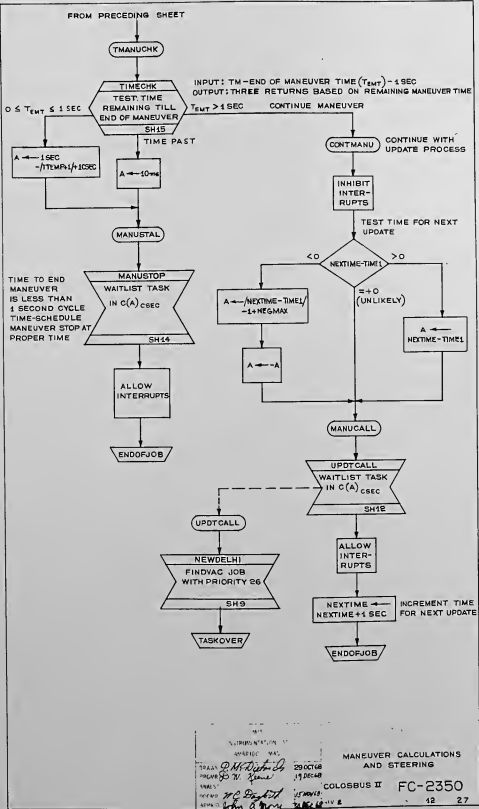


ALLOW INTERRUPTS

NEXT SHEET

WIT NATIONAL LAB MEMPHIS, MISS.	28 OCT 68 19 DEC 68 30 NOV 68	MANEUVER CALCULATIONS AND STEERING COLOSSUS II FC-2350	41 11 41 11 27
DRAWN BY <i>D.H.B.</i> DESIGNED BY <i>W. Kline</i> APPROVED BY <i>W.C. G. Moore</i>	28 OCT 68 19 DEC 68 30 NOV 68	MANEUVER CALCULATIONS AND STEERING COLOSSUS II FC-2350	41 11 41 11 27

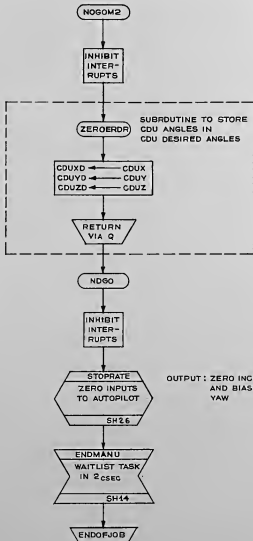




APPROVED: *[Signature]* 29 OCT 68  
 PREPARED BY: *[Signature]* 19 DEC 68  
 CHECKED BY: *[Signature]* 15 NOV 68  
 APPROVED BY: *[Signature]* 20 DEC 68

MANEUVER CALCULATIONS AND STEERING

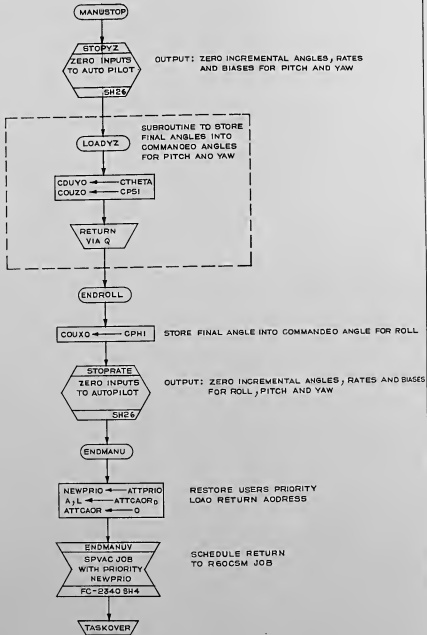
COLOSBUS II FC-2350



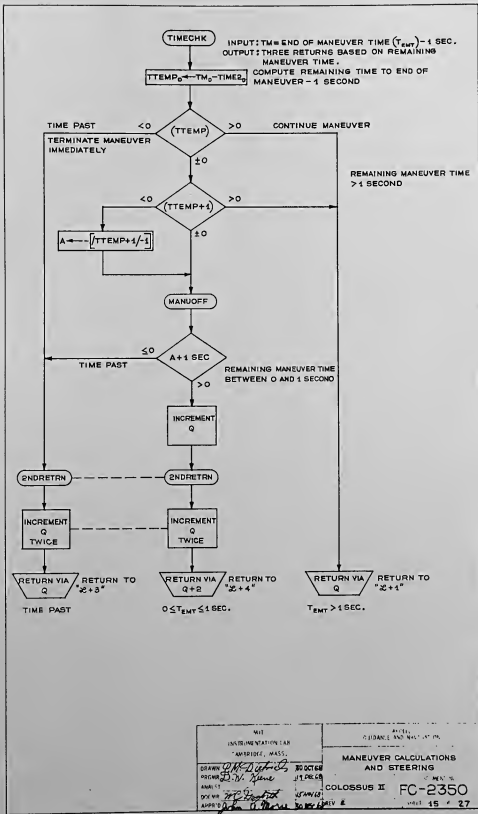
SUBROUTINE TO STORE  
CDU ANGLES IN  
CDU DESIRED ANGLES

OUTPUT: ZERO INCREMENTAL ANGLES, RATES  
AND BIASES FOR ROLL, PITCH AND  
YAW

WIT INSTRUMENTATION AIR AIRFIELD, WALS DRAWN <i>D. H. D. [Signature]</i> CHECKED <i>D. W. [Signature]</i> ANALYST APPROVED <i>[Signature]</i>	PROJECT 1972-68 1972-68 1972-68 1972-68	MANEUVER CALCULATION AND STEERING GOLDSSUS II FC-2350 13 27
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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		MANEUVER CALCULATIONS AND STEERING	
DESIGNER <i>D. H. Johnson</i>	PROJECT 21 OCT 68	COLOSSUS II FC-2350	
PROGRAMMER <i>D. W. Johnson</i>	ANALYST <i>J. C. Johnson</i>	DATE 11 NOV 68	REV #
APPROVER <i>John A. Johnson</i>	APPROVED <i>John A. Johnson</i>	14	27



INPUT:  $T_M$  = END OF MANEUVER TIME ( $T_{EMT}$ ) - 1 SEC.  
 OUTPUT: THREE RETURNS BASED ON REMAINING MANEUVER TIME.  
 COMPUTE REMAINING TIME TO END OF MANEUVER - 1 SECOND

REMAINING MANEUVER TIME > 1 SECOND

REMAINING MANEUVER TIME BETWEEN 0 AND 1 SECOND

RETURN VIA  $Q + 3^\circ$   
 TIME PAST

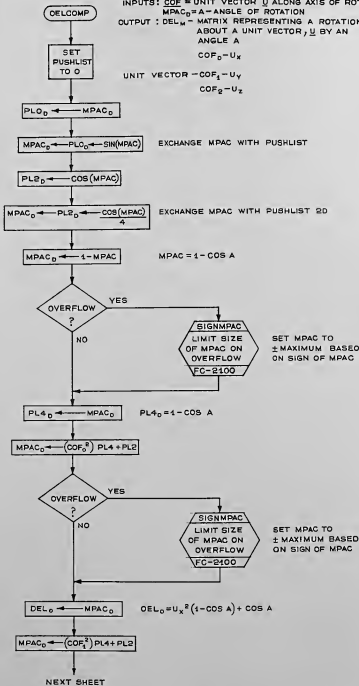
RETURN VIA  $Q + 2^\circ$   
 $0 \leq T_{EMT} \leq 1 \text{ SEC.}$

RETURN VIA  $Q + 1^\circ$   
 $T_{EMT} > 1 \text{ SEC.}$

MIT NAVIGATION LAB AMBRIDGE, MASS.		GUIDANCE AND MANEUVERING	
DRAWN: <i>[Signature]</i>		MANEUVER CALCULATIONS AND STEERING	
DESIGN: <i>[Signature]</i>	30 OCT 68	COLLOSSUS II FC-2350	
ANALYST: <i>[Signature]</i>	11 DEC 68	REV 15 # 27	
CHKD BY: <i>[Signature]</i>	15 MAR 69		
APPROVED: <i>[Signature]</i>	30 MAR 69		

CALCULATION OF MATRIX OEL<sub>M</sub>

INPUTS: COE = UNIT VECTOR  $\underline{U}$  ALONG AXIS OF ROTATION  
 MPAC<sub>0</sub> = A - ANGLE OF ROTATION  
 OUTPUT: DEL<sub>M</sub> = MATRIX REPRESENTING A ROTATION ABOUT A UNIT VECTOR,  $\underline{U}$  BY AN ANGLE A  
 COF<sub>0</sub> = U<sub>x</sub>  
 UNIT VECTOR - COF<sub>1</sub> - U<sub>y</sub>  
 COF<sub>2</sub> - U<sub>z</sub>



4011		30 OCT 68	
ELECTRONIC RESEARCH & DEVELOPMENT		19 DEC 68	
CANTON, MASS.		COLOSSUS II FC-2350	
DRAWN BY <i>P. M. ...</i>		15 NOV 68	
CHECKED BY <i>W. ...</i>		16 DEC 68	
APPROVED BY <i>John G. ...</i>		16 DEC 68	
MANEUVER CALCULATIONS AND STEERING		15 27	

FROM PRECEDING SHEET

OVERFLOW ?

YES

NO

SIGNMPAC  
LIMIT SIZE  
OF MPAC ON  
OVERFLOW  
FC-2100

SET MPAC TO  
± MAXIMUM BASED  
ON SIGN OF MPAC

$DEL_4 \leftarrow MPAC_D$

$DEL_4 = U_V^2(1 - \cos A) + \cos A$

$MPAC_D \leftarrow (COF_2^2) PL4 + PL2$

OVERFLOW ?

YES

NO

SIGNMPAC  
LIMIT SIZE  
OF MPAC ON  
OVERFLOW  
FC-2100

SET MPAC TO  
± MAXIMUM BASED  
ON SIGN OF MPAC

$DEL_B \leftarrow MPAC_D$

$DEL_B = U_z^2(1 - \cos A) + \cos A$

$PL6_D \leftarrow (COF_0)(COF_2) PL4$

$PL6_D = U_x U_y (1 - \cos A)$

$PLB_D \leftarrow (COF_2) PLO$

$PLB = U_z \sin A$

$MPAC_D \leftarrow PL6 + PLB$

OVERFLOW ?

YES

NO

SIGNMPAC  
LIMIT SIZE  
OF MPAC ON  
OVERFLOW  
FC-2100

SET MPAC TO  
± MAXIMUM BASED  
ON SIGN OF MPAC

$DEL_3 \leftarrow MPAC_D$

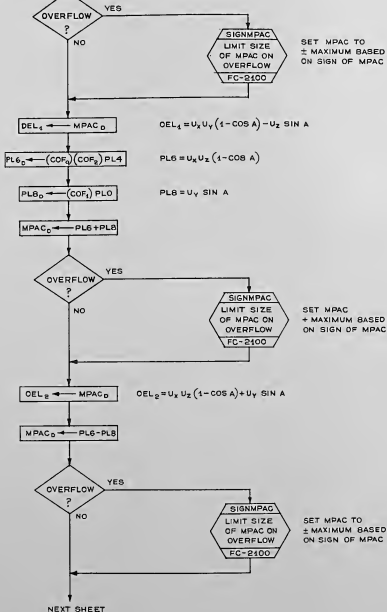
$DEL_3 = U_x U_y (1 - \cos A) + U_z \sin A$

$MPAC_D \leftarrow PL6 - PLB$

NEXT SHEET

44 INSTRUMENTS DIVISION CAMBRIDGE, MASS. DRAWN BY <i>D.M. Dwyer</i> PROJECT <i>D.M. Dwyer</i> ANALYST CHECKED BY <i>J.C. Dwyer</i> APPROVED BY <i>J.C. Dwyer</i>	31 OCT 1968 17 DEC 1968 30 DEC 1968	TITLE MANEUVER CALCULATIONS AND STEERING COLLOSSUS II FC-2350 17 - 27
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FROM PRECEDING SHEET



10 NOV 68  
17 DEC 68  
4 NOV 68  
15 NOV 68  
30 DEC 68

*D.W. Kline*  
*W.C. Doughty*  
*John A. Moore*

MANEUVER CALCULATIONS  
AND STEERING

COLOSSUS II FC-2350

18 27

FROM PRECEDING SHEET

$$\text{DEL}_6 \leftarrow \text{MPAC}_D$$

$$\text{DEL}_6 = U_x U_z (1 - \cos A) - U_y \sin A$$

$$\text{PL6}_D \leftarrow (\text{COF}_z)(\text{COF}_y)\text{PL4}$$

$$\text{PL6} = U_y U_z (1 - \cos A)$$

$$\text{PLB}_D \leftarrow (\text{COF}_y)\text{PLO}$$

$$\text{PLB} = U_x \sin A$$

$$\text{MPAC}_D \leftarrow \text{PL6} + \text{PLB}$$

OVERFLOW  
?

YES

NO

SIGNMPAC  
LIMIT SIZE  
OF MPAC ON  
OVERFLOW  
FC-2400

SET MPAC TO  
± MAXIMUM BASED  
ON SIGN OF MPAC

$$\text{DEL}_7 \leftarrow \text{MPAC}_D$$

$$\text{DEL}_7 = U_y U_z (1 - \cos A) + U_x \sin A$$

$$\text{MPAC}_D \leftarrow \text{PL6} - \text{PLB}$$

OVERFLOW  
?

YES

NO

SIGNMPAC  
LIMIT SIZE  
OF MPAC ON  
OVERFLOW  
FC-2400

SET MPAC TO  
± MAXIMUM BASED  
ON SIGN OF MPAC

$$\text{DEL}_8 \leftarrow \text{MPAC}_D$$

$$\text{DEL}_8 = U_y U_z (1 - \cos A) - U_x \sin A$$

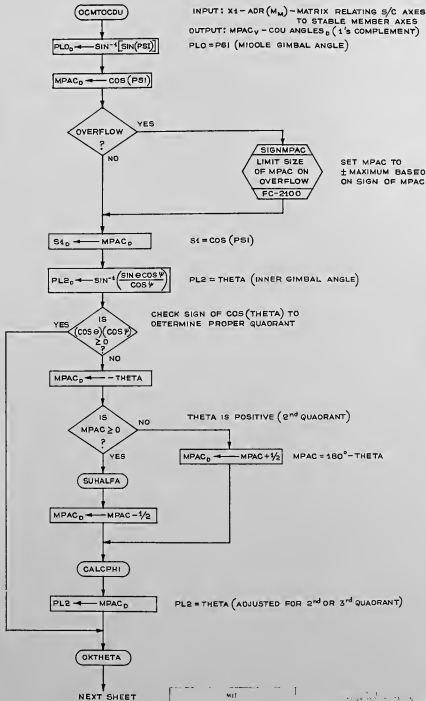
RETURN VIA  
QPRET

MIT SUBMITTANTIAL AB CAMBRIDGE, MASS.	APR 13 1964
DESIGNED BY <i>D. M. ...</i>	MANEUVER CALCULATIONS AND STEERING
PROJECTED BY <i>W. ...</i>	4 NOV 64
ANALYST <i>...</i>	19 DEC 64
CHECKED BY <i>...</i>	COLOSSUS II
APPROVED BY <i>...</i>	FC-2350
	19 27



COMPUTE CDU ANGLES FROM DIRECTION  
COSINE MATRIX

INPUT:  $X1$  - ADR ( $M_w$ ) - MATRIX RELATING S/C AXES  
TO STABLE MEMBER AXES  
OUTPUT: MPAC<sub>v</sub> - CDU ANGLES<sub>v</sub> (1's COMPLEMENT)  
PLO = P61 (MIDDLE GIMBAL ANGLE)



MIT  
INSTRUMENTATION DIV  
- MP6131 -  
DRAWN: *[Signature]* 14 NOV 68  
PUT UP: *[Signature]* 14 DEC 68  
ANAL: *[Signature]*  
CHK MP: *[Signature]* 15 NOV 68  
APPR: *[Signature]* 30 OCT 68

MANEUVER CALCULATIONS  
AND STEERING  
COLOSSUS II FC-2350  
20 27

FROM PRECEDING SHEET

$$PL4_0 \leftarrow \sin^{-1} \left( \frac{\sin \theta \cos \psi}{\cos \psi} \right)$$

PL4 = PHI (OUTER GIMBAL ANGLE)

IS  
(COS  $\theta$ ) (COS  $\psi$ )  
 $\geq 0$ ?

CHECK SIGN OF COS (PHI) TO  
DETERMINE PROPER QUADRANT

YES

OKPHI

$$MPAC_0 \leftarrow PHI$$

NO

$$MPAC_0 \leftarrow -PHI$$

IS  
MPAC  $\geq 0$ ?

NO

PHI IS POSITIVE (2<sup>ND</sup> QUADRANT)

$$MPAC_0 \leftarrow MPAC + \frac{1}{2}$$

MPAC = 180° - PHI

SUHALFAP

$$MPAC_0 \leftarrow MPAC - \frac{1}{2}$$

VECOFANG

$$MPAC_v \leftarrow MPAC_0, PLR_0, PLD_0$$

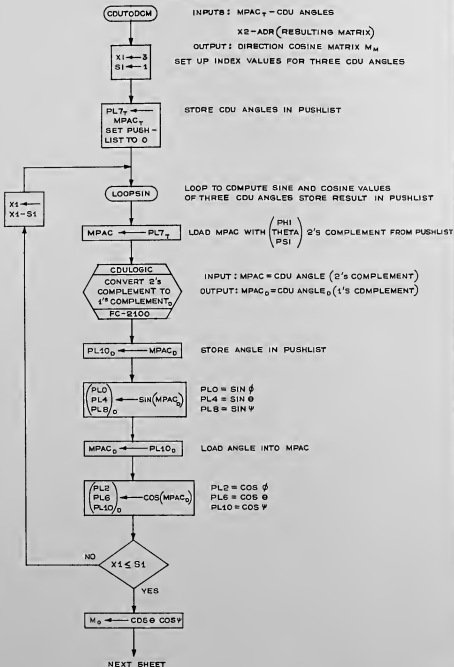
MPAC<sub>v</sub> = PHI, THETA, PSI (1's COMPLEMENT)

RETURN VIA  
QPRET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARDEC GUIDANCE AND MANEUVERING	
DRAWN: <i>[Signature]</i>		MANEUVER CALCULATIONS AND STEERING	
CHECKED: <i>[Signature]</i>		DOCUMENT NO.	
ANALYST: <i>[Signature]</i>		COLOSSUS II FC-2350	
DOCNO: <i>[Signature]</i>		REV 2	
APPROVED: <i>[Signature]</i>		REV 2	

REV 2

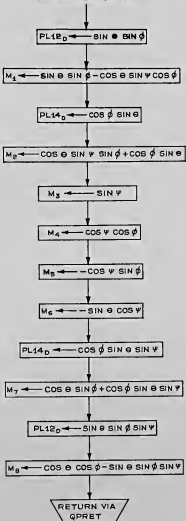
COMPUTE DIRECTION COSINE MATRIX  
RELATING S/C AXES TO STABLE  
MEMBER AXES



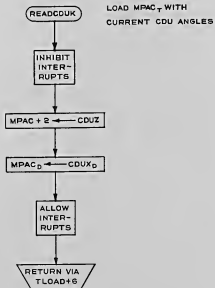
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	
DRAWN <i>C. M. [Signature]</i>	5 NOV 68
FIGURE <i>Sp. N. [Signature]</i>	19 DEC 68
ANALYST	
CHECKED <i>[Signature]</i>	15 NOV 68
APPROVED <i>[Signature]</i>	30 DEC 68

MIT GUIDANCE AND NAVIGATION
MANEUVER CALCULATIONS AND STEERING
COLOSSUS II FC-2350
11 22 27

FROM PRECEDING SHEET



MTC IN COORDINATION LAB CAMBRIDGE MASS		QUADRANT AND MANEUVER <b>MANEUVER CALCULATIONS          AND STEERING</b>	
DRAWN <i>CM Distants</i> FROM <i>D. W. Howe</i> ANALYST DESIGNER <i>John G. Moore</i> PROJECT <i>John G. Moore</i>	6 NOV 68 19 DEC 68 15 MAR 69 30 SEP 68	COLOSSUS II <b>FC-2350</b>	DOCUMENT NO. <b>FC-2350</b> REV 8
		23 27	

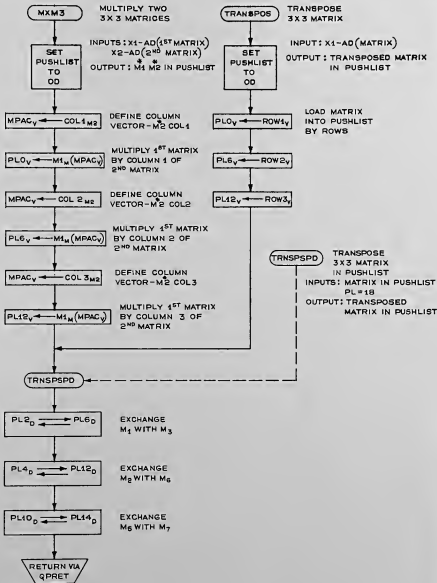


SHEET	
NO. 1	
AVIONICS	
DESIGNED BY <i>D.W. Kline</i>	5 NOV 68
DRAWN BY <i>D.W. Kline</i>	11 DEC 68
CHECKED BY <i>McDonald</i>	25 NOV 68
APPROVED BY <i>John A. Moore</i>	30 DEC 68

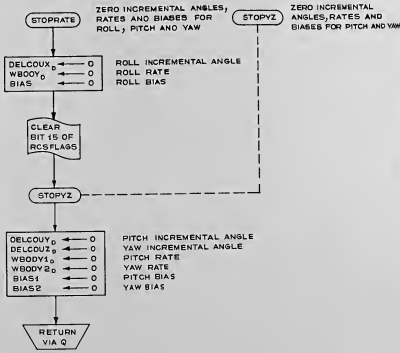
MANEUVER CALCULATIONS  
AND STEERING

COLOSSUS II FC-2350

24 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APD:LG GUIDANCE AND NAVIGATION	
DRAWN: <i>D.M.E. [Signature]</i>		MANEUVER CALCULATIONS AND STEERING	
FRONT: <i>W. [Signature]</i>		DOCUMENT NO.	
ANALYST: <i>[Signature]</i>		COLOSSUS II FC-2350	
DOCNO: <i>[Signature]</i>		REV #	
APPROVED: <i>[Signature]</i>		SHEET 25 OF 27	



MIT INSTRUMENTATION LAB CAMBRIDGE MASS		MANEUVER CALCULATIONS AND STEERING	
DESIGN: <i>W.D. ...</i>	THEY 06	COLOSSUS II FC-2350	
PROGRAM: <i>D.V. ...</i>	1/18/68	REV 26 - 27	
ANALYST: <i>...</i>	ISSUED: <i>...</i>		
DESIGNER: <i>...</i>	REV 2		
APPROVED: <i>John A. ...</i>			

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
CDULOGIC	FC-2100	CONVERT 2'S COMPLEMENT ANGLE TO 1'S COMPLEMENT ANGLE	SH22
SIGNMPAC	FC-2100	LIMIT SIZE OF MPAC ON OVERFLOW	SH7, 16, 17 SH18, 19, 20 SH10
VISTO2S	FC-2100	CONVERT 1'S COMPLEMENT ANGLES TO 2'S COMPLEMENT ANGLES	SH10

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
CALCMAN2 (FLAGWORD 2) (BIT 2)	PERFORM STARTING MANEUVER	BYPASS STARTING MANEUVER	SH9	SH10	SH10
CALCMAN3 (FLAGWORD 2) (BIT 3)	NO FINAL ROLL	FINAL ROLL IS NECESSARY	SH9		
RCSFLAGS BIT 15	HIGH MANEUVER RATE	LOW MANEUVER RATE	SH10	SH26	

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
BCDU <sub>H</sub>		INITIAL S/C CDU ANGLES		REV	2 <sup>-1</sup>
CDUXD CDUYD CDUZD		} CDU COMMANDED ANGLES		REV	2 <sup>-1</sup>
TM <sub>D</sub>		MANEUVER COMPLETION TIME		CSEC	2 <sup>28</sup>
DELCOUX <sub>D</sub> DELCDUY <sub>D</sub> DELCDUZ <sub>D</sub>		} ROLL PITCH YAW } ANGLE INCREMENTS		REV	2 <sup>-1</sup>
WBODY <sub>D</sub> WBODY1 <sub>D</sub> WBODY2 <sub>D</sub>		} ROLL PITCH YAW } ANGLE RATES		REV DECI-SEC	2 <sup>-3</sup>
BIAS BIAS1 BIAS2		} ROLL PITCH YAW } ANGLE BIASES		REV	2 <sup>-1</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ANALYTICAL GUIDANCE AND EVALUATION
<b>MANEUVER CALCULATIONS AND STEERING</b>	
DRAWN <i>[Signature]</i> 10/25/68 CHECKED <i>[Signature]</i> 11/15/68 ANALYST <i>[Signature]</i> 11/15/68 DOC# <i>[Signature]</i> 11/15/68 APPR'D <i>[Signature]</i> 11/15/68	DOCUMENT NO. <b>COLOSSUS II FC-2350</b> SHEET 27 OF 27



R05 S-BAND ANTENNA

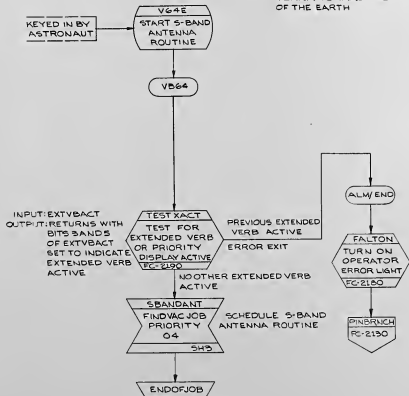
MAJOR SUBROUTINE ON THIS FLOWCHART

EXTENDED VERB 64	START S-BAND ANTENNA ROUTINE	SH 2
SBANDANT	COMPUTE AND DISPLAY S-BAND ANTENNA GIMBAL ANGLES	SH 3

M I ENGINEERING LAB CAMBRIDGE, MASS.	AF 7.0 GUIDANCE AND NAVIGATION
DRAWN <i>J. J. Chiswick</i> DOCTER PROJECT <i>J. J. Chiswick</i> K2168 ASSIST CHECK <i>J. J. Chiswick</i> 180018 APPROV <i>John R. Moore</i> 180018 PV 3	<b>R05 S-BAND ANTENNA</b> COLOSSUS IIC FC-2360 <small>FORM 1</small>

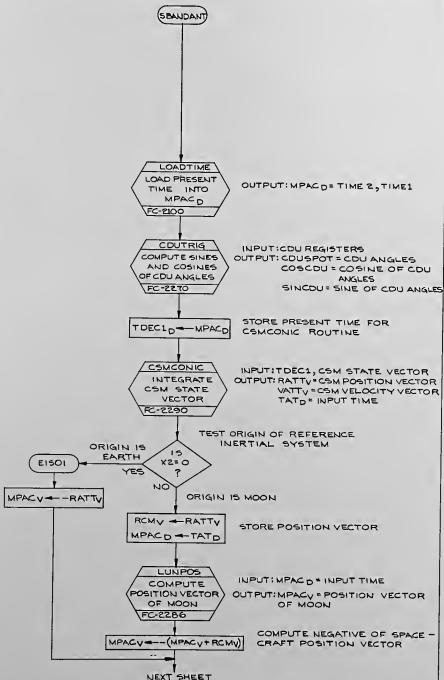
EXTENDED VERB 64: S-BAND ANTENNA

PURPOSE: TO COMPUTE AND DISPLAY THE TWO STEERABLE S-BAND ANTENNA GIMBAL ANGLES WHICH WILL POINT THE ANTENNA TOWARD THE CENTER OF THE EARTH



MIT  
 15-00 MEMORANDUM FOR  
 AIR FORCE MASS.  
 TO: *John A. Moore*  
 FROM: *John A. Moore*  
 ANALYST: *John A. Moore*  
 DOCUMENT: *John A. Moore*  
 APPROVED: *John A. Moore*

ROS S-BAND ANTENNA  
 COLOSSUS IIC  
 FC-2360  
 REV 3



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	RAVSL GUIDANCE AND NAVIGATION
DRAWN <i>J. J. Chmeluk</i> DOCT 66 PROGRAM <i>J. J. Chmeluk</i> 12-2-70 ANALYST DOCUMENT <i>J. J. Chmeluk</i> 12-2-70 APPROVED <i>John A. ...</i> 12-2-70	<b>RO5 S-BAND ANTENNA</b> COLLOSSUS DOCUMENT NO. IC <b>FC-2360</b> REV 3 SHEET 3 OF 6

FROM PRECEDING SHEET

$(EISOI + E)$

SET  
PUSHLIST  
TO  $E$

$RCMV \leftarrow REFSMAT_M(MPACV)$

LOS VECTOR IN STABLE  
MEMBER COORDINATES

$YAWANG_D \leftarrow 0$   
 $MPACV \leftarrow RCMV$

ZERO YAW ANGLE

\*SMNS\*  
TRANSFORMATION  
FROM SM TO NB  
COORDINATES

INPUT:  $MPACV =$  VECTOR IN STABLE  
MEMBER COORDINATES  
OUTPUT:  $MPACV =$  VECTOR IN NAV  
BASE COORDINATES

$R_V \leftarrow MPACV$   
 $UR_V \leftarrow UNIT(R_V)$

$R_V$  IN CM BODY AXES

$RP = R - (R \cdot U_Z) U_Z$   
 $MPACV \leftarrow R_V - (R_V \cdot HIUNITZ) HIUNITZ$

PROJECTION OF  $R$  INTO  
CM XY-PLANE

$HIUNITZ_V = (0, 0, 1)$

CLEAR  
OVERFLOW  
INDICATOR

COVCNV

$MPACV \leftarrow UNIT(MPACV)$

$U_R = UNIT(R)$

TEST FOR NULL VECTOR

DID  
 $MPACV$   
OVERFLOW  
?

YES  
YAW ANGLE IS ZERO

NOADJUST  
SHS

$UR_V \leftarrow MPACV$

STORE  $U_R$

NEXT SHEET

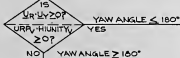
MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.  
DRAWN *J. E. Seaver* 800748  
FROM *J. E. Seaver* 962742  
ANALYST *J. E. Seaver*  
CHECKER *J. E. Seaver*  
APPROV *J. E. Seaver*

47611  
14-00000-100-00000  
RO5 S-BAND  
ANTENNA  
COLOSSUS IIC  
FC-2360  
REV 3  
4 6

FROM PRECEDING SHEET

$$\gamma = \cos^{-1}(U_R \cdot U_X)$$
$$\text{YAWANG}_D \leftarrow \cos^{-1}(\text{MPAC}_Y \cdot \text{HIUNIT}_X)$$

COMPUTE YAW ANGLE  
 $\text{HIUNIT}_Y = (1, 0, 0)$



$\text{HIUNIT}_Y = (0, 1, 0)$

$\text{DPPOSMAX}_D = 1 \text{ REV}$

$$\gamma = 2\pi - \gamma$$
$$\text{YAWANG}_D \leftarrow \text{DPPOSMAX}_D - \text{YAWANG}_D$$

LOADJUST

$$P = \cos^{-1}(U_R \cdot U_Z) - \pi/2$$
$$\text{RHOSB}_D \leftarrow \cos^{-1}(U_R \cdot \text{HIUNIT}_Z) - \text{HIDP1/4}_D$$

STORE PITCH ANGLE  
FOR DISPLAY  
 $\text{HIDP1/4} = 1/4 \text{ REV}$

$$\text{GAMMASB}_D \leftarrow \text{YAWANG}_D$$

STORE YAW ANGLE FOR DISPLAY



DISPLAY HAS BEEN ANSWERED

ENDEXT

IMMEDIATE  
RETURN

GOMARKFR  
V06NS1  
DISPLAY S-BAND  
ANTENNA GIMBAL  
ANGLES

R1-RHOSB-XXX.XX DEG. - PITCH GIMBAL  
ANGLE  
R2-GAMMASB-XXX.XX DEG. - YAW GIMBAL  
ANGLE

TERMINATE / PROCEED

RECYCLE

BLANKET  
BLANK FB  
FC-2130

DELAYJOB  
DELAY ACTIVE  
JOB 1 CSEC  
FC-2070

SBANDANT  
SHB

B5OFF

CLEAR  
BIT 5 OF  
EXTVACT

ENDOFJOB

APR 1964	APR 1964
INSTRUMENTATION LAB	GUIDANCE AND NAVIGATION
AMSTERS, MASS.	
PROJECT: <i>FC-2360</i>	PROJECT: <i>FC-2360</i>
DESIGNER: <i>J. B. ...</i>	DESIGNER: <i>J. B. ...</i>
CHECKED: <i>J. B. ...</i>	CHECKED: <i>J. B. ...</i>
APPROVED: <i>J. B. ...</i>	APPROVED: <i>J. B. ...</i>
REV 3	REV 3
	ROS S-BAND ANTENNA COLOSSUS IC FC-2360
	REV 3

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
BLANKET	FC-2130	BLANK DSKY REGISTERS	SH5
CHKPOON	FC-2190	TEST FOR IOLING PROGRAM	SH2
CSMCONIC	FC-2290	INTEGRATE CSM STATE VECTOR	SH3
OELAYJOB	FC-2078	OELAY ACTIVE JOB GIVEN TIME PERIOD	SH5
FALTON	FC-2180	TURN ON OPERATOR ERROR LIGHT	SH2
LOADTIME	FC-2100	LOAD PRESENT TIME INTO MPAC <sub>0</sub>	SH3
LUNPOS	FC-2286	COMPUTE POSITION VECTOR OF MOON	SH3
RO2BOTH	FC-2210	IMU STATUS CHECK	SH3
TESTXACT	FC-2190	TEST FOR EXTENDED VERB OR PRIORITY DISPLAY ACTIVE	SH2
*SMNB*	FC-2270	TRANSFORMATION FROM SM TO NB COORDINATES	SH4

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N51	FLASHING	R1-RH0SB - XXX.XX DEG. - PITCH GIMBAL ANGLE R2-GAMMASB - XXX.XX DEG. - YAW GIMBAL ANGLE	SH5

ERASABLE LOCATIONS USED

ACC TAG	GEOP SYMBOL	MEANING	ENGINEERING UNITS	ACC UNITS	ACC SCALING
RH0SB <sub>0</sub>	ρ	PITCH GIMBAL ANGLE FOR S-BAND ANTENNA		REV	2 <sup>0</sup>
GAMMASB <sub>D</sub>	γ	YAW GIMBAL ANGLE FOR S-BAND ANTENNA		REV	2 <sup>0</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFSC GUIDANCE AND NAVIGATION	
		ROS S-BAND ANTENNA	
DRAWN <i>J. R. ...</i>	1 OCT 68	COLOSSUS IIC	DOCUMENT NO. FC-2360
PREPARED <i>J. R. ...</i>	16 OCT 68		
ANALYST <i>J. R. ...</i>	17 OCT 68	REV 3	REV 3 OF 6
DOCSM <i>J. R. ...</i>			
APPROVED <i>J. R. ...</i>			

R63 - RENDEZVOUS FINAL ATTITUDE

MAJOR SUBROUTINES ON THIS CHART

EXTENDED }  
VERD 06 }

V05PERT:	REQUEST RENDEZVOUS FINAL ATTITUDE	SH 2
V05CALL:	RENDEZVOUS FINAL ATTITUDE	SH 2
R63 :	CALCULATE FINAL GIMBAL ANGLES	SH 4

THE ENCLOSED REPLACEMENT SHEETS WILL UPDATE THE COLOSSUS 237 FLOWCHART, FC-2361, REV.0, TO THE COLOSSUS II FLOWCHART, FC-2361, REV.1.

THE EFFECTIVE SHEETS FOR COLOSSUS II, FC-2361, REV.1, ARE:

1-4	REV.0
5-6	REV.1
7	REV.0

NOTE: FC-2361 WAS PREVIOUSLY CALLED FC-2190.

R63-RENDEZVOUS  
FINAL ATTITUDE

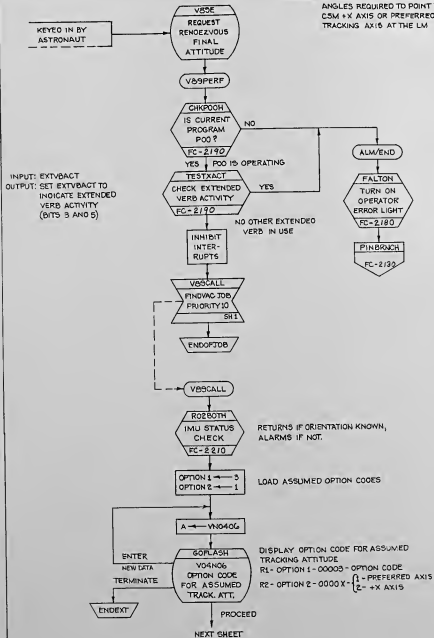
A.C. WILLIAMS 958P68  
*D.V. Kane* 172248  
*M.C. Dwyer* 247948  
*John A. Hines* 703812

COLOSSUS II

FC- 2361

1 7

PURPOSE: TO CALCULATE THE FINAL GIMBAL ANGLES REQUIRED TO POINT THE CSM +X AXIS OR PREFERRED TRACKING AXIS AT THE LM



FORM NO. 10  
REV. 1-64

DATE: 9 SEP 68  
BY: A.C. WILLIAMS  
CHECKED: R. H. KANE  
APPROVED: [Signature]  
15 SEP 68

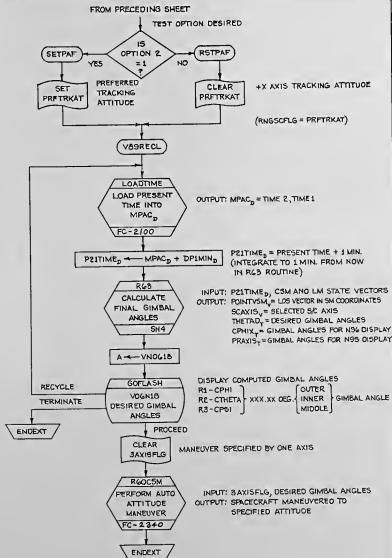
R65 - RENDEZVOUS  
FINAL ATTITUDE

COLOSSUS II

FC-2361

2 7





WIT  
INSTRUMENTS DIVISION  
CAMBRIDGE MASS.

APPROVED: A.C. WILLIAMS 10 SEP 68  
PREPARED BY: D.W. KANE 11 SEP 68  
ANALYST: J.P. GIBSON  
DOCUMENT: FC-2361  
APPROVED: J.P. GIBSON

FC-2361

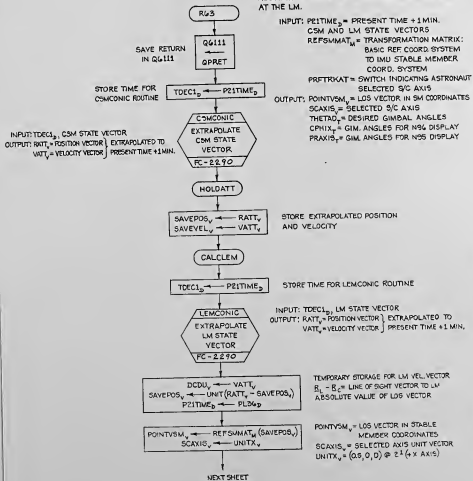
R63 - RENDEZVOUS  
FINAL ATTITUDE

COLOSSUS II

FC-2361

SHEET 8 OF 7

SUBROUTINE TO CALCULATE THE FINAL GIMBAL ANGLES REQUIRED TO POINT THE CSM + X AXIS AT THE LM AND TO CALCULATE THE FINAL GIMBAL ANGLES REQUIRED TO POINT THE PREFERRED TRACKING AXIS AT THE LM.



INPUT: P2TIME<sub>0</sub> = PRESENT TIME + 1 MIN.  
CSM AND LM STATE VECTORS  
REFSMMAT<sub>M</sub> = TRANSFORMATION MATRIX:  
BASIC REF COORD SYSTEM  
TO LM STABLE MEMBER

COORD. SYSTEM  
PRFTRKAT = SWITCH INDICATING ASTRONAUT  
SELECTED S/C AXIS

OUTPUT: POINTVSM<sub>v</sub> = LOS VECTOR IN SM COORDINATES  
SCAXIS<sub>v</sub> = SELECTED S/C AXIS  
THETA<sub>D</sub><sub>v</sub> = DESIRED GIMBAL ANGLES  
CPHIX<sub>v</sub> = GIM. ANGLES FOR N94 DISPLAY  
PRAXIS<sub>v</sub> = GIM. ANGLES FOR N95 DISPLAY

INPUT: TDEC1<sub>0</sub>, LM STATE VECTOR  
OUTPUT: RATT<sub>v</sub> = POSITION VECTOR } EXTRAPOLATED TO  
VATT<sub>v</sub> = VELOCITY VECTOR } PRESENT TIME + 1 MIN.

TEMPORARY STORAGE FOR LM VEL VECTOR  
R<sub>L</sub> - R<sub>C</sub> = LINE OF SIGHT VECTOR TO LM  
ABSOLUTE VALUE OF LOS VECTOR

POINTVSM<sub>v</sub> = LOS VECTOR IN STABLE  
MEMBER COORDINATES  
SCAXIS<sub>v</sub> = SELECTED AXIS UNIT VECTOR  
UNITX<sub>v</sub> = (0,0,0) @ 21(x AXIS)

BY A. C. WILLIAMS  
CHECKED BY B. W. KANE  
DATE: 11/20/68  
BY: John A. Brown

10 SEP 68  
1968 68

COLOSSUS II

R63 = RENDEZVOUS  
FINAL ATTITUDE

FC-2361

4 7

FROM  
PRECEDING SHEET

VECPPOINT  
COMPUTE DESIRED  
GIMBAL ANGLES  
TO POINT VEHICLE  
FC-2340 SH5

INPUT: SCAXIS<sub>v</sub> = DESIRED S/C AXIS TO BE  
POINTED  
POINTVSM<sub>v</sub> = DESIRED POINTING  
DIRECTION  
OUTPUT: MPAC<sub>T</sub> = 3 GIMBAL ANGLES TO  
POINT VEHICLE

CPHX<sub>T</sub> ← MPAC<sub>T</sub>

STORE ANGLES FOR N96 DISPLAY

SCAXIS<sub>v</sub> ← PRFUNIT<sub>v</sub>

STORE PREFERRED TRACKING AXIS  
UNIT VECTOR PRFUNIT<sub>v</sub> = (.40957602, 0,  
.28678822) @ 21 (55° TRACKING AXIS)

VECPPOINT  
COMPUTE DESIRED  
GIMBAL ANGLES  
TO POINT VEHICLE  
FC-2340 SH5

INPUT: SCAXIS<sub>v</sub>, POINTVSM<sub>v</sub>  
OUTPUT: MPAC<sub>T</sub> = 3 GIMBAL ANGLES TO  
POINT VEHICLE

PRAXIS<sub>T</sub> ← MPAC<sub>T</sub>

STORE ANGLES FOR N95 DISPLAY

TEST TRACKING ATTITUDE SPECIFIED BY ASTRONAUT  
IS PRFTRKAT SET?  
PREFERRED TRACKING AXIS

YES

NO + X AXIS

CRSTOR1

SCAXIS<sub>v</sub> ← UNITX<sub>v</sub>

STORE +X AXIS UNIT  
VECTOR IN SELECTED  
AXIS UNIT VECTOR

MPAC<sub>T</sub> ← CPHX<sub>T</sub>

LOAD ANGLES FOR  
N18 DISPLAY

CRSTOR

THETAD<sub>T</sub> ← MPAC<sub>T</sub>

STORE SPECIFIED GIMBAL ANGLES  
FOR N18 DISPLAY  
(THETAD<sub>T</sub> = CPH1, CTHETA, CPS1)

RETURN VIA  
Q6111

WIT: INSTRUMENTATION LAB 1400 RESEARCH BLDG.		R63 - RENDEVOUS FINAL ATTITUDE	
DRYER: PREFR: ANAL 11 CPL NO: APPROV:	<i>R. J. ...</i> <i>S. N. ...</i> <i>J. O. ...</i>	NOREP: MORPH: COLOSSUS II NO REP:	FC-2361 5 7

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
CHKPOOH	FC-2190	TEST CONTENTS OF MODREG	SH2
CSMCONIC	FC-2290	EXTRAPOLATE CSM STATE VECTOR	SH4
FALTON	FC-2180	TURN ON OPERATOR ERROR LIGHT	SH2
LEMCONIC	FC-2290	EXTRAPOLATE LM STATE VECTOR	SH4
LOADTIME	FC-2100	LOAD PRESENT TIME INTO MPAC <sub>0</sub>	SH3
RO2BOTH	FC-2210	IMU STATUS CHECK	SH2
R60CSM	FC-2340	PERFORM AUTO ATTITUDE MANEUVER	SH3
TESTXACT	FC-2190	TEST EXTENDED VERB ACTIVITY OR PRIORITY DISPLAY USING DSKY	SH2
VECPPOINT	FC-2340	COMPUTE DESIRED GIMBAL ANGLES TO POINT VEHICLE	SH5

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
PRPFRKAT (RNGCSFLG) FLAGWRD 5 BIT 10	PREFERRED TRACKING ATTITUDE	+ x AXIS TRACKING ATTITUDE	SH3	SH3	SH5
3AXISFLG FLAGWRD 5 BIT 6	MANEUVER SPECIFIED BY THREE AXES	MANEUVER SPECIFIED BY ONE AXIS		SH3	

DISPLAYS

VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V04N06	FLASHING	R1 - OPTION 1 - 00003 - OPTION CODE R2 - OPTION 2 - 0000x 1 - PREFERRED AXIS 2 - + x AXIS	SH2
V06N18	FLASHING	R1 - CPHI } xxx,xx DEG } DESIRED R2 - CTHETA } } INNER R3 - CPSI } } MIDDLE GIMBAL ANGLES	SH3

ERASABLE LOCATIONS USED

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
P21TIME <sub>D</sub>		PRESENT TIME + 1 MIN.		CSEC	2 <sup>28</sup>
POINTVSM <sub>V</sub>		LOS VECTOR IN SM COORDINATES		UNIT VECTOR	2 <sup>1</sup>
SCAXIS <sub>V</sub>		SELECTED SPACECRAFT AXIS		UNIT VECTOR	2 <sup>1</sup>
THETAD <sub>T</sub>		DESIRED GIMBAL ANGLES		REV	2 <sup>-1</sup>
CPHX <sub>T</sub>		GIMBAL ANGLES FOR N96 DISPLAY		REV	2 <sup>-1</sup>
PRAXIS <sub>T</sub>		GIMBAL ANGLES FOR N95 DISPLAY		REV	2 <sup>-1</sup>
TDEC <sub>D</sub>		INPUT TIME FOR INTEGRATION ROUTINES		CSEC	2 <sup>28</sup>
RATT <sub>V</sub>	B <sub>L</sub> , B <sub>C</sub>	OUTPUT POSITION VECTOR FROM INTEGRATION		METERS	2 <sup>28</sup>
VATT <sub>V</sub>	V <sub>L</sub> , V <sub>C</sub>	OUTPUT VELOCITY VECTOR FROM INTEGRATION		M/CSEC	2 <sup>7</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT RENDZVOUS FINAL ATTITUDE
DRAWN <i>P.M. Smith</i>	DESIGNED <i>J.M.C.</i>	COLLOSSUS II FC-2361 REV 2 6 7
PROGRAM <i>D.N. K...</i>	TESTED <i>J.M.C.</i>	
ANALYST <i>J.P. A...</i>	DESIGNED <i>J.M.C.</i>	
APPROVED <i>J.P. A...</i>	TESTED <i>J.M.C.</i>	

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
UNIT <sub>XV</sub>		+ X AXIS UNIT VECTOR		(.5, 0, 0) UNIT VECTOR	2 <sup>1</sup>
PRFUNIT <sub>V</sub>		55° TRACKING AXIS UNIT VECTOR		(.40957602, 0, .28678822) UNIT VECTOR	2 <sup>1</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		R. 2.11 (E-PAK) AND ASSOCIATES	
DRAWN: <i>L. M. ...</i>		R 63	
DESIGNED: <i>R. ...</i>		RENDEZVOUS FINAL ATTITUDE	
ANALYST		COLOSSUS II	
CHECKED: <i>J. ...</i>		FC-2361	
APPROVED: <i>J. ...</i>		REV 1	
		JULY 7 1967	

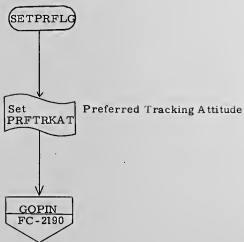
V76, V77 SET/CLEAR PREFERRED ATTITUDE FLAG

SETPRFLG Sh. 2

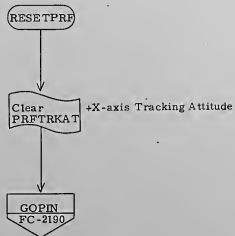
RESETPRF Sh. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>A. Swick</i>	Set/Clear Preferred Attitude Flag	
PRGMR	<i>M. Brennan</i>	COLOSSUS 2D	DOCUMENT NO.
A-ALST			FC-2363
DOCMR	<i>M. Brennan</i>	REV	SHEET 1 OF 3
APPR'D	<i>R. S. O'Donnell</i>		

EXTENDED VERB 76



EXTENDED VERB 77



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.			APOLLO GUIDANCE AND NAVIGATION	
			Set/Clear Preferred Attitude Flag	
DRAWN	<i>A. Bright</i>	<i>1/14/69</i>	COLOSSUS 2D	DOCUMENT 1.0.
PRGMR	<i>M. Brookline</i>	<i>1/27/69</i>		FC-2363
ANALST				
DCCMR	<i>M. Brookline</i>	<i>1/27/69</i>		
APPR'D	<i>R. Smith</i>	<i>1/27/69</i>	REV	SHEET 2 OF 3

FLAG

Name	Meaning When Set	Meaning When Cleared	Where Set	Where Cleared	Where Tested
PRFTRKAT Flag 5 Bit 10	Preferred tracking attitude	+X-axis tracking attitude	Sh. 2	Sh. 2	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Smith</i> 1/22/69		Set/Clear Preferred Attitude Flag	
PROGR <i>T. Bradburn</i> 11/20/68		COLOSSUS 2D	DOCUMENT NO. FC-2363
ANALST			
DCCMR <i>H. English</i> 1/23/69			
APPR'D <i>R. Smith</i> 1/23/69	REV		SHEET 3 OF 3

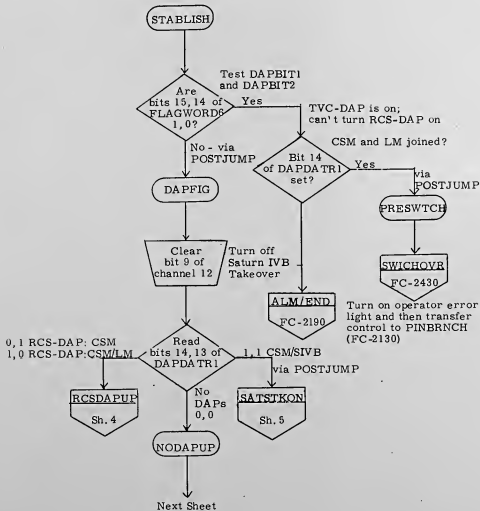


DAP INTERFACE AND SERVICE ROUTINES

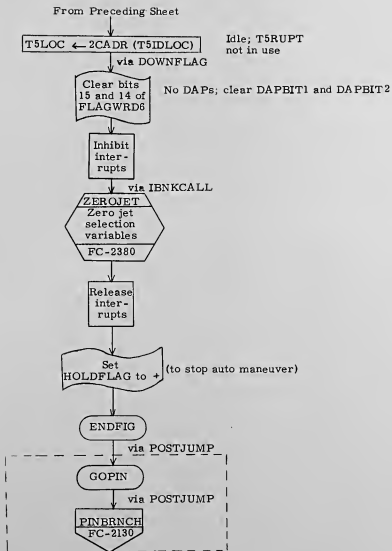
STABLISH	Sh. 2
GOPIN	Sh. 3
RCSDAPUP	Sh. 4
RCSDAPON	Sh. 4
SATSTKON	Sh. 5
DAPDISP	Sh. 6
V79	Sh. 10
S4L 2	Sh. 13
S40.14	Sh. 17
S40.15	Sh. 17
ENATMA	Sh. 18
V60	Sh. 18
V61	Sh. 18
V62	Sh. 19
V63	Sh. 19
NEEDLER	Sh. 20
NEEDLES3	Sh. 21
STICKCHK	Sh. 23
SETMAXDB	Sh. 24
SETMINDB	Sh. 24
AMBGUPDT	Sh. 25
DPADD	Sh. 26
SMALLMP	Sh. 28

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Hartley 11/24/69</i>		DAP Interface and Service Routines	
PRGMR <i>J.F. Harabed 11-26-69</i>		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2370
DOCMR <i>Robert M. Euter 11/24/69</i>		REV 2	SHEET 1 OF 34
APPR'D <i>Robert M. Euter 11/24/69</i>			

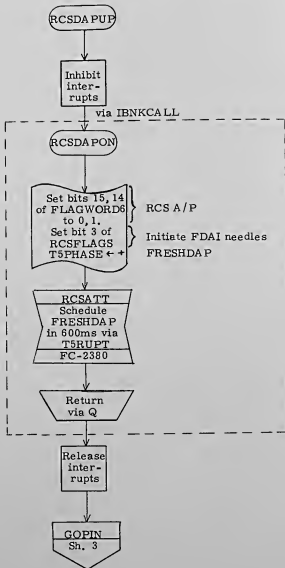
Extended Verb 46: RCS DAP Turn-on



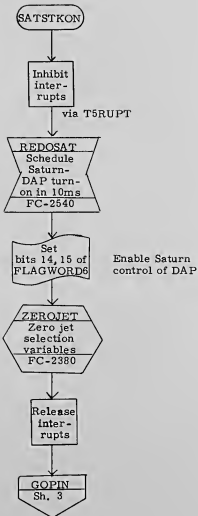
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DRAWN <i>R. Hughes</i> /12/67		DAP Interface and Service Routines	
PROG. <i>F. Dumbell</i>		COLOSSUS 2D	DOCUMENT NO.
CHECK <i>Roberta M. Carter</i> 11/26/67			FC-2370
APPROV. <i>Roberta M. Carter</i> 11/26/67		REV 2	SHEET 2 OF 34



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> 10/16/69		DAP Interface and Service Routines	
PRGMR <i>[Signature]</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYST			
DOCMR <i>[Signature]</i> 11/24/69		REV 2	SHEET 3 OF 34
APPR'D <i>[Signature]</i> 11/26/69			

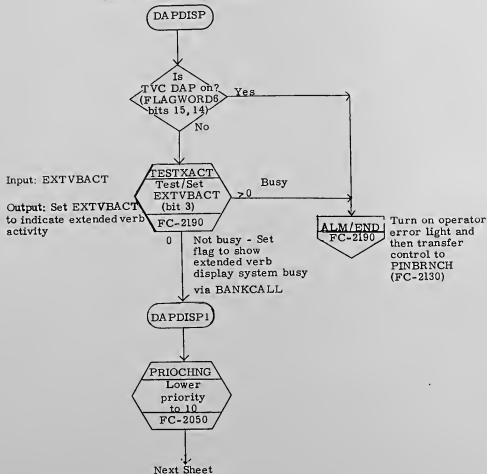


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. Hunter</i> 11/26/69		DAP Interface and Service Routines	
PRGMR <i>D. F. Drum Kelly</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYST			
DOCMR <i>Robert J. M. Estes</i> 11/26/69		REV 2	SHEET 4 OF 34
APPR'D <i>Robert J. M. Estes</i> 11/26/69			

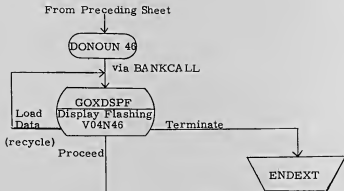


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Hunter</i> 1/26/69		DAP Interface and Service Routines	
PRGMR <i>A.F. Dunbar</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR <i>Robert M. Estes</i> 1/26/69		REV 2	SHEET 5 OF 34
APPR'D <i>Robert M. Estes</i> 1/26/69			

Verb 48: Load Autopilot Data



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>W. Hunter</i>		DAP Interface and Service Routines	
PRGMR <i>W. Hunter</i>		COLOSSUS 2D	DOCUMENT NO.
ANALYST			FC-2370
DOCMR <i>Robert M. Egan</i>	<i>11/26/67</i>	REV	SHEET 6 OF 34
APPR'D <i>Robert M. Egan</i>	<i>11/26/67</i>	2	

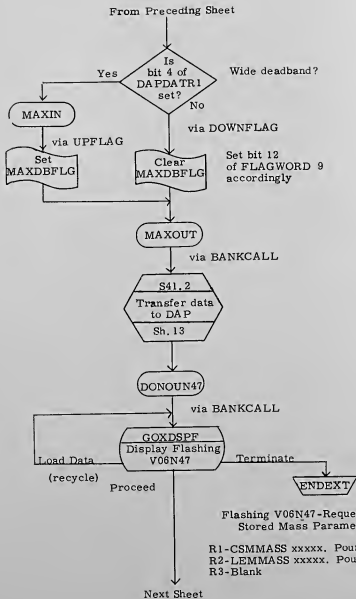


Flashing V04 N46-Request Response  
Autopilot Configuration (Octal Code)

R1-DAPDATR1	R2-DAPDATR2
bits -Vehicle Configuration	bits -Quad AC Roll
15-13	15-13
0-no DAP 2-CSM/LM	0-Fail Quad AC (i. e. use BD)
1-CSM 3-CSM/SIVB	1-Use Quad AC
6-CSM/LM (Ascent)	
bits -X Trans Code Quad AC	bits -Quad A
12-10	12-10
0-Fail Quad AC X-Translation	0-Fail Quad A
1-Use Quad AC	1-Use Quad A
bits -X Trans Code Quad BD	bits -Quad B
9-7	9-7
0-Fail Quad BD X-Translation	0-Fail Quad B
1-Use Quad BD	1-Use Quad B
bits -Deadband	bits -Quad C
6-4	6-4
0-±0.5 deg	0-Fail Quad C
1-±5 deg	1-Use Quad C
bits -Maneuver Rate	bits -Quad D
3-1	3-1
0-0.05 deg/sec	0-Fail Quad D
1-0.2 deg/sec	1-Use Quad D
2-0.5 deg/sec	
3-2 deg/sec	

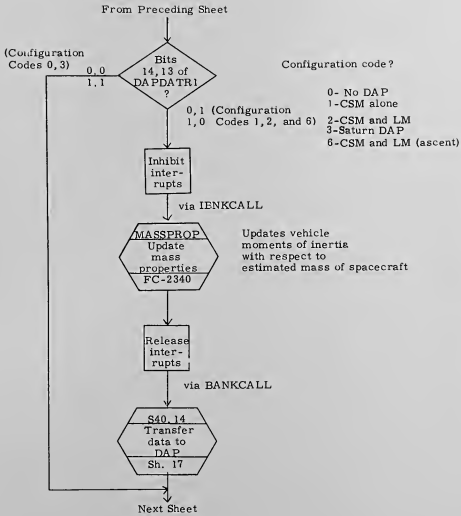
Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		DAP Interface and Service Routines	
PRGMR <i>[Signature]</i>		COLOSSUS 2D	DOCUMENT NO.
ANALYST			FC-2370
DOCMR <i>[Signature]</i>		REV 2	SHEET 7 OF 34
APPR'D <i>[Signature]</i>			

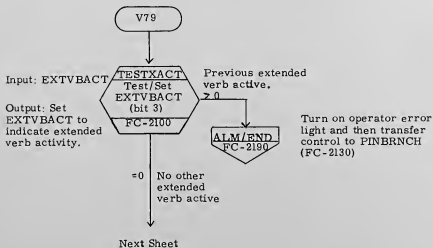
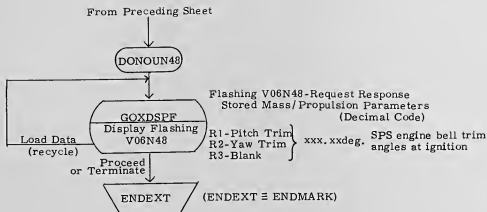


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Smith</i> 11/16/69		DAP Interface and Service Routines	
PRGRM <i>AF. Dumbell</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR <i>R. Smith</i> 11/16/69		REV 2	SHEET 8 OF 34
APPR'D <i>R. Smith</i> 11/16/69			

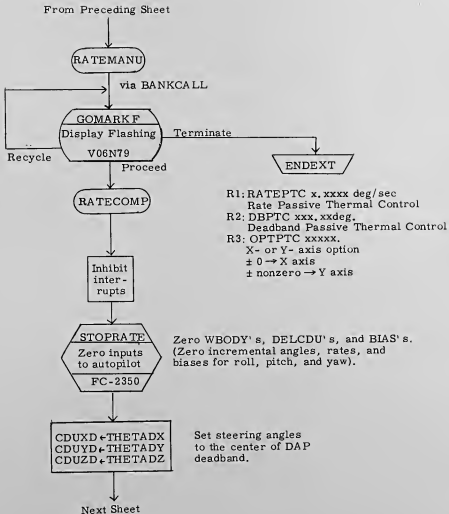




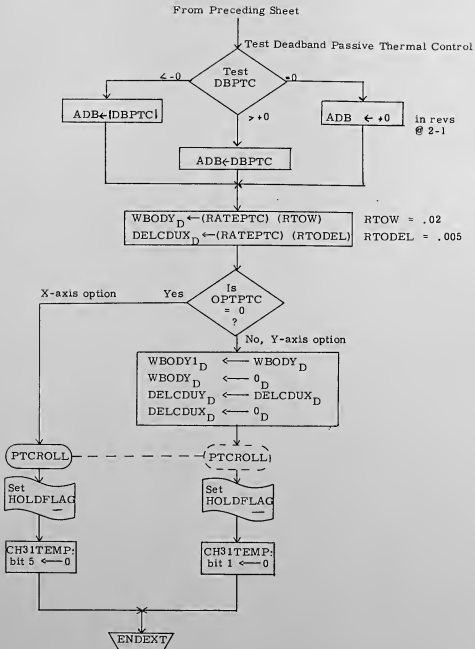
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Hunter</i> / <i>W. H. King</i>		DAP Interface and Service Routines	
PRGMR <i>R. Hunter</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR <i>Robert M. Carter</i> 11/16/69		REV 2	SHEET 9 OF 34
APPR'D <i>Robert M. Carter</i> 11/16/69			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION I	
DRAWN <i>A. Heston</i> 10/26/67		DAP Interface and Service Routines	
PRGMR <i>J.F. Marshall</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYST			
DOCMR <i>R. G. ...</i> 11/22/67		REV 2	SHEET 10 OF 34
APPR'D <i>R. G. ...</i> 11/22/67			

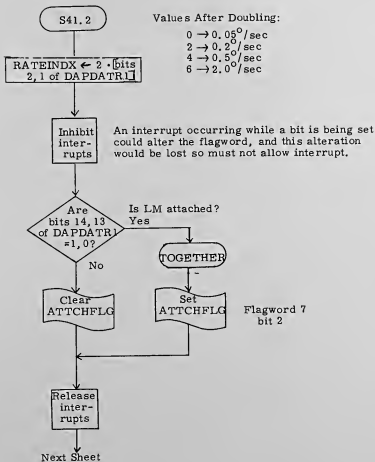


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Hartig</i>		DAP Interface and Service Routines	
PRGMR <i>J.F. Burdick</i>	<i>1/24/69</i>	DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2370
DOCMR <i>Robert M. Estes</i>	<i>11/24/69</i>	REV	
APPR'D <i>Robert M. Estes</i>	<i>1/24/69</i>	2	SHEET 11 OF 34

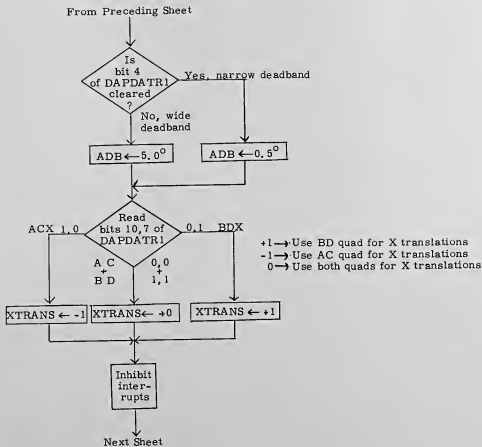


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Hunter</i>		DA P Interface and Service Routines	
PRGMR <i>J.F. Kumbell</i>			
ANALYST		COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR <i>Robert M. Estlin 11/24/69</i>		REV 2	SHEET 12 OF 34
APPR'D <i>Robert M. Estlin 11/24/69</i>			

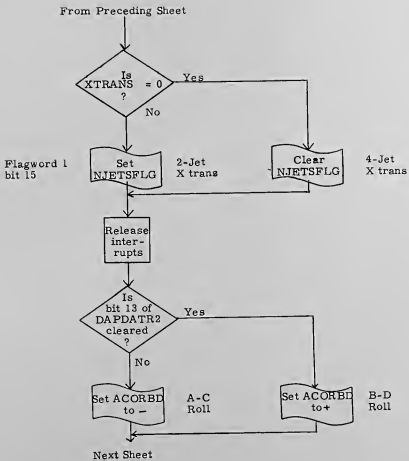
S41. 2, S40. 14 and S40. 15 Decode DAP Data Nouns



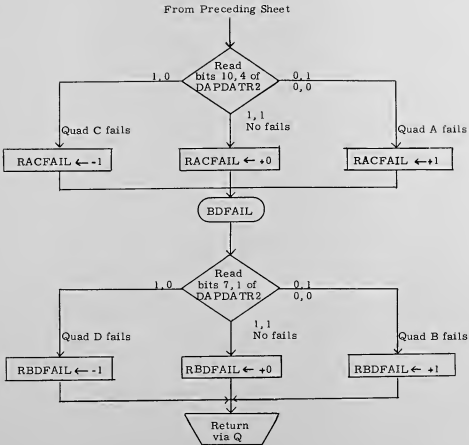
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Hunter</i> / 11/14/69		DAP Interface and Service Routines	
PRGMR <i>J.F. Rumball</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DDCMR <i>R. M. Carter</i> 11/24/68		REV 2	
APPR'D <i>R. M. Carter</i> 11/24/69		SHEET 13 OF 34	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Hunter</i>		DAP Interface and Service Routines	
PRGMR <i>J.F. Marshall</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYST		REV 2	SHEET 14 OF 34
DOCMR <i>Robert M. Estes</i> 11/22/67			
APPR'D <i>Robert M. Estes</i> 11/26/67			

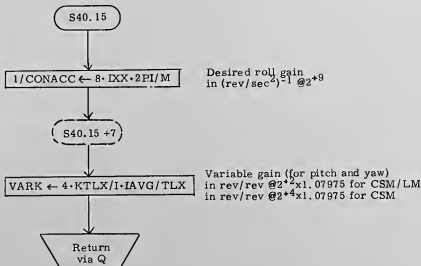
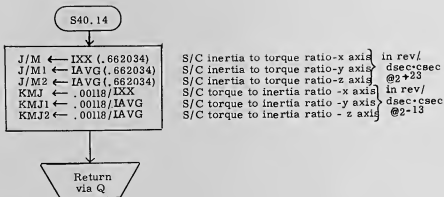


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Hester</i> 11/24/67		DAP Interface and Service Routines	
PRGMR <i>F. Marshall</i>		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2370
DOCMR <i>Robert M. Egan</i> 11/24/67		REV 2	SHEET 15 OF 34
APPR'D <i>Robert M. Egan</i> 11/24/67			



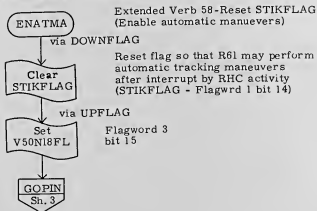
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. H. ...</i> 11/24/62		DAP Interface and Service Routines	
PRGMR <i>J. ...</i>		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>...</i>			FC-2370
DOCMR <i>...</i> 11/24/62		REV 2	
APPR'D <i>...</i> 11/24/62		SHEET 16 OF 34	



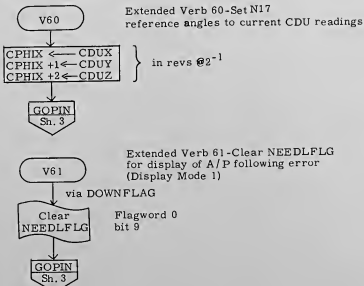


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	R. Han-Tan	10/23/67	
PRGRM	J. F. Canfield		DAP Interface and Service Routines 7
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR	Roberta M. Suter	11/26/68	
APPR'D	Roberta M. Suter	11/26/68	REV 2
			SHEET 17 OF 34

Extended Verb 58-Enable Automatic Maneuvers

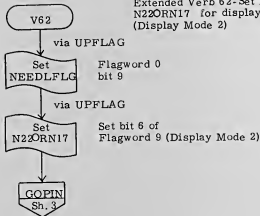


Extended Verbs 60-63 DAP Error Display Configuration

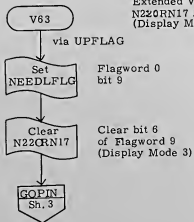


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		DAP Interface and Service Routines	
DRAWN <i>R. Newman</i>	<i>11/24/67</i>	COLOSSUS 2D	DOCUMENT NO.
PRGMR <i>R. Newman</i>			FC-2370
ANALYST		REV 2	SHEET 18 OF 34
DOCMR <i>R. Newman</i>	<i>11/24/67</i>		
APPR'D <i>R. Newman</i>	<i>11/24/67</i>		

Extended Verb 62-Set NEEDLFLG and set N22ORN17 for display of total attitude error (Display Mode 2)

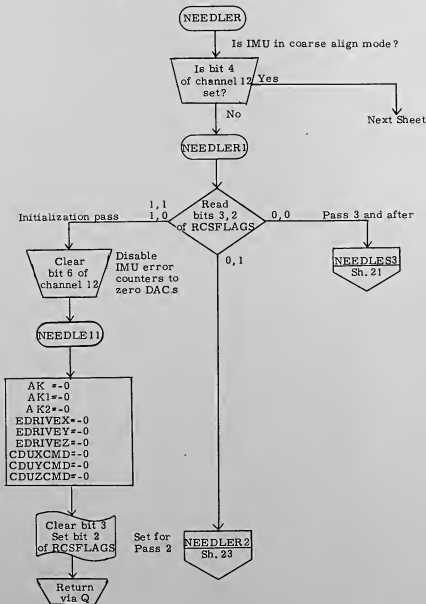


Extended Verb 63-Set NEEDLFLG and clear N22ORN17 for display of total attitude error (Display Mode 3)

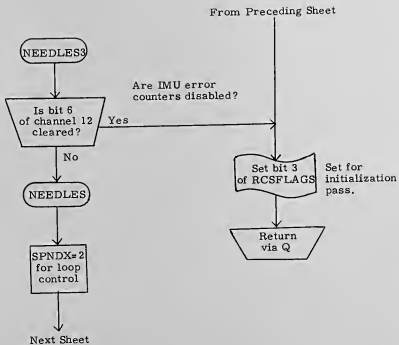


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		DAP Interface and Service Routines	
DRAWN <i>R. Hester</i>	<i>10/20/69</i>	COLOSSUS 2D	DOCUMENT NO.
PRGMR <i>D. F. Marshall</i>			FC - 2370
ANALST			
DOCMR <i>R. Hester</i>	<i>11/26/69</i>		
APPR'D <i>R. Hester</i>	<i>11/26/69</i>	REV 2	SHEET 10 OF 34

FDAI NEEDLE DRIVE ROUTINE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		DAP Interface and Service Routines	
DRAWN <i>R. Hantz</i>	<i>1/2/67</i>	COLLOSSUS 2E	DOCUMENT NO.
PRGRM <i>J. F. ...</i>			FC-2370
ANALST		REV 2	SHEET 20 OF 34
DOCMR <i>Robert M. ...</i>	<i>1/2/67</i>		
APPR'D <i>Robert M. ...</i>	<i>1/2/67</i>		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Hennessey</i> 11/24/67		DAP Interface and Service Routines	
PRGMR <i>J. E. Hunsbald</i>		COLOSSUS 2D	DOCUMENT NO.
ANALYST			FC-2370
DOCMR <i>Robert M. Smith</i> 11/24/67		REV 2	SHEET 21 OF 34
APPR'D <i>Robert M. Smith</i> 11/24/67			

From Preceding Sheet

DACLOOP

Loop control via SPNDX

```

L=-AK2/4
IF|L|>384, L ← 384 sign (L)
CDUZYCMD ← L-EDRIVEZ+CDUZYCMD
EDRIVEZ ← L
L=-AK1/4
IF|L|>384, L ← 384, sign (L)
CDUYCMD ← L-EDRIVEY+CDUYCMD
EDRIVEY ← L
L=-AK/4
IF|L|>384, L ← 384 sign (L)
CDUXCMD ← L-EDRIVEX+CDUXCMD
EDRIVEX ← L
    
```

Loop Pass 1  
Z attitude error

Loop Pass 2  
Y attitude error

Loop Pass 3  
X attitude error

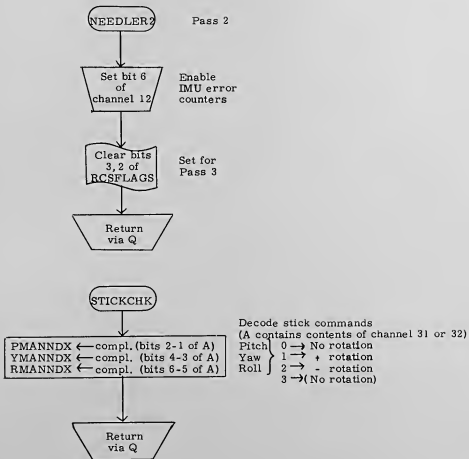
Set bits  
15, 14, 13  
of  
channel 14

Gate IMU error commands  
in cells 50, 51, and 52  
(CDUXCMD, CDUYCMD, CDUZYCMD)  
into CDU error counters.

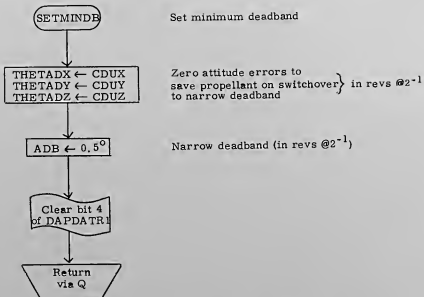
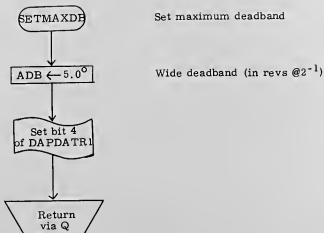
Return  
via Q

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Neuman</i>		DAP Interface and Service Routines	
PROGRAM <i>FC-2370</i>		COLOSSUS 2D	DOCUMENT NO.
ANALYST			FC-2370
DOCNR <i>Robert M. Ewing 11/26/65</i>		REV 2	SHEET 22 OF 34
APPR'D <i>Robert M. Ewing 11/26/65</i>			

RCS-DAP Subroutines



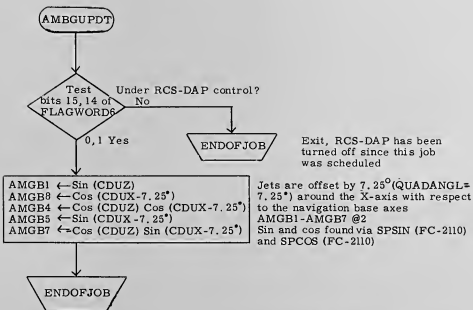
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Neather</i> 11/24/68		DAP Interface and Service Routines	
PRGMR <i>J.F.D. Durbell</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYST			
DOCMR <i>Robert M. Evers</i> 11/24/68		REV 2	SHEET 23 OF 34
APPR'D <i>Robert M. Evers</i> 11/24/68			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Hunter</i>		DAP Interface and Service Routines	
PRGMR <i>P. F. Harrell</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYST			
DOCMR <i>Robert M. Estes</i>	<i>11/24/67</i>	REV <sup>d</sup>	SHEET 24 OF 34
APPR'D <i>Robert M. Estes</i>	<i>11/24/67</i>		



Matrix Update Subroutine



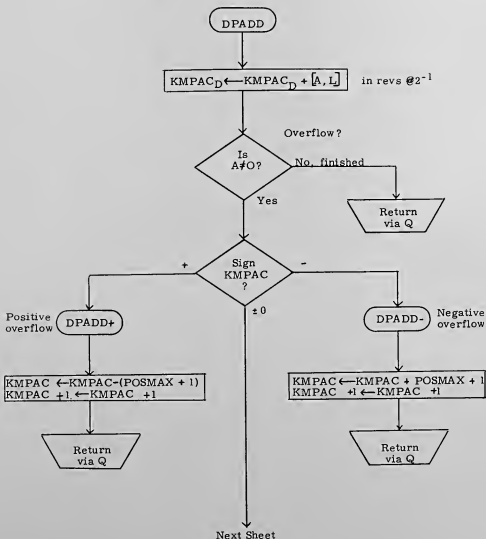
Transformation matrix: gimbal angle differences to body angle differences

$$\begin{pmatrix} 1 & \text{Sin } \psi & 0 \\ 0 & \text{Cos } \psi & \text{Sin } \phi \\ 0 & -\text{Cos } \psi & \text{Cos } \phi \end{pmatrix}$$

$$\begin{pmatrix} 1 & \text{Sin } \psi & 0 \\ 0 & \text{Cos } \psi & \text{Cos } \phi & \text{Sin } \phi \\ 0 & -\text{Cos } \psi & \text{Sin } \phi & \text{Cos } \phi \end{pmatrix}$$

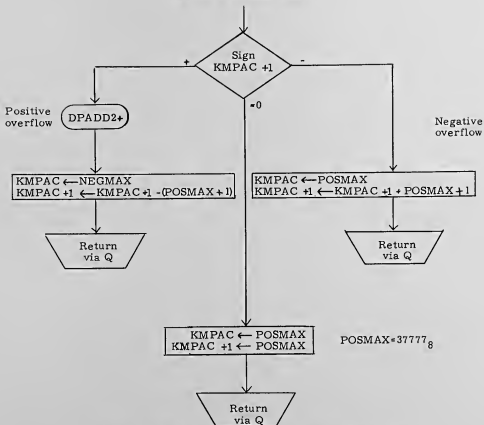
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Hunter</i> <i>11/26/69</i>		DAP Interface and Service Routines	
PRGMR <i>J. F. Marshall</i>		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2370
DOCMR <i>Robert M. Estes</i> <i>11/26/69</i>		REV 2	SHEET 25 OF 34
APPR'D <i>Robert M. Estes</i> <i>11/26/69</i>			

MYSUBS Arithmetic Subroutines



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DRAWN <i>R. Hunter</i> 10/2/67		DAP Interface and Service Routines	
PRGMR <i>J. H. Marshall</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR <i>Robert M. Estes</i> 11/26/67		2	SHEET 26 OF 34
APPR'D <i>Robert M. Estes</i> 11/26/67			

From Preceding Sheet



The real value of the angle stored in KMPAC lies always between  $\pm 360^\circ$ . The storage capacity of KMPAC, however, is between  $\pm 180^\circ$ . If positive overflow, the real value lies between  $+180^\circ$  and  $+360^\circ$ , while the stored value is  $180^\circ$  smaller. However, by subtracting  $180^\circ$  (POSMAX + 1) from this stored value, it becomes equivalent to the real value (as  $\theta - 360^\circ = \theta$ ). This derived value lies between  $0^\circ$  and  $-180^\circ$ , and hence is storable. A similar logic applies to negative overflow. In the case where both KMPAC and KMPAC + 1  $\neq 0$ , and the closest approximation is double precision POSMAX.

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DRAWN <i>R. Bentley</i> 11/24/67		DAP Interface and Service Routines	
PRGMR <i>J.F. Blackburn</i>		COLOSSUS 2D	DOCUMENT NO.
ANALYST			FC-2370
DOCMR <i>Robert M. Estes</i> 11/24/67		REV	2
APPR'D <i>Robert M. Estes</i> 11/24/67			SHEET 27 OF 34

SMALLMP

Double precision product  
of  $KMPAC_D$  and  $A$ ;  
Results in  $KMPAC_D$

Calculation:  $A(X+Y)$

$KMPTEMP \leftarrow A$   
 $KMPAC + 1 \leftarrow A(KMPAC + 1)$   
 $A \leftarrow KMPAC$   
 $[A, L] \leftarrow A(KMPTEMP)$   
 $KMPAC \leftarrow A$   
 $KMPAC + 1 \leftarrow L * (KMPAC + 1)$

$A \cdot Y$  (s. p., low order half lost)

$A \cdot X$  (d. p.)  
 High half }  $AX + AY$   
 Low half }

Return  
via Q

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>C. Bentley</i> 1/16/69		DAP Interface and Service Routines	
PRGMR <i>F. F. ...</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYS			
DOCMR <i>Robert M. ...</i> 1/16/69		REV 2	SHEET 28 OF 34
APPR'D <i>Robert M. ...</i> 1/16/69			

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

Subroutine Name	Flow Chart	Description	Where Called
ALM/END	2190	Turns on operator error light and then transfers control to PINBRNCH (FC-2130)	Sh. 2, 6, 10
MASSPROP	2340	Updates mass properties	Sh. 9
PINBRNCH	2130	Reestablishes last display	Sh. 3
PRIOCHNG	2050	Changes priority	Sh. 6
RCSATT	2380	Normal entry to RCS DAP initialization and Phase 1	Sh. 4
REDOSAT	2450	Initializes stick control of Saturn	Sh. 5
STOPRATE	2350	Zeroes incremental angles, rates, and biases for roll, pitch, and yaw	Sh. 11
SWICHOVR	2430	Switches from one set of filter gains to another	Sh. 2
TESTXACT	2190	Tests/sets EXTVBACT	Sh. 6, 10
ZEROJET	2380	Zeroes jet selection variables	Sh. 3, 5

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DRAWN <i>R. Hunter</i>		DAP Interface and Service Routines	
PRGMR <i>J. F. Campbell</i>	<i>11/16/69</i>	DOCUMENT NO.	
ANALYS		COLOSSUS 2D	
DOCMR <i>Robert M. Estes</i>	<i>11/16/69</i>	FC-2370	
APPR'D <i>Robert M. Estes</i>	<i>11/16/69</i>	REV 2	SHEET 29 OF 34

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
MAXDBFLG (Flagword 9 bit 12)	Maximum deadband selected	Minimum deadband selected	8	8	
N22CRN17 (Flagword 9 bit 6)	Compute total attitude errors with respect to N22 V62	Compute total attitude errors with respect to N17 V63	19	19	
ATTCHFLG (Flagword 7 bit 2)	LM attached to CM	LM not attached to CM	13	13	
DAPBIT 1 (Flagword 6 bit 15)	(bit 15, bit 14)*1, 1: 0, 1: 0, 0:	enable Saturn control of DAP RCS A/P no DA P's	5	3, 4	2, 6, 25
DAPBIT 2 (Flagword 6 bit 14)			4, 5		6, 25
V50N18FLG (Flagword 3 bit 15)	Enable R60 attitude maneuver	Inhibit R60 attitude maneuver	18		
NJETSFLG (Flagword 1 bit 15)	2 jet RCS burn	4 jet RCS burn	15	15	
STIKFLAG (Flagword 1 bit 14)	RHC control	CMC control		18	
NEEDLFLG (Flagword 0 bit 9)	Total attitude error displayed	A/P following error displayed	19	18	
RCSFLAGS bit 3	NEEDLER routine performs the initialization functions for the FDAI display.	NEEDLER routine does not perform initialization functions for the FDAI display.	4, 21	20, 30	20
RCSFLAGS bit 2	First pass of initialization function has been completed.	First pass of initialization function has not been completed.	20	23	20

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DRAWN <i>C. Smith</i>	<i>1/12/69</i>	DAP Interface and Service Routines	
PRGMR <i>J. F. Russell</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYST			
DOCMR <i>Robert M. Estes</i>	<i>11/24/68</i>	REV 2	SHEET 30 OF 34
APPR'D <i>Robert M. Estes</i>	<i>11/24/68</i>		

DISPLAYS

Verb-Noun	Type of Display	Description of Each Register	Where Executed
V04N46	Flashing	R1: xxxxx DAPDATR1 } Autopilot R2: xxxxx DAPDATR2 } Configuration R3: } (octal code)	Sh. 7
V06N47	Flashing	R1: xxxxx. pounds mass of CSM R2: xxxxx. pounds mass of LM R3:	Sh. 8
V06N48	Flashing	R1: xxx. xxdeg. pitch trim R2: xxx. xxdeg. yaw trim R3:	Sh. 10
V06N79	Flashing	R1: x. xxxxddeg/sec rate passive thermal control R2: xxx. xxdeg. deadband passive thermal control R3: xxxxx. x- or y- axis option	Sh. 11

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DRAWN <i>R. Hunter</i> 11/24/69		DAP Interface and Service Routines	
PRGMR <i>F. Van Dyke</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALYST			
DOCMR <i>Robert M. E. Jones</i> 11/24/69		REV 2	SHEET 31 OF 34
APPR'D <i>Robert M. E. Jones</i> 11/24/69			

## ERASABLE LOCATIONS USED

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scaling
ACORBD	Specifies quad pair to be used for roll attitude control in RCS DAP. +1: B-D quad -4096: A-C quad			2 <sup>+14</sup>
ADB	Attitude error deadband	deg	rev	2 <sup>-1</sup>
AK AK1 AK2	Attitude errors	deg	rev	2 <sup>-1</sup>
AMGB1 AMGB4 AMGB5 AMGB7 AMGB8	Matrix elements which are used by RCS DAP to transform information from gimbal to control axes.			2 <sup>0</sup>
CDUXCMD CDUYCMD CDUZCMD	Value to be transmitted to CDU IMU error counters and/or to FDAI needles.	deg	rev	2 <sup>+1</sup>
CDUXD CDUYD CDUZD	Values of desired DAP CDU angles for automatic maneuver.	deg	rev	2 <sup>-1</sup>
CPHI CTHETA CPSI	Noun 22: New ICDU angles and Noun 18: Ball angles auto maneuvers.	deg	rev	2 <sup>-1</sup>
DAPDATR1 DAPDATR2	see end of Erasable Locations			
DELCDUX <sub>D</sub>	CDUX change; calculated every decisecond.	deg	rev	2 <sup>-1</sup>
EDRIVEX EDRIVEY EDRIVEZ	Buffer register used in communicating DAP attitude errors to needles.	deg	rev	2 <sup>+1</sup>
HOLDFLAG	Controls nature of attitude hold performed by RCS DAP. =0: present CDU angles loaded into THETA D's for use as new attitude reference. =+0: DAP in attitude hold <0: automatic maneuvers			2 <sup>+14</sup>
IAVG	Average moment of inertia about y and z axes	kg·m <sup>2</sup>	kg·m <sup>2</sup>	2 <sup>+20</sup>
IAVG/TLX	IAVG/("thrust moment")	sec <sup>2</sup>	sec <sup>2</sup>	2 <sup>+2</sup>
IXX	Moment of inertia about x axis	kg·m <sup>2</sup>	kg·m <sup>2</sup>	2 <sup>+20</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. E. Euter</i> 11/24/63		DAP Interface and Service Routines	
PRGMR <i>J. F. Rasmussen</i>		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2370
DOCMR <i>Roberto M. Euter</i> 11/24/63		REV 2	SHEET 32 OF 34
APPR'D <i>Roberto M. Euter</i> 11/24/63			



## ERASABLE LOCATIONS USED

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scaling
J/M J/M1 J/M2	S/C inertia to torque ratio - x axis S/C inertia to torque ratio - y axis S/C inertia to torque ratio - z axis	(deg/dec-sec-csec <sup>-1</sup> )	(rev/dec-sec-csec)	2 <sup>+23</sup>
KMJ KMJ1 KMJ2	S/C torque to inertia ratio - x axis S/C torque to inertia ratio - y axis S/C torque to inertia ratio - z axis	deg/dec-sec	rev/dec-sec	2 <sup>-13</sup>
KTLX/I	K: DAP gain factor T: thrust LX: distance from engine gimbal point to c. g. of vehicle I: average of moments of inertia about pitch and yaw axes	deg	rev	CSM/LM: 2 <sup>+2</sup> x 1. 07975 CSM: 2 <sup>+4</sup> x 1. 07975
PMANNDX	Pitch decode stick command (bits 2, 1) = 0, 0 = no maneuver 0, 1 = positive maneuver 1, 0 = negative maneuver 1, 1 = no maneuver			2 <sup>+14</sup>
RACFAIL	A-C Quad Failures (see DAPDATR2 bits 10, 4)			2 <sup>+14</sup>
RBDFAIL	B-D Quad Failures (see DAPDATR2 bits 7, 1)			2 <sup>+14</sup>
RMANNDX	Roll decode stick command (see PMANNDX above)			2 <sup>+14</sup>
THETADX THETADY THETADZ	CDU angles in DAP used for attitude errors.	deg	rev	2 <sup>-1</sup>
VARX	Variable gain (for pitch and yaw)	deg/deg	rev/rev	CSM/LM: 2 <sup>+2</sup> x 1. 07975 CSM: 2 <sup>+4</sup> x 1. 07975
WBODY <sub>D</sub>	Desired angular rates	deg/dec-sec	rev/dec-sec	2 <sup>-3</sup>
XTRANS	Used with DAPDATR1, bits 10, 7 +1: use B-D quad for x translations. -1: use A-C quad for x translations. 0: use both quads for x translations.			2 <sup>+14</sup>
YMANNDX	Yaw decode stick command (see PMANNDX above)			2 <sup>+14</sup>
1/CONACC	Reciprocal of roll axis acceleration	(deg/sec) <sup>2-1</sup>	(rev/sec) <sup>2-1</sup>	2 <sup>+9</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION:	
DRAWN <i>R. Hunter</i> 11/24/67		DAP Interface and Service Routines	
PRGMR <i>J. E. McLaughlin</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR <i>Robert M. Smith</i> 11/24/67		REV 2	SHEET 33 OF 34
APPR'D <i>Robert M. Smith</i> 11/24/67			

AGC Tsg	Meaning	Engineering Units	AGC Units	AGC Scaling
DAPDATR1 bit 15-13	Specifies vehicle configuration and desire DAP 0: no DAP 1: CSM alone 2: CSM and LM 3: Saturn DAP 6: CSM and LM (ascent)			
bit 10	1: allow use of A-C quad for x-translations			
bit 7	=1: allow use of B-D quad for x-translation If bits 10, 7=0, -0, allow use of both quads.			
bit 4	=0: narrow deadband (0.5°) =1: wide deadband (5.0°)			
bits 2, -1	= 0: 0.05 deg/sec = 1: 0.2 deg/sec = 2: 0.5 deg/sec = 3: 2.0 deg/sec			
DAPDATR2	Control for RCS DAP			
bit 13	=0: B-D roll =1: A-C roll			
bit 10	=1: quad A may be used =0: quad A may not be used			
bit 7	=1: quad B may be used =0: quad B may not be used			
bit 4	=1: quad C may be used			
bit 1:	=1: quad D may be used			

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>G. Hunter</i>	<i>V. J. ...</i>	DAP Interface and Service Routines	
PRGMR <i>F. ...</i>		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCHR <i>B. ...</i>	<i>11/16/67</i>	REV 2	SHEET 34 OF 34
APPR'D <i>Roberts</i>	<i>11/21/67</i>		

RCS DAP INITIALIZATION AND PHASE 1

THE ENCLOSED SHEETS UPDATE THE COLOSSUS II  
FLOWCHART FC-2380, REV. 0, TO THE COLOSSUS IIA  
FLOWCHART FC-2380, REV. 1.

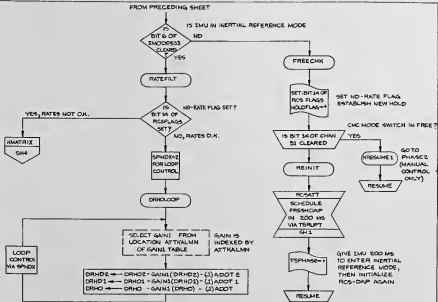
IN ADDITION, THE SHEETS HAVE BEEN RENUMBERED  
TO INCLUDE A TITLE SHEET.

EFFECTIVE SHEETS FOR COLOSSUS IIA FC-2380,  
REV. 1 ARE:

SH. 1	REV. 1
SH. 2-5	REV. 0
SH. 6	REV. 1
SH. 7-8	REV. 0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFIELD GUIDANCE AND NAVIGATION	
		RCS DAP	
DRAWN <i>of an Amos</i>		WULF	INITIALIZATION AND PHASE 1
FIGMR <i>J. F. ...</i>	WULF	DOCUMENT NO.	
ANALST		COLOSSUS II-A	FC-2380
DOCMR <i>Alvin ...</i>		REV 1	SHEET 1 OF 8
APPR'D <i>Alvin ...</i>			





RATE ESTIMATION EQUATIONS

ESTIMATED RATE AT TIME  $T_2$ :

$$\hat{w}(T_2) = \hat{w}(T_1) + \int_{T_1}^{T_2} \mu(T) dT + W_2(T_2) \rho(T_2)$$

WHERE  $\rho(T_1) = \hat{w}(T_1) - \hat{w}(T_1)$  THE DIFFERENCE

BETWEEN MEASURED AND ESTIMATED ATTITUDE

ANGLES AT TIME  $T_1$ .

$$\rho(T_2) = \rho(T_1) + W_2(T_2) \rho(T_1) - \hat{w}(T_2) \Delta T + \int_{T_1}^{T_2} \mu(T) dT + C \Delta T$$

WHERE  $\int \mu(T) dT = C \Delta T$

$\hat{w}$  = ADOT

$\rho$  = DRHO

$W_2$  = GAIN1

$W_1$  = GAIN2

$\mu(T_1)$  = COU

$\hat{w}(T_1)$  = RHO

$C = KMJ$

$\Delta T = DFT$

RHO ← COU      SAVE CURRENT COU ANGLES FOR NEXT CYCLE  
RHO1 ← COU1  
RHOZ ← COU2

DELTEMPX ← (COU1 - RHOZ) + ANGDIS (COU1 - RHOZ)  
DELTEMPY ← ANGDIS (COU2 - RHOZ) + ANGDIS (COU2 - RHOZ)  
DELTEMPZ ← ANGDIS (COU3 - RHOZ) + ANGDIS (COU3 - RHOZ)

DRHO ← DRHO - GAIN1 (DRHOZ) - (I) ADOT E  
DRHO1 ← DRHO1 - GAIN1 (DRHOZ) - (I) ADOT L  
DRHO ← DRHO - GAIN2 (DRHOZ) - (I) ADOT

DRHO ← DRHO + DELTEMPX  
DRHO1 ← DRHO1 + DELTEMPY  
DRHOZ ← DRHOZ + DELTEMPZ

MERRORX ← MERRORX + DELTEMPX  
MERRORY ← MERRORY + DELTEMPY  
MERRORZ ← MERRORZ + DELTEMPZ

ADOT ← ADOT + GAIN2 (DRHOZ) + KMJ1 (DFT)  
ADOT1 ← ADOT1 + GAIN2 (DRHOZ) + KMJ1 (DFT1)  
ADOTE ← ADOTE + GAIN2 (DRHOZ) + KMJ2 (DFT2)

GIVE IMU 300 MS TO ENTER INERTIAL REFERENCE MODE, THEN INITIALIZE FCS-DMP AGAIN

UPDATE DRHO BY A COU ANGLES  
UPDATE ATTITUDE ERROR BY A COU ANGLES  
CALCULATE ESTIMATED BODY RATES

NEXT SHEET

REPURPOSE: I/A	DATE: 11/11/83
CHANGED BY: M.H.	INITIALIZED BY: M.H.
REVISION: 1	DATE: 11/11/83
REVISION: 2	DATE: 11/11/83
REVISION: 3	DATE: 11/11/83
REVISION: 4	DATE: 11/11/83
REVISION: 5	DATE: 11/11/83
REVISION: 6	DATE: 11/11/83
REVISION: 7	DATE: 11/11/83
REVISION: 8	DATE: 11/11/83
REVISION: 9	DATE: 11/11/83
REVISION: 10	DATE: 11/11/83
REVISION: 11	DATE: 11/11/83
REVISION: 12	DATE: 11/11/83
REVISION: 13	DATE: 11/11/83
REVISION: 14	DATE: 11/11/83
REVISION: 15	DATE: 11/11/83
REVISION: 16	DATE: 11/11/83
REVISION: 17	DATE: 11/11/83
REVISION: 18	DATE: 11/11/83
REVISION: 19	DATE: 11/11/83
REVISION: 20	DATE: 11/11/83
REVISION: 21	DATE: 11/11/83
REVISION: 22	DATE: 11/11/83
REVISION: 23	DATE: 11/11/83
REVISION: 24	DATE: 11/11/83
REVISION: 25	DATE: 11/11/83
REVISION: 26	DATE: 11/11/83
REVISION: 27	DATE: 11/11/83
REVISION: 28	DATE: 11/11/83
REVISION: 29	DATE: 11/11/83
REVISION: 30	DATE: 11/11/83
REVISION: 31	DATE: 11/11/83
REVISION: 32	DATE: 11/11/83
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REVISION: 44	DATE: 11/11/83
REVISION: 45	DATE: 11/11/83
REVISION: 46	DATE: 11/11/83
REVISION: 47	DATE: 11/11/83
REVISION: 48	DATE: 11/11/83
REVISION: 49	DATE: 11/11/83
REVISION: 50	DATE: 11/11/83

FROM PRECEDING SHEET

KMATRIX

IS THIS THE TENTH PASS SINCE THE LAST MATRIX UPDATE ?

IS  
ATTSEC  
= 0?

YES

ATTSEC ← ATTSEC - 1  
DECREMENT  
COUNTER

AMBUPT  
SCHEDULE  
MATRIX UPDATE  
AS NOVACJOB  
WITH PRIO 34  
FC-2370

UPDATE MATRIX FOR  
TRANSFORMATION OF  
GIMBAL ANGLES  
TO S/C CO-ORDINATE  
ANGLES.

ATTSEC ← 9  
INITIALIZE COUNTER

TENTHSEK

AUTOMATIC MANEUVERS?

IS  
HOLDFLAG =  
- ?

NO

DCDUINCR

SPNDX ← 2  
FOR  
LOOP  
CONTROL

DE LOOP

LOOP  
CONTROL  
VIA  
SPNDX

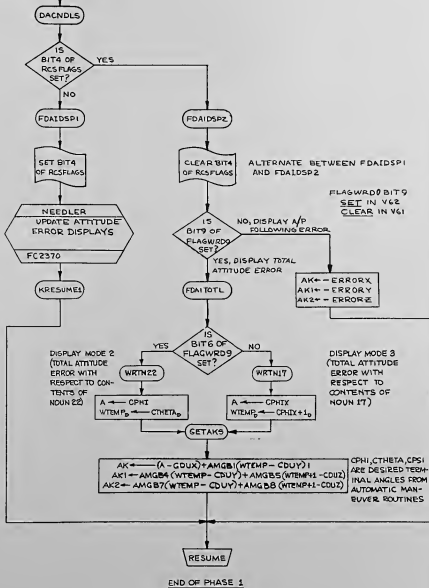
THETADE ← CDUX + DELCDUX  
CDUZD ← THETADE  
THETADY ← CDUY + DELCDUY  
CDUYD ← THETADY  
THETADX ← CDUX + DELCDUX  
CDUXD ← THETADX

ON AUTOMATIC MANEUVERS ADD ΔCDU  
ANGLES TO DESIRED ANGLES TO GET  
NEW DESIRED ANGLES.  
STORE IN THETADY, THETADE, AND THETADE  
FOR USE BY AUTOPILOT ATTITUDE ERROR  
LOGIC

TO NEXT PAGE

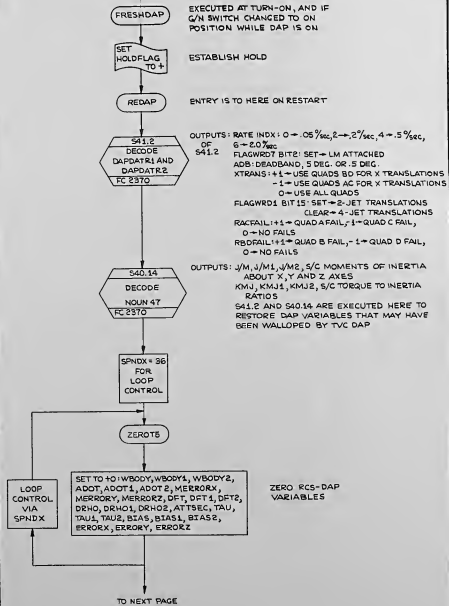
MIT INSTRUMENTATION LAB CAMBRIDGE MASS		FC-2380 INITIALIZATION AND PHASE 1	
DESIGNED BY <i>John P. ...</i>	DESIGNED BY <i>John P. ...</i>	FC-2380 INITIALIZATION AND PHASE 1	
APPROVED BY <i>John P. ...</i>	APPROVED BY <i>John P. ...</i>	COLOSSUS IIA	FC-2380
REV 1		REV 1	

FROM PRECEDING PAGE



	INT	APOLLO
	INSTRUMENTATION LAB	GUIDANCE AND NAVIGATION
	CAMBRIDGE, MASS.	
		RCS DAP
		INITIALIZATION AND PHASE 1
DESIGN	F. Rogers to B-29-2	
PROB	J. W. Kite to B-29-2	
		INCIDENT NO.
DECL	J. A. Moore to B-29-2	COLOSSUS IIA
		FC2380
USED ON	APPROV. J. W. Kite to B-29-2	REV 1
		SHEET 5 OF 8

# DAP INITIALIZATION



EXECUTED AT TURN-ON, AND IF G/N SWITCH CHANGED TO ON POSITION WHILE DAP IS ON

ESTABLISH HOLD

ENTRY IS TO HERE ON RESTART

OUTPUTS: RATE INDX: 0 -> .05%/sec, 2 -> .2%/sec, 4 -> .5%/sec, 6 -> 2.0%/sec  
 OF S41.2  
 FLAGWRD7 BIT5: SET -> LM ATTACHED  
 ADB: DEADBAND, 5 DEG. OR .5 DEG.  
 XTRANS: +1 -> USE QUADS BD FOR X TRANSLATIONS  
 -1 -> USE QUADS AC FOR X TRANSLATIONS  
 0 -> USE ALL QUADS  
 FLAGWRD1 BIT15: SET -> 2-JET TRANSLATIONS  
 CLEAR -> 4-JET TRANSLATIONS  
 RACFAIL: +1 -> QUAD A FAIL, -1 -> QUAD C FAIL,  
 0 -> NO FAILS  
 RBDFAIL: +1 -> QUAD B FAIL, -1 -> QUAD D FAIL,  
 0 -> NO FAILS

OUTPUTS: J/M, J/M1, J/M2, S/C MOMENTS OF INERTIA ABOUT X, Y AND Z AXES  
 KMJ, KMJ1, KMJ2, S/C TORQUE TO INERTIA RATIOS  
 S41.2 AND S40.14 ARE EXECUTED HERE TO RESTORE DAP VARIABLES THAT MAY HAVE BEEN WALLOPED BY TVC DAP

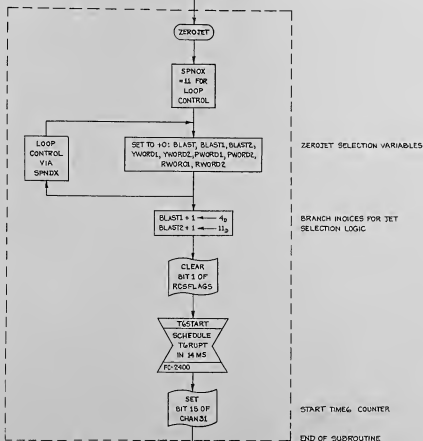
ZERO RCS-DAP VARIABLES

TO NEXT PAGE

NET INVESTIGATION LAB CAMBRIDGE, MASS.		RCS DAP INITIALIZATION AND PHASE 1
DRAWN BY DESIGNED BY ANALYST CHECKED BY APPROVED BY	IS-11460 11/18 11/18 11/18 11/18	COLLOSSUS IIA FC-2380 REV 1 6 8



FROM PRECEING PAGE



ZEROJET SELECTION VARIABLES

BRANCH INDICES FOR JET SELECTION LOGIC

START TIME6 COUNTER

END OF SUBROUTINE

CHANTEMP ← -0  
CH31TEMP ← -0  
SLOPE ← .24  
TSTIME ← 40 MS  
ATTKALMN ← 11p

MINIMUM IMPULSE COMMANDS  
RRC COMMANDS  
SWITCHING LOGIC SLOPE  
DELAY TIME \*  
INITIATE KALMANN FILTER GAINS

\* TIMING LOGIC

1. PHASE 2 BEGINS IN 60MS (SEE NEXT SHEET)
2. PHASE 2 SUBTRACTS TSTIME FROM 80MS AND SETS PHASE 1 TO BEGIN AT THAT TIME.
3. THUS PHASE 1 BEGINS (80-40)=40MS AFTER PHASE 2.
4. AND PHASE 1 BEGINS (40+40)=100MS AFTER INITIAL PHASE SO THAT THE 0.1 SEC FILTER SAMPLE TIME AND 1.0 SEC MATRIX UPDATING ARE CORRECTLY TIMED.

NEXT PAGE

W-1 INSTRUMENTATION LAB CAMBRIDGE MA 5.	REVISED C. JOYAN AND S. W. PATTON
DRAWN A.C. WILLIAMS PROGRAM <i>P. Lumball</i> ANALYST <i>G. Brown</i> APPROVED <i>G. Brown</i>	RCS DAP INITIALIZATION AND PHASE 1 COLLOSSUS IIA FC-2380 7 8

FROM PRECEDING SHEET

$RHO \leftarrow CDUK$   
 $RHO1 \leftarrow CDUY$   
 $RHO2 \leftarrow CDUZ$

OUTER GIMBAL ANGLE  
 INNER GIMBAL ANGLE  
 MIDDLE GIMBAL ANGLE

INITIAL VALUES FOR RATE FILTER

SET  
TSPHASE  
TO +

PHASE 2

IS  
BIT 6 OF  
IMODES 33  
CLEARED?

IS IMU IN INERTIAL REFERENCE MODE?

NO

IMUADK

AMBCUPDT  
(PRIO 34)  
SCHEDULE  
MATRIX UPDATE  
FC 2370

INITIALIZE TRANSLATION MATRIX  
CDU ANGLES TO S/C COORDINATES

$A \leftarrow RCSINIT$  (TO SET RCSFLAGS)

$A \leftarrow RCSINIT$  (TO SET  
RCSFLAGS)

STEP RATE  
FILTER SO  
MANUAL  
COMMANDS  
WILL OPERATE  
WITHOUT 1.1  
DELAY FOR  
INITIALIZATION

RCSWIT

$RCSFLAGS \leftarrow A$

IF IMU IN FINE ALIGN, BIT 14 - CLEAR  
IF IMU NOT IN FINE ALIGN, BIT 14 - SET  
IN EITHER CASE:  
BIT 1 - CLEAR: INITIALIZE TS PROGRAM  
BIT 3 - SET: INITIALIZE NEEDLES  
BIT 4 - CLEAR: FDAIDSP1

RCSATT  
SCHEDULE  
PHASE 2 IN  
60 MS VIA  
TS RUPT  
SH 1

RESUME

END OF FRESHDAP

15 JAN 69 COLLOSSUS IIA FC-2380 0 0 0	RCS DAP INITIALIZATION AND PHASE 1 COLLOSSUS IIA FC-2380 0 0 0
--	--

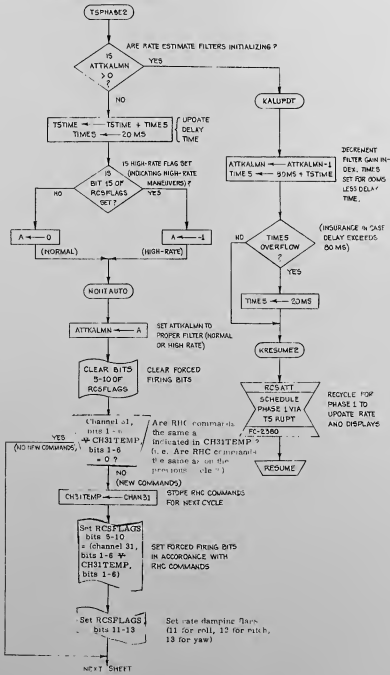
RCS DAP - Phase 2

T5 PHASE 2 Sh. 2

Special Convention:  $\nabla$  indicates "exclusive or" operation.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. L. ...</i>		RCS DAP Phase 2	
PRGMR <i>D. L. ...</i>		COLOSSUS 2D	DOCUMENT NO. FC-2390
ANALST			
DOCMR <i>Robert M. ...</i>		REV 1	SHEET 1 OF 12
APPR'D <i>Robert M. ...</i>			

# RCS-DAP PHASE 2

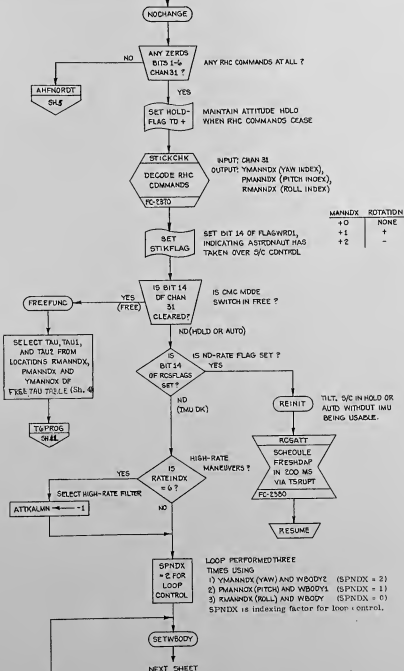


A C WILLIAMS  
*John Ball*  
 COLUSSUS 21

RCS DAP  
 PHASE 2

FC-2390

FROM PRECEDING SHEET



MANNDX	ROTATION
+0	NONE
+1	+
+2	-

LOOP PERFORMED THREE TIMES USING  
 1) YMANNDX (YAW) AND WBODY2 (SPNDX = 2)  
 2) PMANNDX (PITCH) AND WBODY1 (SPNDX = 1)  
 3) RMANNDX (ROLL) AND WBODY (SPNDX = 0)  
 SPNDX is indexing factor for loop control.

FROM SHEET 4

A. C. WILLIAMS 347445  
*[Signature]*  
 14 APR 68

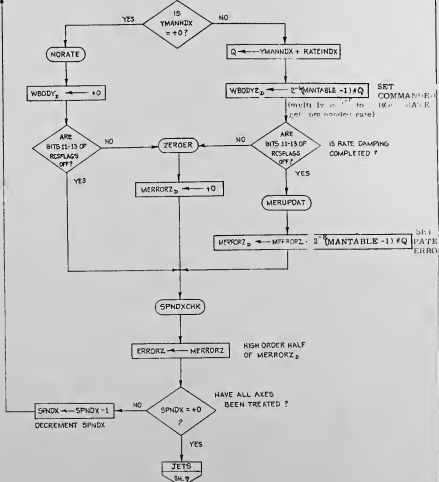
RCS DAP  
 PHASE 2

COLDSSUS 21)

FC-2390

TO SHEET 3

FROM PRECEDING SHEET



FREEZE TABLE

RVA ← DX  
PVA ← DX  
MANNDX

FREEZE  
+1  
+2  
+3  
-3

+1 sec.  
+1.16 sec.  
-1.16 sec.  
0 sec.

A  
A 1  
A 2

A C WILLIAMS

152445

*John Williams*

*1/2/68*

*1/2/68*

*1/2/68*

RLE TAP  
PVA ← C

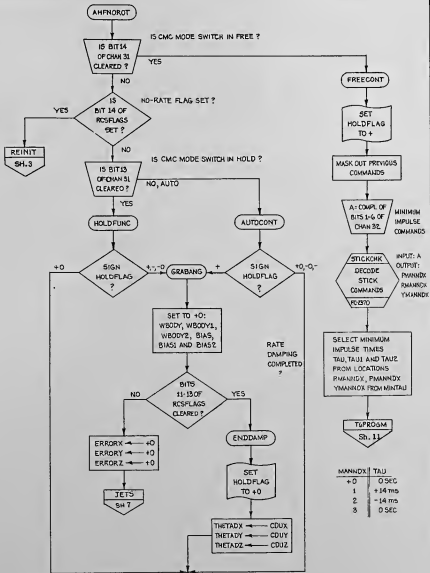
COLLECTOR 23)

FC-2390

1

4

12



NEXT SHEET

WIT  
 REPRESENTATION  
 WMB:DC WMB  
 A.C. WILLIAMS  
 J. J. Gorman  
 J. J. Gorman  
 J. J. Gorman

COLLOSSUS 211  
 RCS DAP  
 PHASE 2  
 FC-2390  
 5 12

FROM PRECEDING SHEET

ATTHOLD

$ERRDRX \leftarrow (CDUX - THETADX) + AMGB1(CDUY - THETADY)$  ROLL ERROR } RESOLVED INTO  
 $ERRDRY \leftarrow AMGB4(CDUY - THETADY) + AMGB5(CDUZ - THETADZ)$  PITCH ERROR } VEHICLE CO-ORDINATES  
 $ERRDRZ \leftarrow AMGB7(CDUY - THETADY) + AMGB6(CDUZ - THETADZ)$  YAW ERROR } VIA KMATRIX (p. 11)

AUTOMATIC MANEUVERS ?

IS  
HOLDFLAG  
= - ?

NO

YES

$ERRDRX \leftarrow ERRDRX + BIAS$   
 $ERRDRY \leftarrow ERRDRY + BIAS1$   
 $ERRDRZ \leftarrow ERRDRZ + BIAS2$  ADD IN BIASES  
(BIASES COMPUTED IN  
KALCMANU)

NEXT SHEET

RCS DAP  
PHASE 2

COLLOSSUS 21

FC-2390

6 12



FROM PRECEDING PAGE

JETS

T5 TEMP ← ADB + .044°

SPNDY ← 2  
FOR  
LOOP  
CONTROL

JLOOP

EDDT<sub>dp</sub> ← ADOT<sub>2dp</sub>

IS  
HOLDFLAG  
= 10?

YES

NO

EDDT<sub>dp</sub> ← EDDT<sub>dp</sub> - WBODY<sub>2dp</sub>

INHOLD

AERR ← ERROR<sub>Z</sub> S/C ATTITUDE ERROR

≤ 0

≥ 0

SIGN  
EDDT?

NEGVEL

POSVEL

EDDTVEL ← -EDDT  
ADBVVEL ← -T5TEMP  
AERRVEL ← -AERR

EDDTVEL ← EDDT  
ADBVVEL ← T5TEMP  
AERRVEL ← AERR

TO NEXT PAGE

DEADBAND + FLAT REGION

INDEXED VARIABLES IN JLOOP

PASS 1	PASS 2	PASS 3
ADOT <sub>2dp</sub>	ADOT <sub>1dp</sub>	ADOT <sub>dp</sub>
WBODY <sub>2dp</sub>	WBODY <sub>1dp</sub>	WBODY <sub>dp</sub>
ERROR <sub>Z</sub>	ERRDRY	ERRORX
TAU <sub>Z</sub>	TAU <sub>1</sub>	TAU
J/M <sub>Z</sub>	J/M <sub>1</sub>	J/M

JLOOP IS EXECUTED ONCE FOR EACH AXIS

S/C ANGULAR RATE (ESTIMATE)

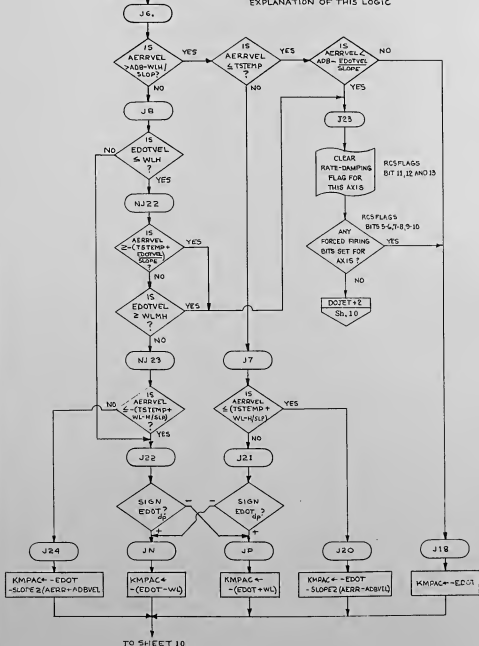
INCLUDE AUTOMATIC MANEUVER RATES

SINCE THE PHASE PLANE IS SYMMETRIC ABOUT THE ORIGIN, THE RATE IS TAKEN AS POSITIVE AND THE SIGNS OF EDDT, T5TEMP AND AERR ADJUSTED ACCORDINGLY. THE SUFFIX "VEL" IN THE MNEMONIC DESIGNATES THE ADJUSTED VALUES.

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP PHASE 2
WRITTEN BY <i>W. R. ...</i>	8-25-61	DOCUMENT NO. FC 2390
PROGRAMMER <i>W. R. ...</i>	8-28-61	
DOC. NO. <i>11-11-61</i>	<i>10-11-61</i>	COLLOSSUS 213
USED ON	APPEL'S <i>P. ...</i>	REV 1
		SHEET 7 OF 12

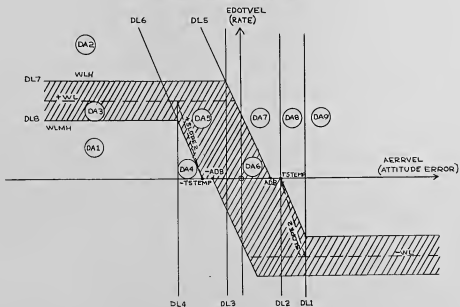
FROM PRECEDING PAGE

SEE NEXT SHEET FOR  
EXPLANATION OF THIS LOGIC



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>Z. Berman</i> 8-24-67		RCS DAP PHASE 2	
PROGRAM <i>E. P. ...</i> 8-11-67		DOCUMENT NO. FC 2390	
DESIGN <i>J. G. ...</i> 8-11-67		COLOSSUS 211	SHEET 8 OF 12
USED ON	APPROV. <i>J. Hoyle</i> 8-11-67	REV 1	

## PHASE PLANE LOGIC



## DECISION LOGIC

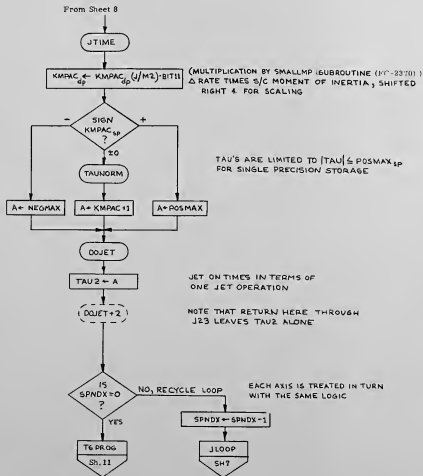
DECISION LINE (DL) ON GRAPH	1	2	3	4	5	6	7	8
DECISION POINT IN LOGIC	J7	J6+1	J6	NJ23	J6+2	NJ22	J8	NJ22+1
OUTCOME { LOGICAL "YES" / LOGICAL "NO" }	LEFT / RIGHT	LEFT / RIGHT	RIGHT / LEFT	LEFT / RIGHT	LEFT / RIGHT	RIGHT / LEFT	BELOW / ABOVE	ABOVE / BELOW

## LOGICAL PATHS

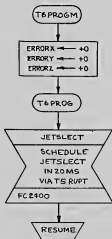
DECISION AREA (DA)	LOGICAL PATHS	RESPONSE
DA1	J6 - J8 - NJ22 - NJ22 + 1 - NJ23 - J22 →	DRIVE RATE TO +WL
DA2	J6 - J8 - J22 →	DRIVE RATE TO +WL
DA3	J6 - J8 - NJ22 - NJ22 + 1 - J23 →	NO ACTION*
DA4	J6 - J8 - NJ22 - NJ22 + 1 - NJ23 - J24 →	DRIVE RATE TO +SLOPE 2
DA5	J6 - J8 - NJ22 - J23 →	NO ACTION*
DA6	J6 - J6+1 - J6+2 - J23 →	NO ACTION*
DA7	J6 - J6+1 - J6+2 - J19 →	DRIVE RATE TO ZERO
DA8	J6 - J6+1 - J7 - J20 →	DRIVE RATE TO -SLOPE 2
DA9	J6 - J6+1 - J7 - J21 →	DRIVE RATE TO -WL

\* IF THERE ARE ANY RHC COMMANDS,  
THEN THE RATE IS DRIVEN TO ZERO  
BEFORE EXECUTION OF THE COMMANDS.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		RCS DAP PHASE 2	
BRANCH <i>J. H. ...</i>	E-28-C	DOCUMENT NO.	
PROGRAM <i>J. H. ...</i>	2-16-57	FC2390	
DOC# <i>J. H. ...</i>	11/6/57	COLDSBUS 2D	
USED ON <i>APPS</i>	<i>11-11-57</i>	REV 1	SHEET 9 OF 12



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
		RCS DAP PHASE 2	
DRAWN <i>J. W. Hesse</i>	8-28-60	DOCUMENT NO.	
FROM <i>J. W. Hesse</i>	8-28-60	FC2390	
DOCTR <i>J. W. Hesse</i>	10-6-60	COLOSSUS 21)	
APPR'D <i>J. Hesse</i>	10-18-60	REV 1	SHEET 10 OF 12
USED ON			



ZERO ATTITUDE ERROR IF IN  
FREE MODE, OR IF MANUAL COMMANDS  
ARE BEING RECOGNIZED

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
		RCS DAP PHASE 2	
	DRAWN <i>J. Kannon</i> 11-10-64		DOCUMENT NO.
	PROGRAM <i>N. Kannon</i> 11-15-64	COLOSSUS 211	FC2390
	DESIGN <i>J. Kannon</i> 10-14-64		
USED ON	APPROVED <i>J. Kannon</i> 10-14-64	REV 1	SHEET 11 OF 12

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

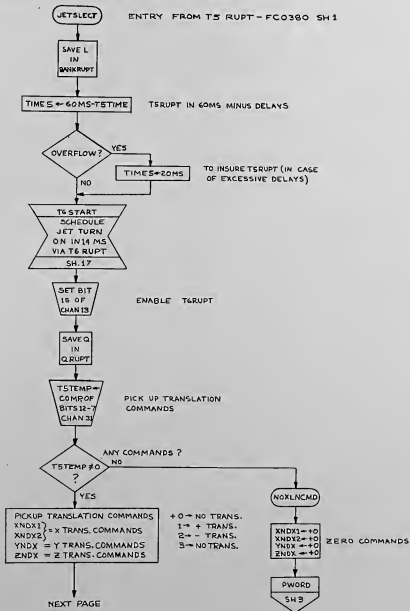
Subroutine Name	Where Flowed	Description	Where Called
JETSLECT	FC-2400	Entry to RCS DAP jet selection logic	Sh. 11
KMATRIX	FC-2380	Resolve roll, pitch, & yaw errors into vehicle co-ordinates	Sh. 6
RCSATT	FC-2380	Entry to Phase 1	Sh. 2, 3
SMALLMP	FC-2370	One and one-half precision multiplication	Sh. 10
STICKCHK	FC-2370	Decode RHC commands	Sh. 3, 5

FLAG

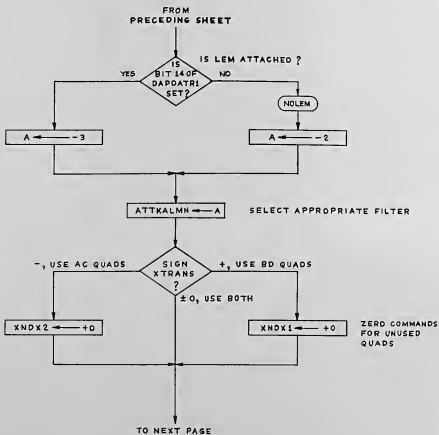
Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
STKFLAG flagword 1 bit 14	RHC control	CMC control	Sh. 3		

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. L. ...</i>		RCS DAP - Phase 2	
FROM <i>...</i>		DOCUMENT NO	
ANALYST <i>...</i>		FC-2390	
DOOR <i>...</i>		COLOSSUS 2D	REV 1
APPROV <i>...</i>		SHEET 12 OF 12	

# RCS-DAP JET SELECTION LOGIC

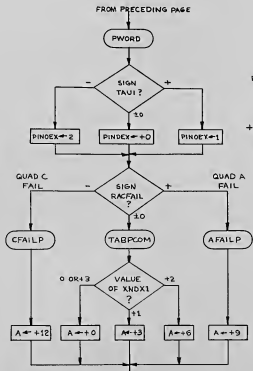


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGN <i>J. N. Moore</i> 8-27-66		RCS DAP JET SELECTION LOGIC	
PROJECT <i>J. N. Moore</i> 10-14-66		DOCUMENT NO. FC 2400	
DCCM <i>J. N. Moore</i> 11-16-66		COLOSSUS II	
APPROV <i>J. N. Moore</i> 11-16-66		SHEET 1 OF 19	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		47701 GUIDE AND WALSH	
DRAWN <i>A. J. Smith</i>	ISJAN	RCS DAP JET SELECTION LOGIC	
PROGRAM <i>J. G. Smith</i>	2/19/58	COLOSSUS	
ANALY <i>A. J. Smith</i>	2/19/58	II	
DOCUMENT <i>A. J. Smith</i>	2/19/58	FC-2400	
APPROV	REV	SHEET 2 OF 10	





PITCH COMMANDS

- +0 → NO PITCH
- 1 → + PITCH
- 2 → - PITCH

- +0 → NO FAILS, NO TRANSLATIONS
- 3 → NO FAILS, + TRANSLATIONS
- 6 → NO FAILS, - TRANSLATIONS
- 9 → QUAD A FAIL, IGNORE TRANSLATIONS
- 12 → QUAD C FAIL, IGNORE TRANSLATIONS

SELECT PWORD1 FROM LOCATION (A + PINDEX) OF PYTABLE BITS 10,9 AND 4-1

BITS 2,1 OF NPJETS ← BITS 10,9 OF PWORD1

NUMBER OF PITCH JETS

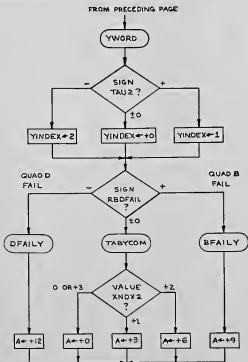
TO NEXT PAGE

PYTABLE - PITCH COMMANDS

A	PINDEX	BITS10,9 ← JETS FOR ROT.	BIT4	BIT3	BIT2	BIT1	ROT.	TRANS.
		JET2	JET3	JET4	JET1			
0	0	0	0	0	0	0	0	0
0	1	2	0	1	0	1	+	0
0	2	2	1	0	1	0	-	0
3	0	0	1	0	0	1	0	+
3	1	1	0	0	0	1	+	+
3	2	1	1	0	0	0	-	+
6	0	0	0	1	1	0	0	-
6	1	1	0	1	0	0	+	-
6	2	1	0	0	1	0	-	-
9	0	0	0	0	0	0	0	0
9	1	1	0	0	0	1	+	* (+)
9	2	1	0	0	1	0	-	* (-)
12	0	0	0	0	0	0	0	0
12	1	1	0	1	0	0	+	* (-)
12	2	1	1	0	0	0	-	* (+)

\* IN THE CASE OF A OR C FAILS, THESE 1-JET ROTATIONS WILL CAUSE TRANSLATIONS WHICH MAY OR MAY NOT CO-INCIDE WITH THE ACTUAL TRANSLATION COMMANDS, WHICH ARE IGNORED.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARLCO GUIDANCE AND NAVIGATION	
		RCS DAP JET SELECTION LOGIC	
SEARCHED <i>J. R. ...</i>	INDEXED <i>...</i>	ODDNESS II	DOCUMENT NO. FC2400
DISCAR <i>J. G. ...</i>	APPROV <i>J. ...</i>	REV	SHEET 3 OF 19

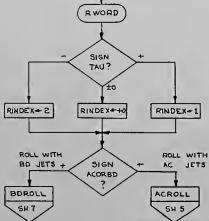


YAW COMMAND

IDENTICAL LOGIC TO ABOVE PITCH JET SELECTION. BITS 12, 11 INDICATE # OF JETS FOR ROTATION. BITS 8-5 INDICATE JETS SELECTED AS FOLLOWS:

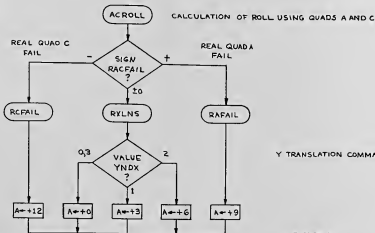
BIT 8 - JET 6  
 BIT 7 - JET 7  
 BIT 6 - JET 8  
 BIT 5 - JET 5

NUMBER OF YAW JETS



ROLL COMMAND

BIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY <i>R. J. Ryan</i> 6-27-61 CHECKED BY <i>R. W. Kane</i> 8-14-61		RES DAP JET SELECTION LOGIC	
DESIGNED BY <i>J. J. Moran</i> 8-2-61 APPROVED BY <i>J. Moran</i> 11-18-61		COLOSSUS II	DOCUMENT NO. FC 2400
USED ON	APPROVED BY	REV	SHEET 4 OF 19



Y TRANSLATION COMMANDS

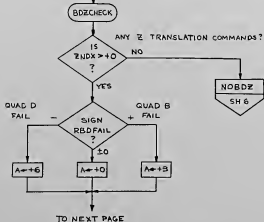
RTABLE

TABRCOM

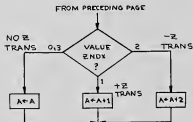
SELECT WORDS FROM LOCATION (A+RINDEY) OF RTABLE, BITS 11-9 AND 8-5

LOC	BITS 11-9	NET ROLL TORQUE	BIT8 JET8	BIT7 JET7	BIT6 JET6	BITS 8-5 JET5	ROLL	Y TRANS
0	010	0	0	0	0	0	0	0
1	100	+2	0	1	0	1	+	+
2	000	-2	1	0	1	0	-	+
3	010	0	1	0	0	1	0	0
4	011	+1	0	0	0	1	+	+
5	001	-1	1	0	0	0	-	+
6	010	0	0	1	1	0	0	-
7	011	+1	0	1	0	0	+	-
8	001	-1	0	0	1	0	-	-
9	010	0	0	0	0	0	0	0
10	011	+1	0	1	0	0	+	*
11	001	-1	1	0	0	0	-	*
12	010	0	0	0	0	0	0	0
13	011	+1	0	0	0	1	+	*
14	001	-1	0	0	1	0	-	*

\* IN CASE OF FAILS, 1 - JET ROTATIONS DO CAUSE TRANSLATIONS, BUT WITH NO CORRELATION TO THE COMMANDS.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARJOL GUIDANCE AND NAVIGATION	
DESIGNED BY <i>J. P. ...</i> 12-24-60		RCS DAP JET SELECTION LOGIC	
PROGRAMMED BY <i>J. N. ...</i> 12-24-60		COLLOSSUS II	
DOCUMENTED BY <i>J. A. ...</i> 12-26-60		MOVEMENT NO. <b>FC2400</b>	
USED ON <i>APPROX J. ...</i>		SHEET 5 OF 19	



A ← (QUADS B-0 Z TRANSLATION CODE) FROM LOCATION A OF YZ TABLE, BITS 11-9 AND 4-1

TSTEMP ← A + RWOR01  
BITS 3-1 OF NRJETS ← (BITS 11-9 OF TSTEMP) - 4

IS NRJETS = +0?

IF NRJETS = +0 AND TAU IS NOT = +0, TRANSLATIONS IN THE PRESENCE OF QUAD FAILS WILL CANCEL THE DESIRED ROLL, SO Z TRANSLATIONS MUST BE REJECTED

TAUCHECK

SIGN TAU?

ACRBOZ

RWOR01 ← TSTEMP

ROLLTIME

SH 9

ACCEPT Z TRANSLATION COMMANDS

YZ TABLE

LOC	BITS 11-9	NET ROLL TORQUE	BIT 4 JET10	BIT 3 JET11	BIT 2 JET12	BIT 1 JET9	QUAO FAIL	Z TRANS
0	010	0	0	0	0	0	0	0
1	010	0	1	0	0	1	0	+
2	010	0	0	1	1	0	0	-
3	010	0	0	0	0	0	B	0
4	001	-1*	1	0	0	0	B	+
5	011	+1*	0	1	0	0	B	-
6	010	0	0	0	0	0	D	0
7	011	+1*	0	0	0	1	D	+
8	001	-1*	0	0	1	0	D	-

\* THESE POSSIBLY UNWANTED TORQUES ARE HANDLED BELOW

ADD IN Z TRANSLATIONS.

BITS 9-11 = NET ROLL TORQUE + 4.

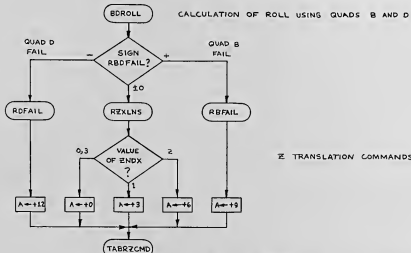
NOBDE

BITS 3-1 OF NRJETS ← (BITS 11-9 OF RWOR01) - 2

IGNORE TRANSLATIONS, REVISE NUMBER OF JETS.

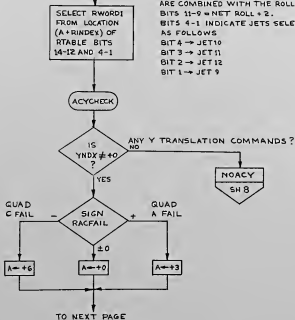
IF THIS HAPPENS, ASTRONAUT SHOULD CHANGE TO B-D ROLL SO THAT Z TRANSLATIONS CAN BE ACCOMMODATED IN THE PRESENCE OF QUAD FAILS

	BIT	APOLLO
	INSTRUMENTATION LAB	QUIBBANCE AND NAVIGATION
	CAMBRIDGE, MASS.	RCS DAP
		JET SELECTION LOGIC
DESIGNED BY	<i>R. B. ...</i>	DATE
PROGRAMMED BY	<i>J. B. ...</i>	DATE
TESTED BY	<i>J. B. ...</i>	DATE
APPROVED BY	<i>J. B. ...</i>	DATE
USED ON	APOLLO	REV
		SHEET 6 OF 19

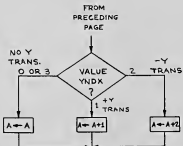


Z TRANSLATION COMMANDS

SAME LOGIC AS ABOVE EXCEPT THAT Z COMMANDS ARE COMBINED WITH THE ROLL COMMANDS.  
 BITS 11-9 = NET ROLL + 2.  
 BITS 4-1 INDICATE JETS SELECTED AS FOLLOWS  
 BIT 4 → JET 10  
 BIT 3 → JET 11  
 BIT 2 → JET 12  
 BIT 1 → JET 9



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
		RCS DAP JET SELECTION LOGIC	
DESIGN <i>F. P. ...</i> DRAWN <i>J. N. ...</i> CHECKED <i>J. N. ...</i> APP'D <i>J. N. ...</i>	8-31-60 8-14-60 10-16-60 10-16-60	COLUSSUS II	DOCUMENT NO. <b>FC2400</b>
USED ON APP'D <i>J. N. ...</i>	10-16-60	SHEET 7 OF 19	



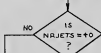
A ← AC QUADS Y  
TRANSLATION CODE  
FROM LOCATION  
A OF YZTABLE  
BITS 14-12 AND 8-5

SAME LOGIC AS ABOVE, BITS 14-11 =  
NET ROLL TORQUE +2, BITS 9-5 INDICATE  
JET COMMANDS AS FOLLOWS:

BIT 8 - JET 14  
BIT 7 - JET 15  
BIT 6 - JET 16  
BIT 5 - JET 13

TSTEMP ← A + RWORD1  
BITS 3-1 OF NRJETS  
+ (BITS 14-12  
OF TSTEMP) - 4

ADD IN Y TRANS. COMMANDS  
NET ROLL TORQUE



TAUCHCK

IGNORE TRANSLATIONS IF  
QUAD FAILS WOULD CAUSE  
CANCELLATION OF ROLL  
COMMANDS

NOACY



BDRACK

BITS 3-1 OF NRJETS  
← (BITS 14-12 OF  
RWORD1) - 2

IGNORE Y TRANSLATIONS  
REVISE NUMBER OF JETS.

RWORD1 + TSTEMP

ACCEPT Y  
TRANSLATION  
COMMANDS

IF THIS HAPPENS ASTRONAUT  
SHOULD CHANGE TO AC ROLL  
SO THAT Y TRANSLATIONS  
CAN BE ACCOMMODATED IN  
THE PRESENCE OF QUAD FAILS.

ROLLTIME

SH 9

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP JET SELECTION LOGIC
DESIGNED BY <i>F. P. ...</i>	DATE <i>8-1-67</i>	
PROGRAMMED BY <i>R. J. ...</i>	DATE <i>8-1-67</i>	
TESTED BY <i>H. L. ...</i>	DATE <i>8-1-67</i>	
USED ON	APPLY TO <i>FC 2400</i>	DOCUMENT NO. COLOSSUS II FC 2400
		SHEET 8 OF 19

NO ROLL SO RWORD1 HAS XLN'S ONLY, AND CAN BE TRANSFERRED INTACT TO RWORD2.

SELECT VALUE OF DFT FROM POSITION NRJETS IN DFTMAX TABLE

RBYPASS

RWORD2 ← RWORD1  
BLAST ← +0

PITCHTIM  
SH11

NET & ROLL RATE FOR RATE FILTER

ROLLTIME

ANY ROLL COMMANDS?

IS  
TAU ≠ +0 ?

RBLAST

SET VALUE OF NJET FROM POSITION NRJETS IN NJET TABLE  
BLAST ← TAU · NJET

BLAST = T / NUMBER OF JETS (JET ON TIME IN SECS.)

NJET TABLE	
POSITION	NJET
-3	-1/2
-2	-1/4
-1	-1
+0	0
1	1
2	+1/4
3	+1/2

ROLL JET ON - TIME

IS  
BLAST > .15 SEC ?

IS BLAST MORE THAN CYCLE TIME OF THE DAP?

ADI4 MSR

GET DFT FROM LOCATION NRJETS OF DFTMAX TABLE  
TAU ← TAU - DFT  
BLAST ← .15 SEC

UPDATE TAU BY ONE CYCLE TIME  
SET BLAST TO CYCLE TIME

IS  
BLAST < 14 MS ?

MINIMUM IMPULSE 14 MS TO INSURE RATE LIMIT CYCLE WILL BE REACHED

BLAST ← 14MS

RBLASTOK

DFTMAX TABLE	
LOCATION	DFT
-3	-.3 SEC
-2	-.2 SEC
-1	-.1 SEC
+0	0 SEC
+1	+ .1 SEC
2	.2 SEC
3	.3 SEC

DFT ← BLAST · NRJETS  
TAU ← +0

NET & ROLL (FOR RATE FILTER)

ASMBLWR

ANY Y TRANSLATION COMMANDS ?

IS  
YNDX = +0 ?

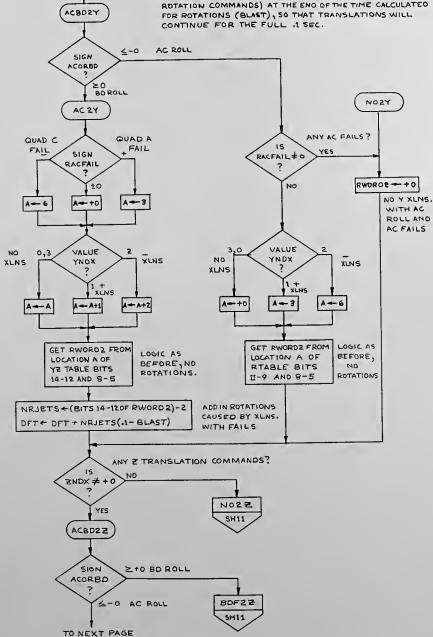
NOZY  
SH 10

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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGN <i>F. Benson</i> 10-24-67		RCS DAP JET SELECTION LOGIC	
PROGRAM <i>D. W. Koon</i> 10-11-67		DOCUMENT NO. COL05505 II FC2400	
DESIGNER <i>V. C. Davis</i> 10-24-67		SHEET 9 OF 19	
USER ON	APPROV <i>J. H. Hodge</i> 10-17-67	REV	

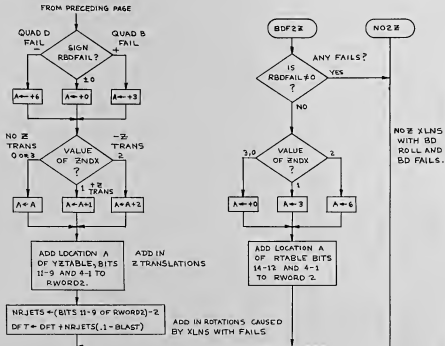
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RWORD2 IS CALCULATED FOR TRANSLATIONS WITHOUT ROTATIONS. IT WILL REPLACE WORD1 (WHICH INCLUDES ROTATION COMMANDS) AT THE END OF THE TIME CALCULATED FOR ROTATIONS (BLAST), SO THAT TRANSLATIONS WILL CONTINUE FOR THE FULL .1 SEC.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
BRANCH <i>F. Ramsey</i> <i>10-63</i>		RCS DAP JET SELECTION LOGIC	
PROGRAM <i>J. W. Sells</i> <i>10-10-61</i>		COLUSSUS II	
DESIGN <i>J. A. Sells</i> <i>10-11-61</i>		DOCUMENT NO.	FC2400
USED ON	APPROV'D <i>J. Sells</i> <i>10-11-61</i>	REV	SHEET 10 OF 19





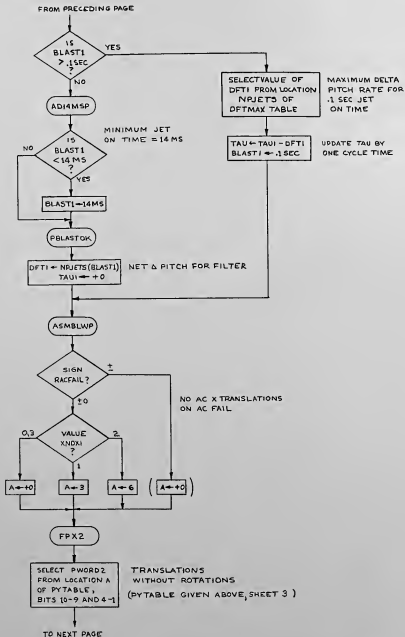
NPJETS WAS COMPUTED AS AN ABSOLUTE VALUE, NOW EQUALS NET TORQUE FACTOR.

NJET LOCATION	TABLE NJET
-3	-1/2
-2	-1/4
-1	-1
0	0
1	+1
2	+1/4
3	+1/2

BLAST =  $\tau$  / NUMBER OF JETS  
JET ON TIME IN SECS.

TO NEXT PAGE

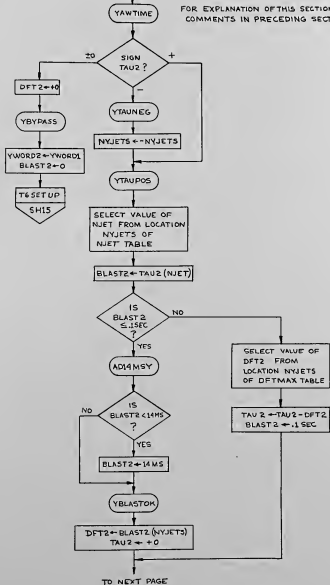
	BIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	DESIGNED BY <i>F. J. ...</i> 7-7-67	RCS DAP JET SELECTION LOGIC
	PROGRAMMED BY <i>F. J. ...</i> 8-11-67	DOCUMENT NO. FC2400
	RELEASED BY <i>J. A. ...</i> 11-16-68	COLOSSUS II
USED ON	APOLLO 7 <i>J. A. ...</i> 12-16-67 REV	SHEET 11 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARIEL GUIDANCE AND NAVIGATION	
		RCS DAP JET SELECTION LOGIC	
DESIGNED BY <i>P. Ragan</i>	9-1-67	COLOSSUS II	DOCUMENT NO. FC2400
PROGRAMMED BY <i>J. W. Hines</i>	10-15-67		
DESIGNED BY <i>J. J. Morris</i>	10-16-67		
USED ON <i>APPROX. 10-11-67</i>	<i>10-11-67</i>	SHEET 12 OF 19	

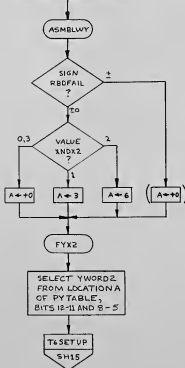
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FOR EXPLANATION OF THIS SECTION, SEE COMMENTS IN PRECEDING SECTION - PITCHIM.



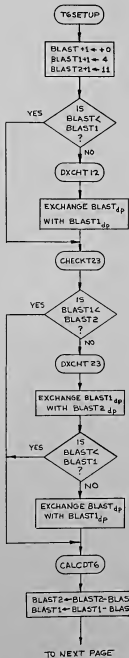
	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP JET SELECTION LOGIC
DESIGN <i>F. Lewis</i> 6-7-67		DOCUMENT NO.
POWER <i>F. Lewis</i> 6-10-67		COLLOSSUS II FC2400
DRAWN <i>J. A. Morse</i> 11-16-67		SHEET 13 OF 19
USED ON	APPROV'D <i>J. A. Morse</i> 12-11-67	REV

FROM PRECEDING PAGE



NO BD X TRANSLATIONS  
ON BD FAIL

NIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGNER: <i>F. Anderson</i> 10-5-67 DRAWING NO: <i>FC 2400</i> 10-11-67		RCS DAP JET SELECTION LOGIC	
CHECKED: <i>J. G. Moore</i> 10-11-67 APPROVED: <i>J. Horgan</i> 10-11-67		COLLOSSUS II	DOCUMENT NO. <b>FC2400</b>
USED ON	APP'D BY	REV	SHEET 14 OF 19



BRANCH INDEX FOR ROLL }  
BRANCH INDEX FOR PITCH } SEE T6START SH17  
BRANCH INDEX FOR YAW }

EXCHANGE IS DP SO THAT BRANCH INDEX REMAINS WITH APPROPRIATE TIME VALUE AND SERVES AS AN IDENTIFYING LABEL.

BLASTS ARE NOW IN ORDER OF INCREASING MAGNITUDE: BLAST, BLAST1, BLAST2.

Δ TIMES

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP JET SELECTION LOGIC
DESIGN <i>F. H. Hesse</i>	9-6-67	
PROJECT <i>F. W. Hesse</i>	11-10-67	
DOC. NO. <i>J. C. Hesse</i>	12-1-67	COLOSSUS II
APPROV. <i>J. Hesse</i>	12-8-67	DOCUMENT NO. FC2400
USED ON		SHEET 15 OF 19

FROM PRECEDING PAGE



TIMES SET TO GOMS AT BEGINNING  
OF JETSLECT AND HAS BEEN RUNNING  
SINCE THEN.

↓

ENDJETS

↓

CLEAR BIT 1  
OF RCSFLAGS

INITIALIZE T6 PROGRAM

↓

TSPHASE ← -D

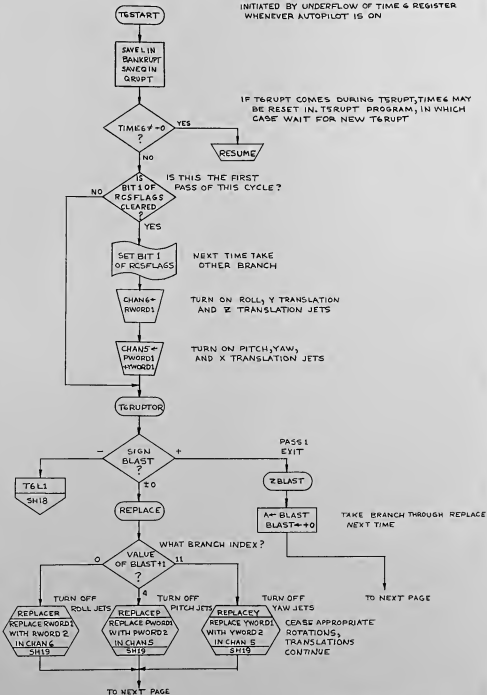
RESET FOR PHASE 1

↓

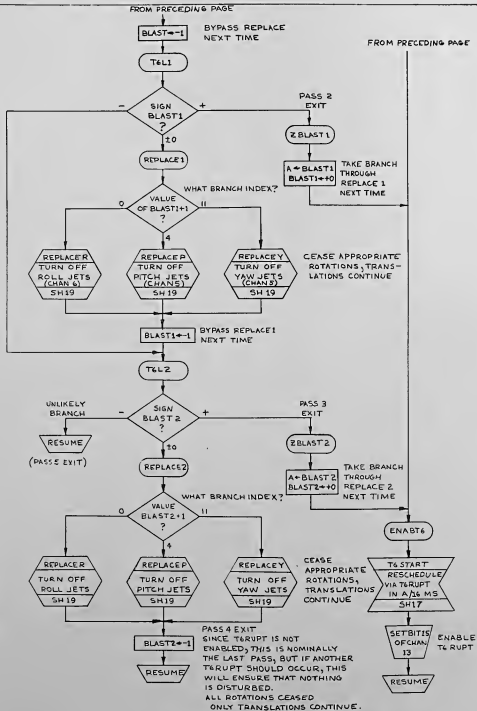
RESUME

	BIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
			RCS DAP JET SELECTION LOGIC	
	DESIGN <i>B. Pennington</i>	7-5-67	DOCUMENT NO.	
	PROGRAM <i>P. W. Hill</i>	11-16-67	COLOSSUS II	FC2400
	DESIGNER <i>J. G. Mass</i>	11-16-67	SHEET 16 OF 19	
USED ON	APPROVED <i>J. Hill</i>	11-17-67	REV	

INITIATED BY UNDERFLOW OF TIME 4 REGISTER  
WHENEVER AUTOPILOT IS ON



	BIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
	DESIGNED BY <i>F. A. Brown</i> 2-7-56		RCS DAP JET SELECTION LOGIC	
	PROGRAMMED BY <i>F. W. Brown</i> 2-14-57		DOCUMENT NO.	
	DRAWN BY <i>J. J. Moya</i> 4-18-57		COLOSSUS II	FC2400
USED ON	APPLD BY <i>J. J. Moya</i> 2-2-57	REV	SHEET 17 OF 19	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. A. Moore</i> 12-567		RSC DAP	
PROB'D <i>E. W. Moore</i> 8-18-67		JET SELECTION LOGIC	
CHECK'D <i>J. A. Moore</i> 12-14-67		COLOSSUS II	DOCUMENT NO. FC 2400
USED ON	APP'D <i>J. A. Moore</i> 12-14-67	REV	SHEET 18 OF 19



# SUBROUTINES FOR T6 START

REPLACR

CHANG←  
RWORD2

REPLACE RWORD1 WITH RWORD2,  
WHICH IN EFFECT STOPS THE ROLL  
JETS, WHILE Y AND Z TRANSLATIONS CONTINUE.

RETURN  
VIA G

REPLACEP

(CHAN5 BITS  
4-1)  
←PWORD2

REPLACE PWORD1 WITH PWORD2  
(STOP PITCH JETS, X TRANSLATIONS CONTINUE)

RETURN  
VIA G

REPLACEY

(CHAN5 BITS  
2-5)  
←YWORD2

REPLACE YWORD1 WITH YWORD2  
(STOP YAW JETS, X  
TRANSLATIONS CONTINUE)

RETURN  
VIA G

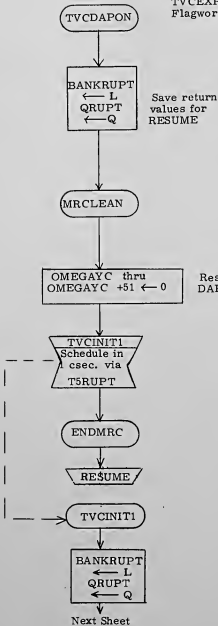
	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP JET SELECTION LOGIC
DESIGN <i>F. B. ...</i>	3-6-67	
PROGRAM <i>W. H. ...</i>	12-18-67	
DOCS <i>J. H. ...</i>	11-1-67	COLLOSSUS II
APPROV <i>J. H. ...</i>	11-1-67	DOCUMENT NO. FC2400
USED ON		REV SHEET 19 OF 19

TVC START-UP AND EXECUTIVE ROUTINES

TVCDAPON	Sh. 2
TVCINIT1	Sh. 2
DAPINIT	Sh. 9
TVCEXEC	Sh. 10
REDOTVC	Sh. 18
ENABL2	Sh. 20
CMDSOUT	Sh. 21
EXRSTR	Sh. 22
MASSPROP	Sh. 23
PRESWTCH	Sh. 28
SWICHOVR	Sh. 28
LOADCOEF	Sh. 31

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>Gen. Sullivan</i>		TVC Start-Up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-8880
ANALST			
DOCMR		REV 1	SHEET 1 of 36
APPR'D			

Called by T5RUPT from SPSON Allows  
 at least .42 sec for SPS thrust buildup.  
 Inputs set by SPSON  
 TVCPHASE=1  
 TVCEPHS=0  
 Flagword 6 bits 15, 14 = 10



Reset 52 temporary  
 DAP variables:

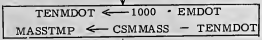
OMEGAYC<sub>D</sub>-OMEGAZC<sub>D</sub>  
 OMEGAXB<sub>D</sub>-OMEGAZB<sub>D</sub>  
 PTMP1-PTMP6  
 YTMP1-YTMP6  
 ROLLFIRE-ROLLWORD  
 TEMREG-STROKER  
 PERRB-YERRB  
 DELPBAR-DELYBAR  
 PDELOFF-YDELOFF

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>Pen Sullivan</i>		TVC Start-Up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2430
DOCMR		REV 1	SHEET 2 OF 36
APPR'D			

From Preceding Sheet



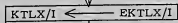
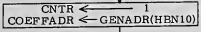
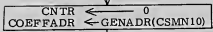
Mass decrement for 1st 10 secs =  $1000 \times \text{SPS}$  fuel flow rate in kg/csec @ $2+3$   
 TENMDOT in kg@ $2+6$   
 Expected vehicle mass after first 10 secs of burn in kg @ $2+6$ .



No, LM off

Yes, LM on

Switch for LM-on/LM-off

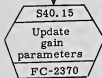


Initialize KTLX/I to pad loaded value in sec $^2$  @  $2+2$  x 1.07975 for CSM/LM; sec $^2$  @ $2+4$  x 1.07975 for CSM

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC Start Up and Executive Routines	
PRGMR <i>[Signature]</i>		COLOSSUS 3E	DOCUMENT NO. FC-2430
ANALST		REV 1	SHEET 3 OF 36
DOCMR			
APPR'D			

From Preceding Sheet



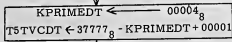
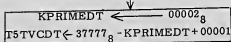
Inputs: IXX (from MASSPROP Routine) in  $kg \cdot m^2 @ 2^{+20}$ ;  
 KTLX/I (above); LAVG/TLX (from MASSPROP Routine) in  $sec^2 @ 2^{+2}$   
 Output: 1/CONACC = 1/ACC in  $sec^2/rev @ 2^{+9}$   
 VARK = DAP filter gain factor @  $2^{+2} \times 1.07975$  for CSM/LM  
 @  $2^{+4} \times 1.07975$  for CSM



CNTR in sec. @  $2^{+13}$

0, LM off

1, LM on

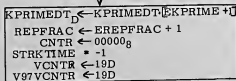
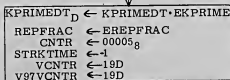


KPRIMEDT in csec @  $2^{+14}$   
 (used as intermediate quantity here)

T5TVCDT in csec @  $2^{+14}$   
 is one-half the sample time for TVC DAP iteration, in T5 form (fixed memory) 2 cs LM-off; 4cs LM-on



FLAGWRD9 bit 15: Reset (clear) → switchover has not occurred yet



KPRIMEDT<sub>D</sub>: Steering gain parameter @  $n/8$   
 REPFrac: Gain for TMC loop @  $2^{+2}$   
 CNTR: Time of one-shot TMC correction in sec @  $2^{+13}$

STRKTIME: Inhibit stroke test  
 VCNTN: Update counter in sec @  $2^{+13}$   
 V97VCNTN: in sec @  $2^{+13}$

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC Start-Up and Executive Routines	
PRGMR <i>[Signature]</i>		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 4 OF 39

From Preceding Sheet

TVCINITS

PDELOFF }  
PCMD } ← PACTOFF  
DELPBAR }

Store initial pitch trim  
value in revs @ 2° x  
1.07975

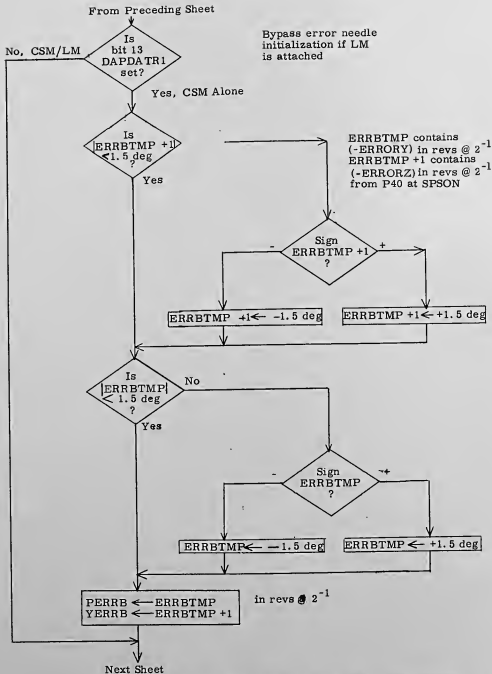
YDELOFF }  
YCMD } ← YACTOFF  
DELYBAR }

Store initial YAW trim  
value in revs @ 2° x  
1.07975

ATTINIT

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> 12-15-68		TVC Start-Up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2469
ANALST			
DOCMR		REV 1	SHEET 5 OF 6
APPR'D			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>John J. Sullivan</i> 10-1-68		TVC Start-Up and Executive Routines	
PRGMR <i>J</i>		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST		REV 1	SHEET 6 OF 36
DOCMR			
APPR'D			

From Preceding Sheet

NEEDLEIN

Set  
bit 3 of  
RCSFLAGS

Set for initialization pass  
of NEEDLER

via IBNKCALL

NEEDLER  
Attitude  
error display  
FC-2370

Initialize attitude-  
error display

TVCINIT4

TVCPHASE  
← 0

Set up TVC restart to  
return to TVCINIT4

OGANOW ← CDUX

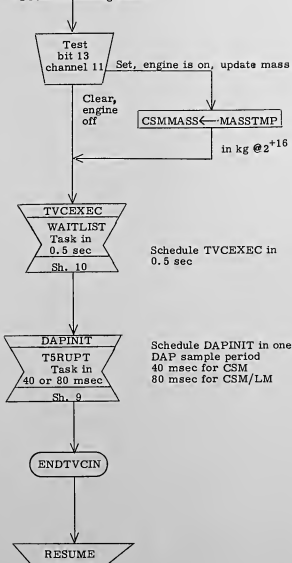
Initial roll angle  
for roll autopilot  
in revs @ 2<sup>-1</sup>

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>John Sullivan</i>	TVC Start-Up and Executive Routines	
PRGMR	<i>John Sullivan</i>	COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST		REV 1	SHEET 7 OF 36
DOCMR			
APPR'D			



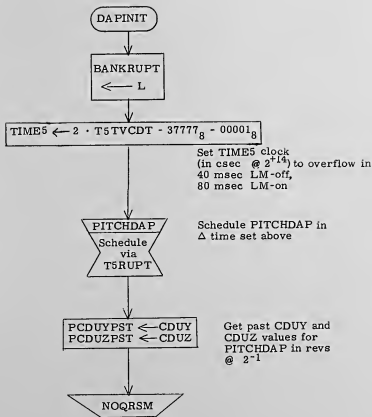
From Preceding Sheet



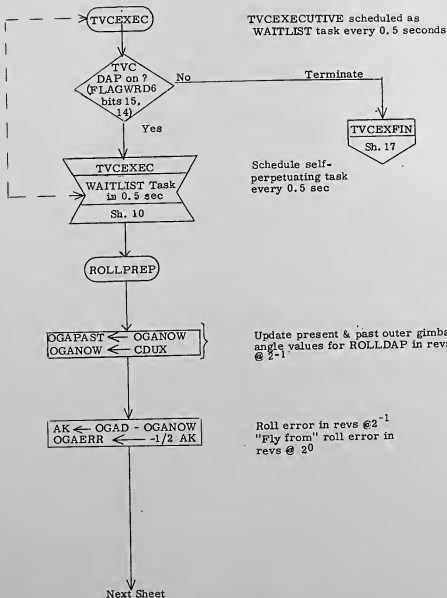
Schedule TVCEXEC in 0.5 sec

Schedule DAPINIT in one DAP sample period  
40 msec for CSM  
80 msec for CSM/LM

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC Start-up and Executive Routines	
PRGMR		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2430
DCMR		REV 1	SHEET 8 OF 36
APPR'D			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Sullivan</i> 2049		TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 21)	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 9 OF 36



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Sullivan</i>		TVC Start-Up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR		REV 1	SHEET 0 OF 36
APPR'D			

From Preceding Sheet



Schedule ROLLDAP, allowing time for completion of TVCEXECUTIVE, processing of other interrupts, etc.

Flowchart element: A rounded rectangular shape representing a call.

NEEDLEUP

via IBNKCALL

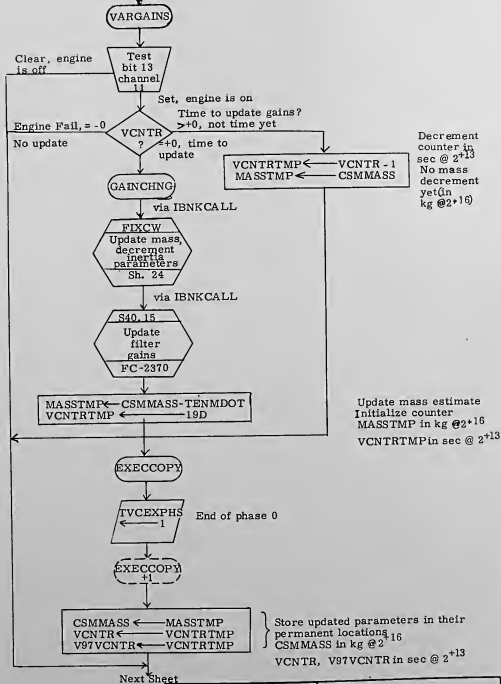


Inputs: AK, AK1, AK2 - roll, pitch, and yaw error in revs @ 2<sup>-1</sup>  
Output: FDAI error needle motion

Next Sheet

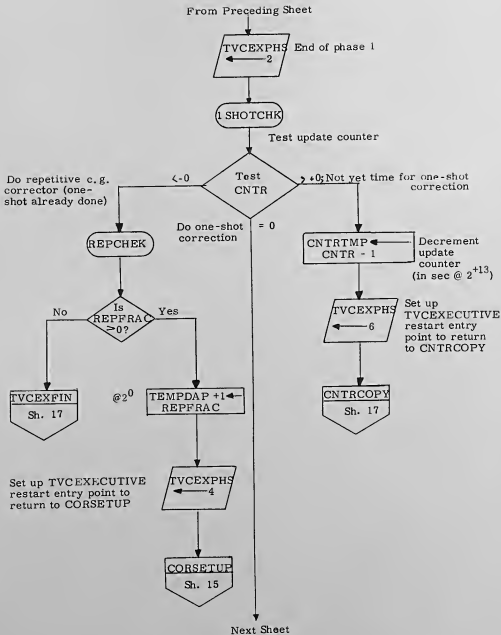
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>V. Burke</i> <i>1/2/68</i>		TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR		REV 1	SHEET 11 OF 36
APPR'D			

From Preceding Sheet



Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>W. S. ...</i>	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST		REV 1	SHEET 12 OF 35
DOCNR			
APPR'D			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> <i>[Date]</i>		TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 13 OF 36

From Preceding Sheet

1SHOTOK

Is bit 13 of channel 11 on?

No SPS engine-off terminate

Do not allow switchover during engine shutdown tailoff

Yes

TVCEXFIN  
Sh. 17

TVCEXPHS  
← 3

Set up TVCEXECUTIVE restart entry point to return to TEMPSET (TVCEXPHS=3)

TEMPSET

TEMPDAP +1 ← FCORFRAC

Load c.g. correction factor  
@2 <sup>+2</sup> for CSM/LM  
@2 <sup>+3</sup> for CSM  
(deg/deg)

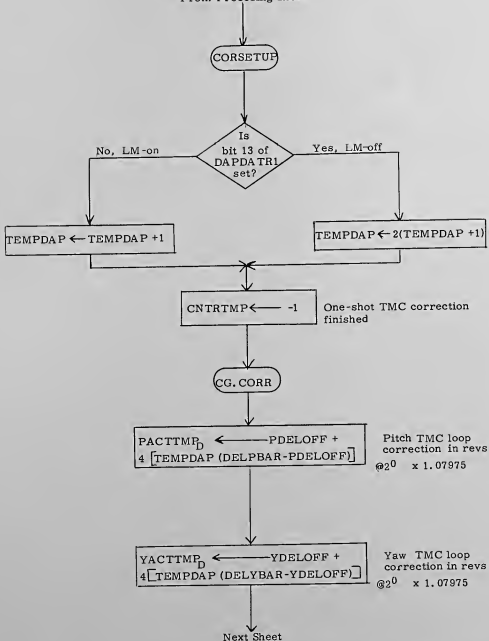
TVCEXPHS  
← 4

Set up TVCEXECUTIVE entry point to return to CORSETUP (TVCEXPHS=4)

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>V. Rucke</i> 1/20/67	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR		REV 1	SHEET 14 OF 36
APPR'D			

From Preceding Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>[Signature]</i>	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR		REV 1	SHEET 15 OF 36
APPR'D			



From Preceding Sheet

CORCOPY

TVCEXPHS  
← 5

Set up TVCEXECUTIVE restart entry point to return to CORCOPY +1 (TVCEXPHS = 5)

CORCOPY +1

PACTOFF<sub>S</sub> ← PACTMP<sub>S</sub>  
PDELOFF<sub>D</sub> ← PACTMP<sub>D</sub>

Store new values for pitch TMC loop correction in revs @  $2^0 \times 1.07975$

YACTOFF<sub>S</sub> ← YACTMP<sub>S</sub>  
YDELOFF<sub>D</sub> ← YACTMP<sub>D</sub>

Store new values for yaw TMC loop correction in revs @  $2^0 \times 1.07975$

TVCEXPHS  
← 6

Set up TVCEXECUTIVE restart entry point to return to CNTRCOPY (TVCEXPHS=6)

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>V. Vasquez</i>	<i>10/24/68</i>	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR		REV 1	SHEET 16 OF 36
APPR'D			

From Preceding Sheet

CNTRCOPY

CNTR ← CNTRTMP

Update TMC loop counter  
in sec@ 2+13

TVCEXPIN

TVCEXPHS  
← 0

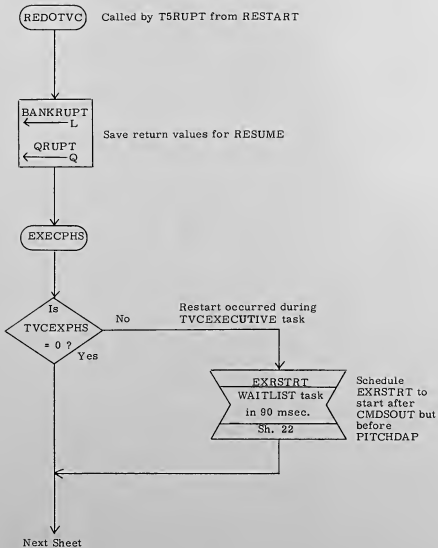
Reset TVCEXECUTIVE  
restart entry point -  
TVCEXECUTIVE finished

TASKOVER

End of TVCEXECUTIVE

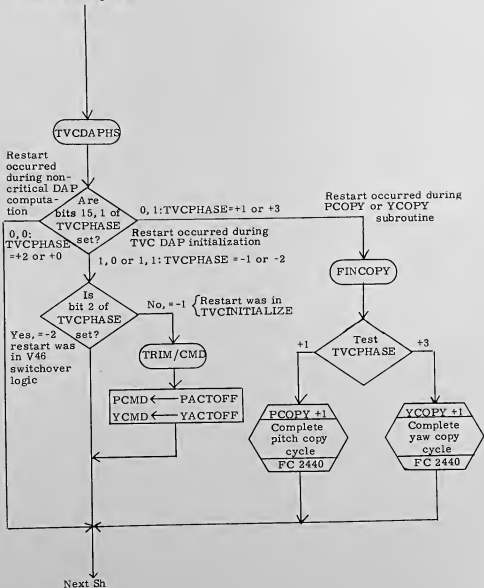
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.			APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>W. B. ...</i>	<i>9/20/63</i>	TVC Start-up and Executive Routines	
PRGMR			COLOSSUS 2D	DOCUMENT NO.
ANALST				FC-2430
DOCMR			REV 1	SHEET 17 OF 36
APPR'D				

TVC Restart Package



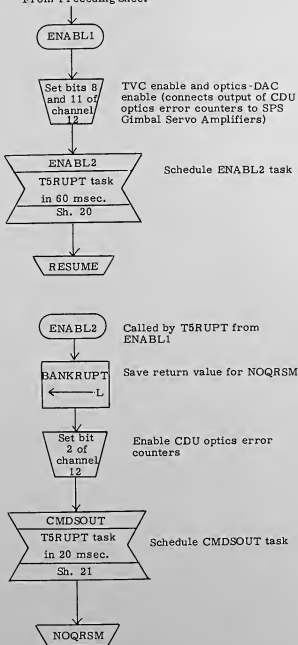
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR		REV 1	SHEET 18 OF 36
APPR'D			

From Preceding Sheet

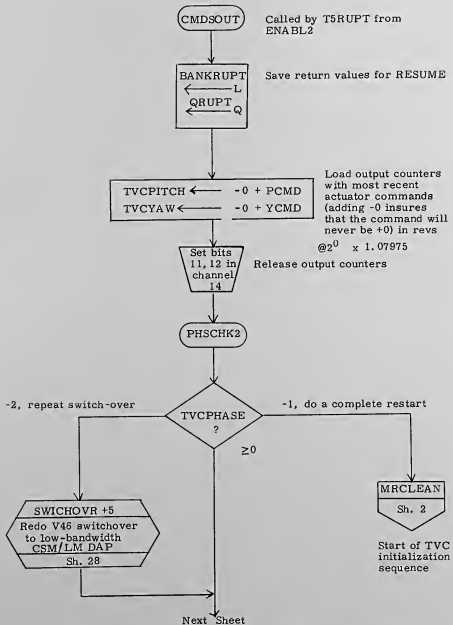


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>W. S. ...</i>		TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 217	DOCUMENT NO. FC-2430
ANALST		REV 1	SHEET 19 OF 36
DOCMR			
APPR'D			

From Preceding Sheet

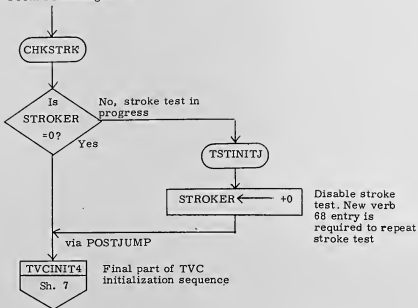


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>D. Runkle</i>	TVC Start-up and Executive Routines	
PRGMR		COLUSSUS 2P	DOCUMENT NO.
ANALST			FC-2430
DOCMR		REV 1	SHEET 20 OF 36
APPR'D			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>D. R. ...</i>	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2430
DOCMR		REV 1	SHEET 21 OF 36
APPR'D			

From Preceding Sheet



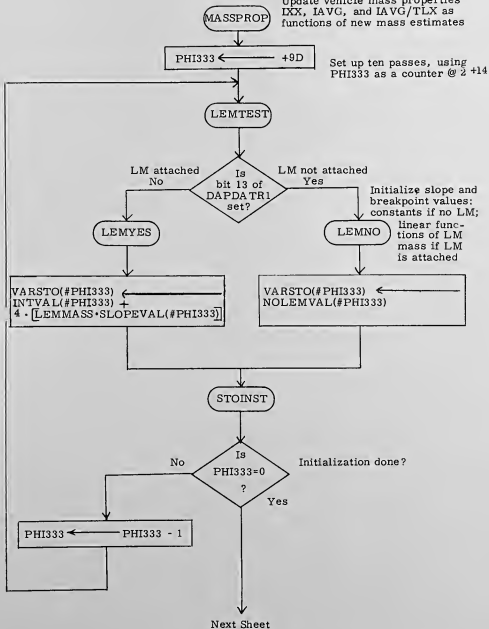
EXRSTRT

Go to location whose address is contained in location TVCEXPHS of TVCEXADR table

TVCEXPHS Value	Entry Point	Sheet No.
1	EXECCOPY +1	12
2	ISHOTCHK	13
3	TEMPSET	14
4	CORSETUP	15
5	CORCOPY +1	16
6	CNTRCOPY	17

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>W. B. ...</i>	<i>5/6/69</i>	TVC Start-up and Executive Routines	
PRGMR		DOCUMENT NO.	
ANALST		COLOSSUS 22	FC-2430
DOCMR		REV 1	
APPR'D		SHEET 22 OF 36	

Update vehicle mass properties  
 IXX, IAVG, and IAVG/TLX as  
 functions of new mass estimates



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>W. Burke</i> 10/67		TVC Start-up and Executive Routines	
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From Preceding Sheet

DXTEST

LM is attached, with ascent and descent stages

Is bit 15 DAPDATR1 set?

No

Yes, LM is attached with ascent stage only (no descent stage)

$$\overline{\text{VARSTO}} + 1 \leftarrow \overline{\text{VARSTO}} + 1 + \overline{\text{VARSTO}} + 8 \overline{\text{D}}$$

$$\overline{\text{VARSTO}} + 2 \leftarrow \overline{\text{VARSTO}} + 2 + \overline{\text{VARSTO}} + 9 \overline{\text{D}}$$

$$\overline{\text{VARSTO}} + 7 \leftarrow \text{DXITFIX} + \overline{\text{VARSTO}} + 7$$

Decrement IAVG breakpoint value in  $\text{kg} \cdot \text{m}^2 @ 2 \cdot 20$   
 Decrement IAVG/TLX breakpoint value  
 Change IAVG/TLX slope for CSMMASS less than breakpoint weight in  $\text{sec}^2 / \text{kg} @ 2 - 12$

FIXCW

$$\text{PHI333} \leftarrow 2$$

$$\text{PSI333} \leftarrow 2$$

$$\text{TEMP333} \leftarrow 2 \left[ \text{CSMMASS} + \text{NEGBP}\overline{\text{W}} \right]$$

Index for slope value  
 Index for breakpoint value and for storage of final result  
 TEMP333 in  $\text{kg} @ 2^{+15}$

CSM breakpoint mass (NEGBP $\overline{\text{W}}$  = -33956 lbs)

Is TEMP333  $\leq 0$ ?

Yes

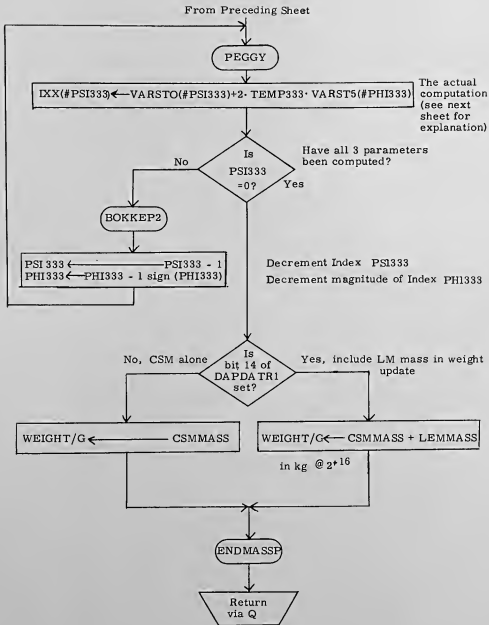
No

PHI333  $\leftarrow -2$

Modify index to pick up slopes for case where CSMMASS > breakpoint mass (33956 lbs)

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>B. S. ...</i>		TVC Start-up and Executive Routines	
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DRAWN	<i>W. S. ...</i>	TVC Start-up and Executive Routines	
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MASSPROP COMPUTATION:

LEMTEST

Step 1: Compute coefficients on basis of LM mass ( $m_{LM}$ )

NO LM	LMON
$v_0 = 25445 \text{ (kg} \cdot \text{m}^2)$	$v_0 = 26850(\text{kg} \cdot \text{m}^2) + 1.86307(\text{m}^2) \cdot m_{LM}(\text{kg})$
$v_1 = 87450 \text{ (kg} \cdot \text{m}^2)$	$v_1 = 127518(\text{kg} \cdot \text{m}^2) + 27.5774(\text{m}^2) \cdot m_{LM}(\text{kg})$
$v_2 = .30715 \text{ (sec}^2)$	$v_2 = .54059(\text{sec}^2) + 2.3548 \cdot 10^{-5} (\text{sec}^2 \text{ kg}) \cdot m_{LM}(\text{kg})$
$v_3 = 1.22877 \cdot 10^{-5} (\text{sec}^2/\text{kg})$	$v_3 = .153964 \cdot 10^{-4} (\text{sec}^2/\text{kg}) + 2.1777 \cdot 10^{-9} (\text{sec}^2/\text{kg}^2) \cdot m_{LM}(\text{kg})$
$v_4 = 1.6086 \text{ (m}^2)$	$v_4 = -.742823(\text{m}^2) + 1.044 \cdot 10^{-3} (\text{m}^2/\text{kg}) m_{LM}(\text{kg})$
$v_5 = 1.54 \text{ (m}^2)$	$v_5 = 1.5398(\text{m}^2) + 0$
$v_6 = 7.77177 \text{ (m}^2)$	$v_6 = 9.68(\text{m}^2) + 2.21068 \cdot 10^{-3} (\text{m}^2/\text{kg}) \cdot m_{LM}(\text{kg})$
$v_7 = 3.46458 \cdot 10^{-5} (\text{sec}^2/\text{kg})$	$v_7 = .647625 \cdot 10^{-4} (\text{sec}^2/\text{kg}) + 1.5166 \cdot 10^{-9} (\text{sec}^2/\text{kg}^2) \cdot m_{LM}(\text{kg})$
$v_8$ computed, but not meaningful and	$v_8 = -27228(\text{kg} \cdot \text{m}^2) - 1.284(\text{m}^2) m_{LM}(\text{kg})$
$v_9$ not used	$v_9 = -.206476(\text{sec}^2) + 2 \cdot 10^{-5} (\text{sec}^2/\text{kg}) \cdot m_{LM}(\text{kg})$

DXTEST

Step 2: If LM ascent stage only attached, modify  $v_1$ ,  $v_2$ , and  $v_7$ :

$$v_1 = v_1(\text{kg} \cdot \text{m}^2) + v_8(\text{kg} \cdot \text{m}^2)$$

$$v_2 = v_2(\text{sec}^2) + v_9(\text{sec}^2)$$

$$v_7 = v_7(\text{sec}^2/\text{kg}) - 1.88275 \cdot 10^{-5} (\text{sec}^2/\text{kg})$$

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Step 3: Compute  $IXX$  ( $\text{kg} \cdot \text{m}^2$ ),  $I AVG$  ( $\text{kg} \cdot \text{m}^2$ ), and  $I AVG/TLX$  ( $\text{sec}^2$ ):

PEGGY

CSM weight $\pm$ 33956 lbs (15402.17kg)	CSM weight $\gamma$ 33956 lbs (15402.17kg)
$IXX = v_0(\text{kg} \cdot \text{m}^2) + v_5(\text{m}^2)(m_{\text{CSM}}^{-15402.17})(\text{kg})$	$IXX = v_0(\text{kg} \cdot \text{m}^2) + v_5(\text{m}^2)(m_{\text{CSM}}^{-15402.17})(\text{kg})$
$I AVG = v_1(\text{kg} \cdot \text{m}^2) + v_6(\text{m}^2)(m_{\text{CSM}}^{-15402.17})(\text{kg})$	$I AVG = v_1(\text{kg} \cdot \text{m}^2) + v_4(\text{m}^2)(m_{\text{CSM}}^{-15402.17})(\text{kg})$
$I AVG/TLX = v_2(\text{sec}^2) + v_7(\text{sec}^2/\text{kg})(m_{\text{CSM}}^{-15402.17})(\text{kg})$	$I AVG/TLX = v_2(\text{sec}^2) + v_3(\text{sec}^2/\text{kg})(m_{\text{CSM}}^{-15402.17})(\text{kg})$

In the above equations:

$IXX$  = Moment of inertia about vehicle X-axis in  $\text{kg} \cdot \text{m}^2 @ 2^{20}$

$I AVG$  = Average moment of inertia about Y and Z axes in  $\text{kg} \cdot \text{m}^2 @ 2^{20}$

$I AVG/TLX$  =  $I AVG /$  (vehicle gain) in  $\text{sec}^2 @ 2^2$

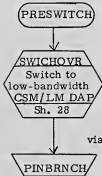
$m_{\text{CSM}}$  = CSM mass in  $\text{kg} @ 2^{16}$

$m_{LM}$  = LM mass in  $\text{kg} @ 2^{16}$

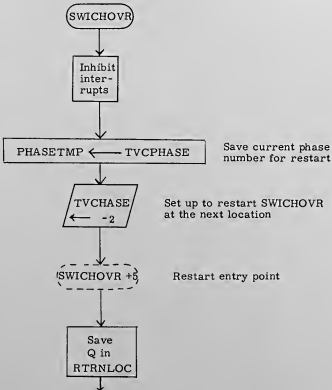
Note: vehicle mass is keyed in in pounds, but internally, mass is stored in kg.

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DRAWN <i>V. B. Lee</i>	<i>4/7/67</i>	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
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CSM/LM V46 Switchover from  
high-bandwidth filter to  
low-bandwidth filter.



Allow interrupts, and terminate  
verb 46



Next Sheet

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DRAWN	<i>S. B. DeLo</i>	TVC Start-up and Executive Routines	
PRGMR	<i>SL/SL</i>	COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 28 OF 36

From Preceding Sheet

MCLEANJR

Zero:  
PTMP<sub>1D</sub> - PTMP<sub>6D</sub>  
YTMP<sub>1D</sub> - YTMP<sub>6D</sub>

Zero temporaries for pitch and yaw filters.

Set bit 15  
FLAGWRD 9

Indicate switchover has occurred

$KTLX/I \leftarrow [EKTLX/I + 2]$

Set gain to low-bandwidth pad loaded value  
in  $\text{sec}^{-2} @ 2^{+2} \times 1.07975$  for CSM/LM

S40.15 +7

Compute  
variable  
gain (VARK)  
FC-2370

Input:  
 $KTLX/I$  in  $\text{sec}^{-2} @ 2^{+2} \times 1.07975$  for CSM/LM

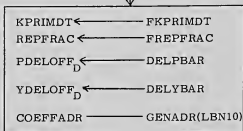
IAVG/TLX in  $\text{sec}^2 @ 2^{+2}$

Output:  
VARK  $@ 2^{+2} \times 1.07975$  for CSM/LM

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. B. ...</i>	TVC Start-up and Executive Routines	
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From Preceding Sheet



Steering gain @  $\pi/8$   
TMC loop gain @  $z^{+2}$

Trim estimates are set to defilter  
values in revs @  $2^0 \times 1.07975$

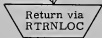
Input to LOADCOEF routine to  
select low bandwidth coefficients



Load N10 thru N10 +14D for low-bandwidth  
DAP filter



Restore phase number

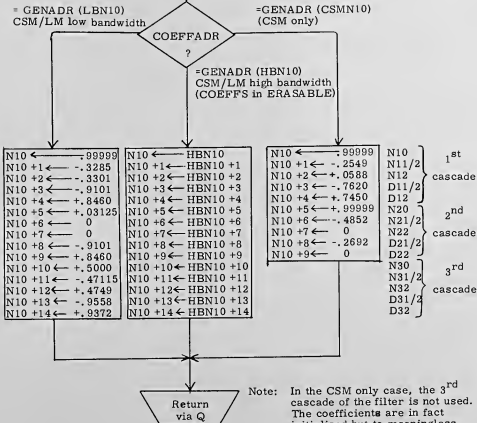


Return to caller

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DRAWN <u>S. S. S. S.</u> <u>1/17/67</u>		TVC Start-up and Executive Routines	
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LOADCOEF

Load TVC DAP filter coefficients



N10 +10 ← +.99999  
 N10 +11 ← -.3285  
 N10 +12 ← -.3301  
 N10 +13 ← -.9101  
 N10 +14 ← +.8460

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>W. Bunker</i>	TVC Start-up and Executive Routines	
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SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Flow Chart	Description	Where Called
S40.15	2370	Updates gain parameters	Sh. 4, 12, 29
NEEDLER	2370	Attitude error display	Sh. 7, 11
ROLLDAP	2460	TVC roll control	Sh. 11
PCOPY	2440	Pitch copy	Sh. 19
YCOPY	2440	Yaw copy	Sh. 19

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
SWTOVER Flagword 9 bit 15	Switchover has occurred	Switchover has not occurred	Sh. 29	Sh. 3	
RCSFLAGS bit 3	Initialize needle drive	Needle drive initialized	Sh. 7		
DAPBIT1 Flagword 6 bit 15	Both set: Saturn DAP controls vehicle attitude.	DAPBIT1=0 } TVC DAPBIT2=1 } DAP controls vehicle attitude			Sh. 10
DAPBIT2 Flagword 6 bit 14	DAPBIT1=1 } TVC DAPBIT2=0 } DAP controls vehicle attitude	Both clear: no DAP control of vehicle attitude			Sh. 10

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>V. Buckle</i>	<i>10/2/66</i>	TVC Start-up and Executive Routines	
PRGMR _____	_____	COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST _____	_____	REV 1	SHEET 32 OF 36
DOCMR _____	_____		
APPR'D _____	_____		

## ERASABLE LOCATIONS USED

AGC TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
AK		Roll attitude error	deg	rev	$2^{-1}$
CSMMASS	$m_{CSM}$	CSM mass (updated version of MASSTMP)	kg	kg	$2^{+16}$
DELPBAR		rate error used for offset (pitch)	deg	rev	$2^0 \times$ 1.07975
DELYBAR		rate error used for offset (yaw)	deg	rev	$2^0 \times$ 1.07975
DXITFIX		Increments VARSTO+7 if LM-on APS-only configuration is specified	$sec^2/kg$	$sec^2/kg$	$2^{-12}$
EMDOT		SPS propellant flow rate	kg/csec	kg/csec	$2^{+3}$
ERRBTMP <sub>D</sub>	$\theta_e$	Updated version of PERRB <sub>D</sub> and YERRB <sub>D</sub> (body attitude error)	deg	rev	$2^{-1}$
IAVG		Average moment of inertia about Y-and Z -axes	$kg \cdot m^2$	$kg \cdot m^2$	$2^{+20}$
IAVG/TLX		IAVG/("thrust moment")	$sec^2$	$sec^2$	$2^{+2}$
IXX		Moment of inertia about vehicle X-axis	$kg \cdot m^2$	$kg \cdot m^2$	$2^{+20}$
KPRIMEDT		Steering gain parameter		(rev/DAP cycle)/rad	$\pi/8$
KTLX/I		Updated version of EKTLX/I (see pad-loads)	$sec^{-2}$	$sec^{-2}$	$2^{+2} \times$ 1.07975 for CSM/LM $2^{+4} \times$ 1.07975 for CSM
LEMMASS	$m_{LM}$	LM mass	kg	kg	$2^{+16}$
MASSTMP		Expected or estimated vehicle mass	kg	kg	$2^{+16}$
OGAD		Value of desired outer gimbal angle (CDUX)	deg	rev	$2^{-1}$
OGAERR		"Fly from " roll error	deg	rev	$2^0$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. B. ...</i>	<i>7/20/67</i>	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR		REV 1	SHEET 33 OF 36
APPR'D			

AGC TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
OGANOW		Roll angle for roll autopilot; updated version of CDUX	deg	rev	$2^{-1}$
OGAPAST		previous value of OGANOW (past CDUX value)	deg	rev	$2^{-1}$
PACTTMP <sub>D</sub>		Pitch trim-correction (temporary storage)	deg	rev	$2^0 \times 1.07975$
PCDUYPST		Past CDUY value (pitch)	deg	rev	$2^{-1}$
PCDUZPST		Past CDUZ value (pitch)	deg	rev	$2^{-1}$
PCMD		Incremental pitch actuator command	deg	rev	$2^0 \times 1.07975$
PDELOFF <sub>D</sub>	PDELOFF	Trim correction (pitch)	deg	rev	$2^0 \times 1.07975$
PERRB <sub>D</sub>		Body attitude error (pitch)	deg	rev	$2^{-1}$
REPF <sub>FRAC</sub>	$K_{CG}$	Updated version of EREF <sub>FRAC</sub> (see pad-loads)	dimensionless	dimensionless	$2^{+2}$
TEMP333		Mass (temporary)	kg	kg	$2^{+15}$
TENMDOT		Amount of mass lost due to 10 seconds of SPS firing	kg	kg	$2^{+16}$
TVC <sub>PITCH</sub>		Actuator command (pitch)	deg	rev	$2^0 \times 1.07975$
TVC <sub>YAW</sub>		Actuator command (yaw)	deg	rev	$2^0 \times 1.07975$
VAR <sub>K</sub>	VAR <sub>K</sub> or $K_z$	Gain for pitch and yaw channels	deg/deg	rev/rev	For CSM $2^{+4} \times 1.07975$ For CSM/LM $2^{+2} \times 1.07975$
VAR <sub>STO +1</sub>		I <sub>AVG</sub> breakpoint value	$kg \cdot m^2$	$kg \cdot m^2$	$2^{+20}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>W. Burke</i>	TVC Start-up and Executive Routines	
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AGC TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
VARSTO +2		IAVG/TLX breakpoint value	sec <sup>2</sup>	sec <sup>2</sup>	2 <sup>+2</sup>
VARSTO +7		IAVG/TLX slope for CSMMASS less than breakpoint value	sec <sup>2</sup> /kg	sec <sup>2</sup> /kg	2 <sup>-12</sup>
VCNTR		Updated version of VCNTRTMP	sec	sec	2 <sup>+13</sup>
VCNTRTMP		Counter	sec	sec	2 <sup>+13</sup>
V97VCNTR		Updated version of VCNTRTMP	sec	sec	2 <sup>+13</sup>
WEIGHT/G		Updated version of CSMMASS and LMMASS	kg	kg	2 <sup>+16</sup>
YACTTMP <sub>D</sub>		Yaw trim-correction (temporary storage)	deg	rev	2 <sup>0</sup> x 1.07975
YCMD		Incremental yaw actuator command	deg	rev	2 <sup>0</sup> x 1.07975
YDELOFF <sub>D</sub>	YDELOFF	Trim correction (yaw)	deg	rev	2 <sup>0</sup> x 1.07975
YERRB <sub>D</sub>		Body attitude error (yaw)	deg	rev	2 <sup>-1</sup>

FIXED LOCATION USED

AGC TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
FCORFRAC		c. g. correction factor	dimensionless	dimensionless	CSM/LM 2 <sup>+2</sup> CSM 2 <sup>+3</sup>

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DRAWN <i>S. B. B.</i>		TVC Start-up and Executive Routines	
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PAD-LOADED ERASABLES

AGC TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
EKPRIME		"Steer law gain" for LM-off	deg/sec/deg	revs/csec/rad	$\pi/8$
EKTLX/1 <sub>D</sub>		K: DAP gain factor T: thrust LX: distance from engine gimbal point to c. g. of vehicle I: average of moments of inertia about pitch and yaw axes	sec <sup>-2</sup>	sec <sup>-2</sup>	CSM/LM: 2 <sup>+2</sup> x 1.07975 CSM: 2 <sup>+4</sup> x 1.07975
EREFFRAC		Gain for TMC loop (LM-off)			2 <sup>+2</sup>
EREFFRAC +1		Gain for TMC loop (LM-on)			2 <sup>+2</sup>
FACTOFF		Actuator trim value (pitch)	deg	rev	2 <sup>0</sup> x 1.07975
YACTOFF		Actuator trim value (yaw)	deg	rev	2 <sup>0</sup> x 1.07975

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>b. Burke</i>		TVC Start-up and Executive Routines	
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TVC DAP

PITCHDAP	Sh. 2
FWDFLTR	Sh. 4
PRECOMP	Sh. 7
PCOPY	Sh. 8
YAWDAP	Sh. 9
YCOPY	Sh. 13
ERRORLIM	Sh. 15
RLIMTEST	Sh. 15
ACTLIM	Sh. 16

Special convention:

TVCDT = 80 msec for CSM/LM  
40 msec for CSM

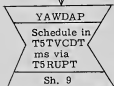
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. L. Johnson</i> 9/15/68		TVC DAP	
PRGMR <i>R. L. Johnson</i> 9/15/68		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2440
DOCMR <i>R. L. Johnson</i> 9/15/68		REV 1	SHEET 1 OF 19
APPR'D <i>R. L. Johnson</i> 9/15/68			

PITCHDAP

Entered via T5RUPT with  
BBANK contents in L



Save BBANK and Q of  
interrupted program



Schedule YAWDAP to run: In 40 ms for CSM/LM  
In 20 ms for CSM

PSTROKER

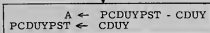
Is  
STROKER  
 $\neq 0$  ?

Yes, start/continue stroke test



No

PCDUDOTS



Past CDUY value - present CDUY value  
All in revs @  $2^{-1}$



Input: A,  $\Delta$  CDUY in revs @  $2^{-1}$

Output: A, unchanged if  $\leq 2.33$  deg  
0 otherwise

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Sulgowski</i> 7/15/69		TVC DAP	
PRGMR <i>R. Gellman</i> 10/29/69		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2440
DOCMR <i>Robert M. Euter</i> 10/29/69		REV 1	SHEET 2 OF 10
APPR'D <i>Robert M. Euter</i> 10/29/69			

From Preceding Sheet

MCDUYDOT ← A

Store CDUY in revs/sec @  
 $2^{-1} \times \frac{1}{TVCDT}$

A ← PCDUZPST - CDUZ  
 PCDUZPST ← CDUZ

In revs @  $2^{-1}$

RLIMTEST

Limit  
Rate

Sh. 15

MCDUZDOT ← A

Store CDUZ in revs/sec @  
 $2^{-1} \times \frac{1}{TVCDT}$

PINTEGRL

$$\dot{\omega}_y = \frac{+ \cos \phi \cdot \cos \psi \cdot \dot{\theta} + \sin \phi \cdot \dot{\psi}}{-4(\text{COSCDUX} \cdot \text{COSCDUZ} \cdot \text{MCDUYDOT}) - 2(\text{SINCDUX} \cdot \text{MCDUZDOT})}$$

OMEGAYB<sub>D</sub> ←

Measured rate in  
revs/sec @  
 $2^{-1} \times \frac{1}{TVCDT}$

COSCDUX, COSCDUZ,  
SINCDUX @  $2^{+1}$

$$\theta_e = \theta_e z^{-1} + \omega_{yc} - \omega_y$$

$$\text{ERRBTMP}_D \leftarrow \text{PERRB} + \text{OMEGAYC} - \text{OMEGAYB}$$

Attitude error =  
 ∫ rate error ( $\omega_{yc}$  =  
 command rate) in  
 revs @  $2^{-1}$

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Lutz</i> 8-15-69		TVC DAP	
PRGRM <i>R. Schubert</i> 10/2/68		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2440
DOCNR <i>APR-FSM-Enter</i> 10/21/69		REV 1	SHEET 3 OF 19
APPR'D <i>Robert D. ...</i> 10/21/69			



From Preceding Sheet

PERORLIM

ERRORLIM  
Limit Attitude  
Error  
Sh. 15

To avoid overflow, attitude error is limited to  $\pm 45^\circ$

PFORWARD

$TMP1_D \leftarrow PTMP1_D$   
 $TMP3_D \leftarrow PTMP3_D$   
 $TMP5_D \leftarrow PTMP5_D$

Set up storage locations for forward filter in revs @  $2^{-1}$

FWDFLTR

$DAP1 \leftarrow 0$   
 $DAP2 \leftarrow 0$   
 $DAP3 \leftarrow 0$   
 $CMDTMP \leftarrow 0$   
 $DELBRTMP \leftarrow 0$

1DAPCAS

1st Cascade

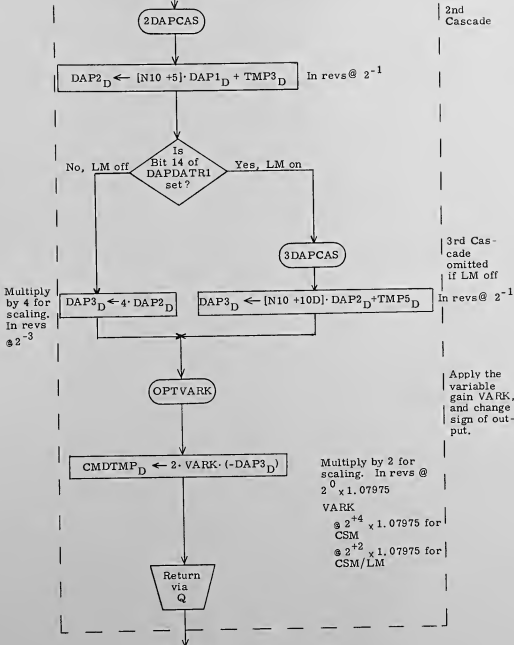
$DAP1_D \leftarrow N10 \cdot ERRBTMP_D + TMP1_D$

In revs @  $2^{-1}$

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. Luffenbach</i> 9/15/69		TVC DAP	
PRGRM <i>R. G. Luffenbach</i> 10/23/69		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2440
DOCMR <i>Robert M. Euter</i> 10/23/69		REV 1	SHEET 4 OF 19
APPR'D <i>Robert M. Euter</i> 10/23/69			

From Preceding Sheet



Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		TVC DAP	
DRAWN <i>D. J. ...</i>	<i>2/15/69</i>	DOCUMENT NO.	
PRGMR <i>R. ...</i>	<i>4/24/69</i>	FC-2440	
ANALST		COLOSSUS 20	REVISION
DOCMR <i>R. ...</i>	<i>...</i>		SHEET 5 OF 19
APPR'D <i>R. ...</i>	<i>...</i>		

From Preceding Sheet

POFFSET

$CMDTMP_D \leftarrow CMDTMP_D + PDELOFF_D$

Add in trim correction  
in revs @  $2^0 \times 1.07975$

PACLIM

ACTLIM  
Limit CMDTMP<sub>D</sub>  
to  $\pm 6$  deg  
Sh. 16

POUT

$TVCPITCH \leftarrow TVCPITCH + CMDTMP - PCMD$

(Add incremental pitch  
command) in revs @  
 $2^0 \times 1.07975$

Set bit 11  
Ch. 14

Release TVCPITCH counts to  
actuators

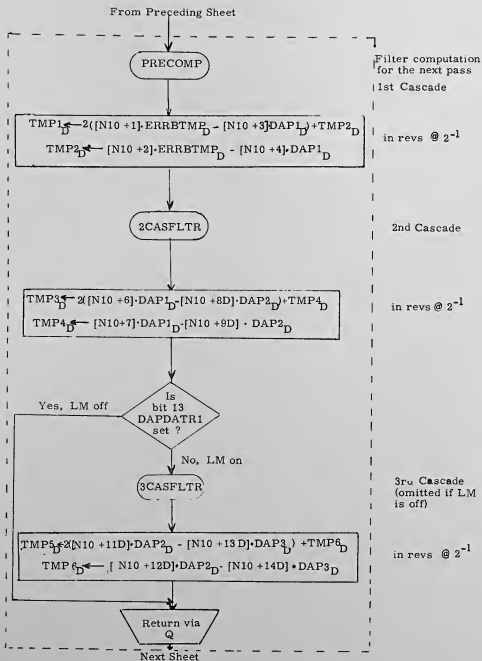
PPRECOMP

$TMP2_D \leftarrow PTMP2_D$   
 $TMP4_D \leftarrow PTMP4_D$   
 $TMP6_D \leftarrow PTMP6_D$

Set up filter storage  
for precomputation in  
revs @  $2^{-1}$

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. L. Bruch</i> 9/12/67		TVC DAP	
PRGMR <i>R. Gehlbach</i> 10/27/67		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2440
DOCNR <i>Doc. No. Ent. 10/27/67</i>		REV 1	SHEET 6 OF 10
APPR'D <i>Robert M. Ent. 10/27/67</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. J. ...</i> 8/1/68		TVC DAP	
PRGMR <i>R. J. ...</i> 10/2/68		COLOSSUS 2D	DOCUMENT NO. FC-2440
ANALST			
DOCMR <i>R. J. ...</i> 10/2/68		REV 1	SHEET 7 OF 19
APPR'D <i>R. J. ...</i> 10/2/68			

From Preceding Sheet

DELBARP

$$\text{DELBRTPMP}_D \leftarrow E(-AT) \cdot \text{DELPBAR}_D + [1-E(-AT)] \cdot \text{CMDTMP}$$

In revs @ 2<sup>-1</sup>

PCOPYCYC

PCOPY

TVCPHASE  
← 1

TVC restarts to redo PCOPY on restart

$$\begin{aligned} \text{PTMP1}_D &\leftarrow \text{TMP1}_D \\ \text{PTMP2}_D &\leftarrow \text{TMP2}_D \\ \text{PTMP3}_D &\leftarrow \text{TMP3}_D \\ \text{PTMP4}_D &\leftarrow \text{TMP4}_D \\ \text{PTMP5}_D &\leftarrow \text{TMP5}_D \\ \text{PTMP6}_D &\leftarrow \text{TMP6}_D \end{aligned}$$

In revs @ 2<sup>-1</sup>

PMISC

$$\begin{aligned} \text{AK1}_S &\leftarrow \text{ERRBTMP}_S \\ \text{PERRB}_D &\leftarrow \text{ERRBTMP}_D \\ \text{PCMD}_S &\leftarrow \text{CMDTMP}_S \\ \text{DELPBAR}_D &\leftarrow \text{DELBRTPMP}_D \end{aligned}$$

In revs @ 2<sup>-1</sup>

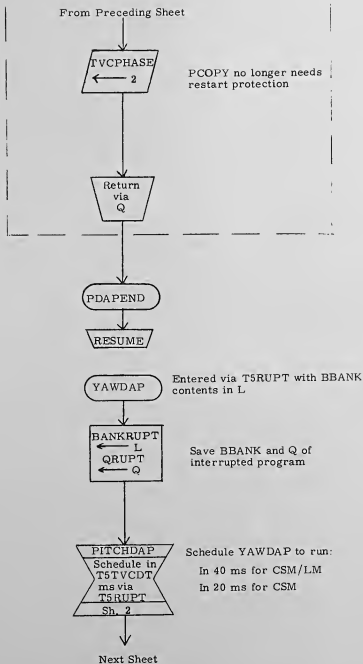
In revs @ 2<sup>-1</sup>

In revs @ 2<sup>0</sup> x 1.07975

In revs @ 2<sup>-1</sup>

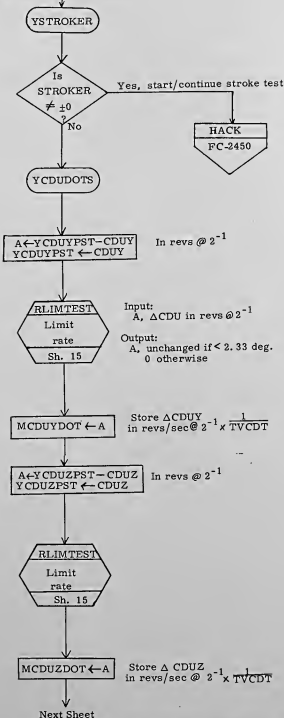
Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		TVC DAP	
DRAWN <i>A. L. ...</i>	PRGRM <i>R. ...</i>	DOCUMENT NO.	
ANALST	DOCMR <i>...</i>	COLOSSUS 2D	FC-2440
APPR'D <i>...</i>		REV 1	SHEET 8 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. G. Eustace</i> 9/15/69		TVC DAP	
PRGMR <i>R. G. Eustace</i> 10/28/69		DOCUMENT NO.	
ANALST		COLOSSUS 2D	
DOCMR <i>R. G. Eustace</i> 10/28/69		FC-2440	
APPR'D <i>R. G. Eustace</i> 10/28/69		REV 1	SHEET 9 OF 19

From Preceding Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. J. [unclear]</i> 10/62		TVC DAP	
PRGMR <i>K. [unclear]</i>		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2440
DOCNR <i>D. [unclear]</i>		REV 1	SHEET 0 OF 19
APPR'D <i>[unclear]</i>			

From Preceding Sheet

YINTEGRL

$$\omega_z = \frac{-\cos \psi \cdot \sin \phi \cdot \dot{\theta} + \cos \phi \cdot \dot{\psi}}{4(\cos \psi \cdot \sin \phi \cdot \dot{\theta} + \cos \phi \cdot \dot{\psi}) - 2(\cos \psi \cdot \sin \phi \cdot \dot{\theta} + \cos \phi \cdot \dot{\psi})}$$

OMEGA ZB<sub>D</sub> ←

Measured rate in revs/sec @ 2<sup>-1</sup> TVC/TT

$$\theta_e = \theta_c z^{-1} + \omega_{ZC} - \omega_z$$

ERRBTMP<sub>D</sub> ← YERRB + OMEGAZC - OMEGAZB

Attitude error =  $\int$  rate error;  
( $\omega_{ZC}$  = command rate)  
in revs @ 2<sup>-1</sup>

YERORLIM

ERRORLIM  
Limit  
attitude error  
Sh. 15

To avoid overflow, attitude error is limited to ±45°

YFORWARD

TMP1<sub>D</sub> ← YTMP1<sub>D</sub>  
TMP3<sub>D</sub> ← YTMP3<sub>D</sub>  
TMP5<sub>D</sub> ← YTMP5<sub>D</sub>

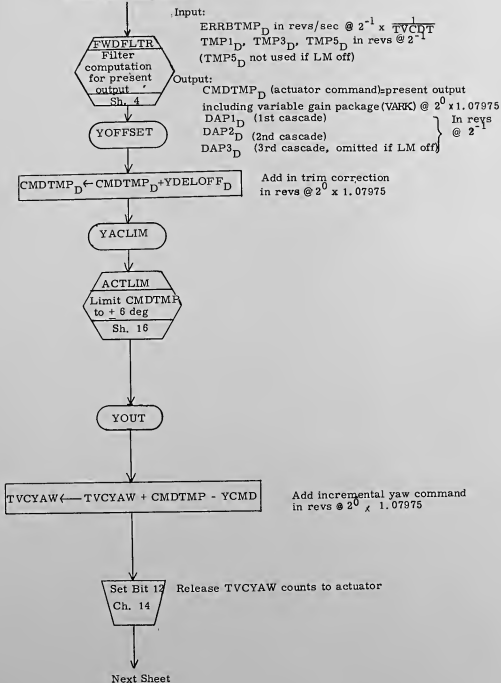
} Set up storage locations for forward filter in revs @ 2<sup>-1</sup>

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		TVC DAP	
DRAWN <i>G. J. ...</i>	PRGRM <i>R. ...</i>	COLOSSUS 2D	DOCUMENT NO.
ANALST	DOCNR <i>...</i>		FC-2440
APPR'D <i>...</i>	REV 1	SHEET 11 OF 19	



From Preceding Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>[Signature]</i> 1/4/69		TVC DAP	
PRGRM: <i>[Signature]</i> 1/4/69		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2440
DOCNR: <i>[Signature]</i> 1/4/69		REV 1	SHEET 12 OF 19
APPR'D: <i>[Signature]</i> 1/4/69			

From Preceding Sheet

YPRECOMP

$TMP2_D \leftarrow YTMP2_D$   
 $TMP4_D \leftarrow YTMP4_D$   
 $TMP6_D \leftarrow YTMP6_D$

Set up filter storage for precomputation  
in revs @  $2^{-1}$

PRECOMP  
 Filter  
 computation for  
 the next pass  
 Sh. 7

Input:  
 $ERRBTMP_D$  in revs/sec @  $2^{-1} \times \frac{1}{TVCDT}$   
 $DAP1_D, DAP2_D, DAP3_D$  in revs @  $2^{-1}$   
 ( $DAP3_D$  not used if LM off)  
 Output:  
 $TMP1_D, TMP2_D, TMP3_D, TMP4_D, TMP5_D,$   
 $TMP6_D$  in revs @  $2^{-1}$   
 ( $TMP5_D$  and  $TMP6_D$  omitted if LM off)

DELBARY

$DELBRTMP_D \leftarrow E(-AT) \cdot DELYBAR_D + [1 - E(-AT)] \cdot CMDTMP$

in revs @  $2^{-1}$

YCOPYCYC

YCOPY

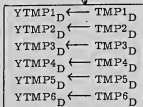
TVCPHASE  
 $\leftarrow 3$

TVC restarts to redo  
 YCOPY on restart

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC DAP	
PRGRM <i>[Signature]</i>		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2440
DOCMR <i>[Signature]</i>		REV 1	SHEET 13 OF 19
APPR'D <i>[Signature]</i>			

From Preceding Sheet

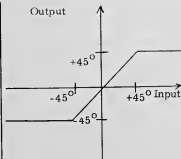
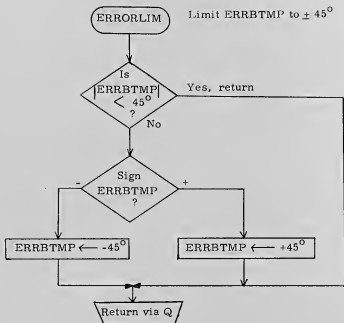


In revs @ 2<sup>-1</sup>

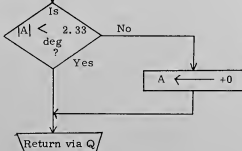
In revs @ 2<sup>-1</sup>  
 In revs @ 2<sup>-1</sup>  
 In revs @ 2<sup>0</sup> x 1.07975  
 In revs @ 2<sup>-1</sup>

YCOPY no longer  
 needs restart  
 protection

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		TVC DAP	
DRAWN <i>A. J. ...</i>			DOCUMENT NO.
PRGRM <i>A. J. ...</i>			
ANALST		COLOSSUS 2D	FC-2440
DOCNR <i>...</i>		REV 1	SHEET 14 OF 19
APPR'D <i>...</i>			

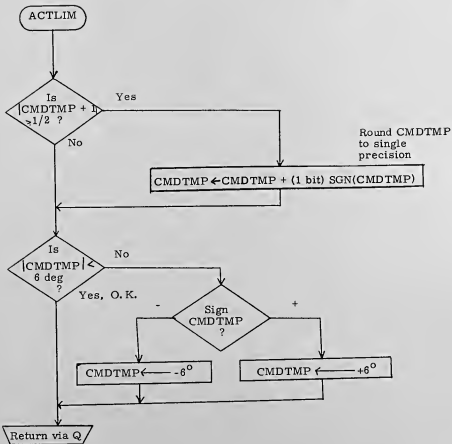


RLIMTEST



If  $|A| > 2.33$  deg, set to zero.  
This filters out spurious pulses  
in the more significant bits  
of the CDU.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. G. ...</i> 4/19/68		TVC DAP	
PRGMR <i>R. G. ...</i> 4/19/68		DOCUMENT NO.	
ANALST <i>R. G. ...</i> 4/19/68		COLOSSUS 2D	FC-2440
DOCMR <i>R. G. ...</i> 4/19/68		REV 1	
APPR'D <i>R. G. ...</i> 4/19/68		SHEET 15 OF 19	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. L. ...</i> 9-15-69		TVC DAP	
PRGMR <i>R. L. ...</i> 10/2/69		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2440
DOCMR <i>Robert M. ...</i> 10/2/69		REV 1	SHEET 16 OF 19
APPR'D <i>Robert M. ...</i>			

SUBROUTINE CALLED WHICH IS  
FLOWED ON OTHER FLOW CHART

Subroutine Name HACK	Where Called Sh. 2, 10
Flow Chart FC-2450	Description Stroke test

ERASABLE LOCATIONS USED

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
AK <sub>1</sub> S		Attitude error for pitch needles	deg	rev	2 <sup>-1</sup>
AK <sub>2</sub> S		Attitude error for yaw needles	deg	rev	2 <sup>-1</sup>
CMDTMP <sub>D</sub>		Actuator command; updated version of PCMD <sub>S</sub> and of YCMD <sub>S</sub>	deg	rev	2 <sup>0</sup> x 1.07975
DELBRTMP <sub>D</sub>		Updated version of DELPBAR <sub>D</sub> and of DELYBAR <sub>D</sub> (below)	deg	rev	2 <sup>-1</sup>
DELPBAR <sub>D</sub>		Output of pitch DELFILTER (filtered engine command signal)	deg	rev	2 <sup>-1</sup>
DELYBAR <sub>D</sub>		Output of yaw DELFILTER (filtered engine command signal)	deg	rev	2 <sup>-1</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
TVC DAP			
DRAWN <i>G. J. ...</i>	PRGMR <i>R. ...</i>	COLOSSUS 2D	DOCUMENT NO. FC-2440
ANALST	DOCNR <i>Robert M. ...</i>	REV 1	SHEET 17 OF 19
APPRD <i>Robert M. ...</i>			

ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
ERRBTMP <sub>D</sub>	$\theta_e$	Updated version of AK1s and AK2s (above) and of PERR <sub>D</sub> and YERRB <sub>D</sub> (below)	deg	rev	$2^{-1}$
MCDUYDOT		Past CDUY value - present CDUY value	deg/sec	rev/sec	$2^{-1} \times \overline{\text{TVCDT}}$
MCDUZDOT		Past CDUZ value - present CDUZ value	deg/sec	rev/sec	$2^{-1} \times \overline{\text{TVCDT}}$
OMEGAYB <sub>D</sub>	$\omega_y$	Measured body - axis pitch rate	rad/sec	rev/sec	$2^{-1} \times \overline{\text{TVCDT}}$
OMEGAYC	$\omega_{yc}$	Pitch body rate command	rad/sec	rev/sec	$2^{-1} \times \overline{\text{TVCDT}}$
OMEGAZB <sub>D</sub>	$\omega_z$	Measured body - axis yaw rate	rad/sec	rev/sec	$2^{-1} \times \overline{\text{TVCDT}}$
OMEGAZC	$\omega_{zc}$	Yaw body rate command	rad/sec	rev/sec	$2^{-1} \times \overline{\text{TVCDT}}$
PCDUYPST		Past CDUY value (pitch)	deg	rev	$2^{-1}$
PCDUZPST		Past CDUZ value (pitch)	deg	rev	$2^{-1}$
PCMD		Incremental pitch engine command	deg	rev	$2^0 \times 1.07975$
PDELOFF <sub>D</sub>	PDELOFF	Engine trim correction (pitch)	deg	rev	$2^0 \times 1.07975$
PERR <sub>D</sub>		Body attitude error (pitch)	deg	rev	$2^{-1}$
TVCPTCH		Pitch engine command error counter	deg	rev	$2^0 \times 1.07975$

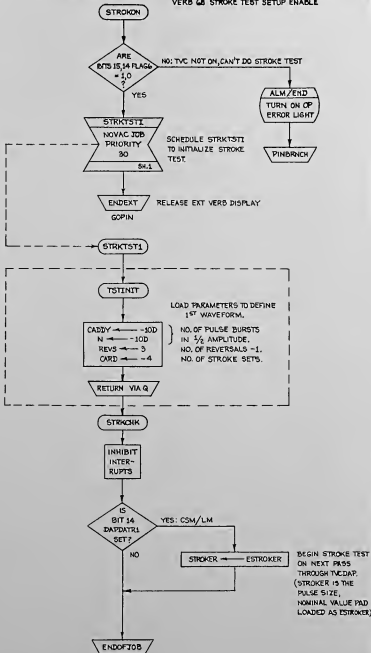
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> 1/24/69		TVC DAP	
PRGRM <i>[Signature]</i>	ANALYST <i>[Signature]</i>	COI.OSSUS 2D	DOCUMENT NO. FC-2440
DOCMR <i>[Signature]</i>	APPR'D <i>[Signature]</i>	REV 1	SHEET 18 OF 19

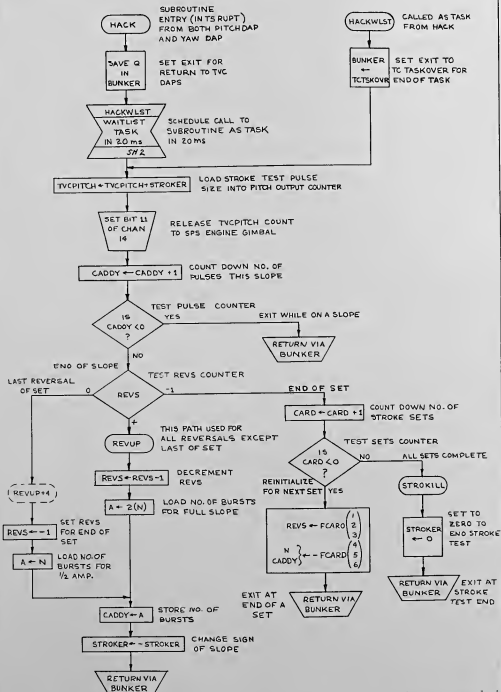
ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
TVCYAW		Yaw engine command error counter	deg/deg	rev/rev	$2^0 \times 1.07975$
VARX	VARX	Gain for pitch and yaw channels	deg/deg	rev/rev	Fof CSM $2^{+4} \times 1.07975$ Fof CSM/LM $2^{+9} \times 1.07975$
YCDUYPST		Past CDUY value (yaw)	deg	rev	$2^{-1}$
YCDUZPST		Past CDUZ value (yaw)	deg	rev	$2^{-1}$
YCMD		Incremental yaw engine command	deg	rev	$2^0 \times 1.07975$
YDELOFFD	YDELOFF	Engine trim correction (yaw)	deg	rev	$2^0 \times 1.07975$
YERRB <sub>D</sub>		Body attitude error (yaw)	deg	rev	$2^{-1}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. L. Smith</i> 9/14/67		TVC DAP	
PRGMR <i>R. G. Johnson</i> 9/14/67		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2440
DOCMR <i>R. G. Johnson</i> 10/24/67		REV 1	SHEET 19 OF 19
APPR'D <i>R. G. Johnson</i> 10/24/67			







STROKE TEST PACKAGE

FC-2450

APPROV: *John A. Moore* 2 April 67

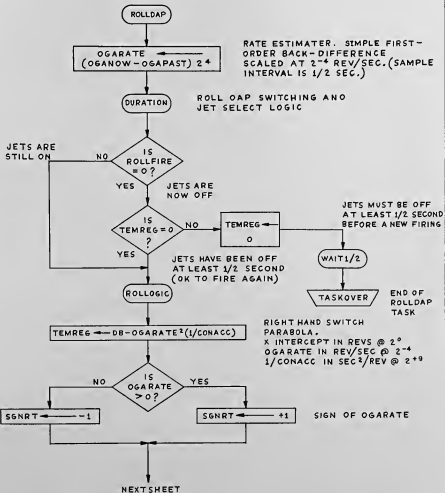
DATE: *17/4/68*

APPROV: *Red*

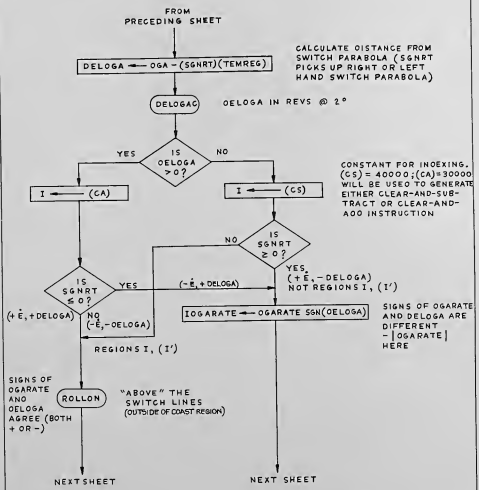
APPROV: *John A. Moore* 2 April 67

FC-2450

DATE: 2 1 2

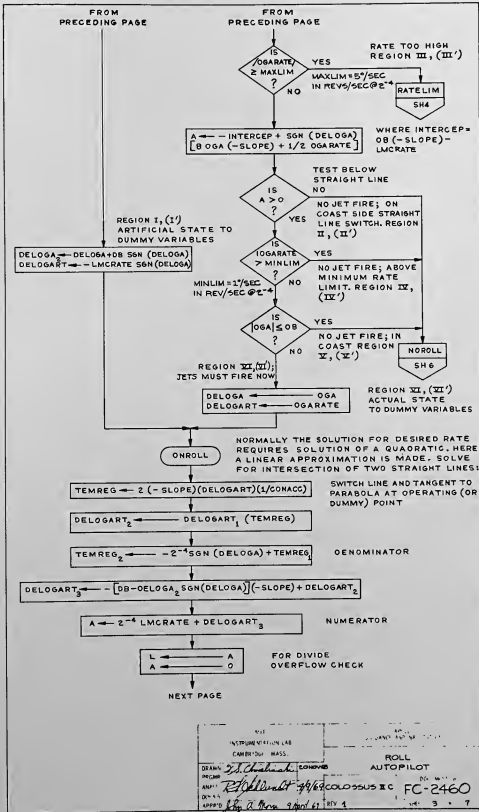


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		RACE GUIDANCE AND NAVIGATION	
DRAWN <i>A. J. Smith</i>		ROLL AUTOPILOT	
PRGMR <i>A. J. Smith</i>		DOCUMENT NO.	
ANALYST <i>A. J. Smith</i>		FC-2460	
DOING		SHEET 1 of 9	
APPROV <i>A. J. Smith</i>		REV 4	

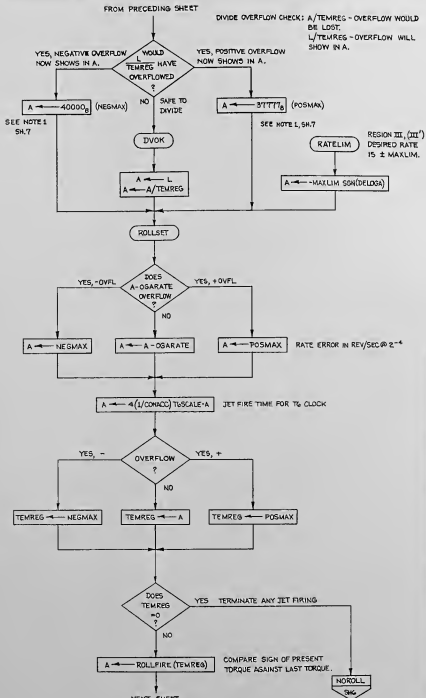


NOTE:  
 1. PHASE PLANE REGIONS REFER TO FIGURE 3.3.14 OF FORTHCOMING COLOSSUS G SOP SECTION 3 R-577 (REV 4 OR 5)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPELL GRADIENT AND ANALYST	
DRAWN <i>A. J. Lemoyne</i>		ROLL AUTOPILOT	
REVISED <i>A. J. Lemoyne 7/19/69</i>		COLOSSUS IIC FC-2460	
APPROVED <i>John A. Tramm 9/10/69</i>		REV 1	



DATE	INSTRUMENTATION LAB CAMBRIDGE MASS.	ROLL AUTOPILOT
DRAWN <i>J.A. Chubbuck</i>	CONTRNO	NO. 1111
APPROV <i>R.H. Bell</i>	4/16/69	COLLOSSUS IIC FC-2460
DATE 9 April 69	REV 1	REV 3 - 7



ROLL AUTOPILOT

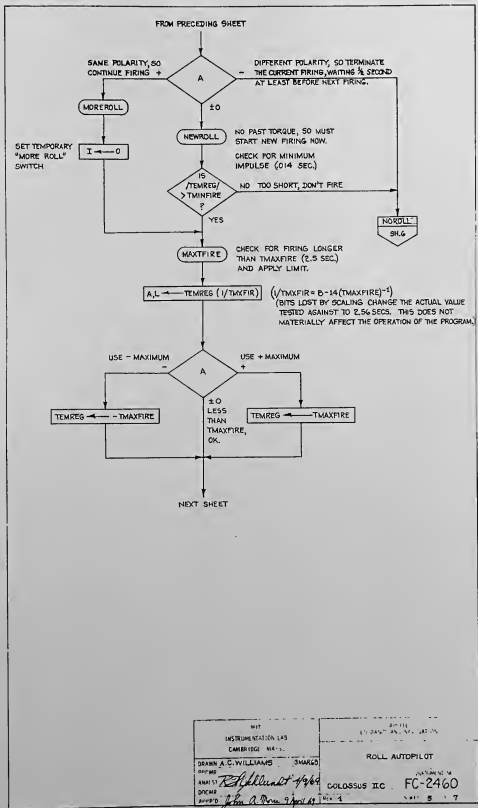
DESIGNED BY A.C. WILLIAMS

DATE 12/1/67

APPROVED BY John A. Brown 7/10/67

COLLOSSUS IIC FC-2460

REL 1 4 7



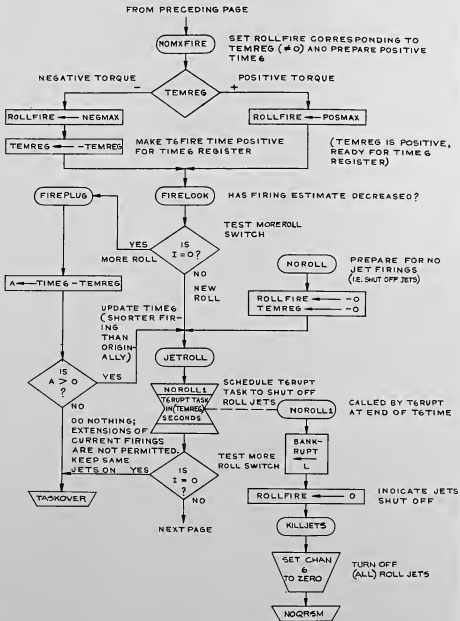
WIT  
INSTRUMENTATION LAB  
CAMBERIDGE MA-1.

DRAWN A.C. WILLIAMS 3MARGO  
OFFICE  
ANALYST *R. Hallinan 4/66*  
CHECKED  
APPROVED *John A. Rowe 9 April 69*

ROLL AUTOPILOT

COLOSSUS IIC FC-2460

REV. 4



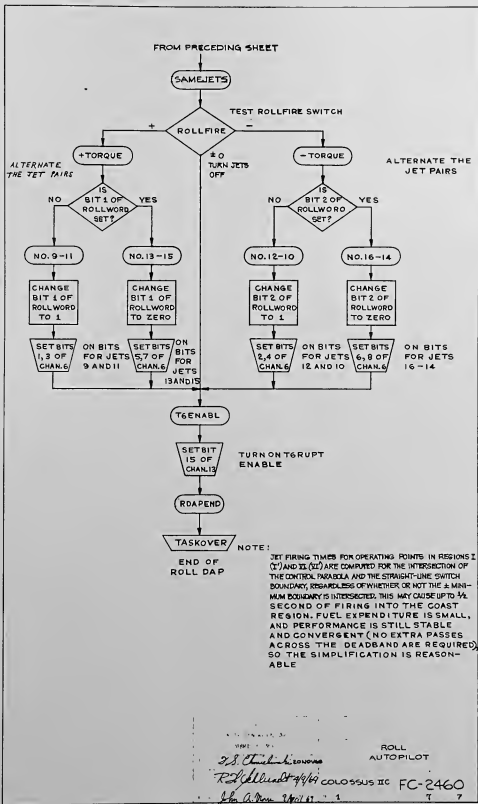
REVISIONS

288  
 289  
 290  
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 297  
 298  
 299  
 300

ROLL  
 AUTOPILOT

COLOSSUS IIC FC-2460





ROLL  
AUTOPILOT

*S.S. Chalkhikov*  
*R. J. Hilliard 9/9/61* COLOSSUS IIC FC-2460  
*John A. Dorn 9/11/61*

T 7

## PRELAUNCH INITIALIZATION &amp; GYRO COMPASSING

## MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

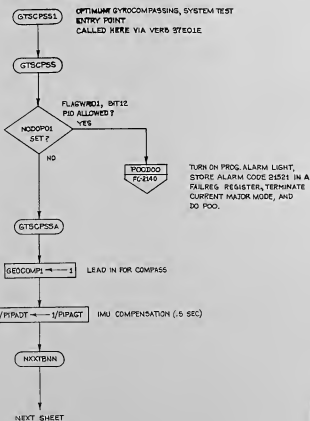
GTSCPSS1	(P01) OPTIMUM GYROCOMPASSING, SYSTEM TEST	SH. 2
GOESTIMS	WAKE ESTIMS	SH. 5
PIPACHK	TORQUE PLATFORM IN PREPARATION FOR PIPA CHECK	SH. 6
PIPATASK	START PIPJOB AT 5.12 SEC INTERVALS	SH. 7
PIPJOB	PIPA CHECK ROUTINE	SH. 8
ESTIMS	(P02)	SH. 11
CHKCOMED	DETERMINE IF LIFT-OFF HAS OCCURRED	SH. 13
SETGWLIST	SET WAITLIST CALL OF ALLOOP	SH. 14
ALLOOP	READ & CLEAR PIPAS EVERY 1 SEC	SH. 15
ALFLT	PROCESS PIPA PULSES READ IN ALLOOP	SH. 16
ALFLT1	RESTART ENTRY TO ALFLT	SH. 16
ALWAYS	COMPASS AND ERECT	SH. 20
VALMIS	DISPLAY VERTICAL DRIFT	SH. 24
TORQUE	CALCULATE EARTH'S ROTATION IN GYRO PULSES	SH. 25
SHOW	DISPLAY VERTICAL GYRO DRIFT	SH. 25
CKOPTVP	(P03) (V85)	SH. 26
COMPVER	OPTICAL VERIFICATION OF GYRO COMPASSING	SH. 26
SYSTEM	(P07) (V92)	SH. 31
EXDAPOFF	SHUT DOWN AUTOPILOT	SH. 31
REDO	PRELAUNCH SERVICE GYROCOMPASSING	SH. 31
LFTFLGON	(V75) INDICATE LIFTOFF HAS OCCURRED	SH. 33
CHAZFOGC	(V78) UPDATE PRELAUNCH AZIMUTH	SH. 33
AZMTHG01	SET NEW AZIMUTH	SH. 34
ZERONG	ZERO A SET OF REGISTERS	SH. 35
OVERFFIX	FIX OVERFLOW IN MPAC <sub>D</sub>	SH. 36
IMUSTLLG	STALL UNTIL IMU OPERATION DONE	SH. 36
COAALIGN	COARSE ALIGN IMU TO ZERO ANGLES	SH. 36
POSN17C	SET SM COORDS TO LAUNCH ALIGNMENT	SH. 36
EARTH* <sup>*</sup>	DO EARTH RATE COMPENSATION	SH. 37
PROUT	DELAY UNTIL GYRO TORQUING DONE	SH. 37
SOMERR2	SEND 1601 ALARM AND EXIT	SH. 37
SOMEERRR	SEND 1600 ALARM AND EXIT	SH. 37
EARTH	DO GYRO TORQUING FOR EARTH RATE COMPENSATION	SH. 38
EARTH* 3	TIME, RETURN VARIABLE ENTRY TO EARTH	SH. 38
CHECKG	MONITOR VERTICAL PIPA FOR PIPA PULSE	SH. 39
FINETIME	READ CLOCK AND SCALERS	SH. 40
ERTHRVSE	INITIALIZE EARTH RATE VECTOR	SH. 41
ERASCALC	ERASABLE SINE, COSINE CALCULATIONS	SH. 42
TARGDRVE	DRIVE OPTICS TO TARGET	SH. 43
TAR/EREF	PUT TARGET IN REFERENCE COORDINATES	SH. 45
LITLSUB	CONVERT SHAFT, TRUNNION ANGLES TO VECTOR IN SM COORDS	SH. 46
LATAZCHK	DISPLAY SM AZIMUTH, LATITUDE	SH. 47

ENCLOSED ARE REPLACEMENT SHEETS TO UPDATE THE COLOSSUS IIA FLOW-CHART FC-2530, REV. 1, TO THE COLOSSUS IIC FLOWCHART FC-2530, REV. 2. CHANGED SHEETS ARE: 2, 31, 34.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY <i>E. J. Quinn</i>		P01, P02, P03, P07 PRELAUNCH INITIALIZATION & GYRO COMPASSING	
PROGRAM <i>E. J. Quinn</i>		DOCUMENT NO. FC-2530	
ANALYST		COLOSSUS IIC	REV B
DRAWN M. LEMAN		SHEET 1 OF 47	
APPROVED BY <i>[Signature]</i>			

PO1-PO2  
PRELAUNCH SERVICE INITIALIZATION PROGRAM

IMU PERFORMANCE TESTS



DRAWN A.G. WILLIAMS DATE E.S. G... CHECKED M.D. Cowan BY John A. ...	INSTRUMENTATION LAB WAREHOUSE, MASS. 23 MAR 68 4789	PO1, PO2, PO3, POT PRELAUNCH INITIALIZATION & GYRO COMPASSING COLOSSAUS IIC FC-2530 2 47
---	--	--

FROM PRECEDING SHEET

LENGTH ← 640  
1 SECT1 ← .5 SEC  
PREMTRX1 ← 1  
PERPDLAY ← +0  
PERFDLAY ← 1  
NEWAZ10 ← LUNCHAZ10  
OLDAZMTH0 ← LUNCHAZ10

LENGTH OF HORIZ. GYRO DRIFT TEST = 640 SEC  
COMPASS IS A .5 SEC LOOP  
NAVIG. BASE ORIENTATION CODE = +0  
(NORMAL SPACECRAFT ORIENTATION)  
INITIALIZE NEW AND OLD LAUNCH  
AZIMUTH

SETUPGC

SET UP GYROCOMPASSING

ZERONDX1 ← DEC17  
A ← GENADR(XSM)

SET UP ROUTINE ZEROING TO SET  
THE 48 REGISTERS STARTING AT XSM  
TO +0

ZEROING  
ZERO STABLE  
MEMBER COORD  
REGISTERS  
SH85

INPUT: ZERONDX1 = (NO. OF REGISTERS TO  
BE ZEROED) - 1.  
A = ADRES OF FIRST REGISTER TO  
BE ZEROED

OUTPUT: XSM<sub>v</sub> = 0<sub>v</sub>  
YSM<sub>v</sub> = 0<sub>v</sub>  
ZSM<sub>v</sub> = 0<sub>v</sub>

POSNI7C  
INITIALIZE  
STABLE MEMBER  
COORDS TO  
LAUNCH ALIGNMENT  
SH36

OUTPUT: XSM<sub>v</sub> = 0, COS(NEWAZ1), SIN(NEWAZ1)  
YSM<sub>v</sub> = 0, SIN(NEWAZ1), COS(NEWAZ1)  
ZSM<sub>v</sub> = -1, +0, +0  
ALL UNIT VECTORS @ 2°

GYCOMUTT

GYROCOMPASSING

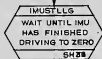
IMUZERO  
ZERO THE IMU  
FC-2210

SWITCH TO IMU ZERO MODE  
SET UP JOB TO DRIVE STABLE  
MEMBER TO ZERO GIMBAL ANGLES;  
INITIALIZE IMU-CDU COUNTERS CDUX,  
CDUY AND CDUZ.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN: <i>[Signature]</i> , 22 NOV 64		POS1, POS2, POS3, POS4	
PREPARED: <i>[Signature]</i> , 17/64		PRELAUNCH INITIALIZATION & GYRO COMPASSING	
ANALYST: <i>[Signature]</i>		DOCUMENT NO.	
DOC NO: <i>[Signature]</i>		COLOSSUS IIC FC-2530	
APPROVED: <i>[Signature]</i> , April 65		REV 2	
		1-41 3 47	

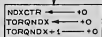
FROM PRECEDING SHEET



PUT THIS JOB TO SLEEP UNTIL IMU MODING FINISHED



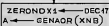
COARSE ALIGN THE IMU TO ZERO GIMBAL ANGLES



INITIALIZE DISPLAY TEMPS  
TORQNOX = HORIZONTAL DRIFTTEST



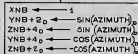
SET UP AZIMUTH AND VERTICAL IN NAVIGATION BASE COORDINATES



SET UP INPUTS TO ZEROING



INPUTS: ZEROND X1 = (NO. OF REGISTERS TO BE ZEROED) - 1.  
A = ADRES OF FIRST REGISTER  
OUTPUT: XNB<sub>v</sub> = 0; YNB<sub>v</sub> = 0; ZNB<sub>v</sub> = 0



SET NAV BASE COORDS TO LAUNCH ALIGNMENT:  
XNB<sub>v</sub> = 1, 0, 0  
YNB<sub>v</sub> = 0, SIN(AZIMUTH), COS(AZIMUTH)  
ZNB<sub>v</sub> = 0, -COS(AZIMUTH), SIN(AZIMUTH)  
ALL UNIT VECTORS @ 2°.



YES

NO

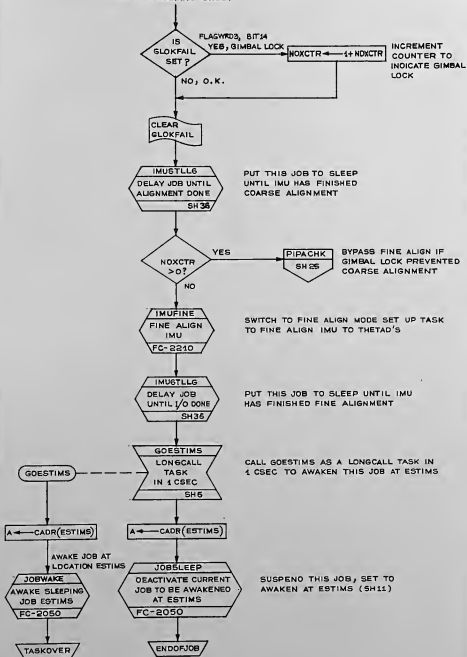
INPUT: XNB<sub>v</sub> YNB<sub>v</sub> ZNB<sub>v</sub> N.B. COORDS  
XSM<sub>v</sub> YSM<sub>v</sub> ZSM<sub>v</sub> S.M. COORDS  
OUTPUT: THETA0, THETA0+1, THETA0+2, -  
DESIRED GIMBAL ANGLES



NEXT SHEET

INST. NO. 1 CAMBRIDGE, MASS.	PRELAUNCH INITIALIZATION & GYRO COMPENSING COLUSSUS IIC FC-2530
DESIGNED BY: <i>P. M. ...</i> DRAWN BY: <i>E. S. ...</i> CHECKED BY: <i>E. S. ...</i> APPROVED BY: <i>E. S. ...</i>	REV 2

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVE LUDWIG AND SAUNDERS	
DESIGNED BY <i>P.H. Dierker</i>		PRELIMINARY INITIALIZATION & GYRO COMPASSING	
DRAWN BY <i>E.J. Quinn</i>		DOCUMENT NO.	
ANALYST <i>E.J. Quinn</i>		COLOSSUS IIC FC-2530	
CHECKED BY <i>J.P. ...</i>		REV 2	
APPROVED BY <i>A. ...</i>		REV 2	

PIPACHK

TORQUE PLATFORM TO CORRECT LEVELING ERROR IN PREPARATION FOR MEASURING VERTICAL PIPA OUTPUT PULSE RATE

YES  
NDXCTR = 1?

COURSE ALIGN MODE

NO

EARTH#  
TORQUE GYROG  
BY EARTH RATE  
ANGLES  
SH38

LENGTHOT ← OCT 25  
RESULTCT ← 1  
PIPAX# PIPINOEX ← +0  
DATAPL ← +0  
GATAPL+4 ← +0

INITIALIZE

ZERO VERTICAL PIPA COUNTER  
GATAPL = DATA STORAGE COUNTER  
GATAPL+4 = OVERFLOW IN PIPA COUNTER

CHECKG  
OBTAIN CONTENTS  
OF VERTICAL PIPA  
COUNTER AND TIME  
SH39

INHIBIT  
INTER-  
RUPTS

PIPATASK  
TWIGOLE  
IN 2 CSEC  
SH7

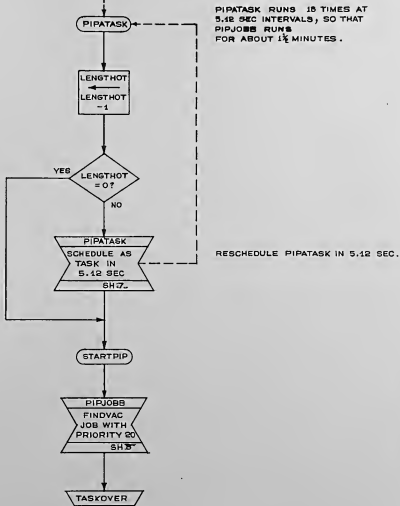
SCHEDULE PIPATASK TO  
RUN IN .02 SEC

ENOOFJOB

NEXT SHEET

MIT INSTRUMENTATION LAB AMBRIDGE, MASS.		CONTROL AND SERVICE	
DRAWN <i>P.H. D'...</i>	DESIGNED <i>J.J. G...</i>	FOI, POE, POS, POT, FREELANCE INITIALIZATION & GYRO COMPASSING	
PROGRAM	ANALYST	COLOSSUS IC	DOCUMENT NO FC-2530
DOCNO <i>2.4</i>	APPROV <i>P.H. D'...</i>	REV 2	REV 6 47

FROM PRECEDING SHEET

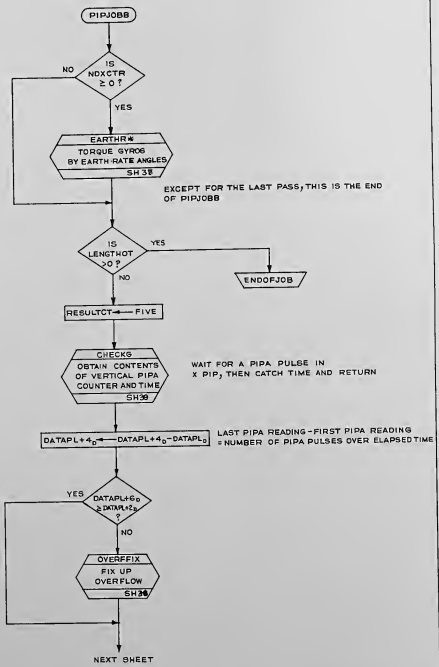


PIPATASK RUNS 18 TIMES AT 5.12 SEC INTERVALS, SO THAT PIPJOB RUNS FOR ABOUT 1½ MINUTES.

RESCHEDULE PIPATASK IN 5.12 SEC.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APC 110 GUIDANCE AND NAVIGATION	
DRAWN <i>D. B. Dwyer</i>		PRELIMINARY INITIALIZATION & GYRO COMPASSING	
PROGRAM <i>S. J. Gorman</i>		DOCUMENT NO.	
ANALYST <i>W. K. L.</i>		COLOSSUS SEC FC-2530	
DOCS <i>M. J. Johnson</i>		REV 2	
APPROV'D <i>J. W. ...</i>		SHEET 7 OF 49	





MIT UNIVERSITY RESEARCH LABORATORY CAMBRIDGE, MASS.		MIT GUIDANCE AND TRAINING CENTER	
DRYAN <i>P.M. Dutton</i>	DOCNO	PO1, PO2, POS, POT,	PRELAUNCH INITIALIZATION & GYRO COMPASSING
PROGMP <i>2.2.2</i>	11/169	COLLOSSUS II C	JOB UNIT NO.
ANAL ST		FC-2530	
DOCNO <i>2.2.2</i>			
APPROV <i>John D. Brown</i>			SHEET 8 OF 47

FROM PRECEDING SHEET

AINGOTN

MPAC<sub>2</sub> ←  $\frac{\text{DATAPL}+4 \times \text{DEC}585}{\text{DATAPL}+6} - \frac{\text{DATAPL}+2}{2}$

DEC. 585 = CSM IDEAL SCALE FACTOR

SGNABREE  
FORCE SIGNS  
TO AGREE  
FC-2100

INPUT : MPAC  
OUTPUT: MPAC WITH SIGN AGREEMENT

DSPTM2<sub>0</sub> ← MPAC<sub>0</sub>

VERTICAL PIPA RATE

YES  
NOXCTR  
> 0 ?

COALIGN  
TAKE PLATFORM  
OUT OF  
GIMBAL LOCK  
SH36

NO

SHOW  
DISPLAY VERTICAL  
PIPA RATE IN (SEC<sup>2</sup>)  
SH25

VERTDRFT

VERTICAL DRIFT TEST

LENGTHOT ← 3990 DEC  
DRIFT ←  $\frac{\text{SOUTH DR}-2}{2}$  POSITION

3990 SECS FOR LENGTH OF TIME FOR  
ESTIMATING VERTICAL DRIFT

(X) YES

XSM+4  
= 0 ?

NO (Z)

PON2

PON4

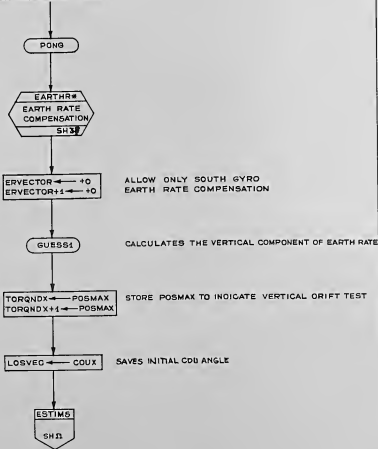
ERCOMP1+2 ← ERCOMP1+2-16D  
ERCOMP1+4 ← ERCOMP1+4+16D

ERCOMP1+2 ← ERCOMP1+2-16D  
ERCOMP1 ← ERCOMP1-16D

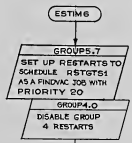
NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFDLO CIVILIAN AND NAUTICAL CA.	
DESI: <i>P.M. [Signature]</i>		6 DEC 68 PRELAUNCH INITIALIZATION & OVRD COMPRESSING	
PRGM: <i>S.J. [Signature]</i> 4781		DOCUMENT NO:	
ANALYST		COLOSSUS IIC FC-2530	
DOCS: <i>[Signature]</i>		REV 2	
APPROV: <i>[Signature]</i>		SHEET 9 OF 47	

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		REV: 0 REV: 1 REV: 2
DRAWN: <i>P.M. Dietrich</i>		PO1, PO2, PO3, PO7
DESIGN: <i>S.L. Gunn</i>	SYNOPSIS: PRELAUNCH INITIALIZATION & GYRO COMPENSATION	
ANALYST:	COLOSSUS Ic	FC-2530
DATE: <i>1/2/68</i>	REV: 2	SHEET 10 OF 47
APPROVED: <i>J. A. Brown</i>		



ENTRY POINT FOR RESTART

CURRENT TIME  
ZERO THE PIPAS

SET PARAMETERS FOR ZEROING SUBROUTINES

ZERO LOCATIONS ALX15 - 1 TO  
ALX15 + 76

IMU COMPENSATION INITIALIZATION

ALX15 USED AS INDEX AT ALKGG IN  
LOADING SLOPES AND TIME CONSTANTS

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	ARJLO STABILITY AND NAVIGATION
TO: SA <i>Phil Dietrich</i> FR: MR <i>E.S. Green</i> ANALYST INCHARGE <i>John A. Moran</i>	14 NOV 64 PRELAUNCH INITIALIZATION OF GYRO COMPENSING COLCUBUS IIC FC-2530 REV 2 11 47

FROM PRECEDING SHEET

YES  
GEOCOMP1  
= 40 ?

NO, DO GYRO COMPASSING

ERTHRV6E  
CALC. EARTH  
RATE VECTOR  
SH43

OUTPUT : ERVECTOR = EARTH RATE VECTOR

ERECTIME ← LENGTHOT

NEWMODEX  
UPDATE PROGRAM  
NO, DISPLAY ON  
DESKY TO PO2  
FC-2030

NOW BECOMES PO2

PIPUSE  
INITIATE PROGRAM  
USE OF PIPA'S  
FC-2240

SET IMODES30 TO CAUSE ISS WARNING  
ON SUBSEQUENT PIPA FAILURE

ANNNNNN

END OF FIRST PASS

LENGTHOT ← 9

COUNTER FOR  
LOOP CONTROL

SLEEPIE

DEACTIVATES THE  
CURRENT JOB- DECREMENT  
LENGTHOT

LENGTHOT ← A

SLEEPIE + 1

GROUPS.13  
SET UP RESTARTS  
TO SCHEDULE WTLISTNT  
AS A FINDVAC JOB  
WITH PRIORITY 20

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	FC1, PO2, PO3, POT, PRELAMBDA INITIALIZATION & GYRO COMPASSING
DRAWN <i>D. McDiarmid</i> 1/15/68	FC-2530
PRIME <i>E. S. Stone</i> 1/16/68	MIT 22 - 47
ANALYST	COLOSSUS IIC
DATE	REV 2
APPROVED <i>J. A. DeW</i> 1/26/68	

FROM PRECEDING SHEET

NO  
TORQNOX  
= 4?

YES, WE ARE DOING VERTICAL DRIFT

EARTH R  
TRUE TORQUE  
SOUTH GYRO  
SH37

WTLISTINT

SEE IF COMPASSING OVER

CHKCOMED

DETERMINE IF LIFT-OFF HAS OCCURRED

INHIBIT  
INTER-  
RUPTS

YES  
MODREG  
= T? POT RUNNING?

NO  
BITS OF  
CHAL300P? YES (LIFTOFF HAS OCCURRED)

NO  
IS  
BITS FLAMERS  
SET? YES (BACKUP LIFTOFF)

ALLOW  
INTER-  
RUPTS

GOBKCALD

RETURN  
VIA Q

PRELTERM

PRIOCHNG  
CHANGE PRIORITY  
TO 22  
FC-2050

PRELAUNCH DONE -  
SET UP P41 INCREASE  
PRIORITY HIGHER  
THAN SERVICER

INHIBIT  
INTER-  
RUPTS

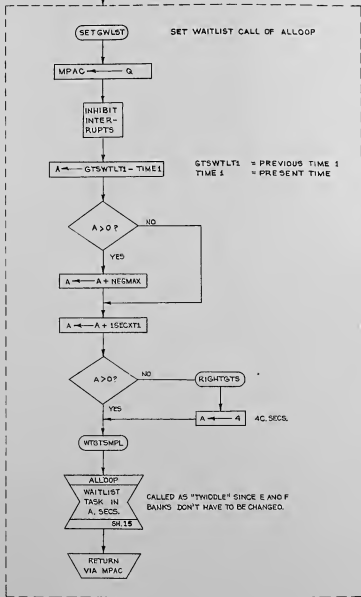
GO TO PROGRAM P41

P41  
FC-2540

NEXT SHEET

UNIT ELECTRIC MECHANICAL LAB 1000 BRIDGE WASS OPERATOR <i>R. S. Green</i> CHECKER <i>R. S. Green</i> ANALYST DOCUMENTED BY <i>R. S. Green</i> APPROVED BY <i>R. S. Green</i>	APPROVED GO-DANCE AND NAVIGATION P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING DOCUMENT NO. COLOSSUS XG FC-2530 SHEET 13 OF 47
---	---

FROM PRECEDING SHEET

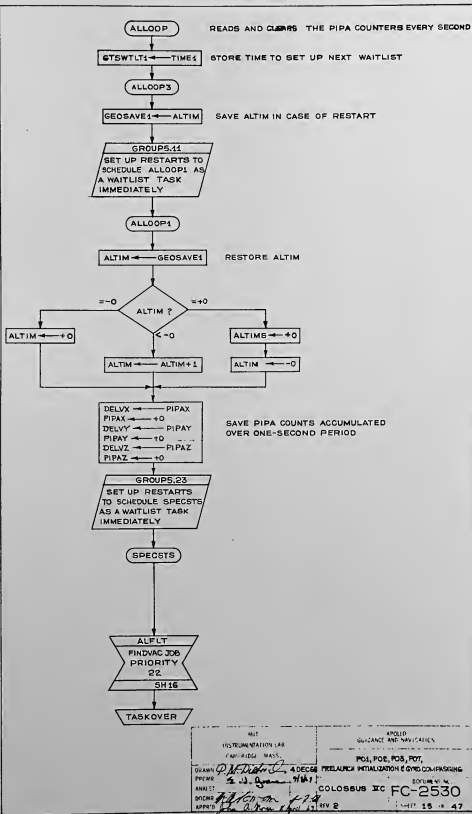


SET WAITLIST CALL OF ALLOOP

GTSWLT1 = PREVIOUS TIME 1  
TIME 1 = PRESENT TIME

CALLLED AS "TWIDDLE" SINCE E AND F BANKS DON'T HAVE TO BE CHANGED.

W. J. WILLIAMS  
 S. INFORMATION I  
 1485-101 3/A  
 A.C. WILLIAMS  
 E.J. Green  
 17/64  
 POS, POZ, PDS, PQT,  
 PRELAPION INITIALIZATION & GYRO COMPRESSING  
 COLOSSUS II C  
 FC-2530  
 14 47

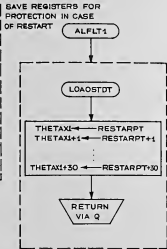
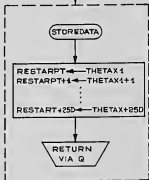


MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		PROJECT GUIDANCE AND VARIABLES	
DRAWN: <i>P. M. ...</i>		POL, POS, PPS, POT,	
PREPARED: <i>S. J. ...</i>		PRELIMINARY INITIALIZATION & GYNO COMPENSATING	
ANALYST:		DOCUMENT NO.	
CHECKED: <i>P. J. ...</i>		COLOSSUS IIC FC-2530	
APPROVED: <i>J. A. ...</i>		REV 2	
		SHEET 15 OF 47	



ALFLT

PROCESS PIPA PULSES READ IN ALLOOP



GROUPS.04  
SET UP RESTARTS TO SCHEDULE ALFLT1 AS A FINDAC JOB WITH PRIORITY 22

GEOCOMP1 = 0?

NO-GYROCOMPASS

YES (IMU)

CHKCME0  
LIFTOFF OCCURRED  
SH13

1/PIPA  
COMPENSATE PIPA COUNTS  
FC-2230

COMPENSATE PIPA COUNTS FOR BRAS AND SCALE FACTOR ERROR

NORML0P

CONVERT DELX<sub>v</sub> TO STABLE MEMBER COORDS

DELX<sub>v</sub> = PIPA COUNTS SAVED BY ALLOOP

MPAC<sub>v</sub> ← XSM<sub>v</sub> X OELX<sub>v</sub>

DPIPAY<sub>0</sub> ← (MPAC+5)  
DPIPAZ<sub>0</sub> ← (MPAC+5)  
X1 ← 8D

Y COMPONENT } OF OELX IN  
Z COMPONENT } S.M. COORDS

GEOCOMP1 > 0?

NO (GYRO)

YES (IMU)

ALWAYS6  
SH10

ALGGKK

ALTIMS < 0?

ALFLT3  
SH17

NEXT SHEET

MIL INSTRUMENTATION LAB CAMBRIDGE MASS		SHELL LIBRARY AND REPERT	
DRAWN BY: <i>[Signature]</i>		REV 001, 002, 003, 004	
PROGRAMMER: <i>[Signature]</i>		PRELIMINARY INITIALIZATION & GYRO COMPENSATION	
ANALYST: <i>[Signature]</i>		REV 005, 006	
CHECKED BY: <i>[Signature]</i>		COLOSSUS IIC FC-2530	
APPROVED BY: <i>[Signature]</i>		REV 2	
		11-16-67	

FROM PRECEDING SHEET

ALKG

ALDK-2 ← ALFDK	NO. OF SECS. FOR THESE PARAMETERS (COMP.)
ALDK ← ALFDK+2	TIME CONSTANT FOR PIPA OUTPUT
ALDK+2 ← ALFDK+4	TIME CONSTANT FOR ERECTION ANGLES
ALDK+4 ← ALFDK+6	SLOPE FOR AZIMUTH ANGLE
ALDK+6 ← ALFDK+8	SLOPE FOR VERTICAL DRIFT
ALDK+8 ← ALFDK+10	SLOPE FOR NORTH-SOUTH DRIFT

ALFLT3

DEMLP

INTY <sub>0</sub> ← INTY - (DPIPAV) (PIPAS <sub>0</sub> )	SOUTH PIPA INTEGRAL FROM GRAVITY AND MISSILE AWAY
INTZ <sub>0</sub> ← INTZ - (DPIPAZ) (PIPAZ <sub>0</sub> )	
DELM <sub>0</sub> ← 4 (VELSC) (VLAUN) - INTY <sub>0</sub>	MEASUREMENT DIFFERENCE
DELM+2 <sub>0</sub> ← 4 (VELSC) (VLAUN+2) - INTY <sub>0</sub>	EAST PIPA INTEGRAL FROM GRAVITY AND MISSILE AWAY
DELM+4 <sub>0</sub> ← 4 (VELSC) (VLAUN+4) - INTY <sub>0</sub>	MEASUREMENT DIFFERENCE
DELM+6 <sub>0</sub> ← 4 (VELSC) (VLAUN+6) - INTY <sub>0</sub>	

ALILP

UPDATE GAINS FOR CURRENT MEASUREMENT

ALK <sub>0</sub> ← (ALK <sub>0</sub> ) (ALDK <sub>0</sub> )
ALK+2 <sub>0</sub> ← (ALK+2 <sub>0</sub> ) (ALDK+2 <sub>0</sub> )

ALKLP

INCORPORATE CURRENT PIPA MEASUREMENTS INTO STATE VECTOR

INTY ← INTY + ALK . DELM	SOUTH PIPA INTEGRAL FROM GRAVITY
ALK+4 ← (ALK+4) + (ALDK+4)	GAIN
ANGX ← ANGX + DELM (ALK+4)	AZIMUTH ALIGNMENT ANGLE
VLAUN ← VLAUN + 2 ALSK . DELM	LAUNCH VEHICLE HORIZ. VELOCITY ALONG NORTH-SOUTH
ANGZ ← ANGZ + (ALK+2) (DELM+2)	EAST AXIS LEVELING ANGLE
ALK+6 ← (ALK+6) + (ALDK+6)	GAIN
DRIFTO ← DRIFTO + (DELM+2) (ALK+6)	VERTICAL GYRO DRIFT
ACCWD ← ACCWD + 2 (ALSK+2) (DELM+2)	LAUNCH VEHICLE HORIZ. ACCELERATION ALONG NORTH-SOUTH
INTZ ← INTZ + ALK (DELM+4)	EAST PIPA INTEGRAL FROM GRAVITY
ALK+8 ← (ALK+8) + (ALDK+8)	GAIN
DRIFT ← DRIFT + (DELM+4) (ALK+8)	SOUTH GYRO DRIFT
VLAUN+4 ← VLAUN+4 + 2 ALSK (DELM+4)	LAUNCH VEHICLE HORIZ. VELOCITY ALONG EAST-WEST
ANGY ← ANGY + (ALK+2) (DELM+6)	SOUTH AXIS LEVELING ANGLE
ALK+10D ← (ALK+10D) + (ALDK+10D)	GAIN
DRIFT+2 ← DRIFT+2 + (DELM+6) (ALK+10D)	EAST GYRO DRIFT
ACCWD+4 ← ACCWD+4 + 2 (ALSK+2) (DELM+6)	LAUNCH VEHICLE HORIZ. ACCELERATION ALONG EAST-WEST

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLC GUIDANCE AND NAVIGATION	
DRAWN BY <i>[Signature]</i>		POL, FOR, POS, POT,	
CHECKED BY <i>[Signature]</i>		PRELAUNCH INITIALIZATION & GYRO COMPENSATION	
APPROVED BY <i>[Signature]</i>		COLOSSUS IIC FC-2530	
DATE <i>1-7-61</i>		REV 2	
		PAGE 17 OF 47	

FROM PRECEDING SHEET

LOOSE

EXTRAPOLATES THE UPDATED WIND EFFECTS FOR NEXT MEASUREMENT TIME

$MPAC_V \leftarrow (TRANS M_{10}) (POS_{NV}, VLAUN_3, ACCWO_3)$   
 $POS_{NV} \leftarrow MPAC_D$   
 $VLAUN_D \leftarrow MPAC + 3_D$   
 $ACCWO_D \leftarrow MPAC + 5_D$   
 $MPAC_V \leftarrow (TRANS M_{10}) (POS_{NV} + 4, VLAUN + 4, ACCWO + 4)$   
 $POS_{NV} + 4 \leftarrow MPAC_D$   
 $VLAUN + 4 \leftarrow MPAC + 3_D$   
 $ACCWO + 4 \leftarrow MPAC + 5_D$

X COMPONENT  
 Y COMPONENT  
 Z COMPONENT  
  
 X COMPONENT  
 Y COMPONENT  
 Z COMPONENT

BOCP

CALCULATES THE SINES AND COSINES OF THE GIMBAL ANGLES

$PL10D \leftarrow 2 \sin(1/4 \text{ GEORGEJ. ANGX})$   
 $PL16D \leftarrow \cos(1/4 \text{ GEORGEJ. ANGX})$   
 $PL12D \leftarrow 2 \sin(1/4 \text{ GEORGEJ. ANGY})$   
 $PL18D \leftarrow \cos(1/4 \text{ GEORGEJ. ANGY})$   
 $PL14D \leftarrow 2 \sin(1/4 \text{ GEORGEJ. ANGZ})$   
 $PL20D \leftarrow \cos(1/4 \text{ GEORGEJ. ANGZ})$

GEORGE J 0.6366... CONVERTS FROM RADIANS TO GYRO PULSES ANGX, Y, Z = GIMBAL ANGLES IN RADIANS THAT THE STABLE MEMBER HAS DRIFTED.

PERFERAS

EBANK ← 70

SET EBANK TO 7

ERASCALC  
CALCULATES SINES AND COSINES  
SH42

CALL ERASABLE PROGRAM STARTING AT LOCATION 1400 OF EBANK 7

ONCEMORE

LENGTHOT > 0?

YES, TEST NOT OVER YET

SLEEPIE  
SH12

NO

TORQNGOS > 0?

YES

NO

LOSVEC + 1 ← CDUX

SAVES FINAL CDU ANGLE

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT POL, POS, POS, POT,	
DRAWN <i>P. M. DeWitt</i>	DESIGNED <i>E. J. Gann</i>	PRELUNGEON INITIALIZATION 2 GYRO COMPENSING	3-2-60
PREPARED <i>E. J. Gann</i>	DATE <i>1/1/61</i>	COLOSSUS IIC	FC-2530
APPROVED <i>E. J. Gann</i>	DATE <i>1/1/61</i>	REV. 2	18-47

FROM PRECEDING SHEET

SETUPER1

SETS UP EARTH RATE TORQUING FOR COMPASS

OGCV ← XSM GEORGE J (ANGX, ANGY, ANGZ)

TORDINCH

GROUP5.0  
DISABLE  
GROUP 5  
RESTARTS

A ← OGCPL

IMUPULSE  
PULSE TORQUE  
THE GYROS  
FC-2210

IMUSTLLG  
DELAY JOB UNTIL  
I/O DONE  
SH 36

TORQNDX  
> 0 ?

YES

VALMIS

SH24

NO

ERTHRVSE  
CALCULATES EARTH  
RATE VECTOR  
SH61

TORQUE

SH25

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ARCUS GUIDANCE AND NAVIGATION FC1, FC2, FC3, FC7, PRELAUNCH INITIALIZATION & GYRO COMPASSING
BY: <i>P.H. Dietrich</i> FRGMP ANALYST DATE: <i>11/1/69</i> APPROV: <i>J. J. Larson</i>	DOCUMENT NO. COLOSSUS IC   FC-2530 REV B
<i>John A. Brown 8/1/71</i>	NOV 11 1969 14 47

ALWAYBG COMPASS AND ERECT

$FILDELV1 \leftarrow (FILDELV1) + GEOCONS1 [DPIPAZ - (FILDELV1)]$   
 $INTEVC1 \leftarrow (INTEVC1) + (FILOELV1)$   
 $(FILDELV1+4) \leftarrow (FILDELV1+4) + GEOCONS1 [DPIPAZ - (FILDELV1+4)]$   
 $(INTEVC1+4) \leftarrow (INTEVC1+4) + (FILOELV1+4)$

ERECTIM1 = 0?

YES - IN GYROCOMPASS

COMPSS

$THETAN1 \leftarrow THETAN1 + FILDELV1$   
 $(THETAN1+4) \leftarrow (THETAN1+4) - GEOCONS3 (FILDELV1)$   
 $(THETAN1+2) \leftarrow (THETAN1+2) - GEOCONS3 (FILDELV1+4)$   
 $\phantom{(THETAN1+2)} \phantom{\leftarrow} - GEOCONS4 (INTEVC1+4)$

$(THETAN1+2) \leftarrow (THETAN1+2) - GEOCONS2 (FILDELV1+4) + GEOCONS2 (INTEVC1+4)$   
 $(THETAN1+4) \leftarrow (THETAN1+4) - GEOCONS2 (FILOELV1) + GEOCONS2 (INTEVC1)$

ADDINDRF

ENDGTSAL

LENGTHHOT = 0?  
PLATFORM TORQUED?  
NO, WAIT

SLEEPIE  
SH12

YES - CHECK PRELAUNCH PHASE

CHKCOMED  
HAS LIFTOFF OCCURRED?  
SH12

LGYRO = 0?  
NO - GYROS BUSY - CHECK THEM IN .5 SEC

SLEEPIE1  
SH12

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	MIT GUIDANCE AND NAVIGATION POI, POE, POS, POT, PRELAUNCH INITIALIZATION & GYRO COMPASSING
DRAWN BY <i>P. M. D...</i>	2 DEC 68
PCRS <i>S. J. ...</i>	47/68
ANALYST <i>J. J. ...</i>	COLOSSUS IIC FC-2530
APPROVED <i>J. J. ...</i>	REV 2
	47

FROM PRECEDING SHEET

LASTGTS

THETA<sub>1</sub> ← ERCOMP<sub>1</sub>  
ALK<sub>0</sub> ← TMARK<sub>0</sub>

OO TORQUING INCL. EARTH RATE BRANCH FOR NEW AZIMUTH

RESTARTER

ALLOW FOR RESTARTS

GROUPS.27  
SET UP RESTARTS  
TO SCHEDULE  
RESTARTS AS A FINDAC JOB  
WITH PRIORITY 20

ERCOMP<sub>1</sub> ← THETA<sub>1</sub> + (XSM)<sub>M</sub> (THETA)<sub>V</sub>

ADD COMPASS COMMANDS INTO ERATE AFTER CONVERTING TO STABLE MEMBER COORDS.

TMARK<sub>2</sub> ← ALK<sub>0</sub>

EARTH\*  
CALCULATE AMOUNT  
OF EARTH RATE  
COMPENSATION  
SH32

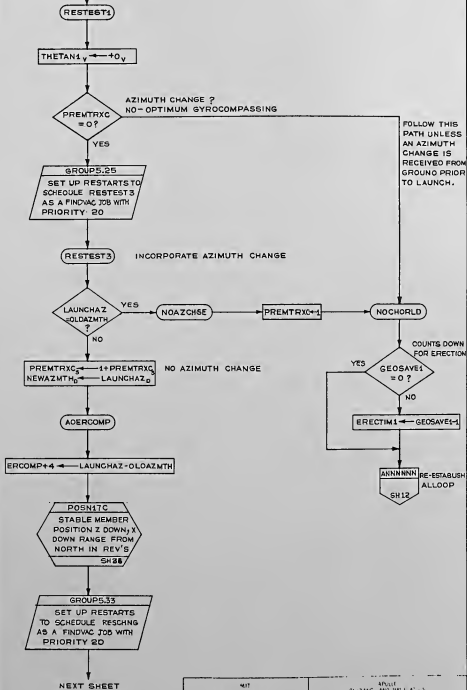
GEOSAVE1 ← ERECTIM1

GROUPS.15  
SET UP RESTARTS TO  
SCHEDULE REEST1  
AS A FINDAC JOB WITH  
PRIORITY 20

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARLCC GUIDANCE AND NAVIGATION	
DRAWN <i>R. J. DeWitt</i>		PO1, PO2, PO3, PO7. PREL LUNCH	
PREPARED <i>E. J. ...</i>		INITIALIZATION AND GYRO COMPASSING	
ANALYST <i>E. J. ...</i>		DOCUMENT NO.	
DESIGNED <i>R. J. DeWitt</i>		COLOSSUS IC FC-2530	
APPROVED <i>E. J. ...</i>		SHEET 21 OF 47	

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ADULT QUAL. AND VALIDATION	
DRAWN BY <i>N. D. ...</i>		POI, POZ, PDS, POT,	
3 DEC 66		PRELAUNCH INITIALIZATION & GYRO COMPASSING	
PCMR <i>S. J. ...</i>		REV 2	
ANALYST		COLOSSUS IIC	
DOCKED BY <i>H. ...</i>		FC-2530	
APPROVED BY <i>A. ...</i>		REV 2	
		22 - 47	

FROM PRECEDING SHEET

RESCHNG

OLOAZMTH<sub>0</sub> ← NEWAZMTH<sub>0</sub>  
 LENGHTOT ← BIT 7

SPEND 320 SEC. ERECTING

GROUP5.7

SET UP RESTARTS  
 TO SCHEDULE RSTGTS1  
 AS A FINOAC JOB WITH  
 PRIORITY 20

SPITGYRO

A ← ERCOMPPL

ERCOMPPL = ECAOR ERCOMP

IMUPULSE  
 PULSE TORQUE  
 THE GYROS  
 FC-2210

TORQUE THE IRIG'S ACCORDING TO  
 O.P. INPUTS BEGINNING AT ERCOMP

IMUSTALL  
 DELAY TO COMPLETION  
 OF PULSE TORQUING  
 FC-2220

WAIT UNTIL TORQUING DONE  
 BAD RETURN

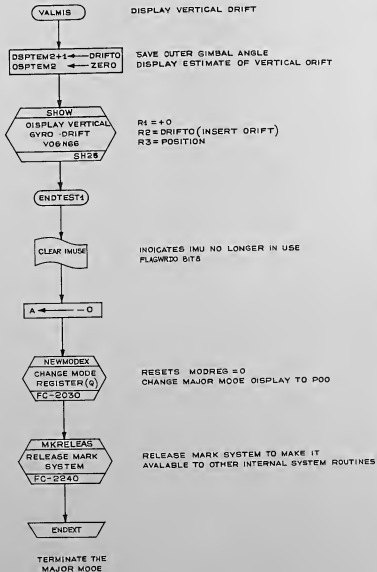
SOMERR2  
 SH37

NORMAL RETURN

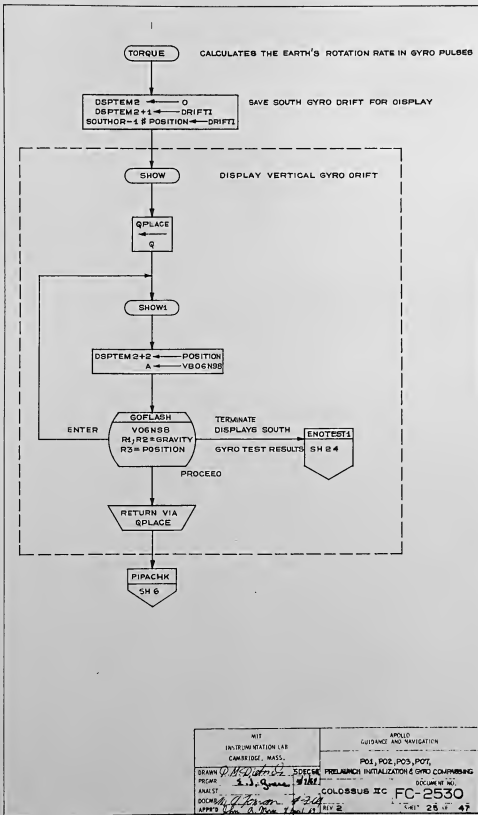
ESTIMS  
 SH11

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFSCD GUIDANCE AND NAVIGATION	
DRAWN <i>P.M. Dickson</i>		FC1, FC2, FC3, FC7,	
CHECK <i>S. S. Quinn</i>		PRELAUNCH INITIALIZATION & WIND CORRECTIONS	
ANALYST <i>S. S. Quinn</i>		DOCUMENT NO.	
DRAWN <i>P.M. Dickson</i>		COLOSSUS IIC	
APPROV <i>John A. Dickson</i>		FC-2530	
4 DEC 68		REV 2	
9761		SHEET 23 OF 47	



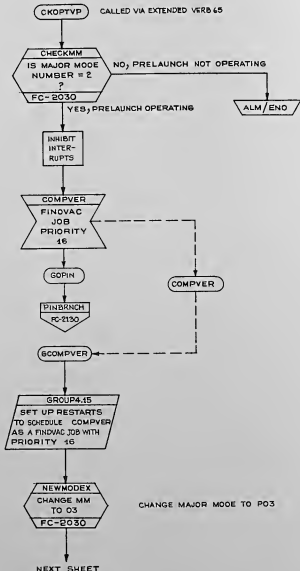


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT SOL, POS, POS, POS	
DESIGNER <i>R. H. DeGroot</i>	5 DEC 68	PRELAUNCH INITIALIZATION & GYRO COMPASSING	
PROGRAMMER <i>S. J. Gorman</i>	11/21/68	COLOSSUS IIC	
ANALYST		FC-2530	
DOCUMENTATION <i>J. J. Gorman</i>	1-22-69	REV B	
APPROVED <i>John J. Gorman</i>		24 47	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>P. M. D. [Signature]</i>		PO1, PO2, PO3, POT,	
PROGME <i>2.3. [Signature]</i>		PRELIMINARY INITIALIZATION & GYRO COMPRESSING	
ANALYST <i>[Signature]</i>		DOCUMENT NO.	
DOCNO <i>[Signature]</i>		COLOSSUS IC FC-2530	
APPROV <i>[Signature]</i>		REV 2	
		PAGE 25 OF 47	

OPTICAL VERIFICATION OF GYROCOMPASSING



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT GYROCOMPASSING	
SPONSOR <i>P.N. Diederich</i>		PROJECT PRELAUNCH INITIALIZATION & GYRO COMPASSING	
ANALYST <i>E. J. ...</i>		COLLOSSUS IIC FC-2530	
APPROVED <i>J. A. Moore</i>		REV 2	

-REV 26 - 47

FROM PRECEDING SHEET

SETNBPOS

CALC. B'C ORIENTATION  
 STARAD ← SCNBAZ + NBPOS = N.B. AZIMUTH  
 STARAD+8 ← SCNBVER + NBPOS = N.B. VERTICAL

NBPOSPL  
 SET UP AZIMUTH  
 AND VERTICAL VECTORS  
 FOR AX ISGEN  
 SH 8

PD<sub>8,7</sub> ← 0  
 PD<sub>9,9</sub> ← COS(AZIMUTH) } AZIMUTH  
 PD<sub>10,11</sub> ← SIN(AZIMUTH) }  
 PD<sub>12...17</sub> ← SCNBVER } VERTICAL

SETNBPOS +1

MKRELEAS  
 RELEASE MARK  
 SYSTEM  
 FC-2240

AXISGEN : EARTH REF. COORDINATES IN XDC, YDC,  
 ZDC; STARAD.  
 STARAD+6; STARAD+12D ← N.B. AZIMUTH

OPTDATA

CALLS FOR AZIMUTH AND ELEVATION OF TARGET 1 THEN 2

A ← 1  
 RUN ← +0

(OPTDATA+2)

DSPTM1+2 ← A

TARGET NUMBER

DSPTM1<sub>0</sub> ← (TAZEL1)<sub>0</sub> #RUN

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFSPD GUIDANCE AND NAVIGATION	
DRAWN <i>R.M. D'Arco</i> 11 DEC 62		PRELAUNCH INITIALIZATION & GRID COMPUTING	
PROGR <i>E.J. Gorman</i> 4/72		DOCUMENT NO.	
ANALYST		COLDSEUS IIC	
DOCUM <i>E.J. Gorman</i> 4/72		FC-2530	
APPR'D <i>J. A. Brown</i> 4/72		SHEET 29 OF 47	
		REV 2	

FROM PRECEDING SHEET

GODSPRET  
V05N30  
FC-2130

SET UP TO DISPLAY  
TARGET NUMBER IN R3

GOFGLASH PASTES AZIMUTH AND ELEVATION  
OVER THE NORMAL R1, R2 CONTENTS OF N30,  
BUT LEAVES THE TARGET NUMBER IN R3 ALONE.

GCOMPS  
SH30

ENTER  
TERMINATE  
GOFGLASH  
V06 N41  
R1 = AZIMUTH  
R2 = ELEVATION

TARGET DATA  
R1 = TARGET AZIMUTH XXX.XX DEG  
R2 = TARGET ELEVATION XXX.XX DEG  
R3 = TARGET NUMBER XXX.XX. (DECIMAL)

PROCEED

TAZEL1#RUN ← DSPTM4  
TAZEL1+1#RUN ← DSPTM4+1

TARGET AZIMUTH  
TARGET ELEVATION

NO  
YES  
RUN > 0?

RUN ← 2

OPTDATA +2  
SH 27

CONTIN33

STARCODE ← 1  
A ← +0

INPUTS TO TARGDRIVE :  
STARCODE : 1 → AZIMUTH AND ELEVATION  
ARE INPUT RATHER THAN CATALOGUE  
A = 0 → TARGET # 1

TARGDRIVE  
DRIVE OPTICS  
TO TARGET 1  
SH43

TAR/EREF  
T1, T2 WITH  
RESPECT TO EREF  
SH46

INPUT: TARGET AZIMUTH, ELEVATION TAZEL1  
OUTPUT: SIN OF ELEVATION OF TARGETS 1 AND 2  
AZIMUTH, AND TARGET VECTORS IN  
PLOG<sub>v</sub> AND PL12<sub>v</sub>

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		POLICE GUIDANCE AND NAVIGATION	
DRAWN BY: <i>M. D. ...</i>		POL1, POL2, POL3, POL7	
PROGMR: <i>E. J. ...</i>		PRELIMINARY INITIALIZATION OF CYRO COMPRESSING	
ANALYST: <i>J. ...</i>		DOCUMENT NO. COLOSSUS IIC FC-2530	
DOCS: <i>J. ...</i>		REV E	
APPROV'D: <i>J. ...</i>		NEXT 28 of 47	

FROM PRECEDING SHEET

NEXTENKS

STARAD<sub>v</sub> ← XSM<sub>v</sub> X PLO6<sub>v</sub>  
 STARAD+6<sub>v</sub> ← XSM<sub>v</sub> X P12<sub>v</sub>

CONVERT LOS VECTORS TO SM COORDS  
 AND SAVE IN STARAD<sub>v</sub> AND STARAD+6<sub>v</sub>.

LITLSUB  
 CONV. SHAFT AND  
 TRUNNION ANGLES  
 INTO VECTOR REFS.  
 SH46

LDSVEC ← MPAC<sub>v</sub>

MKRELEAS  
 RELEASE MARK  
 SYSTEM  
 FC-2240

NEXBNKSS

STARCODE ← 2  
 A ← 6

TARGDRIVE  
 DRIVE TO  
 T2  
 SH43

LITLSUB  
 CONV. SHAFT AND  
 TRUNNION ANGLES  
 INTO VECTOR REFS.  
 SH46

POL12<sub>v</sub> ← MPAC<sub>v</sub>  
 PDLE<sub>v</sub> ← LOSVEC<sub>v</sub>

AXISGEN  
 COMPUTE COORDS  
 OF ONE COORD SYSTEM  
 REF'D TO ANOTHER SYSTEM  
 FC-2260

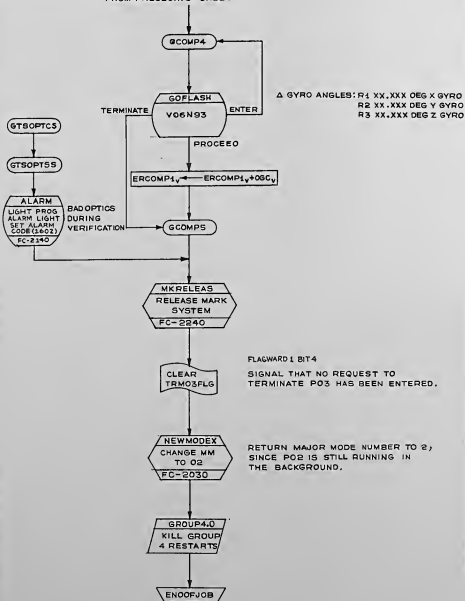
STABLE MEMBER DESIRED WITH RESPECT  
 TO STABLE MEMBER PRESENT

CALCGTA  
 COMPUTES GYRO  
 TORQUE ANGLES  
 FOR S.M. ORIENTATION  
 FC-2260

NEXT SHEET

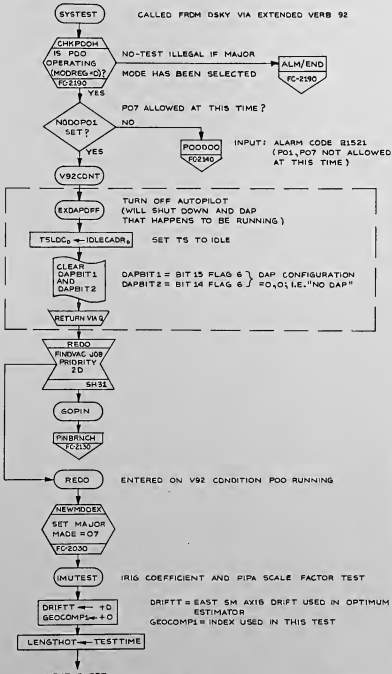
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLIC GUIDANCE AND NAVIGATION	
DRAWN <i>P.M. Dietrich</i>		POL, POL, POS, POT,	
PROGRAM <i>S.J. Quinn</i>		PRELAUNCH INITIALIZATION & GYRO COMPASSING	
ANALYST		DOCUMENT NO.	
DOCS <i>S.J. Quinn</i>		COLOSSUS IIC FC-2530	
APPROVED <i>S.J. Quinn</i>		REV 2	
		SHEET 29 OF 47	

FROM PRECEING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS		SA. CV. NAVIGATION	
DRAWN: <i>S. M. ...</i>	12 DEC 68	P01, P02, P03, P0T, PRELAUNCH INITIALIZATION & GYRO COMPASSING	
FIGURE: <i>S. J. ...</i>	1/1/69	COLOSSUS IIC FC-2530	
ANALYST: <i>J. G. ...</i>		REV 2	
DESIGNED: <i>J. G. ...</i>		30 47	
APPROVED: <i>J. G. ...</i>			

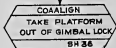
PD7  
PRELAUNCH SERVICE GYRO COMPASSING PROGRAM



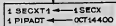
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESKY: <i>FC-2190</i>	22MAY67	PO1, PO2, PO3, PO7 PRELAUNCH INITIALIZATION & GYRO COMPASSING	
PROGRAM: <i>FC-2190</i>	<i>FC-2190</i>	GOLDSSUS IIC	DOCUMENT NO. FC-2530
ANALYST: <i>M. LEHMAN</i>			
DOCNO: <i>M. LEHMAN</i>			
APPROV: <i>FC-2190</i>	TRANS: 1	REV: 2	SHEET 31 OF 47



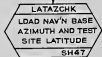
FROM PRECEDING SHEET



TAKE CARE OF DRIFT FLAG

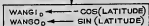


CALC. - COS. LAT. AND SIN. LAT.



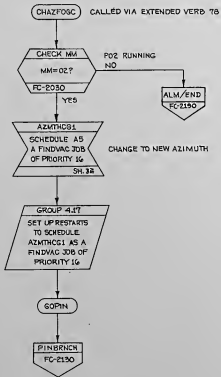
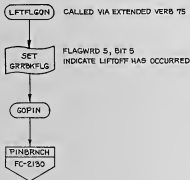
INPUT: STORED N.B. LATITUDE AND AZIMUTH  
TEST SITE LATITUDE

OUTPUT: LATITUDE AND AZIMUTH KEYED IN BY  
ASTRONAUT. MPAC ALSO CONTAINS LATITUDE



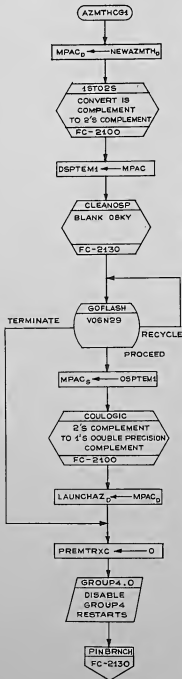
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APR 11 GUIDANCE AND NAVIGATION	
DRAWN <i>D.M. Dietrich</i>		PO1, PO2, PO3, PO7 PRELAUNCH INITIALIZATION (Gyrocompassing)	
PROGRAM <i>E.S. Gurev</i>		DOCUMENT #	
ANALYST <i>E.S. Gurev</i>		COLOSSUS IIC FC-2530	
DATE <i>2/2/67</i>		REV 2	
APPROVED <i>E.S. Gurev</i>		SH 36 11 47	

# EXTENDED VERBS 75 AND 78



W-1 INSTRUMENTATION 1 AUGUST 4, 1961 BY: A. C. WILLIAMS 239 239 239 239	PRELAUNCH INITIALIZATION & gyro COMPASSING EDWARDS 47751 COLLOSSUS II C FC-2530 2 33 47
--	---

*M. G. Johnson*  
*John A. Brown*



CONVERT NEWAZMTH FROM DOUBLE PRECISION 1'S COMPLEMENT TO SINGLE PRECISION 2'S COMPLEMENT IN MPAC<sub>S</sub>.

INPUT : MPAC<sub>D</sub>

NEWAZMTH (SINGLE PRECISION 2'S COMPLEMENT)

CLEARs OUT NORMAL DISPLAY THAT IS CURRENTLY ACTIVE OR ONE THAT IS SET UP TO BE STARTED OR RESTARTED.

R1 = XSM LAUNCH AZIMUTH  
R2, R3 = BLANK.

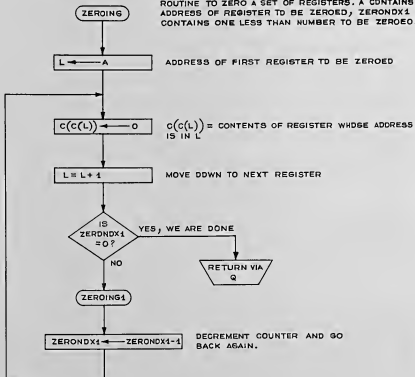
CONVERT OSPTM1 FROM SINGLE PRECISIONS 2'S COMPLEMENT TO DOUBLE PRECISION 1'S COMPLEMENT.

INPUT : MPAC<sub>S</sub>

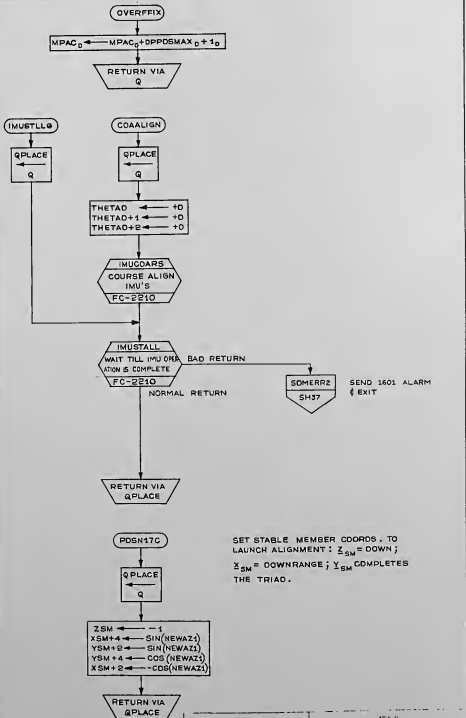
OUTPUT : MPAC<sub>D</sub>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		POS, POS, POS, POS, PRELAUNCH INITIALIZED & GYRO-COMPASSING
DRAWN <i>P.H. Dutton</i>	DESIGNED <i>E.S. Gamm</i>	DOCUMENT NO.
ANALYST	COLLOSSUS IIC	FC-2530
DOCKED <i>24 Jan 68</i>	APPRO'D <i>J.P. Dutton</i>	REV B
		34 47

ROUTINE TO ZERO A SET OF REGISTERS. A CONTAINS ADDRESS OF REGISTER TO BE ZEROED; ZERONDX1 CONTAINS ONE LESS THAN NUMBER TO BE ZEROED.

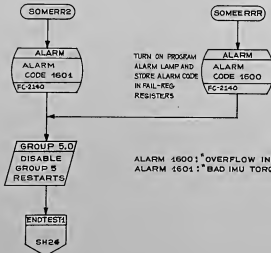
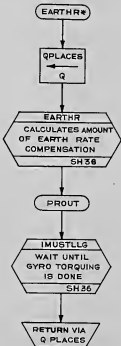


MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		AIRLIE GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		POL, POZ, POS, POT,	
CHECKED <i>E. J. Ryan</i>		PRELAUNCH INITIALIZATION & GYRO COMPRESSING	
ANALYST <i>4/26/53</i>		DOCUMENT NO.	
DOCNO <i>4-7-53</i>		CDLOSSUS IIC FC-2530	
APPROVED <i>[Signature]</i>		REV 2	
		SHEET 35 OF 47	



SET STABLE MEMBER COORDS. TO  
LAUNCH ALIGNMENT:  $Z_{SM} = \text{DOWN}$ ;  
 $Y_{SM} = \text{DOWNRANGE}$ ;  $Y_{GM}$  COMPLETES  
THE TRIAD.

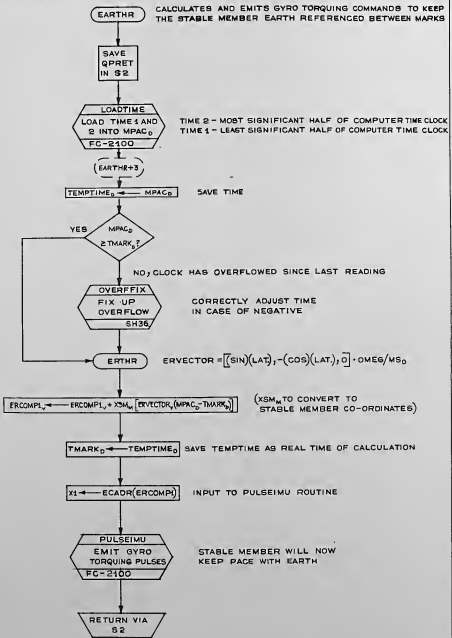
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PRELAUNCH INITIALIZATION	
DRAWN <i>P. N. Dietrich</i>		POL, PO2, PO3, POT,	
PROGWR <i>E. J. Gorman</i>		TO COMPASSING	
ANAL ST		DOCUMENT NO.	
DOCWR <i>E. J. Gorman</i>		COLOSSUS IIC	
APPRD <i>John A. Moran</i>		FC-2530	
REV 2		4-61 36-4 47	



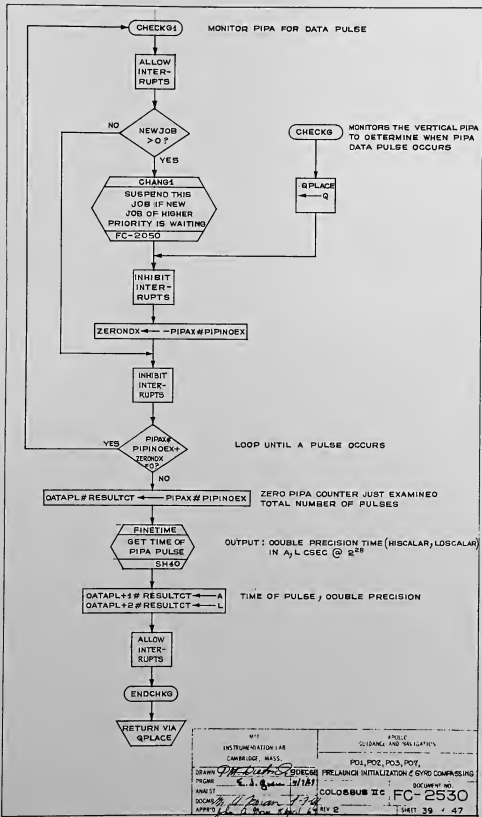
TURN ON PROGRAM  
ALARM LAMP AND  
STORE ALARM CODE  
IN FAIL-REG  
REGISTERS

ALARM 1600: "OVERFLOW IN DRIFT TEST"  
ALARM 1601: "BAD IMU TORQUE, ABORT"

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED DYNAMICS AND NAVIGATION	
DRIVER <i>D. P. ...</i>	BY ENGINEER	POS, POZ, POS, ROT,	DOCUMENT NO.
PIGWR <i>S. J. ...</i>	DATE <i>1/1/61</i>	PRELAUNCH INITIALIZATION GYRO COMPASSING	FC-2530
ANALYST		COLOSSUS IIC	
DOCKW <i>A. G. ...</i>	REV <i>1/2/61</i>		
APPROV <i>A. G. ...</i>	REV <i>2</i>		SHEET 37 OF 47

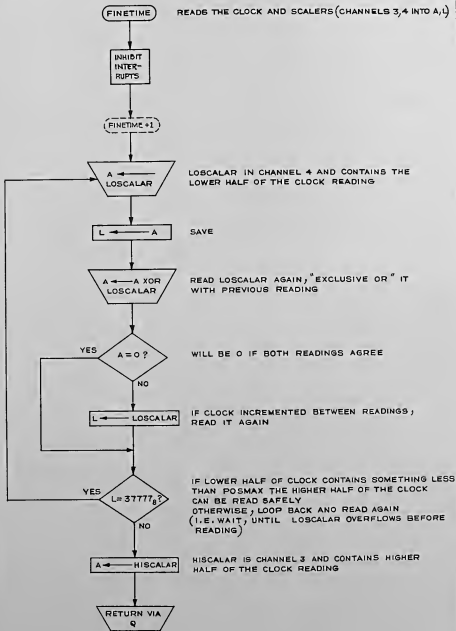


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	PRELAUNCH INITIALIZATION 2 GYRO COMPASSING
DESIGN: <i>W. D. ...</i>	COLOSSUS IIC FC-2530
PROGRAM: <i>...</i>	REV: <i>...</i>
ANALYST: <i>...</i>	NOV 2
REVISION: <i>...</i>	38 4 47
APPROVED: <i>...</i>	



W/F INSTRUMENTATION LAB CAMBRIDGE, MASS.	ARPLE SLIDING AND WELGATH'S PO1, PO2, PO3, POY, PRELAMBCH INITIALIZATION & CYRD COMPASSING
DRAWN <i>[Signature]</i> CHECKED <i>[Signature]</i> PROGRAM <i>E. J. G. 1/18/51</i> ANALYST DOCUMENT <i>[Signature]</i> APPROV <i>[Signature]</i>	DOCUMENT NO. <b>COLOSSUS IIC FC-2530</b> REV 2 SHEET 39 of 47





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	GUSMAN, AN, VERGARA, JR. POS, POS, POS, POT, PRELAUNCH INITIALIZATION CYCLE COMPASSING COLLOSSUS II C FC-2530 NOV 20 1967
DESIGNED BY: <i>P. M. D. S.</i> DRAWN BY: <i>E. J. G.</i> CHECKED BY: <i>W. J. S.</i> DATE: <i>11/16/67</i> APPROVED BY: <i>[Signature]</i> DATE: <i>11/16/67</i>	DOCUMENT NO. FC-2530 NOV 20 1967

ERTHRVSE

INITIALIZES EARTH RATE VECTOR AT THE LAUNCH SITE LATITUDE

ERVECTOR<sub>v</sub> ←  $\Omega_{ME}/M_0 (\sin(\text{LATITUDE})_v - \cos(\text{LATITUDE})_v)$

EARTH RATE = .1504 ARC/10 MSEC  
1.618 GYROPULSES = 4 ARCBSEC  
 $\Omega_{ME}/M_0 = .243$  GYROPULSES/10 MSEC

LOADTIME  
LOAD TIME 2,1  
FC-2100

LOAD TIME 2 AND 1 INTO MPAC<sub>2</sub>

TMARK<sub>0</sub> ← MPAC<sub>2</sub>

CURRENT TIME

ERCOMP1<sub>v</sub> ← 0<sub>v</sub>

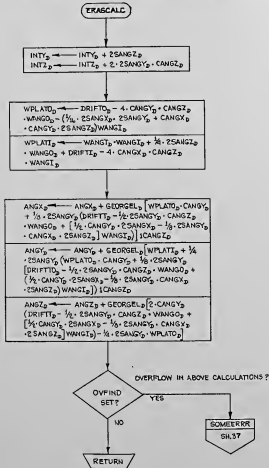
RETURN VIA QPRET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		PO1, PO2, PO3, PO7	
PRGMR <i>[Signature]</i>	DATE 9/2/67	PRELAUNCH INITIALIZATION OF GYRO COMPASSING	
ANALST <i>[Signature]</i>		COLOSSUS IC	FC-2530
DOCMNT <i>[Signature]</i>	4-7-68	REV. 2	SMI 41-47
APPR'D <i>[Signature]</i>	1 April 67		

NOTE: THIS SUBROUTINE USES AS INPUT THE CONTENTS OF PUSH LIST LOCATIONS PL10-PL21.  
THESE LOCATIONS ARE LOADED IMMEDIATELY BEFORE THE SUBROUTINE IS CALLED.

PUSH LIST LOCATION	CONTENTS OF LOCATION	DOCUMENT SYMBOL
PL10 <sub>D</sub>	$2 \sin(\frac{1}{4} \text{GEORGEI} \cdot \text{ANGX})$	2SANGX <sub>D</sub>
PL11 <sub>D</sub>	$2 \sin(\frac{1}{4} \text{GEORGEI} \cdot \text{ANGY})$	2SANGY <sub>D</sub>
PL12 <sub>D</sub>	$2 \sin(\frac{1}{4} \text{GEORGEI} \cdot \text{ANGZ})$	2SANGZ <sub>D</sub>
PL13 <sub>D</sub>	$\cos(\frac{1}{4} \text{GEORGEI} \cdot \text{ANGX})$	CANGX <sub>D</sub>
PL14 <sub>D</sub>	$\cos(\frac{1}{4} \text{GEORGEI} \cdot \text{ANGY})$	CANGY <sub>D</sub>
PL15 <sub>D</sub>	$\cos(\frac{1}{4} \text{GEORGEI} \cdot \text{ANGZ})$	CANGZ <sub>D</sub>

THE DOCUMENT SYMBOLS ARE ONLY USED FOR CONVENIENCE IN REPRESENTING THIS SUBROUTINE.  
THEY ARE NEITHER GSOOP SYMBOLS NOR AGC TAGS AND ARE ONLY ON THIS PAGE.



MIT		1944	
INS TRUM VIBRATION LAB			
CAMBRIDGE, MASS.		PO1, PO2, PO3, PO4	
BY A.C. WILLIAMS	REVISIONS	PRELAUNCH INITIALIZATION & GYRO COMPASSING	
DATE 2-2-50	9/11/51		
BY		COLOSSUS IIC	
APPROV		FC-2530	
		42 47	

TARGDRVE

DRIVES THE OPTICS TO THE SPECIFIED TARGET

GPLAC  
← Q

TARG1/2 ← A

TAR/EREF  
TRANSFORMS AZIMUTH AND ELEVATION INTO VECTORS  
SH45

TRANSFORMS TARGET AZIMUTH AND ELEVATION ANGLES INTO TARGET VECTORS IN EARTH REFERENCE COORDINATES

X1 ← TARG1/2  
STAR<sub>v</sub> ← PLOG<sub>v</sub>, #X1  
MPAC<sub>v</sub> ← PLOD, #X1

A FROM ABOVE : 0 FOR 1<sup>ST</sup> TARGET  
1 FOR SECOND  
PLOG OR PL12

SXTANG  
COMPUTE SEXTANT SHAFT AND TRUNNION ANGLES TO THE TARGET  
FC-2250

INPUT : XNB, YNB, ZNB  
OUTPUT : SAC (SHAFT ANGLE), PAC (TRUNNION ANGLE)

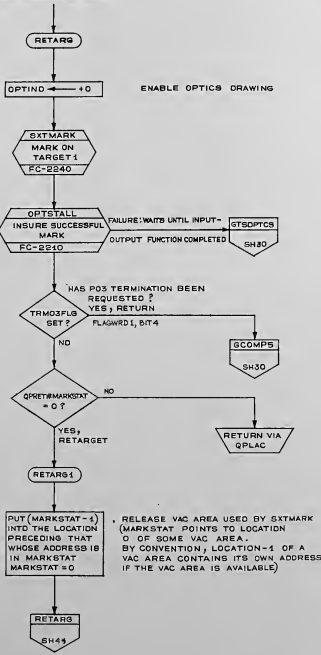
OESOPTS ← SAC  
OESOPTT ← PAC

SHAFT ANGLE  
TRUNNION ANGLE

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		POL, PO2, PO3, POT, PRELAUNCH INITIALIZATION GYRO COMPASSING	
DESIGNED <i>[Signature]</i>	CHECKED <i>[Signature]</i>	DOCUMENT NO	
ANALYST	DATE <i>[Signature]</i>	COLOSSUS IIC	FC-2530
APPROVED <i>[Signature]</i>	DATE <i>[Signature]</i>	REV B	SHEET 43 of 47

FROM PRECEDING SHEET



ENABLE OPTICS DRAWING

HAS P03 TERMINATION BEEN  
REQUESTED?  
YES, RETURN  
FLAGWRD 1, BIT 4

NO

YES,  
RETARGET

RELEASE VAC AREA USED BY SXTMARK  
(MARKSTAT POINTS TO LOCATION  
0 OF SOME VAC AREA.  
BY CONVENTION, LOCATION -1 OF A  
VAC AREA CONTAINS ITS OWN ADDRESS  
IF THE VAC AREA IS AVAILABLE)

MIT INSTRUMENTATION LAB CAMBRIDGE MASS		P01, P02, P03, POT, PRELAUNCH INITIALIZATION & GYRO COMPASSING	
DRAWN BY <i>[Signature]</i>	DESIGNED BY <i>[Signature]</i>	COLLOSSUS II C FC-2530	
PROGRAM <i>[Signature]</i>	ANALYST <i>[Signature]</i>	REV E 44 47	
CHECKED BY <i>[Signature]</i>			
APPROVED BY <i>[Signature]</i>			

TAR/EREF

TRANSFORMS THE TARGET AZIMUTH AND ELEVATION ANGLES INTO TARGET VECTORS IN EARTH REFERENCE COORDINATES.

TAR1

1ST PASS USES FIRST TARGET  
2ND PASS USES SECOND TARGET

PDL0 ← TAZEL1+1  
PDL0 ← TAZEL1+3  
PDL6 ← SIN(TAZEL1+1)  
PDL12 ← SIN(TAZEL1+3)  
PDL0 ← COS(PDL0)  
PDL0 ← COS(PDL0)  
MPAC ← TAZEL1  
MPAC ← TAZEL1+2

1ST PASS - TARGET'S ELEVATION  
2ND PASS - TARGET'S ELEVATION  
1ST PASS - SIN TARGET'S ELEVATION  
2ND PASS - SIN TARGET'S ELEVATION  
1ST PASS - COS TARGET'S ELEVATION  
2ND PASS - COS TARGET'S ELEVATION  
1ST PASS - TARGET'S ELEVATION  
2ND PASS - TARGET'S ELEVATION

COULDSIC

CONVERT  
1'S TO 2'S  
FC-2100

CONVERTS SINGLE PRECISION 2'S COMPLEMENT NUMBER IN MPAC, SCALED IN HALF REVOLUTION TO DOUBLE PRECISION 1'S COMPLEMENT, SCALED IN REVOLUTIONS IN MPAC

PDL 2 ← MPAC  
PDL 10 ← SIN(PDL2) COS(PDL0)  
PDL 16 ← SIN(PDL2) COS(PDL0)  
PDL 8 ← -COS(PDL2) COS(PDL0)  
PDL 14 ← -COS(PDL2) COS(PDL0)

BOTH PASSES - AZIMUTH  
1ST PASS - SIN(AZIMUTH) COS(ELEVATION)  
2ND PASS - SIN(AZIMUTH) COS(ELEVATION)  
1ST PASS - COS(AZIMUTH) COS(ELEVATION)  
2ND PASS - COS(AZIMUTH) COS(ELEVATION)

ND

X2=0?

LOOP THRU 2 TIMES/ONCE FOR EACH TARGET

YES

RETURN VIA  
QPRET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>P.M. Dutton</i> 11/19/68		POL1, POL2, POL3, POL7, PRELAUNCH INITIALIZATION & CYRD COMPENSING	
PCSW <i>S. J. Gorman</i> 11/18/68		DOCUMENT NO.	
ANALYST <i>G. J. Johnson</i> 1/7/69		COLOSSUS IIC	
APPROVED <i>John A. Brown</i> 1/14/69		FC-2530	
		REV 2 SHEET 46 OF 47	

LITTLESUB

CONVERTS SHAFT AND TRUNNION ANGLES AND  
DISTRIBUTOR POSITION TO S.M. COORDINATES

Q PLACE ← Q

CDUSPOT ← PLOZ#(-MARKSTAT)

SXTNB  
CONVERT TO  
N.B. COORDS  
FC-2250

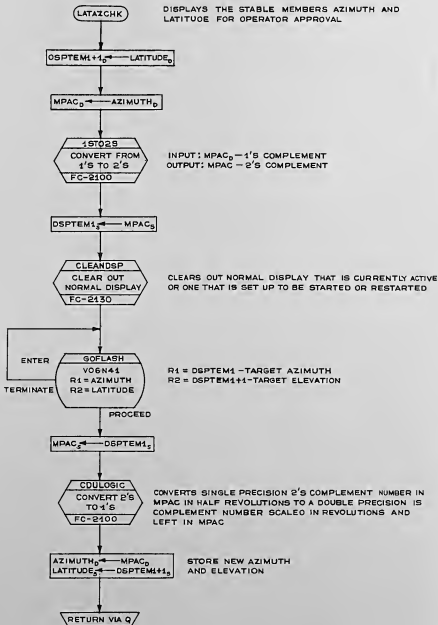
INPUT: CDUSPOT

TRG#NBSM  
CONVERT TO  
STABLE MEMBER  
COORDS  
FC-2270

OUTPUT: MPAC<sub>v</sub>

RETURN VIA  
Q PLACE

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		POL, PO2, PO3, PO7, PRELAUNCH INITIALIZATION & GYRO COMPENSATION	
GRAPHIC <i>[Signature]</i>	STDCODE <i>4711</i>	COLOSSUS IIC FC-2530	
PROGRAM <i>[Signature]</i>	ANALYST <i>[Signature]</i>	DOCSUP NO. 46-47	
DOCSUP <i>[Signature]</i>	APPROV <i>[Signature]</i>	REV 2	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>	DATE <i>11/28/64</i>	POL, POE, POS, POT, PRELAUNCH INITIALIZATION & CYRO COMPRESSING	
PROG. <i>[Signature]</i>	NO. <i>11/28/64</i>	DUFFIN ET AL	
ANALYST <i>[Signature]</i>		COLOBBUS IIC FC-2530	
DOCS <i>[Signature]</i>		REV 2	NET 47-11-47
APPROV. <i>[Signature]</i>			



MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

P11.	READS LIFTOFF TIME; RESETS TIME COUNTER; SETS UP STATE, ATTITUDE ERROR, AND DISPLAY SUBROUTINES.	SH. 3
REP11:	POSSIBLE RESTART ENTRY TO P11 (IF RESTART OCCURS DURING THE TIME SUBROUTINE).	SH. 6
MATRXJOB:	STATE SUBROUTINE: COMPUTES INITIAL STATE VECTOR AND STABLE MEMBER ORIENTATION, STARTS STATE VECTOR UPDATING.	SH. 7
ATERJOB:	COMPUTES AND DISPLAYS ERROR BETWEEN DESIRED AND ACTUAL ATTITUDE DURING BOOST, AND, IF CMC TAKEOVER OF SATURN IS ENABLED, ISSUES CORRECTIVE STEERING SIGNALS TO SATURN INSTRUMENTATION UNIT.	SH. 10
VIIHDOT:	COMPUTES AND DISPLAYS NOUN 62: VELOCITY, ALTITUDE ALTITUDE CHANGE RATE.	SH. 18
S11.1:	COMPUTES VALUES FOR NOUN 62 DISPLAY	SH. 18
SATSTNON:	ORIGINAL ENTRY TO SATURN STICK ROUTINE; SCHEDULES REDOSAT.	SH. 19
REIXOSAT:	INITIALIZES SATURN CREW TAKEOVER FUNCTION. SCHEDULES SATSTICK; RESTART ENTRY FOR SATSTICK.	SH. 20
SATSTICK	TRANSMITS ATTITUDE COMMANDS FROM ASTRONAUT (R H C) TO SATURN INSTRUMENTATION UNIT.	SH. 21

ENCLOSED ARE REPLACEMENT SHEETS TO UPDATE THE COLOSSUS II FLOWCHART FC-2540, REV. 0 TO THE COLOSSUS IIA FLOWCHART FC-2540, REV. 1

EFFECTIVE SHEETS FOR COLOSSUS IIA ARE:

SH. 1	REV. 0
SH. 2	REV. 1
SH. 3, 4	REV. 0
SH. 5	REV. 1
SH. 6	REV. 0
SH. 7	REV. 1
SH. 8-27	REV. 0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFSCAL CUM-DANT AND NAV-SATIC	
DR. W. H. R. ... PRGRM. ... ANALYST ... DOCNR ... APPROV. ...		P11 - EARTH ORBIT INSERTION MONITOR	
		COLOSSUS II A FC-2540 DOCUMENT NO. 1 of 1	

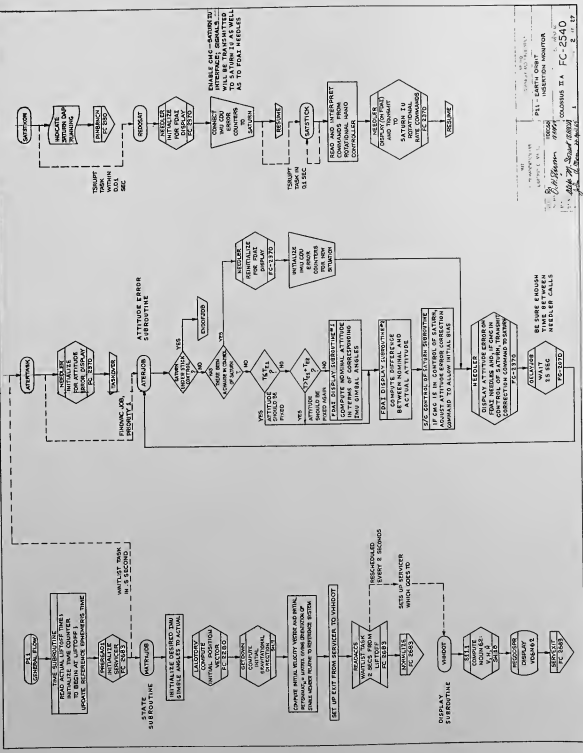
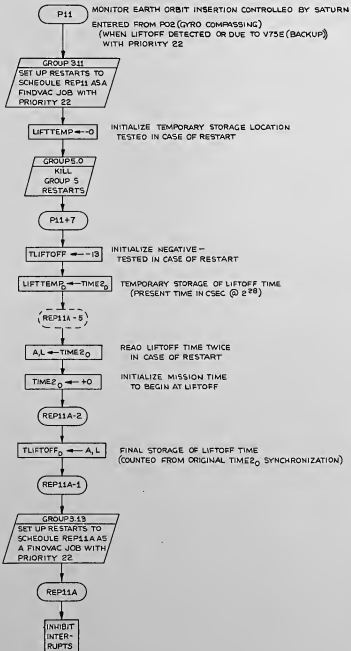


TABLE 2-616-ATTITUDE  
 WILL BE TRANSMITTED  
 TO FC 2635  
 TO FC 2635  
 TO FC 2635  
 TO FC 2635  
 TO FC 2635

FL - EARLY ORBIT  
 INERTION MONITOR  
 COLONUS II A  
 FC-2540  
 2 11 57

ATTITUDE SUBROUTINE  
 ATTITUDE ERROR  
 STATE SUBROUTINE  
 DISPLAY SUBROUTINE



NEXT SHEET

MET INSTRUMENTATION '78 CAMBRIDGE MASS.		APPROVED DIVISION AND QUALITY CONTROL	
DRAWN BY DESIGNED BY ANALYST CHECKED BY APPROVED BY	P11 C. N. Johnson J. H. Johnson J. H. Johnson	SHOWS 1/18/78 COLLOSSUS II A REV 1	FC-2540 SHEET 3 OF 27

FROM PRECEDING SHEET

TEPHEM<sub>1</sub> → TEPHEM + 0, TUJTOFF<sub>D</sub>

CORRECT REFERENCE EPHEMERIS TIME  
TO ACCOUNT FOR ACTUAL LIFTOFF TIME  
IN CSEC @ 2<sup>42</sup>

GROUP 3  
SET UP RESTARTS TO  
SCHEDULE NEXT LOCATION  
AS A FINDVAC JOB  
WITH PRIORITY 22

INHIBIT  
INTER-  
RUPTS

TEPHEM<sub>1</sub> → TEPHEM<sub>1</sub>

STORE UPDATED REFERENCE EPHEMERIS TIME

PREREAO1  
CLEAR PIPAS  
AND  
INITIALIZE  
SERVICER  
FC26B3

GROUP 3  
SET UP RESTARTS TO  
SCHEDULE NEXT LOCATION  
AS A FINDVAC JOB  
WITH PRIORITY 22

ATERTASK  
WAITLIST  
TASK IN  
Q.5 SECOND  
SH.4

ATERTASK

NEWMODEX  
CHANGE  
(AND DISPLAY)  
MAJOR MODE  
TO 11  
FC2030

ATERJOB  
FINDVAC  
JOB WITH  
PRIORITY 1  
SH.10

DOES ATTITUDE ERROR  
COMPUTATION AND DISPLAY  
LOW PRIORITY:  
RUNS AFTER P11,  
SERVICER

SET  
NDDOPOL

ASTRONAUT MAY NO  
LONGER SELECT  
MAJOR MODE P01

SET  
RCSFLAGS  
BIT 3

INDICATE  
FIRST PASS  
THROUGH NEEDLER

DNLSTOOD ← 3

SELECT POWERED  
FLIGHT DOWNLIST

NEEDLER  
DO  
INITIALIZATION  
FOR ATTITUDE  
ERROR DISPLAY  
FC2370

CLEANDSP  
BLANK  
DISPLAY

IF P11 ENTERED  
NORMALLY, ASTRONAUT'S  
INCOMPLETE ACTION  
("V75" WITHOUT "ENTR")  
STILL USING DSKY AND  
DISPLAY INTERFACE  
SYSTEM

SATSW ← BIT1

INITIALIZE SATSW > 0 TO  
INDICATE CMC NOT IN  
CONTROL OF SATURN.

TASKOVER

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APUE1 GUIDANCE AND NAVIGATION	
DRAWN BY <i>[Signature]</i>		P11 - EARTH ORBIT INSERTION MONITOR	
FROM <i>[Signature]</i>		COLOSSUS II A FC-2540	
ANALYST <i>[Signature]</i>		DOE AREA NO. 1	
DOCA <i>[Signature]</i>		REV 1	
APPROVED <i>[Signature]</i>		REV 4	

FROM PRECEDING SHEET

GROUP 4.51  
SET UP RESTARTS TO  
SCHEDULE ATERTASK  
AS A WAITLIST TASK  
IMMEDIATELY  
TBASE4 ← -TIME1

GROUP 5.1  
SET UP RESTARTS TO  
SCHEDULE MATRIXJOB  
AS A FINDMAC JOB  
WITH PRIORITY 22

QPLACES ← GENADR(P11OUT) SET EXIT FROM PROUT  
TO P11OUT

ERCOMP<sub>v</sub> ← ERCOMP<sub>v</sub> + XSM<sub>M</sub> \* THETAN<sub>v</sub> \* 2<sup>21</sup>

CORRECT EARTH ROTATION RATE TO BE COMPENSATED FOR  
BY ADDING DRIFT NOT CORRECTED DURING PRELAUNCH  
IN REVS/CSEC @ 2<sup>21</sup> IN STABLE MEMBER COORDINATES

WHERE: ORIGINAL ERCOMP<sub>v</sub> = EFFECT OF EARTH ROTATION  
RATE ON IMU, IN REVS/CSEC @ 2<sup>21</sup>,  
IN S.M. COORDINATES.  
THETAN<sub>v</sub> = DRIFT NOT CORRECTED DURING PRELAUNCH  
IN REVS/CSEC @ 2<sup>21</sup> IN EARTH-FIXED  
COORDINATES.  
XSM<sub>M</sub> = MATRIX FOR CONVERSION BETWEEN  
EARTH-FIXED AND STABLE MEMBER  
COORDINATE SYSTEMS @ 2<sup>1</sup>.  
2<sup>21</sup> FACTOR IS FOR SCALING.

MPAC<sub>0</sub> ← TLIFTOFF<sub>0</sub>

LOAD LIFTOFF TIME  
FOR EARTH+3

S2 ← FCADR(PROUT)

SET EXIT FROM  
EARTH+3 TO PROUT

EARTH+3  
CALCULATE  
AND COMPENSATE  
FOR EFFECT OF  
EARTH ROTATION  
ON IMU  
ORIENTATION  
FC2530

INPUT: MPAC<sub>0</sub> = TIME OF LIFTOFF IN CSEC @ 2<sup>28</sup>  
ERCOMP<sub>v</sub> = RATE OF ROTATION TO BE COMPENSATED FOR

VIA S2

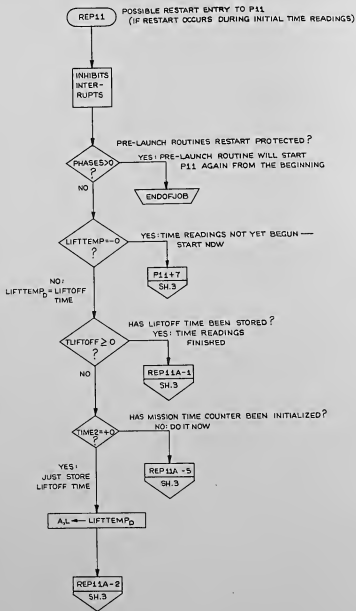
PROUT  
CAUSE  
DELAY UNTIL  
COMPENSATION  
FINISHED  
FC2530

VIA QPLACES

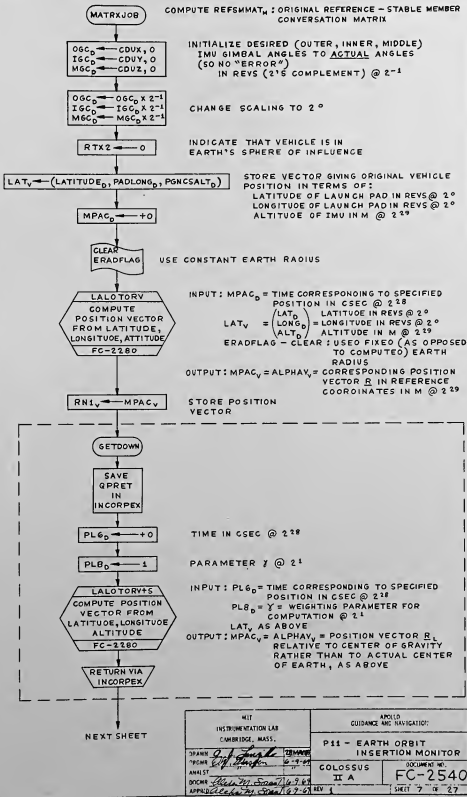
P11OUT

MATRIXJOB  
SH.7

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY <i>E. M. Johnson</i>		P11 - EARTH ORBIT	
PROGRAM <i>E. M. Johnson</i>		INSERTION MONITOR	
ANALYST <i>E. M. Johnson</i>		DOCUMENT NO.	
DOCNO <i>E. M. Johnson</i>		COLOSSUS II A FC-2540	
APPROVED <i>E. M. Johnson</i>		REV 1	
		SHEET 5 OF 27	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT AND NUMBER P11 - EARTH ORBIT INSERTION MONITOR	
DRAWN BY <i>R. M. Sklarson</i>	DESIGNED BY <i>R. M. Sklarson</i>	COLLOSSUS II A	FC-2540
ANALYST <i>W. J. Sklarson</i>	REVISIONS <i>W. J. Sklarson</i>	REV. 1	REV. 27
APPROVED BY <i>W. J. Sklarson</i>	DATE <i>10/1/67</i>		



FROM PRECEDING SHEET

$$\begin{aligned} \text{REFSMMAT}_6 &= \text{UNIT}(S_P) = \text{UNIT}(-B_L) \\ (\text{REFSMMAT} + 12)_V &\leftarrow \text{UNIT}(-M_P C_{L_2}) \end{aligned}$$

$$\begin{aligned} Y &= \omega_E (U_Z \times B) \\ \text{VNL}_{1V} &\leftarrow (-\text{EARTHROT}_D) (\text{RNL}_{1V} \times \text{UNIT}(U_Z)) \times 2^\circ \end{aligned}$$

COMPUTE VELOCITY  
JUST BEFORE LIFTOFF  
IN REFERENCE COORDINATES  
IN M/CSEC @ 2°

WHERE:  
 $\text{UNIT}(U_Z) + U_Z = \text{UNIT}(Z)$   
 = UNIT VECTOR IN THE  
 DIRECTION OF  
 EARTH'S ROTATION  
 IN REFERENCE COORDS  
 @ 2°  
 - EARTHROT<sub>D</sub>  
 = -(RATE OF EARTH ROTATION)  
 = -7.292115138 × 10<sup>-7</sup>  
 RAD/CSEC @ 2°-18

COMPUTE  
REFSMMAT<sub>M</sub>

$$= \begin{bmatrix} \text{REFSMMAT}_V \\ (\text{REFSMMAT} + 6)_V \\ (\text{REFSMMAT} + 12)_V \end{bmatrix}$$

= TRANSFORMATION  
MATRIX BETWEEN  
REFERENCE AND  
STABLE MEMBER  
COORDINATE SYSTEMS  
@ 2°  
USING KNOWN  
INITIAL  
STABLE MEMBER  
ORIENTATION

$$\begin{aligned} E &= \text{UNIT}(\text{REFSMMAT}_6 \times U_Z) \\ \text{PLQ}_V &\leftarrow \text{UNIT}(\text{REFSMMAT} + 12)_V = \text{UNIT}(U_Z) \end{aligned}$$

$$\begin{aligned} S &= \text{UNIT}(E \times \text{REFSMMAT}_6) \\ \text{PLG}_V &\leftarrow \text{UNIT}(\text{PLQ}_V \times (\text{REFSMMAT} + 12)_V) \end{aligned}$$

$$\begin{aligned} \text{REFSMMAT}_0 &= \sin(A_Z) E + \cos(A_Z) S \\ \text{REFSMMAT}_V &\leftarrow \sin(\text{LAUNCHAZ}_D) \text{PLQ}_V + \cos(\text{LAUNCHAZ}_D) \text{PLG}_V \end{aligned}$$

$\text{LAUNCHAZ}_D = A_Z$   
 = LAUNCH AZIMUTH  
 FROM NORTH  
 TO STABLE MEMBER  
 + X-AXIS  
 IN REVS @ 2°

$$\begin{aligned} \text{REFSMMAT}_3 &= \text{UNIT}(\text{REFSMMAT}_6 \times \text{REFSMMAT}_0) \\ (\text{REFSMMAT} + 6)_V &\leftarrow \text{UNIT}(\text{REFSMMAT}_V \times (\text{REFSMMAT} + 12)_V) \end{aligned}$$

$$\begin{aligned} -K_Z &= -(A_Z - 180^\circ - A_{ZP}) \\ \text{PLD}_D &\leftarrow -\text{LAUNCHAZ}_D + \frac{1}{2} A_{ZP} + \text{AZIMUTH}_D \end{aligned}$$

COMPUTE  $K_Z$  = TOTAL ROLL ANGLE NECESSARY  
TO ALIGN SPACECRAFT  
- Z-AXIS WITH STABLE MEMBER  
+ X-AXIS  
IN REVS @ 2°

WHERE:  $\text{LAUNCHAZ}_D = A_Z$  = LAUNCH AZIMUTH FROM  
NORTH TO STABLE MEMBER  
+ X-AXIS IN REVS @ 2°  
 $\text{AZIMUTH}_D = A_{ZP}$  = AZIMUTH (AT LAUNCH)  
FROM NORTH TO  
SPACECRAFT + Z-AXIS  
IN REVS @ 2°

$$\begin{aligned} -\text{SIGN}(K_Z) K_R \\ \text{SATRLRT}_D &\leftarrow \text{SIGN}(\text{PLQ}_D) \text{SATRLRT}_D \end{aligned}$$

INSURE THAT SIGN OF ROLL RATE IS OPPOSITE  
TO THAT OF  $K_Z$   
WHERE ORIGINAL  $\text{SATRLRT}_D K_R$   
= ABSOLUTE VALUE OF SATURN ROLL RATE  
IN REVS/CSEC @ 2°

SET  
REFSMFLG

REFSMMAT<sub>M</sub> IS VALID GIVES KNOWN STABLE MEMBER  
ORIENTATION

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT P11 - EARTH ORBIT INSERTION MONITOR	
DRAWN BY <i>D. K. Hanson</i>	DESIGNED BY <i>UNL</i>	DOCUMENT NO. COLOSSUS II A FC-2540	
ANALYST <i>John M. Sweet</i>	TESTED BY <i>EA</i>	REV 1	SHEET 8 OF 27



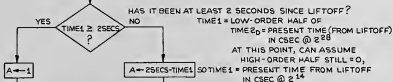
FROM PRECEDING SHEET

GROUP 3  
SET UP RESTARTS TO  
SCHEDULE NEXT LOCATION  
AS A FINDVAC JOB  
WITH PRIORITY 22

AVGEXIT<sub>D</sub> ← 2CADR(VHHDOT) SET EXIT FROM SERVICER TO VHHDOT (5H.16)

1/PIPADT ← 200 CSEC SET ΔT BETWEEN PIPA READINGS IN CSEC @ 2<sup>9</sup>

GROUP 5  
TBASE5 ← 0 Δ TIMES FOR GROUP 5 WAITLIST TASK RESTARTS  
WILL BE MEASURED FROM LIFTOFF



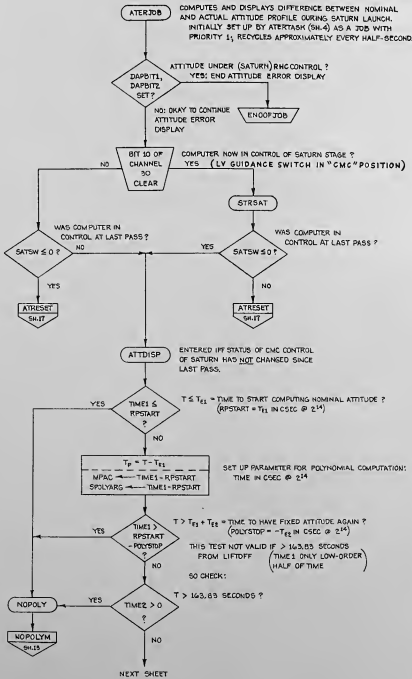
READACCS WANT READACCS TO START 2 SECONDS (AT LEAST)  
AFTER LIFTOFF  
WAITLIST TASK IN A CSEC READS ACCELEROMETERS, SETS UP SERVICER  
FC 2683 (STATE VECTOR UPDATING)  
RESCHEDULES ITSELF EVERY 2 SECONDS UNTIL TURNED OFF

GROUP 3.0  
KILL  
GROUP 3  
RESTARTS

GROUP 5.2  
SET UP RESTARTS TO  
SCHEDULE NORMLIZE  
AS A FINDVAC JOB  
WITH PRIORITY 32  
AND REREADAC AS  
A WAITLIST TASK  
IN 2 SECONDS

NORMLIZE DO INITIAL STATE VECTOR UPDATE AND END JOB  
FC 2683

MIT INSTRUMENTATION LAB - AMBRIDGE, MASS.		APPROVED GUIDANCE AND NAVIGATION	
DRAWN BY <i>R. W. Swartz</i>		P11 - EARTH ORBIT INSERTION MONITOR	
PROGRAM <i>W. H. Swartz</i>		DOCUMENT NO. FC - 2540	
ANALYST <i>W. H. Swartz</i>		COLLOSSUS II A	
DOCNO <i>Alpha M. Swartz</i>		REV 1	
APPROVED <i>John A. Swartz</i>		SHEET 9 OF 27	



IN TRANSMISSION LAB CAMBRIDGE, MASS.	DATE: 23 APR 67
BY: A.C. WILLIAMS	PROJECT: P11 - EARTH ORBIT
APPROVED: <i>D.W. Johnson</i>	INSERTION MONITOR
DATE: 17 APR 67	COLLOSSUS II A
APPROVED: <i>John A. Brown</i>	FC-2540
DATE: 23 APR 67	SD 27

FROM PRECEDING SHEET

L ← POLYNOM  
A → ADRES(POLYLOC)

SET PARAMETERS  
FOR POWRSERS

POWRSERS  
EVALUATE  
POLYNOMIAL  
OF  
DEGREE N  
FC 2090

INPUT: L = N - 1, WHERE N = DEGREE OF POLYNOMIAL  
A = PADR - 3, WHERE PADR  
= ADDRESS OF LAST  
POLYNOMIAL COEFFICIENT A<sub>N</sub>

(COEFFICIENTS MUST BE STORED  
DOUBLE PRECISION, IN THE ORDER:)

A<sub>0</sub>  
A<sub>1</sub>  
⋮  
A<sub>N</sub>

MPAC = ARGUMENT X

OUTPUT: MPAC<sub>D</sub> = VALUE OF POLYNOMIAL  
= A<sub>0</sub> + A<sub>1</sub>X + ⋯ + A<sub>N</sub>X<sup>N</sup>

IN THIS CASE, RESULT IS:  
θ<sub>p</sub> = NOMINAL PITCH ANGLE  
IN REVS @ 2<sup>5</sup>

MPAC<sub>D</sub> ← MPAC<sub>D</sub> × 2<sup>5</sup>

CHANGE SCALING OF θ<sub>p</sub> TO 2<sup>0</sup>

FLO<sub>D</sub> ← MPAC<sub>D</sub>

-C<sub>p</sub> = -COS(θ<sub>p</sub>)  
PL14<sub>D</sub> ← -COS(MPAC<sub>D</sub>)

TRIGONOMETRIC  
FUNCTIONS  
@ 2<sup>1</sup>

S<sub>p</sub> = SIN(θ<sub>p</sub>)  
PL10<sub>D</sub> ← SIN(PL0<sub>D</sub>)

PL12<sub>D</sub> ← +0

COMPUTE REMAINING ROLL ANGLE  
IN REVS @ 2<sup>0</sup>

θ<sub>R</sub> = K<sub>Z</sub> - SIGN(K<sub>Z</sub>)K<sub>R</sub>T<sub>P</sub>  
MPAC<sub>D</sub> ← (LAUNCHAZ<sub>D</sub> - 1/2 - AZIMUTH<sub>D</sub>) + SATRLRT<sub>D</sub> × SPOLYARG × 2<sup>14</sup>

WHERE: LAUNCHAZ<sub>D</sub> = A<sub>Z</sub>  
= LAUNCH AZIMUTH FROM NORTH TO  
STABLE MEMBER + X-AXIS  
IN REVS @ 2<sup>0</sup>

AZIMUTH<sub>D</sub> = A<sub>ZP</sub>  
= AZIMUTH (AT LAUNCH) FROM NORTH TO  
SPACECRAFT + Z-AXIS  
IN REVS @ 2<sup>0</sup>

K<sub>Z</sub> = A<sub>Z</sub> - 180° - A<sub>ZP</sub>  
= TOTAL ROLL ANGLE  
AT LAUNCH TIME

SATRLRT<sub>D</sub> = -SIGN(K<sub>Z</sub>)K<sub>R</sub>  
= ROLL RATE  
WITH SIGN OPPOSITE TO K<sub>Z</sub>  
IN REVS/CSEC @ 2<sup>0</sup>

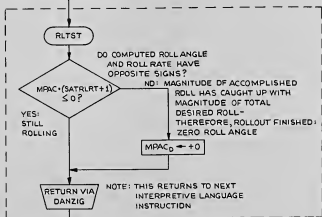
SPOLYARG = T<sub>P</sub>  
= TIME SINCE NOMINAL  
START OF ROLL  
IN CSEC @ 2<sup>14</sup>

2<sup>14</sup> FACTOR IS FOR SCALING

NEXT SHEET

INSTITUTION NATION LAB CAMBRIDGE, MASS		REVISION LAUNCH AND NAVIGATION	
DRAWN BY PROGRAM <i>E. W. Shannon</i>		P11 - EARTH ORBIT INSERTION MONITOR	
ANALYST <i>John D. Brown</i>		DOCUMENT NO. COLOSSUS II A FC-2540	
APPROVED <i>John D. Brown</i>		REV 1 SHEET 11 OF 27	

FROM PRECEDING SHEET



$PL0_D \leftarrow MPAC_D$  SAVE  $\theta_R$  (IN REVS @ 2°)

$$\frac{CR}{PL2_D} = \frac{CDS(\theta_R)}{CDS(MPAC_D)} \quad @ 2^1$$

$$\frac{-CR C_p}{PL22_D} = \frac{-CR X - C_p}{CDS(MPAC_D) \times PL14_D \times 2^1} \quad @ 2^1$$

$$\frac{-CR}{PL18_D} = \frac{-CR}{-PL2_D} \quad @ 2^1$$

$$\frac{-CR S_p}{PL26_D} = \frac{-CR \times S_p}{-PL2_D \times PL10_D \times 2^1} \quad @ 2^1$$

$$\frac{S_R}{MPAC_D} = \frac{SIN(\theta_R)}{SIN(PL0_D)} \quad @ 2^1$$

$PL0_D \leftarrow MPAC_D$  SAVE  $S_R$

$$PL24_D \leftarrow MPAC_D$$

$$\frac{-S_R C_p}{PL16_D} = \frac{-C_p \times S_R}{-PL14_D \times MPAC_D \times 2^1} \quad @ 2^1$$

$$\frac{-S_R S_p}{PL28_D} = \frac{-S_R \times S_p}{-PL0_D \times PL10_D \times 2^1} \quad @ 2^1$$

NEXT SHEET

COMPUTE MATRIX:

$$\begin{bmatrix} PL10_D & PL12_D & PL14_D \\ PL16_D & PL18_D & PL20_D \\ PL22_D & PL24_D & PL26_D \end{bmatrix} = \begin{bmatrix} S_p & 0 & -C_p \\ -S_R C_p & -CR & -S_R S_p \\ -CR C_p & S_R & -CR S_p \end{bmatrix}$$

[TSMV]

@ 2<sup>1</sup>

Administrative stamp area:

SEARCHED INDEXED SERIALIZED FILED

APR 11 1968

COMMUNICATIONS SECTION

PROJECT: P11 - EARTH ORBIT INSERTION MONITOR

COLLOSSUS II A FC-2540

REV: 12 - 22

APPROVED: *[Signature]* DATE: 23 APR 68

FROM PRECEDING SHEET

XDC<sub>v</sub> ← UNIT(PL10<sub>v</sub>)  
YDC<sub>v</sub> ← UNIT(PL16<sub>v</sub>)  
ZDC<sub>v</sub> ← UNIT(PL22<sub>v</sub>)

STORE MATRIX FOR CALCGTA  
@ 2<sup>1</sup>

CALCGTA  
COMPUTE  
EULER ANGLES  
CORRESPONDING  
TO TRANS-  
FORMATION  
FC 2260

INPUT: XDC<sub>v</sub> } DESIRED STABLE MEMBER AXES  
YDC<sub>v</sub> } RELATIVE TO  
ZDC<sub>v</sub> } ORIGINAL STABLE MEMBER COORDINATES  
@ 2<sup>1</sup>

OUTPUT: OGC<sub>D</sub> } EULER ANGLES OF CORRESPONDING  
IGC<sub>D</sub> } TRANSFORMATION  
MGC<sub>D</sub> } = DESIRED IMU GIMBAL ANGLES  
IN REVS @ 2° (1'S COMPLEMENT)

NOPOLYM

COULD ALSO ENTER HERE (WHEN T < T<sub>E1</sub>)  
WITH OGC<sub>D</sub> } PRESET TO ORIGINAL IMU GIMBAL ANGLES  
IGC<sub>D</sub> } IN REVS (2'S COMPLEMENT) @ 2°  
MGC<sub>D</sub> }  
OR WHEN T > T<sub>E1</sub> + T<sub>EE</sub>  
WITH LAST COMPUTED NOMINAL IMU GIMBAL ANGLES

PL2<sub>v</sub> = (IGC<sub>D</sub>, MGC<sub>D</sub>, OGC<sub>D</sub>)

SAVE EULER ANGLES IN Y, Z, X ORDER

CDUTRIG  
GET ACTUAL  
IMU GIMBAL  
ANGLES AND THEIR  
TRIGONOMETRIC  
FUNCTIONS  
FC 2270

OUTPUT: COSPOTY } ACTUAL  
COSPOTZ } IMU GIMBAL ANGLES  
COSPOTX } IN REVS @ 2°  
(1'S COMPLEMENT)

SINCOUY, COSCDOUY } SINES, COSINES  
SINCDUZ, COSCDUZ } OF IMU GIMBAL ANGLES  
SINCDUX, COSCDUX } @ 2<sup>1</sup>

MPAC<sub>v</sub> ← PL2<sub>v</sub>

LOAD DESIRED IMU GIMBAL ANGLES

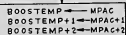
NEXT SHEET

DESIGNED BY DRAWN BY <i>P. W. Johnson</i> CHECKED BY <i>John A. ...</i> ANALYST DESIGNER <i>Alfred M. ...</i> APPROVED <i>John A. ...</i>		APPROVED QUALITY CONTROL <b>P11-EARTH ORBIT INSERTION MONITOR</b> COMPONENT NO. <b>COLOSSUS II A</b> REV 1	
INSTRUMENTATION NO. DRAWING NO.		DOCUMENT NO. <b>FC-2540</b> SHEET 13 OF 27	

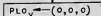
FROM  
PRECEDING SHEET



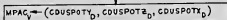
INPUT: MPAC<sub>0</sub>  
MPAC+3<sub>D</sub>  
MPAC+5<sub>D</sub> } 3 ANGLES IN 1'S COMPLEMENT IN REVS @ 2°  
OUTPUT: MPAC  
MPAC+1  
MPAC+2 } SAME 3 ANGLES IN 2'S COMPLEMENT IN REVS @ 2°-1



SAVE DESIRED IMU GIMBAL ANGLES  
2'S COMPLEMENT @ 2°-1



CLEAR VECTOR - HIGH-ORDER WORDS ONLY  
TO BE STORED LATER



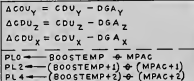
LOAD ACTUAL IMU GIMBAL ANGLES



INPUT: MPAC<sub>0</sub>  
MPAC+3<sub>D</sub>  
MPAC+5<sub>D</sub> } 3 ANGLES IN 1'S COMPLEMENT IN REVS @ 2°  
OUTPUT: MPAC  
MPAC+1  
MPAC+2 } SAME 3 ANGLES IN 2'S COMPLEMENT IN REVS @ 2°-1

DELSTOR

COMPUTE DIFFERENCE BETWEEN  
ACTUAL AND DESIRED IMU GIMBAL  
ANGLES (2'S COMPLEMENT @ 2°-1)



TAKING  
1'S COMPLEMENT DIFFERENCE  
OF 2'S COMPLEMENT  
NUMBERS

RETURN VIA  
DANZIG

GOES TO NEXT INTERPRETIVE LANGUAGE  
INSTRUCTION (AFTER CALL TO DELSTOR)

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		4 WELLS GUIDANCE AND NAVIGATION	
PROJECT: <i>E. J. ...</i> STANARD		P11-EARTH ORBIT INSERTION MONITOR	
ANALYST: <i>E. J. ...</i>		GOLDSSUS	
DATE: <i>11/14/63</i>		II A	
APPROVED: <i>John A. ...</i>		FC-2540	
REV 1		REV 14	

FROM  
PRECEDING SHEET

ATTDISP2

$$\begin{aligned} (E_A)_1 &= 1 - \Delta CDU_X + S_Z \cdot \Delta CDU_Y + 0 \cdot \Delta CDU_Z \\ AK &\leftarrow \frac{1}{(PL4_D + \text{SINC} DU_Z \times \text{PL}0_D \times 2^1) \times 2^{-1}} \end{aligned}$$

COMPUTE  
 $AK = (E_A)_1 @ 2^{+1}$

WHERE:  
 $PL4_D = \Delta CDU_X @ 2^{-1}$   
 $\text{SINC} DU_Z = \text{SIN}(CDU_Z) @ 2^{+1}$   
 $PL0_D = \Delta CDU_Y @ 2^{-1}$   
 $2^1, 2^{-2}$  FACTORS  
ARE FOR SCALING

COMPUTE

$$E_A = \begin{pmatrix} AK \\ AK1 \\ AK2 \end{pmatrix} = [\text{TGSC}] \Delta CDU$$

WHERE:

$$[\text{TGSC}] = \begin{bmatrix} 1 & S_Z & 0 \\ 0 & C_Z C_X & C_Y \\ 0 & -S_X C_Z & C_X \end{bmatrix}$$

= MATRIX FOR CONVERSION TO SPACE-CRAFT AXES

$$\begin{aligned} (E_A)_2 &= 0 \cdot \Delta CDU_X + C_X C_Z \cdot \Delta CDU_Y + S_X \cdot \Delta CDU_Z \\ AK1 &\leftarrow 2^1 (\text{COS} CDU_D \times \text{COS} DU_Z \times \text{PL}0_D \times 2^1 + \text{SINC} DU_Z \times \text{PL}1_D) \end{aligned}$$

COMPUTE  
 $AK1 = (E_A)_2 @ 2^{-1}$

WHERE:  
 $\text{COS} CDU_D = \text{COS}(CDU_X) @ 2^{+1}$   
 $\text{COS} DU_Z = \text{COS}(CDU_Z) @ 2^{+1}$   
 $PL2_D = \Delta CDU_Z @ 2^{-1}$   
 $2^1$  FACTORS ARE FOR SCALING

$$\begin{aligned} (E_A)_3 &= 0 \cdot \Delta CDU_X + (-S_X C_Z) \cdot \Delta CDU_Y + C_X \cdot \Delta CDU_Z \\ AK2 &\leftarrow 2^1 (-\text{SINC} DU_Z \times \text{COS} DU_Z \times \text{PL}0_D \times 2^1 + \text{COS} CDU_X \times \text{PL}2_D) \end{aligned}$$

COMPUTE  
 $AK2 = (E_A)_3 @ 2^{-1}$

WHERE:  
 $\text{SINC} DU_Z = \text{SIN}(CDU_Z) @ 2^{+1}$   
 $2^1$  FACTORS ARE FOR SCALING

>0

CMC NOT IN CONTROL OF SATURN

SATOUT  
SMIG

TEST  
SATSW

<0: CMC IS AND HAS BEEN IN CONTROL OF SATURN

+0: FIRST PASS WITH CMC

IN CONTROL OF SATURN

AKLOAD

$$\begin{aligned} \text{BIASAK} &\leftarrow -AK \\ \text{BIASAK} + 1 &\leftarrow -AK1 \\ \text{BIASAK} + 2 &\leftarrow -AK2 \end{aligned}$$

INITIALIZE BIAS TO HOLD ATTITUDE ERROR TO THAT AT PRESENT.

$$\text{SATSW} \leftarrow -\text{BIT1}$$

SET SATSW < 0 TO INDICATE THAT INITIALIZATION OF CMC CONTROL SITUATION HAS BEEN DONE.

STEERSAT

$$\begin{aligned} AK &\leftarrow AK + \text{BIASAK} \\ AK1 &\leftarrow AK1 + (\text{BIASAK} + 1) \\ AK2 &\leftarrow AK2 + (\text{BIASAK} + 2) \end{aligned}$$

CHANGE ATTITUDE ERRORS TO ALLOW INITIAL BIAS.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS. DRAWN BY <i>J. J. Sullivan</i> CHECKED BY <i>J. J. Sullivan</i> ANALYST <i>John A. Brown</i> APPROVED BY <i>John A. Brown</i>	AVIATION GUIDANCE AND NAVIGATION P11 - EARTH ORBIT INSERTION MONITOR COLOSSUS II A FC-2540 REV 1 11 15 67
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FROM PRECEDING SHEET

AK ←  $2^2 \times \text{SATSCALE} \times \text{AK}$   
AK1 ←  $2^2 \times \text{SATSCALE} \times \text{AK1}$   
AK2 ←  $2^2 \times \text{SATSCALE} \times \text{AK2}$

SCALE ATTITUDE CORRECTION  
COMMANDS APPROPRIATELY  
FOR SATURN HARDWARE.

SATOUT

NEEDLER  
DISPLAY  
ATTITUDE ERROR  
ON  
FOAI NEEDLES  
FC-2370

INPUT: AK @  $2^{+1}$   
AK1 @  $2^{-1}$   
AK2 @  $2^{-1}$  } ATTITUDE ERROR  
ANGLES (IN REVS)  
IN SPACECRAFT  
COORDINATES.

ALSO GIVES STEERING COMMANDS  
(TO CORRECT ERROR) TO SATURN  
IF CMC IS IN CONTROL.

ATERSET

DELAYJOB  
WAIT  
.25 SECOND  
FC-2070

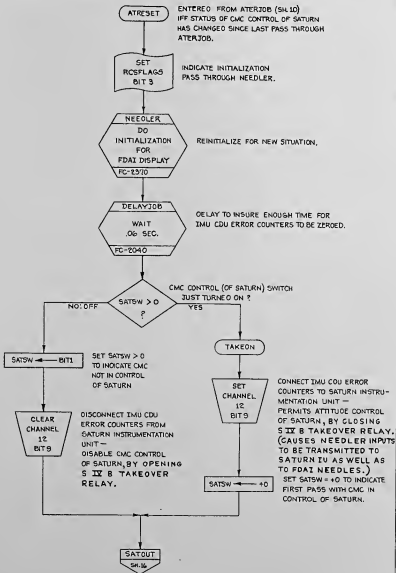
DELAY TO INSURE SUFFICIENT  
TIME BETWEEN CALLS TO  
NEEDLER.

ATERJOB  
SH.30

START CYCLE OVER.

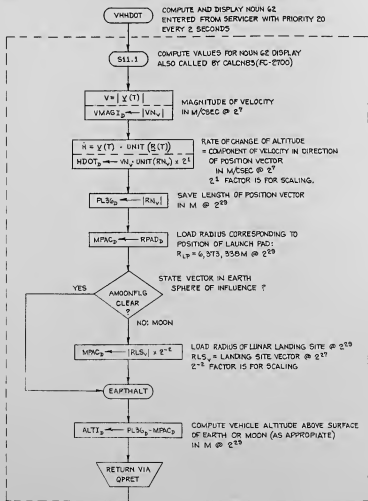
NO. 100	REV. 10
INSTRUMENTATION LAB	RESEARCH AND DEVELOPMENT
FAMRIDGE, MASS.	
PROJECT: C. WILLIAMS	507F845
FORMER: <i>Ch. M. Shuman</i>	<i>44000</i>
ANALYST:	
OPERATOR: <i>Alvin M. Shaw</i>	<i>44000</i>
DATE: <i>Jan 10 1966</i>	REV 5
	P11 - EARTH ORBIT
	INSERCTION MONITOR
	COLOSSUS II A
	FC-2540
	REV 16 * 27





APPROVED BY: [Signature]  
DATE: [Date]  
BY: [Signature]  
DATE: [Date]

P11 - EARTH ORBIT  
INSERTION MONITOR  
COLLOSSUS II A FC-2540



GROUP 53  
 SET UP RESTARTS TO SCHEDULE REREADAC AS A WAITLIST TASK IN 2 SECONDS

NOTE: "2 SECONDS" IS MEASURED FROM LAST TIME READACCS WAS SCHEDULED.

REGDSP  
 DISPLAY NOUN 62

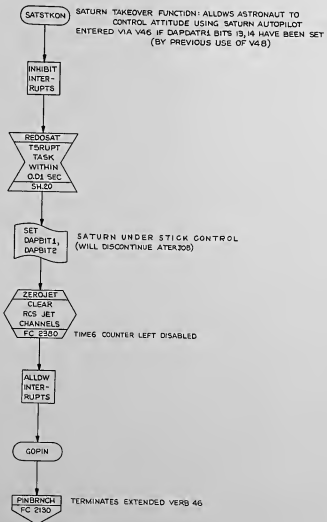
DISPLAY NOUN 62:  
 R1: XXXXX, FT/SEC (VMAG1)  
 R2: XXXXX, FT/SEC (HDOT)  
 R3: XXXXX NM (ALTI)

ENDOFJOB

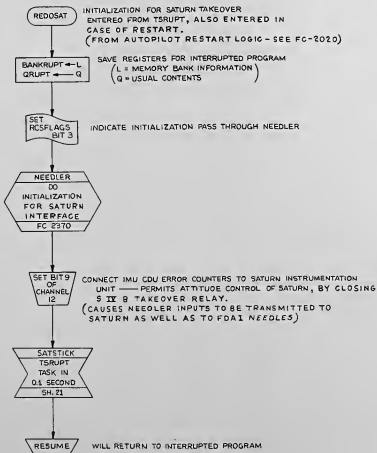
APPROVED BY: A. C. WILLIAMS  
 DATE: 11/18/68  
 BY: A. C. WILLIAMS  
 DATE: 11/18/68

P11 - EARTH ORBIT  
 INSERTION MONITOR

COLOSSUS II A FC-2540



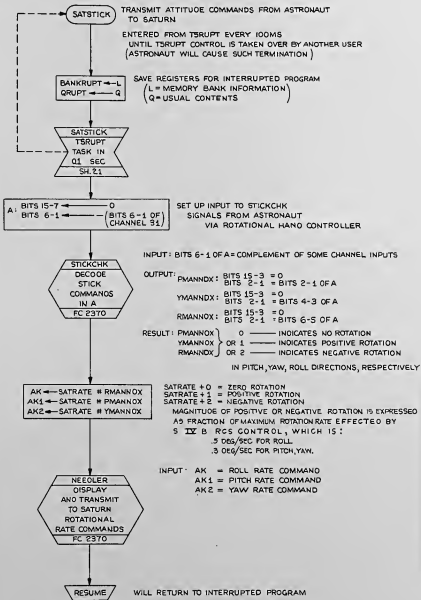
208660 PERIOD: 15 AUG 67 BY: J. W. Johnson DATE: 15 AUG 67 APPROVED: John A. Moore 22 April 67	P11 - EARTH ORBIT INSERTION MONITOR COLDSUS II A FC-2540 19 14 37
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ADCEG8J  
114469  
COLOSSUS II A FC-2540  
20 27

P11 - EARTH ORBIT  
INSERTION MONITOR

O. H. Edson  
R. M. Stewart  
J. A. Moran



WIT APPROVED BY CAMPBELL W. S.	APPROVED BY GUIDANCE AND NAVIGATION DIVISION
SPECIAL OPERATIONS PROJECT O. W. Harrison ANALYST SOME DEPT. OF ASTRONAUTICS APPROV. John A. Brown 8/20/68	P11 - EARTH ORBIT INSERTION MONITOR COLOSSUS II A FC-2540 REV 1 SHEET 21 OF 27

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
CALCGTA	2260	COMPUTES EULER ANGLES NECESSARY TO ACHIEVE DESIRED ATTITUDE	SH. 13
CDUTRIG	2270	READS PRESENT IMU GIMBAL ANGLES AND COMPUTES THEIR TRIGONOMETRIC FUNCTIONS	SH. 13
EARTHUR*3	2530	COMPUTES AND COMPENSATES FOR EFFECT OF EARTH'S ROTATION ON STABLE MEMBER ORIENTATION	SH. 5
LALOTORV	2280	COMPUTES POSITION VECTOR IN REFERENCE COORDINATES GIVEN LATITUDE, LONGITUDE, ALTITUDE	SH. 7
LALOTORV*5	2290	COMPUTES POSITION VECTOR GIVEN LATITUDE, LONGITUDE, ALTITUDE, AND GAMMA (WEIGHTING PARAMETER)	SH. 7
NEEDLER	2370	DISPLAYS (ON FDI) NEEDLES) ATTITUDE ERRORS OR STEERING COMMANDS AND, IF ENABLED, TRANSMITS STEERING COMMANDS TO SATURN IU	SH. 4, 16, 17, 20, 21
NEWMODEX	2030	CHANGES MAJOR MODE AND DISPLAYS IT	SH. 4
NORMLIZE	2683	DOES INITIAL STATE VECTOR UPDATE	SH. 9
POWRSERS	2050	EVALUATES POLYNOMIAL	SH. 11
PREREAD1	2683	CLEARs PIPAS AND INITIALIZES SERVICER	SH. 4
PROUT	2530	CAUSES DELAY UNTIL GYRO TORQUING FINISHED	SH. 5
READACCS	2653	READS ACCELEROMETERS, SETS UP SERVICER; RESCHEDULES ITSELF EVERY 2 SECONDS UNTIL STOPPED	SH. 9
STICKCHK	2370	DECODE RHC COMMANDS INTO PITCH, ROLL, YAW COMMANDS	SH. 21
VISTOAS	2100	CONVERTS ANGLES FROM 1'S COMPLEMENT TO 2'S COMPLEMENT REPRESENTATION	SH. 14
ZEROJET	2380	CLEARs RCS JET CHANNELS	SH. 19

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
AMOOFLG FLAGWRD0 BIT 2	STATE VECTOR IS IN LUNAR SPHERE OF INFLUENCE	STATE VECTOR IS IN EARTH SPHERE OF INFLUENCE			SH. 18
DAPBIT1 FLAGWRD6 BIT 15	BOTH SET- SATURN UNDER TVC STICK	DAPBIT1-0 DAPBIT2-1 RCS NO DAP IN	BOTH CLEAR SH. 19		SH. 10
DAPBIT2 FLAGWRD6 BIT 14	DAP IN CONTROL	DAP IN CONTROL	SH. 19		SH. 10
ERADFLAG FLAGWRD1 BIT 13	COMPUTE EARTH RADIUS, ASSUME FIXED MOON RADIUS	ASSUME CONSTANT EARTH RADIUS, USE RLS FOR MOON RADIUS		SH. 7	
NODOP01	MAJOR MODE P01 MAY NOT BE SELECTED	MAJOR MODE P01 MAY BE SELECTED	SH. 4		
#CSFLAGS BIT 3	FIRST PASS THROUGH NEEDLER	LATER THAN FIRST PASS THROUGH NEEDLER	SH. 4, 17, 20		
REFSMFLG FLAGWRD3 BIT 13	REFSMAT <sub>0</sub> IS VALID GIVES KNOWN ORIENTATION OF STABLE MEMBER	STABLE MEMBER ORIENTATION UNKNOWN	SH. 8		

MIT "ANTI-INTERFERENCE" AMSP-302 MASS	GU-240-480-4-15 P11 - EARTH ORBIT INSERTION MONITOR COLUSSUS II FC-2540 22 - 27
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APPROV'D BY: *[Signature]* DATE: *[Date]*  
 APPROV'D BY: *[Signature]* DATE: *[Date]*

DISPLAYS					
VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER			WHERE EXECUTED
V06N62	NORMAL SNAPSHOT	R1 XXXXX. FT/SEC	VMAGI - (MAGNITUDE OF VELOCITY)	}	SH. 18
		R2 XXXXX. FT/SEC	HDOT - (RATE OF CHANGE OF ALTITUDE)		
		R3 XXXX.X NM	ALT I - (ALTITUDE ABOVE EARTH OR MOON SURFACE, AS APPROPRIATE)		
ERASABLE LOCATIONS USED					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
AK	(E <sub>A</sub> ) <sub>1</sub>	ROLL ATTITUDE ERROR (OR ROLL RATE COMMAND)	DEGREES	REVS	2 <sup>+1</sup>
AK1	(E <sub>A</sub> ) <sub>2</sub>	PITCH ATTITUDE ERROR (OR PITCH RATE COMMAND)	DEGREES	REVS	2 <sup>-1</sup>
AK2	(E <sub>A</sub> ) <sub>3</sub>	YAW ATTITUDE ERROR (OR YAW RATE COMMAND)	DEGREES	REVS	2 <sup>-1</sup>
ALTI <sub>D</sub>	H	ALTITUDE OF VEHICLE ABOVE EARTH OR MOON SURFACE, AS APPROPRIATE	M	M	2 <sup>20</sup>
AVEGEXIT <sub>D</sub>		VARIABLE LOCATION OF SUBROUTINE ENTERED AT END OF SERVICER			
BANKRUPT		USED TO SAVE BBANK REGISTER OF INTERRUPTED PROGRAM			
BIASAK		ROLL ATTITUDE ERROR AT TIME CMC IS PUT IN CONTROL OF SATURN	DEGREES	REVS	2 <sup>+1</sup>
BIASAK+1		PITCH ATTITUDE ERROR AT TIME CMC IS PUT IN CONTROL OF SATURN	DEGREES	REVS	2 <sup>-1</sup>
BIASAK+2		YAW ATTITUDE ERROR AT TIME CMC IS PUT IN CONTROL OF SATURN	DEGREES	REVS	2 <sup>-1</sup>
CDUSPOTX		IMU OUTER GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)	DEGREES	REVS	2 <sup>0</sup>
CDUSPOTY		IMU INNER GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)	DEGREES	REVS	2 <sup>0</sup>
CDUSPOTZ		IMU MIDDLE GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)	DEGREES	REVS	2 <sup>0</sup>
CDUX		IMU OUTER GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-1</sup>
CDUY		IMU INNER GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-1</sup>
CDUZ		IMU MIDDLE GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-1</sup>
COSCDUX		COSINE OF IMU OUTER GIMBAL ANGLE			2 <sup>1</sup>
COSCDUY		COSINE OF IMU INNER GIMBAL ANGLE			2 <sup>1</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> 10 MAR 68		P11 - EARTH ORBIT INSERTION MONITOR	
PROG. NO. <i>[Handwritten]</i>	ANAL. <i>[Handwritten]</i>	COLOSSUS II A	DOCUMENT NO. FC-2540
DOC. NO. <i>[Handwritten]</i>	APPRO. <i>[Handwritten]</i>	REV I	SHEET 23 OF 27

## EHASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
COSCDUZ		COSINE OF IMU MIDDLE GIMBAL ANGLE			$2^1$
DN1STCOD		INDICATES WHICH LIST OF INFORMATION IS TO BE TRANSMITTED BY DOWNLINK			
ERCOMP <sub>V</sub>		ROTATION RATE AFFECTING IMU IN STABLE MEMBER COORDINATES	DEG/SEC	REVS/CSEC	$2^1$
HUOT <sub>D</sub>	ü	RATE OF CHANGE OF ALTITUDE	M/SEC	M/CSEC	$2^7$
IGC <sub>D</sub>		INNER IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE	DEGREES	REVS	$2^0$
LAT <sub>V</sub> = $\begin{pmatrix} LAT_D \\ LONG_D \\ ALT_D \end{pmatrix}$		POSITION SPECIFIED IN TERMS OF LATITUDE, LONGITUDE, ALTITUDE	DEGREES DEGREES M	REVS REVS M	$2^0$ $2^0$ $2^{20}$
LIFTTEMP <sub>D</sub>		TEMPORARY STORAGE FOR LIFTOFF TIME	SEC	CSEC	$2^{28}$
MGC <sub>D</sub>		MIDDLE IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE	DEGREES	REVS	$2^0$
OGC <sub>D</sub>		OUTER IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE	DEGREES	REVS	$2^0$
PMANNIX		INDICATES ZERO, POSITIVE OR NEGATIVE PITCH COMMAND BY VALUE OF 0, 1 OR 2, RESPECTIVELY			
QPLACES		VARIABLE EXIT FROM PROUT			
QRUPT		USED TO SAVE Q REGISTER OF INTERRUPTED PROGRAM			
REFSMMAT <sub>M</sub>	[REFSMMAT]	TRANSFORMATION MATRIX RELATING STABLE MEMBER AND REFERENCE COORDINATE SYSTEMS			$2^1$
RLS <sub>V</sub>		LUNAR LANDING SITE VECTOR IN REFERENCE COORDINATES	M	M	$2^{27}$
RMANNIX		INDICATES ZERO, POSITIVE OR NEGATIVE ROLL COMMAND, BY VALUE OF 0, 1 OR 2, RESPECTIVELY			
RN <sub>V</sub>	R(T)	POSITION VECTOR IN REFERENCE COORDINATES	M	M	$2^{29}$
RN1 <sub>V</sub>	R(T+ΔT)	TEMPORARY UPDATED VERSION OF RN <sub>V</sub> (ABOVE)	M	M	$2^{29}$
RTX2		INDICATES WHETHER IN EARTH OR MOON SPHERE OF INFLUENCE, BY VALUE OF 0 OR 2, RESPECTIVELY			

M.I. INSTRUMENTATION LAB LAFORVILLE, MASS.		P11 - EARTH ORBIT INSERTION MONITOR	
DESIGN <i>D. J. Smith</i>	REVISION <i>10 MAR 68</i>	COLOSSUS II	
PULSES <i>1. W. Smith</i>	DATE <i>10 MAR 68</i>	FC-2540	
ADJUST <i>1. W. Smith</i>	APPROVED <i>1. W. Smith</i>	REV 24 27	



## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
SATRLRT	$-\text{SIGN}(K_{\theta})/K_P$	NOMINAL SATURN ROLL RATE (SEE PAD LOAD SECTION)	DEG/SEC	REVS/CSEC	$2^0$
SATSW		INDICATES WHETHER CMC IS IN CONTROL OF SATURN STAGE AND, IF SO, WHETHER THIS IS FIRST OR LATER PASS THROUGH ATERJOB IN THIS SITUATION, BY VALUE $+0$ , $<0$ , OR $>0$ , RESPECTIVELY			
SINCDUX		SINE OF OUTER IMU GIMBAL ANGLE			$2^1$
SINCDUY		SINE OF INNER IMU GIMBAL ANGLE			$2^1$
SINCDUZ		SINE OF MIDDLE IMU GIMBAL ANGLE			$2^1$
SPOLYARG	$T_P$	TIME SINCE NOMINAL START OF ROLL	SEC	CSEC	$2^{14}$
TRASE5		-LOW-ORDER HALF OF TIME FROM WHICH $\Delta$ TIMES FOR GROUP 5 WAITLIST TASK RESTARTS ARE TO BE COUNTED	SEC	CSEC	$2^{28}$
TEPHEM <sub>T</sub>	$T_{OK}$	REFERENCE EPHEMERIS TIME	SEC	CSEC	$2^{42}$
TEPHEM <sub>I<sub>T</sub></sub>		TEMPORARY UPDATED VERSION OF TEPHEM <sub>T</sub> (ABOVE)	SEC	CSEC	$2^{42}$
THETA <sub>V</sub>		STABLE MEMBER DRIFT, ETC. NOT CORRECTED DURING PRELAUNCH IN EARTH-FIXED COORDINATES	DEG/SEC	REVS/CSEC	$2^{21}$
$\frac{\text{TIME2}_D}{\text{TIME1}}$		PRESENT TIME [AFTER LIFTOFF - PRESENT] [ $\Delta$ TIME FROM LIFTOFF]	SEC	CSEC	$2^{28}$
TLIFTOFF <sub>D</sub>	$T'$	TIME OF LIFTOFF	SEC	CSEC	$2^{28}$
VMAG <sub>D</sub>	$V$	MAGNITUDE OF VELOCITY	M/SEC	M/CSEC	$2^7$
$V_N$	$\underline{V}(T)$	VELOCITY VECTOR, IN REFERENCE COORDINATES	M/SEC	M/CSEC	$2^7$
VNI <sub>V</sub>	$\underline{V}(T+\Delta T)$	TEMPORARY UPDATED VERSION OF $V_N$ (ABOVE)	M/SEC	M/CSEC	$2^7$
XDC <sub>V</sub>		DESIRED STABLE MEMBER X-AXIS IN TERMS OF ORIGINAL STABLE MEMBER ORIENTATION			$2^1$
XSM <sub>M</sub>		MATRIX FOR CONVERSION FROM EARTH-FIXED TO STABLE MEMBER COORDINATE SYSTEM			$2^1$
YDC <sub>V</sub>		DESIRED STABLE MEMBER Y-AXIS IN TERMS OF ORIGINAL STABLE MEMBER ORIENTATION			$2^1$
YMANNDX		INDICATES ZERO, POSITIVE OR NEGATIVE YAW COMMAND, BY VALUE OF 0, 1 OR 2, RESPECTIVELY			
ZDC <sub>V</sub>		DESIRED STABLE MEMBER Z-AXIS IN TERMS OF ORIGINAL STABLE MEMBER ORIENTATION			$2^1$
1/PIPADT		$\Delta$ TIME BETWEEN PIPA READINGS	SEC	CSEC	$2^8$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APC... GUIDANCE AND NAV. LAB	
DRAWN <i>A. J. ...</i> 10/24/68		P11 - EARTH ORBIT INSERTION MONITOR	
PRINR <i>A. J. ...</i> 11/24/68		COLOSSUS IIA	
ANAL. <i>A. J. ...</i>		FC-2540	
DOC. NO. <i>11/24/68</i>		REV 1	
APPROV. <i>A. J. ...</i>		SHEET 25 OF 27	

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
-ERTHRAT <sub>D</sub>	$\omega_E$	-RATE OF EARTH ROTATION FROM NORTH TO SPACECRAFT +Z-AXIS	-7.292115138 $\times 10^{-5}$ RAD/SEC	-7.292115138 $\times 10^{-7}$ RAD/CSEC	$2^{-18}$
RPAD <sub>D</sub>	R <sub>LP</sub>	MAGNITUDE OF POSITION VECTOR FOR LAUNCH PAD	6,373,338 M	6,373,338 M	$2^{29}$

## PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
AZIMUTH <sub>D</sub>	A <sub>ZP</sub>	AZIMUTH (AT LAUNCH) FROM NORTH TO SPACECRAFT +Z-AXIS	DEGREES	REVS	$2^0$	
LATITUDE <sub>D</sub>	LAT <sub>P</sub>	LATITUDE OF LAUNCH PAD	DEGREES	REVS	$2^0$	
LAUNCHAZ <sub>D</sub>	A <sub>Z</sub>	AZIMUTH (AT LAUNCH) FROM NORTH TO STABLE MEMBER +X-AXIS	DEGREES	REVS	$2^0$	
PADLONG <sub>D</sub>	LON <sub>P</sub>	LONGITUDE OF LAUNCH PAD	DEGREES	REVS	$2^0$	
PGNCSALT <sub>D</sub>	ALT <sub>i</sub>	ALTITUDE OF IMU	M	M	$2^{29}$	
POLYNUM	N-1	1 LESS THAN DEGREE OF POLYNOMIAL FOR COMPUTATION OF NOMINAL PITCH ANGLE			$2^{14}$	
POLYSTOP	-T <sub>E2</sub>	- (LENGTH OF TIME DURING WHICH ATTITUDE ERROR IS TO BE COMPUTED)	SEC	CSEC	$2^{14}$	
RPSTART	T <sub>E1</sub>	TIME OF NOMINAL START OF SATURN ROLL - TIME TO BEGIN COMPUTATION OF NOMINAL ATTITUDE	SEC	CSEC	$2^{14}$	
SATRATE		POSSIBLE ROTATION RATE COMMAND TO SATURN - NO ROTATION	0	0		00000
SATRATE*1		POSSIBLE ROTATION RATE COMMAND TO SATURN - FRACTION OF MAXIMUM POSITIVE ROTATION RATE, WHICH IS: .5 DEG/SEC FOR ROLL .3 DEG/SEC FOR PITCH, YAW				
SATRATE*2		POSSIBLE ROTATION RATE COMMAND TO SATURN - FRACTION OF MAXIMUM NEGATIVE ROTATION RATE, WHICH IS: -.5 DEG/SEC FOR ROLL -.3 DEG/SEC FOR PITCH, YAW				

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARLCO CUSTOMER AND PART NO.	
DRAWN <i>A. J. Smith</i> 10/19/68		P11-EARTH ORBIT INSERTION MONITOR	
DESIGNED <i>C. L. Sullivan</i> 11/14/68	APPROVED <i>A. J. Smith</i> 11/14/68	COLOSSUS II	
ANALYST	DATE	FC-2540	
DATE	APPROVED	REV 1	
		REV 2	

REV 1

REV 2

PAD LOADS (CONTINUED)

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
SATRLRT <sub>D</sub>	K <sub>R</sub>	ABSOLUTE VALUE OF NOMINAL SATURN ROLL RATE SIGN ATTACHED DURING THIS PROGRAM (SEE ERASABLE SECTION)	1 DEG/SEC	1/36000 REVS/CSEC	2 <sup>0</sup>	00000 16441
SATSCALE		SCALING FACTOR FOR ATTITUDE CORRECTION COMMANDS TO SATURN HARDWARE				
UNITW <sub>V</sub>	U <sub>ZZ</sub>	UNIT VECTOR IN DIRECTION OF EARTH ROTATION VECTOR (Z) IN REFERENCE COORDINATES	( 3.32402568949 x 10 <sup>-6</sup> 4.18407084553 x 10 <sup>-5</sup> 0.999999998 x 10 <sup>-1</sup> )	SAME	2 <sup>0</sup>	( 77777 78203 00000 25740 37777 37777 )

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFI GUIDANCE AND NAVIGATION DIV.	
DRAWN <i>[Signature]</i>		P11-EARTH ORBIT INSERTION MONITOR	
PRICE: <i>[Signature]</i>	DATE: <i>[Signature]</i>	DOCUMENT NO.	
DESIGN: <i>[Signature]</i>	APPROV: <i>[Signature]</i>	COLOSSUS IIA	FC-2540
APPROV: <i>[Signature]</i>	REV: 1	SCALE: 27	27

THE MAJOR SUBROUTINES IN THE TPI SEARCH PROGRAM ARE

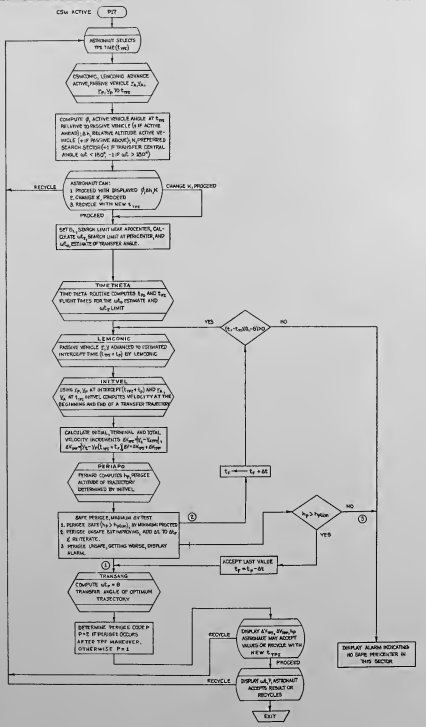
P17, P77, P17.1, P17.2, P17.3, S17.1, S17.2, S17.3

SPECIAL CONVENTIONS

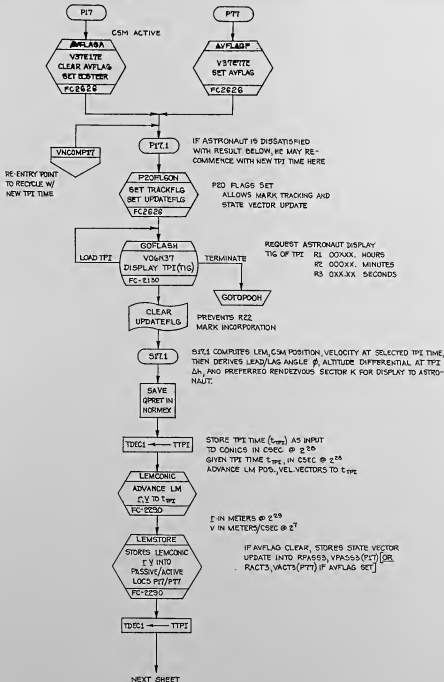
P17/P77 IS A COLOSSUS AND LUMINARY PROGRAM. THE TERMS PERIGEE (EARTH), PERILUNE (MOON), AND PERICENTER, APOGEE, APOLUNE, APOCENTER, ARE USED INTERCHANGEABLY WITHOUT DISTINGUISHING EXPLICITLY THE PROPER SPHERE OF INFLUENCE.

THE NOTATION USED FOLLOWS THE CONVENTIONS ESTABLISHED IN SECTION 5.4.4.4 OF R577, IN PARTICULAR FIG. 4.4.4.

MIT INSTRUMENTATION LAB AMBRIDGE, MASS.		TPI SEARCH PROGRAMS P17 & P77	
DRAWN	<i>[Signature]</i>	APPROVED	
TRACED	<i>[Signature]</i>		
ANALYST	<i>[Signature]</i>	COLOSSUS IIC	FC-2545
DOI NO.	<i>[Signature]</i>		
APPRO'D.	<i>[Signature]</i>		



J. C. WILLIAMS  
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THE SEARCH PROGRAM  
PRT & PRT  
FC-545  
64



REF IN TERMINATION LAB CARRIDGE, MASS.		APPROVALS AND SIGNATURES	
DRYAN A. WILLIAMS 22/2/68		TPI SEARCH PROGRAMS P17 & P177	
DOCSR [Signature] 25/2/68		DOCUMENT NO.	
ADMIN [Signature] 27/2/68		COLOSSUS IIC	
DOCSR [Signature] 28/2/68		FC-2545	
APPROV [Signature] 28/2/68		PAGE 3 OF 18	

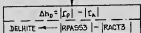
FROM PRECEDING SHEET



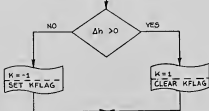
ADVANCE CSM STATE VECTOR



CSM STATE VECTOR  $X, Y$  FROM CONIC SUBROUTINE RATT, VATT ARE STORED INTO RACT3, VACT3 OR RPASS3, VPASS3 DEPENDING ON AVFLAG (CLEAR PIT, SET PIT)

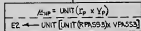


SUBTRACT ABSOLUTE VALUE OF ACTIVE VEHICLE POSITION VECTOR AT  $t_{TPT}$  FROM ABSOLUTE VALUE OF PASSIVE VEHICLE POSITION VECTOR TO FORM,  $\Delta h$ , ALTITUDE OF PASSIVE RELATIVE TO ACTIVE.

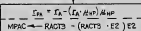


$\Delta h$  POS = ACTIVE VEHICLE BELOW, CLEAR KFLAG

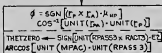
$\Delta h$  NEG = ACTIVE VEHICLE ABOVE, SET KFLAG



FORM  $A_{UP}$ , UNIT VECTOR OF PASSIVE VEHICLE ORBITAL PLANE ( $E_p \times Y_p$ ) AT  $t_{TPT}$



COMPONENT OF ACTIVE VEHICLE POSITION VECTOR, IN PLANE OF PASSIVE VEHICLE,  $E_{PA}$ , OBTAINED BY SUBTRACTING COMPONENT NORMAL (COMPONENT PARALLEL TO PASSIVE VEHICLE UNIT VECTOR  $A_{UP}$ )  $E_A$  IN METERS @ 2<sup>22</sup>



COMPUTE  $\phi$ , ACTIVE/PASSIVE VEHICLE LEAD ANGLE IN PLANE OF PASSIVE VEHICLE, AND AFFIX SIGN OF ANGLE BETWEEN  $E_p, E_a$  (- IF ACTIVE VEHICLE AHEAD)



SAVE CONTENTS OF X1 AND X2 FOR SCALING AND INDEXING IN EARTH/MOON SPHERE OF INFLUENCE



$\Delta h, \phi$  COMPUTED, KFLAG SEARCH SECTOR INDICATOR SET, RETURN TO PIT.1 TO DISPLAY



FINISHED WITH CONICS

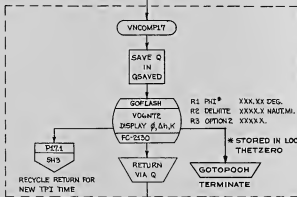
NEXT SHEET

TITLE INFORMATION LAB CAMBRIDGE, MASS.		PROJECT TPI SEARCH PROGRAMS PIT & PTT	
DRAWN BY A. C. WILLIAMS	DESIGNED BY J. W. HARRIS	CHECKED BY R. J. HARRIS	APPROVED BY J. W. HARRIS
APPROVED BY J. W. HARRIS		PROJECT NO. COLOSSUS IIC	FC-2545 REV 4

FROM PRECEDING SHEET



IF KFLAG IS SET (K=-1) OPTIONZ IS LOADED WITH 1, INDICATING PREFERRED SEARCH SECTOR < 180°. OTHERWISE OPTIONZ = 2, SEARCH SECTOR > 180°



ASTRONAUT HAS THE FOLLOWING OPTIONS:

1. PROCEED, IF SATISFIED WITH  $\phi$ ,  $\Delta h$ , K DISPLAYED V33E.
2. TERMINATE, TO END MAJOR MODE, BY V34E.
3. RECYCLE V32E WHICH WILL CAUSE PROGRAM TO RETURN TO PRT1 ABOVE AND REQUEST NEW TPI TIME.

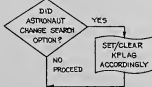
R1 PHZ<sup>o</sup> XXX.XX DEG.  
R2 DELUTE XXXXX NAUTMI.  
R3 OPTIONZ XXXXX.

\* STORED IN LOG  
THEZERO

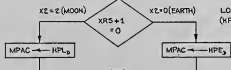
RECYCLE RETURN FOR  
NEW TPI TIME

GOTOPOOH  
TERMINATE

CLEAR  
UPDATFLG



IF ASTRONAUT CHANGED SEARCH SECTOR, ALTER KFLAG ACCORDINGLY.



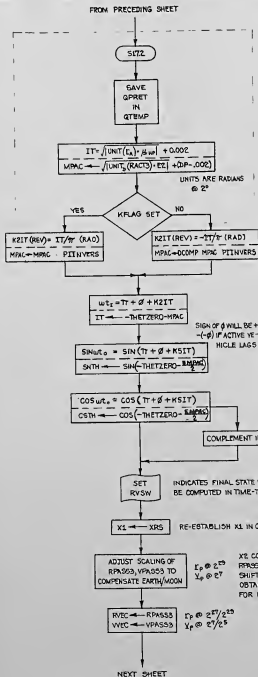
LOAD VALUE OF  $h_p$ , MINIMUM PERIGEE, FOR EARTH (HPE) OR MOON (HPL) DEPENDING ON X2 CONTENTS.

P17.2  
HPERMIN ← MPAC

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROP GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		TPI SEARCH PROGRAMS P17 & P17	
FOR: <i>A.C. Williams</i>	DATE: <i>12/14/60</i>	COLOSSUS IIC	DOCUMENT NO. FC-2545
ANALYST: <i>John Smith</i>	DATE: <i>12/14/60</i>		
DATE: <i>12/14/60</i>	REV: 1	SHEET 5 OF 10	





SIGN OF IT+ IF SEARCH SECTOR < 180°  
SIGN OF IT- IF SEARCH SECTOR > 180°  
CONVERT IT IN RADIAN TO ZIT IN REVS

$w_2$  IS THE INNER SEARCH LIMIT AT  
PERICENTER RELATIVE TO  $I_A(t_{\text{OP}})$ . IT IS  
LESS THAN 180° BY THE AMOUNT  $\phi$  THAT  
THE ACTIVE VEHICLE LEADS, AND THEN IS  
INCREASED  $-(-ZIT)$  (SEE PREVIOUS STEP)  
IF THE KFLAG INDICATES A POST-PERICENTER  
INTERCEPT, DECREASED IF  $K= -1$ .  
INPUT: REV @  $2^6$ ; OUTPUT: @  $2^{-4}$   
 $\text{SIN}(\pi + \phi + KZIT) = \text{SIN}(\phi - KZIT)$  IS STORED  
IN SNTH,  $\text{COS}(-\phi - KZIT)$  IS COMPLEMENTED  
BEFORE STORAGE IF IT IS POSITIVE

$w_2$  IS THE FIRST APPROXIMATION GUESS  
OF TRANSFER CENTRAL ANGLE, WHICH, LIKE  
 $\phi_2 = w_2 - I_A$ , IS RESTRICTED FROM 180° AS "IT"  
INCREASES, SINCE  $\Delta V$  BECOMES EXCESSIVE  
NEAR PERICENTER AS THE OUT-OF-PLANE  
CONDITION WORSENS.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT COLUMN 1 AND 140 247 2	
DRAWN A. C. WILLIAMS		TPI SEARCH PROGRAMS PI T C PTT	
PREPARED BY [Signature]		REVISED BY [Signature]	
ANALYST [Signature]		COLOSSUS IIC FC-2545	
CHECKED [Signature]		REV 1	
APPROVED [Signature]		REV 1	

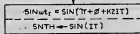
FROM PRECEDING SHEET



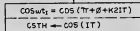
GIVEN  $r_p, V_p$  AT TPI TIME AND  $\sin \omega t_0, \cos \omega t_0$ , TIME THAT RETURNS TIME OF FLIGHT  $t_p$  IN CSEC @  $2^{11}$



TIME OF FLIGHT RETURNED BY TIMETHET STORED AS BOTH  $t_p$ , INTERIM FLIGHT TIME SUBJECT TO ITERATIVE OPTIMIZATION, AND  $t_{p0}$ , FIRST APPROXIMATION  $t_p$



CONVERT  $\omega t_2$  TO  $\sin \omega t_2$  &  $\cos \omega t_2$  FORM REQUIRED BY TIMETHET



COMPLEMENT IF +



RE-ESTABLISH INDICES



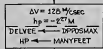
GIVEN  $r_p$  AND  $V_p$  AT TPI AND  $\sin \omega t_2, \cos \omega t_2$  TIMETHET RETURNS THE TIME OF FLIGHT  $t_{p2}$



STORE TIME CALCULATED BY TIMETHET AS  $t_{p2}$



CAUSES VALUES OF PERIGEE HEIGHT  $h_p$  OBTAINED BELOW TO BE TESTED WHEN CLEAR ITSWICH IS SET WHEN ACCEPTABLE  $h_p$  IS FOUND BY TEST, CAUSING  $h_p$  TO BYPASS TEST ON NEXT ITERATION



LARGEST POSSIBLE VALUE OF VELOCITY INCREMENT ( $\Delta V = 125 \text{ M/CSEC}$ ) AND LOWEST PERIGEE HEIGHT ( $h_p = -2^7 \text{ M}$ ) ARE STORED FOR FIRST PERIGEE ITERATION TO INSURE THAT  $h_p$  OF FIRST APPROXIMATION  $\omega t_0$  DOES NOT PASS TEST ON FIRST ITERATION WITHOUT FURTHER OPTIMIZATION.



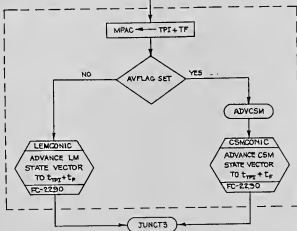
SET  $\theta_1$  OUTER LIMIT ANGLE ACCORDING TO SEARCH SECTOR IN REV @  $2^\circ$



NEXT SHEET

MIT INSTRUMENTATION LAB LAWRENCE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. C. WILLIAMS		TPI SEARCH PROGRAMS RIT & RT7	
PROGRAM <i>[Signature]</i>	DESIGNED <i>[Signature]</i>	COLLOSSUS IIC	DOCUMENT NO. FC-2545
ANALYSIS <i>[Signature]</i>	TESTED <i>[Signature]</i>	REV 4	SHEET 7 OF 10
APPROVED <i>[Signature]</i>			

FROM PRECEDING SHEET



ADD  $t_p$  TO  $t_{TPI}$   
( $t_p = t_{p0}$  ON FIRST PASS)

BRANCH ON AVFLAG TO  
SELECT PASSIVE VEHICLE

ADVANCE PASSIVE VEHICLE  $I_x, Y_p$   
TO INITIAL INTERCEPT AIM POINT

JUNCT3  
 $VPASS4 \leftarrow Y_p(t_{TPI} + t_p)$   
 $TPASS4 \leftarrow I_x(t_{TPI} + t_p)$   
 $RTARG \leftarrow I_x(t_{TPI} + t_p)$   
 $DELTA \leftarrow TF$   
 $HPD \leftarrow HP$   
 $DELVEQ \leftarrow DELVEE$   
 $INTIME \leftarrow TTPI$   
 $RTX1 \leftarrow XRS$   
 $PLOC \leftarrow HIGZEROS$   
 $PLOZ \leftarrow EPSFOUR(\cos 15^\circ)$   
 $RINIT \leftarrow RACT3$   
 $VINIT \leftarrow VACT3$

INITIALIZE INITVEL  
 ENTER PASSIVE VEHICLE POSITION AND VELOCITY AT  
 INTERCEPT FROM CONIC ROUTINE;  $t_p, I_x, Y_p$  ( $-2^{\text{ND}}$  W), DELVEE  
 ( $\Delta V$ ) 120 M/CSEC; INITIALIZE  $X1$  ( $-2$  EARTH,  $-10$  LUNAR);  
 $PLOC$   $N_{p0}$  INDICATES CONIC TRAJECTORY ONLY, NO OFFSETS;  
 $EPSFOUR$  ( $15^\circ$ ) IS ANGLE OF CONE AROUND 180° TRANSFER  
 WITHIN WHICH INPUT TARGET VECTORS MUST BE ROTATED  
 TO AVOID SINGULARITIES; RACT3, VACT3 ARE PASSIVE  
 VEHICLE  $I_x, Y_x$ .

INITVEL  
 CALCULATE  
 $V_1, Y_1$  AND  $\Delta V$   
 FOR TRANSFER  
 TRAJECTORY  
 FC-2630

USING  $t_p, I_x, Y_x$  AT TPI AND PASSIVE  $I_x$ ,  
 AT INTERCEPT, INITVEL CALCULATES ACTIVE VEHICLE  
 VELOCITIES AT BEGINNING  $V_1$  AND END  $V_2$  OF THE TRANSFER  
 TRAJECTORY AND  $\Delta V$  REQUIRED FOR MANEUVER  
 OUTPUT:  $V_1$  IN VI PRIME  
 $V_2$  IN VT PRIME  
 $\Delta V$  IN DELVEE T3

$\Delta V_{TPI} = |V_2 - V_1(t_{TPI} + t_p)|$   
 $REDELVE \leftarrow |VT PRIME - VPASS4|$

$\Delta V$  TPI MANEUVER

$\Delta V_{TPI} = |Y_1 - Y_A|$   
 $MAGVTPI \leftarrow |DELVEE T3|$

$\Delta V$  TPI MANEUVER

$\Delta V = \Delta V_{TPI} + \Delta V_{TPI}$   
 $DELVEE \leftarrow MAGVTPI + REDELVE$

TOTAL  $\Delta V$

$X1 \leftarrow XRS$  LOAD INDEXING CONSTANTS

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		482310 DC JAMES AND NAVIGATH-4	
DRAWN A.C. WILLIAMS PROGRAM ANALYST DOCKER APPROV		TPI SEARCH PROGRAMS R17 & RTT DOCUMENT NO. COLOSSUS IIC FC-2545 SHEET 05 OF 10	

FROM PRECEDING SHEET

SCALE  $V_1, \Gamma_A$  ( $\frac{1}{z^{1.5}}$ )  
 $z^1$  FOR  $z^2/z^1$  (EARTH)  
 $z^2$  FOR  $z^2/z^2$  (MOON)

ADJUST SCALING OF TRANSFER TRAJECTORY INITIAL POS., VEL., ON XZ INDEX REGISTER TO OBTAIN CORRECT  $z^{1.5}/z^1$  OR  $z^2/z^2$  EARTH-MOON SCALING USING XZ.

PERIAPO  
CALCULATE  $h_p$   
PERIGEE HEIGHT  
FOR TRANSFER  
TRAJECTORY  
FC-2630

COMPUTES THE PERIGEE HEIGHT  $h_p$  BASED ON  $\Gamma_A + V_1$  FOR THE TRAJECTORY RETURNED BY INITVEL.

XZ  $\leftarrow$  XRS + 1  
MPAC  $\leftarrow$   $h_p$   
RESTORE  $h_p$  TO  
 $z^{1.5}$  SCALING IF  
LUNAR MISSION

$h_p$  MUST BE SCALED  $z^{1.5}$  IN BOTH EARTH AND MOON SPHERES OF INFLUENCE SO ITS SCALING WILL MATCH THE  $z^{1.5}$  VALUE OF THE THRESHOLD VALUE  $h_{pLim}$  IN THE TESTS THAT FOLLOW.

HP  $\leftarrow$   $h_p$

STORE SCALED  $h_p @ z^{1.5}$  FOR LIMIT TEST.

NEXT SHEET

MIT DOCUMENTATION LAB AMBRIDGE, MASS.		AUG 1964 GL 24-110-144-100	
FORM A A. C. WILLIAMS DR. NO. 11 ANAL. 11 DO. NO. 11 APPD. 11	SEARCHED SERIALIZED INDEXED FILED	TPI SEARCH PROGRAMS FIT & PTT DOCUMENT NO. FC-2545 REV 1	
COLOSSUS IIC		REV 1	



FROM PRECEDING SHEET

$$SG2 = \text{SIGN} [T_p(t_{TP}) \cdot Y_2]$$

$$\frac{\Delta V_{TPF}}{\Delta V} = SG2 \frac{\Delta V_{TPF}}{\Delta V}$$

$$SG1 \leftarrow \text{SIGN} [RPA553 - VACT3]$$

$$\text{REDELV} \leftarrow \text{SIGN} (SG2) \text{REDELV}$$

SG2 INDICATES TPF(TIG) LOCATION:  
+1 BETWEEN PERICENTER AND APOCENTER  
-1 BETWEEN APOCENTER AND PERICENTER

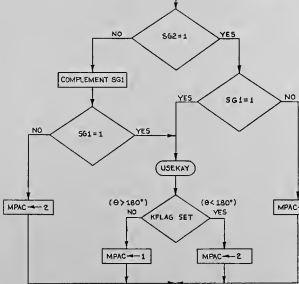


TRANSANG COMPUTES CENTRAL ANGLE OF THE TRANSFER TRAJECTORY CORRESPONDING TO TIME OF FLIGHT TF.  
INPUTS:  $T_p - V_p$  @ TPF t<sub>p</sub>  
OUTPUT: wt

$$SG1 = \text{SIGN} [r_a(t_{TC}) \cdot V_1]$$

$$\text{MPAC} \leftarrow \text{SIGN}(\text{RACT3} - \text{V3PRIME})$$

SG1 INDICATES TPI(TIG) LOCATION:  
+ BETWEEN PERICENTER AND APOCENTER  
- BETWEEN APOCENTER AND PERICENTER



MPAC=1 INDICATES PERICENTER OCCURS DURING TRANSFER TRAJECTORY.  
MPAC=2 INDICATES INTERCEPT COMPLETE BEFORE PERICENTER.

NEXUS

HN1 ← MPAC

STORE PERIGEE CODE FOR SUBSEQUENT DISPLAY

POSTTPI ← HP

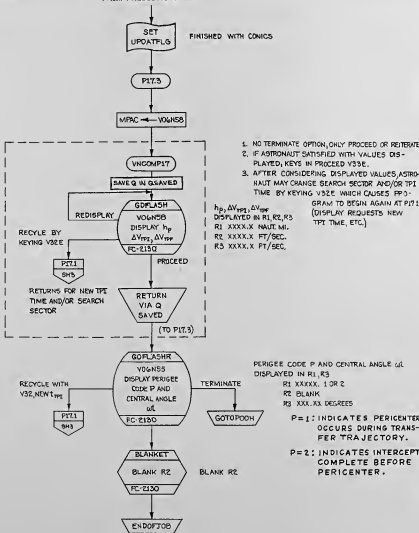
STORE h<sub>p</sub> FOR DISPLAY

RETURN VIA QTRAP TO PILE

NEXT SHEET

MIT "SYSTEMS" RESEARCH LAB CAMBRIDGE, MASS.		ARJLC GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		TPI SEARCH PROGRAMS	
PREP'D [Signature]		PPT & PPT	
ANALY' [Signature]		DOCUMENT NO.	
CHECKED [Signature]		COLOSSUS IIC	
APPROVED [Signature]		FC-2545	
REV 1		SHEET 11 of 18	

FROM PRECEDING SHEET



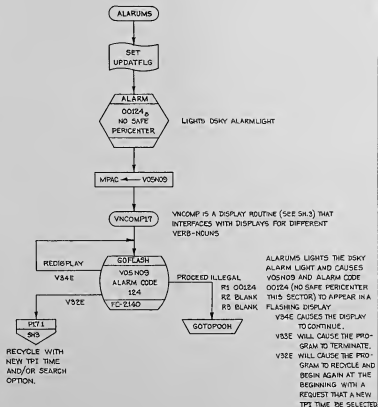
1. NO TERMINATE OPTION, ONLY PROCEED OR RETURNE
2. IF ASTRONAUT SATISFIED WITH VALUES DISPLAYED, KEYS IN PROCEED V33E.
3. AFTER CONSIDERING DISPLAYED VALUES ASTRONAUT MAY CHANGE SEARCH SECTOR AND/OR TPI TIME BY KEYING V32E WHICH CAUSES PROGRAM TO BEGIN AGAIN AT PIT.1 (DISPLAY REQUESTS NEW TPI TIME, ETC.)

$h_p, \Delta V_{TPI}, \Delta V_{TPI}$   
 DISPLAYED IN R1, R2, R3  
 R1 XXXX.X NAUT. MI.  
 R2 XXXX.X FT/SEC.  
 R3 XXXX.X FT/SEC.

PERIGEE CODE P AND CENTRAL ANGLE  $\alpha$   
 DISPLAYED IN R1, R3  
 R1 XXXX. 1 OR 2  
 R2 BLANK  
 R3 XXX.XX DEGREES

- P=1: INDICATES PERICENTER OCCURS DURING TRANSFER TRAJECTORY.  
 P=2: INDICATES INTERCEPT COMPLETE BEFORE PERICENTER.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARMLL COMBANT AND NAV. TACTO	
DRAWN A.C. WILLIAMS		TPI SEARCH PROGRAMS PIT & PIT	
PROGRAM	ANALYST	COLLOSSUS IIC	FC-2545
DATE	APPROVED	REV 1	Sheet 12 of 15



M.T INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARCUS CORPORATION AND SPACELAB
TPI SEARCH PROGRAMS R17 & R77		
OPAMP A. C. WILLIAMS	EMAY8	
RECAP <i>[Signature]</i>	<i>[Signature]</i>	
ANALYST <i>[Signature]</i>	<i>[Signature]</i>	COLOSSUS IIC
DOCMP <i>[Signature]</i>	<i>[Signature]</i>	FC-2545
APPR <i>[Signature]</i>	<i>[Signature]</i>	1971 15 16



TRANSANG

TRANSANG COMPUTES THE CENTRAL ANGLE OF TRANSFER BY CALCULATING  $\omega$ , THE ANGULAR VELOCITY OF THE PASSIVE VEHICLE (USING  $r_p$  AND  $v_p$  AT INTERCEPT) AND MULTIPLYING BY  $t_p$ , THE TIME OF FLIGHT.

SAVE QPRET IN SUBEXIT

X1 ← XRS  
X2 ← XRS + 1

X1 AND X2 LOADED WITH ADDRESSING AND SCALING INDICES FOR EARTH OR MOON

X1	X2
EARTH - 2	0
MOON - 10	2

SCALE VPASS4 ON X2, STORE VVEC ← VPASS4

$v_p$  AT INTERCEPT SCALED ON X2 (0, 2) TO OBTAIN  $2^5/2^7$  SCALING

FLO0 ←  $\sqrt{v_p}$

$\sqrt{v_p} = 1.99650495 \times 10^3 @ 2^{16}$  IF EARTH,  
 $= 2.21422176 \times 10^4 @ 2^{15}$  IF MOON

SCALE RPASS4  
FLO2 ← RPASS4 @  $2^{15}$

SCALE  $r_p$  TO  $2^{27}$  BY SHIFTING ON X2

FLO4 ←  $1/\mu$

$1/\mu = .25087606 \times 10^{-10} @ 2^{34}$  IF EARTH  
 $= .205946 \times 10^{-8} @ 2^{28}$  IF MOON

$2 - a_p/r_p = r_p v_p^2 / \mu$   
MPAC ← RPASS4 (VVEC)<sup>2</sup> FLO4

$a_p = r_p / (2 - \frac{r_p v_p^2}{\mu})$   
FLO2 ← RPASS4 / (0/X2 - MPAC)

$a_p$  IS THE SEMI-MAJOR AXIS OF THE ELLIPSE

$\omega t = \sqrt{\mu/a_p^3} t_p$  (IN RADIANS)  
MPAC ← TF FLO0/FLO2<sup>3/2</sup>

MEAN ANGULAR VELOCITY IS INVERSELY PROPORTIONAL TO  $a_p^{3/2}$

MPAC ← MPAC / 2 PISC

CONVERT TO REVOLUTIONS BY DIVIDING BY 2PISC  
2PISC = 6.28318530 @  $2^{-4}$

OUTPUT =  $\omega t$  (REV)  
CENTANG ← MPAC

RETURN VIA SUBEXIT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT GUIDANCE AND NAVIGATION	
DRAWN A. C. WILLIAMS		TPE SEARCH PROGRAMS	
PROGRAM <i>W. J. ...</i>		PIT & PTT	
ANALYST <i>W. J. ...</i>		DOCUMENT	
OFFICE <i>W. J. ...</i>		COLOSSUS IIC	
APPROVED <i>W. J. ...</i>		FC-2545	
		REV 1	
		PAGE 14 OF 18	

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
AVFLAGA	2630	CLEAR AVFLAG, SETS ECSTEER BIT 13	SH. 3
AVFLAGP		SETS AVFLAG	SH. 3
P20FLGON	2550	SETS TRACKFLAG, UPDATEFLAG	SH. 3
LEMCONIC	2290	ADVANCES LM $r_v$ TO SPECIFIED TIME W/ORBITAL INTEGRATION	SH. 3, 8
LEMSTORE		STORES LEMCONIC OUTPUT IN ACTIVE LOCS IF AVFLAG SET, PASSIVE LOCS. IF AVFLAG CLEAR	SH. 3
CSMCONIC	2290	ADVANCES CSM $r_v$ TO SPECIFIED TIME, $t_{TP}$	SH. 4, 5
CSMSTORE		STORES CSM OUTPUT IN ACTIVE/PASSIVE LOCS. IF AVFLAG CLEAR/SET	SH. 4
TIMETHET	2310	COMPUTES TIME OF FLIGHT GIVEN INITIAL $r_A, v_A$ AND TERMINAL $r_P, v_P$ OF TRANSFER TRAJECTORY	SH. 7(2)
INITVEL	2630	USING $r_A, v_A$ AT $t_{TP}$ AND $r_P, v_P$ AT $t_{TP}$ , $t_P$ INITVEL COMPUTES $v_1, v_2$ ACTIVE VEHICLE VELOCITY AT BEGINNING AND END OF TRANSFER TRAJECTORY	SH. 8
PERIAPO	2630	COMPUTES $h_P$ FOR THE TRAJECTORY COMPUTED BY INITVEL	SH. 9

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
AVFLAG	LM ACTIVE	CSM ACTIVE	SH. 4	SH. 4	SH. 3, 4, 8
TRACKFLG	MARK TRACKING ALLOWED	MARK TRACKING INHIBITED	SH. 3		
UPDATFLG	STATE VECTOR UPDATE ALLOWED	STATE VECTOR UPDATE ALLOWED	SH. 3, 4, 12, 13	SH. 3, 5	
KFLAG	$\Delta h$ (ACTIVE ABOVE) SEARCH SECTOR $< 180^\circ$	$\Delta h$ (PASSIVE VEHICLE ABOVE) SEARCH SECTOR $180^\circ$	SH. 4, 5	SH. 4, 5	SH. 5, 6, 7, 10, 11
RVSW	FINAL STATE VECTOR NOT TO BE COMPUTED IN TIMETHET	COMPUTE FINAL STATE VECTOR IN TIMETHET	SH. 6		
ITSWICH	ACCEPT NEXT $h_P$ AS SOLUTION	TEST NEXT $h_P$ . REITERATE	SH. 10	SH. 7	SH. 10

MIT  
SYSTEMS RESEARCH LAB  
CAMBRIDGE, MASS.

DRAWN: *[Signature]* 4 NOV 68  
 PROGRAM: *[Signature]* 153, 110  
 ANALYST: *[Signature]* 153, 110  
 DOCUMENT: *[Signature]* 153, 110  
 APPROVED: *[Signature]* 153, 110

MIT  
GUIDANCE AND NAVIGATION  
TPI SEARCH PROGRAMS  
P17 & P77

COLLOSSUS IIC  
FC-2545  
REV. 15 7 15

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N37	GOFLASH	TPI TIME IN R1 O0XX. HOURS R2 O0XX. MINUTES R3 OXX. XX SECONDS	SH. 3
V06N72	GOFLASH	R1 PHI XXX. XX DEG ACTIVE VEHICLE LEAD ANGLE R2 BELHTE XXXX. X NM PASSIVE VEHICLE ALT. R3 OPTION2 XXXX. RELATIVE ACTIVE (+ ABOVE) SEARCH SECTOR 1 < 180°, 2 > 280°	SH. 5
V06N58	GOFLASH	R1 hp XXXX. X NM PERIGEE HEIGHT R2 $\Delta V_{TPI}$ XXXX. X FT/SEC VELOCITY INCREMENT R3 $\Delta V_{TPF}$ XXXX. X FT/SEC IMPARTED AT $t_{TPI}$ VELOCITY DIFFERENTIAL AT INTERCEPT	SH. 12
V06N55	GOFLASHR	R1 XXXX. P (PERICENTER P = 1 TRANSFER COMPLETED R2 BLANK CODE) BEFORE PERICENTER R3 XXX. XX DEGREES P = 2 TRANSFER TRAJECTORY SPANS PERICENTER	SH. 12
V05N09	ALARM	R1 00124 DISPLAYS 124 ALARM CODE IN R1 INDICATING R2 BLANK NO SAFE PERICENTER THIS SECTOR R3 BLANK	SH. 13

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TPI	$t_{TPI}$	STORAGE LOC FOR TPI TIME	SEC	CSEC	$2^{28}$
TDEC1		STORAGE LOC FOR TIME INPUT TO CONICS	SEC	CSEC	$2^{28}$
RPASS3	$r_p(t_{TPI})$	PASSIVE VEHICLE POSITION AT TPI (TIG)	NM	M	$2^{29}/2^{27}$
VPASS3	$v_p(t_{TPI})$	PASSIVE VEHICLE VELOCITY AT TPI (TIG)	NM	M/CSEC	$2^7/2^5$
RACT3	$r_A(t_{TPI})$	ACTIVE VEHICLE POSITION AT TPI (TIG)	NM	M	$2^{29}/2^{27}$
VACT3	$v_A(t_{TPI})$	ACTIVE VEHICLE VELOCITY AT TPI (TIG)	NM	M/CSEC	$2^7/2^5$
DELHTE	$\Delta h$	ACTIVE-TO-PASSIVE VEHICLE ALTITUDE	NM	M	$2^{29}/2^{27}$
R2	$\hat{u}_{HP}$	UNIT VECTOR OF PASSIVE VEHICLE ORBITAL PLANE	UNITLESS FRACTION		$2^1$
THETZERO	$\phi$	LEAD ANGLE OF PASSIVE VEHICLE RELATIVE TO ACTIVE VEHICLE AT $t_{TPI}$	DEG (TO NEAREST . 01)	REV	$2^0$
OPTION2		LOC CONTAINING SEARCH SECTOR k	DECIMAL 1 OR 2	NO UNITS	
HIPERMIN	hplm	TEMP LOC FOR HPL/HPE MOON/EARTH MINIMUM PERICENTER ALTITUDE	HPL 35,000 FT HPE 85 NM	M	$2^{29}$
IT	IT	LOC WHERE "OUT OF PLANE" FACTOR IS STORED FOR USE IN $G_1$ & $G_0$ COMPUTATION	RAD		$2^0$

MIT INSTRUMENTATION LAB CAMBRIDGE MASS		TPI SEARCH PROGRAMS P17 & P77	
DESIGN	<i>John R. ...</i>	4 NOISE	
PROGRAM	<i>A. H. ...</i>	13147	
ANALYST	<i>P. ...</i>	COLOSSUS IIC	FC-2545
COMMENTS	<i>...</i>		
APPROVED	<i>...</i>		

MAY 16 1964

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
SNTH		STORAGE LOC IN SIN, COS FORM REQUIRED FOR			2 <sup>-1</sup>
CSTH		$\Theta_0(w_{t_0})$ AND $\Theta_1(w_{t_1})$ INPUT TO TIMETHET			2 <sup>1</sup>
TF	$t_F$	FLIGHT TIME FOR INTERCEPT TRAJECTORY	CSEC	2 <sup>28</sup>	2 <sup>28</sup>
TF0	$t_{F0}$	FLIGHT TIME FOR FIRST APPROXIMATION $t_F$	CSEC	2 <sup>28</sup>	2 <sup>28</sup>
TFI	$t_{FI}$	FLIGHT TIME FOR INNER LIMIT $(w_{t_1}) t_F$	CSEC	2 <sup>28</sup>	2 <sup>28</sup>
DELVEE	$\Delta V$	VELOCITY INCREMENT REQUIRED FOR TRANSFER	M/SEC	M/CSEC	2 <sup>7</sup>
HP	$h_p$	PERICENTER HEIGHT	NM	M	2 <sup>29</sup>
VPASS4	$\underline{V}_P(t_{TPI}+t_F)$	PASSIVE VEHICLE VELOCITY VECTOR AT INTERCEPT	M/SEC	M/CSEC	2 <sup>7</sup>
RPASS4	$\underline{r}_P(t_{TPI}+t_F)$	PASSIVE VEHICLE POSITION VECTOR AT INTERCEPT	NM	M	2 <sup>29</sup>
RTARG	$\underline{r}_T$	PASSIVE VEHICLE POSITION VECTOR AT INTERCEPT		M	2 <sup>29</sup>
HPO	$h_{p0}$	MINIMUM SAFE $h_p$ (IPPERMIN, SEE ABOVE)	FT(MOON)/ NM(EARTH)	M	2 <sup>24</sup> /2 <sup>27</sup>
DELVEO	$\Delta V_0$	VELOCITY INCREMENT TO ACHIEVE $w_{t_0}$ TRAJECTORY	M/SEC	M/CSEC	2 <sup>7</sup>
INTIME	$t_{TPI}$	TEMP LOC FOR $t_{TPI}$ INPUT TO INITVEL	SEC	CSEC	2 <sup>28</sup>
XRS		TEMP LOC FOR INDEX REG STORAGE	-	-	-
RINIT	$\underline{r}_A(t_{TPI}+t_F)$	STORAGE FOR ACTIVE VEHICLE POSITION (INITVEL)	M	M	2 <sup>29</sup>
VINIT	$\underline{v}_A(t_{TPI}+t_F)$	STORAGE FOR ACTIVE VEHICLE VELOCITY (INITVEL)	M/SEC	M/CSEC	2 <sup>7</sup>
RELDELV	$\Delta V_{TPF}$	ACTIVE-PASSIVE VELOCITY DIFFERENTIAL AT INTERCEPT	FT/SEC	M/CSEC	2 <sup>7</sup>
MAGVTPI	$\Delta V_{TPI}$	ACTIVE-PASSIVE VELOCITY DIFFERENTIAL AT $t_{TPI}$	FT/SEC	M/CSEC	2 <sup>7</sup>
NNI		STORAGE LOC FOR PERIGEEOCODE	-	-	-
POSTTPI		LOC FOR OUTPUT $h_p$ (TO BE DISPLAYED)	FT		2 <sup>29</sup>
RVEC	$\underline{r}_P(t_{TPI}+t_F)$	STORAGE LOC FOR PASSIVE VEHICLE POSITION VECTOR @ INTERCEPT	-	M	2 <sup>29</sup> /2 <sup>27</sup>
VVEV	$\underline{v}_P(t_{TPI}+t_F)$	STORAGE LOC FOR PASSIVE @ INTERCEPT VEHICLE VELOCITY	-	M/CSEC	2 <sup>7</sup> /2 <sup>5</sup>

INSTRUMENTATION LAB AMHERST, MASS.		TPI SEARCH PROGRAMS P17 & P77	
DRAWN	<i>[Signature]</i>	DESIGNED	
PLANNED	<i>[Signature]</i>	ANALYSIS	
APPROVED	<i>[Signature]</i>	COLLOSSUS IIC	FC-2545
			UNIT 17 OF 10

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
IIPE	h <sub>p</sub>	EARTH } MINIMUM PERICENTER ALTITUDE	85 NM	157420.0M	2 <sup>20</sup>
IIPL		MOON }	35,000 FT	10668.0 M	2 <sup>20</sup>
CDSEC	Δ t	INCREMENTS FOR SAFE h <sub>p</sub> TEST MIN Δ V TEST	400 SEC	40000 CSEC	2 <sup>28</sup>
CLSEC			15000 CSEC	2 <sup>28</sup>	
PHNVERS		1/√ (USED FOR SCALING)	—	.3183098882	—
SEC1THET	θ <sub>L</sub>	OUTER SEARCH LIMIT 70° IF K+1 330° IF K+1	—	1944444444	2 <sup>0</sup>
SEC2THET			—	9166866687	2 <sup>0</sup>
MANYFEET		LARGE VALUE OF h <sub>p</sub> CHOSEN FOR h <sub>p</sub> TEST	—	-2 <sup>27</sup> M	2 <sup>2</sup>
LIMVEL		THRESHOLD FOR Δ V- Δ V <sub>0</sub> MINIMUM TEST	2 FPS	M	10 <sup>-2</sup> x 10 <sup>2</sup>
DEFTMOON		MARGIN TO ALLOW FOR UNCERTAINTY IN MOON POSITION	500 FT	102 M	2 <sup>20</sup>
2PISC	2π	CONSTANT FOR RADIANS-TO-DEGREES SCALING	6.28318530	6.28318530	2 <sup>-6</sup>
MUTABLE+2,1	√μ	SQUARE ROOT OF UNIVERSAL GRAVITY CONSTANT		EARTH: 1.98650495 x 10 <sup>30</sup> MOON: 2.21422176 x 10 <sup>24</sup>	2 <sup>18</sup> 2 <sup>15</sup>
MUTABLE,1			1/μ	RECIPROCAL OF UNIVERSAL GRAVITY CONSTANT	

INSTRUMENTATION  
2 APR 68 1021 874

TPI SEARCH PROGRAM  
P17 & P77

APPROVED: *[Signature]* APPROVER  
DATE: *[Signature]* 15-4-68  
APPROVED: *[Signature]* 15-4-68

COLOSSUS IIC FC-2545

15 13

## RENDEZVOUS NAVIGATION PACKAGE

THE FOLLOWING PROGRAMS AND THEIR RELATED SUBROUTINES WILL BE FOUND IN THIS FLOW CHART.

PROG20	RENDEZVOUS NAVIGATION PROGRAM (P20)	SH. 3
V56E	TERMINATE P20	SH. 8
R61CSM	ATTITUDE MANEUVER ROUTINE	SH. 10
CR561.1	CALCULATES DAP INPUTS	SH. 11
V54E	COAS RENDEZVOUS SIGHTING MARK ROUTINE (R23)	SH. 17
R23CSM	COAS MARK TAKING	SH. 18
V57E	SXT RENDEZVOUS SIGHTING MARK ROUTINE (R21)	SH. 17
R21CSM	SXT MARK TAKING	SH. 18
R22	RENDEZVOUS MARK PROCESSING ROUTINE	SH. 19
RANGERD	READS VHF RADAR RANGE DATA	SH. 32
INITIALW	INITIALIZES W-MATRIX	SH. 36
GETUM	CALCULATES LOS VECTOR	SH. 38
BVECTORS	COMPUTES 6Q AND BVECTOR	SH. 38

## SPECIAL CONVENTIONS.

- SCALING INDICATED AS  $2^X/Y$  MEANS  $2^X$  IS THE SCALING IN EARTH SPHERE OF INFLUENCE, AND  $2^Y$  IS THE SCALING IN MOON SPHERE OF INFLUENCE.
- 'VARIABLE' IN THE SCALING FIELD OF THE SUMMARY SHEETS INDICATES THAT THE ERASABLE LOCATION IS EITHER A MATRIX WHOSE COMPONENTS HAVE DIFFERENT SCALINGS OR A TEMPORARY REGISTER WITH MANY DIFFERENT SCALINGS.

- THE SYMBOL '#' INDICATES INDIRECT ADDRESSING  
I. E., ABLE # X1 MEANS ABLE IS INDIRECTLY ADDRESSED BY X1

NOTE IF THE QUANTITY TO THE RIGHT OF THE '#' SIGN IS X1 OR X2, THEN THESE ARE SUBTRACTED FROM THE QUANTITY ON THE LEFT OF THE '#' SIGN TO FORM THE ADDRESS.

IF THE QUANTITY TO THE RIGHT OF THE '#' SIGN IS NOT X1 OR X2, THE READER SHOULD REFER TO THE CODING TO DETERMINE IF IT MUST BE ADDED OR SUBTRACTED FROM THE QUANTITY ON THE LEFT TO FORM THE ADDRESS.

ENCLOSED ARE REPLACEMENT SHEETS TO CORRECT THE COLOSSUS IIA FLOW CHART FC-2550, REV. 1, TO THE COLOSSUS IIC FLOW CHART FC-2550, REV. 2. THE FOLLOWING SHEETS HAVE BEEN CHANGED: 3, 10, 16, 41, 45.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		TITLE: RENDEZVOUS NAVIGATION	
DESIGN: <i>J.P. ...</i>	PROGRAM: <i>J.P. ...</i>	ANALYST: <i>R. F. ...</i>	DOCUMENT: <i>R. F. ...</i>
APPROVED: <i>John A. ...</i>		REV 2	COLOSSUS IIC FC-2550 SHEET 1 OF 46



PROG80  
RENDEZVOUS NAVIGATION

VIA BANKCALL

ROZBOTH  
IMU STATUS  
TEST  
FC-2230

REQUESTS SELECTION OF APPROPRIATE PROGRAMS  
IF IMU IS NOT ON AND ALIGNED (VIA ALARM)

TRKMKCNT ← ZERO  
VHRCNT ← ZERO

NUMBER OF TRACKING (OPTICS) MARKS INCORPORATED  
COUNTER  
NUMBER OF VHF RANGING MARKS INCORPORATED  
COUNTER

SET PRFRTRAT  
CLEARVHPRG  
SET TRACKFLG  
SET UPDATFLG  
SET RNDVZFLG  
SET VSONIBRL

USE PREFERRED TRACKING ATTITUDE  
LEM STATE VECTOR TO BE UPDATED  
ALLOW TRACKING  
ALLOW UPDATING BY MARKS  
INDICATE P20 IS OPERATING  
ENABLE R60 ATTITUDE MANEUVER

GROUP4.0

KILL  
GROUP4  
RESTARTS

GROUP2

SET UP RESTARTS  
TO SCHEDULE NEXT  
LOCATION AS A FINDVAC  
JOB WITH PRIORITY 26

LOADTIME

GET PRESENT  
TIME FROM  
COMPUTER  
FC-2100

OUTPUT: MPAC<sub>0</sub> = TIME2, TIME1

NEXT SHEET

P20'S MAIN FUNCTION IS TO CYCLE R22-  
RENDEZVOUS MARK PROCESSING ROUTINE-  
AND R52-AUTOMATIC OPTICS ROUTINE. THESE  
JOBS CAN TEMPORARILY BE TERMINATED BY  
CLEARING TRACKFLG AND UPDATFLG, BUT  
THEY WILL BE RESCHEDULED BY THE V37E  
LOGIC (SEE 9H.5). P20 (R22 AND R52) CAN  
BE PERMANENTLY TERMINATED ONLY BY  
CLEARING RNDVZFLG, OR VIA V37EOOE OR  
V56E (SEE 9H.6)

TITLE: RENDEZVOUS NAVIGATION PROJECT: <i>R. H. Finkbeiner</i>		APPROVED: _____ DESIGNER AND MANUFACTURER: RENDEZVOUS	
DRAWN: <i>R. H. Finkbeiner</i>		NAVIGATION P20	
CHECKED: <i>R. H. Finkbeiner</i>		DOCUMENT NO. FC-2550	
DATE: _____		COLLOQUIOUS IIC	
DRAWN BY: <i>R. F. SCATELLI</i>		SHEET 3 of 45	
CHECKED BY: <i>R. H. Finkbeiner</i>		REV: _____	



FROM PRECEDING SHEET

MARKTIME<sub>D</sub> ← MPAC<sub>D</sub> SAVE TIME FOR INPUT TO INTEGRV

SETINTG  
INITIALIZE  
FOR  
INTEGRATION  
SH7

SETS FLAGS  
CALLS INSTALL

IS  
RENDFWLG  
SET ?  
NO YES  
IS W-MATRIX VALID FOR RENDEZVOUS NAVIGATION?

SET  
DIMOFLAG

INDICATE THAT W-MATRIX IS TO BE INTEGRATED

P20.1

IS  
VEHUF LG  
SET ?  
YES NO  
IS OSM STATE VECTOR TO BE UPDATED ?

CLEAR  
VINTFLAG

INDICATE LEM STATE VECTOR TO BE UPDATED

P20.2

INTEGRV  
EXTRA POLATE  
LEM/OSM STATE  
VECTOR TO TDEC1  
FC-2290

INPUT:  
TDEC1 = PRESENT TIME SCALED 2<sup>25</sup> CSEC  
OUTPUT:  
UPDATED STATE VECTOR

GROUP 2  
SET UP RESTARTS  
TO SCHEDULE NEXT  
LOCATION AS A  
FINDVAC JOB WITH  
SAME PRIORITY

NEXT SHEET

WIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPROV GUIDANCE DIV RENDEZVOUS NAVIGATION P20
DESIGN <i>J.P. Chalmers</i>	BY M. W.
GENR <i>M.B. Boudine</i>	COLOSSUS IIC FC-2550
ANALST <i>R. S. D'ATELLA</i>	REV 2
CONFR <i>R. S. D'ATELLA</i>	5411 4 18 46
APPRO <i>J.P. Chalmers</i>	

FROM PRECEDING SHEET



SETS FLAGS  
CALLS INTSTALL



IS CSM STATE VECTOR TO BE UPDATED?

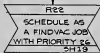
INDICATE LEM STATE VECTOR TO BE UPDATED IF VEHUPFLG IS SET, PREVIOUS INTEGRATION HAS UPDATED CSM STATE VECTOR AND THIS ONE WILL UPDATE LEM STATE VECTOR. IF VEHUPFLG IS CLEAR, PREVIOUS INTEGRATION HAS UPDATED LEM STATE VECTOR AND THIS ONE WILL UPDATE CSM STATE VECTOR



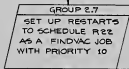
P20.3



INPUT:  
TDEC1 = PRESENT TIME SCALED 2<sup>28</sup> CSEC  
OUTPUT:  
UPDATED STATE VECTOR

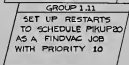


THIS IS THE RENDEZVOUS MARK PROCESSING ROUTINE. IT CHECKS FOR OPTICS MARKS OR VHF RANGE DATA EVERY 4 SEC. IT WILL TERMINATE ONLY IF TRACKFLG AND UPDATFLG ARE CLEARED.



NOTE:

THESE TWO RESTARTS WILL CAUSE R22 AND R52 (VIA PIKUP20) TO START RUNNING (IF THEY HAVE BEEN TEMPORARILY TERMINATED) WHEN A YSTE XIX IS KEYED IN AND IF RNDVZFLG IS SET. IF THE MAJOR MODE (XX) ENTERED SETS TRACKFLG AND UPDATFLG, R22 AND R52 WILL CONTINUE TO RUN; OTHERWISE THEY WILL TEMPORARILY TERMINATE AGAIN AS SOON AS THEY FIND TRACKFLG AND UPDATFLG CLEARED. THESE FLAG SETTING MAJOR MODES ARE THE TARGETING PROGRAMS (P30'S AND P70'S). A LIST CAN BE FOUND IN G40P SECTION 4 UNDER P20. TO SAY THAT R22 AND R52 ARE RUNNING WITH OR WITHOUT ANOTHER MAJOR MODE DOES NOT MEAN ALL HAVE CONTROL BECAUSE R22 HAS A 4 SEC AND R52 HAS A 1/8 SEC DELAY, & DURING THE TIME THESE TWO OVERLAP THE MAJOR MODE CAN OPERATE.



NEXT SHEET

M. S. INSTRUMENT (IN 4) CAMERA (C) (PA 2)	APPLIC. SUPPORT AND MAINT'G RENDEZVOUS
DESIGNED BY <i>D. J. ...</i> DRAWN BY <i>M. ...</i> CHECKED BY <i>...</i> APPROVED BY <i>...</i>	NAVIGATION P20 COLLOSSUS IIC FC-2550 5 of 48

FROM PRECEDING SHEET



IS TRACKING ALLOWED ?



NO

YES

IS IMU ON  
AND ALIGNED ?

NO

YES

ENDOFJOB

TEMPORARY END OF P20

INDICATES TO R61 TO CALCULATE THE  
PREFERRED OR +X AXIS S/C ATTITUDE AND  
THE NECESSARY DIGITAL AUTOPILOT INPUTS  
TO ACHIEVE AND MAINTAIN THIS ATTITUDE

R61CNTR ← ZERO



INPUT:

R61CNTR (SEE 5M.10)

OUTPUT:

DESIRED VEHICLE ATTITUDE

SET  
TARS1FLG

INDICATE TARGET IS LEM

P20R52JB

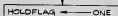
NEXT SHEET

WIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	REVISED BY L. BAYNE AND W. J. ... RENDEZVOUS NAVIGATION PCO
DESIGNED BY John A. Pisciotta	DATE 12/28/65
ANALYST R. Pisciotta	PROJECT COLOSSUS IIC FC-2550
ISSUED BY John A. Pisciotta	REVISED BY 6 of 48

FROM PRECEDING SHEET



THIS ROUTINE CYCLES EVERY 2 SECS TO POINT THE CSM OPTICS AT THE LEM. EVERY 4TH CYCLE IT WILL ALSO CALL R61 TO COMPUTE THE PREFERRED (OR +X AXIS) ATTITUDE AND ALIGN THE CSM ALONG THIS ATTITUDE. ITS OPERATION WILL BE TERMINATED ONLY WHEN IT FINDS TRACKFLG CLEARED (SEE S45) AND CONTROL WILL BE RETURNED TO P20 AT THE POINT FOLLOWING THE CALL TO R52.



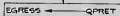
INDICATES TO DIGITAL AUTOPILOT (DAP) TO HOLD PRESENT ATTITUDE



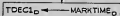
TEMPORARY END OF P20

SETINTG

SUBROUTINE TO SET FLAGS AND CALL INTSTALL



SAVE RETURN



TIME INPUT TO INTEGRV

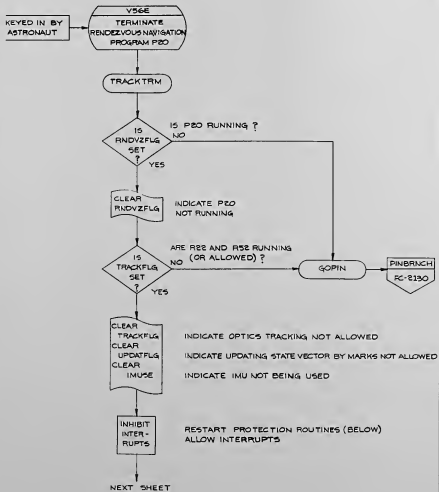


UPDATE PERMANENT STATE VECTOR  
USE ENCKE INTEGRATION  
DO NOT INTEGRATE W-MATRIX  
INTEGRATE CSM STATE VECTOR  
USE 6 DIMENSIONAL W-MATRIX



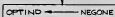
RETURN TO P20

1700 WASHINGTON ST WASHINGTON, MASS.	APR 11 1964 11 04 AM '64 RENDEZVOUS NAVIGATION P20 COLLOSSUS IIC FC-2550 7 OF 48
DESIGNED BY <i>R. Pisatelli</i> DRAWN BY <i>R. Pisatelli</i> CHECKED BY <i>R. Pisatelli</i> APPROVED BY <i>R. Pisatelli</i>	27 APR 1964 27 APR 1964



V56E RENDEZVOUS NAVIGATION PROGRAM P20 28 <i>Chapman</i> <i>27 Nov 68</i> 2000 <i>R. PISCATELLI</i> <i>22 JAN 68</i> 2000 <i>John A. Pisci</i> <i>22 JAN 68</i>	RENDEZVOUS NAVIGATION V56E COLOSSUS IIC FC-2550 REV 6 8 0 28
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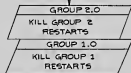
FROM PRECEDING SHEET



INHIBIT OPTICS DRIVING BY T4RUPT  
(DRIVEN IN R5E)



THIS WILL ALLOW INTEGRATION TO BE  
COMPLETED IF IT IS IN PROGRESS



THIS WILL NOT ALLOW THE R2E JOB  
OF P2O TO RESTART

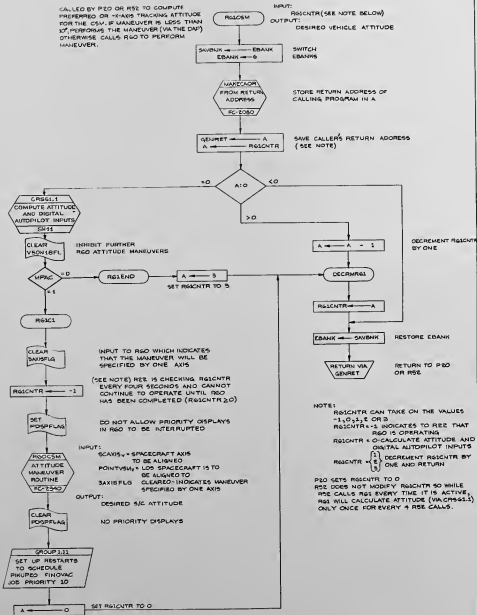
THIS WILL NOT ALLOW THE R5E JOB  
OF P2O TO RESTART



A RESTART OCCURS  
IN ENEMA WHICH  
TERMINATES THE  
OPERATION OF P2O

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARTICLE GUIDANCE AND NAVIGATION RENDEZVOUS	
DRAWN <i>J. P. FISCATELLI</i>		NAVIGATION V55E	
CHECKED <i>J. P. FISCATELLI</i>		COLLOSSUS II C	
DATE <i>2/7/66</i>		DOCUMENT NO. FC-2550	
APPROVED <i>J. P. FISCATELLI</i>		REV 2	
		PAGE 9 OF 46	

CALLED BY PEO OR RSE TO COMPUTE PREFERRED OR X-AXIS TRACKING ATTITUDE FOR THE CSM. IF MANEUVER IS LESS THAN 10° PERFORMS THE MANEUVER (VA THE CAP) OTHERWISE CALLS RGO TO PERFORM MANEUVER.



24 October 1964  
 1. PRODUCT: FVAC  
 2. ITEM: 111  
 3. CONTROL: FC-2550  
 4. P: 48

REVISIONS  
 1. 24 OCT 1964  
 2. 11 NOV 1964  
 3. 11 NOV 1964  
 4. 11 NOV 1964

INPUT:

CDUX, CDUY, CDUZ = IMU GIMBAL ANGLES SCALED  $2^4$  REVS  
 PRFRTRKAT, STIKFLAG, R60FLAG

OUTPUT:

MPCAL = CALL R60 INDICATOR: 1 = YES, 0 = NO  
 CDUXD, CDUXD, CDUZD = DESIRED IMU GIMBAL ANGLES SCALED  $2^4$  REVS  
 $WBODY_V$  = DESIRED LOS ATTITUDE RATE SCALED  $5/4$  REVS/SEC  
 DELCDUX<sub>V</sub> = INCREMENTAL IMU GIMBAL CHANGES SCALED  $2^4$  REVS  
 HOLDFLAG = DIGITAL AUTOPILOT (DAP) MANEUVER INDICATOR

SAVE RETURN



OUTPUT:

MPCAD = TIMES, TIME 1  
 SCALED  $2^{30}$  CSEC



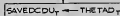
STORE TIME FOR INPUT TO R60

INPUT:

PELTIME = TIME SCALED  $2^{30}$  CSEC  
 PRFRTRKAT = S/C AXIS FLAG  
 0 = X-AXIS 1 = PREFERRED AXIS

OUTPUT:

THETAD<sub>T</sub> = DESIRED GIMBAL ANGLES TO POINT S/C AXIS AT LEM (IGA, MGA, OGA) SCALED  $2^4$  REVS  
 $SCAXIS_V$  = DESIRED S/C AXIS UNIT VECTOR SCALED  $2^4$  REVS  
 $SAVELOS_V$  = LOS VECTOR TO LEM (UNIT(R<sub>L</sub> - R<sub>C</sub>)) SCALED  $2^4$  REVS  
 PELTIME<sub>D</sub> = LOS (|R<sub>L</sub> - R<sub>C</sub>|) SCALED  $2^{30}$  METERS  
 SAVEVEL<sub>V</sub> = OSM VELOCITY (V<sub>L</sub>) SCALED  $2^7$  METERS/CSEC  
 DCDU<sub>V</sub> = LEM VELOCITY (V<sub>L</sub>) SCALED  $2^7$  METERS/CSEC



SAVE IMU GIMBAL ANGLES IGA, MGA, AND OGA



NEXT SHEET

INSTRUMENTATION LAB		ARTICLE	
AMERICAN AIR FORCE		GUIDANCE AND NAVIGATION	
DESIGNED BY <i>J. J. Chisholm</i> DRAWN BY <i>R. W. Perrier</i> CHECKED BY <i>J. PISCATECH</i> APPROVED BY <i>John S. Moran</i>		RENDEZVOUS NAVIGATION R64 COLLOSSUS II C FC-2550	
NOV 2 1958		PAGE 11 OF 48	



FROM PRECEDING SHEET



DTHETASM ← 2 TEMPORARY INDEX REGISTER

COULOOP

THIS LOOP CYCLED 3 TIMES TO CHECK X, Y, AND Z COORDINATES

DO THE PRESENT AND DESIRED ATTITUDES DIFFER BY 10° FOR THIS COORDINATE?

YES

NO - CHECK NEXT COORDINATE

STKTEST

SH16

NO - CHECK NEXT COORDINATE

DTHETASM ← DTHETASM - 1

DECREMENT INDEX

DTHETASM = 0?

YES

NO

THIRD TIME THROUGH?

AUTOCK

IS THE COMPUTER MODE SWITCH IN 'AUTO' (COMPUTER IN CONTROL OF S/C)?

NO

CHAN3 (BITS 15, 14, 13) = 011?

YES

NO

ASET

SH16

DAPCK

AUTOMATIC MANEUVER TO BE BYPASSED (SEE NOTE)

IS STIKFLAG SET?

YES - MANUAL

NO - AUTOMATIC

NEXT SHEET

NOTE:

IF THE ROTATIONAL HAND CONTROL HAS MOVED FROM REST POSITION STIKFLAG IS SET, INDICATING AUTOMATIC MANEUVER TO BE BYPASSED.

RENDZVOUS  
NAVIGATION R61  
COLOSSUS IIC FC-2550  
REV 2  
12 46

3/27/68  
2/7/68  
2/7/68

FROM PRECEDING SHEET

STEPP3CH

THIS PATH CALCULATES  
 $\dot{\omega}_{ca}$  - DESIRED LOS RATE IN CONTROL AXIS  
 COORDINATES  
 AND  $\Delta g_a$  - DESIRED INCREMENTAL CHANGES IN  
 IMU GIMBAL ANGLES EVERY .1 SEC  
 FOR INPUT TO RCS DAP IN ORDER TO ESTABLISH  
 THE TRACKING ATTITUDE  
 (SEE R-577 COLOSSUS G40P REV 2 SEC 5.2.2.5.1)

PUSHLIST POINTER SET  
TO 0

CR561.2

$$\frac{PDLO_v}{PDL0_v} = \frac{UNIT(Y_L - Y_C) \times UNIT(R_L - R_C)}{UNIT((DCDU_v - SAVEVEL_v) \times SAVERDS_v) \times RVC/RDS_v}$$

RVC/RDS IS A CONVERSION FACTOR  
TO CONVERT RAD/CSEC TO REV/SEC

$$\frac{PDLO_v}{PDL0_v} = \frac{|R_L - R_C|}{PETIME}$$

ABSOLUTE VALUE OF LOS VECTOR

$$\frac{\dot{\omega}_{LOS}}{PDL0_v} = \frac{[REFSHMAT] \sqrt{UNIT(B_L - B_C) \times (Y_L - Y_C)} / |R_L - R_C|}{[REFSHMAT] [(DCDU_v - SAVEVEL_v) / PDL0_v] \times PDL0_v}$$

DESIRED LOS RATE (INCREMENTAL  
CHANGES PER SEC) IN STABLE  
MEMBER COORDINATES.  
G40P EQU. ON PG. 5.2-65

$$DTHETASM_v \leftarrow \text{TENTH}(PDL0_v)$$

$\cdot 1 \dot{\omega}_{LOS}$  USED BY SMC DURES TO  
CALCULATE  $\Delta g_a$ .

INPUT:

CDU TRIG  
COMPUTE SINES  
AND COSINES OF IMU  
GIMBAL ANGLES  
FC-2270

CDUX, CDUY, CDUZ = IMU GIMBAL ANGLES  
SCALED 2° REVS

OUTPUT:

SINCDU<sub>v</sub> = SINES OF IMU GIMBAL ANGLES  
SCALED 2°  
COSCDU<sub>v</sub> = COSINES OF IMU GIMBAL ANGLES  
SCALED 2°

SMCDURES  
COMPUTE  
CHANGES IN IMU  
GIMBAL ANGLES  
FC-2270

INPUT:

DTHETASM<sub>v</sub> = INCREMENTAL STABLE MEMBER  
ANGULAR CHANGES ( $\cdot 1 \dot{\omega}_{LOS}$ ) SCALED  
2° REVS

OUTPUT:

SINCDU<sub>v</sub>, COSCDU<sub>v</sub> (SEE CDU TRIG OUTPUT ABOVE)  
DCDU<sub>v</sub> = INCREMENTAL IMU GIMBAL ANGLE  
CHANGES ( $\Delta g_a$ ) SCALED 2° REVS

$$PDL14_v \leftarrow DCDU_v$$

SAVE  $\Delta g_a$  FOR DAP

NEXT SHEET

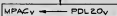
WPT INSTRUMENT APPROVAL LOWER 7.2, MASS.	AIRCRAFT COORDINATE AND NAVIGATION
DESIGN <i>J. J. Chastain</i> MEMBER OF THE BOARD AND MEMBER R. FISCATELLI AND <i>John A. Ryan 22 Nov 67</i>	RENDEZVOUS NAVIGATION R61 COLOSSUS IIC FC-2550 REV 2 SHEET 15 OF 48

FROM PRECEDING SHEET



INPUT:  
 $CDUX, CDUY, CDUZ, =$  IMU GIMBAL ANGLES SCALED 2° REVS

OUTPUT:  
 $SINCDU_v =$  SINES OF IMU GIMBAL ANGLES SCALED 2°  
 $COSCDU_v =$  COSINES OF IMU GIMBAL ANGLES SCALED 2°

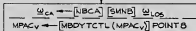


$\omega_{LOS}$  INPUT TO \*SMNB\*

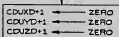


INPUT:  
 $MPAC_v =$  VECTOR IN STABLE MEMBER COORDINATES

OUTPUT:  
 $MPAC_v =$  VECTOR IN NAVIGATION BASE COORDINATES



DESIRED LOS RATE IN CONTROL AXIS COORDINATES Q50P EQU. PG. B.2-67  
 POINT B IS A SCALE FACTOR TO CONVERT 360° REVS TO 450° REVS



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	REVISION REV. NO. 1 RENDERVOUS
DRAWN BY <i>J. A. [unclear]</i> PROGRAM BY <i>[unclear]</i> ANALYST CHECKED BY <i>DISCATELLI</i> APPROVED BY <i>[unclear]</i>	NAVIGATION RES COLOSSUS IIC FC-2550 REV E 14-46

FROM PRECEDING SHEET

CDUXD ← SAVEDCDU  
CDUYD ← SAVEDCDU+1  
CDUZD ← SAVEDCDU+2

TRANSFER DESIRED GIMBAL ANGLES  
(GA, MGA, OGA) FOR INPUT TO DAP

WBODY<sub>0</sub> ← MPAC<sub>0</sub>  
WBODY<sub>10</sub> ← (MPAC+β)<sub>0</sub>  
WBODY<sub>20</sub> ← (MPAC+5)<sub>0</sub>

TRANSFER  $\omega_{ca}$  FOR INPUT TO DAP

DELCDUX<sub>0</sub> ← PDL14<sub>0</sub>  
DELCDUY<sub>0</sub> ← PDL16<sub>0</sub>  
DELCDUZ<sub>0</sub> ← PDL18<sub>0</sub>

TRANSFER  $\Delta\theta_A$  FOR INPUT TO DAP

HOLDFLAG ← -1

SIGNALS TO DAP TO PERFORM MANEUVER

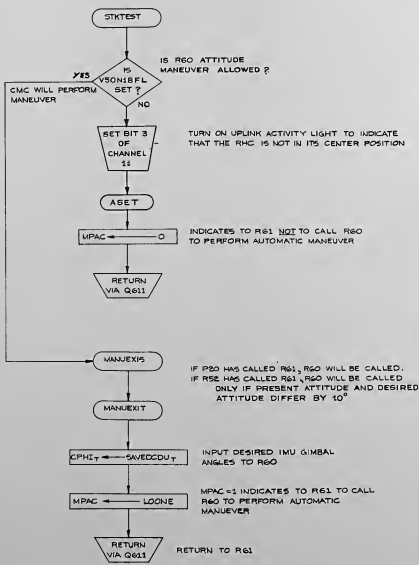
RELINT

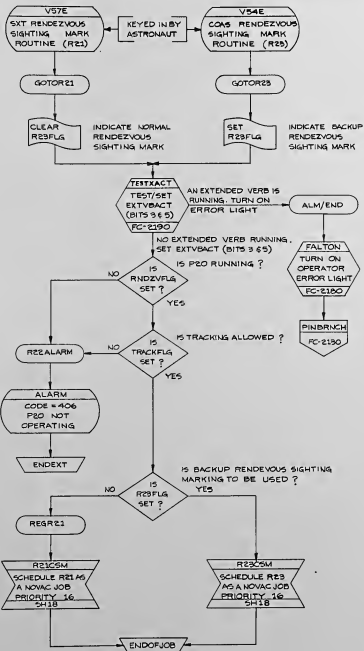
NOTE:

THE DAP INTERRUPTS EVERY .1 SEC TO CHECK  
HOLDFLAG. WHEN THE DAP FINDS HOLDFLAG=-1  
IT WILL PERFORM AN ATTITUDE MANEUVER  
USING THE ABOVE INFORMATION.

ASET  
SH16

W7 INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARC110 GUIDANCE AND NAVIGATION RENDEZVOUS	
DRAWN <i>[Signature]</i>		NAVIGATION R61	
PROGRAM <i>[Signature]</i>		DOY 4441 01	
ANALYST		COLOSSUS IIC	
CHECKED <i>[Signature]</i>		FC-2550	
APPROVED <i>[Signature]</i>		1 JUL 15 1948	





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	AFOL GUIDANCE AND NAVIGATIC
	RENDEZVOUS
FORM 3-64 PROGRAM 21-11 ANALYST 307MR APPRO	NAVIGATION R21, R23 COLOSSUS IIC DOCUMENT NO. FC-2550 REV 17 0 46

3-64  
 PROGRAM 21-11  
 ANALYST  
 307MR  
 APPRO

ENTRY FOR NORMAL (SIX)  
RENDEZVOUS SIGHTING  
MARK

RE1CSM

SET  
REL1MARK

INDICATE TO MARKRUPT THAT  
RE1 IS MARK

ENTRY FOR BACKUP (COM)  
RENDEZVOUS SIGHTING  
MARK

RE1CSM

IF RE1 IS USED TO TAKE MARKS, THE MARKING  
SYSTEM (MARKRUPT) IS NOT USED BECAUSE  
THE ASTRONAUT CANNOT REACH THE MARK BUTTON.  
HE KEYS IN VSS (ENTER) AT THE VSS DISPLAY  
TO TAKE MARKS

MRKBUF1 ← NEGONE  
MRKBUF2 ← NEGONE

INDICATE THAT MARK BUFFERS ARE  
EMPTY BY SETTING TO -1.

IS BACKUP RENDEZVOUS  
MARKING TO BE USED?

NO

IS RE1  
SET?

YES

GOMARKP  
VSS/94  
REQUEST AND DISPLAY  
COMS ANGLES

RL=000.00-SHAFT NORMAL  
RE=57.450-TRUNNION REPOSE

ENTER ANGLES

PROCEED

RE1C1  
(WAIT FOR  
NEXT MARK)

NO

RE1C1

YES

GOMARKP

VSS

PLEASE MARK  
(SEE NOTE)

TERMINATE

PROCEED (NORMAL  
TERMINATION OF REL)

RE1CSMA

HAS A MARK BEEN TAKEN?

NO

MRKBUF1 ← -1?

YES

A ← SIX

INPUT TO GENTRAN

GENTRAN  
TRANSFER DATA  
FROM MRKBUF1  
AND MRKBUF2  
TO GENRTO

A ← ONE LESS THAN NO.  
OF REGISTERS TO BE  
TRANSFERRED

RELINT (INHINT IS IN GENTRAN)

RELEND

CLEAR  
REL1MARK

INDICATES RE1  
IS NOT  
MARKING

ENDMARK

END OF RE1  
OR RE2

RELEND

RELEND

RELEND

RELEND

RELEND

RELEND

RELEND

RELEND

RELEND

RELEND

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RELEND

RELEND

NOTE:

WHEN MARK BUTTON IS PRESSED, RE1 IS  
INTERRUPTED AND MARKRUPT ENTERED  
TO MOVE (7 REGISTERS) MRKBUF1 INTO  
MRKBUFE AND THEN MOVE +1 INTO MRKBUF1.  
THIS RESULTS IN:

MRKBUF1 ← TIME  
MRKBUF1+1 ← TIME1  
MRKBUF1+2 ← CODY  
MRKBUF1+3 ← CODY  
MRKBUF1+4 ← CODY  
MRKBUF1+5 ← CODY  
MRKBUF1+6 ← CODY

MRKBUF1 ← THREE  
MRKBUF1+2 ← CODY  
MRKBUF1+4 ← CODY  
MRKBUF1+6 ← CODY

GET MARK  
DATA

RELINT (INHINT IS IN GENTRAN)

FC-0550  
RENDEZVOUS  
NAVIGATION REPLY  
FC-0550  
RE-100

THIS ROUTINE CYCLES EVERY FOUR SECONDS TO CHECK FOR OPTICS MARK DATA OR VHF RADAR RANGE DATA. WHEN IT FINDS DATA PRESENT, IT THEN PROCEEDS TO INCORPORATE IT INTO THE APPROPRIATE VEHICLE'S STATE VECTOR. AFTER THE INCORPORATION, THE ROUTINE CONTINUES TO CYCLE CHECKING FOR DATA.

R22  
RENDEZVOUS MARK PROCESSING

PHSPRDT2 ← PRIORITY

SET RESTART PRIORITY OF R22 TO 26

PRICING  
CHANGE  
PRIORITY OF  
R22 TO 26  
FC-2050

MRKBUF2 ← NEG3

INDICATES NO OPTICS MARK DATA IN BUFFER

LOADTIME  
GET PRESENT  
TIME FROM  
COMPUTER CLOCK  
FC-2100

OUTPUT:

MPAC<sub>0</sub> = TIME<sub>R</sub>, TIME<sub>I</sub>

VHFTIME<sub>0</sub> ← MPAC<sub>0</sub>

SET TIME<sub>VHF</sub> TO PRESENT TIME

REND1

GROUP2  
SET UP RESTARTS TO  
SCHEDULE NEXT  
LOCATION AS A  
FINDVAC JOB WITH  
SAME PRIORITY

WAITONE  
WAIT  
4,0,12,...SEC  
SH 31

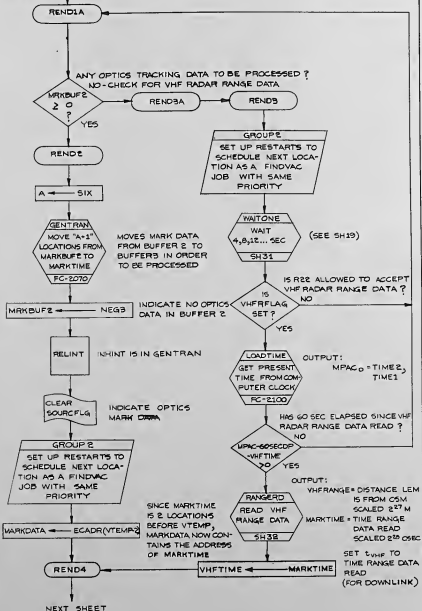
PROGRAM WILL WAIT HERE 4,0,12,... SEC UNTIL PGO FINISHES RUNNING AND UPDATFLG IS SET (IF TRACKFLG SET). R22 WILL TERMINATE TEMPORARILY AT THIS POINT IF IMU NOT ON AND ALIGNED OR UPDATFLG AND TRACKFLG BOTH CLEARED.

NEXT SHEET

1151 INSTRUMENTATION LAB CAMBRIDGE, MASS.		APR210 GUIDANCE AND NAVIGATION RENDEZVOUS	
DRAWN <i>J. A. Mose</i>		NAVIGATION R22	
DESIGNED <i>M. Dunbar</i>		COLUSSUS IIC	
ANALYST <i>J. A. Mose</i>		FC-2550	
DOWNS <i>J. A. Mose</i>		SHEET 19 OF 46	
APPROVED <i>John A. Mose</i>		REV E	



FROM PRECEDING SHEET

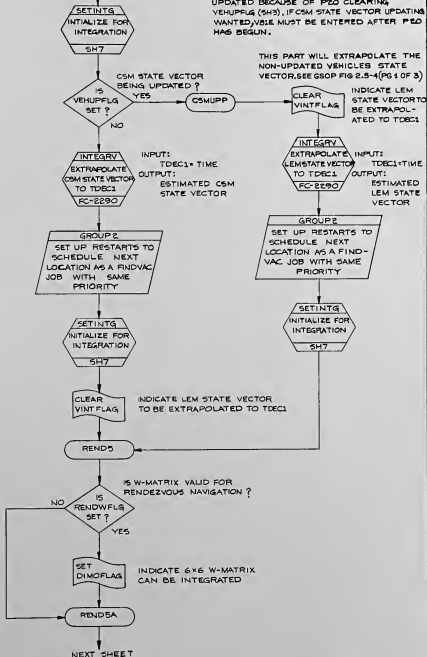


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED C. BAW AND M. HIGGINS	
REVISION 5/28/64 BY SP5		NAVIGATION R22	
DATE 5/28/64	BY B. B. 22260	COLOSSUS IIC FC-2550	
APPROVED J. P. GARDNER 5/27/64	REV B	DATE 20 MAR 66	

FROM PRECEDING SHEET

NOTE:

NORMALLY THE LEM'S STATE VECTOR IS UPDATED BECAUSE OF P20 CLEARING VEHUPFLG (SH3). IF CSM STATE VECTOR UPDATING WANTED, V01E MUST BE ENTERED AFTER P20 HAS BEGUN.



THIS PART WILL EXTRAPOLATE THE NON-UPDATED VEHICLES STATE VECTOR. SEE GSOP FIG 2.5-4 (PG 4 OF 3)

UNIT NAVIGATION LAB ANDOVER, MASS.	PROJECT GUIDANCE AND NAVIGATION RENDEZVOUS
DESIGN BY: J. J. Campbell CHECKED BY: M. W. Brubaker	NAVIGATION R22
ANALYST DR. W. T. PICCATELLA APPROVED BY: John A. Moran	COLLOSSUS IIC DOCUMENT NO. FC-2550 REV 2 (5/11) 21 of 46

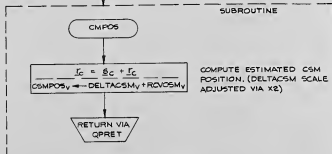
FROM PRECEDING SHEET



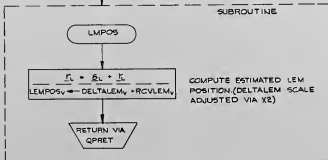
INPUT:  
TDEC1 = TIME  
OUTPUT:  
UPDATED PERMANENT STATE VECTOR



OUTPUT:  
X2 = SCALE ADJUSTING FACTOR FOR  
EARTH OR MOON SPHERE OF INFLUENCE



FLAG = 1  
INDICATES FIRST INCORPORATION PASS  
(USED FOR OPTICS MARK DATA ONLY)



INDICATE THAT W-MATRIX  
IS INVALID FOR ORBITAL  
NAVIGATION

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	PROJECT GUIDANCE AND NAVIGATION RENDEZVOUS NAVIGATION R22
DESIGNER <i>J. P. Scatell</i>	REV. 2
ANALYST <i>J. A. Borden</i>	FC-2550
DATE <i>12/1/66</i>	REV. 2
APPROVED <i>John A. Moore</i>	REV. 2

FROM PRECEDING SHEET

IS  
RENDFWFLG  
SET?

IS W-MATRIX VALID FOR RENDEZVOUS NAVIGATION?

YES

NO

$PDL0_0 \leftarrow WRENDFOS_0$

THIS PLACES  $PDL0_0 = W_{FF}$   
 $PDL1_0 = W_{FV}$

INITIAL  
W-MATRIX FOR  
RENDEZVOUS  
NAVIGATION  
SH56

INPUT:  
 $PDL0$  = POSITION INITIALIZATION VALUE ( $W_{FF}$ )  
 $PDL1$  = VELOCITY INITIALIZATION VALUE ( $W_{FV}$ )  
OUTPUT:  
INITIALIZED W-MATRIX

$VHFCNT_0 \leftarrow ZEROVECS_0$

CLEAR VHF MARKS INCORPORATED COUNTER  
( $VHFCNT_0$ ) AND OPTICS TRACKING MARKS  
INCORPORATED COUNTER ( $TRKMKCNT_0$ )

REND6

SET  
RENDFWFLG

INDICATE W-MATRIX VALID FOR  
RENDEZVOUS NAVIGATION

$\frac{I_{CL}}{RCLV} = \frac{r_L - r_C}{CSM}$   
 $RCLV \leftarrow LEMPOS_V - CSMPOS_V$

CALCULATE LEM TO CSM  
LINE OF SIGHT VECTOR

REND7

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		RENDEZVOUS	
		NAVIGATION R22	
DRYAN	<i>J. C. ...</i>	COLUSSUS II C	DOC PLAN NO
PCHE	<i>...</i>	REV 2	FC-2550
ANAT			23 of 46
DCV			
APPR	<i>John A. ...</i>		

FROM PRECEDING SHEET  
SC = 1 TEST  
IS THIS VHF RADAR RANGING DATA?

IS SOURCE  
SET?

NO-OPTICS TRACKING DATA

$U_{CL} = \text{UNIT}(I_{CL})$   
 $U_{CLV} = \text{UNIT}(R_{CLPV})$

LEM TO CSM LOS  
DIRECTION

IS THIS THE FIRST  
INCORPORATION PASS?

IS INCORPUS  
SET?

SETUP  
CALCULATE LOS  
VECTOR FROM NEW  
MEASUREMENT DATA  
SH2B

INPUT:  
MARKDATA = ADDRESS OF  
MARKDATA  
OUTPUT:  
MPAC = LOS UNIT VECTOR IN BASIC  
REFERENCE COORDINATES

$LM_{\theta} = MPAC_{\theta}$

$U_{\theta}$  = MEASURED LINE OF  
SIGHT UNIT VECTOR

$MPAC = \text{UNIT}(U_{CL} X U_{\theta})$   
 $MPAC_{\theta} = \text{UNIT}(U_{CLV} X U_{\theta})$

INITIALIZE FICTITIOUS  
STAR DIRECTION

IS OVFIND  
SET?

YES

REND5  
SH2B

NO

IF  $U_{CL}$  AND  $U_{\theta}$  ARE SEPARATED BY AN ANGLE  
OF LESS THAN  $5 \times 10^{-8}$  RADIAN, THEN THIS SET OF  
MEASUREMENT DATA IS DISCARDED BECAUSE  
THE STATE VECTOR DEVIATIONS WILL BE  
NEGLECTIBLE. THIS PATH RECYCLES AND CHECKS  
FOR VHF DATA.

$U_{\theta} = MPAC_{\theta}$   
 $U_{STAR_{\theta}} = MPAC_{\theta}$

USE FICTITIOUS  
STAR DIRECTION

REND5

NEXT SHEET

THIS PATH INITIALIZES  
VECTOR AND BQ FOR  
VHF RADAR RANGING DATA

$R_0 = \text{UNIT}(I_{CL})$   
VECTOR  $V = \text{UNIT}(R_{CLPV})$

INITIALIZE VECTOR  
FOR LEM UPDATE

$B_1 = 0$   
 $B_2 = 0$   
VECTOR  $H = \text{ZERO}$   
VECTOR  $H_{\theta} = \text{ZERO}$

$F_{CL} = |I_{CL}|$   
 $POL_{\theta} = |R_{CLPV}|$

$BQ = R_{\theta} - F_{CL}$   
 $DELTA_{\theta} = VHF_{FRANSE} - POL_{\theta}$

CALCULATE THE MEASURED  
DEVIATION  
(VHF FRANGE SCALE ADJUSTED  
TO MATCH  $F_{CL}$ )

SET  
INCORPUS

INDICATE FIRST  
INCORPORATION PASS

IS VEHPLUG  
SET?

NO

CSM STATE VECTOR  
BEING UPDATED?

YES

$R_0 = -R_0$   
VECTOR  $V = -\text{VECTOR}_V$

IF CSM UPDATE  
 $R_0 = \text{UNIT}(I_{CL})$

REND5A

GROUPS  
SET UP RESTARTS  
TO SCHEDULE NEXT  
LOCATION AS A  
FINDAC JOB WITH  
SAME PRIORITY

$MPAC_{\theta} = R_{\theta}$

FETCH RANGE ERROR  
VARIANCE,  $VBF_{\theta}$

REND5  
SH2B

THIS PATH LEADS TO INCORPORATION  
OF DATA

FROM PRECEDING SHEET

INPUT:

UMV = MEASURED LOS UNIT VECTOR (U<sub>M</sub>) SCALED 2<sup>1</sup>

USTAR<sub>V</sub> = FICTITIOUS STAR DIRECTION (U<sub>S</sub>) SCALED 2<sup>1</sup>

RCLP<sub>V</sub> = ESTIMATED LOS VECTOR (L<sub>CL</sub>) SCALED 2<sup>20</sup>/2<sup>27</sup> M

OUTPUT:

USTAR<sub>V</sub> = ARTIFICIAL STAR DIRECTION (U<sub>S</sub>) SCALED 2<sup>1</sup>

BVECTOR = 9 DIM GEOMETRY VECTOR (B<sub>0</sub>, B<sub>1</sub>, B<sub>2</sub>);

SCALED (2<sup>1</sup>, "-", "-")

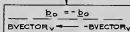
DELTA = MEASURED DEVIATION (BQ) SCALED 2<sup>20</sup>/2<sup>27</sup> M



CSM STATE VECTOR BEING UPDATED?



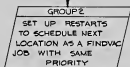
NO-LEM



IF LEM UPDATE

$b_0 = -U_{CL}$

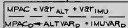
RENSA



IS THE BACKUP MARK ROUTINE  
(R2B) TAKING THE MARKS?



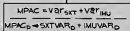
REND15



VBF<sub>ALT</sub> = ANGULAR ERROR  
VARIANCE OF ALTER-  
NATE LOS MEASURE-  
MENT

VBF<sub>IMU</sub> = IMU ANGULAR ERROR  
VARIANCE

VBF<sub>SET</sub> = SXT ANGULAR ERROR  
VARIANCE



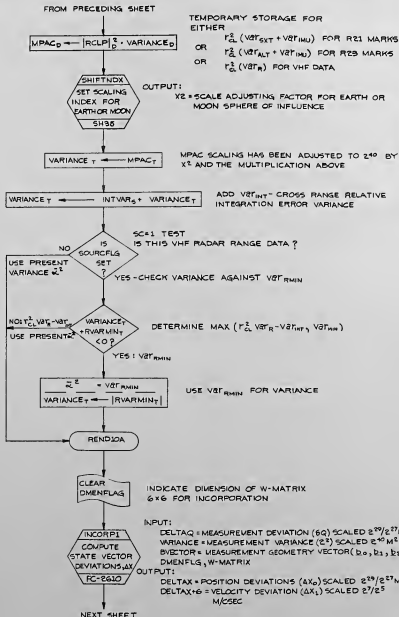
REND10

TEMPORARY STORAGE FOR  
VARIANCE CALCULATION



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		RPLD GUIDANCE AND NAVIGATION RENDEZVOUS	
DR. RICHARD M. BRONSTEIN PROJECT MANAGER 4441 ST.		NAVIGATION R22 COLOSSUS IIC DOCUMENT NO. FC-2550	
DOCUMENT TO: J3120A TEL. 271-6661 APPROV: John A. Brown 20 APR 66		REV 2 13 14 46	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	REPORT SERIAL AND ANALYST'S NO.
PROJECT <i>J. W. Chandler</i>	RENDEZVOUS
ANALYST <i>J. W. Chandler</i>	NAVIGATION R22
APPROVED <i>J. W. Chandler</i>	COLLOSSUS II C. FC-2550
DATE <i>12/2/64</i>	26-46

FROM PRECEDING SHEET

GROUP 2

SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINDVAC JOB WITH SAME PRIORITY

IS THIS THE FIRST INCORPORATION PASS ?

NO  
IS INCORFLG SET?

YES

SHIFTNOX  
SET SCALING INDEX FOR EARTH OR MOON  
SH35

OUTPUT:

X2 = SCALE ADJUSTING FACTOR FOR EARTH OR MOON SPHERE OF INFLUENCE

$(N49DISP + 2) \leftarrow (DELTAx * 6)$   
 $N49DISP_D \leftarrow |DELTAx_v|$

PLACE STATE VECTOR VELOCITY AND POSITION DEVIATIONS IN THEIR DISPLAY NOUNS (SCALE ADJUSTED VIA X2)

IS THE POSITION DEVIATION LARGER THAN PREDETERMINED MAXIMUM ?

YES  
 $RMAX \leftarrow N49DISP < 0 ?$

NO

IS VELOCITY DEVIATION LARGER THAN PREDETERMINED MAX ?

YES  
 $VMAX \leftarrow (N49DISP * 2) < 0 ?$

NO

RENDISP  
SH29

THIS PATH DISPLAYS THE STATE VECTOR DEVIATIONS

REND12

INCORP2  
INCORPORATE DEVIATIONS INTO STATE VECTOR  
RC-2610

INPUT:

DELTAx = STATE VECTOR DEVIATIONS (ΔX)  
DIMENFLG = DIMENSION OF W-MATRIX

OUTPUT:

UPDATED STATE VECTOR

SC=1TEST

IS THIS VHF RADAR RANGE DATA ?

NO  
IS SOURCFLG SET?

YES

REND16

INCREMENT VHF MARKS INCORPORATED COUNTER

THIS PATH RE-CYCLES TO CHECK FOR OPTICS TRACKING DATA

REND1  
SH18

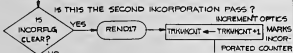
NEXT SHEET

MIL INSTRUMENTATION LAB  
CAMBRIDGE, MASS.  
FORM 21-2  
APPROVED FOR RELEASE  
DATE 10-27-2011

APOLLO GUIDANCE AND NAVIGATION  
RENDEZVOUS  
NAVIGATION R2E  
DOCUMENT NO.  
FC-2550  
PAGE 27 OF 46



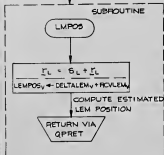
FROM PRECEDING SHEET



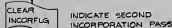
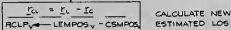
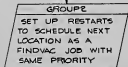
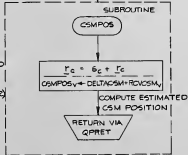
THIS PATH RE-CYCLES AND CHECKS FOR VHF RADAR RANGE DATA.



OUTPUT:  
 XE = SCALE ADJUSTING FACTOR FOR EARTH OR MOON SPHERE OF INFLUENCE



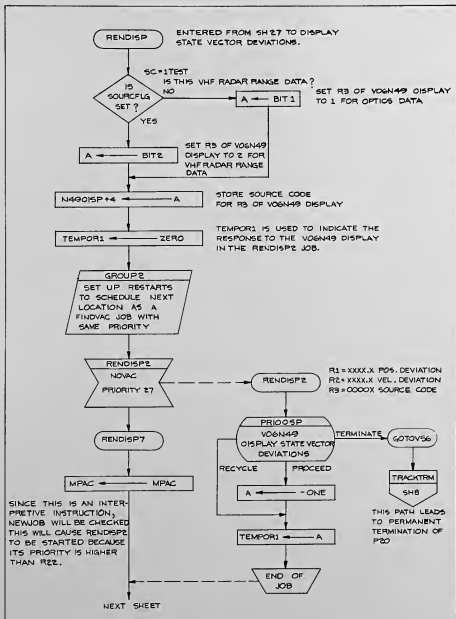
(RCVLEM AND RCLOSM ARE SCALE ADJUSTED VIA XE)



THIS PATH LEADS TO SECOND INCORPORATION OF OPTICS MARK DATA.

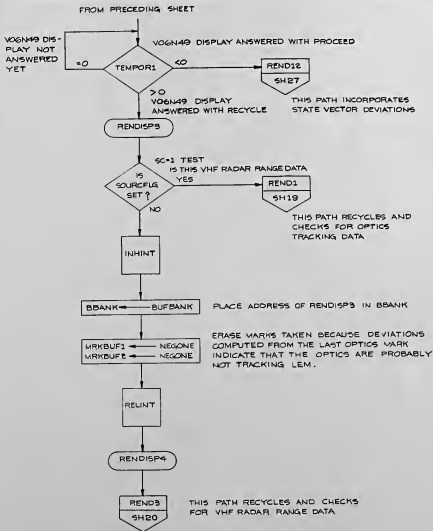
UNIT	COLONY
INSTRUMENTATION LAB	RENDEZVOUS
EXPERIMENT HAS...	NAVIGATION R22
1. NAME <i>J. J. Chisholm</i>	MISSION
2. NAME <i>R. W. Bostler</i>	DATE
3. NAME	TIME
4. NAME	DATE
5. NAME	TIME
6. NAME	DATE
7. NAME	TIME
8. NAME	DATE
9. NAME	TIME
10. NAME	DATE
11. NAME	TIME
12. NAME	DATE
13. NAME	TIME
14. NAME	DATE
15. NAME	TIME
16. NAME	DATE
17. NAME	TIME
18. NAME	DATE
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20. NAME	DATE
21. NAME	TIME
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40. NAME	DATE
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42. NAME	DATE
43. NAME	TIME
44. NAME	DATE
45. NAME	TIME
46. NAME	DATE
47. NAME	TIME
48. NAME	DATE
49. NAME	TIME
50. NAME	DATE

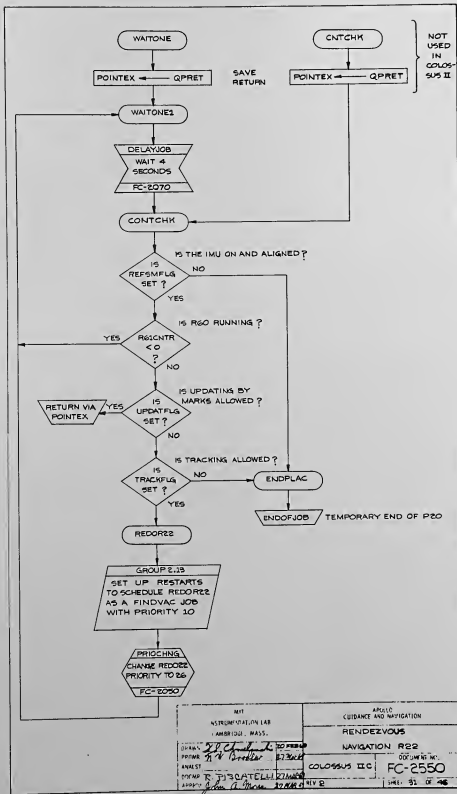
COLOSSUS IIC FC-2550



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED GUIDANCE AND NAVIGATION RENDEZVOUS NAVIGATION R22
DRAWN <i>J. J. Chomkowski</i> RECDR <i>N. W. Partridge</i> ANALYST DTCW R. T. SCATELL APPROV <i>John A. Brown</i>	DOCUMENT NO. <b>FC-2550</b> SHEET 29 OF 46

GOLDSSUS IIC  
REV 2





NOT USED IN COLOSSUS II

MIT ASTRONOMICAL LAB CAMBRIDGE, MASS.		ARGO GUIDANCE AND NAVIGATION	
DRAWN BY <i>J. J. Chouinard</i>		RENDERINGS	
FORMER BY <i>H. W. Bricker</i>		NAVIGATION R22	
ANALYST		COLOSSUS IIC	
DRAWN BY <i>R. J. Bate</i>		FORM NO. FC-2550	
CHECKED BY <i>J. J. Chouinard</i>		DATE: 31 OF 66	

RANGERO

THIS SUBROUTINE READS VHF RADAR RANGE DATA.

THERE ARE TWO RETURNS, DEPENDING UPON

STATUS OF THE VHF RANGE DATA I/O OPERATION.

1. I/O GOOD - RETURN IS TO LOCATION CALLING RANGERO WITH:

VHFRANGE = DISTANCE LM 18

FROM CSM @ 27M

MARKTIME = TIME VHF RANGE

DATA TAKEN

2. I/O BAD - RETURN IS TO LOCATION IN

R22 WHICH RECYCLES TO

CHECK FOR MARK DATA WITH:

VHFTIME = TIME VHF RANGE

DATA WAS READ

INMINT

CHAN 13 (BITS 4-1) → 1001

SET BITS 3-1 TO 001 TO SPECIFY VHF RANGE INFORMATION TO BE PROVIDED TO THE COMPUTER

SET BITS 4 TO 1 TO INITIATE TRANSMISSION OF VHF RANGE DATA TO THE COMPUTER

RELINT

MARKTIME<sub>0</sub> → TIME 2<sub>0</sub>

SAVE TIME VHF RANGE DATA TAKEN

CLEAR SHIPVHF

PROCEED NORMALLY WITH RADAR READ

I/O COMPLETE AND GOOD

RADSTALL  
WAIT FOR  
VHF  
RANGE DATA  
FC 2210

I/O COMPLETE BUT BAD

LIGHTON

VHFREAD  
GET VHF  
RANGE  
DATA  
SH. 34

YES  
VHFRANGE = 0?

INDICATE ERROR IN DATA READ IN BY COMPUTER

TRFAILON  
TURN ON  
TRACKER  
FAIL  
LIGHT  
FC-2070

LIGHTONS

NEXT SHEET

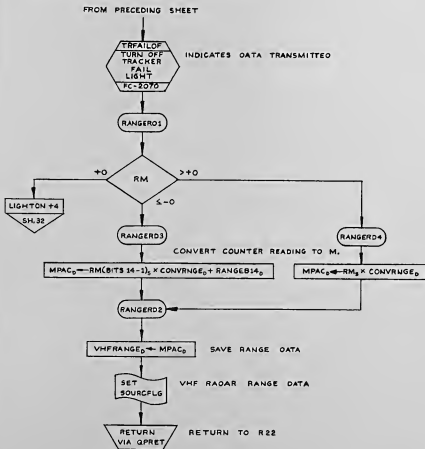
VHFTIME<sub>0</sub> → MARKTIME<sub>0</sub>

STORE TIME VHF RANGE DATA READ

REND1  
SH. 19

THIS PATH RETURNS TO R22 TO RECYCLE AND CHECK FOR OPTICS MARK OF VHF RANGE DATA

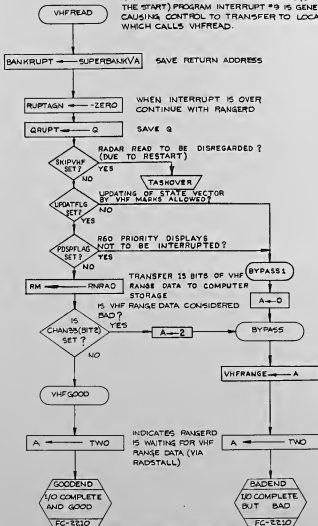
WIP INSTRUMENTATION LAB FARMER ROAD, MASS.	MODEL CUSTOMER NO. 001 21 <b>RENDEZVOUS</b> NAVIGATION R22
CREW: P.O. LAVERRIERE 17 MAR 68 PR. MURPHY & DODDNER 27 MAR 68 ANALYST OFFICER R. BUCCHIELLI 17 MAR 68 APPROV. John A. Mason 27 MAR 68	COLOSSUS IIC FC-2550 DATE: 32 12 68



NOTE: VHF RANGE DATA IS STORED IN A 15-BIT COUNTER WITH ALL BITS BEING MAGNITUDE BITS, THUS A CHECK OF BIT 15 IS NEEDED TO CONVERT CORRECTLY.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DESIGNED: LAVERGIERE		RENDERZVOUS	
DRAWN: <i>W. B. B...</i>		NAVIGATION R22	
CHECKED: R. P. DI STAJELLA		DOCUMENT NO.	
APPROVED: <i>J. A. ...</i>		COLOSSUS II C	
		FC-2550	
		SHEET 33 OF 46	

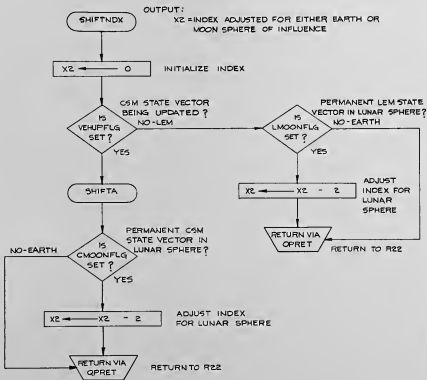
BITS 9-1 OF CHANNEL 13 SET TO COS SIGNAL THE COMPUTER TO READ OUT VHF RANGE DATA. THE READOUT PROCESS BEGINS WHEN BIT 4 OF CHANNEL 13 IS SET TO 1. AT THE END OF THE READOUT PROCESS (85-95 MS AFTER THE START) PROGRAM INTERRUPT #9 IS GENERATED, CAUSING CONTROL TO TRANSFER TO LOCATION 4041<sub>8</sub> WHICH CALLS VHFREAD.



THESE TWO SUBROUTINES RETURN CONTROL TO RADSTALL WHICH RETURNS CONTROL TO RANGERO DEPENDENT UPON STATUS OF I/O OPERATION

DATE	TIME
45-10-10-10-10-10	10:10:10
CAMBRIDGE MASS.	RENDZVOUS
PROJECT	NAVIGATION R22
ANALYST	COLOSSUS IIC FC-2550
OPERATOR	FC-2550
REPORT	FC-2550

THIS SUBROUTINE ADJUSTS AN INDEX REGISTER FOR THE PROPER SPHERE OF INFLUENCE FOR EITHER CSM OR LEM COMPUTATIONS.

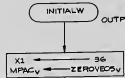


14-00000 WASHINGTON, D.C. 20340 WASHINGTON, MASS.	REPORT GUIDANCE AND NAVIGATION <b>RENDEZVOUS</b> NAVIGATION R22 DOCUMENT NO.
22-0000 <i>S. J. Christensen</i>	27-0000 <i>R. W. Bookless</i>
23-0000 <i>R. Piscatelli</i>	27-0000 <b>COLOSSUS IIC</b>
24-0000 <i>John A. New</i>	27-0000 <b>FC-2550</b> REV 2 JUN 68



THIS SUBROUTINE INITIALIZES THE W-MATRIX FOR  
EITHER P25-CISLUNAR MIDCOURSE NAVIGATION OR  
R22-RENDEZVOUS MARK PROCESSING

INPUT:  
PDLO = POSITION INITIALIZATION VALUE ( $W_{PP}$  OR  $W_{MP}$ )  
PDL1 = VELOCITY INITIALIZATION VALUE ( $W_{PV}$  OR  $W_{VP}$ )  
OUTPUT:  
INITIALIZED 6x6 W-MATRIX



INITIALIZE INDEX  
AND CLEARING  
VALUE

$$\begin{bmatrix} W_0 & W_1 \\ W_2 & W_3 \\ W_4 & W_5 \end{bmatrix} = \begin{bmatrix} W_{PP} & 0 & 0 & 0 & 0 & 0 \\ 0 & W_{MP} & 0 & 0 & 0 & 0 \\ 0 & 0 & W_{VP} & 0 & 0 & 0 \\ 0 & 0 & 0 & W_{PV} & 0 & 0 \\ 0 & 0 & 0 & 0 & W_{PP} & 0 \\ 0 & 0 & 0 & 0 & 0 & W_{MP} \end{bmatrix}$$

THIS LOOP CYCLED  
6 TIMES

NOTE:  
 $W_{VP}$  AND  $W_{PV}$  REPRESENT EITHER  $W_{MP}$  AND  $W_{PP}$  OR  $W_{VP}$  AND  $W_{PV}$  DEPENDING UPON WHICH PROGRAM CALLED INITIALW  
SETS  $W_0 = 0$   
AND  $W_1 = 0$

$W_1 = 0$   
I IS ONE LESS THAN  
LOOP NUMBER

DECREMENT INDEX

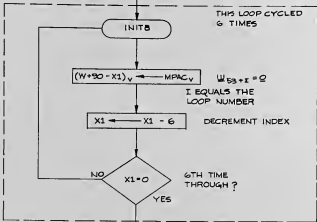
6TH TIME  
THROUGH ?

INITIALIZE INDEX

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		RENDEZVOUS	
		NAVIGATION R22	
DRAWN <i>[Signature]</i>	PROGRAM <i>[Signature]</i>	COLLOSSUS IIC	DOCUMENT NO. FC-2550
ANALYST	DOOR <i>[Signature]</i>	APPROV <i>[Signature]</i>	SHEET 36 OF 46

FROM PRECEDING SHEET



SETS  $\overset{R}{W}_3 = \overset{R}{0}$   
AND  $\overset{R}{W}_4 = \overset{R}{0}$

$\left. \begin{matrix} W_5 \\ (W+8)_5 \\ (W+16)_5 \end{matrix} \right\} \rightarrow PDLOS$

$W_3 = W_{XR}$   
 $W_4 = W_{XR}$   
 $W_8 = W_{XR}$

$\left. \begin{matrix} (W+72)_5 \\ (W+80)_5 \\ (W+88)_5 \end{matrix} \right\} \rightarrow PDL15$

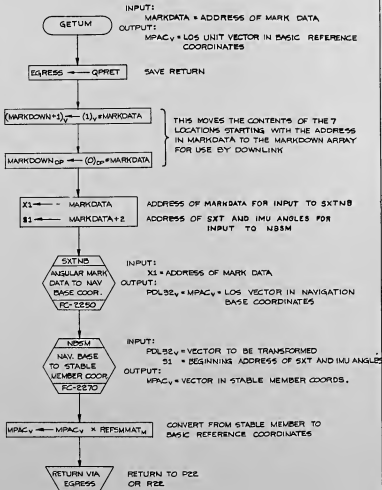
$W_{36} = W_{XV}$   
 $W_{40} = W_{XV}$   
 $W_{44} = W_{XV}$

RETURN VIA QPRET

RETURN TO P23 OR R22

REF	APPROV
EXPERIMENTAL DATA	LABORATORY AND NAVIGATION
LABORATORY DATA	RENDEZVOUS
DATE: <i>J. J. Chakrabarti</i>	NAVIGATION R22
BY: <i>R. W. Douglas</i> 27 MAR 57	COLOSSUS IIC FC-2550
BY: <i>R. P. GIOVARELLI</i> 27 MAR 57	37 46
BY: <i>J. A. New</i> 27 MAR 57	

THIS SUBROUTINE IS CALLED BY P22 AND R22 TO CALCULATE THE LOS VECTOR (IN BASIC REFERENCE COORDINATES)



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		RENDEZVOUS	
DRAWN <i>J. C. ...</i>		NAVIGATION R22	
PERFORMED <i>J. H. ...</i>		DOCUMENT NO.	
ANALYST		FC-2550	
CHECKED <i>R. FISCATELLI</i>		COLOSSUS II C	
APPROVED <i>J. A. ...</i>		REV B	
		SHEET 04 OF 48	

CALLED BY P22 AND R22 TO COMPUTE DELTAQ (BQ)  
AND BVECTOR

INPUT:

UM<sub>v</sub> = MEASURED LOS UNIT VECTOR (U<sub>M</sub>)

USTAR<sub>v</sub> = FICTITIOUS STAR DIRECTION (U<sub>S</sub>)

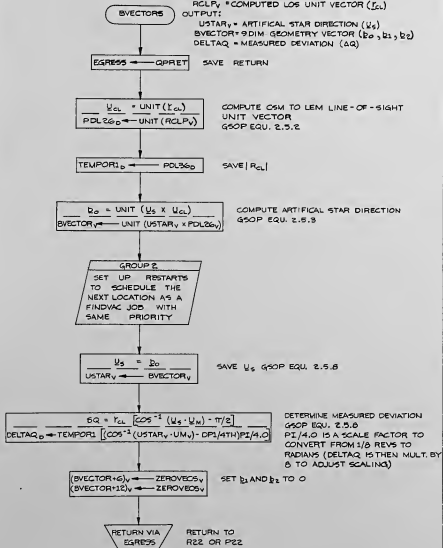
RCLP<sub>v</sub> = COMPUTED LOS UNIT VECTOR (U<sub>CL</sub>)

OUTPUT:

USTAR<sub>v</sub> = ARTIFICIAL STAR DIRECTION (U<sub>S</sub>)

BVECTOR = 9 DIM GEOMETRY VECTOR (B<sub>0</sub>, b<sub>1</sub>, b<sub>2</sub>)

DELTAQ = MEASURED DEVIATION (ΔQ)



SI	APR 71
14 "COMM NAV" UNCLAS	44 04075 443 44 1547 6
CAN 88122, 21452	RENDZEVIOUS
FORM 1	NAVIGATION R22
FORM 1	FC-2550
FORM 1	39 OF 46

APPROVED: [Signature] DATE: 27 MAR 71

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
R02BOTH	2210	CHECKS STATUS OF IMU	SH. 3
LOADTIME	2100	GET PRESENT TIME FROM COMPUTER CLOCK	SH. 3, 11, 19, 20
INTEGRV	2290	EXTRAPOLATE CSM/LBM STATE VECTOR TO TDECI	SH. 4, 5, 21, 22
PRIOCHNG	2050	CHANGE JOB PRIORITY	SH. 6, 19, 31
R52	2730	AUTOMATIC OPTICS ROUTINE	SH. 7
MKRLEES	2240	RELEASE MARK SYSTEM	SH. 7
INTSTALL	2260	RESERVE INTEGRATION ROUTINE	SH. 7, 9
STOPRATE	2350	ZERO INPUTS TO DIGITAL AUTOPILOT	SH. 9
MAKECADR	2080	FORM RETURN ADDRESS	SH. 10
R60CSM	2340	ATTITUDE MANEUVER ROUTINE	SH. 10
R53	2361	RENDEZVOUS FINAL ATTITUDE	SH. 11
UPACTOFF	2160	TURN OFF UPLINK ACTIVITY LIGHT	SH. 12
CDUTRIG	2270	COMPUTE SINES AND COSINES OF IMU GIMBAL ANGLES	SH. 13, 14
SMCDURES	2270	COMPUTE CHANGES IN IMU GIMBAL ANGLES	SH. 13
*SMNB*	2270	STABLE MEMBER TO NAVIGATION BASE TRANSFORMATION	SH. 14
FALTON	2180	TURN ON OPERATOR ERROR LIGHT	SH. 17
KLEENEX	2130	CLEAN OUT ALL MARK DISPLAYS	SH. 18
GENTRAN	2070	MOVE DATA	SH. 18, 20
INCORP1	2610	COMPUTE STATE VECTOR DEVIATIONS	SH. 26
INCORP2	2610	INCORPORATE STATE VECTOR DEVIATIONS	SH. 27
DELAYJOB	2070	DELAY JOB FOR A CERTAIN TIME	SH. 31
RADSTALL	2210	WAIT FOR VHF RANGE DATA	SH. 32
TRFAIL0F	2070	TURN OFF TRACKER FAIL LIGHT	SH. 33
TRFAIL0N	2070	TURN ON TRACKER FAIL LIGHT	SH. 33
GOODEND	2210	I/O COMPLETE AND GOOD	SH. 34
BADEND	2210	I/O COMPLETE BUT BAD	SH. 34
SXTNB	2250	ANGULAR MARK DATA TO NAVIGATION BASE COORDINATES	SH. 38
NBSM	2270	NAVIGATION BASE TO STABLE MEMBER COORDINATES	SH. 38

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
		RENDEZVOUS	
		NAVIGATION	
DRAWN <i>J. Tiscatelli</i>	DATE <i>12/20/64</i>		
PREPARED BY <i>J. Tiscatelli</i>	DATE <i>12/20/64</i>		
ANALYST		COLOSSUS IIC	
DOCSM <i>J. Tiscatelli</i>	DATE <i>12/20/64</i>	FC-2550	
APPROVED <i>J. Tiscatelli</i>	DATE <i>12/20/64</i>	REV 40 TW 46	

FLAGS					
NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
PRFTRKAT FLAGWRD5 BIT 10	USE PREFERRED TRACKING ATTITUDE	USE + X-AXIS TRACKING ATTITUDE	SH, 3		
VEHUPFLG FLAGWRD1 BIT 8	CSM STATE VECTOR TO BE UPDATED	LEM STATE VECTOR TO BE UPDATED		SH, 3	SH, 4, 5, 21, 24, 25, 28, 33
TRACKFLG FLAGWRD1 BIT 5	TRACKING ALLOWED	TRACKING NOT ALLOWED	SH, 3	SH, 8	SH, 6, 8, 17, 31
UPDATFLG FLAGWRD1 BIT 7	UPDATING STATE VECTOR BY MARKS ALLOWED	UPDATING STATE VECTOR BY MARKS NOT ALLOWED	SH, 3	SH, 8	SH, 31, 34
RNDVZFLG FLAGWRD0 BIT 7	P20 IS RUNNING	P20 IS NOT RUNNING	SH, 3	SH, 8	SH, 8, 17
RENDFWFLG FLAGWRD5 BIT 1	W-MATRIX VALID FOR RENDEZVOUS NAVI- GATION	W-MATRIX NOT VALID FOR RENDEZVOUS NAVIGATION	SH, 23		SH, 4, 21, 23
DMOFLAG FLAGWRD3 BIT 1	W-MATRIX IS TO BE INTEGRATED	W-MATRIX NOT TO BE INTEGRATED	SH, 4, 21	SH, 7	
VINTFLAG FLAGWRD3 BIT 3	CSM STATE VECTOR TO BE INTEGRATED	LEM STATE VECTOR TO BE INTEGRATED	SH, 7	SH, 4, 5, 21	
REFSMFLG FLAGWRD3 BIT 13	REFSMMAT IS GOOD	REFSMMAT IS NOT GOOD			SH, 6, 31
TARG1FLG FLAGWRD1 BIT 10	TARGET IS LEM	TARGET IS NOT LEM	SH, 6		
STATEFLG FLAGWRD3 BIT 5	PERMANENT STATE VECTOR TO BE UPDATED	PERMANENT STATE VECTOR NOT TO BE UPDATED	SH, 7		
INTYPFLG FLAGWRD3 BIT 4	CONIC INTEGRATION	ENCKE INTEGRATION		SH, 7	
D6OR9FLG FLAGWRD3 BIT 2	W-MATRIX IS 8 DIMENSIONAL FOR INTEGRATION	W-MATRIX IS 6 DIMENSIONAL FOR INTEGRATION		SH, 7	
IMUSE FLAGWRD0 BIT 8	IMU IN USE	IMU NOT IN USE		SH, 8	
3AXISFLG FLAGWRD5 BIT 6	MANEUVER SPECIFIED BY 3 AXES	MANEUVER SPECIFIED BY 1 AXIS		SH, 10	
PDSPFLAG FLAGWRD4 BIT 12	DO NOT ALLOW R60 PRIORITY DISPLAYS TO BE INTERRUPTED	NO PRIORITY DISPLAYS	SH, 10	SH, 10	SH, 34
V5ON18FL FLAGWRD3 BIT 15	R60 ATTITUDE MANEUVER ENABLED	R60 ATTITUDE MANEUVER INHIBITED	SH, 3	SH, 10	SH, 16
SKIPVHF FLAGWRD2 BIT 10	DISREGARD RADAR READ BECAUSE OF RESTART	RADAR READ TO PROCEED NORMALLY		SH, 32	SH, 34

UNIT 15 TERMINATION LAB LANSFORD, MASS.	DATE 15 JAN 68	TIME 1500	TEST RENDEZVOUS NAVIGATION
TESTER J. A. [Signature]	APPROVED J. A. [Signature]	COLOSSUS IIC	FC-2550
REVISION 1	DATE 15 JAN 68	BY E	41 - 46

FLAGS (CONTINUED)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
R23FLG FLAGWRD1 BIT 9	BACKUP RENDEZVOUS MARK ROUTINE (R23)	NORMAL RENDEZVOUS MARK ROUTINE (R21)	SH. 17	SH. 17	SH. 17, 18 25
R21MARK FLAGWRD2 BIT 14	R21 IS MARKING	R21 IS NOT MARKING	SH. 18	SH. 18	
SOURCFLG FLAGWRD9 BIT 8	VHF RADAR RANGE DATA	OPTICS MARK DATA	SH. 33	SH. 20	SH. 24, 28 27, 29, 30
VHFRFLAG FLAGWRD9 BIT 9	ACCEPT VHF RADAR RANGE DATA	DO NOT ACCEPT VHF RADAR RANGE DATA			SH. 20
INCORFLG FLAGWRD5 BIT 11	FIRST INCORPORATION PASS	SECOND INCORPORATION PASS	SH. 22, 24	SH. 28	SH. 24, 27 28
ORBWFLAG FLAGWRD3 BIT 6	W-MATRIX VALID FOR ORBITAL NAVIGATION	W-MATRIX INVALID FOR ORBITAL NAVIGATION		SH. 22	
DMENFLG FLAGWRD5 BIT 9	W-MATRIX IS 8 DIMENSIONAL FOR INCORPORATION	W-MATRIX IS 6 DIMENSIONAL FOR INCORPORATION		SH. 26	
CMOONFLG FLAGWRD8 BIT 12	CSM STATE VECTOR IS IN LUNAR SPHERE OF INFLUENCE	CSM STATE VECTOR IS IN EARTH SPHERE OF INFLUENCE			SH. 35
LMOONFLG FLAGWRD8 BIT 11	LEM STATE VECTOR IS IN LUNAR SPHERE OF INFLUENCE	LEM STATE VECTOR IS IN EARTH SPHERE OF INFLUENCE			SH. 35

DISPLAYS

VERB- NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
ALARM		CODE = 406 P20 NOT RUNNING (MUST KEY IN V05N09 TO DISPLAY ALARM CODE)	SH. 17
V51	FLASHING	R1 = BLANK REQUEST FOR ASTRONAUT TO MARK R2 = BLANK R3 = BLANK	SH. 18
V53	FLASHING	R1 = BLANK REQUEST FOR ASTRONAUT TO R2 = BLANK PERFORM ALTERNATE LOS R3 = BLANK SIGHTING	SH. 18
V06N94	FLASHING	R1 = 000.00 - SHAFT DISPLAY OF COAS ANGLES R2 = 57.470 - TRUNNION R3 = BLANK	SH. 18
V06N49	FLASHING PRIORITY	R1 = XXXX.X - POSITION DEVIATION DISPLAY OF R2 = XXXX.X - VELOCITY DEVIATION EXCESSIVE UPDATE R3 = 00000X - SOURCE CODE PARAMETERS	SH. 29

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		RENDZVOUS NAVIGATION	
DRAWN <i>D. J. Chouh</i>	REMARKS	REV. 01 '64	
PROGRAM <i>N. Partridge</i>	373-000	FC-2550	
ANALYST		42 46	
DOCWR <i>R. P. SATELLI</i>	271000		
APPROV <i>John A. Moore</i>	271000	REV 2	

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TRMKMCNT		COUNTER FOR NO. OF OPTICS MARKS INCORPORATED		(INTEGER)	$2^{14}$
VHFCNT		COUNTER FOR NO. OF VHF RADAR RANGE MARKS INCORPORATED		(INTEGER)	$2^{14}$
MARKTIME		TEMPORARY STORAGE LOCATION FOR PRESENT TIME (P20) AND TIME VHF RANGE DATA TAKEN (R22)	SEC	CSEC	$2^{28}$
R61CNTR		LOCATION USED TO CONTROL OPERATION OF R61 (SEE SH. 10)		(INTEGER)	$2^{14}$
HOLDFLAG		LOCATION USED TO CONTROL OPERATION OF DAP		(INTEGER)	$2^{14}$
TDEC1		TIME TO INTEGRATE TO	SEC	CSEC	$2^{28}$
OPTIND		LOCATION USED TO CONTROL OPERATION OF OPTICS		(INTEGER)	$2^{14}$
SAVBNK		TEMPORARY STORAGE OF CALLEIN'S EBANK		(INTEGER)	$2^{14}$
EBANK		ERASABLE BANK NUMBER		(INTEGER)	$2^{14}$
GENRET		RETURN ADDRESS FROM R61		(INTEGER)	$2^{14}$
Q611		RETURN ADDRESS FROM CRS61.1		(INTEGER)	$2^{14}$
P21TIME		TIME INPUT TO R63 (ALSO USED AS TEMPORARY STORAGE BY R63)	SEC	CSEC	$2^{28}$
THETAD	IGA, MGA, OGA	DESIRED IMU GIMBAL ANGLES FROM R63	DEGREES	REVS	$2^{-1}$
SAVEDCDU		TEMPORARY STORAGE OF ABOVE ANGLES	DEGREES	REVS	$2^{-1}$
CPHI		INPUT OF ABOVE ANGLES TO R60	DEGREES	REVS	$2^{-1}$
DTHETASM	$\Delta$ LOS	INCREMENTAL STABLE MEMBER ANGULAR CHANGES (ALSO USED AS A TEMPORARY INDEX REGISTER)	DEGREES	REVS	VARIABLE
CDUX } CDUY } CDUZ }		PRESENT IMU GIMBAL ANGLES	DEGREES	REVS	$2^{-1}$
DSALMOUT		INPUT/OUTPUT CHANNEL 11		(INTEGER)	$2^{14}$
DCDU	$V_L$ $\Delta QA$	LEM VELOCITY FROM R63 ALSO USED FOR DESIRED INCREMENTAL CHANGES IN IMU ANGLES	FT/SEC DEGREES	METERS/CSEC REVS	$2^7$ $2^0$
SAVEVEL	$V_C$	CSM VELOCITY FROM R63	FT/SEC	METERS/CSEC	$2^7$
SAVEPOS		LOS UNIT VECTOR TO LEM			$2^1$
REFSMAT		BASIC REFERENCE TO STABLE MEMBER COORDINATES TRANSFORMATION MATRIX			$2^1$

W.T.		RENDZVOUS	
NAVIGATION		NAVIGATION	
DRANK	<i>J. J. Chiswick</i>	DRANK	<i>10/1/68</i>
DRANK	<i>N. A. ...</i>	DRANK	<i>27/1/68</i>
DRANK	<i>...</i>	DRANK	<i>...</i>
COLOSSUS IIC		FC-2550	
43		46	



## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
WBODY	$\omega_{CA}$	DESIRED LOS RATE FOR DAP (1 REV = 450°)	DEG/SEC	REVS/SEC	4/5
DELCDEX	$\Delta GA$	DESIRED INCREMENTAL CHANGES IN IMU ANGLES	DEGREES	REVS	2 <sup>-1</sup>
MRKBUF1		7-LOCATION MARK DATA BUFFER 1			(VARIABLE)
MRKBUF2		7-LOCATION MARK DATA BUFFER 2			(VARIABLE)
PHSPRT2		RESTART PRIORITY REGISTER		(INTEGER)	2 <sup>14</sup>
VIIFTIME		TIME VHF RADAR RANGE DATA READ	SEC	CSEC	2 <sup>28</sup>
MARKSTAT		ADDRESS FOR MARK DATA VAC AREA IN CASE OF RESTART		(INTEGER)	2 <sup>14</sup>
MKBUFAD		ADDRESS OF MARK DATA VAC AREA		(INTEGER)	2 <sup>14</sup>
MARKDATA		ADDRESS OF TIME MARK TAKEN		(INTEGER)	2 <sup>14</sup>
VTEMP		ADDRESS OF MARK ANGLES		(INTEGER)	2 <sup>14</sup>
CSMPOS	$\epsilon_C$	CSM PRECISION POSITION VECTOR	NAUT. MI.	METERS	2 <sup>29</sup> /2 <sup>27</sup>
DELTACSM	$\delta_C$	CSM POSITION DEVIATION	NAUT. MI.	METERS	2 <sup>22</sup> /2 <sup>18</sup>
RCVCSM	$\epsilon_C$	CSM CONIC POSITION VECTOR	NAUT. MI.	METERS	2 <sup>29</sup> /2 <sup>27</sup>
LEMPOS	$\epsilon_L$	LEM PRECISION POSITION VECTOR	NAUT. MI.	METERS	2 <sup>29</sup> /2 <sup>27</sup>
DELTALEM	$\delta_L$	LEM POSITION DEVIATION	NAUT. MI.	METERS	2 <sup>22</sup> /2 <sup>18</sup>
RCVLEM	$\epsilon_L$	LEM CONIC POSITION VECTOR	NAUT. MI.	METERS	2 <sup>29</sup> /2 <sup>27</sup>
RCLP	$\epsilon_{CL}$	LEM TO CSM LOS VECTOR	NAUT. MI.	METERS	2 <sup>29</sup> /2 <sup>27</sup>
UCL	$\omega_{CL}$	ESTIMATED LEM TO CSM LOS DIRECTION			2 <sup>1</sup>
UM	$\omega_M$	MEASURED LEM TO CSM LOS DIRECTION			2 <sup>1</sup>
USTAR	$\omega_S$	FICTITIOUS STAR DIRECTION ALSO USED BY VVECTOR SUBROUTINE FOR ARTIFICIAL STAR DIRECTION			2 <sup>1</sup>
BVECTOR	$(b_0, b_1, b_2)$	GEOMETRY OF MEASUREMENT VECTOR			2 <sup>1</sup> , ...
DELTAQ	$\delta Q$	MEASUREMENT DEVIATION	NAUT. MI.	METERS	2 <sup>29</sup> /2 <sup>27</sup>
VHFRANGE	$R_M$	VHF RANGE READING	NAUT. MI.	METERS	2 <sup>27</sup>
VARIANCE	$\sigma^2$	MEASUREMENT ERROR VARIANCE ALSO USED AS A TEMPORARY LOCATION DURING VARIANCE CALCULATION		METERS <sup>2</sup>	2 <sup>40</sup>
DELTA X	$\Delta x_0$	STATE VECTOR POSITION DEVIATION	NAUT. MI.	METERS	2 <sup>29</sup> /2 <sup>27</sup>
DELTA X+6	$\Delta x_1$	STATE VECTOR VELOCITY DEVIATION	FT/SEC	METERS/CSEC	2 <sup>7</sup> /2 <sup>5</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		C. DEWEY AND ASSOCIATES RENEZVOUS NAVIGATION	
DESIGNED BY <i>J. C. Chalmers</i>	DESIGNED BY <i>J. W. Corbridge</i>	COLLOSSUS IIC	FC-2550
ANALYST	APPROVED BY <i>John A. Morse</i>	REV B	44 X 46

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
N49DISP		POSITION DEVIATION DISPLAY NOUN	NAUT. MI.	METERS	$2^{20}$
N49DISP+2		VELOCITY DEVIATION DISPLAY NOUN	FT/SEC	METERS/ CSEC	$2^7$
TEMPOR1		LOCATION USED TO DETERMINE RESPONSE TO V06N49 PRIORITY DISPLAY; ALSO USED AS TEMPORARY REGISTER BY BVECTOR		(INTEGER)	$2^{14}$
BUFRANK		ADDRESS OF RENDISP3		(INTEGER)	$2^{14}$
CHAN13		INPUT/OUTPUT CHANNEL 13		(INTEGER)	$2^{14}$
TIME2		PRESENT TIME FROM COMPUTE CLOCK	SEC	CSEC	$2^{28}$
RM		VHF RADAR RANGE COUNTER	.01 NAUT. MI.		
RNRAD		REGISTER 46 <sub>B</sub> USED TO RECEIVE RADAR RANGE DATA			
CHAN33		INPUT/OUTPUT CHANNEL 33		(INTEGER)	$2^{14}$
MARKDOWN		DOWNLINK MARK DATA REGISTERS (7)			VARIABLE

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
ZERO		REGISTER CONTAINING OCTAL ZERO	0	00000	$2^{14}$
NEGONE		REGISTER CONTAINING DECIMAL -1	-1	-1	$2^{14}$
DEGREE10		10 DEGREES	$10^0$	.11112 REVS	$2^{-1}$
RVCS/RDS		CONVERSION FACTOR RAD/ CSEC TO REV/SEC	$100/2^{\pi}$ REV-CSEC RAD-SEC	15.915494 (SAME UNITS)	2
TENTH	.1	DECIMAL .1	.1	.1	$2^3$
MBDYCTL <sub>M</sub>	[NBCA]	NAVIGATION BASE TO CONTROL AXES TRANSFORMATION MATRIX	$\begin{bmatrix} .5, 0, 0 \\ 0, \cos 7.5, \sin 7.5 \\ 0, \sin 7.5, \cos 7.5 \end{bmatrix}$	$\left. \begin{array}{l} .5 \\ 0 \\ 0 \\ 0 \\ .99200495 \\ -.12619897 \\ 0 \\ .12619897 \\ .99200495 \end{array} \right\}$	$2^1$
POINT8		SCALE FACTOR 1 REV = $360^0$ TO 1 REV = $450^0$	.8	.8	$2^0$
SIX		DECIMAL 6	6	6	$2^{14}$
PRIQ26		OCTAL 26000		26000 <sub>B</sub>	$2^{14}$
NEG3		DECIMAL -3	-3	+3	$2^{14}$

37-AN 28 37-AN 29 37-AN 30 37-AN 31 37-AN 32 37-AN 33 37-AN 34 37-AN 35 37-AN 36 37-AN 37 37-AN 38 37-AN 39 37-AN 40 37-AN 41 37-AN 42 37-AN 43 37-AN 44 37-AN 45 37-AN 46 37-AN 47 37-AN 48 37-AN 49 37-AN 50 37-AN 51 37-AN 52 37-AN 53 37-AN 54 37-AN 55 37-AN 56 37-AN 57 37-AN 58 37-AN 59 37-AN 60 37-AN 61 37-AN 62 37-AN 63 37-AN 64 37-AN 65 37-AN 66 37-AN 67 37-AN 68 37-AN 69 37-AN 70 37-AN 71 37-AN 72 37-AN 73 37-AN 74 37-AN 75 37-AN 76 37-AN 77 37-AN 78 37-AN 79 37-AN 80 37-AN 81 37-AN 82 37-AN 83 37-AN 84 37-AN 85 37-AN 86 37-AN 87 37-AN 88 37-AN 89 37-AN 90 37-AN 91 37-AN 92 37-AN 93 37-AN 94 37-AN 95 37-AN 96 37-AN 97 37-AN 98 37-AN 99 37-AN 100	RENDEZVOUS NAVIGATION COLOSSUS IIC FC-2550 45-48
---	--

## PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
60SECDP		60 SECONDS IN DOUBLE PRECISION	60 SEC	8000 CSEC	$2^{28}$
ZEROVECS		THE BEGINNING ADDRESS OF 6 LOCATIONS CONTAINING ZEROS	0	0	$2^{14}$
SXTVAR	var <sub>SXT</sub>	SXT ERROR VARIANCE	$.04 \times 10^{-6} \text{ RAD}^2$	$.04 (\text{MR})^2$	$2^{18}$
IMUVAR	var <sub>IMU</sub>	IMU ERROR VARIANCE	$.04 \times 10^{-6} \text{ RAD}^2$	$.04 (\text{MR})^2$	$2^{18}$
BIT1		OCTAL 1	1	00001	$2^{14}$
BIT2		OCTAL 2	2	00002	$2^{14}$
ONE		DECIMAL 1	1	00001	$2^{14}$
CONVRNGE		CONVERSION FACTOR FROM .01 N.M. TO METERS	18.52 METERS/NM		$2^{13}$
RANGEB14		VALUE OF 15TH BIT OF VHF RANGE COUNTER	163.84 NAUT. MI.	303431.7 METERS	$2^{27}$
DP1/4TH		DECIMAL 1/4	1/4	.25	$2^0$
PI/4.0		CONVERSION FACTOR 1/8 REVS TO RADIAN	$\frac{\pi}{4} \text{ RAD}$ 4 REV	.785398164 RAD/REV	$2^0$

## PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
WRENDPOS	$q_{rr}$	INITIAL W-MATRIX POSITION VALUES				00012
WRENDVEL	$q_{rv}$	INITIAL W-MATRIX VELOCITY VALUES				00062
RVAR	var <sub>R</sub>	VHF MEASUREMENT ERROR VARIANCE				
RVARMIN	var <sub>RMIN</sub>	MINIMUM VHF ERROR VARIANCE	-16,384	-16,384	$2^{40}$	77777 77776
ALTVAR	var <sub>ALT</sub>	ALTERNATE LOS ERROR VARIANCE				66142
INTVAR	var <sub>INT</sub>	INTEGRATION ERROR VARIANCE				
RMAX	$\delta r_{MAX}$	MAXIMUM POSITION CHANGE WITHOUT APPROVAL				
VMAX	$\delta v_{MAX}$	MAXIMUM VELOCITY CHANGE WITHOUT APPROVAL				

M11		COLOSSUS IIC	
INSTRUMENTATION IIC		CAMBRIDGE, MASS.	
DRAWN <i>J.P. [unclear]</i>		RENAVIGIOUS	
CHECKED <i>A.R. [unclear]</i>		NAVIGATION	
ANALYST		COLOSSUS IIC FC-2550	
SHIPPER P. SCATELLI, COMNAV		46 46	
APPROVED <i>[Signature]</i>		E	

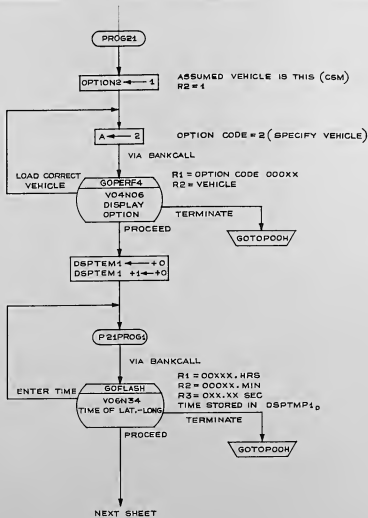
GROUND TRACK DETERMINATION - P21

MAJOR SUBROUTINES ON THIS CHART

PROG 21 GROUND TRACK DETERMINATION

54 2

DATE: 11/19/67	TIME: 11:00 AM	NO. OF TRACKS: 1	NO. OF POINTS: 1
NAME: J. C. Larkin	PROJECT: 44017	GROUND TRACK DETERMINATION P21	
APPROVED: J. C. Larkin	DATE: 11/19/67	COLOSSUS IIC	FC-2580
APPROVED: J. C. Larkin	DATE: 11/19/67	NO. 2	REV. 1 - 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT GUIDANCE AND NAVIGATION	
DRAWN <i>W. H. ...</i>		GROUND TRACK DETERMINATION	
P21		P21	
ANN ST		COLOSSUS IIC	DOCUMENT NO. FC-2580
DOCN		REV 2	SHEET 2 OF 7
APPR'D			

FROM PRECEDING SHEET

TEST  
D6PTEM1<sub>0</sub>

= 0

≠ 0

P21PRTM  
SH.5

P21PROG2

TDEC1<sub>0</sub> ← D6PTEM1<sub>0</sub>

INSTALL  
TEST AVAIL-  
ABILITY OF  
INTEGRATION  
FC-2350

SUCCESSING PASS  
THRU P21

1ST PASS THRU P21

YES

NO

IS  
P21FLAG  
SET ?

P21CONT

SET  
VINTFLAG

CSM STATE VECTOR  
BEING INTEGRATED

RCV<sub>0</sub> ← P21BASE<sub>0</sub>  
VCV<sub>0</sub> ← P21BASE<sub>0</sub>  
TET<sub>0</sub> ← P21TIME<sub>0</sub>

CLEAR  
DIMOFFLAG  
CLEAR  
MOONFLAG

W MATRIX IS NOT  
TO BE USED  
EARTH IS SPHERE  
OF INFLUENCE

IS  
OPTON2=0  
?

CLEAR  
VINTFLAG

LM STATE VECTOR  
BEING INTEGRATED

NEXT SHEET

IS  
P21ORIG=0  
?

YES

NO

A  
SH4

NEXT SHEET

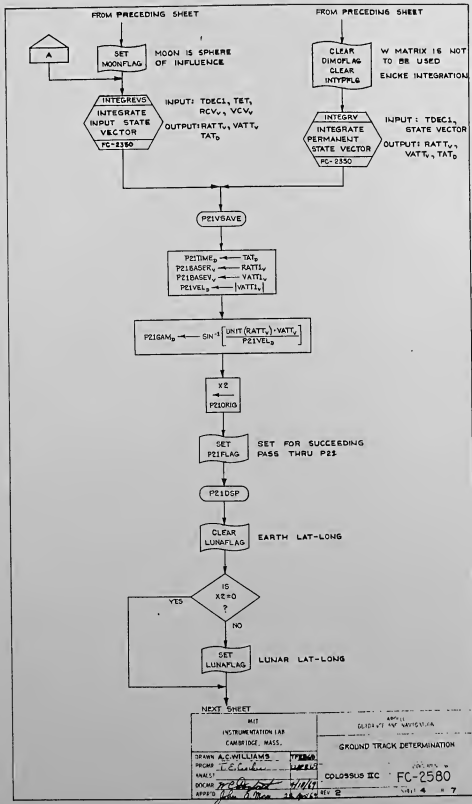
FORM 1  
1. WILLIAMS  
NAME J.E. Carter  
DATE 11/11/57  
APPROVED [Signature]  
20 April 61

GROUND TRACK DETERMINATION  
P21

COLOSSUS IIC

FC-2580

3 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARPA GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		7/19/60	
PROJ. J.C. ...		2/10/60	
ANALYST		COLLOSSUS IIC	
DOC. NO. 7/19/60		FC-2580	
APPROVED John A. ...		REV 2	

GROUND TRACK DETERMINATION  
 COLLOSSUS IIC  
 FC-2580  
 REV 4 7

FROM PRECEDING SHEET

ALPHA<sub>0</sub> ← RATT<sub>0</sub>  
MPAC<sub>0</sub> ← TAT<sub>0</sub>

CLEAR ERADFLAG  
EARTH, USE FIXED RADIUS  
MOON, USE RL5 FOR LUNAR RADIUS

LAT-LONG  
RADIUS VECTOR  
TO LAT, LONG  
AND ALT  
FC-2290

P21ALT<sub>0</sub> ← MPAC<sub>0</sub>(K.00)

GOFLASH  
VOLN43  
DISPLAY  
LAT, LONG, ALT

R1 - LATITUDE XXX.XX DEG  
R2 - LONGITUDE XXX.XX DEG  
R3 - ALTITUDE XXXX.X NAUT. MI.

GOTOPOOH  
THIS IS THE  
EXIT FOR P21

PROCEED  
TERMINATE  
ENTER - RECYCLE

D5PTM1<sub>0</sub> ← P21TIME<sub>0</sub> + 600 SEC<sub>0</sub> INCREMENT TIME BY 10 MINUTES

P21PROG1  
PERFORM  
CALCULATION  
FOR NEW  
TIME  
SH2

P21PRTM

LOADTIME  
LOAD PRESENT  
TIME INTO  
MPAC<sub>0</sub>  
FC-2100

SET TO INTEGRATE  
TO PRESENT TIME

P21PROG2  
SH3

APPROVED: *[Signature]*  
DATE: *[Date]*  
BY: *[Name]*  
FOR: *[Name]*  
TITLE: *[Title]*

GROUND TRACK DETERMINATION

COLLOSSUS IIC FC-2580

5 7



SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
INSTALL	FC-2350	TEST AVAILABILITY OF INTEGRATION	SH 3
INTEGREVS	FC-2380	INTEGRATE INPUT STATE VECTOR	SH 4
INTEGRV	FC-2360	INTEGRATE PERMANENT STATE VECTOR	SH 4
LAT-LONGS	FC-2290	RADIUS VECTOR TO LAT., LONG. AND ALT.	SH 5
LOADTIME	FC-2100	LOAD PRESENT TIME INTO MPAC <sub>0</sub>	SH 5

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DIM0FLAG FLAG 3 BIT1	W MATRIX IS TO BE USED	W MATRIX IS NOT TO BE USED		SH 3, 4	
ERADFLAG FLAG 1 BIT13	EARTH; COMPLETE EARTH RADIUS MOON; USE FIXED RADIUS	EARTH; USE FIXED RADIUS MOON; USE RLS FOR LUNAR RADIUS		SH 5	
INTYPFLAG FLAG 3 BIT4	CONIC INTEGRATION	ENCKE INTEGRATION		SH 4	
LUNAFFLAG FLAG 3 BIT12	LUNAR LAT-LONG	EARTH LAT-LONG	SH 4	SH 4	
MOONFLAG FLAG 0 BIT12	MOON IS SPHERE OF INFLUENCE	EARTH IS SPHERE OF INFLUENCE	SH 4	SH 3	
P21FLAG FLAG 2 BIT12	SUCCEEDING PASS THRU P21	FIRST PASS THRU P21	SH 4		SH 3
VINTFLAG FLAG 3 BIT3	CM STATE VECTOR BEING INTEGRATED	LM STATE VECTOR BEING INTEGRATED	SH 3	SH 3	

DISPLAYS

VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V04N06	OPTION CODE	R1 = XXXXX - OPTION CODE R2 = XXXXX - VEHICLE	SH 2
V06N34	FLASHING	R1 = OXXXX. HR R2 = OXXXX. MIN R3 = OXXXX. SEC	SH 2
V06N43	FLASHING	R1 = XXXXX DEG R2 = XXXXX DEG R3 = XXXXX NAUT. MI	SH 5

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
OPTION 2		VEHICLE CODE		(INTEGER)	2 <sup>14</sup>
DSPTM1		DISPLAY NOUN FOR TIME		CSEC	2 <sup>10</sup>
P21TIME		TIME FOR LAT-LONG		CSEC	2 <sup>10</sup>
TOEC1	t	TIME FOR INTEGRATION		CSEC	2 <sup>10</sup>
RATT	T <sub>CON</sub>	CONIC POSITION VECTOR		METERS	2 <sup>10</sup>
TAT	t	TIME OF POSITION		CSEC	2 <sup>10</sup>
ALPHAV		POSITION VECTOR		METERS	2 <sup>10</sup>
LAT		LATITUDE	DEG	REVS	2 <sup>0</sup>
LONG		LONGITUDE	DEG	REVS	2 <sup>0</sup>
ALT		ALTITUDE	NAUT. MI	METERS	2 <sup>10</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		GROUND TRACK DETERMINATION P21	
DRAWN BY: <i>J. C. ...</i>	DESIGNED BY: <i>J. C. ...</i>	COLOSSUS IIC	
PROMO: <i>J. C. ...</i>	DATE: <i>12/15/67</i>	FC-2580	
ANALYST: <i>J. C. ...</i>	APPROVED: <i>J. C. ...</i>	REV 2	
DOCNR: <i>J. C. ...</i>	DATE: <i>12/15/67</i>	REV 5 SH 7	

## PROGRAM CONSTANTS

AGC -TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
PZ10NENN		VEHICLE TEST VALUE		00001	2 <sup>14</sup>
600 SEC		10 MINUTES	10 MINUTES	60000CSEC	2 <sup>28</sup>

UNIT	
INDUSTRY/AGENCY: IBM	
CAMBRIDGE MASS.	
TRAINING	<i>R. J. Farrell</i>
ANALYST	<i>R. J. Farrell</i>
DOCK	<i>R. J. Farrell</i>
APPROVED	<i>R. J. Farrell</i>

GROUND TRACK DETERMINATION  
P21

GOLOSSUS MC FC-2580

7 7

P22 - ORBITAL NAVIGATION

MAJOR SUBROUTINES:

- 522.1 - PROCESSES MARK DATA TO UPDATE GSM STATE VECTOR.  
 0DWTD6DW - CONVERTS W-MATRIX FROM 5 TO 6 DIMENSIONS.

SPECIAL CONVENTIONS:

- 1) "\*" IS USED TO REPRESENT A MATRIX.  
 i.e.  $B^*$  IS MATRIX B.
- 2) "VARIABLE" IN THE SCALING FIELD OF THE SUMMARY SHEETS INDICATES THAT THE ERASABLE LOCATION IS USED EITHER TO STORE A MATRIX WHOSE COMPONENTS HAVE DIFFERENT SCALINGS OR AS A TEMPORARY LOCATION HAVING MANY DIFFERENT SCALINGS.
- 3)  $Z^x/Z^y$  IN THE SCALING FIELD OF THE SUMMARY SHEETS IS USED FOR EARTH/MOON SPHERE OF INFLUENCE.  
 i.e.  $Z^x$  IS THE SCALING IN EARTH SPHERE.  
 $Z^y$  IS THE SCALING IN MOON SPHERE.

THE ENCLOSED REPLACEMENT SHEETS WILL UPDATE THE COLOSSUS I (REV 237) FLOWCHART FC-2590, REV 0, TO COLOSSUS II FC-2590, REV 1.

THE EFFECTIVE SHEETS FOR COLOSSUS II ARE:

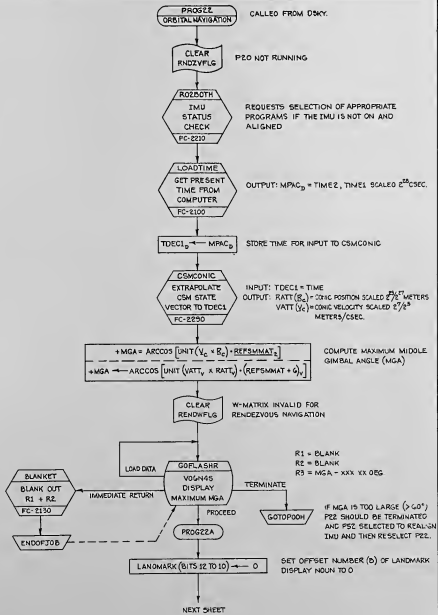
1	REV 0
2	REV 1
3	REV 0
4-8	REV 1
9	REV 0
10	REV 1
11	REV 0
12-14	REV 1
15-16	REV 0
17-19	REV 1
20	REV 0
21	REV 1
22	REV 0
23	REV 1
24	REV 0
25	REV 1
26-27	REV 0
28-31	REV 1
32-40	REV 0
41-42	REV 1
43-44	REV 0

11/20/76  
 13 NOV 1976  
 P22 - ORBITAL NAVIGATION  
 COLOSSUS II FC-2590

EDWIN A.C. WILLIAMS  
 FOR MR N. E. LIND  
 BY R. Cassell  
 JOHN A. BOON

1 44





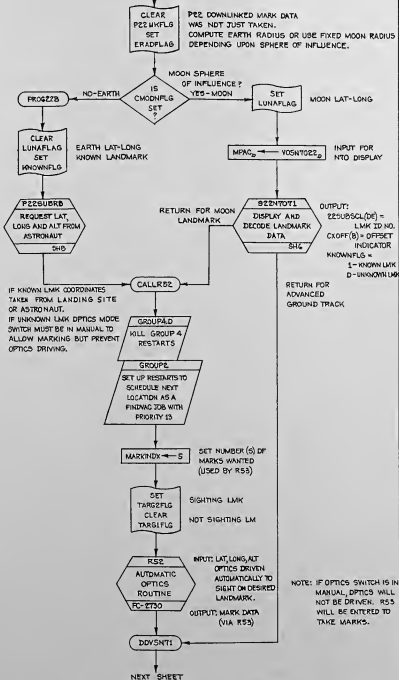
115076  
 13 2/78  
 24047  
 21 05 12

P22-ORBITAL NAVIGATION

COLOSSUS II

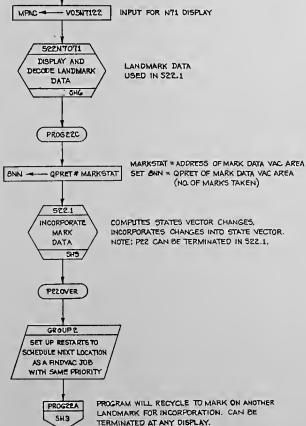
FC-2590

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARTIM CJ-441 AND NAVIGAT' CN	
DRAWN A. C. WILLIAMS		P22 - ORBITAL NAVIGATION	
DATE	10/27/65	DOCUMENT NO.	FC-2590
ANALYST	<i>A. C. Williams</i>	COLLOSSUS II	Sheet 4 of 24
DOCNR	FC-2590	REV 1	
APPROV			

FROM PRECEDING SHEET



PZ2- ORBITAL NAVIGATION

AC WILLIAMS

R. E. Smith

R. E. Smith

John A. Moore

16 SEP 68

13 SEP 74

PROTIS

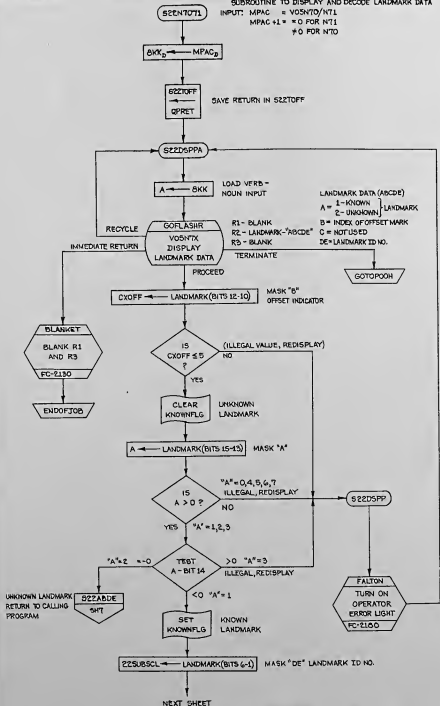
13 DEC 68

COLOSSUS II

FC-2590

5

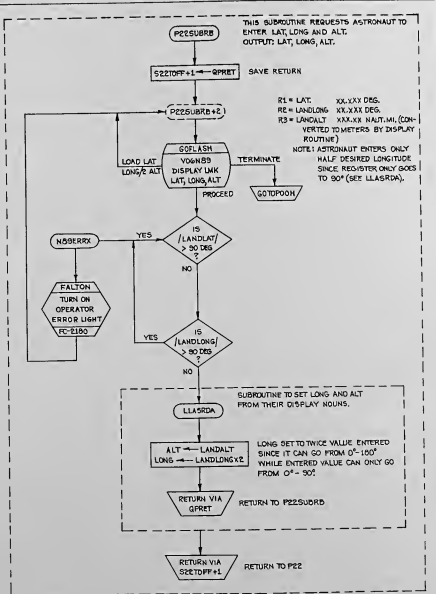
SUBROUTINE TO DISPLAY AND DECODE LANDMARK DATA  
 INPUT: MPAC = VOSYTD/NTL  
 MPAC+1 = \*0 FOR NTL  
 \*0 FOR NTO



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC. CLAUDE AND "A" CATION.	
DRAWN A.C. WILLIAMS		PROJECT PEE - ORBITAL NAVIGATION	
PROGRAM	ANALYST	DOCUMENT NO.	
DOC#	APPROV.	COLOSSUS II	FC-2590
APP'D	REV	SHEET 6 OF 44	

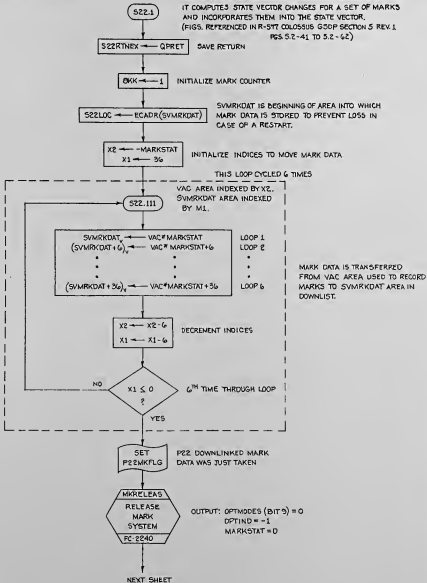






MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
	P22 - ORBITAL NAVIGATION	
DESIGNER A. C. WILLIAMS	16 APR 69	DOCUMENT NO. FC-2590
PERFORMER R. J. M. D.	12 APR 69	
ANALYST		COLOSSUS II
DOORMAN		
APPROVER		REV 1
		SHEET 8 OF 44

THIS SUBROUTINE PERFORMS MAJOR CALCULATIONS OF PZ2. IT COMPUTES STATE VECTOR CHANGES FOR A SET OF MARKS AND INCORPORATES THEM INTO THE STATE VECTOR, (FIGS. REFERENCED IN R-57T COLOSSUS II G5OP SECTION 5 REV. 1 PGS. 5.2-41 TO 5.2-62)



PER - ORBITAL NAVIGATION  
 COLLOSSUS II  
 FC-2590  
 44

A.C. WILLIAMS  
 J.E. Smith  
 R. Riccietelli  
 J. J. Moore

27 APR 68  
 21 APR 68  
 21 APR 68

FROM PRECEDING SHEET

GROUP4  
KILL GROUP  
4 RESTARTS

GROUP2.1  
SET UP RESTARTS  
TO SCHEDULE NEXT  
LOCATION ASA  
FINDVAC JOB WITH  
PRIORITY 13

X1 ← 0 X1 USED AS A SHIFT INDICATOR

NO-EARTH IS DIMONFLG SET? MOON SPHERE OF INFLUENCE?

YES X1 ← -2 SET SHIFT FOR MOON SPHERE OF INFLUENCE

SET SHIFT

SZEEORM ← X1 SZEEORM CONTAINS EITHER 0 OR -2 WHICH WILL BE USED TO ADJUST CERTAIN QUANTITIES HAVING A SCALE DIFFERENCE DEPENDING ON SPHERE OF INFLUENCE.

FIGZEAIT

INTSTALL  
RESERVE  
INTEGRATION  
ROUTINE  
FC-2290

SZEEFLGS SUBROUTINE WHICH INITIALIZES FLAGS FOR INTEGRATION ROUTINE

SET DIMOFLAG USE W-MATRIX  
SET DBOORFLAG 9 DIMENSION W-MATRIX  
SET VINTFLAG INTEGRATING CSM STATE VECTOR  
SET STATEFLAG UPDATE PERMANENT STATE VECTOR  
CLEAR INTYFLG ENCKE INTEGRATION

RETURN VIA  
QPRET

NEXT SHEET

DESIGN: A. C. WILLIAMS  
FOR: W. P. L. L. L.  
DATE: 1/11/68  
APP: J. A. L. L. L.

FC-2290 ORBITAL NAVIGATION  
COLOSSUS II  
10 44

FROM PRECEDING SHEET

IS W-MATRIX VALID FOR ORBITAL NAVIGATION ?  
(START G50P FIG. 2.4-1)



YES - VALID W-MATRIX

NO - INVALID W-MATRIX

SETWWS0

THIS SECTION INITIALIZES & DIMENSION W-MATRIX FOR ORBITAL NAVIGATION

CLEAR DIMOFLAG  
CLEAR RENDWFLG

D=0

NOTE: D IS THE W-MATRIX INDICATOR DETERMINED BY DIMOFLAG AND DLOORSPLG.

D=0 W-MATRIX 0 DIM. DIMOFLAG CLEARED

D=16 W-MATRIX 6 DIM. DIMOFLAG SET AND DLOORSPLG CLEARED

D=9 W-MATRIX 9 DIM. DIMOFLAG SET AND DLOORSPLG SET

X1 ← 108

INITIALIZE INDEX FOR LOOP CONTROL

CLEARWWS

THIS LOOP CYCLED 18 TIMES TO SET & DIMENSION W-MATRIX TO 0.

$W_0$  TO  $W_9 = 0$

$W_0 = 0$

$W_1 \leftarrow \text{ZEROVECS}$   
 $W_2 \leftarrow \text{ZEROVECS}$   
 $W_3 \leftarrow \text{ZEROVECS}$   
 $W_4 \leftarrow \text{ZEROVECS}$   
 $W_5 \leftarrow \text{ZEROVECS}$   
 $W_6 \leftarrow \text{ZEROVECS}$   
 $W_7 \leftarrow \text{ZEROVECS}$   
 $W_8 \leftarrow \text{ZEROVECS}$   
 $W_9 \leftarrow \text{ZEROVECS}$

LOOP1  
 LOOP2  
 .  
 .  
 .  
 LOOP18

N IS ONE LESS THAN LOOP NO.

X1 ← X1 - 16

DECREMENT INDEX

NO

FINISHED 18 TIMES ?

YES

CLEAR DLOORSPLG

D=6

$W_0 = W_{17}, I$

$W_1 \leftarrow \text{WORBP0S}$   
 $W_2 \leftarrow \text{WORBP0S}$   
 $W_3 \leftarrow \text{WORBP0S}$   
 $W_4 \leftarrow \text{WORBP0S}$   
 $W_5 \leftarrow \text{WORBP0S}$

INITIALIZE POSITION ELEMENT ( $W_0$ ) OF W-MATRIX FOR ORBITAL NAVIGATION

$W_6 = W_{17}, I$

$W_7 \leftarrow \text{WORBV0L}$   
 $W_8 \leftarrow \text{WORBV0L}$   
 $W_9 \leftarrow \text{WORBV0L}$   
 $W_{10} \leftarrow \text{WORBV0L}$   
 $W_{11} \leftarrow \text{WORBV0L}$

INITIALIZE VELOCITY ELEMENT ( $W_6$ ) OF W-MATRIX FOR ORBITAL NAVIGATION

NOTE:  $I = \begin{pmatrix} 100 \\ 010 \\ 001 \end{pmatrix}$  = IDENTITY MATRIX

$W_{17}$  AND  $W_{18}$  ARE PRE LOADED CONSTANTS

SETVANOI

NEXT SHEET

FRANK A.C. WILLIAMS  
 MICHAEL M. E. LIND  
 JOHN A. BOW

302064  
 302064  
 310014

PEZ-ORBITAL NAVIGATION

COLOSSUS II

FC-2590

11 44

FROM PRECEDING SHEET

CLEAR  
OMENFLG

W-MATRIX IS 6 DIMENSIONAL  
(FLAG USED BY MEASUREMENT  
INCORPORATION ROUTINE)

SENXTIN

AFTER EACH MARK HAS BEEN PROCESSED,  
THE PROGRAM RETURNS HERE TO PROCESS  
THE NEXT MARK. (START OF GSOP FIG. 2.4-2)

SUBROUTINE

GETTF

GET TIME FOR NEXT MARK ( $t_2$ )

MPAC<sub>2</sub> ← Q#S2ZLOC

RETURN VIA  
QPRET

TDECI<sub>2</sub> ← MPAC<sub>2</sub>

TRANSFER TIME FOR  
INPUT TO INTEGRY.

INTEGRY  
EXTRAPOLATE  
CSM STATE  
VECTOR TO TDECI  
FC-2250

INPUT: TDECI=TIME  
OUTPUT: STATE VECTOR UPDATED

SUBROUTINE

SECCALRC

DETERMINE CSM POSITION VECTOR

$$r_c = \hat{a} + r_c$$
  
$$CSMPOS_v \leftarrow \Delta TACSM_v + RCVCSM_v$$

RETURN VIA  
QPRET

MARKDATA ← S2ZLOC

TRANSFER ADDRESS OF MARK  
DATA FOR INPUT TO GETUM

GETUM  
GET CONVERT SIX  
ANGLES TO  
LDS VECTOR  
FC-2570

INPUT: MARKDATA = ADDRESS OF MARK ANGLES  
OUTPUT: MPAC<sub>v</sub> = LINE OF SIGHT VECTOR IN  
BASIC REFERENCE COORDINATES

UM<sub>v</sub> ← MPAC<sub>v</sub>  
UM<sub>v</sub> ← MPAC<sub>v</sub>

STORE LOS VECTOR  
FOR FUTURE USE

NEXT SHEET

DESIGN	A.C. WILLIAMS
PROGRAM	A.P. Smith
ANALYSIS	
DESIGNED BY	J.P. Smith
APPROVED	J.P. Smith

P22-ORBITAL NAVIGATION

COLOSSUS II

FC-2590

12 44

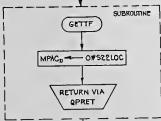
FROM PRECEDING SHEET

DMPINTES

IS THIS MARK AN OFFSET  
LANDING SITE?

YES  
NO

SE2OFF=I



SET TIME FOR  
THIS MARK ( $t_p$ )

SE2TDF<sub>p</sub> ← MPAC<sub>D</sub>  
SE2UOFF<sub>v</sub> ← UM<sub>v</sub>

SAVE TIME AND POSITION FOR  
OFFSET LANDING SITE PROCESSING

SE2I=N  
SHIT

THIS PATH CHECKS  
FOR LAST MARK

D=9 TEST  
IS W-MATRIX 9 DIMENSIONAL?  
NO-INITIALIZE W-MATRIX FOR LANDMARK PROCESSING

IS DMENFLG  
SET?

YES

SE2D=0

PDL0<sub>v</sub> ← r<sub>e</sub>  
PDL0<sub>v</sub> ← X70<sub>v</sub>

FOR INPUT  
TO R-T-RP

PDL0<sub>v</sub> = t'  
PDL0<sub>v</sub> ← SE2PRIM

INPUT TO  
R-T-RP

MPAC ← SE2EORM

INPUT TO  
R-T-RP

R-T-RP  
CONVERT FROM  
BASIC TO  
PLANETARY  
COORD. SYSTEM  
FC-2203

INPUT:  $OO_v$  = RADIUS VECTOR  
 $t_0$  = TIME  
MPAC = PLANET SYSTEM  
INDICATOR  
O = EARTH  
M = MOON  
OUTPUT: MPAC<sub>v</sub> = RADIUS VECTOR  
IN PLANETARY  
COORDINATES

GRUPE  
SET UP RESTARTS TO  
SCHEDULE NEXT LOCATION  
AS A FINOAC JOB  
WITH SAME PRIORITY

SET ORDWFLG  
SET DMENFLG  
SET SE2OPFLG  
SET ERADFLAG

W-MATRIX VALID FOR ORD. NAV  
D=9 W-MATRIX 9 DIM.  
DSP=1 DISPLAY ΔR + ΔV FLAG  
WHICH RADIUS FLAG?

IS KNOWNFLG  
SET?

YES

SE2BOXE2  
SHE2

THIS PATH INITIALIZES  
W-MATRIX FOR KNOWN  
LANDMARK.

NO

AAA  
SHE4

THIS PATH INITIALIZES W-MATRIX  
FOR UNKNOWN LANDMARK.  
NOTE: AAA IS A FLOWCHART  
NOT PROGRAM MNEMONIC.

NEXT SHEET

FORM 1  
REV. 1-64  
A.C. WILLIAMS  
P. L. ...  
P. ...  
A. ...

PE2-ORBITAL NAVIGATION

COLOSSUS II

FC-2290

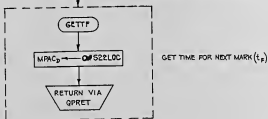
1

10

44

FROM PRECEDING SHEET

$PDLQ_v \leftarrow MPAC_v$  RP VECTOR FROM P-TO-RP ROUTINE  
USED AS INPUT TO RP-TO-R ROUTINE



$PDLQ_D = t_p$  INPUT TO RP-TO-R  
 $PDLQ_D \leftarrow MPAC_D$

$MPAC \leftarrow S22EORM$  INPUT TO RP-TO-R



INPUT:  $GO_0$  = RADIUS VECTOR IN PLANETARY COORDINATES  
 $GO_D$  = TIME  
MPAC = PLANET INDICATOR  
0 = EARTH, NST 0 = MOON  
OUTPUT:  $MPAC_v$  = RADIUS VECTOR IN BASIC COORDINATES  
NOTE: THE CALLS TO R-TO-RP AND RP-TO-R ROUTINES  
HAVE UPDATED THE LANDMARK POSITION  
VECTOR FROM TIME ( $t'$ ) TO TIME ( $t_p$ ).

S22BOX32

$I_t = MPAC_v$  SAVE LANDMARK POSITION  
 $XT63_v \leftarrow MPAC_v$

SET INCORFLG FIRST INCORPORATION PASS  
FLAG = 1

CLEAR DVFIND

$I_c = I_t - I_0$  CALCULATE ESTIMATED CSM TO  
 $RCLP_v \leftarrow MPAC_v - CSMPOS_v$  LANDMARK LINE OF SIGHT  
GSOP EQU. 2.4.3

NEXT SHEET

DRAWN: A.C. WILLIAMS PROJ. NO.: P. L. Smith ANALYST: DATE: J. Giacatelli APPROVED: J. A. Smith	REVISIONS: 02 047 00 03 047 00 04 047 00 05 047 00 06 047 00 07 047 00 08 047 00 09 047 00 10 047 00 11 047 00 12 047 00	PRE-ORBITAL NAVIGATION COLLOSSUS II FC-2590 14 44
--	---	--



FROM PRECEDING SHEET

$$U_s = \text{UNIT} \left[ \frac{U_{CL} \times U_M}{MPAC_V \leftarrow \text{UNIT} \left( \left( \text{UNIT}(\text{RCLP}_V) \right) \times U_M \right)} \right]$$

INITIALIZE FICTITIOUS STAR DIRECTION  
GSOP EQU. 2.4.4

IF OVERFLOW, THEN ANGLE LESS THAN  $2^{-15}$   
AND STATE VECTOR CHANGES WILL BE NEGLIGIBLE.  
THUS THIS SET OF MEASUREMENT DATA WILL BE  
DISCARDED AND NEXT MARK WILL BE PROCESSED.

S225AVET  
GHI7

THIS PATH WILL  
PROCESS NEXT MARK

$$U_s = MPAC_V$$

$$USTAR_V \leftarrow MPAC_V$$

SAVE FICTITIOUS STAR DIRECTION FOR USE  
BY BVECTOR TO COMPUTE ARTIFICIAL STAR  
DIRECTION

S22BOX12

NOTE: THIS IS THE ENTRY FOR SECOND  
INCORPORATION PASS.

SET DMENFLG  
SET VEHUPFLG

W-MATRIX 9 DIMENSIONAL  
VEHICLE IS CSM

$$\sigma^2 = \sigma_{CL}^2 (\text{VAR}_{ACT} + \text{VAR}_{IM})$$

$$\text{VARIANCE} \leftarrow \frac{(\text{RCLP}_V)^2 (\text{CTVAR}_0 + \text{IMVAR}_0)}{(\text{RCLP}_V)^2 (\text{CTVAR}_0 + \text{IMVAR}_0)}$$

COMPUTE INSTRUMENT  
ERROR VARIANCE  
GSOP EQU. 2.4.15

BVECTORS  
COMPUTE  
DELTAQ AND  
BVECTOR  
FC-2570

COMPUTE GSOP EQU. 2.4.12  
INPUT:  $U_M$  = MEASURED LOS VECTOR ( $U_M$ )  
 $USTAR_V$  = FICTITIOUS STAR DIRECTION ( $U_s$ )  
 $RCLP_V$  = COMPUTED LOS VECTOR ( $RCLP_V$ )  
OUTPUT:  $USTAR_V$  = ARTIFICIAL STAR DIRECTION ( $U_s$ )  
BVECTOR = 3 DIM. GEOMETRY VECTOR ( $b_0, b_1, b_2$ )  
DELTAQ = MEASURED DEVIATION ( $\Delta Q$ )

$$\hat{b}_2 = -b_0$$

$$(\text{BVECTOR} + 12)_V \leftarrow -(\text{BVECTOR})_V$$

INITIALIZE  $b_2$

INCORP1  
COMPUTE  
STATE VECTOR  
CHANGE  $\Delta X$   
FC-2610

INPUT: DELTAQ = ESTIMATED AND MEASURED  
POSITION DEVIATION ( $\Delta Q$ )  
VARIANCE = INSTRUMENT ERROR  
VARIANCE ( $\sigma^2$ )  
BVECTOR = 3 DIM. GEOMETRY VECTOR  
( $b_0, b_1, b_2$ )  
DMENFLG = DIMENSION OF W-MATRIX  
SET = 3 DIM. CLEARED = 5 DIM.  
OUTPUT: DELTAX = STATE VECTOR DEVIATIONS ( $\Delta X$ )

NEXT SHEET

P22-ORBITAL NAVIGATION

SPONSOR	A.C. WILLIAMS	DATE	07/16/68
PROGRAM	ORBITAL NAVIGATION	DATE	23 OCT 68
DESIGNER	R. P. PAVELLE	DATE	11/01/68
APPROVED	J. A. M. ...	DATE	11/01/68

FC-2590  
REV 15 44

FROM PRECEDING SHEET

GROUP2  
SET UP RESTARTS  
TO SCHEDULE  
NEXT LOCATION  
AS A FINDVAC JOB  
WITH SAME PRIORITY

NO - DO NOT DISPLAY  
DEVIATIONS

IS  
Z2DSPLG  
SET ?

WILL DEVIATIONS  
BE DISPLAYED ?

YES - DISPLAY STATE  
VECTOR DEVIATIONS  
CLEAR  
Z2DSPLG  
DO NOT DISPLAY  
DEVIATIONS

NOTE: STATE VECTOR DEVIATIONS WILL BE DISPLAYED FOR APPROVAL ONLY FOR THE FIRST MARK. IF THESE ARE ACCEPTED, ALL OTHER DEVIATIONS (FOR THIS SET OF MARKS) WILL BE INCORPORATED WITHOUT BEING DISPLAYED.

GROUP2  
SET UP RESTARTS  
TO SCHEDULE  
NEXT LOCATION  
AS A FINDVAC JOB  
WITH SAME PRIORITY

N490ISP, ← DELTA<sub>x</sub>  
(N490ISP+2)<sub>v</sub> ← (DELTA<sub>x</sub>+G)<sub>v</sub>

PLACE POSITION ( $\delta r$ ) AND VELOCITY ( $\delta v$ ) DEVIATIONS IN THEIR DISPLAY HOURS.

BLANKET  
BLANK OUT  
R3  
FC-2130

IMMEDIATE  
RETURN

GOFLASHR  
V06M45  
DISPLAY  $\delta r$  AND  $\delta v$   
FOR APPROVAL

TERMINATE → GOTOPODH

R1 =  $\delta r$  XXXXX NAUT MI.  
R2 =  $\delta v$  XXXXX FT/SEC.  
R3 = BLANK

REJECT DEVIATIONS (ENTER DATA)

PROCEED

S22EXEX

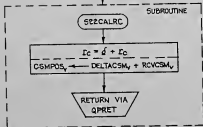
RETURN VIA  
S22RTNEX

ENDOFJOB

S22BOX42

INCORP2  
INCORPORATE  
STATE VECTOR  
DEVIATIONS  
FC-2510

INPUT: DELTA<sub>x</sub> = STATE VECTOR DEVIATIONS ( $\Delta x$ )  
OMENPLG = DIMENSION OF W-MATRIX  
OUTPUT: UPDATED STATE VECTOR



DETERMINE CSM  
POSITION VECTOR

NEXT SHEET

MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

REPORT AND SUBROUTINES

PER-ORBITAL NAVIGATION

DRAWN A.C. WILLIAMS  
PROGRAM R.P. *R.P.*  
ANALYST  
DOCUM *R.P. mobile*  
APP'D *R.P. mobile*

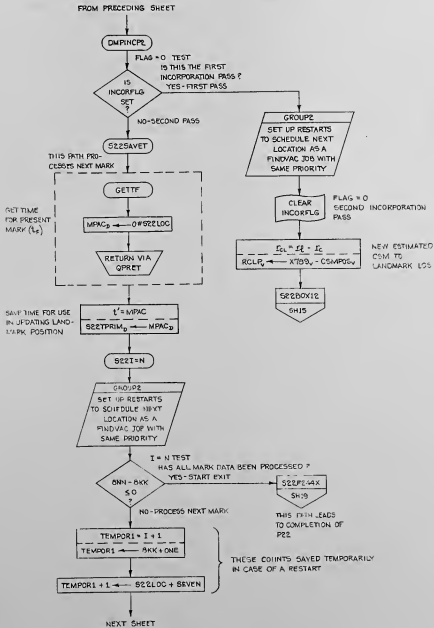
2300P6  
2300P6  
2300P6  
2300P6

COLOSSUS II

FIGURE NO.

FC-2590

SHEET 16 OF 44



P22-ORBITAL NAVIGATION

A. WILLIAMS  
M. P. Smith  
J. A. ...  
...

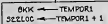
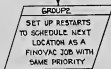
258916  
17 0077  
214716  
214716

COLOSSUS II

FC-2590

44

FROM PRECEDING SHEET



TRANSFER MARK DATA COUNTERS  
TO PERMANENT LOCATIONS



SEZFLGS

SUBROUTINE

SET DIMOFLG  
SET D6ORDFLG  
SET VINTFLAG  
SET STATEFLG  
CLEAR INTYPLG

USE W-MATRIX  
9 DIM. W-MATRIX  
INTEGRATE CSM SV.  
UPDATE PERMANENT SV.  
ENCODE INTEGRATION

INITIALIZE FLAGS FOR  
INTEGRATION ROUTINE

RETURN VIA  
QPRET



IS W-MATRIX 9 DIMENSIONAL  
(LANDMARK PORTION INITIALIZED) ?

NOTE: THIS BRANCH TAKEN ONLY IF  
THE FIRST MARK IS AN OFFSET  
LANDING SITE.

YES-9 DIMENSIONAL

THIS PATH TAKEN IF FIRST  
MARK NOT AN OFFSET  
LANDING SITE.

NO-6 DIMENSIONAL

0 \* 0 (W-MATRIX NOT  
INITIALIZED)

CLEAR  
DIMOFLG



IS W-MATRIX VALID FOR  
ORBITAL NAVIGATION ?

NO  
THIS PATH WILL PROHIBIT  
W-MATRIX INTEGRATION  
BECAUSE IT HAS NOT BEEN  
INITIALIZED FOR ORBITAL  
NAVIGATION.

YES  
D=6 (6 DIM. W-MATRIX)

THIS PATH ALLOWS 6-DIMENSIONAL  
W-MATRIX INTEGRATION

SET DIMOFLAG  
CLEAR D6ORDFLG

SEZXTIN  
SHZ

THIS BRANCH PROCESSES  
NEXT MARK.

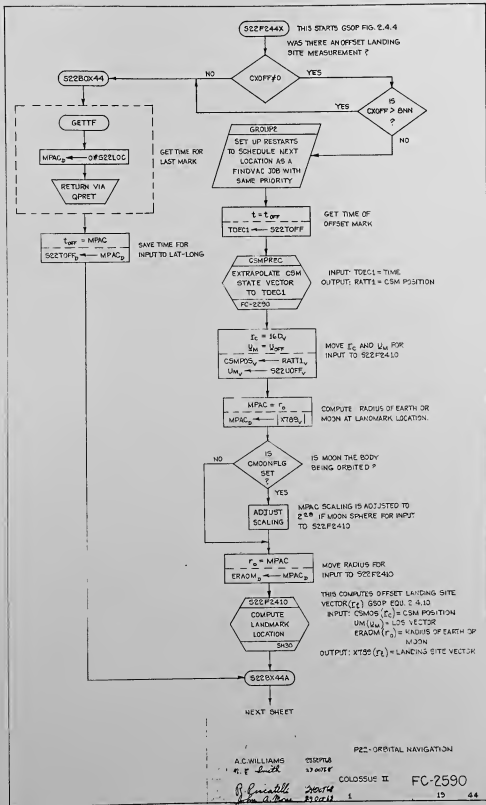
MIT	
"RESEARCH LABORATORY"	
- AERIAL NAVIGATION	
SEARCHED	INDEXED
SERIALIZED	FILED
APR 19 1954	
R. P. Smith	
J. A. Brown	

P22-ORBITAL NAVIGATION

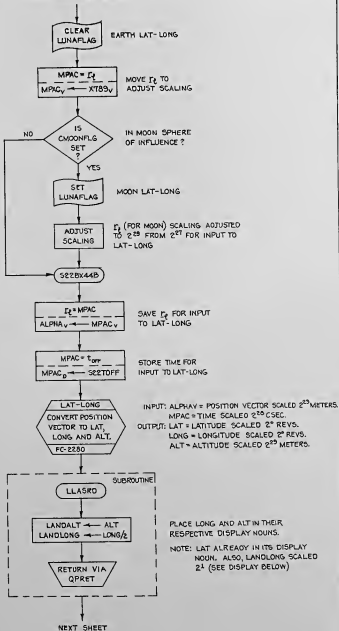
COLDSPRUS II

FC-2590

11 15 - 44



FROM PRECEDING SHEET



WIT WASHINGTON STATION 148 CAMPBELL, MASS.	
DRAWN A.C. WILLIAMS PFC MR. R. E. Smith ANALYST 20148 R. P. Swindle APP'D John A. Brown	1352016 230210 170000 230217

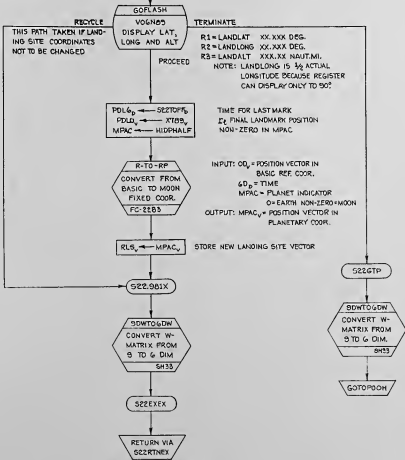
PER-ORBITAL NAVIGATION

COLOSSUS II

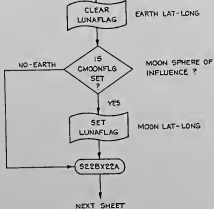
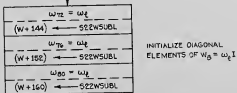
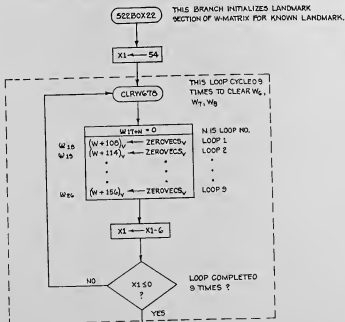
FC-2590

20 44

FROM PRECEDING SHEET



THIS IS A RETURN WHICH WILL RECYCLE P22 TO TAKE MARK DATA ON ANOTHER LANDMARK (OR THE SAME ONE AGAIN) OR TO TERMINATE P22 AT ANY DISPLAY.



NO. 1

DATE: 11/11/54

BY: A.C. WILLIAMS

CHKD: A.C. WILLIAMS

APPD: J. P. Conatelli

1

P22 - ORBITAL NAVIGATION

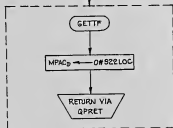
COLOSSUS II

FC-2590

22 44



FROM PRECEDING SHEET



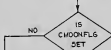
GET TIME FOR THIS MARK



INPUT: LAT = LANDMARK LATITUDE SCALED  $2^8$  REVS  
 LONG = LANDMARK LONGITUDE SCALED  $2^8$  REVS  
 ALT = LANDMARK ALTITUDE SCALED  $2^{13}$  METERS  
 MPAC = TIME SCALED  $2^{20}$  C/SRG.  
 ERADFLAG, LUNAFAG  
 OUTPUT: ALPHAV = LANDMARK RADIUS VECTOR  
 SCALED  $2^{13}$  METERS.



MOVE LANDMARK VECTOR TO ADJUST SCALING



MOON SPHERE OF INFLUENCE ?



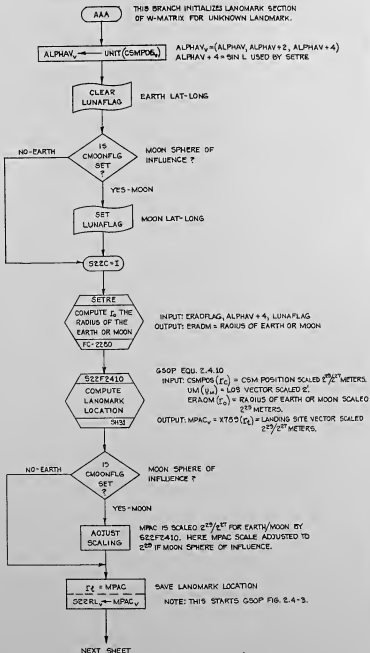
ADJUST  $E_g$  SCALING  $2^{27}$  METERS MOON LANDMARK



THIS BRANCH LEADS TO INCORPORATION OF THIS MARK.

WIT EMITTING STATION I & R CAMBRIDGE, MASS.		AND GUIDANCE AND NAVIGATION  PZE - ORBITAL NAVIGATION	
DRAWN A.C. WILLIAMS	DATE 11/15/51	COLOSSUS II	REV 1
PROG. R. E. Smith	DATE 11/15/51	FC-2590	REV 1
ANALYST R. Cavatelli	DATE 11/15/51		
DESIGNER John A. Moore	DATE 11/15/51		

COLOSSUS II  
 FC-2590  
 REV 1



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
		PSE-ORBITAL NAVIGATION	
DRAWN A.C. WILLIAMS	DATE 5/10/58	COLOSSUS II	DOCUMENT NO.
CHKD BY R. E. S. 2/28	DATE 5/10/58		FC-2590
APPROV. R. Russell	DATE 5/10/58		JUL 24 1958
APPROV. John A. Moore	DATE 5/10/58		REV 4

FROM PRECEDING SHEET

$d = U_M \cdot I_E$   
 $SE2Z \leftarrow U_M \cdot MPAC_V$

EVALUATE SCALAR USED TO INITIALIZE  $W_6$  AND  $W_7$

SET  
 OD TO 17D  
 EQUAL TO 0

CLEAR FIRST 15 LOCATIONS OF PUSHLIST

$PDLA_V \leftarrow \text{MIDPHALF}$   
 $PDLB_V \leftarrow \text{MIDPHALF}$   
 $PDLIC_V \leftarrow \text{MIDPHALF}$

SET PUSHLIST EQUAL TO IDENTITY MATRIX  $(I)$  (USED IN LOOP BELOW)

$\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}$

OD TO 5D  
 6D TO 11D  
 12D TO 17C

$SE23X1_V \leftarrow U_M$   
 $MPAC_V \leftarrow SE2RL_V$

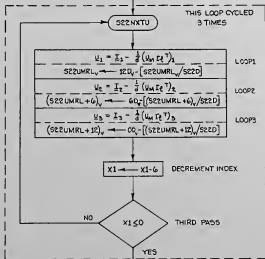
$U_M$  AND  $I_E$  MOVED FOR INPUT TO  $SE231 \times 13$

$SE231 \times 13$   
 DO  $3 \times 1$  BY  $1 \times 3$  MATRIX MULTIPLICATION  
 SWSI

INPUT:  $SE23X1_V = 3 \times 1$  MATRIX  
 $MPAC_V = 1 \times 3$  MATRIX  
 OUTPUT:  $SE2UMRL = 3 \times 3$  MATRIX  $(U_M \cdot I_E^T)$

$X1 \leftarrow 15$

INITIALIZE FOR LOOP CONTROL



$U = I - \frac{1}{3} U_M \cdot I_E^T$   
 THIS IS A MATRIX USED TO INITIALIZE  $W_6$  AND  $W_7$

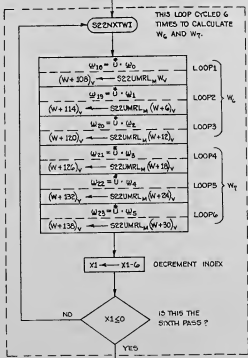
NEXT SHEET

WIT INSTRUMENTATION LAB AMP/120 W	PERM 3300749
SPANNY & WILLIAMS PERRY ST. S. S. C. Bldg. ANNET 274 W. R. Russell APPROX. Jan 2, 1968	PERM 3300749 COLOSSUS II FC-2590 25 44

PERC - ORBITAL NAVIGATION

FROM PRECEDING SHEET

$X1 \leftarrow 36$  INITIALIZE INDEX FOR LOOP CONTROL



INITIALIZE  $W_6$  AND  $W_7$ .  
 $W_{1-16} = \vec{0} \cdot W_i \quad (i=0,1,\dots,5)$

$MFRAC \leftarrow SZZRHO$  FETCH  $P$  TO CHECK SCALING.

IS  $CMOONFLG$  SET? MOON SPHERE OF INFLUENCE?

ADJUST SCALING  $P$  SCALING ADJUSTED TO  $2^{30}$  FROM  $2^{20}$  IF MOON SPHERE.

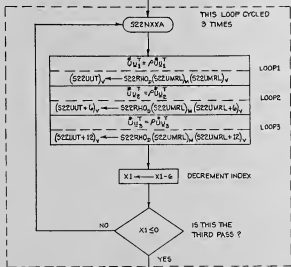
$P = \frac{1}{2} P^2 VAR_{ACT}$   
 $SZZRHO \leftarrow \frac{1}{2} (MFRAC)_B^2 (SCTVAR)_B$  START OF  $W_8$  INITIALIZATION

$X1 \leftarrow 10$  INITIALIZE INDEX FOR LOOP CONTROL

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED ELECTRONICS AND NAVIGATION	
DRAWN A. C. WILLIAMS PROJ. ENG. R. P. ELLIOTT ANALYST DTIC REP. R. P. ELLIOTT APPROVED John A. Moore		PERIODIC ORBITAL NAVIGATION COLLOSSUS II FC-2590 SHEET 26 OF 44	

FROM PRECEDING SHEET



FIRST TERM OF SMALL  $\epsilon$  MATRIX  
 $\frac{1}{2} \rho^2 \text{VAR SET } U_i^T$   
 (SEE NEXT SHEET)

X1 ← X1 - 6 DECREMENT INDEX

IS THIS THE THIRD PASS?  
 YES

S223X1 ← U<sub>v</sub>  
 MPAC ← U<sub>v</sub> INPUT TO S2231X13

S2231X13  
 DO 3X1 BY 1x3 MATRIX MULTIPLICATION  
 SW1

INPUT: S223X1 (U<sub>v</sub>) = 3x1 MATRIX  
 MPAC (U<sub>v</sub>) = 1x3 MATRIX  
 OUTPUT: S22UMRL (U<sub>v</sub>, U<sub>v</sub><sup>T</sup>) = 3x3 MATRIX

$\rho = \text{VAR}_R (r/d)^2$   
 S22RHO<sub>v</sub> ← RPVAR<sub>v</sub> (ERAD<sub>D</sub> / S22D<sub>v</sub>)<sup>2</sup>

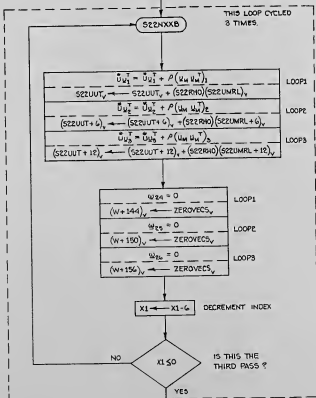
X1 ← 18 INITIALIZE INDEX FOR LOOP CONTROL

NEXT SHEET

APPROVED FOR RELEASE  
 1994  
 DRAWN A C WILLIAMS  
 FROM R. E. Smith  
 BY R. Smith  
 FOR J. A. Moore

APR 67  
 C. DANF AND M. IG...  
 P22 - ORBITAL NAVIGATION  
 COLOSSUS II  
 FC-2590  
 44

FROM PRECEDING SHEET



THIS PART COMPLETES CALCULATION OF SMALL  $\epsilon$  MATRIX

$$\begin{pmatrix} \epsilon_1 & 0 & 0 \\ \epsilon_2 & 0 & 0 \\ \epsilon_3 & \epsilon_4 & \epsilon_5 \end{pmatrix} =$$

$$\frac{1}{2} \rho^2 VAR_{3CT} \hat{U}^T + VAR_{\epsilon} \left( \frac{\rho}{6} \right)^2 U_M U_M^T$$

THIS PART CLEARS  $W_{2}$ .

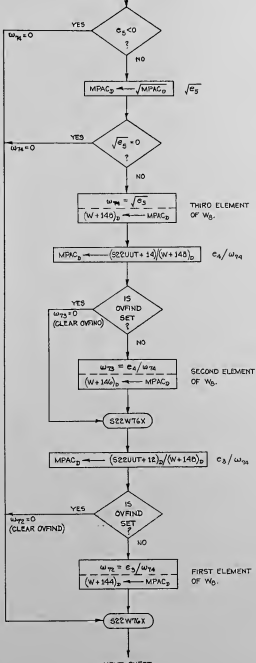
CLEAR OVRIND

$MPAC_b \leftarrow (SE2UUT + 16)_b$  FETCH  $\theta_b$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P22 - ORBITAL NAVIGATION	
PROF. M. E. L. ...	3/2/56	DOCUMENT NO.	
ANALYST		FC-2590	
DOCS. R. ...		COLOSSUS II	
APPRO. ...		REV 1	
		SEP 25 OF 44	

FROM PRECEDING SHEET



DRAWN A.C. WILLIAMS CHECKED R.F. Smith ANALYST DESIGNED R. Piccattelli APPROVED John A. Moore		JOSEPHINE DIRECTOR COLUSSUS II PROJECT	
P22-ORBITAL NAVIGATION		FC-2590 44	

FROM PRECEDING SHEET

$$MPAC_D \leftarrow \frac{(S22UUT + \theta)_D - (W + 144)_D^2}{D} \quad e_2 - \omega_{T2}^2$$

MPAC < 0 ?

YES  $\omega_{T2} = 0$

$$MPAC_D \leftarrow \frac{1}{MPAC_D} \quad \sqrt{e_2 - \omega_{T2}^2}$$

MPAC < 0 ?

YES  $\omega_{T2} = 0$

$$\frac{\omega_{T2} = \sqrt{e_2 - \omega_{T2}^2}}{W + 152}_D \leftarrow MPAC_D \quad \text{FIFTH ELEMENT OF } W_0$$

$$MPAC_D \leftarrow \frac{((S22UUT + \theta)_D - (W + 144)_D (W + 146)_D) / (W + 152)_D}{(e_2 - \omega_{T2} \omega_{T3}) / \omega_{T3}}$$

IS OVFFIND SET ?

YES  $\omega_{T2} = 0$  (CLEAR OVFFIND)

$$\frac{\omega_{T2} = (e_2 - \omega_{T2} \omega_{T3}) / \omega_{T3}}{(W + 150)_D} \leftarrow MPAC_D \quad \text{FOURTH ELEMENT OF } W_0$$

S22W10X

$$MPAC_D \leftarrow \frac{S22UUT_D - (W + 144)_D^2 - (W + 150)_D^2}{D} \quad e_0 - \omega_{T2}^2 - \omega_{T3}^2$$

MPAC < 0 ?

YES  $\omega_{T2} = 0$

$$\frac{\omega_{T2} = \sqrt{e_0 - \omega_{T2}^2 - \omega_{T3}^2}}{(W + 154)_D} \leftarrow \frac{1}{MPAC_D} \quad \text{SEVENTH ELEMENT OF } W_0$$

S22SCLW

$$W_0 = \begin{pmatrix} \omega_{T2} & \omega_{T3} & \omega_{T4} \\ \omega_{T5} & \omega_{T6} & 0 \\ \omega_{T7} & 0 & 0 \end{pmatrix} = \text{INITIALIZATION OF } W_0 \text{ FOR UNKNOWN LANDMARK.}$$

ADJUST SCALING  $W_0$  IS SCALED  $2^{15}$  METERS FROM  $2^{10}$  METERS.

S22SAVET

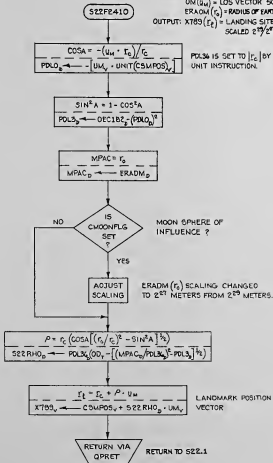
SHIT

THIS PATH PROCESSES NEXT MARK

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		SPR'D GUIDANCE AND NAVIGATION	
DRAMA A.C. WILLIAMS		P22 - ORBITAL NAVIGATION	
PROGRAM	ANALYST	COLOSSUS II	DOCUMENT NO.
DATE	APPROVED	FC-2590	UNIT 50 44



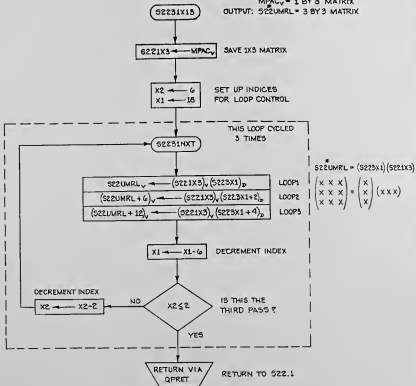
THIS SUBROUTINE CALCULATES GSOP EQU. 2.4-10.  
 INPUT: CSMPOS ( $r_c$ ) = CSM POSITION SCALED  $2^{29}$  METERS.  
 $UM(U_M)$  = LOS VECTOR SCALED  $2^7$ .  
 $ERADM(r_c)$  = RADIUS OF EARTH ON MOON SCALED  $2^{28}$  METERS.  
 OUTPUT: XTBS ( $r_t$ ) = LANDING SITE POSITION VECTOR  
 SCALED  $2^{29}$  METERS.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
BROWN A. C. WILLIAMS		PER - ORBITAL NAVIGATION	
PICKER G. E. Smith		NOV 60	
B. Prucelle		31-769	
21 OCT 62		COLOSSUS II	
21 OCT 62		FC-2590	
21 OCT 62		3	
		44	

SUBROUTINE TO MULTIPLY A 3 BY 1 MATRIX BY A  
1 BY 3 MATRIX YIELDING A 3 BY 3 MATRIX.

INPUT: SEZ2X1 = 3 BY 1 MATRIX  
MPAC = 1 BY 3 MATRIX  
OUTPUT: SEZUMRL = 3 BY 3 MATRIX



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P2R-ORBITAL NAVIGATION	
PROGRAM T. P. Smith	400768	DOCUMENT NO.	
ANALYST	314673	COLOSSUS II	
DESIGN R. Russell	1000	FC-2590	
APPROVED J. A. ...	REV 1	15417 32 OF 44	

THIS SUBROUTINE CONVERTS W-MATRIX FROM 5 TO 4 DIMENSIONS.

NOTE: W-MATRIX CONVERSION ROUTINE IS DESCRIBED IN SPACE GUIDANCE SYSTEM MEMO #20-66.

SDWTOGDW

SDWXX ← QPRT

SAVE RETURN

PDL<sub>0</sub> ← HIGZEROS<sub>v</sub>  
PDL<sub>1</sub> ← HIGZEROS<sub>v</sub>  
PDL<sub>2</sub> ← HIGZEROS<sub>v</sub>

WORKW  
XTEMP1  
INITIALIZE: SDWP } = 0  
SDWI  
SDWN  
SDWI

J = 25  
SDWI ← 50

NOTE: COMPUTER VALUES FOR COUNTERS (I, J AND P) ARE TWICE GSOP VALUES BECAUSE VARIABLES ARE DOUBLE PRECISION.  
THIS BEGINS GSOP FIG. 2.4-5.

SDWI = J

I = J  
SDWI ← SDWI

SPWPCAL

ROWOOT  
CALCULATE  
ROW DOT  
PRODUCT  
SH40

INPUT: SDWI = I  
SDWI = J  
W-MATRIX  
OUTPUT:  $\sum_{k=0}^3 W_{1+3k} W_{2+3k} = MPAC_0$   
K=0

(EMATRIX + 40)<sub>0</sub> # SDWP ← MPAC<sub>0</sub>

THIS PART OF CONVERSION CALCULATES

$$E = W^T W^T = \begin{pmatrix} e_0 & e_1 & e_2 & e_3 & e_{10} & e_{15} \\ 0 & e_2 & e_4 & e_7 & e_{11} & e_{16} \\ 0 & 0 & e_6 & e_8 & e_{12} & e_{17} \\ 0 & 0 & 0 & e_9 & e_{13} & e_{18} \\ 0 & 0 & 0 & 0 & e_{14} & e_{19} \\ 0 & 0 & 0 & 0 & 0 & e_{20} \end{pmatrix}$$

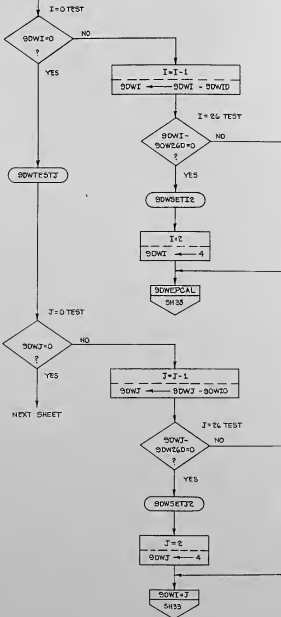
NOTE: P IS GOING FROM 0 TO 60 INSTEAD OF GSOP 20 TO 0.

P = P + 1  
SDWP ← SDWP + 2

NEXT SHEET

50485 A.C. WILLIAMS 50486 R.F. Smith 50487 J.P. Matell 50488 John A. Rose		50489 50490 50491 50492 50493 50494 50495 50496 50497 50498 50499 50500	
50501 50502 50503 50504 50505 50506 50507 50508 50509 50510		PEZ-ORBITAL NAVIGATION COLOSSUS II FC-2590 33 44	

FROM PRECEDING SHEET



MIT  
INSTRUMENTATION LAB  
CAMBRIDGE MASS

DESIGNER A. C. WILLIAMS	DATE 10/26/68
ANALYST B. E. Smith	REVISED 3/20/70
DOCTOR G. Panatelli	PROJECT SH33
APPROVED John A. Rose	REVISED 2/2/70

PER-ORBITAL NAVIGATION

MIT 68-001-001

COLOSSUS III

FC-2590

REV 1

REV 1 24 44

FROM PRECEDING SHEET

START OF GSOP FIG. 2.4-6

SDWFIG6

GROUP2

SET UP RESTARTS TO  
SCHEDULE NEXT LOCATION  
AS A FINDVAC JOB  
WITH SAME PRIORITY

J=29

SDWJ ← 55

SDW<sub>P</sub> ← HIGZEROS<sub>V</sub>

P=0  
I=0  
N=0 } INITIALIZE COUNTERS

X1 ← 108

INITIALIZE INDEX FOR  
LOOP CONTROL

CLEARWS4

THIS LOOP CYCLED  
16 TIMES.

W<sub>10,1} = 0</sub>

W<sub>1,1} ← HIGZEROS<sub>V</sub></sub>

(W+6)<sub>1} ← HIGZEROS<sub>V</sub></sub>

⋮

(W+100)<sub>1} ← HIGZEROS<sub>V</sub></sub>

LOOP1 W<sub>1,0} = 0</sub>

LOOP2 W<sub>1,1} = 0</sub>

⋮

⋮

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SET W<sub>1,0} TO W<sub>25,0}</sub></sub>

X1 ← X1-6

DECREMENT INDEX

X1 ≤ 0

IS THIS THE  
16<sup>TH</sup> PASS?

NO

YES

SDWI=JA

I=J

SDWI ← SDWJ

ROWDOT

CALCULATE

ROW DOT

PRODUCT

SDW40

INPUT: SDWI=I  
SDWJ=J  
W-MATRIX

OUTPUT: MPAC<sub>D} = ∑<sub>k=0</sub> W<sub>1+3k} W<sub>2+3k}</sub></sub></sub>

$$W_{00} = e^p - \sum_{k=0}^3 W_{1+3k} W_{2+3k}$$

$$MPAC_D \leftarrow (EMATRIX + 40) \# SDW - MPAC_D$$

NEXT SHEET

REVISIONS

DATE: A.C. WILLIAMS  
BY: R.P. LATH  
REV: R. L. Scahill  
BY: J. A. Hesse

PE2 - ORBITAL NAVIGATION

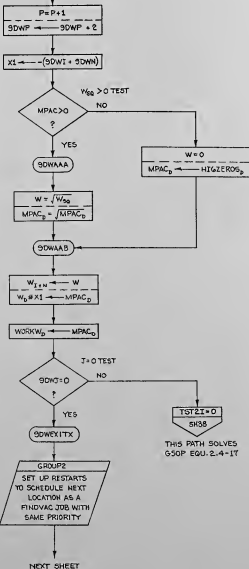
COLOSSUS II

FC-2590

35

4.4

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS		PROJECT STUDENT AND RESEARCHER	
DRIVEN BY A. C. WILLIAMS		PROJECT	
DESIGNED BY R. E. 2-20		COLLOSSUS II	
DRAWN BY R. Russell		REV 2	
APPROVED BY J. A. May 23/64		FC-2590	
		REV 2	

FC-2590  
REV 2

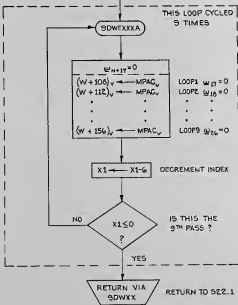
FROM PRECEDING SHEET

$X1 \leftarrow 54$

INITIALIZE INDEX FOR LOOP CONTROL

$MPAC_v \leftarrow HI6ZEROS_v$

CLEAR MPAC



SET  $w_6, w_7$  AND  $w_8$  TO ZERO.

LOOP1  $w_{11} = 0$

LOOP2  $w_{12} = 0$

...

...

...

LOOP9  $w_{16} = 0$

DECREMENT INDEX

IS THIS THE 9TH PASS ?

RETURN TO 52.1

MIT  
INSTRUMENTATION LAB  
CAMBRIDGE MASS.

DRARY A.C. WILLIAMS  
PROF. *A.F. Smith*  
ANALYST  
DICKIE R. PROBERT  
APPROV. *John A. Moore*

SOCTUS  
NO ACTION  
NOCTUS  
NOCTUS

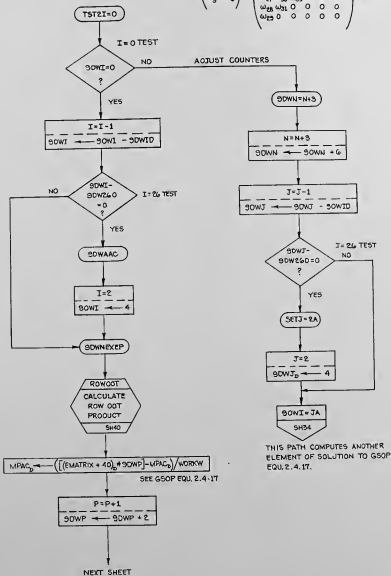
PROJECT AND DIVISION  
PER-ORBITAL NAVIGATION

COLOSSUS II FC-2590

4. 57 44

THIS PART CALCULATES THE SOLUTION (EQU. 2.4-16)  
TO GSOP EQU. 2.4-17.

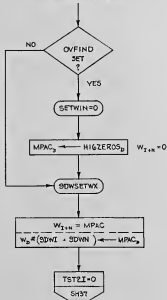
$$\begin{pmatrix} W_0^T & W_1^T \\ W_2^T & W_4^T \end{pmatrix} = \begin{pmatrix} W_0 & W_1 & W_2 & W_3 & W_4 & W_5 & W_6 \\ W_7 & W_8 & W_9 & W_{10} & W_{11} & 0 & 0 \\ W_{12} & W_{13} & 0 & 0 & 0 & 0 & 0 \\ W_{14} & W_{15} & 0 & 0 & 0 & 0 & 0 \\ W_{16} & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad \text{EQU. 2.14-16}$$



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PERZ-ORBITAL NAVIGATION	
PROW #	805746	DOCUMENT NO.	
ANALYST	W. L. 6-28	COLLOSSUS II	
DOCS	R. P. Cassatelli	FC-2590	
APPROV	John A. Moore	REV 1	SHEET 35 OF 44



FROM PRECEDING SHEET



THIS PATH RECYCLES TO COMPUTE ANOTHER ELEMENT OF SOLUTION TO EQ. 2.4 - II.

INSTRUMENTATION LAB (M. S. WALK)		PRE-ORBITAL NAVIGATION	
DRAWN A.C. WILLIAMS CHECKED M.F. Smith ANALYST DESIGNER R.P. Smith APPROVED J.H. O'Meara	SECTION 53 40 10 PROJECT COLOSSUS II BLOCK 1	FC-2590 REV 35 - 44	

THIS SUBROUTINE CALCULATES  $c_p = \sum_{k=0}^2 W_{1+3k} W_{2+3k}$

INPUT: ROWI = I  
 ROWJ = J  
 W-MATRIX  
 OUTPUT: MPAC<sub>p</sub> =  $\sum_{k=0}^2 W_{1+3k} W_{2+3k}$

ROWDOT

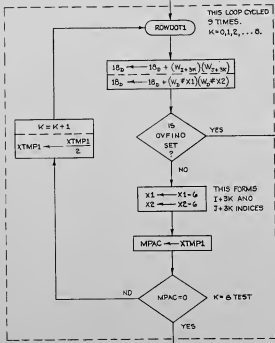
XTMP1 ← 377<sub>9</sub>

377<sub>9</sub> = 2<sup>8</sup> - 1 THIS IS THE K INDEX. IT IS DIVIDED BY 2 (5 TIMES) UNTIL IT IS ZERO.

CLEAR  
 OVFINO

X1 ← -ROWI  
 X2 ← -ROWJ  
 18D<sub>9</sub> ← 0

INITIALIZE I AND J INOICES FOR INDIRECT ADDRESSING



ROWDOT2

MPAC<sub>p</sub> ← 18D<sub>9</sub>

RESULT OF  $\sum_{k=0}^2 W_{1+3k} W_{2+3k}$  WILL BE OUTPUT IN MPAC.

RETURN VIA  
 QPRET

RETURN TO ROWD0&DW

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PER-ORBITAL NAVIGATION	
PROGR M.C. 6-6	DOCTMR 374077	DOC NO. FC-2590	
ANALST R. Cassatt	YEAR 1968	SHEET 40 OF 44	
APPRD J. A. ...	REV 1		

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
ROZBOTH	2210	CHECKS STATUS OF IMU	SH3
LOADTIME	2100	GETS PRESENT TIME FROM COMPUTER	SH3, 7
CSMCONIC	2290	EXTRAPOLATES CSM STATE VECTOR TO TIME TDEC1 (CONIC)	SH3
BLANKET	2130	BLANKS OUT CERTAIN DISPLAY REGISTERS	SH3, 8, 16
R52	2730	AUTOMATIC OPTICS DRIVING ROUTINE	SH4
ADVORB	2730	ADVANCED GROUND TRACK ENTRY POINT OF R52	SH7
RP-TO-R	3283	CONVERT FROM PLANETARY TO BASIC REFERENCE COORDINATES	SH7, 14
LAT-LONG	2280	CONVERT RADIUS VECTOR TO LAT, LONG, AND ALT.	SH7, 20
MKRELEAS	2240	RELEASE MARK SYSTEM	SH9
INTSTALL	2200	RESERVE INTEGRATION ROUTINE	SH10, 18
INTEGRV	2290	EXTRAPOLATE CSM STATE VECTOR TO TIME TDEC1	S H12
GETUM	2570	CONVERT SIGHTING ANGLES TO LINE OF SIGHT VECTOR	SH12
R-TO-RP	2283	CONVERT FROM BASIC REFERENCE TO PLANETARY COORDINATES	SH13, 21
BVECTORS	2570	COMPUTE MEASURED TO ESTIMATED POSITION DEVIATION AND MEASUREMENT GEOMETRY VECTOR	SH15
INCORP1	2610	COMPUTE STATE VECTOR CHANGE $\delta X$	SH15
INCORP2	2610	INCORPORATE STATE VECTOR DEVIATIONS	SH16
CSMPREC	2290	EXTRAPOLATE CSM STATE VECTOR TO TIME TDEC1 (PRECISION)	SH19
LALOTORV	2280	CONVERT LAT, LONG, AND ALT TO RADIUS VECTOR	SH23
SETRE	2280	COMPUTE EARTH OR MOON RADIUS	SH24

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
RNDVZFLG FLAGWORD 0 BIT 7	P20 IS RUNNING	P20 IS NOT RUNNING		SH3	
RENDWFLG FLAGWORD 5 BIT 1	W-MATRIX IS VALID FOR RENDEZVOUS NAVIGATION	W-MATRIX IS INVALID FOR RENDEZVOUS NAVIGATION		SH3, 11	
P22MKFLG FLAGWORD 3 BIT 11	P22 DOWNLINK MARK DATA WAS JUST TAKEN	P22 DOWNLINK MARK DATA WAS NOT JUST TAKEN	SH9	SH4	
ERADFLAG FLAGWORD 1 BIT 13	EARTH: COMPUTE FISHER ELLIPSOID RADIUS MOON: USE FIXED RADIUS	EARTH: USE FIXED RADIUS MOON: USE RLS FOR LUNAR RADIUS	SH4		
CMOONFLG FLAGWORD 8 BIT 12	CSM STATE VECTOR IS IN LUNAR SPHERE OF INFLUENCE	CSM STATE VECTOR IS IN EARTH SPHERE OF INFLUENCE			SH4, 19, 20, 22, 23, 24, 25, 30
LUNAFAG FLAGWORD 3 BIT 12	LAT-LONG IS FOR MOON	LAT-LONG IS FOR EARTH	SH4, 20, 22, 24	SH4, 20, 22, 24	
KNOWNFLG FLAGWORD 6 BIT 8	LANDMARK IS KNOWN	LANDMARK IS UNKNOWN	SH6	SH6	SH7, 13
TARG2FLG FLAGWORD 1 BIT 9	SIGHTING LANDMARK	SIGHTING STAR	SH7		
TARG1FLG FLAGWORD 1 BIT 10	SIGHTING LEM	NOT SIGHTING LEM		SH7	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APR 1964 GUTHRIE AND VERA-ATINA	
DRAWN <i>P. M. Dutton</i>		P22-ORBITAL NAVIGATION	
PCBAR <i>S. G. Smith</i>	16SEP64 13-709	COLOSSUS II FC-2590 REV 1	
ANALYST			
DOCNR <i>R. P. Cantello</i>			
APPROV <i>John A. Brown</i>		REV 1 NOV 41 44	

FLAGS (CONT'D)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DIMOPFLAGWORD 3 BIT 1	W-MATRIX IS TO BE USED	W-MATRIX IS NOT TO BE USED	SH10, 18	SH11, 18	
D6OR3FLAGWORD 3 BIT 2	W-MATRIX IS 9 DIMENSIONAL FOR INTEGRATION	W-MATRIX IS 6 DIMENSIONAL FOR INTEGRATION	SH10, 18	SH11, 18	
VINTFLAGWORD 3 BIT 3	INTEGRATE CSM STATE VECTOR	INTEGRATE LEM STATE VECTOR	SH10, 18		
STATEFLAGWORD 3 BIT 5	PERMANENT STATE VECTOR TO BE UPDATED	PERMANENT STATE VECTOR NOT TO BE UPDATED	SH10, 18		
INTYFLAGWORD 3 BIT 4	CONIC INTEGRATION	ECKNE INTEGRATION		SH10, 18	
ORBWFLAGWORD 3	W-MATRIX IS VALID FOR ORBITAL NAVIGATION	W-MATRIX IS INVALID FOR ORBITAL NAVIGATION	SH15	SH39	SH11, 18
DMENFLAGWORD 5 BIT 9	W-MATRIX IS 9 DIMENSIONAL FOR INCORPORATION	W-MATRIX IS 6 DIMENSIONAL FOR INCORPORATION	SH15	SH12	SH13, 18
INCORFLAGWORD 5 BIT 11	FIRST INCORPORATION PASS	SECOND INCORPORATION PASS	SH14	SH17	SH17
VEHUFLAGWORD 1 BIT 8	CSM STATE VECTOR IS BEING UPDATED	LEM STATE VECTOR IS BEING UPDATED	SH15		
22DSPFLAGWORD BIT	DISPLAY ΔR AND ΔV	DO NOT DISPLAY ΔR AND ΔV		SH16	SH16

DISPLAYS

VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N45	FLASHING	R1 = BLANK R2 = BLANK R3 = XXX, XX DEG { MAXIMUM MIDDLE GIMBAL ANGLE	SH3
V05N70	FLASHING	R1 = BLANK R2 = XXXXX = ABCDE = LANDMARK DATA (BEFORE TAKING MARKS) R3 = BLANK	SH6
V05N71	FLASHING	R1 = BLANK R2 = XXXXX = ABCDE = LANDMARK DATA (AFTER TAKING MARKS) R3 = BLANK	SH6
V06N89	FLASHING	R1 = XX, XXX DEG - LATITUDE R2 = XX, XXX DEG - LONGITUDE R3 = XXX, XX NAUT. MI. - ALTITUDE	SH8, 21
V06N49	FLASHING	R1 = XXXX, X NAUT. MI. - STATE VECTOR POSITION CHANGE R2 = XXXX, X FT/SEC - VELOCITY CHANGE R3 = BLANK	SH16

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOELI GUIDANCE AND NAVIGATION	
DRAWN <i>DHC</i> 10SEP68		PER-ORBITAL NAVIGATION	
PREPARED BY <i>A.E.</i> 13079	ANALYST	COLOSSUS II	
DOCUMENTED BY <i>A. P. Santelli</i> 21027	APPROVED BY <i>J. A. Rose</i> 21027	FC-2590	
		SHEET 42 OF 44	

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TDEC1	t	TIME FOR INTEGRATION	SEC	CSEC	2 <sup>28</sup>
VATT	V <sub>C</sub>	CONIC VELOCITY VECTOR	METERS/SEC	METERS/SEC	2 <sup>7</sup> /2 <sup>5</sup>
RATT	R <sub>C</sub>	CONIC POSITION VECTOR		METERS	2 <sup>29</sup> /2 <sup>27</sup>
REFSMAT		BASIC REFERENCE TO STABLE MEMBER COORDINATE SYSTEM TRANSFORMATION MATRIX			2 <sup>1</sup>
* MGA		MIDDLE GIMBAL ANGLE	DEG	REV	2 <sup>1</sup>
LANDMARK		LANDMARK DATA DISPLAY NOUN		(INTEGER)	2 <sup>14</sup>
MARKINDX		REGISTER CONTAINING NUMBER OF MARKS TO BE TAKEN BY R53		(INTEGER)	2 <sup>14</sup>
MARKSTAT		ADDRESS OF MARK DATA VAC AREA		(INTEGER)	2 <sup>14</sup>
8NN	N	NUMBER OF MARKS TAKEN		(INTEGER)	2 <sup>14</sup>
S22TOFF		RETURN LOCATION FROM P22SUBRA		(INTEGER)	2 <sup>14</sup>
22SUBSCL	DE	LANDMARK COORDINATE INDICATOR		(INTEGER)	2 <sup>14</sup>
LAT		LANDMARK LATITUDE	DEG	REV	2 <sup>0</sup>
LONG		LANDMARK LONGITUDE	DEG	REV	2 <sup>0</sup>
ALT		LANDMARK ALTITUDE	NAUT. MI.	METERS	2 <sup>29</sup>
RLS		LANDING SITE COORDINATE VECTOR	NAUT. MI.	METERS	2 <sup>27</sup>
ALPIAV		TEMPORARY STORAGE VECTOR			VARIABLE
CXOFF	B	OFFSET MARK INDICATOR		(INTEGER)	2 <sup>14</sup>
LANDALT		LANDMARK ALTITUDE DISPLAY NOUN	NAUT. MI.	METERS	2 <sup>29</sup> /2 <sup>27</sup>
LANDLONG		LANDMARK LONGITUDE DISPLAY NOUN	DEG	REV	2 <sup>1</sup>
S22RTNEX		RETURN LOCATION FROM S22.1		(INTEGER)	2 <sup>14</sup>
8KK	M	NUMBER OF MARK BEING PROCESSED		(INTEGER)	2 <sup>14</sup>
S22LOC		ADDRESS OF DATA FOR Mth MARK		(INTEGER)	2 <sup>14</sup>
SVMRKDAT		BEGINNING ADDRESS OF MARK DATA SAVE AREA		(INTEGER)	2 <sup>14</sup>
S22EORM		EARTH/MOON SCALE ADJUSTING REGISTER		(INTEGER)	2 <sup>14</sup>
CSMPOS	r <sub>c</sub>	CONIC POSITION VECTOR		METERS	2 <sup>20</sup> /2 <sup>27</sup>
DELTA <sub>CSM</sub>	δ	CONIC POSITION DEVIATION		METERS	2 <sup>29</sup> /2 <sup>27</sup>
RCVCSM	r <sub>c</sub>	CONIC REFERENCE POSITION		METERS	2 <sup>29</sup> /2 <sup>27</sup>
MARKDATA		ADDRESS OF MARK ANGLES		(INTEGER)	2 <sup>14</sup>
UM	U <sub>M</sub>	LINE OF SIGHT VECTOR			VARIABLE
S22TOFF		OFFSET LANDING SITE TIME	SEC	CSEC	2 <sup>28</sup>
S22UOFF		OFFSET LANDING SITE LOS UNIT VECTOR			2 <sup>1</sup>
X789	r <sub>L</sub>	LANDMARK POSITION VECTOR		METERS	2 <sup>29</sup> /2 <sup>27</sup>
S22TRIM	t <sup>1</sup>	TIME FOR LANDMARK POSITION	SEC	CSEC	2 <sup>28</sup>
RCLP	r <sub>CL</sub>	CSM TO LANDMARK LOS		METERS	2 <sup>29</sup> /2 <sup>27</sup>
USTAR	U <sub>S</sub>	FIXTURE/STAR LINEATION UNIT VECTOR			2 <sup>1</sup>
VARIANCE	σ <sup>2</sup>	INSTRUMENT ERROR VARIANCE			2 <sup>29</sup> /2 <sup>27</sup>
BVECTOR	(b <sub>1</sub> , b <sub>2</sub> , b <sub>3</sub> )	GEOMETRY OF MEASUREMENT UNIT VECTOR			(2 <sup>1</sup> , 2 <sup>1</sup> , 2 <sup>1</sup> )
DELTA <sub>X</sub>	δr	STATE VECTOR POSITION DEVIATION		METERS	2 <sup>29</sup> /2 <sup>27</sup>
DELTA <sub>X</sub> +6	δv	STATE VECTOR VELOCITY DEVIATION	METERS/SEC	METERS/SEC	2 <sup>7</sup> /2 <sup>5</sup>
ERADM	r <sub>o</sub>	RADIUS OF EARTH/MOON		METERS	2 <sup>29</sup> /2 <sup>27</sup>
W		W-MATRIX			VARIABLE
S22RL	r <sub>L</sub>	TEMPORARY STORAGE OF LANDMARK POSITION		METERS	2 <sup>29</sup> /2 <sup>27</sup>
S22D	d	INTERMEDIATE SCALAR			2 <sup>30</sup> /2 <sup>28</sup>

MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

APPLIC  
CONTRACTS AND NAVIGATION

SPRAN *R.M. Duffin*  
PRGM *4.1.1*  
ANALST  
DCRMR *R. Cecchetti*  
APPRD *J. A. ...*

PER-ORBITAL NAVIGATION

COLOSSUS II FC-2590

REV 1

43 44

## ERASABLE LOCATIONS USED (CONT'D)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
S22UMRL	U	WORK MATRIX			VARIABLE
S22RHO	$\rho$	VARIABLE USED IN INITIALIZING $W_B$			$2^{30}/2^{26}$
S22UUT	$\theta^T$	VARIABLE USED IN INITIALIZING $W_B$			VARIABLE
9DWX		RETURN LOCATION FROM S22.1		(INTEGER)	$2^{14}$
9DWJ	J	J INDEX		(INTEGER)	$2^{28}$
9DWI	I	I INDEX		(INTEGER)	$2^{28}$
9DWP	P	P INDEX		(INTEGER)	$2^{28}$
EMATRIX	E	1ST PART OF SOLUTION MATRIX			VARIABLE
9DWN	N	N INDEX		(INTEGER)	$2^{28}$
WORKW		TEMPORARY STORAGE REGISTER			VARIABLE
XTEMP1		K INDEX		(INTEGER)	$2^{14}$

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
9DWID		DECIMAL 2	2	(INTEGER)	$2^{14}$
DECIB2		DECIMAL 1	1		$2^2$
9DW26D		DECIMAL 52	52	(INTEGER)	$2^{14}$
IMUVAR	VAR <sub>IMU</sub>	IMU ERROR VARIANCE	$.1313 \times 10^{-3} \text{ DEG}^2$	$.04 \times 10^{-6} \text{ RAD}^2$	$2^{-18}$
SCTVAR	VAR <sub>SCT</sub>	SCT ERROR VARIANCE	$.328 \times 10^{-2} \text{ DEG}^2$	$1.0 \times 10^{-6} \text{ RAD}^2$	$2^{-18}$

## PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
WORBPOS	$\omega_{ir}$	ORBITAL NAVIGATION W-MATRIX POSITION INITIALIZATION VALUE	TO BE DETERMINED	METERS	$2^{19}$	
WORBEVL	$\omega_{iv}$	ORBITAL NAVIGATION W-MATRIX VELOCITY INITIALIZATION VALUE		METERS/CSEC	$2^0$	
S22WSUBL	$\omega_l$	ORBITAL NAVIGATION W-MATRIX LANDMARK INITIALIZATION VALUE		METERS	$2^{19}$	
RPVAR	VAR <sub>RH</sub>	VARIANCE OF PRIMARY BODY RADIUS ERROR		METERS <sup>2</sup>	$2^{28}$	

MIT ESTABLISHMENT LAB CAMBRIDGE, MASS.		40-110 GUIDANCE AND NAV. AT-1-N	
DRAWN <i>D.M. [Signature]</i>		P22-ORBITAL NAVIGATION	
PROGR. <i>M.E. [Signature]</i>	57007-00	COLUSSUB II	DOCUMENT NO.
ANALYST			FC-2590
DOXMA <i>R. [Signature]</i>	29074		
APPROV. <i>John A. [Signature]</i>	2111		-NET 44 OF 44

P23 - CISELUNAR MIDCOURSE NAVIGATION  
CALLED FROM OSKY

POINTAX - COMPUTES THE CSM TO LANDMARK/HORIZON POINTING VECTOR  
HORIZ - COMPUTES HORIZON LOCATION VECTOR

SH. 13

SH. 18

SPECIAL CONVENTIONS

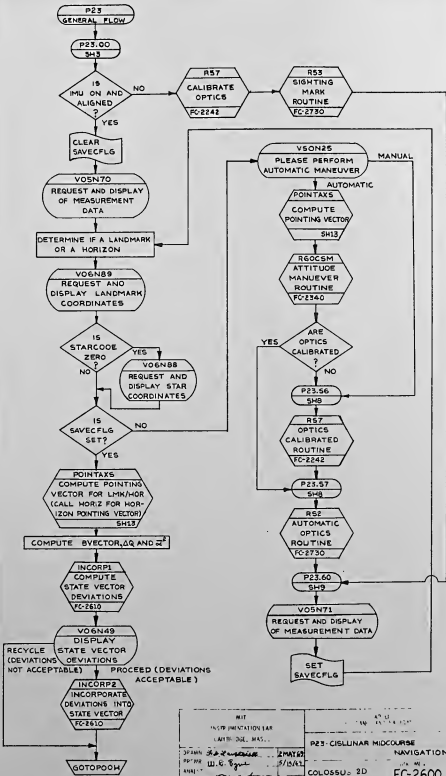
- 1) SCALING INDICATED AS  $2^x/2^y$  MEANS  $2^x$  IS THE SCALING IN EARTH SPHERE OF INFLUENCE AND  $2^y$  IS THE SCALING IN MOON SPHERE OF INFLUENCE.
- 2) \*VARIABLE\* IN THE SCALING FIELD OF THE SUMMARY SHEETS INDICATES THAT THE ERASABLE LOCATION IS EITHER A MATRIX WHOSE COMPONENTS HAVE DIFFERENT SCALING OR A TEMPORARY REGISTER WITH MANY DIFFERENT SCALINGS.
- 3) THE SYMBOL \*#\* INDICATES INDIRECT ADDRESSING,  
I.E. ABLE# X1 MEANS ABLE IS INDIRECTLY ADDRESSED BY X1. (SEE NOTE)
- 4) THE NOTATION "LANDMARK/HORIZON" IS USED WHEN THE TARGET COULD BE EITHER A LANDMARK OR A HORIZON.

NOTE: IF THE QUANTITY TO THE RIGHT OF "\*" SIGN IS X1 (OR X2), THEN THE ADDRESS IS FORMED BY SUBTRACTING X1 (OR X2) FROM THE QUANTITY ON THE LEFT OF THE "\*".

IF THE QUANTITY ON THE RIGHT OF THE "\*" SIGN IS NOT X1 (OR X2), THE READER SHOULD REFER TO THE CODING TO DETERMINE IF IT MUST BE ADDED TO OR SUBTRACTED FROM THE QUANTITY ON THE LEFT OF THE "\*" TO FORM THE ADDRESS.

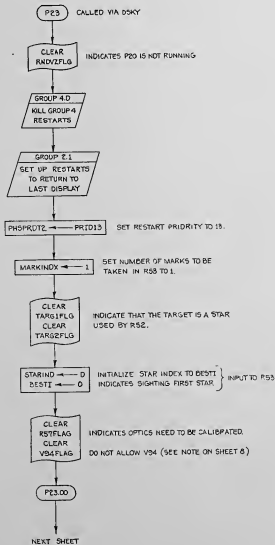
- 5) WHILE THE GENERAL MEANING OF A DISPLAY NOUN IS A 2 DIGIT NUMBER, I.E. N10, IN THIS CHART THE CELL CONTAINING THE DATA USED BY THE NOUN (VIA PINBALL) WILL BE CALLED THE DISPLAY NOUN; I.E. "LANDMARK" WILL BE CALLED A DISPLAY NOUN ALTHOUGH IT IS REALLY THE CELL CONTAINING INFORMATION USED BY "N10".

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. G. Bussack</i> <i>1/15/67</i>		P23 - Cislunar Midcourse Navigation	
PRGR <i>J. G. Bussack</i> <i>1/15/67</i>			DOCUMENT NO.
ANALYST		COLOSSUS 2D	PC-2600
DOCHR <i>J. G. Bussack</i> <i>1/15/67</i>		REV 1	SHEET 1 OF 27
APPROB <i>J. G. Bussack</i> <i>1/15/67</i>			



UNIT INSTRUMENTATION LAB LAB: DGL, BR5...		10 11 63 10 11 63
37444 J. E. S... 37444 W. E. S... 37444 M. D. S... 37444 J. A. S...	2MAY63 5/15/63 1963 21 May 63	P23 - CISLUNAR MIDCOURSE NAVIGATION COLOSSUS- 2D FC-2600 2 27





MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		PROJECT NO. 58-147-1	
DRAWN A.C. WILLIAMS		DATE	5/15/67
BY	W.E. Payne	REV	1
CHKD	<i>[Signature]</i>	DATE	5/23/67
APP'D	<i>[Signature]</i>	DATE	5/23/67
P23 - LUNAR MIDCOURSE NAVIGATION		COLLUSU. 2D	FC-2600
		REV	3 27

FROM PRECEDING SHEET

IS TMU ON AND ALIGNED ?  
15 REFSMFLG SET ?

NO - MANUALLY MANEUVER VEHICLE FOR LMK/HORIZON SIGHTING

YES  
P23.05

CLEAR SAVECFLG  
INDICATES DISPLAY AND DATA STORAGE BEFORE MARK TAKEN.

P23.06

LOAD MEASUREMENT DATA

GOLFLASH  
VOSHITO REQUEST AND DISPLAY OF MEASUREMENT DATA

TERMINATE  
GOTOPOOH

PROCEED  
P23.15

A ← LANDMARK  
LOAD LMK DISPLAY NOUN

IS THIS A STAR LMK MEASUREMENT ?  
A = 0

NO - STAR LMK

YES - STAR HORIZON  
P23.151

A ← HORIZON  
LOAD HORIZON DISPLAY NOUN

IS A = 0 ?

YES

R23.10  
Sh. 5

NO

NEXT SHEET

R57  
OPTICS CALIBRATION ROUTINE  
FC-2242

OUTPUT:  
TRUNDBIAS = TRUNNION BIAS ANGLE (SEE NOTE ON SHEET 8)

R53  
SIGHTING MARK ROUTINE  
FC-2750

INPUT: MARKINDX = NO. OF MARKS WANTED  
STARIND = 0 OR 1 = INDEX TO BEST1 OR BEST2 (1<sup>ST</sup> OR 2<sup>ND</sup> STAR SIGHTING)  
OUTPUT: MARKSTAT = ADDRESS OF MARKDATA VAC AREA

P23.60  
SH

THIS BRANCH LEADS TO THE PROCESSING OF THE MARK DATA

R1 = 0000E STAR ID NO. (STARCODE)  
R2 = ABCDE LMK DATA (LANDMARK)  
R3 = 0000D HORIZON DATA (HORIZON)

NOTE: FOR LMK  
A = NOT USED  
B = NOT USED  
C = 1 EARTH LMK  
2 MOON LMK  
DE = NOT USED  
FOR HORIZON  
C = 1 EARTH HOR  
2 MOON HOR  
DE = 1 NEAR HOP  
2 FAR HOR

R2 = 0000D FOR HORIZON MEASUREMENTS  
R3 = 0000D FOR LANDMARK MEASUREMENTS.  
ALSO, NO DATA NEED BE ENTERED AT THIS DISPLAY IF SIGHTING WILL BE DONE MANUALLY. IT WILL BE ENTERED AT DISPLAY AFTER MARK IS TAKEN. (SEE SHEET 5).

IS HORIZON = 0 ?

NO

YES  
A ← LANDMARK

MIT  
K. THOMPSON STATION 148  
CAMBRIDGE, MASS.

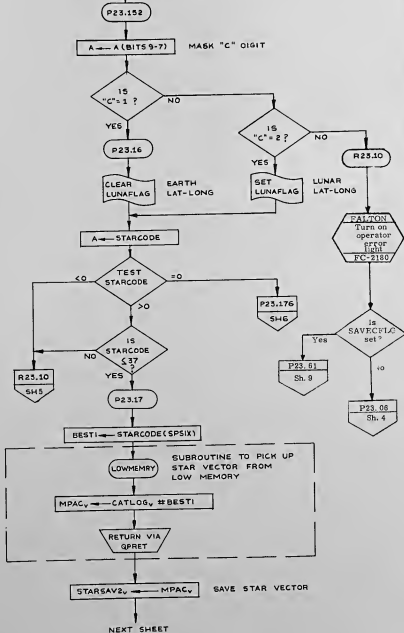
OPEN A.C. WILLIAMS (INDIVIDUAL)  
NAME W.E. Byrnes 5/16/67  
NUMBER  
ISSUED BY  
APPROVED

P23 - CISLUNAR MIDCOURSE NAVIGATION

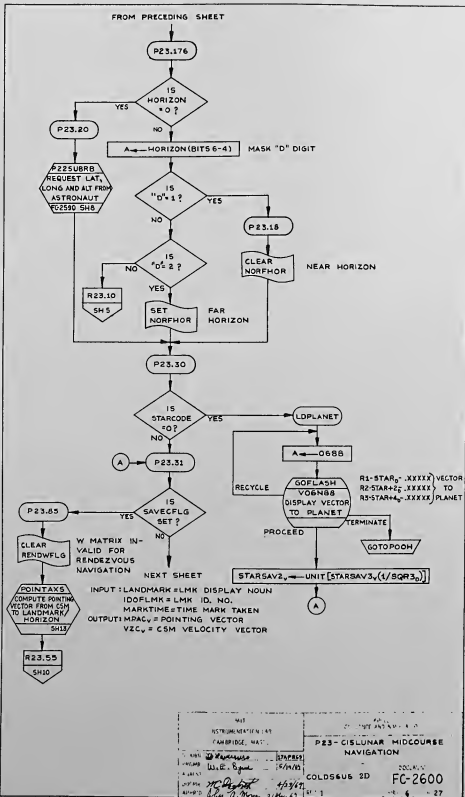
COLOSSUS 2D FC-2600

RIV 1 4 27

FROM PRECEDING SHEET

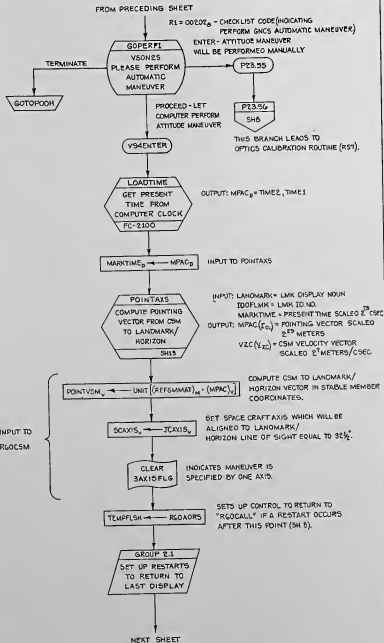


DRAWN CHECKED DESIGNED APPROVED	W. E. G. gun 15/8/51 16/2/51 21/2/51	NET INFORMATION LAB CAMBRIDGE MASS. 36APR51 15/8/51	P23-CISLUNAR MIDCOURSE NAVIGATION COLOSSUS 2D FC-2600 5 27
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WAS INSTRUMENTATION BY FAN BRIDGE, MAT. 10/24/62  
 10/24/62  
 10/24/62  
 10/24/62  
 10/24/62  
 10/24/62

P23 - CISLUNAR MIDCOURSE NAVIGATION  
 COLD56US 2D  
 FC-2600  
 4/24/67  
 10/24/62



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ENCL GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS	138NOV60	P23 - CIRCULAR MIDCOURSE NAVIGATION	
FRONT W. B. Egan	5/11/61	COLOSSUS 2D FC-2600	
ANALYST		REV 1	
DEV MS <i>W. B. Egan</i>	11/2/61	REV 1	
APPROV <i>J. H. Dyer</i>	11/2/61	REV 1	

FROM PRECEDING SHEET

R60CALL

R60CSM  
ATTITUDE  
MANEUVER  
ROUTINE  
FC-2340

INPUT: POINTVSM = DIRECTION OF ALIGNMENT  
SCAXIS = SPACECRAFT BODY VECTOR TO BE ALIGNED  
3AXISFLG = SET = 3 AXIS MANEUVER  
CLEAR = 1 AXIS MANEUVER  
OUTPUT: SCAXIS WILL BE ALIGNED TO POINTVSM

GROUP2

SET UP RESTARTS  
TO SCHEDULE NEXT  
LOCATION AS A FINDVAC  
JOB WITH SAME PRIORITY

HAVE OPTICS BEEN CALIBRATED ?

IS  
R5TFLAG  
SET  
?

YES

NO

P2356

R57  
OPTICS  
CALIBRATION  
ROUTINE  
FC-2342

OUTPUT: TRUNBIAS = TRUNNION BIAS ANGLE  
I.e. ANGLE DETERMINED WHEN SHAFT  
AND LMK LINE OF SIGHTS ARE SUPER-  
IMPOSED (NOT NECESSARILY ZERO  
BECAUSE OF UNEVEN HEATING BY SUN)

P2357

SET  
V54FLAG  
SET  
R5TFLAG

ALLOW YERD 94 TO BE ENTERED WHILE IN R52 (R53).  
NOTE: IF THE ASTRONAUT WISHES TO RECYCLE AND REMANEUVER THE VEHICLE,  
HE WILL ENTER V54 BEFORE ACCEPTING THE MARK (VIA R53) AND THE  
PROGRAM RETURNS TO "V45CENTER" (S16.7).  
INDICATES THAT OPTICS HAVE BEEN CALIBRATED.

R52  
AUTOMATIC  
OPTICS  
ROUTINE  
FC-2730

INPUT: STARSVE = STAR VECTOR  
OPTICS DRIVEN AUTOMATICALLY TO SIGHT  
ON GIVEN STAR.  
OUTPUT: MARKSTAT = ADDRESS OF MARK DATA TAKEN IN R53  
NOTE: R52 WILL CONTINUE TO POINT SXT LOS AT THE GIVEN  
STAR UNTIL THE OPTICS SWITCH IS PLACED IN MANUAL  
(FROM AUTOMATIC) WHICH AUTOMATICALLY CALLS  
R53 TO TAKE MARKS.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	
DESIGNED BY SPARK A C WILLIAMS	DATE 5/20/68
PROGRAMMER W. E. B. Jones	REVISED 5/20/68
ANALYST	APPROVED 4/21/69
DOCUMENTED J. B. Jones	DATE 24 May 68
APPROVED	REV. 1

RAND CORPORATION AUGUST 1968	
PES-CISLUNAR WINDOWOURSE NAVIGATION	
COLLOSSUS 2D	FC-2600
8	27

FROM PRECEDING SHEET

CLEAR  
V94FLAG  
CLEAR  
R87FLAG

DO NOT ALLOW V94 TO BE ENTERED  
AFTER THIS POINT.  
INDICATES THAT THE OPTICS SHOULD BE  
RECALIBRATED IF ANOTHER MARK IS TO BE TAKEN.

P23.60

INHIBIT  
INTER-  
RUPTS

MARKDATA ← MARKSTAT (BITS 10 TO 1)

GET ADDRESS OF MARK  
DATA TAKEN BY R53

MARKSTAT LOCATIONS  
0,1 = TIME  
2,4,6 = IMU ANGLES  
5 = TRUNNION ANGLE  
3 = SHAFT ANGLE

MARKTIME ← O<sub>2</sub> # MARKDATA

GET TIME OF MARK

TRUNION ← O<sub>5</sub> # MARKDATA

GET TRUNNION ANGLE

RELEASE  
INTER-  
RUPTS

MARKDOWN ← MARKDATA  
MARKDOWN+6 ← MARKDATA+6

P23.61

LOAD  
MEASUREMENT  
DATA

GOFASH  
V0GNT1  
REQUEST AND  
OASPLAY OF  
MEASUREMENT DATA

TERMINATE

R1 = 000DE STAR ID  
R2 = ABC0E LMK ID  
R3 = 00C0D HOR ID

SEE NOTE ON SHEET 4  
FOR CODES.

GOTOPODH

PROCEED

P23.65

SET  
SAVECFLG

INDICATES THAT MARK HAS BEEN TAKEN AND IT SHOULD  
BE INCORPORATED INTO STATE VECTOR AFTER ABOVE  
MEASUREMENT DATA IS PROCESSED.

P23.15  
SHA

THIS BRANCH LEADS TO  
PROCESSING OF ABOVE  
MEASUREMENT DATA.

DATE	13NOV60
BY	A. C. WILLIAMS
CHKD BY	U. E. Dyer
APPROVED	<i>[Signature]</i>
REVISION	5/11/75

P23 - Cislunar Midcourse Navigation

COLOSSUS 2D

FC-2600

REISS

$$\begin{aligned} U_{CL} &= \text{UNIT}(F_{CL}) \\ \text{POL0}_v &\leftarrow \text{UNIT}(MPAC)_v \end{aligned}$$

COMPUTE UNIT POINTING VECTOR FROM CSM TO LANDMARK/HORIZON.  
GSOP EQU. 2.6.2

$$\begin{aligned} \text{POL30} &= \frac{r_{CL}}{r_{CL}} \\ \text{POL32} &= \frac{r_{CL}}{r_{CL}} \\ \text{POL30}_v &\leftarrow \text{POL34}_v \end{aligned}$$

SAVE  $r_{CL}^2$  FOR USE IN COMPUTING THE VARIANCE,  $\sigma^2$ .  
NOTE:  $r_{CL}^2$  (AND  $|F_{CL}|$  IN POL.32) ARE FORMED BY THE ABOVE UNIT INSTRUCTION.

$$\begin{aligned} U_{CL}^* &= \text{UNIT}(U_{CL} + V_{CL}/c) \\ \text{UCLSTAR}_v &\leftarrow \text{UNIT}(\text{POL0}_v + (V_{CL})_v \text{ (ONE/C)}) \end{aligned}$$

CORRECT POINTING VECTOR FOR ABERRATION.  
GSOP EQU. 2.6.4

$$\begin{aligned} U_{S}^* &= \text{UNIT}(U_S + (V_S - V_{S1})/c) \\ \text{USSTAR}_v &\leftarrow \text{UNIT}(U_{S^*}_v + [(V_{S^*} - V_{S1})_v \text{ (ONE/C)}]) \end{aligned}$$

CORRECT STAR VECTOR FOR ABERRATION.  
GSOP EQU. 2.6.3  
 $V_{S1}$  = VELOCITY OF SUN RELATIVE TO THE EARTH.

$$\begin{aligned} \text{COSQ} &= U_{S^*} \cdot U_{CL}^* \\ \text{POL0}_b &\leftarrow \text{USSTAR}_v \cdot \text{UCLSTAR}_v \end{aligned}$$

COMPUTE COSINE OF ESTIMATED ANGLE BETWEEN STAR AND POINTING VECTOR.  
GSOP EQU. 2.6.21

$$\begin{aligned} b_2 &= \text{UNIT}(U_{S^*} - \text{COSQ} \cdot U_{CL}^*) \\ \text{BVECTOR}_v &\leftarrow \text{UNIT}(\text{USSTAR}_v - (\text{POL0}_b \cdot \text{UCLSTAR}_v)_v) \end{aligned}$$

COMPUTE GEOMETRY OF MEASUREMENT VECTOR  $(R_0, b_1, b_2)$ .  
GSOP EQU. 2.6.21

$$\begin{aligned} b_1 &= 0 \\ b_2 &= 0 \\ (\text{BVECTOR} + b_1)_v &\leftarrow \text{ZEROVECS}_v \\ (\text{BVECTOR} + b_2)_v &\leftarrow \text{ZEROVECS}_v \end{aligned}$$

$$\begin{aligned} \text{POL2} &= -\cos^{-1}(\text{COSQ}) \\ \text{POL2}_b &\leftarrow -\text{ARCOS}(\text{POL0}_b) \end{aligned}$$

SAVE STAR TO POINTING VECTOR ANGLE

$$\begin{aligned} \text{MPAC}_b &\leftarrow \text{ZEROVECS}_b \\ \text{MPAC} &\leftarrow \text{TRUNION} - \text{VARSUBL} \\ \text{POLA}_b &\leftarrow \text{MPAC}_b \end{aligned}$$

CLEAR MPAC.  
CONVERT TRUNION ANGLE FROM 1'S TO 2'S COMPLEMENT.  
(BY SPECIAL SUBTRACT INSTRUCTION)  
STORE TRUNION ANGLE FOR LATER USE.

NOTE: VARSUBL IS DEFINED TO BE 3 WORDS, THE FIRST WORD OF WHICH IS ZERO.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AP-111 CALCULUS AND OBSERVATION	
DESIGNER: A.C. THILLEMANS	DATE: 11/20/65	PES-CISLAMP MICROCURSE NAVIGATION	
APPROVED: W.C. S. [Signature]	DATE: 5/11/65	COLOSSUS 21D	FC-2600
APPROVED: J.C. [Signature]	DATE: 4/23/65	REV 1	10 27



FROM PRECEDING SHEET

$$MPAC = \left[ (A - TRUNION_{BLAS}) \cdot \cos^{-1}(\cos \Omega) + 19.77 \right] (r_{CL})$$

COMPUTE MEASUREMENT DEVIATION  
GSOIP EQU. 2.6.21

$$MPAC_D \leftarrow \left( (PDLA_D - TRUNVAR_D)_Y + PDLZ_D + TRUNIS \right) \cdot PDLB_D \cdot (PI/4.0)_D$$

IS MOON SPHERE OF INFLUENCE?  
CMOONFLG SET

NO

YES

ADJUST SCALING

MPAC SCALED 2<sup>27</sup> METERS FROM 2<sup>25</sup> METERS IF IN MOON SPHERE OF INFLUENCE.

REC.51

$\Delta Q = MPAC$

DELTAAQ  $\leftarrow MPAC_D$

DEVIATION BETWEEN MEASURED ANGLE AND ESTIMATED ANGLE.

$$\frac{\sigma^2}{\Delta Q} = r_{CL}^2 \cdot VAR_{TRUN} + VAR_{CL}$$

VARIANCE OF MEASUREMENT ERRORS  
GSOIP EQU. 2.6.22

$$VARIANCE_T \leftarrow (PDL30_D - TRUNVAR_D)_Y + VAR_{SUBL}_T$$

CLEAR DIMENFLG

INDICATES W-MATRIX IS 6x6 FOR INCORPORATION

INCRP1

COMPUTE STATE VECTOR DEVIATIONS

$\Delta X = (\Delta \delta, \Delta V)$

FC=26.10

INPUT: VARIANCE ( $\sigma^2$ ) = MEASUREMENT OF ERROR VARIANCE SCALED 2<sup>25</sup> METERS<sup>2</sup>

DELTAAQ ( $\Delta Q$ ) = MEASUREMENT DEVIATION SCALED 2<sup>29</sup> METERS

BVECTOR = MEASUREMENT GEOMETRY VECTOR

DIMENFLG = DIMENSION OF W-MATRIX

OUTPUT: DELTAX = STATE VECTOR DEVIATIONS

GRUPE2

SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINDVAC JOB WITH SAME PRIORITY

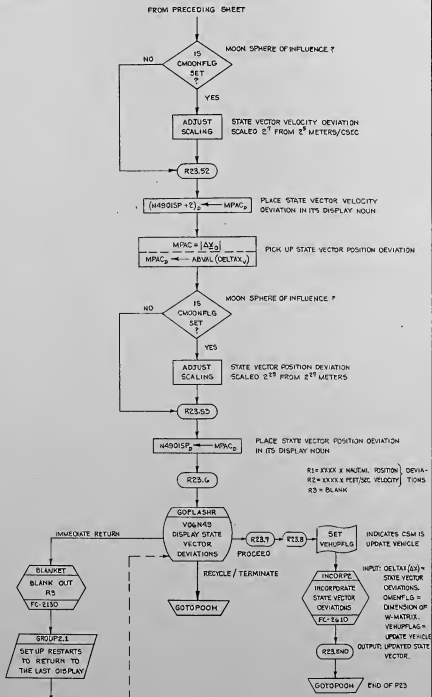
$MPAC = |\Delta X_1|$

MPAC\_D  $\leftarrow ABVAL(DELTA X + \omega)_V$

PICK UP STATE VECTOR VELOCITY DEVIATION

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		BASED ON GUIDANCE AND NAVIGATION	
DRYAN A.C. WILLIAMS	11/19/60	P29 - CELESTIAL MIDCOURSE NAVIGATION	
PR. MR. W. E. BYRNE	5/19/61	COLLOSSUS 2D	FC-2600
ANALYST			
DEV. MR. <i>W.C. ...</i>	1/25/61		
APPROV. <i>L.H. ...</i>	2/24/61	REV 1	REV 11



MIT  
 177 MASSACHUSETTS AVE  
 CAMBRIDGE, MASS.

484 0  
 011-260-1 AND 344-2271

5/11/67  
 5/11/67  
 26/5/67

P23-CISLUNAR MIDCOURSE NAVIGATION

COL0556 2D FC-2600

12 27

SUBROUTINE WHICH COMPUTES THE CSM TO  
LANDMARK/HORIZON POINTING VECTOR

INPUT: LANDMARK = LMK DISPLAY NOUN  
MARKTIME = TIME MARK TAKEN  
OUTPUT: POLO = MPAC(LC) = POINTING VECTOR  
          SCALED  $2^{29}$  METERS  
VZC(V<sub>ZC</sub>) = CSM VELOCITY VECTOR  
          SCALE  $2^7$  METERS/CSEC



SAVE RETURN

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		U. S. NAVY	
COPYED BY <i>J. R. Stone</i> 2 MAY 68		P25 CISELUNAR MIDCOURSE NAVIGATION	
PREPARED BY <i>W. R. D. Jones</i>	DATE <i>5/1/65</i>	DOC. NO. 13	
APPROVED BY <i>J. R. Stone</i>	DATE <i>2 May 68</i>	COLOSSUS 2D :	FC-2600
APPROVED BY <i>J. R. Stone</i>	DATE <i>2 May 68</i>	REV 1	REV 13

FROM PRECEDING SHEET



PLOD<sub>2</sub> ← WMIDPOS<sub>2</sub>

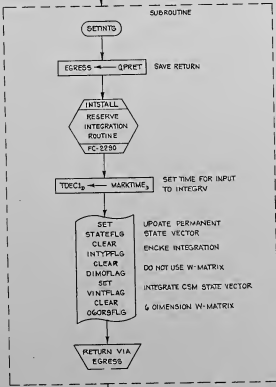
PLACE PLOD LOADED W-MATRIX POSITION (w\_mv) AND VELOCITY (w\_v) INITIALIZATION ELEMENTS IN THE PUSHLIST FOR INPUT TO INITIALW



INPUT: PLOD(WMIDPOS) = W-MATRIX POSITION INITIALIZATION VALUE  
 PLOD(WMIDVEL) = W-MATRIX VELOCITY INITIALIZATION VALUE  
 OUTPUT: INITIALIZED W-MATRIX

$$\begin{bmatrix} W_0 & W_1 \\ W_3 & W_6 \end{bmatrix} = \begin{bmatrix} w_{mv} & 0 & 0 & 0 & 0 & 0 \\ 0 & w_{mv} & 0 & 0 & 0 & 0 \\ 0 & 0 & w_{vr} & 0 & 0 & 0 \\ 0 & 0 & 0 & w_{vr} & 0 & 0 \\ 0 & 0 & 0 & 0 & w_{mv} & 0 \\ 0 & 0 & 0 & 0 & 0 & w_{mv} \end{bmatrix}$$

RES.1



SUBROUTINE

SETINTG

EGRESS ← QPRET

SAVE RETURN



RESERVE INTEGRATION ROUTINE

TDEC1 ← MARKTIME

SET TIME FOR INPUT TO INTEGRV

SET STATEFLG  
 CLEAR INTYPELG  
 CLEAR DIMOFLAG  
 SET VINTFLAG  
 CLEAR OGORS/LG

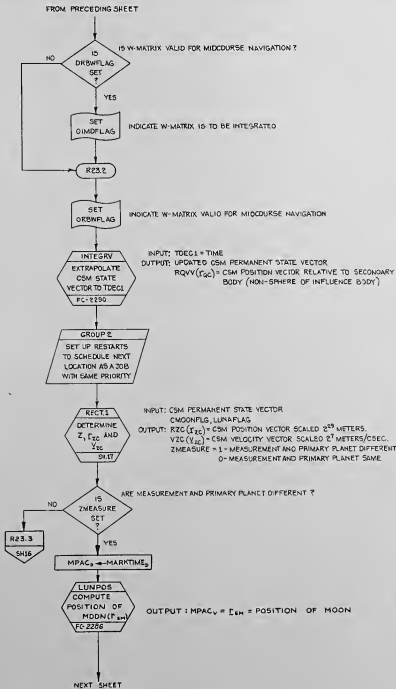
UPDATE PERMANENT STATE VECTOR  
 ENCKE INTEGRATION  
 DO NOT USE W-MATRIX  
 INTEGRATE CSM STATE VECTOR  
 6 DIMENSION W-MATRIX

RETURN VIA EGRESS

NEXT SHEET

MIL INSTRUMENTATION LAB  
 CAMBRIDGE, MASS.  
 DRAWN A.C. WILLIAMS  
 CHECKED W.E. B. JUNE  
 ANALYST  
 DOCNO  
 APP'D  
 25MAY68  
 4/13/68  
 2/13/68

GUIDANCE AND NAVIGATION  
 FC-2600  
 COLLOSSUS 2D  
 REV 1  
 14 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		RPHLO GPOCANY, AND, SA, II, ET, AL.	
BY: A.C. WILLIAMS	3508US	PSS - DEFLUNAR MIDCOURSE NAVIGATION	
DATE: 4. E. Byers	5/19/67	COLDDBSUS 2D	
APPROVED: <i>W. E. Byers</i>	212/67 65	FC-2600	
REV 1		25 27	

FROM PRECEDING SHEET

IS  
CMOONFLG  
SET ?

NO

YES

$\Gamma_{eq} = \Gamma_{EM}$   
 $MPAC_V \leftarrow -MPAC$

GSOP EQU. 2.2.19

$\Gamma_{ec} = -\Gamma_{EM} + \Gamma_{c}'$   
 $MPAC_V \leftarrow MPAC_V + RZC_V$

GSOP EQU. 2.2.20

$\Gamma_{ec} = \Gamma_{ec}$   
 $RZC_V \leftarrow MPAC_V$

GSOP EQU. 2.6.1

R23.3

IS THIS A STAR HORIZON MEASUREMENT?

LANDMARK  
= 0 ?

YES

NO - STAR LMK

SET  
ERRADFLAG  
MOON: USE  
FIXED RADIUS  
EARTH: COM-  
PUTE RADIUS

$MPAC_0 \leftarrow MARKTIME_0$

TIME  
INPUT TO  
LATOTRV

LALOTRV  
CONVERT LAT,  
LONG, ALT TO  
RADIUS VECTOR  
FG-2280

INPUT: LAT=LATITUDE  
LONG=LONGITUDE  
ALT = ALTITUDE  
MPAC=TIME  
ERRADFLAG, LUNA-  
FLAG  
OUTPUT: MPAC( $r_e$ )=  
LANDMARK LOCA-  
TION VECTOR

HORIZ  
COMPUTE HOR-  
IZON LOCATION  
VECTOR  
SHIB

INPUT: RZC ( $r_{ec}$ )  
= CSM POSITION VECTOR  
US ( $U_s$ ) = STAR VECTOR  
NORFHOR, LUNAFLAG  
OUTPUT: MPAC ( $r_e$ ) = HORIZON  
LOCATION VECTOR

R23.5

$\Gamma_{cl} = r_e - \Gamma_{ec}$   
 $MPAC_V \leftarrow MPAC_V - RZC_V$

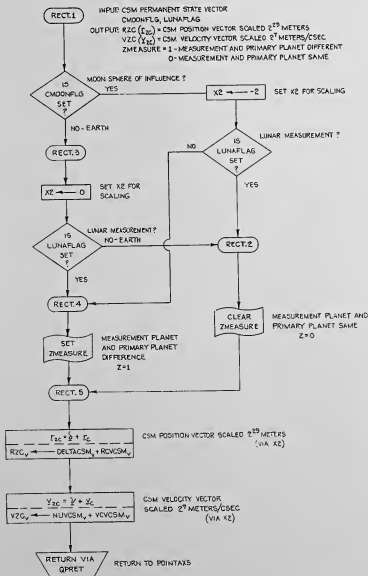
COMPUTE ESTIMATED POINTING VECTOR  
GSOP EQU. 2.6.2.

RETURN VIA  
POINTEX

RETURN TO P23

MIT HYPERINTEGRATION LAB AMBRIDGE, MASS.		ADP-111 2 JAN 1968 10 217	
14414 J.D. Berman		SMAYAS	
14748 B.L.R. Bryant		5/1/62	
448187		COLOSSUS 2D FC-2600	
148187		11/1/67	
148187 J.D. Berman 2/1/68 #1		REV 1 116 27	

SUBROUTINE TO COMPUTE Z,  $\vec{r}_{zc}$  AND  $\vec{v}_{zc}$



DATE: \_\_\_\_\_  
 INFORMATION ON: \_\_\_\_\_  
 AIRFIELD: \_\_\_\_\_  
 DRAWN: A.C. WILLIAMS  
 PROGRAM: WSR, Bym  
 ANA: \_\_\_\_\_  
 DESIGNED BY: *W. R. Bym*  
 APPROVED BY: *W. R. Bym*

ISSUES: 5/1/61  
 2/21/67  
 2/21/65

PEB-CISLUNAR MIDCOURSE NAVIGATION  
 GOLDSCHEID 2D FC-2600  
 1 IT 27

SUBROUTINE WHICH COMPUTES HORIZON LOCATION VECTOR

INPUT:  $RZC(\underline{r}_{RC}) =$  CSM POSITION VECTOR RELATIVE TO MEASUREMENT PLANET  
 SCALED  $2^{29}$  METERS.  
 $US(\underline{u}_S) =$  STAR UNIT VECTOR  
 $LUNAFLAG, INORPHOR$   
 OUTPUT:  $MPAC(\underline{r}_E) =$  HORIZON LOCATION VECTOR SCALED  $2^{29}$  METERS.

HORIZ

SAVE RETURN ← QPRET

$PDL0_y \leftarrow -AY0_y$   
 $PDL2_y \leftarrow AX0_y$   
 $PDL4_y \leftarrow DPPOS/AX0_y$

DEFINE  $\underline{u}_2 = \begin{pmatrix} -A_y \\ A_x \end{pmatrix}$

WHERE  
 $A_y =$  EARTH NUTATION ANGLE  
 $A_x =$  EARTH PRECESSION ANGLE

$\underline{u}_0 = \text{UNIT}(\underline{u}_0 \times \underline{r}_{RC})$   
 $UBAR2_y \leftarrow \text{UNIT}(US_y \times RZC_y)$

GSOP EQU 2.6.6  
 DEFINE ORTHOGONNAL  
 COORDINATE SYSTEM  
 WITH:

$\underline{u}_0$  ALONG SEMI MAJOR  
 AXIS OF HORIZON ELLIPSE.  
 $\underline{u}_1$  ALONG SEMI MINOR  
 AXIS OF HORIZON ELLIPSE.  
 $\underline{u}_2$  PERPENDICULAR TO  
 HORIZON ELLIPSE.

NOTE:

THE HORIZON ELLIPSE IS THE  
 INTERSECTION OF THE PLANE  
 DEFINED BY THE STAR UNIT  
 VECTOR,  $US_y$  AND THE CSM  
 POSITION VECTOR,  $\underline{r}_{RC}$ , WITH  
 THE HORIZON OF THE EARTH  
 (MOON).

$\underline{u}_0 = \text{UNIT}(\underline{u}_0 \times \underline{u}_2)$   
 $UBAR2_y \leftarrow \text{UNIT}(PDL0_y \times UBAR2_y)$

$\underline{u}_1 = \underline{u}_2 \times \underline{u}_0$   
 $UBAR1_y \leftarrow \text{UNIT}(UBAR2_y \times UBAR2_y)$

MOON HORIZON ?  
 IS LUNAFLAG SET ?

YES

HORIZ.6

$b_M = r_{EM}$   
 $PDL0_y \leftarrow \text{RADMOON}_y$

GSOP EQU 2.6.20  
 SET SEMI MINOR  
 AND SEMI MAJOR  
 AXES OF HORIZON  
 ELLIPSE TO MOON  
 RADIUS.

$a_M = r_{EM}$   
 $PDL2_y \leftarrow \text{RADMOON}_y$

L IS THE INCLINATION  
 ANGLE OF THE HORIZON  
 ELLIPSE WITH RESPECT  
 TO THE EQUATORIAL  
 PLANE OF THE EARTH.

$\text{SIN } L = \underline{u}_1 \cdot \underline{u}_2$   
 $\text{ALPHA} + 4 \leftarrow \text{UBAR1}_y \cdot \text{PDL0}_y$

GSOP EQU 2.6.8

GETERA0  
 COMPUTE  
 EARTH  
 RADIUS  
 FC-2280

INPUT: ALPHA + 4 (SIN L)  
 = SINE OF LATITUDE  
 SCALED 2<sup>1</sup>  
 OUTPUT: MPAC = ERAIM  
 = RADIUS OF EARTH  
 SCALED 2<sup>29</sup> METERS

$b_H = r_E + h$   
 $PDL2_y \leftarrow \text{MPAC}_y + \text{HORIZALT}_y$

DETERMINE SEMI MINOR AXIS  
 OF HORIZON ELLIPSE  
 GSOP EQU 2.6.9

$a_H = a + h$   
 $PDL0_y \leftarrow \text{AEARTH}_y + \text{HORIZALT}_y$

DETERMINE SEMI MAJOR AXIS  
 OF HORIZON ELLIPSE  
 GSOP EQU 2.6.10

HORIZ.1

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	
DRAWN A.C. WILLIAMS PROF. W.E. 8 June 54/62	SCALED
ANALYST CHECKED BY <i>[Signature]</i>	DATE 2/10/65
APPROVED <i>[Signature]</i>	DATE 2/10/65

GUIDE	REV. 1.1
PES-CESLINAR MIDCOURSE NAVIGATION	
COLLUSUS 2D	FC-2600
REV. 1.1	DATE 10 65



FROM PRECEDING SHEET

$$\vec{r}_H = M \vec{r}_{15}$$

$$\text{PDL4}_D \leftarrow (\text{UBARO}_D)(RZC_D)$$

TRANSFORM POINTING VECTOR TO THE HORIZON COORDINATE SYSTEM. GSOP EQU. 2.6.12

$$\vec{u}_{SH} = M \vec{u}_S$$

$$\text{PDL10}_D \leftarrow (\text{UBARO}_D)(\vec{u}_S)$$

TRANSFORM STAR VECTOR TO THE HORIZON COORDINATE SYSTEM. GSOP EQU. 2.6.12

NOTE:

$$M = \begin{pmatrix} T \\ V_0 \\ V_1 \\ V_2 \end{pmatrix}$$

$$\text{PDL34}_D \leftarrow \text{PDL2}_D$$

$$\text{MPAC}_D \leftarrow \text{PDL4}_D$$

PICK UP  $\Delta_H$   
PICK UP  $X_H$

DIVIDE

$$\text{MPAC}_D = \frac{\text{MPAC}_D}{\text{PDL34}_D}$$

FORM  $\frac{X_H}{\Delta_H}$

SHZ2

$$\text{POL30}_D \leftarrow \text{MPAC}_D - \text{MPAC}_D$$

FORM  $\frac{Y_H^2}{\Delta_H^2}$

$$\text{PDL34}_D \leftarrow \text{POL0}_D$$

$$\text{MPAC}_D \leftarrow \text{POL6}_D$$

PICK UP  $b_H$   
PICK UP  $Y_H$

DIVIDE

$$\text{MPAC}_D = \frac{\text{MPAC}_D}{\text{PDL34}_D}$$

FORM  $\frac{Y_H}{b_H}$

SHZ2

$$A = \frac{X_H^2}{\Delta_H^2} + \frac{Y_H^2}{b_H^2}$$

$$\text{PDL16}_D \leftarrow \text{POL30}_D + \text{MPAC}_D - \text{MPAC}_D$$

GSOP EQU. 2.6.17

$$\text{PDL15}_D = \sqrt{A - 1}$$

$$\text{PDL15}_D \leftarrow \text{SQRT}(\text{PDL16}_D - 1.0815)$$

$$\text{PDL34}_D \leftarrow \text{PDL16}_D$$

$$\text{MPAC}_D \leftarrow \text{PDL4}_D$$

PICK UP  $X_H$   
PICK UP A

NEXT SHEET

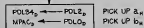
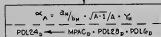
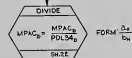
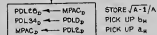
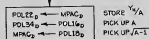
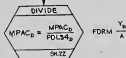
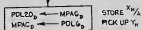
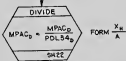
REVISION 18  
DATE 04/18/64  
BY A.C. WILLIAMS  
CHECKED BY E. Byrne  
DATE 04/18/64  
DRAWN BY J. G. ...  
DATE 04/18/64

PER-CISLUNAR COURSE NAVIGATION  
POL 3553. 2D  
FC-260J

FC-260J

11 19 67

FROM PRECEDING SHEET



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	
SPARR A. E. WILLIAMS	26 NOV 60
PREPARED BY	W. C. Bywater
ANALYST	P/S/1/60
APPROVED BY	<i>John D. Brown</i>
DATE	6/23/67

PES - CIRCULAR MIDCOURSE NAVIGATION	
COLLOSSUS: 2D	FC-2600
DATE	NOV 20 1967

FROM PRECEDING SHEET

DIVIDE

$$\frac{MPAC_D}{FDL34_D} = \frac{MPAC_D}{FDL34_D} \cdot \frac{FORM \frac{b_H}{a_H}}{FORM \frac{b_H}{a_H}}$$

$$\frac{\beta/A}{PDL26_D} \leftarrow \frac{b_H/\beta_H \cdot \sqrt{A \cdot I} / A \cdot X_H}{MPAC_D \cdot PDL20_D \cdot POL4_D}$$

$$\frac{t_{01} = X_H/A + \alpha/A}{PDL28_D} \leftarrow \frac{X_H/A + \alpha/A}{PDL20_D + PDL24_D}$$

GSOP EQU. 2.6.15

$$\frac{t_{02} = Y_H/A - \beta/A}{PDL30_D} \leftarrow \frac{Y_H/A - \beta/A}{PDL20_D - PDL24_D}$$

$$\frac{t_{11} = X_H/A - \alpha/A}{PDL16_D} \leftarrow \frac{X_H/A - \alpha/A}{PDL20_D - PDL24_D}$$

GSOP EQU 2.6.16

$$\frac{t_{12} = Y_H/A - \beta/A}{PDL10_D} \leftarrow \frac{Y_H/A - \beta/A}{PDL20_D + PDL26_D}$$

$$\frac{t_{13} = 0}{PDL20_D} \leftarrow \frac{0}{ZEROVECS_D}$$

$$\frac{t_{03} = 0}{PDL30_D} \leftarrow \frac{0}{ZEROVECS_D}$$

$$\frac{A_2 = V_{0H} \cdot UNIT(t_{10} - t_{14})}{PDL22_D} \leftarrow \frac{V_{0H} \cdot UNIT(t_{10} - t_{14})}{POL10_D \cdot UNIT(PDL20_D - POL4_D)}$$

GSOP EQU 2.6.18

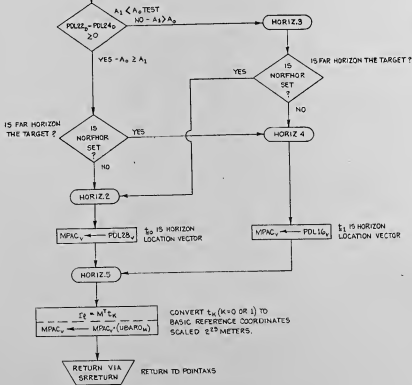
$$\frac{A_1 = V_{0H} \cdot UNIT(t_{11} - t_{14})}{PDL24_D} \leftarrow \frac{V_{0H} \cdot UNIT(t_{11} - t_{14})}{POL10_D \cdot UNIT(PDL30_D - POL4_D)}$$

NEXT SHEET

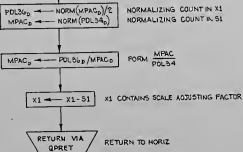
PHI  
 14-018147470743  
 AMERICAN  
 A.C. WILLIAMS  
 W.G. Brown  
 10/24/72  
 2/28/73

RES-CISLUNAR MITCOURSE NAVIGATION  
 COLOSSUS 2D FC-2600

FROM PRECEDING SHEET



DIVIDE



MIT AMNH, WASH. D.C. AMNH, WASH. D.C.	RES-CISLUNAR MIDCOURSE NAVIGATION
LEAHY, A. G. WILLIAMS	270000
TRIGER, W. G. B.	5/1/65
ANALYST	COLLOSSUM: 2D
ENGINEER	FC-2600
APPROVED	12/1/65

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
R57	2242	OPTICS CALIBRATION ROUTINE	SH 4, 8
FALTON	2180	TURN ON OPERATOR ERROR LIGHT	SH 4
R53	2730	SIGHTING MARK ROUTINE	SH 4
P22SUBRB	2500	REQUEST LAT, LONG AND ALT FROM ASTRONAUT	SH 6
LOADTIME	2100	GET PRESENT TIME FROM COMPUTER CLOCK	SH 7
R60CSM	2340	ATTITUDE MANEUVER ROUTINE	SH 8
R52	2730	AUTOMATIC OPTICS ROUTINE	SH 8
INCORP1	2610	COMPUTE STATE VECTOR DEVIATIONS	SH 11
INCORP2	2610	INCORPORATE STATE VECTOR DEVIATIONS	SH 12
BLANKET	2130	BLANK OUT CERTAIN DISPLAY REGISTERS	SH 12
INTSTALL	2290	RESERVE INTEGRATION ROUTINE	SH 14
INTEGRV	2290	EXTRAPOLATE CSM STATE VECTOR TO DTECI	SH 15
L1NPOS	2266	COMPUTE POSITION OF MOON	SH 15
LALOTORV	2280	CONVERT LAT. LONG. ALT TO RADIUS VECTOR	SH 16
GETERAD	2280	COMPUTE EARTH RADIUS	SH 16

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
RNDVZFLG FLAGWORD 0 BIT 7	P20 IS RUNNING	P20 IS NOT RUNNING		SH 3	
TARG1FLG FLAGWORD 1 BIT 10	SIGHTING ON LEM	NOT SIGHTING ON LEM		SH 3	
TARG2FLG FLAGWORD 1 BIT 9	SIGHTING LANDMARK	SIGHTING STAR		SH 3	
R57FLG FLAGWORD 6 BIT 8	DO NOT DO R57. TRUNNION BIAS HAS BEEN OBTAINED	DO R57. TRUNNION BIAS NEEDED	SH 8	SH 3, 9	SH 8
V94FLG FLAGWORD 9 BIT 11	V94 ALLOWED DURING P23	V94 NOT ALLOWED DURING P23	SH 8	SH 3, 9	
REFSMFLG FLAGWORD 3 BIT 13	IMU ON AND ALIGNED	IMU NOT ALIGNED			SH 4
SAVECFGL FLAGWORD 9 BIT 10	P23 DISPLAY AND DATA STORAGE AFTER MARK IS TAKEN	P23 DISPLAY AND DATA STORAGE BEFORE MARK IS TAKEN	SH 9	SH 4	SH 5 6
L1NAFLG FLAGWORD 3 BIT 12	LUNAR LAT-LONG	EARTH LAT-LONG	SH 5	SH 5	SH 17 18
NORPHOR FLAGWORD 0 BIT 11	SIGHTING ON FAR HORIZON	SIGHTING ON NEAR HORIZON	SH 6	SH 6	SH 22
RENDFWFLG FLAGWORD 5 BIT 1	W - MATRIX VALID FOR RENDEZVOUS NAVIGATION	W - MATRIX INVALID FOR RENDEZVOUS NAVIGATION		SH 6	
3AXISFLG FLAGWORD 5 BIT 6	MANEUVER SPECIFIED BY 3 AXES	MANEUVER SPECIFIED BY 1 AXIS		SH 7	

MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

APPLIED  
GUIDANCE AND NAVIGATION

P23 - Cislunar  
MIDCOURSE NAVIGATION

DRAWN *G. J. Farrell* *3/1/62*  
 PRGMR *A. S. B. Jones*  
 ANLST  
 DOCMR *J. P. DeGroot* *4/15/62*  
 APPR'D *John F. Moore* *2/10/62*

COLOSSUS 2D

DOCUMENT NO.

FC-2600

REV 1

SHEET 23 OF 27

FLAGS (CONTINUED)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
CMOONFLG FLAGWORD 8 BIT 12	PERMANENT CSM STATE VECTOR IN LUNAR SPHERE	PERMANENT CSM STATE VECTOR IN EARTH SPHERE			SH 11, 12, 17
DMENFLG FLAGWORD 5 BIT 9	DIMENSION OF W-MATRIX IS 9 FOR INCORPORATION	DIMENSION OF W-MATRIX IS 6 FOR INCORPORATION		SH 11	
VEHUFFLG FLAGWORD 1 BIT 8	CSM STATE VECTOR IS BEING UPDATED	LEM STATE VECTOR IS BEING UPDATED	SH 12		
ORBWFLAG FLAGWORD 3 BIT 6	W - MATRIX VALID FOR MIDCOURSE NAVIGATION	W - MATRIX INVALID FOR MIDCOURSE NAVIGATION	SH 15		SH 14, 15
STATEFLG FLAGWORD 3 BIT 5	PERMANENT STATE VECTOR TO BE UPDATED	PERMANENT STATE VECTOR NOT TO BE UPDATED	SH 14		
INTYFFLG FLAGWORD 3 BIT 4	CONIC INTEGRATION	ENCKE INTEGRATION		SH 14	
DMOFLAG FLAGWORD 3 BIT 1	W - MATRIX IS TO BE USED	W - MATRIX NOT TO BE USED	SH 15	SH 14	
VINTFLAG FLAGWORD 3 BIT 3	CSM STATE VECTOR TO BE INTEGRATED	LEM STATE VECTOR TO BE INTEGRATED	SH 14		
DBOR9FLG FLAGWORD 3 BIT 2	DIMENSION OF W-MATRIX IS 9 FOR INTEGRATION	DIMENSION OF W - MATRIX IS 6 FOR INTEGRATION		SH 14	
ZMEASURE FLAGWORD 0 BIT 10	MEASUREMENT PLANET AND PRIMARY PLANET DIFFERENT	MEASUREMENT PLANET AND PRIMARY PLANET SAME	SH 17	SH 17	SH 15
ERADFLAG FLAGWORD 1 BIT 13	EARTH: COMPUTE FISCHER ELLIPSOID RADIUS MOON: USE FIXED RADIUS	EARTH: USE FIXED RADIUS MOON: USE RLS FOR RADIUS	SH 16		

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED	
V05N70	FLASHING	R1 = 000DE = STAR ID NO R2 = ABCDE = LMK DATA R3 = 00C0D = HORIZON DATA	REQUEST MEASUREMENT DATA BEFORE MARK IS TAKEN	SH 4
V08N88	FLASHING	R1 = STAR <sub>D</sub> - .XXXXX R2 = STAR*2 <sub>D</sub> - .XXXXX R3 = STAR*4 <sub>D</sub> - .XXXXX	VECTOR TO PLANET	SH 6
V50N25	FLASHING	R1 = 00202	PLEASE PERFORM AUTOMATIC MANEUVER	SH 7
V05N71	FLASHING	R1 = 000DE = STAR ID NO R2 = ABCDE = LMK DATA R3 = 00C0D = HORIZON DATA	REQUEST MEASUREMENT DATA AFTER MARK IS TAKEN	SH 9
V06N49	FLASHING	R1 = XXXX.X NAUT. MI R2 = XXXX.X FEET/SEC R3 = BLANK	POSITION DEVIATION VELOCITY DEVIATION	SH 12

WIT INSTRUMENTATION LAB 45-501002, MA15.		P 23 - CISLUNAR MIDCOURSE NAVIGATION	
(STAR) <i>G. J. ...</i> (DATE) <i>W. C. ...</i> (TIME) <i>...</i> (APP) <i>...</i>	16 DEC 68 5/1/68	COLOSSUS 2D	FC-2600
		24	27

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNIT	AGC UNIT	AGC SCALING
PIISPRD72		RESTART PRIORITY REGISTER		(INTEGER)	$2^{14}$
MARKINDX		NUMBER OF MARKS WANTED REGISTER		(INTEGER)	$2^{14}$
STARIND		STAR INDEX TO BESTI OR BESTJ		(INTEGER)	$2^{14}$
BESTI		RELATIVE ADDRESS OF DESIRED IN STAR TABLES		(INTEGER)	$2^{14}$
LANDMARK		LANDMARK DATA DISPLAY NOUN		(INTEGER)	$2^{14}$
HORIZON		HORIZON DATA DISPLAY NOUN		(INTEGER)	$2^{14}$
STARCODE		STAR ID NO DISPLAY NOUN		(INTEGER)	$2^{14}$
STARSAV2 (ALSO TAGGED US)		TEMPORARY STORAGE OF STAR I UNIT VECTOR			$(2^1, 2^1, 2^1)$
IDOFLMK		LANDMARK ID NUMBER		(INTEGER)	$2^{14}$
MARKTIME		TIME OF MARK	SEC	CSEC	$2^{28}$
REFSMMAT		TRANSFORMATION MATRIX- BASIC REFERENCE TO STABLE MEMBER COORDINATES			$2^1$
POINTVSM		DESIRED TRACK AXIS			$(2^1, 2^1, 2^1)$
SCANIS		SPACE CRAFT AXIS TO BE ALIGNED WITH POINTVSM			$(2^1, 2^1, 2^1)$
R60ADRS		DESIRED ADDRESS OF 'R60 CALL'		(INTEGER)	$2^{14}$
TEMPFLSH		RESTART RETURN ADDRESS		(INTEGER)	$2^{14}$
MARKDATA		ADDRESS OF MARK DATA STORAGE LOCATIONS		(INTEGER)	$2^{14}$
MARKSTAT		MARK DATA INFORMATION REGISTER FROM R53		(INTEGER)	$2^{14}$
TRUNNION		MEASURED TRUNNION ANGLE	DEG	REV	$2^3$
UCLSTAR	$\underline{U}^{\circ} \text{CL}$	CSM TO LANDMARK/HORIZON UNIT VECTOR CORRECTED FOR ABERRATION			$(2^1, 2^1, 2^1)$
VZC	$\underline{V}^{\circ} \text{C}$	CSM VELOCITY VECTOR	FEET/SEC	METERS/ CSEC	$(2^7, 2^7, 2^7)$
USSTAR	$\underline{U}^{\circ} \text{S}$	STAR UNIT VECTOR CORRECTED FOR ABERRATION			$(2^1, 2^1, 2^1)$
US	$\underline{U}^{\circ} \text{S}$	STAR UNIT VECTOR			$(2^1, 2^1, 2^1)$
BVECTOR	$(b_0, b_1, b_2)$	GEOMETRY OF MEASUREMENT MATRIX			VARIABLE
TRUNBIAS		CALIBRATION ANGLE FOR SEXTANT	DEG	REV	$2^3$
DELTAQ	$\Delta Q$	MEASURED AND ESTIMATED DEVIATION	NAUT. MI.	METERS	$2^{20}, 2^{27}$
VARIANCE	$\Delta^2$	VARIANCE OF MEASUREMENT ERRORS		METERS <sup>2</sup>	$2^{40}$
DELTA $\underline{X}$	$\Delta \underline{X}_0$	STATE VECTOR POSITION DEVIATIONS	NAUT. MI.	METERS	$2^{20}, 2^{27}$
DELTA $\underline{X}$ *6	$\Delta \underline{X}_1$	STATE VECTOR VELOCITY DEVIATIONS	FEET/SEC	METERS/ CSEC	$2^7, 2^5$
N49DISP		DISPLAY NOUN FOR DELTA $\underline{X}$	NAUT. MI.	METERS	$2^{20}$
N40DISP*6		DISPLAY NOUN FOR DELTA $\underline{X}$ *6	FEET/SEC	METERS/ CSEC	$2^7$
POINTEX		RETURN ADDRESS FROM POINTAXS		(INTEGER)	$2^{14}$

P23 - Cislunar  
MIDCOURSE NAIGATION

COLOSSUS 2D

FC-2600

25 27

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNIT	AGC UNIT	AGC SCALING
ALT		ALTITUDE	NAUT. MI.	METERS	$2^{29}$
LAT		LATITUDE	DEG	REV	$2^0$
LONG		LONGITUDE	DEG	REV	$2^0$
LANDALT		ALTITUDE DISPLAY NOUN	NAUT. MI.	METERS	$2^{29}$
LANDLONG		LONGITUDE DISPLAY NOUN	DEG	REV	$2^0$
EGRSS		SUBROUTINE RETURN ADDRESS		(INTEGER)	$2^{14}$
TDEC1		TIME FOR INTEGRATION	SEC	CSEC	$2^{28}$
RZC	$\underline{r} z c$	CSM POSITION VECTOR RELATIVE TO MEASUREMENT PLANET		METERS	$2^{29}$
RQVV	$\underline{r} q c$	CSM POSITION VECTOR RELATIVE TO SECONDARY PLANET		METERS	$2^{29}$
RL	$\underline{r} l$	LANDMARK/HORIZON LOCATION VECTOR		METERS	$2^{29}$
RCLL	$\underline{r} c l$	CSM TO LANDMARK/HORIZON VECTOR		METERS	$2^{29}$
DELTACSM	$\underline{d} c$	CSM CONIC POSITION DEVIATION		METERS	$2^{22}/2^{18}$
RCVCSM	$\underline{r} c$	CSM REFERENCE CONIC POSITION		METERS/ CSEC	$2^{29}/2^{27}$
NUVCSM	$\underline{v} c$	CSM CONIC VELOCITY DEVIATION		METERS/ CSEC	$2^7/2^5$
VCVCSM	$\underline{v} c$	CSM REFERENCE CONIC VELOCITY		METERS/ CSEC	$2^3/2^{-1}$
SRRETURN		RETURN ADDRESS FROM HORIZ			
UBAR0	$\underline{u}_0$	DEFINE HORIZON COORDINATE SYSTEM			$(2^1, 2^1, 2^1)$
UBAR1	$\underline{u}_1$				$(2^1, 2^1, 2^1)$
UBAR2	$\underline{u}_2$				$(2^1, 2^1, 2^1)$
ALPHA*4		SINE OF LATITUDE (FOR GETERAD)			$2^1$

911  
 4 DECEMBER 68  
 16 DEC 68  
 W. E. B. *W. E. B.*  
 M. E. *M. E.*  
 4/15/69  
 John A. *John A.*

P23 - Cislunar  
 MIDCOURSE NAVIGATION  
 COLOSSUS 2D FC-2600  
 26 27



PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
PR1013		PRIORITY 13 REGISTER	13	13000	2 <sup>14</sup>
SPSIX		SINGLE PRECISION 6	6	00006	2 <sup>14</sup>
CATLOG		BEGINNING ADDRESS OF STORED STAR VECTORS		(INTEGER)	2 <sup>14</sup>
JCAXIS		TRACK AXIS VECTOR	$57\frac{1}{2}^{\circ}$ 90° $32\frac{1}{2}^{\circ}$	$\begin{cases} 268649805 \\ 0 \\ 421685725 \end{cases}$	$2^1$ $2^1$ $2^1$
ONE/C		RECIPROCAL OF SPEED OF LIGHT	$1/9.835712 \times 10^{-8}$ FT/SEC	.333564049 $\times 10^{-6}$ CSEC/METERS	2 <sup>-21</sup>
ZEROVECS		BEGINNING ADDRESS OF 6 REGISTERS OF 0	0	0	2 <sup>14</sup>
VARSUBL		LANDMARK/HORIZON ERROR VARIANCE		3.4299040 $\times 10^6$	2 <sup>10</sup>
TRUN19		TRUNNION BIAS ANGLE	19.77 DEG	.055 REVS	2 <sup>0</sup>
PI/4.0		CONVERSION FACTOR REVS TO RADIAN	$2\pi \frac{\text{RAD}}{\text{REV}}$	.1502 $\frac{\text{RAD}}{\text{REV}}$	2 <sup>3</sup>
TRUNVAR		TRUNNION ERROR VARIANCE		$2.5 \times 10^{-9}$	2 <sup>-18</sup>
9DWID		DECIMAL 2		(INTEGER)	2 <sup>14</sup>
LATTAB		BEGINNING ADDRESSES OF STORED LANDMARK		(INTEGER)	2 <sup>14</sup>
LONGTAB		LATITUDE, LONGITUDE, AND ALTITUDE TABLES			
ALTTAB					
DPPOSMAX		DOUBLE PRECISION REGISTER CONTAINING MAXIMUM VALUE	.999999996	37777 37777	2 <sup>0</sup>
PADMOON	r <sub>m</sub>	RADIUS OF MOON		1738090 METERS	2 <sup>29</sup>
AEARTH	a	A - AXIS OF EARTH		6378166 METERS	2 <sup>29</sup>

PAD LOADS

AGC TAG	GSOP TAG	MEANING
WMIDPOS	w <sub>mr</sub>	W - MATRIX POSITION INITIALIZATION VALUE
WMIDVEL	w <sub>vr</sub>	W - MATRIX VELOCITY INITIALIZATION VALUE
VESO	v <sub>ES</sub>	VELOCITY OF SUN RELATIVE TO EARTH
-AYO	A <sub>Y</sub>	EARTH NUTATION ANGLE
AXO	A <sub>X</sub>	EARTH PRECESSION ANGLE
HORIZALT	h	EARTH HORIZON ALTITUDE

VII  
 WASHINGTON LAB  
 AMERSIDE, WA 5.  
 DESIGN *A. J. Young* 16DEC68  
 DRAWN *E.R. Byles* 5/1/69  
 ANNOT  
 CHECKED *W. C. ...* 4/13/69  
 APPROV *John A. ...* 2/20/68

P23-CISLUNAR  
 MIDCOURSE NAVIGATION  
 COLOSSUS II  
 FC-2600  
 27 27

NAVIGATION EXTENDED VERBS

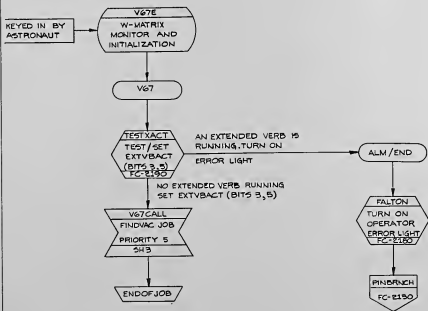
V67	-	W-MATRIX MONITOR	SH2
V82	-	INDICATE OFFSET LANDING SITE	SH6
V86	-	R23 MARK REJECT	SH7
V87	-	ALLOW VHF RADAR RANGE DATA	SH7
V88	-	DO NOT ALLOW VHF RADAR RANGE DATA	SH7
V93	-	INDICATE W-MATRIX INVALID FOR RENDEZVOUS NAVIGATION	SH7

ENCLOSED ARE REPLACEMENT SHEETS TO UPDATE THE COLOSSUS II FLOWCHART FC-2605, REV. 0, TO THE COLOSSUS IIA FLOWCHART FC-2605, REV. 1.

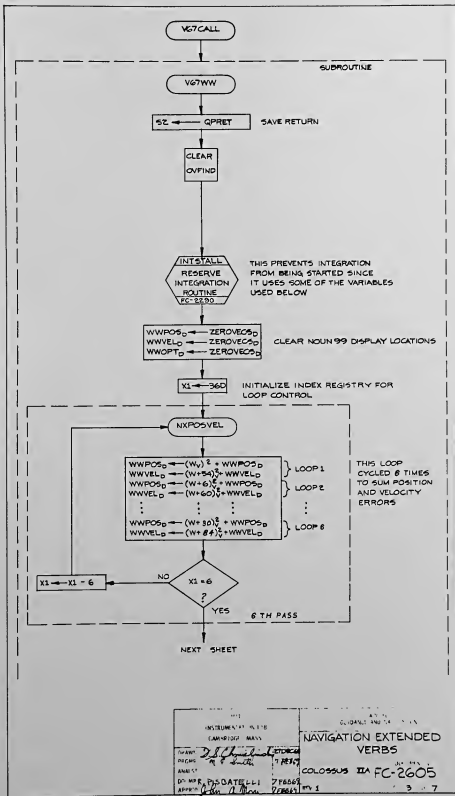
EFFECTIVE SHEETS FOR FC-2605, REV. 1:

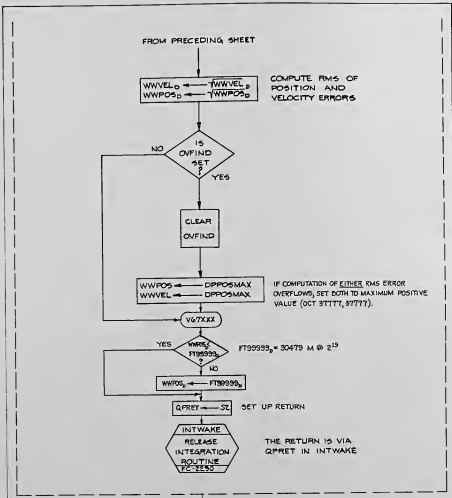
SH. 1-3	REV. 0
SH. 4-5	REV. 1
SH. 6-7	REV. 0

<p>NAVIGATION EXTENDED VERBS</p>	
<p>APPROVED: <i>[Signature]</i></p> <p>DATE: 7 JAN 67</p>	<p>ENCLOSURE</p> <p>COLOSSUS IIA FC-2605</p>
<p>BY: R. PISCATELLI</p> <p>DATE: 7 FEB 67</p>	<p>1</p>
<p><i>[Signature]</i></p>	<p>1 7</p>



NAVIGATION EXTENDED VERBS  
 COLOSSUS IIA FC-2605  
 R. PISCATELLI  
 7 FEB 67

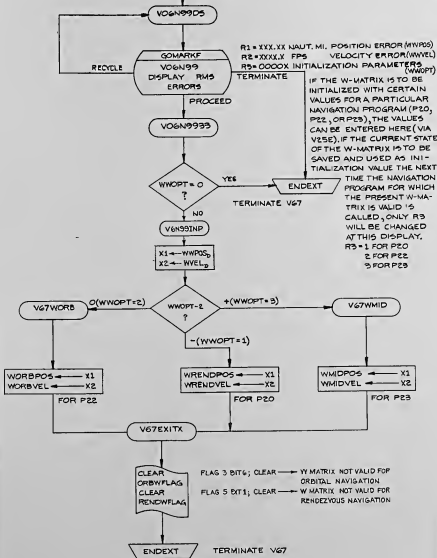




NEXT SHEET

UNIT INSTRUMENTATION LAB LANESBORO MASS.	AREA GUIDANCE AND NAVIGATION <b>NAVIGATION EXTENDED VERBS</b>
DRAWN <i>J. J. Chiswick</i>	DOCUMENT NO. <b>FC-2605</b>
PROGRAM <i>R. P. Scatell</i>	REV. 2 SHEET 4 OF 7
ANALYST REVIEWED <i>R. P. Scatell</i>	DATE APPROVED <i>J. A. M...</i>

FROM PRECEDING SHEET



NAVIGATION EXTENDED VERBS  
 DRAWN BY *[Signature]*  
 CHECKED BY *[Signature]*  
 ANALYST *[Signature]*  
 DTD BY R. DISCATALLI  
 APP'D BY *[Signature]*  
 GOLDSSUS IIA FC-2605  
 REV 1

KEYED IN BY  
ASTRONAUT

V52E  
INDICATE  
OFFSET  
LANDING SITE

V5E

CHECKMM  
DETERMINE  
IF P22 IS  
RUNNING  
FC-2080

NO

ALM/END

YES

STORE MARK NUMBER  
IN APPROPRIATE BITS

LANDMARK (BITS 12, 11, 10) = 5 - (MARKSTAT (BITS 14, 13, 12))  
MARKSTAT (BITS 14, 13, 12)  
= 5 - MARK NUMBER

GOPIN

PINPINC  
FC-2180

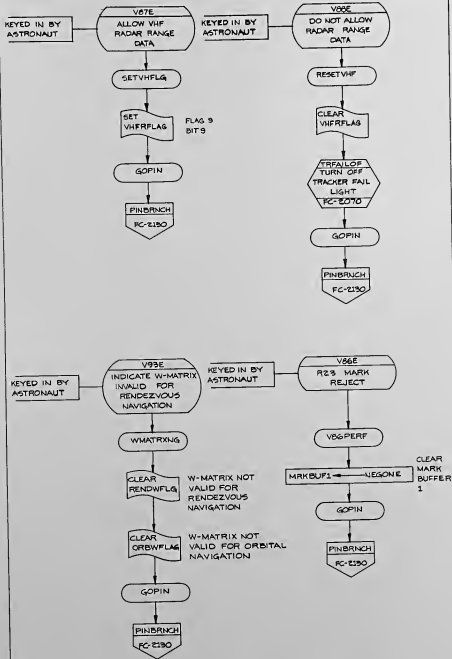
AFTER TAKING A MARK IN P22, THE  
ASTRONAUT HAS THE OPTION OF DESIGNATING IT  
AS BEING AN OFFSET LANDING SITE BY KEYING  
IN V52E. THIS CAUSES THE MARK TO BE NOTED  
AS BEING AN OFFSET LANDING SITE BY  
SETTING THE OFFSET INDICATOR IN THE LANDMARK  
REGISTER TO THE MARK NUMBER.  
LANDMARK = ABCDE

A = TYPE OF LMK  
B = INDEX OF OFFSET LMK  
C = (NOT USED)  
DE = LMK ID NO.

FALTON  
TURN ON  
OPERATOR  
ERROR LIGHT  
FC-2180

W1  
INSURING STATE IN CAR  
CAMBRIDGE, MASS.  
DRAWN *D. J. Chalupka*  
PREPARED *A. E. Smith*  
ANALYST  
DOWNER *P. P. OATLI*  
APPROVED *John A. Moran*

APR 64  
US-BAND AND VOLTAGE  
NAVIGATION EXTENDED  
VERBS  
COLOSSUS IIA FC-2605  
REV 1  
SHEET 6 OF 7



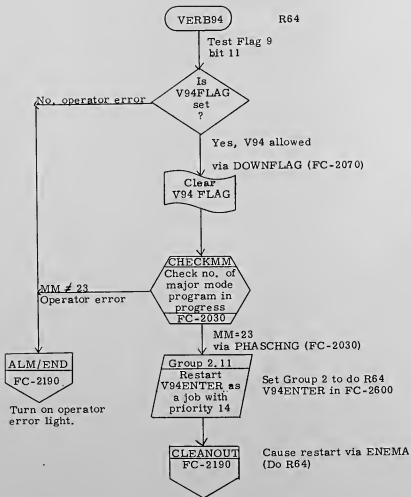
TITLE INSTRUMENT ON LAB CAMBRIDGE, MASS.		33 BU DATA 100 101	
DRAWN <i>[Signature]</i>		NAVIGATION EXTENDED VERBS	
CHECKED <i>[Signature]</i>		COLOSSUS IIA FC-2605	
ANALYST DOCNR R. BISLATELLI		ELEMENT 5 7 7	
APPROV <i>[Signature]</i>		REV 1	



V94 (R64)

VERB94 Sh. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		V94 (R64)	
DRAWN	<i>R. H. ...</i> 10/24/67	COLOSSUS 2D	DOCUMENT NO. FC - 26 06
PRGMR	<i>R. H. ...</i> 11/23/67		
ANALST		REV	SHEET 1 OF 3
DOCMR	<i>R. H. ...</i> 11/25/67		
APPR'D	<i>R. H. ...</i> 11/25/67		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		V94 (R64)	
DRAWN <i>R. M. E. 10/6/67</i>		COLOSSUS 2D	DOCUMENT NO.
PRGMR <i>R. M. E. 11/2/67</i>			FC-2606
ANALST		REV	SHEET 2 OF 3
DOCMR <i>R. M. E. 11/25/67</i>			
APPR'D <i>R. M. E. 11/25/67</i>			

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
ALM/END	FC-2190	Turns on operator error light	Sh. 2
CHECKMM	FC-2030	Checks major mode	Sh. 2
CLEANOUT	FC-2190	Causes restart	Sh. 2
DOWNFLAG	FC-2070	Clears flag	Sh. 2
PHASCHNG	FC-2030	Changes phase for restarts	Sh. 2

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
V94FLAG (flag 9 bit 11)	V94 allowed	V94 not allowed		Sh. 2	Sh. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		V94 (R64)	
DRAWN <i>R. Hunter</i>	<i>11/25/67</i>		
PRGMR <i>R. Hunter</i>	<i>11/25/67</i>		
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2606
DOCMR <i>R. Hunter</i>	<i>11/25/67</i>		
APPR'D <i>R. Hunter</i>	<i>11/25/67</i>	REV	SHEET 3 OF 3

MEASUREMENT INCORPORATION

MAJOR SUBROUTINES:

INCORP1 - COMPUTES STATE VECTOR DEVIATIONS

INCORP2 - INCORPORATES STATE VECTOR DEVIATIONS  
INTO STATE VECTOR

SPECIAL CONVENTIONS:

1.  $Z^1/Z^2$  IN THE SCALING FIELD OF THE SUMMARY SHEETS  
IS USED TO DENOTE EARTH/MOON SPHERE OF INFLUENCE
2. THE WORD VARIABLE IN THE SCALING FIELD INDICATES  
EITHER THE VARIABLE IS USED AS A TEMPORARY LOCATION  
WITH MANY DIFFERENT SCALINGS, OR THE CALLING  
PROGRAM SETS THE SCALE. (SEE NOTE 5H14)

W T	ED 2	AD	NO
INCORPORATION TAB	ED 2	AD	NO
CAMPS-024 MK-3.	MEASUREMENT INCORPORATION		
CDR. <i>D. S. Christensen</i>	COLOSSUS II		
FORM 12	FC-2610		
DOY NR. <i>100</i>	1 16		
APPRO. <i>John A. Thompson 12 MAR 69</i>	1 16		

GENERAL FLOW  
MEASUREMENT INCORPORATION

CALLED BY  
 P22 RENDEZVOUS NAVIGATION FOR OSM  
 P23 RENDEZVOUS NAVIGATION FOR OSM  
 P24 CYCLINAR NAVIGATION FOR OSM  
 P20 RENDEZVOUS NAVIGATION FOR LEM  
 P22 RR LINAR SURFACE NAVIGATION FOR LEM  
 AFTER INITIALIZING  
 DIMENFLG - DIMENSION OF STATE VECTOR  
 $\alpha^2$  - VARIANCE OF MEASUREMENT ERRORS  
 $\Delta Q$  - DEVIATION OF MEASURED AND ESTIMATED POSITION  
 B - VECTOR OF MEASUREMENT GEOMETRY

INCRP1

COMPUTE STATE VECTOR DEVIATIONS  
 OF POSITION, VELOCITY, AND  
 (IF NINE DIMENSIONAL) LANDMARK  
 POSITION OR RADAR BIAS.

RETURN TO CALL-  
ING PROGRAM

VALID  
DEVIATIONS  
?

NO

YES

RETURN FOR  
NEW MARK

INCRP2

UPDATE W MATRIX

UPDATE APPROPRIATE  
STATE VECTOR

RETURN TO CALL-  
ING PROGRAM

TITLE INS TERMINATION LAP COMMANDING MAJORS		CLASSIFICATION MEASUREMENT INCORPORATION	
DRAWN DESIGNED ANALYST CHECKED APPROVED	<i>John A. Brown</i> <i>John A. Brown</i> <i>John A. Brown</i> <i>John A. Brown</i> <i>John A. Brown</i>	COLONOUS II FC-2610	REV 2 16

SUBROUTINE WHICH CALCULATES THE SIX DIMENSIONAL STATE VECTOR DEVIATIONS FOR POSITION AND VELOCITY OR THE NINE DIMENSIONAL DEVIATION OF POSITION, VELOCITY, AND LANDMARK POSITION OR RADAR BIAS.

INPUT

W = ERROR TRANSITION MATRIX  
6 X 6 OR 9 X 9

DELTAQ =  $\Delta Q$  = DEVIATION BETWEEN ESTIMATED AND ACTUAL TRACKING MEASUREMENT (SCALAR)

VARIANCE =  $\sigma^2$  = VARIANCE INHERENT IN MEASUREMENT AND STATE VECTOR UNCERTAINTIES (SCALAR)

BVECTOR = 6 OR 9 DIMENSIONAL GEOMETRY OF MEASUREMENT VECTOR

DMENFLG = DIMENSION OF W  
0 = 6 X 6 1 = 9 X 9

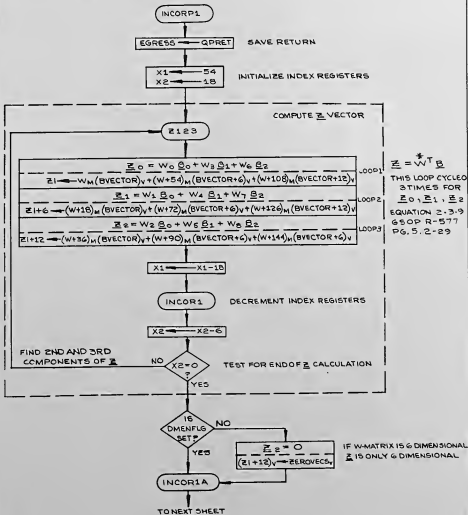
OUTPUT

DELTA X =  $\Delta X$  = 6 OR 9 DIMENSIONAL STATE VECTOR DEVIATIONS

ZI = 6 OR 9 DIMENSIONAL VECTOR USED FOR THE INCORPORATION

OMEGA = W = 6 OR 9 DIMENSIONAL OMEGA WEIGHTING VECTOR

GAMMA = Y = SCALAR USED FOR INCORPORATION



$Z = W^T B$

THIS LOOP CYCLED 3 TIMES FOR  $Z_0, Z_1, Z_2$

EQUATION 2-3-9  
68OP R-577  
PG. 5. 2-29

IF W-MATRIX IS 6 DIMENSIONAL  
 $Z$  IS ONLY 6 DIMENSIONAL

MEASUREMENT INCORPORATION

FC-2610

5 16

*Handwritten notes:*  
of 10/1/68  
R. J. Jennings  
R. J. Jennings  
John A. Brown

FROM PRECEDING SHEET

$$A = \bar{z}^2 + \alpha^2$$

$$A = \bar{z}_0 \bar{z}_0 + \bar{z}_1 \bar{z}_1 + \bar{z}_2 \bar{z}_2 + \alpha^2$$

$$\text{TRIPAT} \rightarrow \frac{(\bar{z}_1)^2}{\sqrt{1+\bar{z}_1^2}} + \frac{(\bar{z}_2)^2}{\sqrt{1+\bar{z}_2^2}} + \frac{(\bar{z}_3)^2}{\sqrt{1+\bar{z}_3^2}} + \text{VARIANCE}$$

A IS AN INTERMEDIATE  
VALUE USED IN CALCULATING  
 $\Delta X$ . EQUATION 2.3.9

$$X2 \leftarrow 0$$

$$\text{MPACT} \leftarrow \text{VARIANCE}$$

$$\text{OVFIND} \leftarrow 0$$

$$\text{TEMPVAR} \leftarrow \text{MPACT}$$

$\alpha^2$  IS PLACED IN A  
TEMPORARY LOCATION

IS  
MPACT =  
0?

YES

NO

THIS LOOP PERFORMS  
NORMALIZATION

INCOR1B

NORMALIZE  $\alpha^2$  IN PREPARATION  
FOR USE IN SQUARE ROOT.

X2 CONTAINS THE  
NORMALIZING COUNT

SHIFT MPACT  
LEFT 2 PLACES

$$X2 \leftarrow X2 + 1$$

TEMPVAR CONTAINS THE  
NORMALIZED VARIANCE

$$\text{TEMPVAR} \leftarrow \text{MPACT}$$

OVERFLOW?

NO

YES

INCOR1C

$$\text{MPACT} = A + \sqrt{A \alpha^2}$$

$$\text{MPAC}_0 \leftarrow \text{TRIPAC}_0 + \sqrt{\text{TRIPAC}_0 (\text{TEMPVAR})_0}$$

$$\text{NORMALIZE MPAC}$$

$$\text{NORMGAM} \leftarrow X2 - 2$$

$$X2 \leftarrow 162$$

X2 CONTAINS NORMALIZING COUNT.  
NORMGAM CONTAINS NORMALIZING COUNT-2  
FOR GAMMA, USED IN INCORP2.

$$Y = 1 / (A + \sqrt{A \alpha^2})$$

$$\text{GAMMA}_0 \leftarrow 0.1 / 4 \text{TH} / (\text{MPAC}_0)$$

GAMMA IS USED IN INCORP2.  
EQUATION 2.3.10

$$\text{NORMALIZE TRIPAT}$$

$$\text{NORMALIZE DELTAG}_0$$

X1 CONTAINS NORMALIZING COUNT OF A.  
31 CONTAINS NORMALIZING COUNT OF  $\Delta Q$

$$X1 \leftarrow X1 - 31$$

$$\text{PCLO} = \Delta Q / A$$

$$\text{PDL}_0 \leftarrow \text{DELTAG}_0 / \text{TRIPAC}_0$$

SCALING ADJUSTED VIA X1

TO NEXT SHEET

MEASUREMENT INCORPORATION

MEASUREMENT INCORPORATION

DATE: 2/14/68  
BY: R. P. ...  
CHECKED: ...  
APPROVED: ...

COLOSSUS II

FC-2610

4 16

FROM PRECEDING SHEET

NEWZCOMP

SUCCESSIVE WEIGHTED MEASUREMENTS DECREASE ZI WEIGHTING VECTOR. NEWZCOMP NORMALIZES COMPONENTS OF ZI ON LARGEST Z COMPONENT PREVENTING LOSS OF SIGNIFICANCE.

$36D = |Z_0|$   
 $NORMZ1_D \leftarrow |Z1|$

$PDL1_D \leftarrow |Z1|$   
 $POL1_D \leftarrow |Z1 + 6|$

$|Z1| - |Z_0|$   
 $MPRC_D \leftarrow MPRC_D - NORMZ1_D$

$|Z1| > |Z_0|?$  YES  
 NO

$36D = |Z1|$   
 $NORMZ1_D \leftarrow PDL1_D$

$PDL2_D \leftarrow |Z_2|$   
 $POL2_D \leftarrow |Z1 + |Z_2||$

$|Z_2| - |Z_0| \text{ OR } |Z_1|$   
 $MPRC \leftarrow MPRC - NORMZ1_D$

$|Z_2| > |Z_0| \text{ OR } |Z_1|$  YES (+)  
 NO:  $|Z_0| \text{ OR } |Z_1| > |Z_2|$  (-)

$NORMZ1 \leftarrow |Z1|$

NEWZCMP1

$MPAC \leftarrow NORMZ1$   
 $NORMZ1 \leftarrow X1$

NORMZ1 CONTAINS MAX ( $|Z_0|, |Z_1|, |Z_2|$ )  
 X1 CONTAINS NORM COUNT OF A MINUS NORM COUNT OF  $\Delta Q$ .

NORMALIZE MPAC (CONTAINS MAX  $|Z|$ )  
 SAVE NORM COUNT +Z IN X1

NORMALIZE LARGEST Z COMPONENT,  
 SAVE COUNT

NEXT SHEET

N 1 INSTRUMENTATION LAB CAMBRIDGE, MASS.		6070 CALCULATIONS AND ANALYSIS	
DRAWN <i>A.C. WILLIAMS</i>		MEASUREMENT INCORPORATION	
PROGRAM <i>A. Williams</i>		COLOSSUS II	
ANALYST <i>[Signature]</i>		FC-2610	
CHECKED <i>[Signature]</i>		5 16	
APPROVED <i>[Signature]</i>		5 16	



FROM PRECEDING SHEET

$$\begin{array}{l} Z_0 = Z_0 \times 2^{X1} \\ ZI_0 \leftarrow VSL \# 0, 1 ZI_0 \end{array} \quad \begin{array}{l} \text{SHIFT } Z_0 \text{ LEFT BY } X1 \\ (\text{NORM COUNT} + 2) \end{array}$$

$$\begin{array}{l} Z_1 = Z_1 \times 2^{X1} \\ ZI + 6 \leftarrow VSL \# 0, 1 ZI + 6 \end{array} \quad \begin{array}{l} \text{SHIFT } Z_1 \text{ LEFT BY } X1 \\ (\text{NORM COUNT} + 2) \end{array}$$

$$\text{NORMZI} + 1 \leftarrow SXA, 1 \quad \begin{array}{l} \text{SAVE } \# \text{ SHIFTS FROM } X1 \\ (\text{NORM COUNT} + 2) \end{array}$$

$$\begin{array}{l} Z_2 = Z_2 \times 2^{X1} \\ ZI + 12D \leftarrow VSL \# 0, 1 ZI + 12D \end{array}$$

$$\begin{array}{l} X1 = \#^2 \text{ NORMCOUNT} - 2 \\ X1 \leftarrow \text{NORMGAM} \end{array} \quad \begin{array}{l} \text{NORMGAM CONTAINS GAMMA} \\ \text{NORMALIZING COUNT MINUS 2.} \end{array}$$

$$\begin{array}{l} \#^2 \text{ NORMCOUNT} - 2 + 2 (\text{MATRIX NORMCOUNT}) \\ \text{NORMGAM} \leftarrow \text{NORMGAM} - 2 (\text{NORMZI} + 1) \end{array} \quad \begin{array}{l} \text{NORMALIZING COUNT FOR } Y \text{ MINUS 2 RETURNED} \\ \text{TO } X1 \text{ WHERE TWICE NUMBER OF SHIFTS} \\ \text{REQUIRED FOR MATRIX NORMALIZATION} \\ (\text{NORMZI} + 1) \text{ ARE SUBTRACTED.} \end{array}$$

$$\begin{array}{l} X1 = \text{COMPLEMENT OF MATRIX NORMCOUNT} \\ X1, 1 \text{ NORMZI} + 1 \end{array} \quad \begin{array}{l} \text{STORE NORMGAM COMPLEMENT} \\ \text{IN } X1. \end{array}$$

$$\begin{array}{l} \text{NEW NORMCOUNTS (COMPLEMENT OF MATRIX SHIFTS) + (NORMCOUNT) - (NORMCOUNT 0)} \\ X1 \leftarrow X1 + \text{NORMZI} \end{array} \quad \begin{array}{l} \text{OLD NORMALIZING COUNT (X1-51)} \\ \text{FOR } \Delta Q/\Delta \text{ MODIFIED BY} \\ \text{SHIFTS NEEDED TO NORMALIZE} \\ \text{ZI VECTOR.} \end{array}$$

$$POL = 2D$$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS PROGRAM <i>A. Williams</i> ANALYST DYNAMIC <i>John J. Kelly</i> APPROV <i>John A. Moore</i>	EXTENSION 11 AUG 69 COLLOSSUS II 1269	MEASUREMENT INCORPORATION JULY 1969 FC-2610 1969 6 16	

FROM PRECEDING SHEET

52 ← 54

COMPUTE  $\underline{\omega}$  VECTOR

INCOR2

$\underline{\omega}_0 = \underline{z}_0 W_0 + \underline{z}_1 W_1 + \underline{z}_2 W_2$	LOOP 1	$\underline{\omega}^T = \underline{z}^T W^T$
$PDL2_v \rightarrow z1_v(W)_m + (z1+G)_v(W+1B)_m + (z1+12)_v(W+3G)_m$		
$\underline{\omega}_1 = \underline{z}_0 W_3 + \underline{z}_1 W_4 + \underline{z}_2 W_5$	LOOP 2	THIS LOOP CYCLED 3 TIMES FOR $\underline{\omega}_0, \underline{\omega}_1, \underline{\omega}_2$ EQUATION 2.3.9 $\underline{\omega}$ IS USED IN INCOR2
$PDLB_v \rightarrow z1_v(W+5G)_m + (z1+G)_v(W+7G)_m + (z1+12)_v(W+9G)_m$		
$\underline{\omega}_2 = \underline{z}_0 W_6 + \underline{z}_1 W_7 + \underline{z}_2 W_8$	LOOP 3	
$PDL14_v \rightarrow z1_v(W+10B)_m + (z1+G)_v(W+12G)_m + (z1+12)_v(W+14G)_m$		

X2 ← X2 - 54

FIND 2ND AND 3RD  
COMPONENTS OF  $\underline{\omega}$

X2 = 0 ?

YES

(OMEGA+12)<sub>v</sub> ← PDL14<sub>v</sub>  
(OMEGA+6)<sub>v</sub> ← PDLB<sub>v</sub>  
(OMEGA)<sub>v</sub> ← PDL2<sub>v</sub>

MOVE  $\underline{\omega}$  FROM PUSH LIST TO STORAGE.

IS  
DMENFLG  
SET?

NO

YES

$\underline{\omega}_i = 0$   
(OMEGA+12)<sub>v</sub> ← ZEROVECS

IF W-MATRIX IS G  
DIMENSIONAL  $\underline{\omega}$  IS  
ONLY G DIMEN-  
SIONAL

INCOR2AB

X2 ← 18  
52 ← G

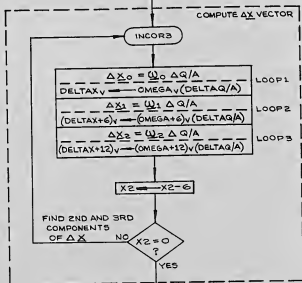
TO NEXT SHEET

MEASUREMENT INCORPORATION

FILED  
NAME: *J. R. Gunning*  
EXT: *1024*  
DATE: *1/27/68*  
APPRO: *R. Pristelli*  
*for G. Moore*

COLOSSUS II FC-2610

FROM PRECEDING SHEET



FIND 2ND AND 3RD COMPONENTS OF  $\Delta X$

$X_2 \leftarrow X_2 - 6$

$X_2 = 0 ?$

$\Delta X_2 = \Delta X_2 (e^3)$   
 $(\Delta X_2)_v \leftarrow (\Delta X_2)_v (e^3)$

CHANGE  $\Delta X_2$  TO CORRECT SCALE

RETURN VIA EGRESS

RETURN TO CALLING PROGRAM

DESIGN: <i>J. C. [unclear]</i> PFCN: <i>R. J. [unclear]</i> ANM: <i>R. [unclear]</i> DCLM: <i>R. [unclear]</i> APPR: <i>[unclear]</i>	MEASUREMENT INCORPORATION COLUSSUS II FC-2610 16
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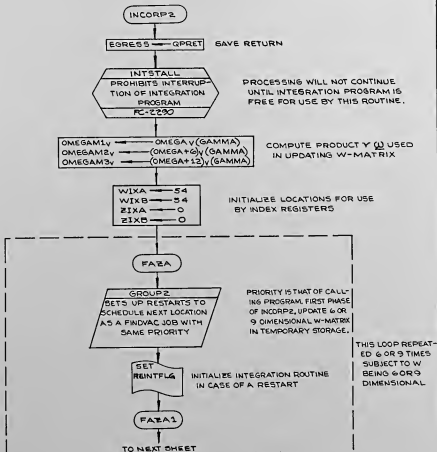
SUBROUTINE WHICH INCORPORATES THE COMPUTED STATE VECTOR DEVIATIONS INTO THE ESTIMATED STATE VECTOR FOR EITHER THE CSM OR LEM. CALLED AFTER STATE VECTOR DEVIATIONS CALCULATED BY INCORP1 HAVE BEEN ACCEPTED EITHER BY ASTRO-NAUT OR BY CALLING PROGRAM.

INPUT :

VEHUPFLAG = UPDATE VEHICLE 1=CSM, 0=LEM  
 W = ERROR TRANSITION MATRIX  
 DELTAX =  $\Delta X$  = 6 OR 9 DIMENSIONAL STATE VECTOR DEVIATIONS  
 DMENFLG = DIMENSION OF W 1=9X9, 0=6X6  
 OMEGA =  $\omega$  = 6 OR 9 DIMENSIONAL OMEGA WEIGHTING VECTOR USED TO MINIMIZE STATISTICAL ERRORS  
 GAMMA =  $\gamma$  = SCALAR USED IN THE INCORPORATION  
 ZI = 6 OR 9 DIMENSIONAL VECTOR USED IN THE INCORPORATION  
 PERMANENT STATE VECTOR FOR EITHER LEM OR CSM  
 NORMGAM = NORMALIZATION COUNT FOR RESTORING W MATRIX UPDATE

OUTPUT :

UPDATED PERMANENT STATE VECTOR  
 UPDATED W MATRIX



MEASUREMENT INCORPORATION  
 COLLOSSUS II  
 FC-2610  
 9 16

*Handwritten notes:*  
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FROM PRECEDING SHEET

WIXA ← WIXB  
 ZIXA ← ZIKB  
 X1 ← WIXA  
 X2 ← ZIXA  
 S1 ← G

INITIALIZE INDEX AND STEP  
 REGISTERS FOR LOOP  
 CONTROL

CALCULATION OF UPPER 3x9  
 PARTITION OF W-MATRIX

$W_i = W_i - Y \sum Z_i U_i$   
 I IS ONE LESS THAN LOOP NO.  
 LOOP1  
 LOOP2  
 LOOP3  
 LOOP4  
 LOOP5  
 LOOP6  
 LOOP7 (90 ONLY)  
 LOOP8 (90 ONLY)  
 LOOP9 (90 ONLY)

HOLDWV ←  $(W_1) - (Z_1) D$  (OMEGAM1)V  
 HOLDWV ←  $(W_2) - (Z_2) D$  (OMEGAM1)V  
 HOLDWV ←  $(W_3) - (Z_3) D$  (OMEGAM1)V  
 HOLDWV ←  $(W_4) - (Z_4) D$  (OMEGAM1)V  
 HOLDWV ←  $(W_5) - (Z_5) D$  (OMEGAM1)V  
 HOLDWV ←  $(W_6) - (Z_6) D$  (OMEGAM1)V  
 HOLDWV ←  $(W_7) - (Z_7) D$  (OMEGAM1)V  
 HOLDWV ←  $(W_8) - (Z_8) D$  (OMEGAM1)V  
 HOLDWV ←  $(W_9) - (Z_9) D$  (OMEGAM1)V

THIS PART OF  
 LOOP COMPUTES  
 $W = W - Y \sum U_i$   
 AND LEAVES  
 THE NEW W IN  
 TEMPORARY  
 STORAGE  
 REGISTERS.

CALCULATION OF MIDDLE 3x9 PARTITION OF W-MATRIX

$W_{i+9} = W_{i+9} - Y \sum Z_i U_i$   
 I IS ONE LESS THAN LOOP NO.  
 LOOP1  
 LOOP2  
 LOOP3  
 LOOP4  
 LOOP5  
 LOOP6  
 LOOP7 (90 ONLY)  
 LOOP8 (90 ONLY)  
 LOOP9 (90 ONLY)

(HOLDW+6)V ←  $(W+54) - (Z+1) D$  (OMEGAM2)V  
 (HOLDW+6)V ←  $(W+60) - (Z+2) D$  (OMEGAM2)V  
 (HOLDW+6)V ←  $(W+66) - (Z+3) D$  (OMEGAM2)V  
 (HOLDW+6)V ←  $(W+72) - (Z+4) D$  (OMEGAM2)V  
 (HOLDW+6)V ←  $(W+78) - (Z+5) D$  (OMEGAM2)V  
 (HOLDW+6)V ←  $(W+84) - (Z+6) D$  (OMEGAM2)V  
 (HOLDW+6)V ←  $(W+90) - (Z+7) D$  (OMEGAM2)V  
 (HOLDW+6)V ←  $(W+96) - (Z+8) D$  (OMEGAM2)V  
 (HOLDW+6)V ←  $(W+102) - (Z+9) D$  (OMEGAM2)V

IS DMENFLG SET ?  
 NO-6 DIMENSIONAL W-MATRIX  
 YES-9 DIMENSIONAL W-MATRIX

CALCULATION OF LOWER 3x9 PARTITION OF W-MATRIX

$W_{i+18} = W_{i+18} - Y \sum Z_i U_i$   
 I IS ONE LESS THAN LOOP NO.  
 LOOP1  
 LOOP2  
 LOOP3  
 LOOP4  
 LOOP5  
 LOOP6  
 LOOP7  
 LOOP8  
 LOOP9

(HOLDW+12)V ←  $(W+108) - (Z+1) D$  (OMEGAM3)V  
 (HOLDW+12)V ←  $(W+114) - (Z+2) D$  (OMEGAM3)V  
 (HOLDW+12)V ←  $(W+120) - (Z+3) D$  (OMEGAM3)V  
 (HOLDW+12)V ←  $(W+126) - (Z+4) D$  (OMEGAM3)V  
 (HOLDW+12)V ←  $(W+132) - (Z+5) D$  (OMEGAM3)V  
 (HOLDW+12)V ←  $(W+138) - (Z+6) D$  (OMEGAM3)V  
 (HOLDW+12)V ←  $(W+144) - (Z+7) D$  (OMEGAM3)V  
 (HOLDW+12)V ←  $(W+150) - (Z+8) D$  (OMEGAM3)V  
 (HOLDW+12)V ←  $(W+156) - (Z+9) D$  (OMEGAM3)V

FAZB

GROUP2  
 SET UP RESTARTS  
 TO SCHEDULE NEXT  
 LOCATION AS A JOB  
 WITH SAME PRIORITY

END PHASE OF INCORP2  
 TRANSFER OF W-MATRIX  
 FROM TEMPORARY TO  
 PERMANENT REGISTERS.

FAZB1

TO NEXT SHEET

MIT  
 INSTRUMENTATION LAB  
 CAMBRIDGE, MASS

DRAWN: *[Signature]*  
 PROGRAM: *[Signature]*  
 ANALYST: *[Signature]*  
 DESIGNER: *[Signature]*  
 APPROVED: *[Signature]*

MEASUREMENT INCORPORATION

COLOSSUS II  
 FC-2610  
 10 16

FROM PRECEDING SHEET

W1XB ← W1XA+6  
 Z1XB ← Z1XA-2  
 X1 ← W1XA  
 S1 ← 6

INCREMENT LOOP  
 CONTROL REGISTERS

TRANSFER UPPER 3x9 PARTITION OF  
 W-MATRIX TO PERMANENT CORE

W<sub>v</sub> ← HOLDW<sub>v</sub>  
 (W+6)<sub>v</sub> ← HOLDW<sub>v</sub>  
 (W+12)<sub>v</sub> ← HOLDW<sub>v</sub>  
 (W+18)<sub>v</sub> ← HOLDW<sub>v</sub>  
 (W+24)<sub>v</sub> ← HOLDW<sub>v</sub>  
 (W+30)<sub>v</sub> ← HOLDW<sub>v</sub>  
 (W+36)<sub>v</sub> ← HOLDW<sub>v</sub>  
 (W+42)<sub>v</sub> ← HOLDW<sub>v</sub>  
 (W+48)<sub>v</sub> ← HOLDW<sub>v</sub>

LOOP1  
 LOOP2  
 LOOP3  
 LOOP4  
 LOOP5  
 LOOP6  
 LOOP7 (9D ONLY)  
 LOOP8 (9D ONLY)  
 LOOP9 (9D ONLY)

TRANSFER MIDDLE 3x9 PARTITION OF  
 W-MATRIX TO PERMANENT CORE

(W+54)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>  
 (W+60)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>  
 (W+66)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>  
 (W+72)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>  
 (W+78)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>  
 (W+84)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>  
 (W+90)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>  
 (W+96)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>  
 (W+102)<sub>v</sub> ← (HOLDW+6)<sub>v</sub>

LOOP1  
 LOOP2  
 LOOP3  
 LOOP4  
 LOOP5  
 LOOP6  
 LOOP7 (9D ONLY)  
 LOOP8 (9D ONLY)  
 LOOP9 (9D ONLY)

THIS PART OF LOOP  
 MOVES W-MATRIX  
 FROM TEMPORARY  
 REGISTERS TO  
 PERMANENT CORE

NO - 6 DIMENSIONAL W-MATRIX

IS  
 DIMENFLS  
 SET?

YES - 9 DIMENSIONAL W-MATRIX  
 TRANSFER LOWER 3x9 PAR-  
 TITION OF W-MATRIX TO  
 PERMANENT CORE

FAZB5

(W+108)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>  
 (W+114)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>  
 (W+120)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>  
 (W+126)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>  
 (W+132)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>  
 (W+138)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>  
 (W+144)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>  
 (W+150)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>  
 (W+156)<sub>v</sub> ← (HOLDW+12)<sub>v</sub>

LOOP1  
 LOOP2  
 LOOP3  
 LOOP4  
 LOOP5  
 LOOP6  
 LOOP7  
 LOOP8  
 LOOP9

Z1XB+12 =  
 0?

NO

YES

IF W-MATRIX IS 6 DI-  
 MENSIONAL THIS EXIT  
 WILL BE TAKEN AFTER  
 6 ITERATIONS

X1 ← X1-6

THIS PART OF LOOP  
 CONTROLS EXIT.

X1 = 0  
 ?

NO

YES

IF W-MATRIX IS 9 DI-  
 MENSIONAL THIS EXIT  
 WILL BE TAKEN AFTER  
 9 ITERATIONS

FAZA  
 EN.6

MAKE ANOTHER PASS  
 THROUGH LOOP.

END OF LOOP WHICH  
 STARTS ON SHEET G

TO NEXT SHEET

INSTRUCTIONS: 48  
 DATE: 11/1/55

MEASUREMENT INCORPORATION

DESIGN: *Silvest* 1 page  
 PART NO: *LR-200* 1 out of 1  
 DRAWN BY: *LR-200* 1 out of 1  
 CHECKED BY: *LR-200* 1 out of 1  
 APPROVED BY: *LR-200* 1 out of 1

COLLOSSUS II

FC-2610

11 16

FROM PRECEDING SHEET

GROUP 2  
SET UP RESTARTS  
TO SCHEDULE NEXT  
LOCATION AS A JOB  
WITH SAME PRIOR-  
ITY

3RD PHASE OF INCORP.  
UPDATE OF VEHICLE STATE VECTOR IN  
TEMPORARY REGISTERS.

$$TX789_v \leftarrow X789_v + (\Delta X_{21} + 12)$$

$\Delta X_2 + 3RD$  COMPONENT OF VEHICLE  
STATE VECTOR IS SAVED IN TEMPORARY  
REGISTER FOR FUTURE USE

IS  
VEHUFFLG  
SET?

WHICH VEHICLE STATE VECTOR  
IS BEING UPDATED ?

YES-CSM

NO-LEM

DOCSM  
MOVEPCSM  
CSM STATE VECTOR  
TRANSFERRED FROM  
PERMANENT CORE TO  
TEMPORARY WORK AREA  
FC-2290

MOVEPLEM  
LEM STATE VECTOR  
TRANSFERRED FROM  
PERMANENT CORE TO  
TEMPORARY WORK AREA  
FC-2290

LEM and CSM STATE VECTORS  
ARE NOT WORKED WITH DIRECT-  
LY. A WORK AREA, COMMON  
TO BOTH, IS USED TO PREVENT  
LOSS OF STATE VECTOR  
DURING MANIPULATIONS.

STATE VECTOR QUANTITIES

RCV =  $V_c$  = CONIC POSITION  
VCV =  $V_c$  = CONIC VELOCITY  
TDLTAV =  $\delta$  = POSITION DEVIATION FROM CONIC  
TNLV =  $V$  = VELOCITY DEVIATION FROM CONIC

FAZAB

CLEAR  
OVFIND

$$X2 \leftarrow 0$$

NO-EARTH

IS  
MOONTHIS  
SET?

DETERMINE BODY WHICH IS THE CENTER OF THE  
STATE VECTOR COORDINATE SYSTEM.

YES-MOON

$$X2 \leftarrow 2$$

X2 IS USED TO ADJUST SCALING

$$MPAC_v \leftarrow \frac{\delta}{X2} + \Delta X_0$$

$$MPAC_v \leftarrow TDLTAV_v + \Delta X_{21}$$

MPAC IS SCALED  $2^{27}$  FOR MOON,  $2^{29}$  FOR EARTH ORBIT.  
ADD UPDATING STATE VECTOR DEVIATIONS ( $\Delta X_0$ )  
TO POSITION DEVIATION FROM CONIC ( $\delta$ )

OVFIND=1  
?

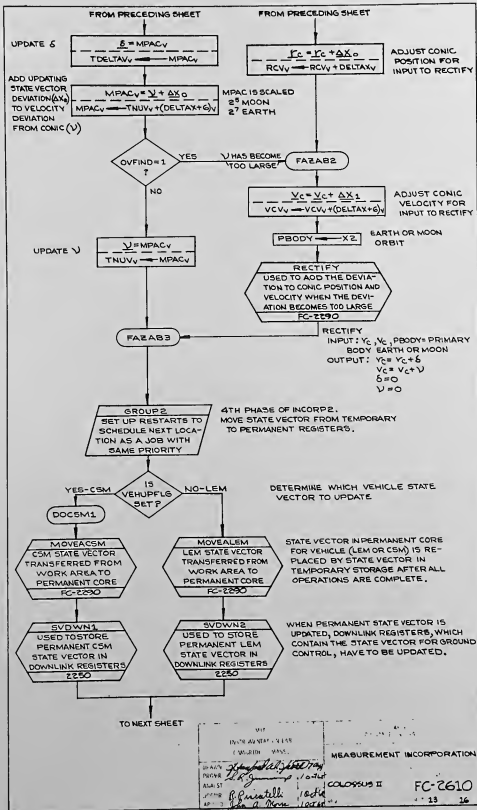
YES  $\delta$  HAS BECOME  
'TOO LARGE'

FAZAB1

TO NEXT SHEET

TO NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED FOR RELEASE MEASUREMENT INCORPORATION	
DRAWN <i>S. J. ...</i>	DESIGNED <i>S. J. ...</i>	ANALYST <i>S. J. ...</i>	PROJECT <i>S. J. ...</i>
COLUSSUS II		DOCUMENT NO. FC-2610	





FROM PRECEDING SHEET

FAZAB4

GROUP 2  
SET UP RESTARTS TO  
SCHEDULE NEXT LOCA-  
TION AS A JOB WITH  
SAME PRIORITY

5TH PHASE OF INCORP2.  
UPDATE 3RD COMPONENT (LANDMARK POSITION OR  
RADAR BIAS) OF STATE VECTOR IF W-MATRIX IS  
9 DIMENSIONAL.

NO-6 DIMENSIONAL IS DMENFLG SET? DIMENSION OF W-MATRIX

YES-9 DIMENSIONAL

X789<sub>v</sub> ← TX789<sub>v</sub>

MOVE UPDATED 3RD COMPONENT CALCULATED  
PREVIOUSLY FROM TEMPORARY REGISTERS  
TO STATE VECTOR.

FAZAB5

QPRET ← CGRESS

RESTORE RETURN VALUE

INTWAKE  
RELEASE INTEGRATION  
FOR USE BY OTHERS  
FC-2230

WAKES UP JOBS WAITING FOR  
INTEGRATION AND PERFORMS THEM  
ACCORDING TO PRIORITY.

RETURN VIA  
QPRET

RETURN IS IN INTWAKE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		MEASUREMENT INCORPORATED	
GRABER <i>J. G. J. 7/68</i>	<i>Ward</i>	COLOSSUS II FC-2610	
FRGME <i>R. G. J.</i>	<i>Latier</i>	APR 14 1968	
ANUSI <i>R. G. J.</i>	<i>Latier</i>	APR 14 1968	
DOCMF <i>R. G. J.</i>	<i>Latier</i>	APR 14 1968	
APPROV <i>John A. New</i>	<i>Latier</i>	APR 14 1968	

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
INSTALL	2290	RESERVES INTEGRATION ROUTINE	SH7
MOVEPCSM	2290	MOVECSM STATE VECTOR FROM PERMANENT TO TEMPORARY REGISTERS	SH10
MOVEPLEM	2290	MOVE LEM STATE VECTOR FROM PERMANENT TO TEMPORARY REGISTERS	SH10
RECTIFY	2290	ADDS DEVIATIONS TO CONIC POSITION AND VELOCITY	SH11
MOVEACSM	2290	MOVE CSM STATE VECTOR FROM TEMPORARY TO PERMANENT REGISTERS	SH11
MOVEALEM	2290	MOVE LEM STATE VECTORS FROM TEMPORARY TO PERMANENT REGISTERS	SH11
SVWDN1	2250	STORES CSM STATE VECTOR IN DOWNLINK REGISTERS	SH11
SVWDN2	2250	STORES LEM STATE VECTOR IN DOWNLINK REGISTERS	SH11
INTWAKE	2290	RELEASES INTEGRATION ROUTINE	SH12

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DMMENFLG FLAGWORD 5 BIT 9	W-MATRIX IS 9 DIMENSIONAL	W-MATRIX IS 6 DIMENSIONAL			SH3, 5, 8, 9, 12
REINTEFLG FLAGWORD 10 BIT 7	INTEGRATION ROUTINE TO BE RESTARTED	INTEGRATION ROUTINE NOT TO BE RESTARTED	SH7		
VEHUPFLG FLAGWORD 1 BIT 8	CSM STATE VECTOR BEING UPDATED	LEM STATE VECTOR BEING UPDATED			SH10, 11
MOONTHIS FLAGWORD 8 BIT 11	PERMANENT LM STATE VECTOR IN LUNAR SPHERE	PERMANENT LM STATE VECTOR IN EARTH SPHERE			SH10

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
EGRESS		RETURN FOR CALLING PROGRAM		(INTEGER)	2 <sup>14</sup>
W		W-MATRIX			VARIABLE
ZI	Z	VECTOR USED IN THE INCORPORATION			VARIABLE
TRIPA	A	SCALAR USED IN THE INCORPORATION			VARIABLE
VARIANCE	$\sigma^2$	INSTRUMENT ERROR VARIANCE			VARIABLE
BVECTOR	(b1, b2, b3)	GEOMETRY OF MEASUREMENT VECTOR			VARIABLE
TEMPVAR		TEMPORARY STORAGE FOR VARIANCE			VARIABLE
NORMGAM		NORMALIZING COUNT FOR GAMMA		(INTEGER)	2 <sup>14</sup>
GAMMA	$\gamma$	SCALAR USED IN THE INCORPORATION			VARIABLE
DELTAQ	$\Delta Q$	MEASUREMENT TRACKING DEVIATIONS			VARIABLE
OMEGA	$\omega$	STATISTICAL WEIGHTING VECTOR			VARIABLE
DELTA X	$\Delta X$	STATE VECTOR DEVIATIONS			VARIABLE
OMEGAM1, 2, 3		VECTOR USED IN THE INCORPORATION			VARIABLE
WIXA, WIXB		SCALARS USED FOR INDEXING		(INTEGER)	2 <sup>14</sup>
ZIXA, ZIXB		SCALARS USED FOR INDEXING		(INTEGER)	2 <sup>14</sup>
HOLDW		TEMPORARY STORAGE FOR W-MATRIX			VARIABLE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED COSMOS AND MATHEMATICS
MEASUREMENT INCORPORATION	
DRAWN: <i>J.H. Roberts</i> <span style="float: right;">CHECKED: <i>...</i></span> PROGRAM: <i>...</i> ANALYST: <i>...</i> DOCNO: <i>...</i> APPROV: <i>John A. Moore</i>	COSMOS II FC-2610 REV: <i>...</i>

## ERASABLE LOCATIONS USED (CONT'D)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TX789		TEMPORARY STORAGE FOR THIRD COMPONENT OF STATE VECTOR			VARIABLE
X789		THIRD COMPONENT OF STATE VECTOR			VARIABLE
TDELTA V	$\delta$	POSITION DEVIATION FROM CONIC		METERS	$2^{29}/2^{27}$
TNUV	$v$	VELOCITY DEVIATION FROM CONIC	METERS/SEC	METERS/SEC	$2^7/2^5$
RCV	$r_c$	CONIC POSITION		METERS	$2^{29}/2^{27}$
VCV	$v_c$	CONIC VELOCITY	METERS/SEC	METERS/SEC	$2^7/2^5$
PBODY		SCALE ADJUSTING VARIABLE		(INTEGER)	$2^{14}$
NOTE: VARIABLE INDICATES SCALING AND UNITS DEPEND ON CALLING PROGRAM. SEE FIG 1 TEST PACKAGE LEVEL II #72 FOR COLOSSUS, SUNDANCE, AND LUMINARY					

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
ZEROVECS		A VECTOR OF ZEROS		(INTEGER)	$(2^{28}, 2^{28}, 2^{28})$
DPI/4TH		DOUBLE PRECISION ONE FOURTH	1/4	.25	$2^0$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFRL/D GUIDANCE AND NAVIGATION	
MEASUREMENT INCORPORATION			
DESIGN <i>P. M. ...</i>	PROGRAM <i>P. M. ...</i>	ANALYST <i>R. ...</i>	DOCTR <i>R. ...</i>
APPR'D <i>John A. ...</i>			
		COLOSSUS II	FC-2610
		REV	Sheet 16 of 16

P30 EXTERNAL  $\Delta V$  MANEUVER AND  
P31 LAMBERT AIM POINT MANEUVER  
PRE-THRUST COMPUTATIONS

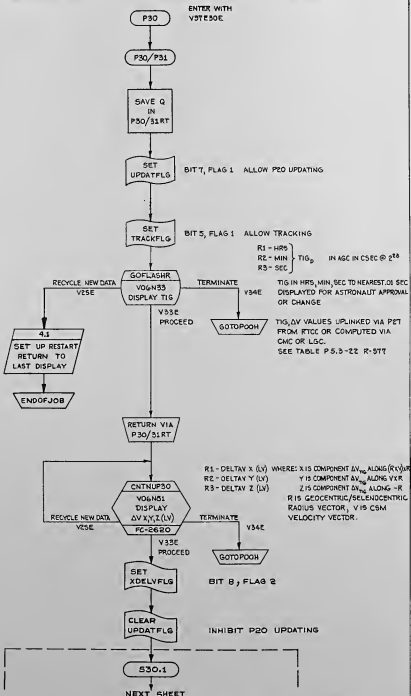
MAJOR SUBROUTINES

P30/P31 (USED BY P30 AND P31)  
S00.I (P30 ONLY)  
S01.I (P31 ONLY)

EXTERNAL ENTRY POINTS:

DISPMGA (SHS), CNTNUP30 (SH6)

NO. 1	FORM 16
INSTRUMENTATION LAB	GUIDANCE AND NAVIGATION
AKR 7111 NA-5	
AKR 7111 NA-5	P30/P31
DRAWN A.C. WILLIAMS 100000	EXTERNAL DELTA VELOCITY
PROGRAM <i>W. Williams</i> 7-14-65	REF ID: A6
ANALYST	COLLOSSUS II C FC-2620
CHKD BY <i>Stan Wilson</i> 7-14-65	
APPROV <i>John A. Moore</i> 14 April 65	12



R1 - HRS  
R2 - MIN  
R3 - SEC } TIG<sub>0</sub> IN ASC IN CSEC @ 2<sup>10</sup>

TIG IN HRS, MIN, SEC TO NEAREST .01 SEC DISPLAYED FOR ASTRONAUT APPROVAL OR CHANGE  
TIG, ΔV VALUES UPLINKED VIA PET FROM RTCC OR COMPUTED VIA CMC OR LSC.  
SEE TABLE P.5.5-22 R-977

R1 - ΔELTA X (LV) WHERE: X IS COMPONENT ΔV<sub>0</sub> ALONG (R)X/R  
R2 - ΔELTA Y (LV) Y IS COMPONENT ΔV<sub>0</sub> ALONG Y/R  
R3 - ΔELTA Z (LV) Z IS COMPONENT ΔV<sub>0</sub> ALONG -R  
R IS GEOCENTRIC/SELENCENTRIC RADIUS VECTOR, V IS CSM VELOCITY VECTOR.

MIT  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

DRAWN BY G.W. WILLIAMS  
PDCMR  
ANALYST  
DATE  
APPROV

ROCKET GUIDANCE AND NAVIGATION  
P30/P31  
EXTERNAL DELTA VELOCITY  
DOCUMENT ID  
FC-2620  
REV 2

FROM PRECEDING SHEET

SAVE  
QPRRT IN  
QTEMP

TDECI<sub>2</sub> ← TIG<sub>2</sub>

CSEC @ 2<sup>25</sup>

THIS PREC  
(SAME AS CSMPREC)  
UPDATE CSM  
TO TIG  
FC-2290

INPUT: TIG IN TDECI @ 2<sup>25</sup>  
OUTPUT: RAT<sub>v</sub> IN METERS @ 2<sup>29</sup>

RTX<sub>2</sub> ← X<sub>2</sub>

SAVE CONTENTS X<sub>2</sub> (0 EARTH, 2 MOON) @ 2<sup>24</sup>

YVIG<sub>v</sub> ← VATT<sub>v</sub>

STORE ACTIVE VEHICLE VELOCITY M/SEC @ 2<sup>27</sup>

RTIS<sub>v</sub> ← RAT<sub>v</sub>  
RACTS<sub>v</sub> ← RATT<sub>v</sub>

METERS @ 2<sup>29</sup>

$V_A = \text{UNIT} \left[ \begin{matrix} X(t_{12}) \\ Y(t_{12}) \end{matrix} \right]$   
UNRM<sub>v</sub> ←  $\underline{U}_A$

COMPUTE UNIT VECTOR OF ACTIVE VEHICLE (CSM)

LOWAT  
COMPUTES X<sub>v</sub>, Y<sub>v</sub>, Z<sub>v</sub>  
COMPONENTS IN  
INERTIAL COORDINATES  
OF LV UNIT VECTORS  
FC 2630 9H.15

INPUT: UNRM<sub>v</sub>, RACTS<sub>v</sub>  
OUTPUT: UNIT X<sub>v</sub> (LV) IN 00, OF PL  
UNIT Y<sub>v</sub> (LV) IN 00,  
UNIT Z<sub>v</sub> (LV) IN 120,  
PD POINTER AT 180

LV COORDINATES  
DEFINED THUS:  
 $X(LV) = Y \times Z$   
 $Y(LV) = -U_A$   
 $Z(LV) = -S_A$

$\Delta Y(\text{REC}) = M_{RP/LV}^T \Delta V_{LV}$   
DELVSIN<sub>v</sub> ←  $(\text{DELVS}_{LV} \times \text{OD}_{LV}) 2^{-1}$

TRANSFORM ACTIVE VEHICLE  $\Delta Y$  AT  
TIG FROM LV TO INERTIAL COORDINATES

RTX<sub>1</sub> ← X<sub>1</sub>  
MAG  $\Delta Y = |\Delta Y_{LV}|$   
VSDISP ← [DELVSIN]  
OD<sub>v</sub> ← RTIG<sub>v</sub>  
 $Y_i = \Delta Y_{LV} + Y(t_{12})$   
MPAC ← DELVSIN + YVIG

SAVE CONTENTS X<sub>1</sub> (-2, -10)

STORE ABSOLUTE VALUE OF  $\Delta Y$  IN BASIC  
REF. COORDINATES FOR DISPLAY.  
OBTAIN  $\pm Y$  OF ACTIVE VEHICLE AFTER  $\Delta Y$   
BURN FOR PERIAPOL TRAJECTORY CALCULATION

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		PERIODIC CONTROL AND NAVIGATION	
DRAWN A.C. WILLIAMS PREP BY J. W. ... ANALYST DOC# APPROV'G		P30/P31 EXTERNAL DELTA VELOCITY DOCUMENT # COLLOSSUS IIc FC-2620 REV 3 JUL 5 1962	

FROM PRECEDING SHEET



INPUT: CD RACTS }  $\Gamma_A, V_A$  POST-  
MPAC VACTS }  $\Delta V$  BURN  
OUTPUT: MPAC  $\leftarrow H_p$   
40  $\leftarrow H_a$  IN METERS @  $2^{27}/2^{10}$

$H_p \times 2^{-RTX1}$

SCALE  $H_p$  @  $2^{29}$  TO COMPENSATE FOR PINBALL SCALING.



CHECK  $H_p$  FOR VALUE GREATER  
THAN DSKY REGISTER CAPACITY.

HPR  $\leftarrow H_p$  OR 9999.9NM

STORE  $H_p$  OR 9999.9NM,  
WHICHEVER IS GREATER,  
IN METERS @  $2^{27}/2^{10}$

MPAC  $\leftarrow H_p \times 2^{RTX2}$

LOAD APOGEE HEIGHT ( $H_a$ )  
FROM 4D AND SHIFT RIGHT ON CONTENTS OF RTX2  
 $H_a @ 2^{29}$  M



HAPO  $\leftarrow H_a$  OR 9999.9

STORE APOGEE HEIGHT  $H_a$  IF LESS THAN  
9999.9NM, OTHERWISE  $H_a = 9999.9$  NM.

RETURN VIA  
Q TEMP

PKRAM 30

SAVE Q  
IN  
P30/31RT

GOLASH  
Y06 NAE  
DISPLAY  
 $H_p, H_a, \Delta V$

RECYCLE WITH NEW DATA

R0 - APOGEE HT. | ALTITUDE ABOVE LAUNCH PAD RADIUS (EARTH)  
R1 - PERIGEE HT. | OR MOST RECENT LANDING SITE TO NEAREST .1NM  
R2 - DELTA V | MAGNITUDE IN FPS TO NEAREST .1FPS.

ASTRONAUT WILL PROCEED AFTER GROUND COORDINATION OF PNA-  
METERS. IF GROUND COORDINATION IS NOT AVAILABLE, OPTIONS ARE:

- 1- PROCEED PERFORM THRUSTING MANUEVER  
USING UNCONFIRMED CMC VALUES.
- 2- ADJUST PARAMETERS THEN DO THRUSTING  
MANUEVER.
- 3- WAIT FOR GROUND COORDINATION.
- 4- RUN OTHER PROGRAMS, THEN 3.
- 5- SELECT NEW PROGRAM, USE BACKUP  
PROCEDURE.

TERMINATE

GOTDPOON

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS 11906408		P30/P31	
PROGRAM 11/16/62		EXTERNAL DELTA VELOCITY	
ANALYST		DOCUMENT NO.	
DOCTOR		COLOSSUS II C FC-2620	
APPROV		SHEET 4 OF 12	

FROM PRECEDING SHEET

REFTEST

REFPMFLAG SET ?

NO

YES

BIT 15,  
FLAG 3

NOTDET

OD ← OELVGIN

MGA ← -02°  
+ MGA ← -MARSOP

GET+MGA  
COMPUTE MGA  
STORE IN MPAC AS  
POSITIVE ANGLE  
FC-2641 54.10

REFPMFLAG SET = IMU ON, ALIGNED  
AND REFORMAT  
GOOD.

COMPUTE ANGLE BETWEEN  
IMU Y-AXIS AND ΔV.  
MGA = ARCSIN [ Y<sub>IMU</sub> / UNIT (ΔV) ]

FLASHMGA

DISPMGA

SAVE  
OPRET IN  
RGEXIT

COMPTGO  
START CLOCK-  
TASK TO COMPUTE  
TIDGO EACH 1SEC  
FC-2626 54.9

SCHEDULE COMPUTATION OF TFI =  
TIME TO IGNITION\* AT ONE SECOND  
INTERVALS (- BEFORE TIG, + AFTER).  
SET TIMERFLAG.  
\* NOTE TFI (TIME FROM IGNITION)  
AND TIDGO ARE THE SAME.

DISP45

GOFASHR  
V16N45  
DISPLAY MARKCOUNT,  
TFI, + MGA

SET UP RESTARTS  
AND IMMEDIATE RETURN

R1 - MARKCOUNT NO. OF MARKS  
PROCESSED BY P20.  
R2 - TFI\* TIME FROM TIG IN MIN (C  
SEC (MAX. READING: 50000,  
- BEFORE TIG, + AFTER)  
R3 - MGA MIDDLE GIMBAL ANGLE  
AT TIG. IF +X AXIS  
ALIGNED WITH THRUST  
VECTOR, DISPLAYED AS  
POSITIVE ANGLE WHEN IMU  
IS ALIGNED, SET TO -00000  
IF IMU NOT ALIGNED.

PROCEED

GOTOPOOH

PSOPHSI

4.1  
SET UP RESTART  
TO RETURN  
TO DISPLAY

STOP TFI 1 SEC COMPUTATION

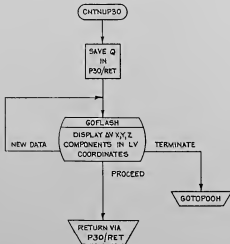
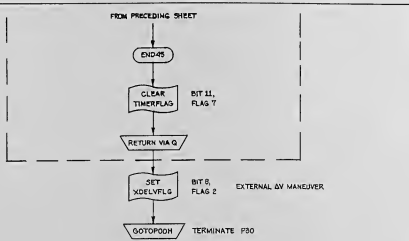
ENDOFJOB

NEXT SHEET

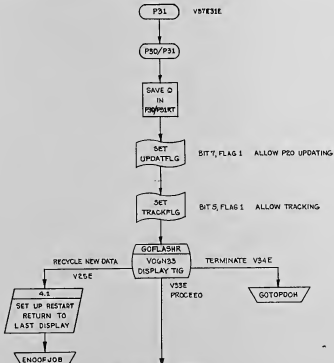
RETURN TO DISPLAY VIA PINDALL

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIC GUIDANCE AND NAVIGATION
DRAWN A. C. WILLIAMS PROGRAM 2322 ANALYST CHECKED APPROVED	P30/P31 EXTERNAL DELTA VELOCITY COLUSSUS II C FC-2620 REV 3





MIT INSTRUMENTATION '48 CAMBRIDGE, MASS.		ANSOLE CONTRACT AND MAINTENANCE	
SPAWN A.C. WILLIAMS		P30/P31 EXTERNAL DELTA VELOCITY	
PLUM	INDEXER	DOCUMENT NO.	
ANALYST	2.4.52	COLOSSUS IIc FC-2620	
DCMR	John S. Bell 11/15/52	REV 2	
APPRO	John S. Bell 11/15/52	4-11 6 / 12	



RETURN VIA P30/P31RT

CLEAR  
UPDATFLG  
& NDRMSH

S31.1

SAVE  
QPRET IN  
QTEMP

TDEC1 ← TIG<sub>0</sub>

AGAIN  
INTEGRATE CSM  
TO TIG, USE INTVEL  
TO COMPUTE TRANSFER  
PARAMETERS  
FC-2600 SH-35

INPUT: TIG<sub>0</sub> INTERCEPT IN CSEC @ 2<sup>13</sup>, RTIG<sub>0</sub> IN M @ 2<sup>13</sup>, DELTA = t<sub>0</sub> SEC @ 2<sup>13</sup>  
 OUTPUT: VYPRIME, INITIAL TRANSFER TRAJECTORY VELOCITY, ALL IN METERS/SEC  
 VYPRIME, TERMINAL TRANSFER VELOCITY @ 2<sup>7</sup>  
 DELVETS, INITIAL VELOCITY INCREMENT AT TIG TO ACHIEVE TRANSFER  
 RTIG<sub>1</sub> } CONTAINS RATE, @ TIG IN M @ 2<sup>13</sup>  
 RINT<sub>1</sub> }  
 VYIGV } CONTAINS VINT, @ TIG IN M/SEC @ 2<sup>7</sup>  
 VINT<sub>1</sub> }  
 ALSO RTX1 & RTXE (-2-10 @ QZ FOR EARTH/MOON SCALING)  
 DELTA = TIME OF FLIGHT (t<sub>0</sub> INTERCEPT t<sub>ig</sub>) IN CSEC  
 @ 2<sup>28</sup>

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APX10 GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P30/P31 EXTERNAL DELTA VELOCITY	
PREPARE	DATE	FC-2620	
ANALYST	REV	REV 2	
DOCK	REV	REV 2	
APPROV	REV	REV 2	

FC-2620  
REV 2

FROM PRECEDING SHEET

OD ← RTIG<sub>v</sub>  
MPAC ← VPRIME

POS. VEL. FOR PERIAP<sub>0</sub> IN M @ 2<sup>27</sup> AND M/CSEC @ 2<sup>7</sup>

PERIAP<sub>0</sub>  
COMPUTE H<sub>p</sub>, H<sub>a</sub>  
OF ACTIVE VEHICLE  
TRANSFER ORBIT  
FC-2641 SHLD

INPUT: OD-RACT3 } X<sub>A</sub>, Y<sub>A</sub> AT BEGINNING OF  
MPAC-VACT3 } TRANSFER TRAJECTORY  
OUTPUT: MPAC - H<sub>p</sub> }  
40 - H<sub>a</sub> } IN M @ 2<sup>29</sup>/2<sup>27</sup>

H<sub>p</sub> X 2<sup>-RTX2</sup>

SCALE FOR PINBALL

MAXCHK  
IF H<sub>p</sub> > 9999.9  
NM, REPLACE H<sub>p</sub>  
WITH 9999.9NM  
FC-2325

CHECK H<sub>p</sub> FOR VALUE GREATER THAN DSKY  
REGISTER CAPACITY

H<sub>PER</sub> ← H<sub>p</sub> OR 9999.9NM

STORE H<sub>p</sub> OR 9999.9NM,  
WHICHEVER IS GREATER IN M @ 2<sup>23</sup>

H<sub>a</sub> X 2<sup>-RTX2</sup>

SCALE H<sub>a</sub> FOR PINBALL

MAXCHK  
IF H<sub>a</sub> > 9999.9  
NM, REPLACE H<sub>a</sub>  
WITH 9999.9NM  
FC-2325

LIMIT H<sub>a</sub> AT 9999.9NM FOR DSKY

H<sub>AP0</sub> ← H<sub>a</sub> OR 9999.9NM

STORE APGEE ALTITUDE (9999.9NM IF H<sub>a</sub>  
EXCEEDS REGISTER CAPACITY) IN M @ 2<sup>23</sup>

OD ← DELVEET3

ΔV AT TIG TO INITIATE TRANSFER  
IN M/CSEC @ 2<sup>7</sup> (INERTIAL COORDINATES)

SET  
AVFLAG

OBTAINS LV CONVERSION OPTION IN MIDGIM

MIDGIM  
CONVERT ΔV FROM  
INERTIAL TO LV  
FOR DISPLAY  
FC-2641 SHLD

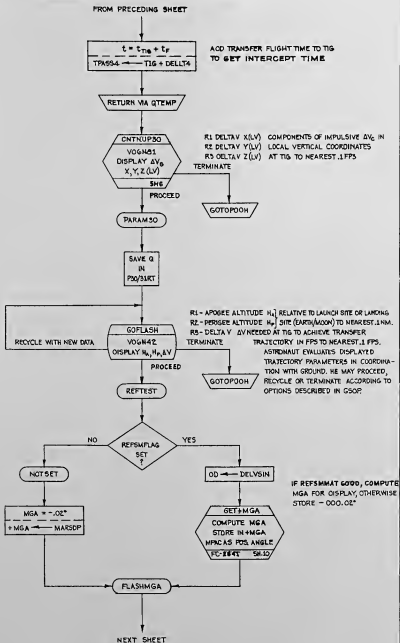
INPUT: AVFLAG & COMPUTER (BOTH SET)  
DELVEET<sub>v</sub> IN OD<sub>v</sub>, RINIT<sub>v</sub>, AND VINIT,  
(EARTH SCALING)  
OUTPUT: DELVLVC<sub>v</sub> = ΔV CONVERTED TO LV COORDINATES  
IN M/CSEC @ 2<sup>7</sup>  
MGLVFLAG SET INDICATING ΔV TRANSFORMED

VGDISP ← DELVLVC

STORE ΔV<sub>LV</sub> FOR DISPLAY IN M/CSEC @ 2<sup>7</sup>

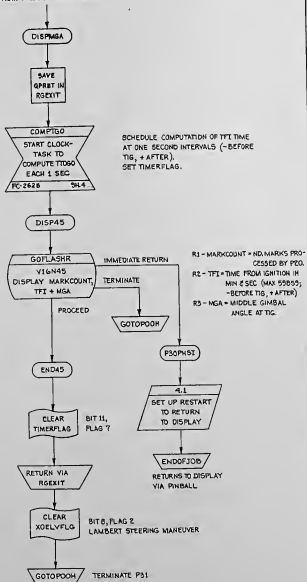
NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT GUIDANCE AND NAVIGATION	
DRAWN BY: A.C. WILLIAMS		P30/P31	
DATE: 1/11/67		EXTERNAL DELTA VELOCITY	
ANALYST: [Signature]		DOCUMENT NO.	
SYNOPSIS: [Signature]		COLLOSSUS IIC	
APPROVED: [Signature]		FC-2620	
		REV 2	
		PAGE 6 OF 12	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS		P30/P34 EXTERNAL DELTA VELOCITY
PREPARED	1/27/64	DOCUMENT NO.
ANALYST	FC-2841	FC-2620
DOCWR	John A. Williams	REV 1
APPROV	14 April 64	9 12

FROM PRECEDING SHEET



R1 - MARKCOUNT = NO. MARKS PROCESSED BY PED.  
R2 - TFI = TIME FROM IGNITION IN MIN & SEC (MAX 99999);  
-BEFORE TIG, +AFTER  
R3 - MGA = MIDDLE GIMBAL ANGLE AT TIG.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AF-510 GUIDANCE AND NAVIGATION	
		P30/P34 EXTERNAL DELTA VELOCITY	
DR. REV. A. C. WILLIAMS	BOOK NO.	COLONEL'S IIC	FC-2620
DATE: 7/2/61	6-6-61		
APPROV. [Signature]	REV. 2		10 12

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
THISPREC	FC-1350	UPDATES CSM TO TORC1 TIME	SH. 3
LOMAT	FC-1740	CONVERTS REF TO LV COORDINATES	SH. 3
PERIAP01	FC-1780	COMPUTES $H_p$ , $H_A$ OF ACTIVE VEHICLE	SH. 4, 8
MAXCHK	FC-2325	LIMITS $H_p/H_A$ AT DSKY REGISTER CAPACITY 9999.9 NM	SH. 4, 8
GET+MGA	FC-1760	COMPUTES MIDDLE GIMBAL ANGLE	SH. 5, 9
COMPTGO	FC-1710	COMPUTES TFI (VIA CLOCTASK) AT ONE SEC. INTERVALS	SH. 5, 10
AGAIN	FC-2680	INTEGRATES CSM TO TIG AND USES $r(t_{IG})$ , $v(t_{IG})$ IN INITVEL TO COMPUTE	SH. 7
MIDGIM	FC-1760	CONVERTS $\Delta V$ FROM INERTIAL TO LV COORDINATES	SH. 8

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
UPDATFLG BIT7, FLAG1	ALLOW P20 UPDATING	DISALLOW P20 UPDATING	SH. 2, 7	SH. 2, 7	
TRACKFLG BITS, FLAG1	ALLOW TRACKING	DISALLOW TRACKING	SH. 2, 7		
REFSMFLAG BIT13, FLG3	REFSMAT GOOD	REFSMAT NOT AVAILABLE			SH. 5, 9
TIMERFLAG BIT11, FLG7	CONTINUE 1 SEC. TFI CLOCTASK	STOP COMPUTING TFI	SH. 6, 10	SH. 6, 10	
XDELVFLG BITS, FLAG2	EXTERNAL $\Delta V$ MANEUVER	LAMBERT STEERING MANEUVER	SH. 1, 6	SH. 10	
NORMSW BIT10, FLG7	UNIT NORMAL COMPUTED	LAMBERT MUST COMPUTE UNIT NORMAL		SH. 7	
AVFLAG	LM ACTIVE ON THIS CASE USED TO SELECT LV CONVERSION OPTION IN MIDGIM)	CSM ACTIVE	SH. 8		

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N3	FLASHING	R1, R2, R3 CONTAIN TIG IN HRS, MIN & SEC, RESPECTIVELY	SH. 2, 7
V06N81	FLASHING	R1, R2, R3 CONTAIN DELTA V X, Y & Z COMPONENTS IN LOCAL VERTICAL COORDINATES	SH. 2, 9
V06N42	FLASHING	DISPLAYS $H_A$ , $H_p$ , $\Delta V$ FOR TRANSFER TRAJECTORY	SH. 4, 9
V16N45	FLASHING	DISPLAYS MARKCOUNT, TFI & +MGA	SH. 5, 10

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	APR 11 DANCE AND MANLEY
<i>P.M. Dietrich</i>	P30/P31 EXTERNAL DELTA VELOCITY
10-100 10-100 10-100	COLOSSUS II FC-2620
<i>John A. Brown</i>	11 12

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
P30/31RT		RETURN ADDRESS FOR P30			
TDEC1	$t_{IG}$	STORAGE LOC FOR TIME $t_{IG}$ INTEGRATED TO	HRS, MIN, SEC	CSEC	$2^{28}$
VTIG <sub>V</sub>		ACTIVE VEHICLE VELOCITY AT TIG	FPS	M/CSEC	$2^7$
RTIG <sub>V</sub>		ACTIVE VEHICLE POSITION AT TIG	NAUTICAL MILES	METERS	$2^{28}$
RACT3 <sub>V</sub>		SAME AS RTIG	NAUTICAL MILES	METERS	$2^{27}/2^{29}$
UNRM <sub>V</sub>	$\underline{u}_{TD}$	UNIT VECTOR OF ACTIVE VEHICLE			$2^1$
DELVSIN <sub>V</sub>	$\Delta v_{LV}$	STORAGE LOC FOR $\Delta v_{LV}$	FPS	M/CSEC	$2^7$
VGDISP	$ \Delta v_{LV} $	STORAGE LOC FOR $ \Delta v_{LV} $	FPS	M/CSEC	$2^7$
HPER	$H_P$	PERIGEE HEIGHT STORAGE LOC	NM	METERS	$2^{29}$
HAPO	$H_A$	APOGEE HEIGHT STORAGE LOC	NM	METERS	$2^{29}$
RTARG	$r(t_T)$	AIM POINT TARGET VECTOR FOR INITVEL (CALLED BY AGAIN)	NM	M	$2^{29}$
TDELL4	$t_F$	TIME OF FLIGHT FROM RINT TO RTARG	M	CSEC	$2^{28}$
VIPRIME		INITIAL TRANSFER VELOCITY	FPS	M/CSEC	$2^7$
VTPRIME		TERMINAL TRANSFER VELOCITY	FPS	M/CSEC	$2^7$
RINT		SAME AS RTIG, VTIG ABOVE	NM	M	$2^{29}$
VINIT		EXCEPT EARTH SCALING	NM	M/SEC	$2^7$

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
MARSDP	-000, 02 <sup>D</sup>	IMU/REFSMAT NOT READY FOR MGA COMP.	DEGREES	REV	$2^0$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DRAWN <i>P.M. Dutton</i> 10 FEB 68		P30/P31 EXTERNAL DELTA VELOCITY	
CHECKED <i>[Signature]</i> 4/16/68		COLOSSUS II C	
APPROV <i>[Signature]</i> 4/16/68		FC-2620 REV 3	

P32, P72- CO-ELLIPTIC SEQUENCE INITIATION

THE ENCLOSED REPLACEMENT SHEET  
WILL UPDATE THE COLOSSUS II FLOW  
CHART FC-2626, REV. 0 TO THE  
COLOSSUS II-A FLOW CHART FC-2626, REV. 1

THE EFFECTIVE SHEETS FOR COLOSSUS  
II-A FC-2626, REV. 1

1 - 22	REV. 0
23	REV. 1
24 - 26	REV. 0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
DESIGN <i>St. J. Lawrence</i>	277910	DOCUMENT NO. FC-2626	
PERFORM		COLOSSUS II-A	
ANALYST <i>H. Berggren</i>	<i>J. Rouse</i>	REV. 1	
DOCK <i>Paul Hill</i>	<i>St. J.</i>	SHEET 1 OF 26	
APPROV <i>Stella M. Lawrence</i>			



FROM SHEET 6

P32/PT2B

ADVANCE

PROG: INIT INTERSECTION OF  
ACTIVE AND PASSIVE VEHICLE  
STATE VECTORS TO TIME (T<sub>1</sub>)

SHA

INPUT: TIG, AVFLAG

OUTPUT: RPASS1, T<sub>P1</sub> POSITION OF PASSIVE VEHICLE AT CSI  
VPASS1, V<sub>P1</sub> VELOCITY OF PASSIVE VEHICLE AT CSI  
RACT1, V<sub>A1</sub> POSITION OF ACTIVE VEHICLE AT CSI  
VACT1, V<sub>A1</sub> VELOCITY OF ACTIVE VEHICLE AT CSI  
UPL = UNIT((T<sub>P1</sub> × V<sub>P1</sub>) UNIT NORMAL TO PLANE OF PASSIVE VEHICLE  
XDELVPLG = 1 EXTERNAL DELTA V MANEUVER (NOT LAMBERT AIRPORT)

OD<sub>OP</sub> ← VPASS1<sub>y</sub>  
GD<sub>OP</sub> ← RPASS1<sub>x</sub>  
12D<sub>OP</sub> ← TC91<sub>OP</sub>  
14D<sub>OP</sub> ← TTPT<sub>OP</sub>  
16D<sub>OP</sub> ← 2PI9C × R<sup>2</sup>

V<sub>P1</sub> = VEL VECTOR OF PASSIVE VEHICLE AT CSI  
P<sub>P1</sub> = POS. VECTOR OF PASSIVE VEHICLE AT CSI  
t<sub>1</sub> = TIME OF CSI MANEUVER  
t<sub>2</sub> = TIME OF TPI MANEUVER  
DO CONIC INTEGRATION

INTINT

CONIC INTEGRATION  
OF PASSIVE VEHICLE  
STATE VECTOR TO  
TPI TIME

FC-2630

INPUT: 16D<sub>OP</sub>, 14D<sub>OP</sub>, 12D<sub>OP</sub>, GD<sub>OP</sub>, OD<sub>OP</sub>, PFX1, RTK2  
OUTPUT: RATT<sub>y</sub> = T<sub>P2</sub> POSITION OF PASSIVE VEHICLE AT CSI  
VATT<sub>y</sub> = V<sub>P2</sub> VELOCITY OF PASSIVE VEHICLE AT CSI

PASSIVE

RPASS3<sub>y</sub> ← RATT<sub>y</sub>  
VPASS3<sub>y</sub> ← VATT<sub>y</sub>

FC-2641

STATE VECTOR OF PASSIVE VEHICLE AT TPI

CSI/A

COMPUTE CSI/COH  
MANEUVER PARAMETERS  
ISSUE ALARM IF NO  
SOLUTION CAN BE ATTAINED

SH10

INPUT: RACT1, VACT1, RPASS1, VPASS1, UPL, RPASS2, VPASS2,  
TCL<sub>OP</sub>, TPI<sub>OP</sub>, VDELVE<sub>OP</sub>, ASSUM<sub>OP</sub>, PFA<sub>OP</sub>, RTK1, RTK2  
OUTPUT: DELVEET<sub>OP</sub> = ΔY REQUIRED AT CSI  
DELVEET<sub>COH</sub> = ΔY REQUIRED AT COH  
T2TOT<sub>OP</sub> = TIME FROM CSI TO COH  
T2TOT<sub>COH</sub> = TIME FROM COH TO TPI  
DIFFALT<sub>OP</sub> = ALTITUDE BETWEEN ACTIVE AND  
PASSIVE VEHICLE ORBITS AT COH  
RACT2<sub>OP</sub> = POSITION OF ACTIVE VEHICLE  
AT COH

P32/PT2C

FINAL FLG  
SET

SET INDICATES LAST PASS THRU RENDEZVOUS PROGRAM COMPUTATIONS

SET UPDATFLG

ALLOW PPO UPDATING

P32/PT2D

MPAC<sub>OP</sub> ← T1TOT<sub>OP</sub>ΔT<sub>2</sub> TIME FROM CSI TO COH

TO NEXT PAGE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION P32 AND PT2 CO-ELLIPTIC SEQUENCE INITIATION	
DESIGNER A. GUYTON/JAMES	DATE 1-28-59	COLLUSION III	DOCUMENT NO. FC-2626
ANALYST R. GUYTON	DATE 2-18-59		
ENGINEER R. GUYTON	DATE 2-18-59	REV 1	SHEET 2 OF 2

FROM  
PRECEDING PAGE

P32/P72E

T1TOT2<sub>DP</sub> ← MPAC<sub>DP</sub>

MPAC<sub>DP</sub> ← T1TOT2<sub>DP</sub> - 60MIN<sub>DP</sub>

MPAC<sub>DP</sub> ≥ 0 ?

SET TIME FROM CSI TO CDH < 60 MIN.

MPAC<sub>DP</sub> ← T2TOT3<sub>DP</sub>

ΔT<sub>3</sub> TIME FROM CDH TO TPI

P32/P72F

T2TOT3<sub>DP</sub> ← MPAC<sub>DP</sub>

MPAC<sub>DP</sub> ← T2TOT3<sub>DP</sub> - 60MIN<sub>DP</sub>

SET TIME FROM CDH TO TPI < 60 MIN.

MPAC<sub>DP</sub> ≥ 0 ?

R1 = DIFFALT<sub>DP</sub> = ALTITUDE BETWEEN ACTIVE AND PASSIVE VEHICLES AT CDH IN NM.  
R2 = T1TOT2<sub>DP</sub> = Δt BETWEEN CSI AND CDH MANEUVERS IN MIN AND SEC.  
R3 = T2TOT3<sub>DP</sub> = Δt BETWEEN CDH AND TPI MANEUVERS IN MIN AND SEC.

VNPDOH  
VO6N75  
DISPLAY CSI/CDH  
PARAMETERS  
FC-2630

PROCEED

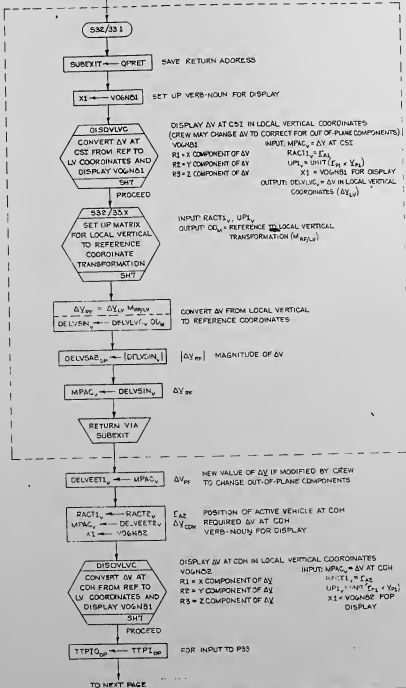
MPAC<sub>V</sub> ← DELVEETS

REQUIRED ΔV FOR CSI MANEUVER

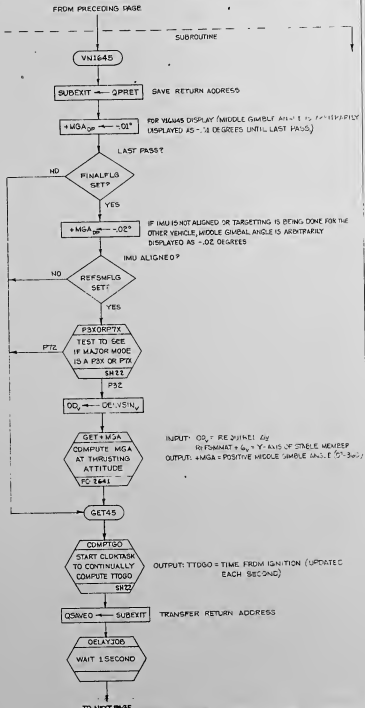
TO NEXT PAGE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		P32 AND P72	
PROGRAM <i>[Signature]</i>		CO-ELLIPTIC SEQUENCE INITIATION	
ANALYST <i>[Signature]</i>		COLOSSUS	
DOCOR <i>[Signature]</i>		II	
APPROV <i>[Signature]</i>		DOCUMENT NO. FC-2626	
		SHEET 3 OF 25	

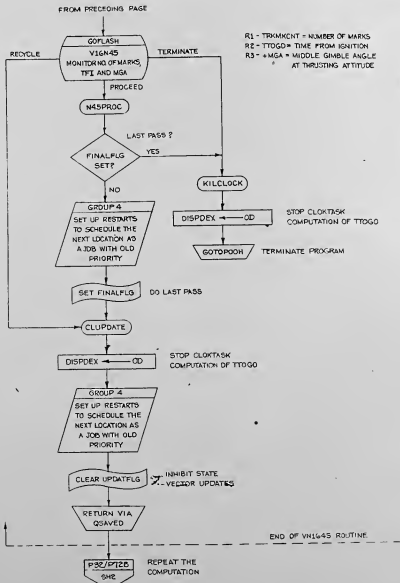
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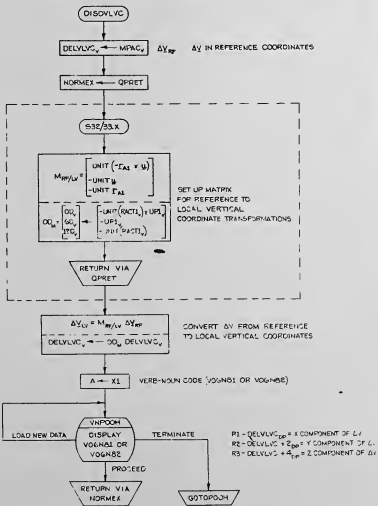
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
BRANCH A.C. WILLIAMS		PSE AND PPE	
PROGRAM <i>Flight</i>		CO-ELLIPTIC SEQUENCE INITIATION	
ANALYST <i>M. Thompson</i>		DOCUMENT NO.	
DOCAM <i>W. J. ...</i>		COLOSSUS II	FC-2626
APPROV <i>J. ...</i>		REV 1	SHEET 4 OF 25



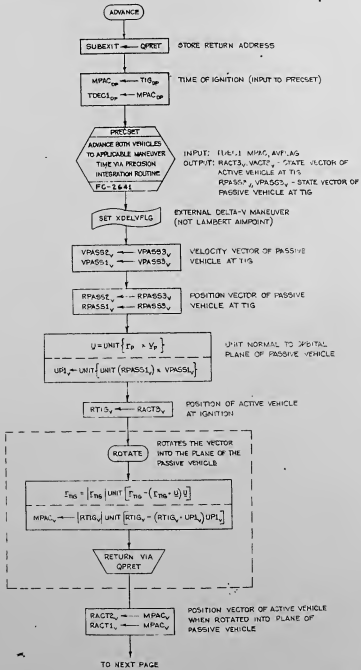
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		PSE AND PTZ CO-ELLIPTIC SEQUENCE INITIATION	
DRWEN	L.C. WILLIAMS	4-25-66	
PROGR	<i>R. Williams</i>	7-22-66	
ANALST	<i>R. Williams</i>		DOCUMENT NO.
BOOKR	<i>Robert Shuttle</i>		COLOSSUS II
APPRD	<i>John H. ...</i>	6-7-66	FC-2626
REV I			SHEET 5 OF 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARJOL DISTANCE AND NAVIGATION	
		P32 AND PT2	
		CO-ELLIPTIC SEQUENCE INITIATION	
BRNTH	A.C. WILLIAMS	4-24-60	
PRGRM	<i>Prolog</i>	7-22-62	
ANALY	<i>[Signature]</i>		DOCUMENT NO.
NOCHR	<i>[Signature]</i>		COLDGUS III
APPRO	<i>[Signature]</i>	6-9-61	FC-2626
		REV 1	SHEET 6 OF 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P52 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN A.C. WILLIAMS	4-25-65	COLDEGUS II	DOCUMENT NO.
PROG. P52/72	8-11-65		FC-2626
ANALYST J. Williams		REV 1	SHEET 7 OF 25
BOOK Manual (P52/72)	4-25-65		
APPROV. J. Williams	4-7-65		



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$VTIG_v \leftarrow VACTE_v$

VELOCITY OF ACTIVE VEHICLE AT IGNITION

ROTATE

$$V_{TIG} = |V_{ng}| \text{ UNIT } [Y_{ng} - (Y_{ng} \cdot W) Q]$$

$$MPAC_v \leftarrow |VTIG_v| \text{ UNIT } [VTIG_v - (VTIG_v \cdot UPL_v) UPL_v]$$

RETURN VIA  
QORET

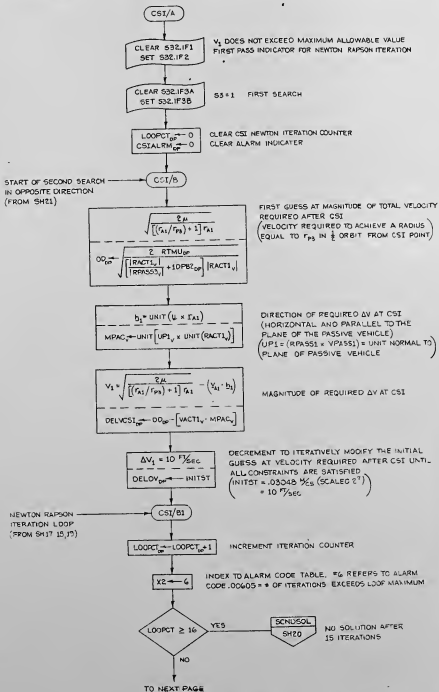
$VACTE_v \leftarrow MPAC_v$   
 $VACTI_v \leftarrow MPAC_v$

VELOCITY VECTOR OF ACTIVE VEHICLE  
ROTATED INTO PLANE OF PASSIVE  
VEHICLE

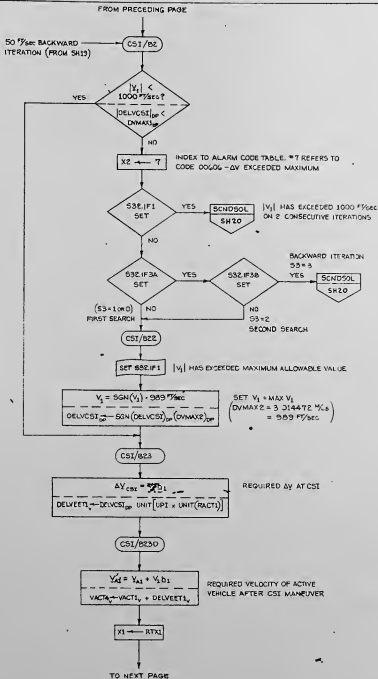
RETURN VIA  
SUBEXIT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P32 AND I72 CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN: A.C. WILLIAMS	6-9-60	COLOSSUS II	DOCUMENT NO. FC-2626
FIGURE: <i>Prologue</i>	2-22-61		SHEET 3 OF 16
ANALYST: <i>R. Langley</i>			
DOOR: <i>Richard Stoddard</i>	<i>6-2-61</i>		REV 1





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
ARMY A.C. WILLIAMS 2-25-68		P32 AND P72	
PRGR: P32/42		CO-ELLIPTIC SEQUENCE INITIATION	
ANALST: P32/42		DOCUMENT NO.	
DOCTR: P32/42		COLOSSUS II	FC-2626
APPR: J. H. H. 1/27/68		REV 1	SHEET 10 OF 15



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO ORBITANCE AND NAVIGATION	
DESIGNER: A.C. WILLIAMS		PBR AND P72	
PROGRAM: Apollo 11		CO-ELLIPTIC SEQUENCE INITIATION	
ANALYST: [Signature]		DOCUMENT NO.	
SCHEMATIC: [Signature]		COLLISION # 11	
APPROVED: [Signature]		FC-2626	
DATE: 6-2-68		SHEET 11 OF 19	

FROM PRECEDING PAGE

$$\begin{aligned} VVEC_{op} &= VACTA_{op} & Y_{A1} \\ RVEC_{op} &= RACT1_{op} & E_{A1} \end{aligned}$$

SET RVSW

DO NOT COMPUTE STATE VECTOR DURING TIME-THETA, JUST OBTAIN SPECIFIED TIME

$$\begin{aligned} SNTH_{op} &= SN35ST \\ CSTH_{op} &= CS35ST \\ 1 - CSTH_{op} &= 0 \end{aligned}$$

$\theta = 359.99^\circ (= 1 \text{ ORBIT}) - \text{THE TRUE ANOMALY ANGLE USED TO COMPUTE PERIOD } t_p$

TIMETHET

OBTAIN PERIOD ( $t_p$ ) OF NEW ORBIT  
FC-2310

INPUT: RVEC, VVEC, SNTH, CSTH, RVSW, X1  
OUTPUT: MPAC<sub>op</sub> =  $t_p$  CS

$$HAFFAT_{op} = \frac{1}{2} MPAC_{op}$$

TIME BETWEEN APSIDAL CROSSINGS

$$X1 = RTX1$$

PERIAPO  
COMPUTE APOGEE AND PERIGEE ALTITUDE ALSO APOCENTER AND PERICENTER RADIUS  
FC-2641

INPUT: RVEC, VVEC, X1  
OUTPUT: ECC = ECCENTRICITY OF CONIC TRAJECTORY (e) (SCALE =  $10^3$ )  
MPAC = PERIGEE ALTITUDE AFTER CSI  
 $R1 = |RVEC_{op}|$   
 $P_{op} = \frac{\text{SEMI-MAJOR AXIS}}{P_1}$

$$POSTCSI_{op} = MPAC_{op}$$

$h_{p1}$  PERIGEE ALTITUDE AFTER CSI MANEUVER

NO CENTANG = 0?

IF CENTANG IS NOT ZERO, ASTRONAUT HAS USED 180° OPTION.

YES

YES  $e < .0001$ ?

CIRCULAR ORBIT?

YES

CIRCULAR ORBIT

NO

$ONEITH = .0001$  (SCALED  $10^3$ )

NO

YES  $|V_{op}| < 7 \text{ } \mu\text{SEC}$ ?

IS THE VERTICAL VELOCITY ( $V_{op}$ ) AT THE CSI POINT LESS THAN  $7 \text{ } \mu\text{SEC}$ ?

YES

CSI IS AT AN APSIS

NO

NOW CALCULATE THE ANGLE  $\psi$  FROM CSI TO THE NEAREST PERIGEE. THEN COMPUTE TIME OF FLIGHT THERE TO,  $\Delta t$ , WHICH IS USED TO DETERMINE  $t_{CON}$

$$\begin{aligned} e \cos \psi &= \frac{P_1}{P_{op}} - 1 \\ 14D_{op} &= \frac{P_1}{P_{op}} - 10P2_{op} \end{aligned}$$

ECCENTRICITY  $\times$  COS OF TRUE ANOMALY ANGLE (TRANSFER ANGLE FROM CSI TO PERIGEE)

TO NEXT PAGE

CIRCL  
SH14

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P3E AND P7E	
		CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN A.C. WILLIAMS	4-52-68	COLOSSUS II	DOCUMENT NO.
PROGRAM	4-21-68		FC-2626
ANALYST			
DESIGNER			
APPROVER			
			SHEET 13 OF 18

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CSI/DS

$$RDOTV_{DP} = \frac{E_{A1} \cdot Y_{A1}}{R_{1DP}} - RACTL_V \cdot VACT4_V$$

$$e \sin \psi = \left| \frac{E_{A1} \cdot Y_{A1}}{R_{1DP}} \right| \sqrt{\frac{R_1}{R_{1DP}^2}}$$

$$IP_{DP} = |RDOTV_{DP}| \sqrt{\frac{R_{1DP} R_{1DP}}{RTSR1/MU_{DP}}} \frac{RTSR1/MU_{DP}}{R_{1DP}}$$

ECCENTRICITY X SIN OF TRUE ANOMALY ANGLE  
(TRANSFER ANGLE FROM CSI TO PERIGEE)

160<sub>DP</sub> ← 0

$$\begin{pmatrix} \sin \psi \\ \cos \psi \\ 0 \end{pmatrix} = \text{UNIT} \begin{pmatrix} e \sin \psi \\ e \cos \psi \\ 0 \end{pmatrix}$$

$$MPAC_{DP} \leftarrow \text{UNIT} \begin{pmatrix} 120_{DP} \\ 140_{DP} \\ 160_{DP} \end{pmatrix}$$

UNITIZING HAS THE EFFECT OF  
DIVIDING BY e

SIN<sub>DP</sub> ← MPAC<sub>DP</sub> SIN ψ

COS<sub>DP</sub> ← (MPAC 43)<sub>DP</sub> COS ψ

X1 ← RTX1

$$-SGN(E_{A1} \cdot Y_{A1}) Y_{A1}$$

$$VVEC_{DP} \leftarrow -SGN(RDOTV_{DP}) VACT4_V$$

MAKE  $Y_{A1}$  POSITIVE IF ITS VERTICAL COMPONENT  
POINTS DOWN, NEGATIVE IF ITS VERTICAL  
COMPONENT POINTS UP  
THIS ENSURES THAT THE TIME OF FLIGHT CALCU-  
LATED BY TIMETHET WILL BE TO THE NEAREST  
PERIGEE.

SET RVS<sub>W</sub>

DO NOT UPDATE STATE VECTOR,  
JUST COMPUTE ΔL DURING TIMETHET ROUTINE

RVEC<sub>DP</sub> = RACTL<sub>W</sub> E<sub>A1</sub>

TIMETHET  
COMPUTE ΔL THE TIME  
OF FLIGHT FROM THE  
CSI POINT TO THE  
NEAREST PERIGEE  
FC=2310

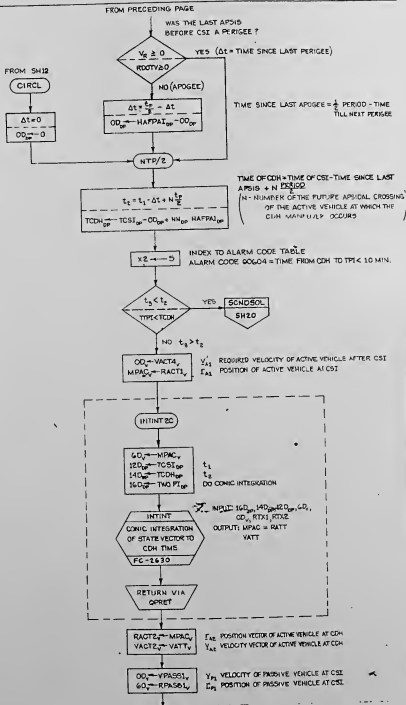
INPUT: COS<sub>DP</sub>, SIN<sub>DP</sub>, RVEC, +SG X1, RVS<sub>W</sub>  
OUTPUT: MPAC

OD<sub>DP</sub> ← MPAC<sub>DP</sub>

MPAC = ΔL  $\begin{cases} = \text{TIME TILL NEXT PERIGEE, IF } V_{\psi} < 0 \\ = \text{TIME SINCE LAST PERIGEE, IF } V_{\psi} > 0 \end{cases}$

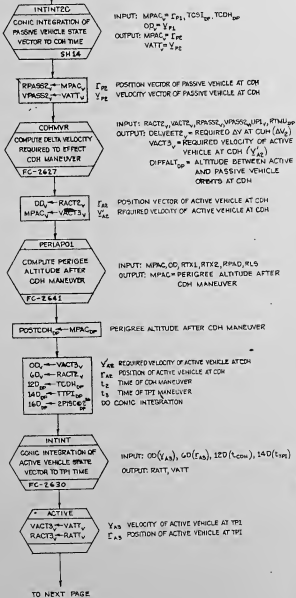
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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		- APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILSONS		PS2 AND P72	
PDRW <i>[Signature]</i>		CO-ELLIPTIC SEQUENCE INITIATION	
ANALYST <i>[Signature]</i>		COLOSSUS II	DOCUMENT NO.
DOCSM <i>[Signature]</i>			FC-2626
APPR <i>[Signature]</i>		4-7-66	SHEET 13 OF 28



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLO GUIDANCE AND NAVIGATION	
		PSE AND PTE CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN A.C. WILLIAMS	4-30-68	COLOMBUS II	FC-2620
PROVIN <i>[Signature]</i>	5-12-68		
WORKED <i>[Signature]</i>	<i>[Signature]</i>	REV 1	SHEET 2 OF 11

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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		SPOLLO DISTRANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PDC AND PTE	
PRODR: <i>[Signature]</i>		CO-ELLIPTIC ORBITANCE INITIATION	
ADMIN: <i>[Signature]</i>		COLOSSUS II	DOCUMENT NO.
CHECKED: <i>[Signature]</i>		REV 1	FC-2626
APPROVED: <i>[Signature]</i>		REV 1	SHEET 13 OF 15

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$$u_1 = \cos \epsilon \text{ UNIT}(u_1 \times r_{A2}) + \sin \epsilon \text{ UNIT}(r_{A1})$$

$$OD_v \leftarrow \cos(\text{ELEV}) \text{ UNIT}[\text{MPC}_v \times \text{UNIT}(\text{RACTS}_v)] + \sin(\text{ELEV}) \text{ UNIT}(\text{RACTS}_v)$$

DESIRED LINE-OF-SIGHT FROM ACTIVE VEHICLE TO PASSIVE VEHICLE AT TPT

ELEV<sub>pp</sub> = DESIRED ANGLE BETWEEN THE LM/SM LOS AND THE HORIZONTAL PLANE OF THE ACTIVE VEHICLE AT TPT

$$C_1 = r_{A2} \cdot B_1$$

$$MPC_{pp} \leftarrow \text{RACTS}_v \cdot OD_v$$

$$C_2 = C_1^2 - r_{A2}^2 + r_{A3}^2$$

$$MPC_{pp} \leftarrow \text{RACTS}_v \cdot \sqrt{r_{A3}^2 + \text{RACTS}_v^2} + \text{RACTS}_v \cdot \sqrt{r_{A3}^2 + \text{RACTS}_v^2}$$

REAL SOLUTION?  
(X DOES NOT INTERSECT)  
NO (CIRCLE OF RADIUS  $r_{A3}$ )

LOOPCT ← LOOPCT - 1 DISCOUNT THE LAST LOOP

XZ ← -1  
GO TO ALARM CODE TABLE (ALARM CODE 600 = HAZARD) (ROOTS ON FIRST ITERATION)

LOOPCT = 0 FIRST ITERATION?

YES

ALMXTA  
SHZ1

NO  
 $\Delta V_1 = \frac{1}{2} \Delta V_1$   
DELIN<sub>pp</sub> ←  $\frac{1}{2}$  DELIN<sub>pp</sub> REDUCE ITERATION DECREMENT BY  $\frac{1}{2}$

$V_1 = V_0 - \Delta V_1$   
DELIN<sub>pp</sub> ← DELIN<sub>pp</sub> - DELIN<sub>pp</sub> REDUCE ESTIMATE OF REQUIRED  $\Delta V$  AT CSI AND TRY AGAIN

CSI/D1  
SH10

DETERMINE A RADIUS VECTOR  $B_1$  OF THE SAME LENGTH AS  $r_{A2}$  THAT INTERSECTS THE DESIRED LINE-OF-SIGHT,  $u_1$

$$B_1 = r_{A2} \cdot X u_1$$

$$B_1^2 = r_{A2}^2 = r_{A2}^2 + 2k(r_{A2} \cdot u_1) + k^2$$

$$k^2 + 2k(r_{A2} \cdot u_1) + (r_{A2}^2 - r_{A2}^2) = 0$$

$$k = -(r_{A2} \cdot u_1) \pm \sqrt{(r_{A2} \cdot u_1)^2 - (r_{A2}^2 - r_{A2}^2)}$$

$$k = -C_1 \pm \sqrt{C_2}$$

YES

K1 OR K2

$$K_2 = -C_1 - \sqrt{C_2}$$

$$100_{pp} \leftarrow -60_{pp} - \sqrt{MPC}$$

$$K_1 = -C_1 + \sqrt{C_2}$$

$$120_{pp} \leftarrow -60_{pp} + \sqrt{MPC}$$

YES ( $K_1 > K_2$ )  
NO ( $K = K_1$ )

$$100_{pp} \leftarrow 120_{pp} \quad K_1$$

XZ

$$\text{UNIT } B_1 = \text{UNIT}(r_{A2} + K u_1)$$

$$OD_v \leftarrow \text{UNIT}(\text{RACTS}_v + 100_{pp} OD_v)$$

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NET INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILSON/IAWIS		PDR AND PTE	
PROGRAM <i>Proximity</i>		CO-ELLIPTIC SEQUENCE INITIATION	
ANALYST <i>W. J. ...</i>		DOCUMENT NO.	
DOCNO <i>...</i>		COLOSSUS II	
APPROV <i>J. ...</i>		FC-2626	
		SHEET 16 OF 25	

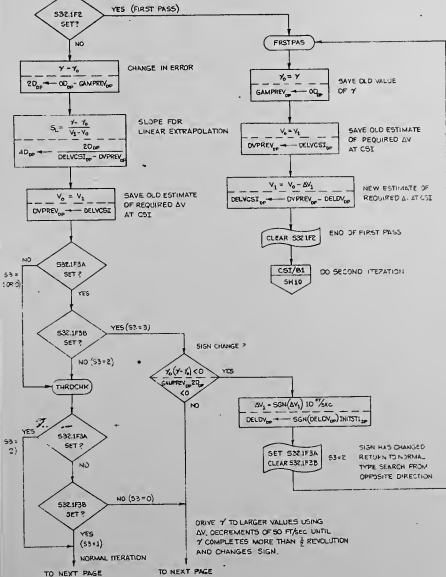
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$$\gamma \cos^2(\text{UNIT } \gamma_1 \cdot \text{UNIT } \Gamma_{P2}) \text{ SGN} \left[ (\text{UNIT } \Gamma_{P2} \times \text{UNIT } \gamma) - (\text{UNIT } \gamma_{P2} \times \text{UNIT } \Gamma_{P2}) \right]$$

$$\text{CO}_{OP} = \text{CO}^2 \text{ CO}_{UNIT} (\text{RPMSS}_2) \text{ SGN} \left[ (\text{UNIT } (\text{RPMSS}_2) \times \text{CO}) - (\text{UNIT } (\text{RPMSS}_2) \times \text{UNIT } (\text{RPMSS}_2)) \right]$$

ERROR ANGLE FROM  $\gamma$  TO  $\Gamma_{P2}$

(POSITIVE IF  $\gamma$  IS BEHIND  $\Gamma_{P2}$ )  
(NEGATIVE IF  $\gamma$  IS AHEAD OF  $\Gamma_{P2}$ )



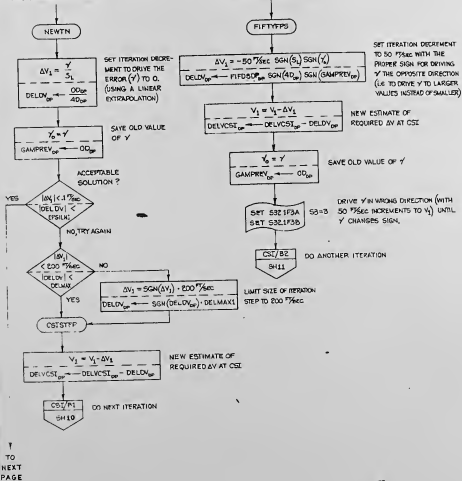
DRIVE  $\gamma$  TO LARGER VALUES USING  $\Delta V$  DECREMENTS OF 50 FT/ACC UNTIL  $\gamma$  COMPLETES MORE THAN  $\frac{1}{2}$  REVOLUTION AND CHANGES SIGN.

MIT ENGINEERING LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P52 AND P72	
		CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN A.C. WILLIAMS	5-3-68	COLLOQUIUM II	DOC. NO. FC-2626
PROG. <i>[Signature]</i>	2-22-67		
ANALYST <i>[Signature]</i>	11-6-68		
DOC. <i>[Signature]</i>	6-7-68		
APPROV. <i>[Signature]</i>		REV 1	MIT 17 OF 25



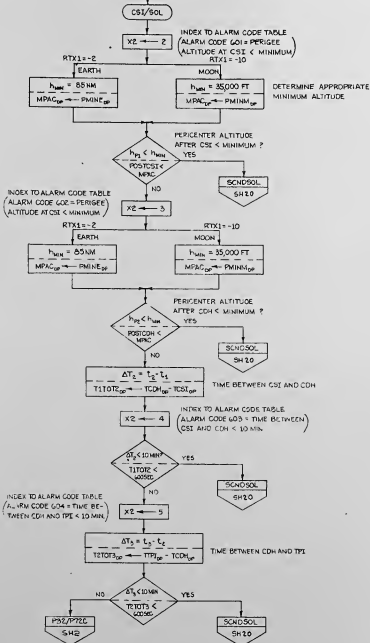
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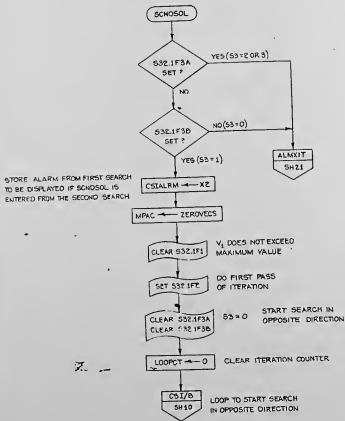
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN A.C. WILLIAMS	5-6-50	DOCUMENT NO.	
PROW <i>P. Williams</i>	8-22-68	FC-2626	
ANLST <i>P. Williams</i>		COLOSSUS II	SHEET 18 OF 25
BOOK <i>J. Stange</i>	4-9-68	REV 1	

FROM PRECEDING PAGE

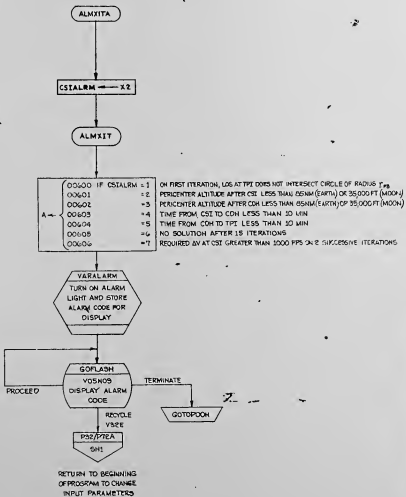


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFPOD GUIDANCE AND NAVIGATION	
		PRZ AND PTEC	
		CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN A.C. WILLIAMS	5-9-65	COLLOSSUS II	SCHEM NO. 1
FIGURE 1	2-21-64		FC-2626
ANALYST H. J. ...			
SKETCH			
APPROVED			SHEET 19 OF 25

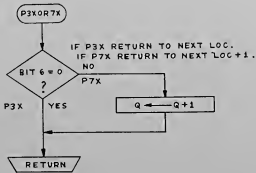
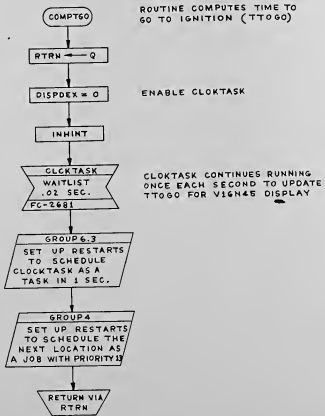
ALARM CONDITIONS THAT CAUSE ENTRY OF SOND50L ARE:  
 NO SOLUTION AFTER 15 ITERATIONS  
 $V_1 > 1000$  FT/SEC ON 2 SUCCESSIVE ITERATIONS  
 $t_0 < t_2$   
 $h_{e1} < 85$  NM OR 30,000 FT  
 $h_{e2} < 85$  NM OR 30,000 FT  
 $\Delta T_e < 10$  MIN  
 $\Delta T_s < 10$  MIN



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION PS2 AND 272 CO-ELLIPTIC SEQUENCE INITIATION	
DESNR A.G.WILLIAMS	56-68	DOCUMENT NO.	FC-2626
PRGRM <i>FC-2626</i>	FC-2626	COLLOSSUS II	
DOCNR <i>FC-2626</i>	FC-2626	REV 1	SHEET 20 OF 25
APPRD <i>J. S. ...</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY C. WILLIAMS		P22 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
FROM	<i>Williams</i>	DATE	5-7-68
ANALYST	<i>J. Williams</i>	DOCUMENT NO.	FC-2626
DOOR	<i>Williams</i>	COLLOSSUS II	
PPPS	<i>Williams</i>		SHEET 21 OF 23



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN <i>[Signature]</i>	DATE 11 APR 68	COLOSSUS II	DOCUMENT NO. FC-2626
PROGRAM <i>[Signature]</i>	11 APR 68		SHEET # 25
ANALYST <i>[Signature]</i>	11 APR 68		
BOOKED <i>[Signature]</i>	11 APR 68		
APPROV <i>[Signature]</i>	11 APR 68		

COMPT60

ROUTINE COMPUTES TIME TO GO TO IGNITION (TT0GO)

RTRN ← Q

DISPDEX = 0

ENABLE CLOKTASK

CLOKTASK  
WAITLIST  
.02 SEC.  
FC-2681

CLOKTASK CONTINUES RUNNING ONCE EACH SECOND TO UPDATE TT0GO FOR V16N45 DISPLAY

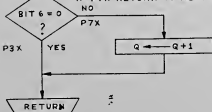
GROUP 6.3  
SET UP DESTARTS TO SCHEDULE CLOKTASK AS A TASK IN 1 SEC.

GROUP 4  
SET UP RESTARTS TO SCHEDULE THE NEXT LOCATION AS A JOB WITH PRIORITY 13

RETURN VIA RTRN

P3X0R7X

IF P3X RETURN TO NEXT LOC.  
IF P7X RETURN TO NEXT LOC+1.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
DESIGN	<i>[Signature]</i>	DATE	<i>[Signature]</i>
PROG	<i>[Signature]</i>	REV	<i>[Signature]</i>
ANALY	<i>[Signature]</i>	DATE	<i>[Signature]</i>
DOCS	<i>[Signature]</i>	REV	<i>[Signature]</i>
APPR	<i>[Signature]</i>	DATE	<i>[Signature]</i>
		DOCUMENT NO.	FC-2626
		SHEET	28

P32 - COELLIPTIC SEQUENCE INITIATION (CONT.)

DISPLAYS	MEANING	USED	
V06N30	DISPLAY CSI TIME	SH1	
V06N35	DISPLAY DESIRED NUMBER OF APSIDAL CROSSING AT CDH AND ELEV. ANGLE AT TPI	SH1	
V06N37	DISPLAY TIME OF TPI MANEUVER	SH1	
V06N45	DISPLAY MARKS, TIME FROM IGNITION, MIDDLE GIMBAL ANGLE	SH6	
V06N50	DISPLAY CSI/CDH PARAMETERS	SH3	
V06N61	DISPLAY REQUIRED ΔV FOR CSI	SH4, SH7	
V06N82	DISPLAY REQUIRED ΔV FOR CDH		
V06N89	DISPLAY APPROPRIATE ALARM CODE	SH21	
ALARMS	MEANING	USED	
00601	ON FIRST ITERATION, LOS AT TPI DOES NOT INTERSECT CIRCLE OF RADIUS $r_{p3}$	SH17	
00601	PERICENTER ALTITUDE AFTER TPI LESS THAN 85 NM (EARTH) OR 35,000 FT (MOON)	SH19	
00602	PERICENTER ALTITUDE AFTER CDH LESS THAN 85 NM (EARTH) OR 35,000 FT (MOON)	SH19	
00604	TIME FROM CSI TO CDH LESS THAN 10 MIN	SH19	
00604	TIME FROM CDH TO TPI LESS THAN 10 MIN	SH14, SH19	
00605	NO SOLUTION AFTER 15 ITERATIONS	SH10	
00606	REQUIRED ΔV AT CSI GREATER THAN 1000 FT/SEC ON 2 SUCCESSIVE ITERATIONS	SH11	
PARAMETERS	MEANING	UNITS	SCALING
CSI/ALRM	ALARM CODE		B28
CSITH	CSH OF $\theta$ THE TRUE ANOMALY ANGLE	REVOLUTIONS	B1
DELTA	ΔV STORAGE	M/C/SEC	B7
DELTA/EFT1	ΔV FOR CSI MANEUVER	M/C/SEC	B7
DELTA/EFT2	ΔV FOR CDH MANEUVER	M/C/SEC	B7
DELTA/CSI	ΔV AT CSI	M/C/SEC	B7
DELTA/VC	ΔV IN LOCAL VERTICAL COORDINATES	M/C/SEC	B7
DELTA/NSH	MAGNITUDE OF ΔV AT CSI	M/C/SEC	B7
DELTA/NSH	ΔV AT CSI IN REFERENCE COORDINATES	M/C/SEC	B7
DELTA/ALT	DISTANCE BETWEEN ACTIVE AND PASSIVE VEHICLE ORBITS AT CDH	METERS	B29
DELTA/REV	PREVIOUS CSI ΔV VALUE	M/C/SEC	B7
DELTA/CC	ECCENTRICITY		B3
DELTA/FA	DESIRED LOS ANGLE AT TPI	REVOLUTIONS	B1
DELTA/MPREV	PREVIOUS VALUE OF $\gamma$ , THE ERROR ANGLE FROM $b$ TO $r_{p3}$	REVOLUTIONS	B0
DELTA/PA	TIME BETWEEN APSIDAL CROSSINGS	CENTISECONDS	B28
DELTA/LOOPCT	ITERATION COUNTER		B28
DELTA/XX	NUMBER OF APSIDAL CROSSINGS OF ACTIVE VEHICLE		B28
DELTA/POSTCDH	PERIGEE ALTITUDE AFTER CDH MANEUVER	METERS	B29
DELTA/POSTCSI	PERIGEE ALTITUDE AFTER CSI MANEUVER	METERS	B29
DELTA/RACT1	POSITION OF ACTIVE VEHICLE AT CSI TIME	METERS	B29
DELTA/RACT2	POSITION OF ACTIVE VEHICLE AT CDH TIME	METERS	B29
DELTA/RACT3	POSITION VECTOR OF ACTIVE VEHICLE AT TPI	METERS	B29
DELTA/RAT	POSITION VECTOR OUTPUT FROM INTEGRATION	METERS	B36
DELTA/RIPASS1	$r_{p1} + \Delta r_{p1}$ POSITION VECTOR OF PASSIVE VEHICLE AT CSI TIME	METERS	B29
DELTA/RIPASS2	POSITION VECTOR OF PASSIVE VEHICLE AT CDH	METERS	B29
DELTA/RIPASS3	POSITION VECTOR OF PASSIVE VEHICLE AT TPI	METERS	B29
DELTA/RTG	POSITION OF ACTIVE VEHICLE AT CSI BEFORE ROTATION	METERS	B29
DELTA/RTML	$\mu_e$ OR $\mu_m$	$M^3/CS/C^2$	B36 OR B30
DELTA/RTSR1/MU	$1/\sqrt{\mu_e}$ OR $1/\sqrt{\mu_m}$	$CS/C/M^{3/2}$	B17 OR B14
DELTA/RTN1	SHIFT COUNTER; -2 FOR EARTH ORBIT, -10 FOR LUNAR ORBIT		B14
DELTA/RTN2	SHIFT COUNTER; 0 FOR EARTH-ORBIT, 2 FOR LUNAR ORBIT		B14
DELTA/RVC	POSITION VECTOR (INPUT TO CONIC ROI TENS)	METERS	B20
DELTA/NSH	SINE OF $\theta$ THE TRUE ANOMALY ANGLE	REVOLUTIONS	B1
DELTA/T1TDP2	TIME FROM CSI TO CDH	CENTISECONDS	B28
DELTA/T2TDP3	TIME FROM CDH TO TPI	CENTISECONDS	B28

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. Schmitt</i>		P32 AND P72 COELLIPTIC SEQUENCE INITIATION	
PREPARED <i>Walter G. G. G.</i>	DATE <i>1-25-64</i>	COLOSSUS II	DOCUMENT NO. <b>FC-2626</b>
ANALYST <i>W. J. G. G.</i>	DATE <i>1-15-64</i>		SHEET 14 OF 25
DOCSN <i>W. J. G. G.</i>	DATE <i>1-15-64</i>		
APPROVED <i>Walter G. G. G.</i>	DATE <i>1-15-64</i>		

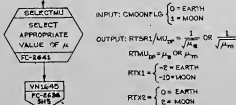
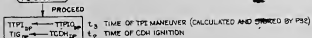
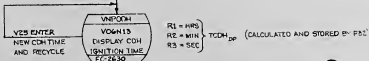
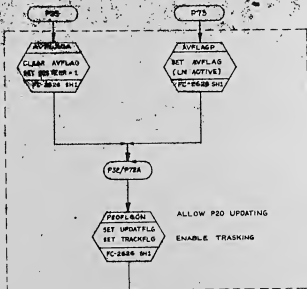
## P32 - COELLIPTIC SEQUENCE INITIATION

ERASABLES	MEANING		UNITS	SCALING
TCDH	TIME OF CDH MANEUVER		CENTISECONDS	B28
TCNI	TIME OF CSI MANEUVER		CENTISECONDS	B28
TIG	TIME OF IGNITION		CENTISECONDS	B28
TTPI	TIME OF TPI MANEUVER		CENTISECONDS	B28
TTPI0	TIME OF TPI MANEUVER FOR P33		CENTISECONDS	B28
UPI	UNIT-NORMAL TO PLANE OF PASSIVE VEHICLE			B1
VACT1	VELOCITY OF ACTIVE VEHICLE AT CSI		M/CSEC	B7
VACT2	VELOCITY VECTOR OF ACTIVE VEHICLE AT CDH		M/CSEC	B7
VACT3	VELOCITY VECTOR OF ACTIVE VEHICLE AT TPI		M/CSEC	B7
VACT4	VELOCITY VECTOR OF ACTIVE VEHICLE AT INTERCEPT		M/CSEC	B7
VATT	VELOCITY VECTOR OUTPUT FROM INTEGRATION		M/CSEC	B7
VPASS1	VELOCITY VECTOR OF PASSIVE VEHICLE AT CSI TIME		M/CSEC	B7
VPASS2	VELOCITY VECTOR OF PASSIVE VEHICLE AT CDH		M/CSEC	B7
VPASS3	VELOCITY VECTOR OF PASSIVE VEHICLE AT TPI		M/CSEC	B7
VVIC	VELOCITY VECTOR (INPUT TO CONIC ROUTINES)		M/CSEC	B7
CONSTANTS		VALUE	UNITS	SCALING
MULTA1-F	$\mu_E$ GRAVITATIONAL CONSTANT OF EARTH	$3.986032 \times 10^{10}$	$M^3/CSEC^2$	B36
MULTA1-F-B	$1/\sqrt{\mu_E}$	$.50087529 \times 10^{-5}$	CSEC/M <sup>3/2</sup>	B17
MULTA1-F-B	$\mu_M$ GRAVITATIONAL CONSTANT OF MOON	$4.902778 \times 10^8$	$M^3/CSEC^2$	B30
MULTA1-F-14	$1/\sqrt{\mu_M}$	$.45162595 \times 10^{-4}$	CSEC/M <sup>3/2</sup>	B14

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P32 AND P72 COELLIPTIC SEQUENCE INITIATION	
DRAWN <i>G. J. Smith</i>	DESIGNED <i>William J. Smith</i>	COLLUSION II	DOCUMENT NO. <b>FC-2626</b>
ANALYST <i>W. J. Smith</i>	PROGRAMMER <i>P-12-78</i>		
DOOR <i>W. J. Smith</i>	TESTER <i>W. J. Smith</i>		
APPROVED <i>W. J. Smith</i>	REVISION <b>#2</b>	REV 1	SHEET 26 OF 28





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
FORM NO. 10-62-11-10-1		P20 AND P75 CONSTANT CDH ALTITUDE TARGETTING	
FORM REV. 1-6-62	10-6-62	COLOSSUS II	SERIES NO. FC-2627
ANALYST DICKSON	10-6-62	REV 1	SHEET 1 OF 7

FROM SHEET 4

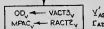
P85/P738



INPUT:  $T16_{DP} = t_2$  TIME OF CDH MANEUVER  
OUTPUT:  $RACTE_v = E_{A2}$  POSITION OF ACTIVE VEHICLE AT CDH  
 $VACTE_v = V_{A2}$  VELOCITY OF ACTIVE VEHICLE AT CDH  
 $RPASS2_v = E_{P2}$  POSITION OF PASSIVE VEHICLE AT CDH  
 $VPASS2_v = V_{P2}$  VELOCITY OF PASSIVE VEHICLE AT CDH  
 $UPI_v = E_{P2} \times Y_{A2}$  UNIT NORMAL TO PLANE OF PASSIVE VEHICLE  
 $XDELVEL0 = 1$  EXTERNAL DELTA MANEUVER (NOT LAMBERT AIRPOINT)



INPUT:  $RACTE_v, VACTE_v, RPASS2_v, VPASS2_v, UPI_v, RTMU_{DP}$   
OUTPUT:  $DELVEETE_v =$  REQUIRED  $\Delta V$  AT CDH ( $\Delta V_2$ )  
 $VACTS_v =$  REQUIRED VELOCITY OF ACTIVE VEHICLE  
AFTER CDH ( $V_{A2}$ )



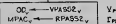
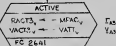
INTINTSP



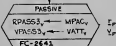
INPUT:  $16D_{DP}, 14D_{DP}, 12D_{DP}, GD_{DP}, OO_v, RTX1, RTX2$   
OUTPUT:  $MPAC_v = E_{A3}$  POSITION OF ACTIVE VEHICLE AT TPI  
 $VATT_v = V_{A3}$  VELOCITY OF ACTIVE VEHICLE AT TPI



RETURN VIA  
QPRET



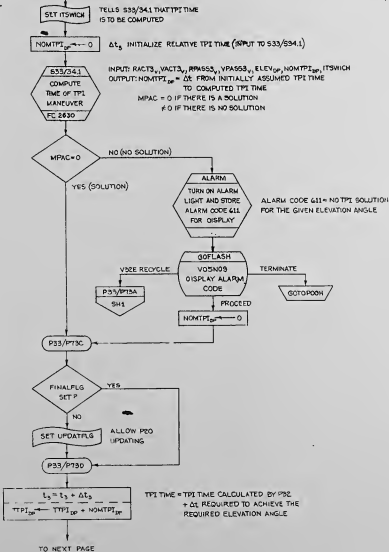
INPUT:  $RPASS2_v, VPASS2_v, TCOH_{DP}, TTPI_{DP}$   
OUTPUT:  $MPAC_v = E_{P3}$  POSITION OF PASSIVE VEHICLE AT TPI  
 $VATT_v = V_{P3}$  VELOCITY OF PASSIVE VEHICLE AT TPI



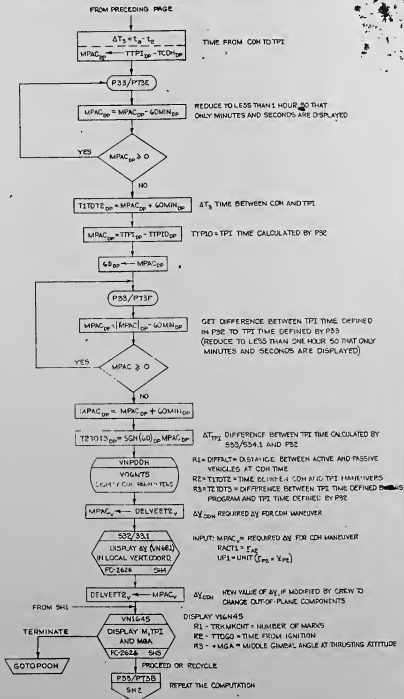
TO NEXT PAGE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARPA GUIDANCE AND NAVIGATION P85 AND P73 CONSTANT DELTA ALTITUDE HANGING	
BRANCH: <i>J.C. WILLIAMS</i> PROGRAM: <i>10/1/68</i> ANALYST: <i>Walter Longshore</i> DOCNO: APP'D: <i>J. Hays</i>	6-7-68 6-9-68 6-11-68 6-11-68	COLOSSUS II	DOCUMENT NO. FC-2627
		REV 1	SHEET 2 OF 3

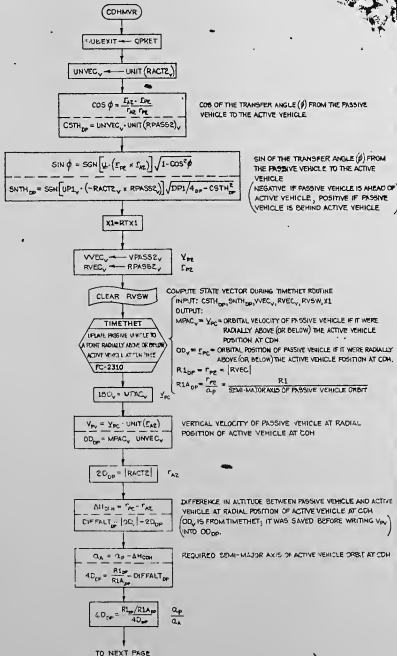
FROM PRECEDING PAGE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AROLIS GUIDANCE AND NAVIGATION	
DRAWN BY <i>C. WILLIAMS</i>		P53 AND P73	
PROGRAM <i>6-7-68</i>		CONSTANT DELTA ALTITUDE TRACKING	
ANALYST <i>Raymond S. ...</i>		DOCUMENT NO.	
CHECKER <i>...</i>		COLOSSUS II	
APPROVED <i>J. ...</i>		FC 2627	
		REV 1 SHEET 3 OF 7	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARIELD GUIDANCE AND NAVIGATION	
		P33 AND P73	
		CONSTANT DELTA ALTITUDE TARGETING	
DEAN A.C. WILLIAMS	6-1-68	COLOSSUS II	DOCUMENT NO. FC-2627
FRANK J. WILSON	6-4-68		
ANNALYN J. WILSON	6-22-68		
BOCAR	6-26-68		
APPROV. J. Wilson	6-27-68	REV 1	SHEET 4 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		PBT AND PTS	
		CONSTANT DELTA ALTITUDE TARGETING	
DESIGNER: A.C. WILLIAMS	6-10-60	COLOSSUS II	DOCUMENT NO.
PROGRAM: <i>W. J. Kelly</i>	6-3-60		FC-2627
ANALYST: <i>W. J. Kelly</i>	1-20-61		
DOCTOR: <i>J. Kelly</i>	4-11-61		
APPROVED: <i>J. Kelly</i>	4-11-61	REV 1	SHEET 5 OF 7

FROM PRECEDING PAGE

$$V_{AV} = V_{AV} \frac{d_m}{d_A} \frac{3}{2}$$

$$80_{DP} = 80_{DP} (\frac{d}{d_A})^{\frac{3}{2}}$$

REQUIRED VERTICAL VELOCITY OF ACTIVE VEHICLE AT CDH

$$V_{AH} = \sqrt{H \left( \frac{2}{r_{AZ}} - \frac{1}{d_A} \right) - V_{AV}^2}$$

$$100_{DP} = \sqrt{2 \frac{RTM_{DP}}{2D_{DP}} - \frac{RTM_{DP}}{4D_{DP}} - 80_{DP}^2}$$

REQUIRED HORIZONTAL VELOCITY OF ACTIVE VEHICLE AT CDH

$$V_{AZ} = V_{AH} \text{ UNIT} (\frac{1}{2} \times r_{AZ}) + V_{AV} \text{ UNIT} (r_{AZ})$$

$$VACTZ_v = 100_{DP} \text{ UNIT} (\frac{1}{2} \times UNVECV_v) + 80_{DP} \text{ UNVECV}_v$$

TOTAL REQUIRED VELOCITY OF ACTIVE VEHICLE AT CDH

$$\Delta V_Z = V_{AZ} - V_{AZ}$$

$$DELVEETZ_v = VACTZ_v - VACTZ_v$$

REQUIRED  $\Delta V$  AT CDH

RETURN VIA SUBSUIT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		- APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A.C. Williams</i>		PSS AND PTF	
PRGMR <i>Bill Williams</i>		CONSULT DELTA ALTITUDE TARGETTING	
ANALST <i>Robert Longshore</i>		DOCUMENT NO.	
DCMR <i>A.C. Williams</i>		COLOSSUS II	FC-2627
APPR'S <i>J. Hooper</i>		REV 1	SHEET 6 OF 7

P33 - CONSTANT DELTA ALTITUDE

SUBROUTINES

IN THIS CHART

P30PLGON SET TRACKFLG, UPDATFLG  
CDHMVR COMPUTE REQUIRED ΔV FOR CDH MANEUVER

ON OTHER CHARTS

SELECTMTC SELECTS # ACCORDING TO LUNAR OR EARTH SPHERE OF INFLUENCE  
INTINT PERFORMS HOUSEKEEPING PRIOR TO INTEGRATION CALL  
S32/34,I COMPUTES EITHER E OR TPI TIME  
S32/33,I DISPLAY ΔV IN LOCAL VERT. COORDINATES  
VN1645 DISPLAY M, TFI, MGA  
TIMETRET CALCULATES DELTA TIME OF FLIGHT  
ACTIVE ACTIVE VEHICLE POSITION, VELOCITY TO RACT3, VACT3  
PASSIVE PASSIVE VEHICLE POSITION, VELOCITY TO RPASS3, VPASS3

FLAGS	MEANING	SET	CLEARED	TESTED
HSWICH	SET TPI TIME TO BE COMPUTED	SH4		
FINALFLG	CLEARED TPI TIME HAS BEEN COMPUTED			SH4
UPDATFLG	SET LAST PASS THRU RENDEZVOUS PROGRAM	SH4		
ADLVAFLG	CLEARED INTRIMPASS THRU RENDEZVOUS PROGRAM	SH6		
RYSW	SET UPDATING VIA MARKS ALLOWED		SH8	
ΔV FLAG	CLEARED UPDATING VIA MARKS DISALLOWED	SR1	SH1	
TRACKFLG	SET EXT. LAMBERT AIM POINT MANEUVER	SH1		
DISPLAYS	SET COMPUTE FINAL STATE VECTOR IN TIME/TET IN ADDITION TO Δt		USED	
V06N13	CLEARED COMPUTE Δt ONLY			SH1
V06N11	LA IS ACTIVE VEHICLE			SH3
V06N75	CLEARED CSM IS ACTIVE VEHICLE			SR4
V16N45	SET ENABLE TRACKING			SH4
V06N81	CLEARED MEANING		USED	
ALARMS	MEANING		USED	
00811	NO TPI SOLUTION FOR THE GIVEN ELEVATION ANGLE			SH3
ERRORS	MEANING	UNITS	SCALING	
TPIR0	TIME OF TPI MANEUVER FROM P33	CENTISECS	B28	
TPII	TIME OF TPI MANEUVER	CENTISECS	B28	
TIG	TIME OF IGNITION	CENTISECS	B28	
TCDH	TIME OF CDH MANEUVER	CENTISECS	B28	
VACT13	REQUIRED VELOCITY OF ACTIVE VEHICLE AT CDH	M/CSC	B7	
VACT2	ACTIVE VEHICLE POSITION VECTOR AT CDH TIME	METERS	B28	
VACT7	VELOCITY VECTOR OF ACTIVE VEHICLE AT CDH	METERS	B28	
VPASS2	PASSIVE VEHICLE VELOCITY VECTOR AT CDH TIME	M/CSC	B7	
VPASS2	PASSIVE VEHICLE POSITION VECTOR AT CDH TIME	METERS	B28	
NOM TPI	Δ FROM NOMINAL TPI TO COMPUTED TPI	CENTISECS	B28	
TITOT2	TIME FROM CDH TO TPI	CENTISECS	B28	
TZTOT3	TIME FROM TPI (P33) TO TPI (COMPUTED IN P33)	CENTISECS	B28	
DELTA ELT2	ΔV REQUIRED FOR CDH MANEUVER	M/CSC	B7	
UPI	$\hat{e}_{p2} \times \hat{v}_{p2}$ UNIT NORMAL TO PLANE OF PASSIVE VEHICLE			
SN FI	SINE θ ANGLE BETWEEN ACTIVE AND PASSIVE VEHICLES AT CDH		B1	
CS FI	COS θ ANGLE BETWEEN ACTIVE AND PASSIVE VEHICLES AT CDH		B1	
RVEC	POSITION VECTOR OUTPUT FROM INTEGRATION	METERS	B28	
VVC	VELOCITY VECTOR OUTPUT FROM INTEGRATION	M/CSC	B7	
DIF ALT	DIFFERENCE BETWEEN ACTIVE AND PASSIVE VEHICLES ALTITUDES	METERS	B28	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION P33 AND P73 CONSTANT DELTA ALTITUDE TARGETING	
DRAWN <i>[Signature]</i>	20 APR 68	DOCUMENT NO.	
PROGRAM <i>[Signature]</i>	4.4.68	COLOSSUS II	
ANALYST <i>[Signature]</i>	4.4.68	FC-26274	
DOCTR <i>[Signature]</i>	4.4.68	SHEET 7 OF 7	
APPROV <i>[Signature]</i>	REV 1		

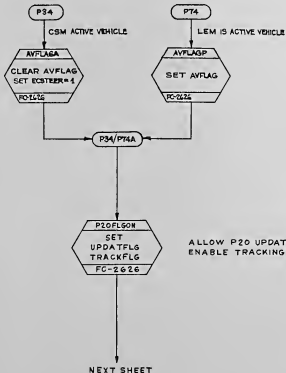
P34, P74 TRANSFER PHASE INITIATION TARGETING

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

P34  
 P74  
 S33/34.1  
 S34/35.1  
 VNPOOH  
 S34/35.2  
 S34/35.3  
 GOINT  
 INTINT  
 LOMAT  
 S34/35.5  
 S34/35.4  
 S3435.25

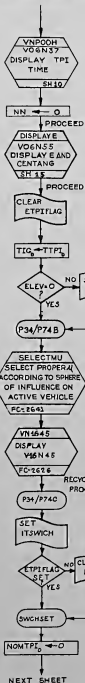
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT COLOSSUS AND INITIATION	
DRAWN		P34, P74 TRANSFER PHASE INITIATION TARGETING	
PROCED		DOCUMENT #	
ANALYST <i>M. J. ...</i>		COLOSSUS	
DOCTR <i>...</i>		II A	
APPROV <i>...</i>		FC-2630	
		REV 1	
		SHEET 1 OF 20	





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		P34, P74 TRANSFER PHASE INITIATION TARGETING	
DRAWN <i>A.S. Williams</i>	DATE <i>1/15/66</i>	COLLOSSUS II A	DOCUMENT NO. <b>FC-2630</b>
PROG <i>FC-2630</i>	CHKD BY <i>John A. Brown</i>	REV 1	SHEET 2 OF 2
DOCMP <i>John A. Brown</i>	APPROV <i>John A. Brown</i>		

FROM PRECEDING SHEET



R1 - } TPI<sub>0</sub> { 00XXX.-HRSE } TIME OF TPI  
 R2 - } 000XX.-MIN } IGNITION  
 R3 - } 0XX.XX -SEC }

E-ELEV. ANGLE BETWEEN CBM/LEM LINE OF SIGHT AND LOCAL HORIZONTAL PLANE OF ACTIVE VEHICLE REFERENCED TO THE DIRECTION OF FLIGHT.

CENTANG-ORBITAL CENTRAL ANGLE OF PASSIVE VEHICLE DURING TRANSFER FROM TPI TO TIME OF INTERCEPT.

R1 - NN \* NUMBER OF OFFSETS

R2 - ELEV = ELEVATION ANGLE IN DEGREES

R3 - CENTANG = ORBITAL CENTRAL ANGLE OF THE PASSIVE VEHICLE DURING TRANSFER FROM TPI IGNITION TO TIME OF INTERCEPT.

INDICATES TPI TIME SUPPLIED FOR P34.

TPI<sub>0</sub> = INPUT TPI TIME

INDICATES ELEV ANGLE IS SUPPLIED FOR P34

R1 = TRKMCNT \* NO. OF MARKS SINCE LAST MANUEVER OR INITIATION OF P20

R2 = T DGO = TIME TILL TPI MANUEVER

R3 = +MGA = MIDDLE GIMBAL ANGLE AT THRUSTING ATTITUDE

ITERATE FOR TIG WHEN SET

IF ETPIFLAG CLEAR, TIG IS INPUT AND ITERATION TO COMPUTE TIG FROM AN INPUT E-ANGLE IS UNNECESSARY

P34, P74 TRANSFER PHASE  
INITIATION TARGETING

J. Campbell

8 JUL 68

W. Thompson

11 OCT 68

M. J. B. B. B.

11 SEP 68

Ken A. B. B.

12 OCT 68

3 MAY 67

COLOSSUS IIA

FC-2630

20

FROM PRECEDING SHEET

INTLOOP

TDEC1 ← TTP1<sub>0</sub> + NOMTPI<sub>0</sub>

PRECEET  
UPDATE ACTIVE AND  
PASSIVE VEHICLES TO  
TIME (← TDEC1)  
TCEM1

S33/344  
COMPUTE E OR TPI  
DEPENDING ON SETTING  
OF ETPI FLAG  
SH 6

TTP1 ← INPUTTED TPI TIME.  
NOMTPI ← COMPUTED Δt FROM 533/344  
= 0 FIRST PASS.

INPUT : TDEC 1, LM AND CSM STATE VECTORS  
OUTPUT : RACT 3, VACT 3, RPASS 3, VPASS 3

INPUT : RACT 3, VACT 3, RPASS 3, VPASS 3, TTP1,  
NOMTPI, ELEV, ITSWICH  
OUTPUT : ELEV OR NOMTPI

CLEAR  
ITSWICH

MPAC = 0 ?

NO  
GOF LASH  
DISPLAY ALARM 0066  
NO TIG FOR GIVEN  
ELEV ANGLE  
TERMINATE  
GOTDPOOH

NO SOLUTION POSSIBLE  
SOLUTION POSSIBLE  
ADJUST INPUT PARAMETERS

PROCEED  
P34/P74A  
SH 2

ITSWICH  
SET ?

E COMPUTATION  
FOR TPI NOT  
REQUIRED

NO  
ITERATION COMPLETE,  
DISPLAY RESULT

R1 - BLANK  
R2 - ELEV - XXX.XX DEG. - ELEVATION ANGLE  
R3 - CENTANG - XXX.XX DEG. - ORBITAL CENTRAL ANGLE  
OF THE PASSIVE VEHICLE  
DURING TRANSFER  
FROM TPI TO TIME OF  
INTERCEPT.

ETPIFLAG  
SET ?

NO  
DISP  
DISP  
E  
AND  
CENTANG  
SH 15

YES  
TIG  
DISP  
TIG

P34/P74D

VNPOOH  
VOM37  
DISP  
TPI  
TIME  
SH 10

R1 - } TTP1<sub>0</sub> { 00XX.-HRS  
R2 - } TIME OF TPI  
R3 - } IGNITION  
000XX.-MIN  
0XX.XX-SEC

PROCEED  
P34/P74E

SET  
PUSHLIST  
TO ZERO

X1<sub>0</sub> ← RTX1<sub>0</sub>  
OD<sub>0</sub> ← CENTANG<sub>0</sub>  
CSTH<sub>0</sub> ← COS(CENTANG<sub>0</sub>)  
SINTH<sub>0</sub> ← SIN(CENTANG<sub>0</sub>)  
RVEC<sub>v</sub> ← RPASS<sub>3v</sub>  
VVEC<sub>v</sub> ← VPASS<sub>3v</sub>

SET  
RVSW

DO NOT COMPUTE FINAL STATE VECTOR IN TIME-THETA.  
(ONLY TIME IS TO BE OUTPUT OF TIMETHET ROUTINE)

NEXT SHEET

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P34, P74 TRANSFER PHASE  
INITIATION TARGETING  
COLOSSUS IIA  
FC-2630

FROM PRECEDING SHEET



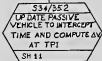
INPUT: RVEC, VEC, SNTH, CSTH, OD (CENTANG)  
 OUTPUT: T<sub>0</sub> = TIME FOR THE PASSIVE VEHICLE  
 TO TRAVERSE THE ANGLE (CENTANG)  
 BETWEEN THE TPI AND INTERCEPT POINTS.

INTIME<sub>0</sub> ← TPI<sub>0</sub>

FOR INIT VEL

TPASS<sub>4</sub> ← TPI<sub>0</sub> + T<sub>0</sub>

T<sub>0</sub> = TIME FROM TPI TO INTERCEPT TIME



INPUT: RPA33, VPASS3, INTIME, TPA34, UNRM, RACT3, VACT3  
 OUTPUT: RTAR6, VPASS4, DELVLVC, DELVEET3, VTPRIME  
 VI PRIME

DELVTPI<sub>0</sub> ← DELVEET3<sub>0</sub>

VTPRIME = VELOCITY AT TARGET AFTER  
 RENDEZVOUS MANEUVER

DELVTFF<sub>0</sub> ← VPASS4<sub>0</sub> - VTPRIME<sub>0</sub>

VI PRIME = VELOCITY REQUIRED TO  
 EFFECT RENDEZVOUS

OD ← RACT3<sub>0</sub>  
 MPAC<sub>0</sub> ← VI PRIME<sub>0</sub>

INPUT: OD (POSITION VECTOR OF ACTIVE VEH)  
 MPAC (VELOCITY VECTOR OF ACTIVE VEH)  
 OUTPUT: MPAC (PERIGEE ALTITUDE)



POSTTPI<sub>0</sub> = MPAC<sub>0</sub>  
 TIO<sub>0</sub> = TPI<sub>0</sub>

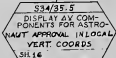
POSTTPI = PERIGEE ALTITUDE DISPLAYED TO INSURE ACTIVE  
 VEHICLE IS A SAFE DISTANCE FROM EARTH.

POSTTPI<sub>0</sub> ← MPAC<sub>0</sub>  
 TIO<sub>0</sub> ← TPI<sub>0</sub>



R1 = POSTTPI = PERIGEE ALTITUDE  
 R2 = DELVTPI = ΔV<sub>TPI</sub> = REQUIRED VELOCITY FOR TPI MANEUVER  
 R3 = DELVTFF = ΔV<sub>TFF</sub> = REQUIRED VELOCITY FOR FINAL  
 INTERCEPT MANEUVER

PROCEED



INPUT: DELVEET3, DELVLVC



R<sub>8</sub> = TRIMCNT = NO. OF MARKS MADE SINCE THE LAST  
 THRUSTING MANEUVER OR INITIATION OF P20  
 R<sub>2</sub> = TIO50 = TIME TO OR FROM TPI  
 R<sub>3</sub> = MGA = MIDDLE GIMBAL ANGLE

RECYCLE OR PROCEED

P34/P74C



533/34.1

NDRMEX  
←  
QPRET

SET  
PUSHLIST  
TO ZERO

TITER ← 40000<sub>D</sub>  
SECMAX<sub>D</sub> ← MAX250<sub>D</sub>  
RAPREC<sub>V</sub> ← RACT3<sub>V</sub>  
VAPREC<sub>V</sub> ← VACT3<sub>V</sub>  
RPPREC<sub>V</sub> ← RPASS3<sub>V</sub>  
VPPREC<sub>V</sub> ← VPASS3<sub>V</sub>

ELCALC

534/35.1

$\underline{U}_L = \text{UNIT}(\underline{I}_P - \underline{I}_A)$   
 $\text{ULOS}_V \leftarrow \text{UNIT}(\text{RPASS3}_V - \text{RACT3}_V)$

CALCULATES THE UNIT LOS VECTOR AND THE UNIT NORMAL VECTOR TO THE LOS VECTOR

LOS UNIT VECTOR

$\underline{U} = \text{UNIT}(\underline{I}_A \times \underline{U}_L)$   
 $\text{UNRM}_V \leftarrow \text{UNIT}(\text{RACT3}_V \times \text{VACT3}_V)$

UNIT VECTOR NORMAL TO LOS VECTOR

RETURN VIA  
QPRET

$\text{OO}_V = \text{ULOS}_V = \underline{U}_L$   
 $\text{MPAC}_V = \text{UNRM}_V = \underline{U}$

$\text{OO} = \underline{U} \times \underline{I}_A$   
 $\text{OO}_V \leftarrow \text{MPAC}_V \times \text{RACT3}_V$

$\text{GD} = \underline{I}_A / r_A$   
 $\text{GD}_V \leftarrow \text{UNIT}(\text{RACT3}_V)$

$\underline{U}_P = \text{UNIT}[\underline{U}_L - (\underline{U}_L \cdot \underline{I}_A) \underline{I}_A / r_A^2]$   
 $\text{MPAC}_V \leftarrow \text{UNIT}[\text{ULOS}_V - (\text{ULOS}_V \cdot \text{GD}_V) \text{GD}_V]$

$\text{OO} = \underline{U}_P \cdot (\underline{U} \times \underline{I}_A)$   
 $\text{OO}_D \leftarrow \text{MPAC}_V \cdot \text{OD}_V$

$E_A = \text{COS}^{-1}[\underline{U}_L \cdot \underline{U}_P \text{SGN}(\underline{U}_P \cdot \underline{U} \times \underline{I}_A)]$   
 $\text{OO}_D \leftarrow \text{COS}^{-1}[\text{ULOS}_V \cdot \text{MPAC}_V \text{SGN}(\text{OO}_D)]$

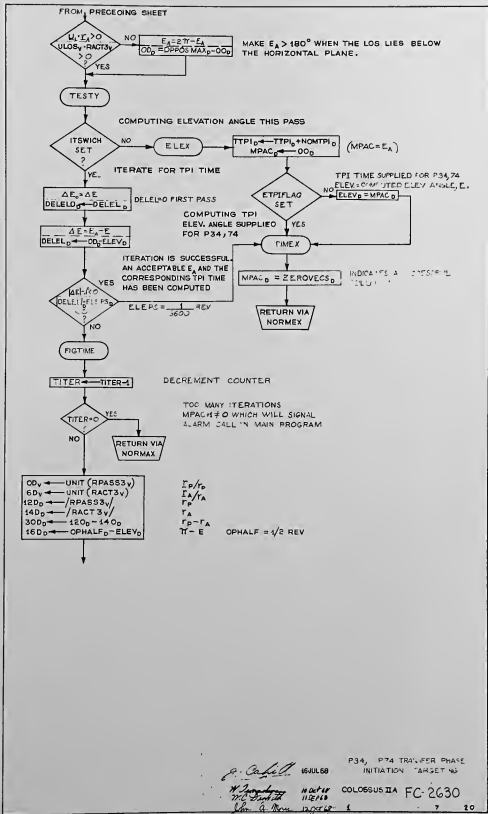
COMPUTED ELEVATION ANGLE

NEXT SHEET

COMPUTES ONE OF TWO QUANTITIES: ① ELEVATION ANGLE E BETWEEN GSM/LM LINE OF SIGHT AND LOCAL HORIZONTAL OF THE ACTIVE VEHICLE, OR ② THE TIME CORRECTION Δt TO THE TPI TIME AT WHICH THE ELEVATION ANGLE E IS ATTAINED.

INPUT: RACT3, VACT3, VPASS3, RPASS3, TTPI, NOMTPI, ITSWICH, ELEV  
OUTPUT: ELEV OR NOMTPI (Δt)

VHT VEHICLE STATION AR NAME: G MASS DRAWN: <i>P. M. [Signature]</i> DESIGNED: ANAL: <i>M. [Signature]</i> CHECKED: <i>[Signature]</i> APPROVED: <i>John A. [Signature]</i>	29 JAN 68 P34, P74 TRANSFER PHASE INITIATION TARGETING COLOSSUS IIA FC-2630 6 20
---	---



*J. Campbell* 16JUL68  
*John A. Morris* 11SEP68  
 12OCT68  
 5 Aug 69

P34, P74 TRANSFER PHASE  
 INITIATION TARGET 45  
 COLOSSUS IIA FC-2630

FROM PRECEDING SHEET

$$\begin{aligned} & \text{YES} \\ & \frac{(\pi-E) \text{SGN}(r_p/r_A)}{16D_0} < 0 \\ & \frac{\text{SGN}(300_0)}{16D_0} < 0 \\ & ? \end{aligned}$$

THE ELEVATION ANGLE  $E$ , IS INCONSISTENT WITH THE RELATIVE ALTITUDES OF THE TWO VEHICLES: RETURN AND DISPLAY ALARM 00611

YES

RETURN VIA NORMEX

NO

$$\begin{aligned} & 2B_0 = -\cos(\pi-E) r_A / r_p \\ & 2B_0 \leftarrow \text{MPAC}_0 \leftarrow -\cos(16D_0) 14D_0 / 12D_0 \end{aligned}$$

USED LATER IN CALCULATION OF  $\Delta t$   
 $-\cos(\pi-E) = \cos E$

$$\begin{aligned} & \text{YES} \\ & 1 - r_A \cos E / r_p < 0 \\ & \text{DPHALF}_0 / \text{MPAC}_0 < 0 \\ & ? \end{aligned}$$

THE LOS FROM THE ACTIVE VEHICLE DOES NOT INTERSECT THE CIRCULAR ORBIT WITH RADIUS EQUAL TO THAT OF PASSIVE VEHICLE: RETURN AND DISPLAY ALARM 00611

YES

RETURN VIA NORMEX

NO

$$\begin{aligned} & \omega_A = \text{UNIT}(X \Gamma_A, Y \Gamma_A) r_p \\ & 16D_0 \leftarrow \text{UNIT}(UNRM_V X 6D_V, YACT3_V) 12D_0 \end{aligned}$$

$$\begin{aligned} & \omega_p = \text{UNIT}[(r_p X \Gamma_p) X \Gamma_p + Y_p] r_A \\ & \text{MPAC}_0 \leftarrow \text{UNIT}[(O_D V X VPASS3_V) X O_D V + VPASS3_V] 14D_0 \end{aligned}$$

$$\begin{aligned} & 18D = \omega_A - \omega_p \\ & 16D_0 \leftarrow 16D_0 - \text{MPAC}_0 \end{aligned}$$

DENOMINATOR IN  $\Delta t$  CALCULATION BELOW.

$$\begin{aligned} & 18D = (r_A X \Gamma_p) \cdot \hat{u} \\ & 18D_0 \leftarrow (6D_V X O_D V) \cdot \text{UNRM}_V \end{aligned}$$

$$\begin{aligned} & \text{MPAC} = \text{SGN}(r_A X \Gamma_p \cdot \hat{u}) \cos(r_A \Gamma_p / r_A r_p) \\ & \text{MPAC}_0 \leftarrow \text{SGN} 18D_0 [\cos(6D_V \cdot O_D V)] \end{aligned}$$

$6D_V = \text{UNIT VECTOR} = \Gamma_A / r_A$   
 $O_D V = \text{UNIT VECTOR} = \Gamma_p / r_p$

$$\begin{aligned} & \kappa - \pi = \text{MPAC} + E - \pi \\ & 18D_0 \leftarrow \text{MPAC}_0 + \text{ELEV}_0 - \text{DPHALF}_0 \end{aligned}$$

USED IN CALCULATION OF  $\Delta t$   
 $\text{DPHALF} = 1/2 \text{ REV}$

$$\begin{aligned} & \Delta t = \left\{ \left[ (\pi - \cos^{-1}(r_A \cos E / r_p)) \text{SGN}(r_p - r_A) + (\kappa - \pi) \right] 2\pi / (\omega_A - \omega_p) \right\} r_A r_p \\ & 12D_0 \leftarrow \left\{ \left[ (\text{DPHALF}_0 - (\cos^{-1} 2B_0)) \text{SGN}(300_0) + 18D_0 \right] \text{TWOP}_0 / 16D_0 \right\} 44D_0 12D_0 \end{aligned}$$

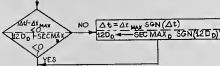
NEXT SHEET

$2\pi$  CANCELS REV. UNITS SO THAT THE UNITS OF THE FINAL EXPRESSION WILL BE CSEC.

WT  
 INFORMATION 1A  
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 14 OCT 67  
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 14 OCT 67

P34, P74 TRANSFER PHASE INITIATION TARGETING  
 COLLOSSUS IIA FC-2630  
 8 20

FROM PRECEDING SHEET

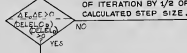


$\Delta t > 250$  SEC SO REDUCE  $\Delta t$  TO 250 SEC TO HELP ASSURE CONVERGENCE IN QUEST OF TPI TIME



TITER AFTER 14 MORE ITERATIONS WILL BE REDUCED TO ZERO IN PGTIME AREA.

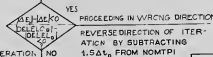
REPETE



SOLUTION POINT HAS BEEN BYPASSED, REVERSE DIRECTION OF ITERATION BY 1/2 OF CALCULATED STEP SIZE. REDUCING SEC MAX HELPS PREVENT AN OSCILLATION OF 1/2 ITERATION

MPAC  $\leftarrow$   $-\Delta t / 2$   
 MPAC<sub>0</sub>  $\leftarrow$   $-1200 / 2$

NEXTES



REVERS

MPAC  $\leftarrow$   $-1.5 \Delta t_0$   
 MPAC<sub>0</sub>  $\leftarrow$   $-4.5 \Delta t_{D_0}$

MPAC  $\leftarrow$   $\Delta t$   
 MPAC<sub>0</sub>  $\leftarrow$   $1200$

$\Delta t_0 \leftarrow \Delta t_0 / 2$   
 $\Delta t_{D_0} \leftarrow \Delta t_{D_0} / 2$

RESIGN

$\Delta t \leftarrow MPAC \text{SGN}(\Delta t_0)$   
 $MPAC_0 \leftarrow MPAC_0 \text{SGN}(\Delta t_{D_0})$

STORELT

$\Delta t_0 \leftarrow \Delta t$   
 $\Delta t_{D_0} \leftarrow MPAC_0$

ADTIME

$\Sigma \Delta t \leftarrow \Delta t + \Sigma \Delta t$   
 $NOMTPI_0 \leftarrow MPAC_0 + NOMTPI_0$

NOMTPI = SUM OF  $\Delta t$ 'S = DIFFERENCE BETWEEN INPUTTED TPI TIME AND COMPUTED TPI TIME  
 $\Sigma \Delta t_h = t - t_s$  WHERE:  $t_s$  IS INPUT TIME  
 $t$  IS COMPUTED TPI TIME

LOAD ACTIVE VEHICLE STATE VECTOR FOR POINT ROUTINE

$1d \leftarrow VAPREC_v$   
 $MPAC \leftarrow RAPREC_v$

NEXT SHEET

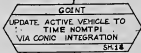
18 JUL 68  
 W. J. ...  
 APPROVED: ...

P34, P74 TRANSFER PHASE INITIATION TARGETING

COLOSSUS IIA FC-2630



FROM PRECEDING SHEET



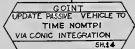
INPUT: NOMTPI<sub>0</sub>, VAPREC<sub>v</sub>, RAPREC<sub>v</sub>  
OUTPUT: VATT<sub>v</sub>, RATT<sub>v</sub>



STORE UPDATED ACTIVE VEHICLE STATE VECTOR VALUES



LOAD PASSIVE VEHICLE STATE VECTOR FOR GOINT ROUTINE



INPUT: NOMTPI<sub>0</sub>, VPPREC<sub>v</sub>, RPPREC<sub>v</sub>  
OUTPUT: RATT<sub>v</sub>, VATT<sub>v</sub>



STORE UPDATED PASSIVE VEHICLE STATE VECTOR VALUES



RECYCLE FOR NEXT ITERATION



SAVE RETURN IN RTRN



STORE REQUESTED VERB/HOUR TO BE USED ON DSKY



VN BANK

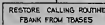
KEY IN NEW PARAMETERS



TERMINATE

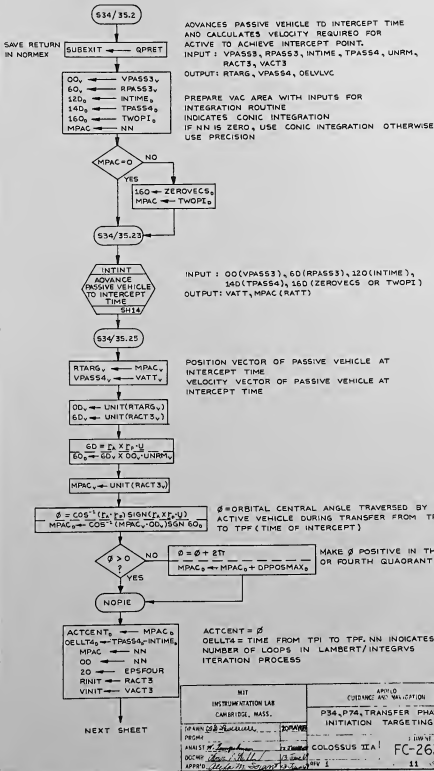
R1  
R2  
R3 } DEPENDS ON REQUEST

PROCEED

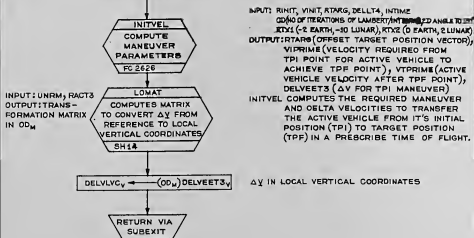


15 JUN 68  
 PREP: [Signature]  
 ANAL: [Signature]  
 CHECK: [Signature]  
 APPV: [Signature]

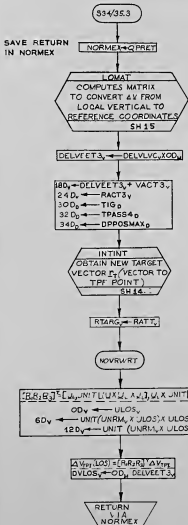
P34, P74 TRANSFER PHASE  
 INITIATION TARGETING  
 COLOSSUS IIA  
 FC-2630  
 10 - 20



FROM PRECEDING SHEET



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DRAWN <i>[Signature]</i> 2568208		P14, P74 TRANSFER PHASE INITIATION TARGETING	
PROGRAM		DOCUMENT NO.	
ANALYST <i>[Signature]</i> W.A.M.		COLOSSUS IIA	FC-2630
DOCNO <i>[Signature]</i> 20CT48		REV 1	SHEET 12 OF 20
APPRO'D <i>[Signature]</i>			



CALCULATES NEW TARGET VECTOR IF ΔV OVERWRITE AND LINE OF SIGHT ΔV

INPUT: DELVLCV, VACT3, RACT3, TIG, TPASS 4, UNRM, ULOS  
OUTPUT: DVLOS, RTARG

INPUT: UNRM, RACT3  
OUTPUT: TRANSFORMATION MATRIX IN OD<sub>v</sub>

PUSH LIST COUNTER IS 18 UPON RETURN FROM LOMAT  
DELVEET3 = ΔV<sub>REF</sub> IN REFERENCE COORDS.  
DELVLCV = NEW ΔV<sub>REF</sub> INPUTTED BY ASTRONAUT OVERWRITE

SET UP VAC AREA FOR INTEGRATION ROUTINE

INDICATES PRECISION INTEGRATION

INPUT: SEE PREVIOUS BOX  
OUTPUT: RATF<sub>v</sub>

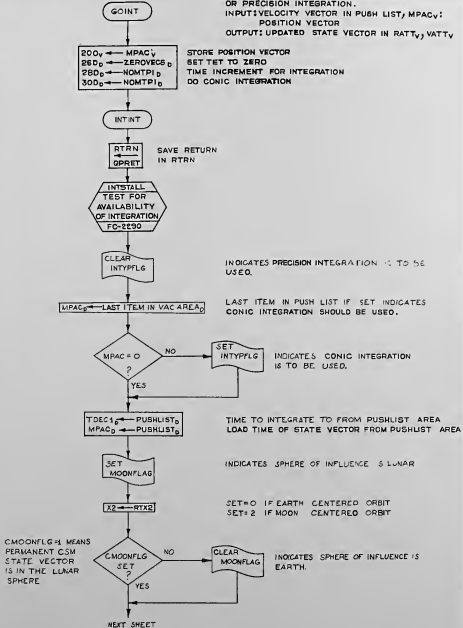
NEW OFFSET TARGET VECTOR

THIS MATRIX IS USED TO CONVERT ΔV FROM REFERENCE COORDINATES TO LINE OF SIGHT COORDINATES

LINE OF SIGHT DELTA VELOCITY

22 JUN 68 11 00 PM 11 SEP 68 1200 00 13 20	P34 P74 TRANSFER PHASE INITIATION TARGETING COLOSSUS IIA FC-2630
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ROUTINE TO PREPARE USER FOR CONIC  
OR PRECISION INTEGRATION.  
INPUT: VELOCITY VECTOR IN PUSH LIST; MPAC<sub>y</sub>:  
POSITION VECTOR  
OUTPUT: UPDATED STATE VECTOR IN RAT<sub>vj</sub>, VATT<sub>y</sub>



INSTRUMENTAL CONTROL  
OPERATIONS, A-3  
REVISION  
APPROVED  
DATE

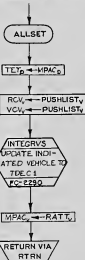
P34, P74 TRANSFER PHASE  
INITIATION TARGETING

COLOSSUS IIA

FC-2630

14 20

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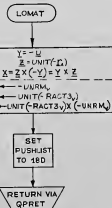


TIME OF STATE VECTOR

PRESENT POSITION IN LAST PUSHLIST AREA USED  
PRESENT VELOCITY IN NEXT TO LAST PUSHLIST AREA USED

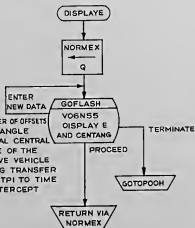
INPUT: RCV, VCV, TDEC1, TET  
OUTPUT: VATT, MPAC (RATT)

POSITION AT TDEC1



COMPUTE TRANSFORMATION MATRIX TO CONVERT  $\Delta Y$  FROM REFERENCE COORDINATES TO LOCAL VERTICAL COORDINATES

R1- NN      XXXX.   - NUMBER OF OFFSETS  
R2- ELEV   -XXX.XX DEG.- ELEV. ANGLE  
R3- CENTANG -XXX.XX DEG.- ORBITAL CENTRAL ANGLE OF THE PASSIVE VEHICLE DURING TRANSFER FROM TPI TO TIME OF INTERCEPT



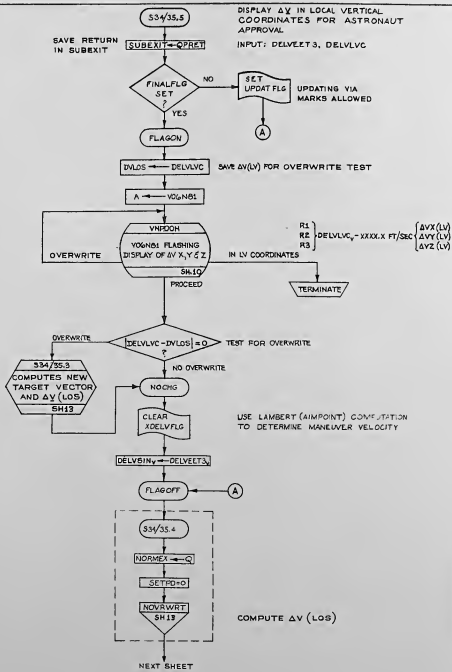
P34, P74 TRANSFER PHA I  
INITIATION TARGET NO

22 JUL 68

COLOSSUS IIA FC-2630

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P34, P74 TRANSFER PHASE  
 INITIATION TARGETING  
 COLOSSUS IIA FC-2630  
 16 20

FROM PRECEDING SHEET

AREG ← V06N59

VNPOOH  
 DISPLAY ΔY  
 IN LOS  
 COORDINATES  
 SH10

R1 - }  
 R2 - } DVLOS<sub>v</sub> - XXXX.X FT/SEC - { ΔVX (LOS)  
 R3 - } { ΔVY (LOS)  
 { ΔVZ (LOS)

PROCEED

RETURN VIA  
 SUBEXIT

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P34, P74 TRANSFER PHASE INITIATION TARGETING		DOCUMENT NO. FC-2630	
DATE: 12/10/63	BY: [Signature]	REV I	17 of 20
ANALYST: [Signature]	DATE: 12/10/63	COLLOSSUS IIA	
DRWR: [Signature]	DATE: 12/10/63		
APPROV: [Signature]			



## P34 TRANSFER PHASE INITIATION (TPI)

## SUBROUTINES

## IN THIS CHART

VNPOOH	DISPLAY REQUESTED VERB/NOUN	SH, 10
DISPLA <sub>E</sub>	DISPLAY V06N55	SH, 15
SELECTMU	SELECT $\mu$ VALUE ACCORDING TO LUNAR OR EARTH SPHERE OF INFLUENCE	SH, 17
S33/34,1	COMPUTES EITHER ANGLE E OR TPI TIME	SH, 6
S34/35,2	UPDATE PASSIVE VEHICLE TO INTERCEPT TIME	SH, 11
S34/35,3	$\Delta V(L,V)$ IN REF, NEW TARGET, $\Delta V$ IN LOS COORDINATES	SH, 13
S34/35,5	DISPLAY $\Delta V$ COMPONENTS	SH, 16
LOMAT	COMPUTES TRANSFORMATION MATRIX	SH, 15

## OTHER CHARTS

AVFLAG	CLEAR AVFLAG, SET ECSTEER = 1, SET UPDATFLG AND TRACKFLG
AFLAGP	SET AVFLAG
TIMETHET	CALCULATES DELTA TIME OF FLIGHT
INTEGRVS	UPDATE VEHICLE TO SPECIFIED TIME
COMPTGO	COMPUTES TIME TO OR FROM MANEUVER TIME
LEMPREC	UPDATES LEM TO SPECIFIED TIME VIA INTEGRATION
CSMPREC	UPDATES CSM TO SPECIFIED TIME VIA INTEGRATION
PRECSET	EXECUTES PRECISION UPDATE OF BOTH VEHICLES
INITVEL	COMPUTES REQUIRED MANEUVER AND DELTA VELOCITIES
PEHAP01	CALCULATES PERIGEE ALTITUDE TO ACTIVE VEHICLE
VN1645	DISPLAY M TPI MGA
P20FLGON	SETS TRACKFLG, UPDATFLG

FLGS	MEANING	SET	CLEARED	TESTED
ETPFLG	SET ELEVATION ANGLE IS INPUT CLEARED TPI TIME IS INPUT	SH2	SH2	SH2,SH3 SH6
ITSWICH	SET FORCE ANOTHER ITERATION OF S34/35,1 TO COMPUTE TPI TIME CLEARED ACCEPT CURRENT TPI TIME/FINAL ITERATION S34/35,1 PRIOR TO COMPUTING ELEV ANGLE	SH2	SH2,SH3	SH3,SH6
RVS	SET ONLY TIME IS AN OUTPUT FROM TIMETHET CLEARED STATE VECTOR UPDATE AND TIME ARE OUTPUTS FROM TIMETHET	SH3		
MOONFLAG	SET MOON IS SPHERE OF INFLUENCE CLEARED EARTH IS SPHERE OF INFLUENCE	SH13	SH13	
INTYFLG	SET CONIC INTEGRATION CLEARED PRECISION INTEGRATION	SH13	SH13	
CMOONFLG	SET PERMANENT CSM STATE VECTOR IN LUNAR SPHERE CLEARED PERMANENT CSM STATE VECTOR IN EARTH SPHERE			SH13,SH15
FINALFLG	SET LAST PASS THRU RENDEZVOUS PROGRAM COMPUTATIONS CLEARED INTERIM PASS THRU RENDEZVOUS PROGRAM COMPUTATIONS		SH16	SH15
UPDATFLG	SET UPDATING VIA MARKS ALLOWED CLEARED UPDATING VIA MARKS DISALLOWED	SH15		
AVFLAG	SET LM ACTIVE VEHICLE CLEARED CSM ACTIVE VEHICLE			
NDELVFLG	SET USE EXTERNAL $\Delta V$ COMPUTATION FOR MANEUVER VELOCITY CLEARED USE LAMBERT COMPUTATION TO DETERMINE MANEUVER VELOCITY		SH15	
TRACKFLG	SET TRACKING ALLOWED CLEARED TRACKING DISALLOWED			

ALARMS	MEANING	USED
00811	NO TIME OF IGNITION FOR GIVEN ELEV. ANGLE	SH3

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DRAWN <i>P.M. [Signature]</i>		P34 P74 TRANSFER PHASE INITIATION TARGETING	
DATE	4 SEP 68	PROJECT	COLOSSUS IIA
ANALYST	<i>[Signature]</i>	FC-2630	
DESIGNER	<i>[Signature]</i>	REV 1	18 of 20
APPROVED	<i>[Signature]</i>		

## P34 (CONT'D)

ERASABLES		UNITS	
TPI	TIME OF TPI MANEUVER	CENTISECS.	2 <sup>28</sup>
TIG	IGNITION TIME OF MANEUVER	CENTISECS.	2 <sup>28</sup>
ELEV.	DESIRED LOS ANGLE AT TPI	REVOLUTIONS	2 <sup>1</sup>
NN	NUMBER OF INTEGRATION OFFSETS; 0 = CONIC, 2 = PRECISION		
NOMTPI	DELTA TIME BETWEEN ASSIGNED AND COMPUTED TPI TIME	CENTISECS.	2 <sup>28</sup>
TDEC1	INPUT TIME TO INTEGRATION	CENTISECS.	2 <sup>28</sup>
DELVEET3	$\Delta Y$ FOR TPI MANEUVER	M/CSC	2 <sup>7</sup>
CENTANG	ANGLE TRAVERSED BY PASSIVE VEHICLE FROM TPI TO TPF TIME	REVOLUTIONS	2 <sup>1</sup>
CSTH	COS OF CENTANG	REVOLUTIONS	2 <sup>1</sup>
SINTH	SIN OF CENTANG	REVOLUTIONS	2 <sup>1</sup>
RVEC	STATE VECTOR POSITION VALUE	METERS	2 <sup>29</sup>
RPASS3	PASSIVE VEHICLE POSITION VECTOR AT TPI TIME	METERS	2 <sup>29</sup>
VPASS3	PASSIVE VEHICLE VELOCITY VECTOR AT TPI TIME	M/CSC	2 <sup>7</sup>
VVEC	STATE VECTOR VELOCITY VALUE	M/CSC	2 <sup>7</sup>
INTIME	INPUT TIME TO INITVEL ROUTINE	CENTISECS.	2 <sup>28</sup>
T	TIME FROM TPI TO TPF	CENTISECS.	2 <sup>28</sup>
TPASS4	RENDEZVOUS TIME	CENTISECS.	2 <sup>28</sup>
DELVTPI	MAGNITUDE OF $\Delta Y$ AT TPI	M/CSC	2 <sup>7</sup>
DELVTPF	MAGNITUDE OF $\Delta Y$ AT TPF	M/CSC	2 <sup>7</sup>
RPASS4	PASSIVE VEHICLE POSITION VECTOR AT TPF TIME	METERS	2 <sup>29</sup>
VPASS4	PASSIVE VEHICLE VELOCITY VECTOR AT TPF TIME	M/CSC	2 <sup>7</sup>
VTPRIME	VELOCITY AT TARGET AFTER MANEUVER	M/CSC	2 <sup>7</sup>
VIPRIME	MANEUVER VELOCITY REQUIRED	M/CSC	2 <sup>7</sup>
RTARG	OFFSET TARGET POSITION VECTOR	METERS	2 <sup>29</sup>
RTX1	SHIFT COUNTER; -2 FOR EARTH ORBIT, -10 FOR LUNAR ORBIT		2 <sup>14</sup>
RTX2	SHIFT COUNTER; 0 FOR EARTH ORBIT, 2 FOR LUNAR ORBIT		2 <sup>14</sup>
+MGA	MIDDLE GEMBAL ANGLE	REVOLUTIONS	2 <sup>0</sup>
TTOGO	TIME TO IGNITION	CENTISECS.	2 <sup>28</sup>
TRMRCNT	NO. OF OPTICS MARKS INCORPORATED SINCE LAST MANEUVER		2 <sup>14</sup>
TITER	OR ITERATION OF P20 ITERATION COUNTER FOR S33/34.1	B14	2 <sup>14</sup>
SECMAN	$\Delta L$ UPPER LIMIT FOR CURRENT ITERATION		2 <sup>28</sup>
RACT3/RINIT	POSITION VECTOR OF ACTIVE VEHICLE AT TPI	METERS	2 <sup>29</sup>
VACT3/VINIT	VELOCITY VECTOR OF ACTIVE VEHICLE AT TPI	M/CSC	2 <sup>7</sup>
ULOS	UNIT LINE OF SIGHT VECTOR	METERS	2 <sup>1</sup>
UNOM	UNIT NORMAL VECTOR TO ACTIVE VEHICLE'S PLANE	METERS	2 <sup>1</sup>
DELEL	DIFFERENCE BETWEEN DESIRED AND COMPUTED ELEVATION ANGLE	REVOLUTIONS	2 <sup>1</sup>
DELEL0	TEMP. STORAGE FOR DELEL	REVOLUTIONS	2 <sup>1</sup>
DELTEE0	CURRENT ITERATION'S VALUE OF $\Delta t$	CENTISECS.	2 <sup>28</sup>
RAVREC	POSITION VECTOR OF ACTIVE AT TPI TEMP. STORAGE	METERS	2 <sup>29</sup>
VAVREC	VELOCITY VECTOR OF ACTIVE AT TPI TEMP. STORAGE	M/CSC	2 <sup>7</sup>
RPVREC	POSITION VECTOR OF PASSIVE AT TPI TEMP. STORAGE	METERS	2 <sup>29</sup>
VPVREC	VELOCITY VECTOR OF PASSIVE AT TPI TEMP. STORAGE	M/CSC	2 <sup>7</sup>
VATT	POSITION VECTOR AFTER INTEGRATION UPDATE	M/CSC	2 <sup>7</sup>
RATT	VELOCITY VECTOR AFTER INTEGRATION UPDATE	METERS	2 <sup>29</sup>
ACTCENT	CENTRAL ANGLE TRAVERSED BY ACTIVE FROM TPI TO TPF	REVOLUTIONS	2 <sup>0</sup>
TET	TIME INPUT TO INTEGRATION ROUTINE	CENTISECS.	2 <sup>28</sup>
VCV	PRESENT VELOCITY INPUT TO INTEGRATION ROUTINE	M/CSC	2 <sup>7</sup>
RCV	PRESENT POSITION INPUT TO INTEGRATION ROUTINE	METERS	2 <sup>29</sup>

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 28-4750-1  
 P. M. [Signature]  
 1 SEP 68  
 PREPARED BY [Signature]  
 ANALYSIS BY [Signature]  
 30% [Signature]  
 APPROVED BY [Signature]  
 20 OCT 68  
 4 Aug 67

101  
 28-4750-1  
 P34 D74 TRANSFER PHASE  
 INITIATION TARGETING  
 COLOSSUS II A FC-2630  
 19 20

## P34 (CONT'D)

## DISPLAYS

VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N37	FLASHING	R1 - } TTP1 <sub>D</sub> { $\left. \begin{array}{l} 00XX, \text{ HRS.} \\ 000XX, \text{ MIN.} \\ 0XX, XX \text{ SEC.} \end{array} \right\}$ TIME OF TPI IGNITION	SH2, 3
V06N55	FLASHING	R1 - NN NUMBER OF OFFSETS. 0 - CONIC, 2 - PRECISION R2 - ELEV } $\left. \begin{array}{l} XXX, XX \text{ DEG.} \\ \text{ORBITAL CENTRAL ANGLE OF THE} \\ \text{PASSIVE VEH. DURING TRANSFER} \\ \text{FROM TPI TO TIME OF INTERCEPT} \end{array} \right\}$ R3 - CENTANG	SH2, 3, 14
V06N58	FLASHING	R1 - POSTTPI XXXX,X NAUT. MI, PERIGEE ALTITUDE R2 - DELVTPI XXXX,X FT/SEC DELTA V REQUIRED FOR TPI MANEUVER R3 - DELVTPF XXXX,X FT/SEC DELTA V REQUIRED FOR TPF MANEUVER	SH4
V06N81	FLASHING	R1 - } DELVLVC <sub>V</sub> XXXX,X FT/SEC { $\left. \begin{array}{l} \Delta V X \text{ (LV)} \\ \Delta V Y \text{ (LV)} \\ \Delta V Z \text{ (LV)} \end{array} \right\}$ DELTA V REQUIRED FOR TPI MANEUVER IN LOCAL VERTICAL COORDINATES	SH15
V06N59	FLASHING	R1 - } DVLOS <sub>V</sub> XXXX,X FT/SEC { $\left. \begin{array}{l} \Delta V X \text{ (LOS)} \\ \Delta V Y \text{ (LOS)} \\ \Delta V Z \text{ (LOS)} \end{array} \right\}$ DELTA V REQUIRED FOR TPI MANEUVER IN LINE OF SIGHT COORDINATES	SH16

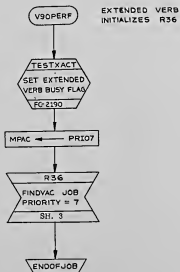
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DRAWN P. H. D. [Signature]	6 SEP 68	COLOSSUS IIA	FC-2630
ANALYST [Signature]	6 SEP 68	REV 1	20 OF 20
DOCTR [Signature]			
APPROV [Signature]			

## R36. OUT-OF-PLANE RENDEZVOUS ROUTINE

V90PERF  
R36SH. 2  
SH. 3

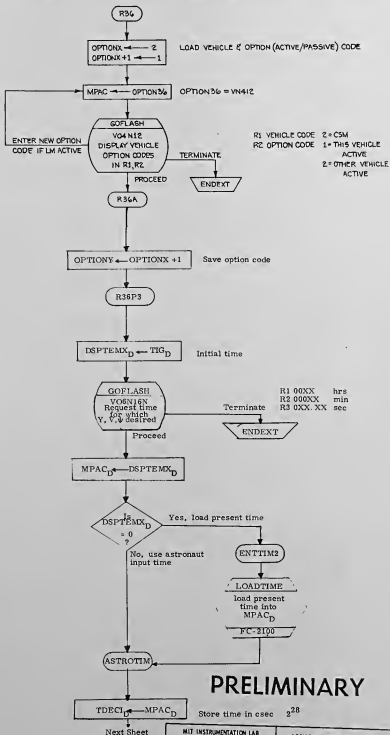
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Johnson</i>	<i>1/15/68</i>	RENDEZVOUS OUT-OF-PLANE DISPLAY	
PRGRM		COLOSSUS 2D	DOCUMENT NO. FC-2831
ANALST			
DCMR			
APPR'D		REV 2	SHEET 1 OF 7



PRELIMINARY

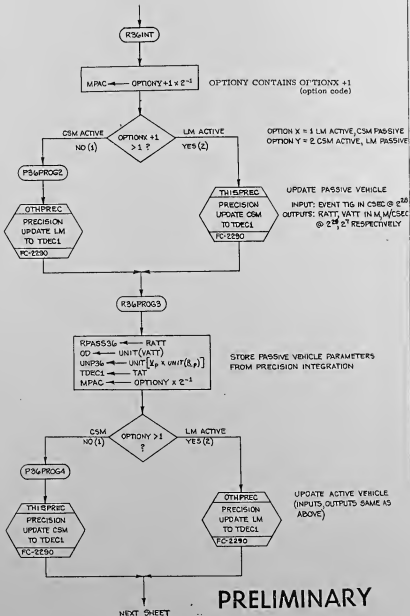
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		RENDEZVOUS <sup>R36</sup> OUT-OF-PLANE DISPLAY	
PROGR		COLOSSUS 2D	DOCUMENT NO. FC-2631
ANALST		REV 2	SHEET 2 OF 7
DOCHR			
APP'D			



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. J. ...</i>		R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PROGRAM		COLOSSUS	DOCUMENT NO.
ANALYST		2D	FC-2631
SOCHR		REV	SHEET 3 OF 7
APPROD			

FROM PRECEDING SHEET



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Delmonico</i>		RENDEZVOUS "OUT-OF-PLANE" DISPLAY	
PROGR		COLOSSUS	DOCUMENT NO.
ANALST		2D	FC-2631
DOCMR		REV 2	SHEET 4 OF 4
APPRD			

FROM PRECEDING SHEET

R36-PROGS

OOD	←	VATT <sub>v</sub>
OOD	←	RATT <sub>v</sub>
O&D	←	RATT <sub>v</sub>
12D	←	RATT <sub>v</sub>
3OD	←	TATT <sub>v</sub>
MPAC	←	RATT <sub>v</sub>

LOS <sub>v</sub>	=	r <sub>p</sub> - r <sub>a</sub>
12D	←	PPASS36 - MPAC

LINE OF SIGHT VECTOR

Y	=	U · r <sub>a</sub>
RANGE	←	(UNP36 - MPAC) × 2 <sup>-1</sup>

ACTIVE VEHICLE DISTANCE FROM PLANE OF PASSIVE VEHICLE (ALONG PASSIVE Y-AXIS)

Y-dot	=	U · V <sub>a</sub>
RATE	←	UNP36 - OOD

OUT-OF-PLANE COMPONENT OF ACTIVE VEHICLE VELOCITY

MPAC	←	UNIT(r <sub>a</sub> )
O&D	←	UNIT(r <sub>a</sub> )

U <sub>ra</sub>	=	U <sub>ra</sub> × V <sub>a</sub>
MPAC	←	MPAC × OOD

ACTIVE VEHICLE MOMENTUM (PLANE) VECTOR

U <sub>ra</sub>	=	(U <sub>ra</sub> × V <sub>a</sub> ) × U <sub>ra</sub>
MPAC	←	UNIT(MPAC × 12D)

ACTIVE VEHICLE UNIT FORWARD HORIZONTAL

R36B

OOD	←	MPAC
MPAC	←	12D

U <sub>lv</sub>	=	U <sub>ra</sub> × (U <sub>l</sub> · r <sub>a</sub> )
MPAC	←	OOD × (12D - 12D)

UNIT VERTICAL × COS<sup>-1</sup>(U<sub>l</sub> · r<sub>a</sub>)  
= VERTICAL COMPONENT OF UNIT LOS

UNIT(V <sub>HL</sub> )	=	U <sub>lv</sub> - U <sub>ra</sub> × (U <sub>l</sub> · r <sub>a</sub> )
12D	←	UNIT(12D - MPAC)

UNIT HORIZONTAL COMPONENT OF LOS  
= UNIT LOS - UNIT VERTICAL COMPONENT LOS

PRELIMINARY

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. G. Johnson</i>	R36 RENDEZVOUS OUT-OF-PLANE DIST. 13	
PROGRAM		COLOSSUS	DOCUMENT NO.
ANALYST		3D	FC-2831
DOCTR		REV 2	SHEET 5 OF 7
APPROB			



FROM PRECEDING SHEET

$$\psi = \cos^{-1} \left( \frac{V_{AP} - V_{M}}{V_{A}} \right)$$

$$RTHETA \leftarrow \text{ARCCOS}(\text{OOD} - \text{MPAC})$$

PSI

$$\text{MPAC} \leftarrow (\text{OOD} \times \text{MPAC}) - \text{O&D}$$

UNIT HORIZONTAL OF ACTIVE VEHICLE CROSSED INTO LOS PROJECTION ON HORIZONTAL; RESULT COMPARED WITH VERTICAL FOR SENSE (PARALLEL UP MEANS PASSIVE VEHICLE IS LEFT OF ACTIVE VEHICLE PLANE/ FORWARD HORIZONTAL.)



$$\beta = 360^\circ - \psi$$

$$RTHETA \leftarrow \text{DPP05MAX} - RTHETA$$

IF  $\psi$  SUBTRACT FROM  $360^\circ$  TO GIVE POS ANGLE.

RS&TAC2

$$\text{MPAC} \leftarrow \text{30D}$$

RETRIEVE EVENT TIME



OUTPUT IN MPAC, MPAC + 1

$$\text{DSPTMX}_D \leftarrow \text{MPAC}_D$$



R1 XXX.XX Y IN NAUTICAL MILES TO NEAREST .01 NM  
R2 XXX.XX Y DOT IN FPS TO NEAREST .1 FPS  
R3 XXX.XX PSI, ANGLE BETWEEN LOS VECTOR PROJECTED ON HORIZONTAL PLANE AND UNIT HORIZONTAL ACTIVE

RECYCLE FOR NEW EVENT TIME



PROCEED

TERMINATE



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>L. Goldstein</i> 2/27/68		RENDZVOUS OUT-OF-PLANE DISPLAY	
PROGR		COLOSSUS	DOCUMENT NO.
ANALST		2D	FC-2631
DOCNR		REV 2	SHEET 6 OF 7
APPR'D			

## SUBROUTINES

LOADTIME	FC-2100	LOADS PRESENT TIME INTO MPAC	SH 3
THISPREC	FC-2290	ENKE UPDATE OF CSM	SH 4
OTHPREC	FC-2290	ENKE UPDATE OF LM	SH 4
SGNAGREL	FC-2100	FORCE SIGN AGREEMENT (TRIPLE PRECISION)	SH 6
TESTXACT	FC-2190	SETS EXTENDED VERB BUSY FLAG	SH 2

## DISPLAYS

## WHERE

VO4N1Z	DISPLAY VEHICLE CODE (1=LM, 2=CSM) IN R1 AND OPTION CODE (1=THIS VEHICLE ACTIVE, 2=PASSIVE) IN R2	SH 3
VO6N16N	REQUEST TIME FOR WHICH $\dot{Y}$ , $\dot{Y}$ , $\phi$ DESIRED	SH 3
VO6N3ON	DISPLAY $\dot{Y}$ , $\dot{Y}$ , $\phi$	SH 6

## ERASABLES

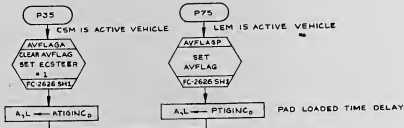
## UNITS

## SCALING

OPTIONX	VEHICLE OPTION CODE (LM=1, CSM=2)		$2^1$
OPTIONX +1	(EQUALS OPTIONX) VEHICLE CODE (1=CSM ACTIVE, 2=LM ACTIVE)		$2^1$
DISPTMX	DISPLAY BUFFER AREA (SAME AS OPTIONX)		
TDEC1	TIME STORAGE LOS	CSEC	$2^{28}$
RPASS36	STORAGE FOR PASSIVE VEHICLE POSITION VECTOR	METERS	$2^{25}$
UNP36	UNIT VECTOR OF PASSIVE VEHICLE MOMENTUM/ PLANE		
RANGE	$\dot{Y}$ ACTIVE VEHICLE DISTANCE FROM PASSIVE VEHICLE PLANE	METERS	
RRATE	$\dot{Y}$ ACTIVE VEHICLE VELOCITY COMPONENT NORMAL TO PASSIVE PLANE	M/CSEC	
RTHETA	$\phi$ ANGLE BETWEEN ACTIVE VEHICLE UNIT FORWARD HORIZONTAL LOS PROJECTED INTO HORIZONTAL PLANE		

PRELIMINARY

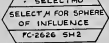
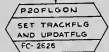
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. G. ...</i>		R336 RENDEZVOUS OUT-OF-PLANE DISP. & V.	
DESIGN		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2631
DOCHR		REV 2	SHEET 4 OF 7
APPR'D			



P35/P75A



STORE TIME DELAY



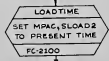
OUTPUT: RTSR1/MU,RTMU



VME OPTICS  
R1-TRKMCNT-XYBXX-NO. OF MARKS SINCE  
LAST THRUSTING MANEUVER (SEE P20)  
R2-TTOSO-XYBXX MIN-SEC-TIME TO/FROM TIG  
R3-+MGA-XXX.XX DEG-MIDDLE GIMBLE ANGLE  
-00001 UNTIL LAST PASS, THEN -00002

PROCEED/ENTER

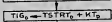
P35/75B



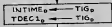
OUTPUTS:  
SLOAD2  $\rightarrow$  TIME2 (PRESENT TIME)  
MPAC  $\rightarrow$  (PRESENT TIME)



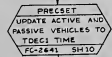
IGNITION TIME = PRESENT TIME +  
PRESELECTED TIME DELAY



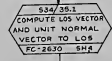
IGNITION TIME USED IN INITVEL



INPUT: TDEC1, CSM AND LM STATE VECTORS  
OUTPUT: RACT3<sub>v</sub>, VATT3<sub>v</sub>, RPA53<sub>v</sub>, VPA53<sub>v</sub>

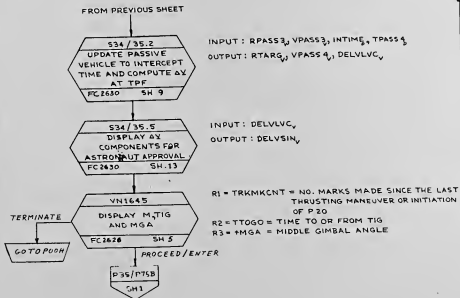


INPUT: RPA53<sub>v</sub>, RACT3<sub>v</sub>, VACT3<sub>v</sub>  
OUTPUT: UNRM<sub>v</sub>, ULOS<sub>v</sub>



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARJLO GUIDANCE AND NAVIGATION	
DRAWN: <i>[Signature]</i>		P35, P75 TRANSFER PHASE TARGETING	
PREPARED: <i>[Signature]</i>		DOCUMENT NO.	
ANALYST: <i>[Signature]</i>		FC-2640	
DOCNO: <i>[Signature]</i>		REV 1	
APPROVED: <i>[Signature]</i>		SHEET 1 OF 5	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P 35, P75 TRANSFER PHASE MIDCOURSE TARGETING	
DRAWN <i>J. Amundson</i>	18 AUG 64	COLOSSUS II-D	DOCUMENT NO.
PROGRAM <i>P35/P75</i>	17 JUL 64		FC-2640
ANALYST <i>P. J. ...</i>	21 SEP 64		
DOCTR <i>P. J. ...</i>	23 MAR 64		
APPROV <i>J. O. ...</i>	21 SEP 64	REV 2.	SHEET 2 OF 3

*J. May 64*

P35 TRANSFER PHASE MIDCOURSE  
SUBROUTINES

ON OTHER CHARTS

AVFLAGA	CLEAR AVFLAG, SETS KCSTEER #1
AVFLAGP	SETS AVFLAG
LOADTIME	SETS MPAC TO PRESENT TIME
SELECTMU	SELECT $\mu$ VALUE ACCORDING TO LUNAR OR EARTH SPHERE OF INFLUENCE
PRECSET	EXECUTES PRECISION UPDATE OF BOTH VEHICLES
S34/35.1	COMPUTE LOS AND UNIT NORMAL VECTORS
S34/35.2	UPDATE PASSIVE VEHICLE TO INTERCEPT TIME
S34/35.5	DISPLAY $\phi$ COMPONENTS
VN164 5	DISPLAY M, TFI AND MGA
P20FLGON	SET UPDATFLG, TRACKFLG

FLAGS	AVFLAG	TRACKFLG	FINALFLG	} ALL SET AND CLEARED ON SH1	
	UPDATFLG	AVFLAG			
DISPLAYS	R1-TRMKMCNT-XXXX.	-NO OF MARKS			USED
V16N45	R2-TTDOGO-XXBXX	MIN.-SEC.-TIME TO/ FROM THG		SH. 2	
	R3-+MGA-XXX.XX	DEG. MIDDLE GIMBAL ANGLE			

ALARMS

NONE

ERASABLES

		UNITS	SCALING
KT	TIMEDELAY STORAGE	CENTISECS	2 <sup>14</sup>
TSTRT	PRESENT TIME STORAGE	CENTISECS	2 <sup>14</sup>
TIG	TIME OF MANEUVER	CENTISECS	2 <sup>11</sup>
ATIGINC	PAD LOADED TIME DELAY FOR P35	CENTISECS	2 <sup>11</sup>
PTIGINC	PAD LOADED TIME DELAY FOR P75	CENTISECS	2 <sup>11</sup>
INTIME	INPUT TIME TO INITVEL	CENTISECS	2 <sup>11</sup>
TDEC1	INPUT TIME TO INTEGRATION	CENTISECS	2 <sup>11</sup>

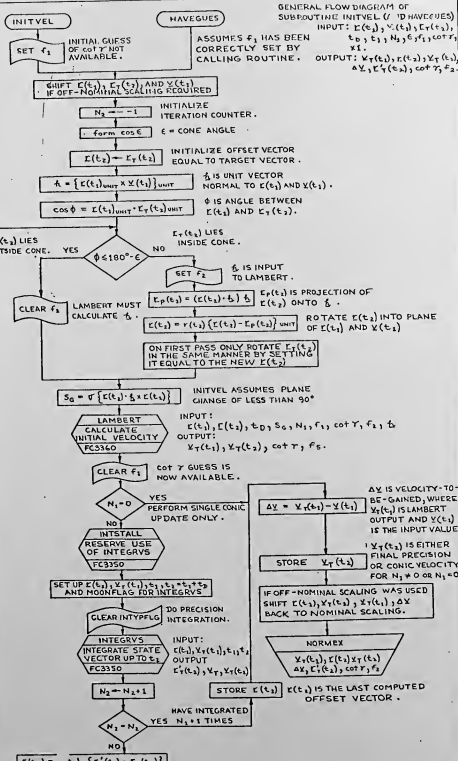
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P35, P75 TRANSFER PHASE MIDCOURSE TARGETING	
DRAWN <i>F. Newman</i>	2-11-68	BOOKING NO.	
PROG. <i>F. Newman</i>	19-71168	COLLOSSUS II- $\rightarrow$	FC-2640
ANALYST <i>J. P. ...</i>	2-5-68		
ROCKE <i>J. P. ...</i>	12-24-68		
APPROV. <i>John A. ...</i>	2 Sep 68		
	2 Aug 68		
		SHEET 3 OF 3	

## COMMON TARGETING SUBROUTINES

## MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

INITVEL	Sh. 4
HAVEGUES	Sh. 4
VECSHIFT	Sh. 10
SHIFTR1	Sh. 10
GET+MGA	Sh. 11
GET. LVC	Sh. 12
PERIAPO	Sh. 13
PERIAPO1	Sh. 13
SELECTMU	Sh. 14
PRECSET	Sh. 15
LEMSTORE	Sh. 15
CSMSTORE	Sh. 15

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>L. Dolestone</i> / 12/16	Common Targeting Subroutine INITVEL, MIDGIV, PERIAPO	
PRGMR	<i>J. Sear</i> / 1/14/67		DOCUMENT NO.
ANALST			
DOCMR	<i>M. Beal</i> / 12/23/67	COLOSSUS 2D	FIG. NO.
APPR'D	<i>P. Beal</i> / 1/14/67	REV	SHEET



GENERAL FLOW DIAGRAM OF SUBROUTINE INITVEL (I'D HAVE GUES)  
 INPUT:  $E(t_1)$ ,  $X(t_1)$ ,  $E_T(t_2)$ ,  $t_0$ ,  $t_1$ ,  $N_2$ ,  $\epsilon$ ,  $f_1$ ,  $\cot \gamma$ ,  $f_2$ ,  $X_T$ .  
 OUTPUT:  $X_T(t_1)$ ,  $X_T(t_2)$ ,  $\cot \gamma$ ,  $f_5$ ,  $\Delta X$ ,  $E_T(t_2)$ ,  $\cot \gamma$ ,  $f_2$ .

ASSUMES  $f_1$  HAS BEEN CORRECTLY SET BY CALLING ROUTINE.

INITIAL GUESS OF  $\cot \gamma$  NOT AVAILABLE.

SHIFT  $E(t_1)$ ,  $E_T(t_2)$ , AND  $X(t_2)$  IF OFF-NOMINAL SCALING REQUIRED

$N_2 = -1$  INITIALIZE ITERATION COUNTER.

form  $\cos \epsilon$   $\epsilon =$  CONE ANGLE

$E(t_2) = E_T(t_2)$  INITIALIZE OFFSET VECTOR EQUAL TO TARGET VECTOR.

$\hat{n} = \{E(t_1)_{UNIT} \times X(t_1)\}_{UNIT}$   $\hat{n}$  IS UNIT VECTOR NORMAL TO  $E(t_1)$  AND  $X(t_1)$ .

$\cos \phi = E(t_1)_{UNIT} \cdot E_T(t_2)_{UNIT}$   $\phi$  IS ANGLE BETWEEN  $E(t_1)$  AND  $E_T(t_2)$ .

$E_T(t_2)$  LIES OUTSIDE CONE. YES  $\phi < 180^\circ - \epsilon$  NO  $E_T(t_2)$  LIES INSIDE CONE.

CLEAR  $f_1$  LAMBERT MUST CALCULATE  $\hat{b}$ .

SET  $f_2$   $\hat{b}$  IS INPUT TO LAMBERT.

$E_P(t_2) = (E(t_2) \cdot \hat{b}) \hat{b}$   $E_P(t_2)$  IS PROJECTION OF  $E(t_2)$  ONTO  $\hat{b}$ .

$E(t_2) = r(t_2) \{E(t_2) - E_P(t_2)\}_{UNIT}$  ROTATE  $E(t_2)$  INTO PLANE OF  $E(t_1)$  AND  $X(t_2)$

ON FIRST PASS ONLY ROTATE  $E_T(t_1)$  IN THE SAME MANNER BY SETTING IT EQUAL TO THE NEW  $E(t_2)$

$S_0 = \sigma \{E(t_1) \cdot \hat{b} \times E(t_2)\}$  INITVEL ASSUMES PLANE CHANGE OF LESS THAN  $90^\circ$

LAMBERT CALCULATE INITIAL VELOCITY FC3360  
 INPUT:  $E(t_1)$ ,  $E(t_2)$ ,  $t_0$ ,  $S_0$ ,  $N_1$ ,  $f_1$ ,  $\cot \gamma$ ,  $f_2$ ,  $\hat{b}$   
 OUTPUT:  $X_T(t_1)$ ,  $X_T(t_2)$ ,  $\cot \gamma$ ,  $f_5$ .

CLEAR  $f_1$   $\cot \gamma$  GUESS IS NOW AVAILABLE.

$N_1 = 0$  YES PERFORM SINGLE CONIC UPDATE ONLY. NO

INSTALL RESERVE USE OF INTEGRVS FC3350

SET UP  $E(t_2)$ ,  $X_T(t_1)$ ,  $t_0$ ,  $t_1$ ,  $t_2$ ,  $t_3$ ,  $t_4$ ,  $t_5$ ,  $t_6$ ,  $t_7$ ,  $t_8$ ,  $t_9$  AND MOONFLAG FOR INTEGRVS

CLEAR INTPFLG DO PRECISION INTEGRATION.

INTEGRVS INTEGRATE STATE VECTOR UP TO  $t_2$  FC3350  
 INPUT:  $E(t_1)$ ,  $X_T(t_1)$ ,  $t_1$ ,  $t_2$   
 OUTPUT:  $E_T(t_2)$ ,  $X_T$ ,  $X_T(t_2)$

$N_2 = N_2 + 1$

STORE  $E(t_2)$   $E(t_2)$  IS THE LAST COMPUTED OFFSET VECTOR.

HAVE INTEGRATED YES  $N_2 = N_2$  TIMES

$\Delta X = X_T(t_1) - X(t_1)$   $\Delta X$  IS VELOCITY TO BE GAINED, WHERE  $X_T(t_1)$  IS LAMBERT OUTPUT AND  $X(t_1)$  IS THE INPUT VALUE.  
 $X_T(t_2)$  IS EITHER FINAL PRECISION OR CONIC VELOCITY FOR  $N_2 \neq 0$  OR  $N_2 = 0$ .

STORE  $X_T(t_2)$

IF OFF-NOMINAL SCALING WAS USED SHIFT  $E(t_2)$ ,  $X_T(t_2)$ ,  $X_T(t_1)$ ,  $\Delta X$  BACK TO NOMINAL SCALING.

NORMEX  
 $X_T(t_1)$ ,  $E(t_1)$ ,  $X_T(t_2)$ ,  $\Delta X$ ,  $E_T(t_2)$ ,  $\cot \gamma$ ,  $f_2$

$E(t_2) = \dots - [E_T(t_2) - E_T(t_1)]$

CALCULATE NEW OFFSET VECTOR  $E(t_2)$ , WHERE  $E_T(t_2)$  IS RESULT OF A PRECISION INTEGRATION.

*G.P. Clark*  
 12/15/68  
 10/1/69

## INITVEL (AND HAVEGUES)

GIVEN THE INITIAL TIME  $t_1$ , THE INITIAL POSITION  $\mathbf{r}(t_1)$ , THE FINAL POSITION  $\mathbf{r}_T(t_2)$  AND THE CORRESPONDING TRANSFER TIME  $t_D$ , THIS SUBROUTINE CALCULATES THE FOLLOWING VECTORS:

- 1) THE INITIAL VELOCITY VECTOR  $\mathbf{v}_T(t_1)$  WHICH WILL TAKE ONE IN A PRECISION INTEGRATION FROM  $\mathbf{r}(t_1)$  TO  $\mathbf{r}_T(t_2)$ , AND
- 2) THE FINAL POSITION VECTOR  $\mathbf{r}(t_2)$  WHICH ONE WOULD ARRIVE AT IF ONE USED THE ABOVE INITIAL VELOCITY VECTOR  $\mathbf{v}_T(t_1)$  AND UPDATED USING ONLY A CONIC CALCULATION. THIS VECTOR IS REFERRED TO AS THE OFFSET TARGET VECTOR.

INITVEL IS CALLED BY:

PIQ (OR P11), CALLVEL, S40.1, MANUPARM

HAVEGUES IS CALLED BY:

S40.9.

INPUT:

- 1) RINIT<sub>v</sub> =  $\mathbf{r}(t_1)$ , INITIAL POSITION VECTOR, IN METERS, AT 2<sup>30</sup>.
- 2) VINIT<sub>v</sub> =  $\mathbf{v}(t_1)$ , INITIAL VELOCITY VECTOR, IN METERS/SEC, AT 2<sup>7</sup>. IT IS USED TO DETERMINE WHETHER THE TRANSFER ANGLE FROM THE INITIAL POSITION VECTOR TO THE TARGET VECTOR IS LESS THAN OR GREATER THAN 180°. IT IS ALSO USED TO SPECIFY THE TRANSFER PLANE IF AND ONLY IF THE TARGET VECTOR LIES WITHIN THE CONE.
- 3) RTARG<sub>v</sub> =  $\mathbf{r}_T(t_2)$ , THE TARGET VECTOR, IN METERS, AT 2<sup>30</sup>. IF  $N_1 \neq 0$  IT IS THE TRUE TARGET VECTOR. IF  $N_1 = 0$  IT IS THE OFFSET TARGET VECTOR.
- 4) DELT4 =  $t_D$ , DESIRED TRANSFER TIME FROM  $\mathbf{r}(t_1)$  TO  $\mathbf{r}_T(t_2)$ , IN CSEC, AT 2<sup>30</sup>.
- 5) INTIME =  $t_1$ , TIME OF VALIDITY OF  $\mathbf{r}(t_1)$ , IN CSEC, AT 2<sup>30</sup>.
- 6) PL5 =  $N_1$ , THE NUMBER OF OFFSETS TO BE USED IN CALCULATING THE OFFSET TARGET VECTOR. IT IS ALSO EQUAL TO THE NUMBER OF ITERATIONS MINUS 1.  $N_1 = 0$  IMPLIES A SINGLE CONIC CALCULATION BUT NO INTEGRATION NOR OFFSET CALCULATION. IN THIS CASE RTARG<sub>v</sub> IS ASSUMED TO BE THE OFFSET VECTOR.
- 7) PL+2 =  $\epsilon$ , THE CONE ANGLE OF A CONE MEASURED ABOUT  $-\mathbf{r}(t_1)$ , IN REVOLUTIONS, AT 2<sup>0</sup>.
- 8) GUESSW =  $f_1$ , A FLAG, IS CLEAR IF AN INITIAL GUESS OF  $\cot \gamma$  IS TO BE INPUT TO LAMBERT, IS SET IF  $\cot \gamma$  IS NOT INPUT BUT MUST BE CALCULATED BY LAMBERT.
- 9) COGA =  $\cot \gamma$ , THE INITIAL GUESS OF  $\cot \gamma$  IF  $f_1$  IS CLEAR.
- 10) B2FFLAG = A FLAG, IS CLEAR IF EARTH IS CENTRAL BODY AND SUBROUTINE SHOULD CALCULATE WITH NOMINAL SCALING, IS SET IF MOON IS CENTRAL BODY AND OFF - NOMINAL SCALING IS REQUIRED.
- 11) X1 = INDEX REGISTER CONTAINING VALUE USED BY LAMBERT TO SET UP PROPER M - TABLE, IS -2 FOR EARTH, IS -100 FOR MOON.
- 12) AVEFLAG = A FLAG, IF SET ITERCTR<sub>5</sub> IS SET EQUAL TO 5, IF CLEAR ITERCTR<sub>5</sub> IS SET EQUAL TO 200.
- 13) PUSH LIST POINTER IS AT THE GENERAL VALUE PL, WHERE  $0 \leq PL \leq 630D$ .

OUTPUT:

- 1) VIPRIME<sub>v</sub> =  $\mathbf{v}_T(t_1)$ , THE VELOCITY REQUIRED AT TIME  $t_1$  IN ORDER TO REACH  $\mathbf{r}_T(t_2)$  IN A PRECISION MANNER IN TIME INTERVAL  $t_D$ , IN METERS/SEC, AT 2<sup>7</sup>. THIS IS THE FINAL VELOCITY OUTPUT FROM LAMBERT AND IS THE VELOCITY USED IN THE VELOCITY-TO-BE-GAINED EQUATIONS.
- 2) RTARG<sub>v</sub> =  $\mathbf{r}(t_2)$ , THE COMPUTED OFFSET TARGET VECTOR, IN METERS, AT 2<sup>30</sup>.
- 3) VTPRIME<sub>v</sub> =  $\mathbf{v}_T(t_2)$ , THE FINAL PRECISION VELOCITY VECTOR RESULTING FROM A PRECISION UPDATE OF THE INITIAL POSITION VECTOR  $\mathbf{r}(t_1)$  AND THE REQUIRED INITIAL VELOCITY VECTOR  $\mathbf{v}_T(t_1)$  IF  $N_1 \neq 0$ . IT IS THE FINAL CONIC VELOCITY VECTOR RESULTING FROM A CONIC UPDATE OF  $\mathbf{r}(t_1)$  AND  $\mathbf{v}_T(t_1)$  IF  $N_1 = 0$ . IT IS IN METERS/SEC AT 2<sup>7</sup>.
- 4) DELVEET<sub>v</sub> =  $\Delta \mathbf{v}$ , THE VELOCITY TO BE GAINED, IN METERS/SEC, AT 2<sup>7</sup>.
- 5) RATT1<sub>v</sub> =  $\mathbf{r}_T(t_2)$ , THE POSITION VECTOR RESULTING FROM A PRECISION INTEGRATION FROM  $\mathbf{r}(t_1)$  USING  $\mathbf{v}_T(t_1)$  AS THE INITIAL VELOCITY, IN METERS, AT 2<sup>30</sup>/2<sup>30</sup>.
- 6) COGA =  $\cot \gamma$ , COTANGENT OF FLIGHT PATH ANGLE OF THE VECTORS  $\mathbf{r}(t_1)$  AND  $\mathbf{v}_T(t_1)$ , MEASURED FROM THE VERTICAL, AT 2<sup>7</sup>.
- 7) NORMSW =  $f_2$ , A FLAG, IS CLEAR IF THE TARGET VECTOR  $\mathbf{r}_T(t_2)$  LIES OUTSIDE OF THE CONE, IS SET IF  $\mathbf{r}_T(t_2)$  LIES INSIDE THE CONE.
- 8) ITERCTR<sub>5</sub> = ITERATION COUNT USED IN LAMBERT.
- 9) PUSH LIST POINTER IS AT 0 D.

COMMON TARGETING SUBROUTINE  
INITVEL, MIDRIM  
PERIAP, SELECTING, FLECO  
CO, OSSUB, DD, PC, 2, 1

Johnson  
1/21/62

PARPAR

6/1/62

11-1-62



ENTER HERE IF  
INITIAL GUESS OF  
COT Y NOT AVAILABLE

ENTER HERE IF  
INITIAL GUESS OF  
COT Y IS AVAILABLE

INITVEL

HAVEGUES

SET  
 $F_1(\text{GUESSW})$

$F_1$  IS SET TO  
INDICATE TO LAMBERT  
AN INITIAL GUESS OF  
COT Y IS NOT AVAILABLE

AN ENTRY AT HAVEGUES  
ASSUMES THAT THE FLAG  
 $F_1 = \text{GUESSW}$  HAS BEEN CLEARED  
BY THE CALLING ROUTINE, OR BY  
PREVIOUS USE OF INITVEL.

STORE RETURN ADDRESS IN NORMEX

$\text{RTARGL} \leftarrow \text{RTARGV}$

$\neq 0$   $\text{RTXZ}$   $= 0$

SHIFT BINARY POINT TO OFF-  
NOMINAL SCALING,  $X(t_1)$  AND  
 $Y(t_1)$  FROM  $2^{19}$  TO  $2^{27}$  AND  
 $Y(t_1)$  FROM  $2^7$  TO  $2^4$ .

FOR MOON  
CENTERED SYSTEM WITH  
OFF-NOMINAL SCALING.

NO SHIFT REQUIRED;  
USE NOMINAL SCALING

FOR EARTH CENTERED  
SYSTEM OR MOON  
CENTERED SYSTEM  
WITH NOMINAL  
SCALING.

INITVEL1

$\text{ITCTR}_2 \leftarrow -1$

INITIALIZE ITERATION COUNTER  
 $N_2$  TO -1.

$\text{COZY}_4 \leftarrow \cos(\text{PL}+2)$   
SCALED AT  $2^4$

FORM THE COSINE OF  
THE CONE ANGLE  $\theta$ .

$\text{VTARGIAG}_2 \leftarrow \text{PL}_2$

STORE ITERATION COUNT  $N_1$ . IF  $N_1 \neq \phi$  DO A  
CONIC UPDATE ONLY. IF  $N_1 \neq \phi$  DO A PRECISION  
INTEGRATION WITH  $N_1$  OFFSETS.

$\text{RIVECV} \leftarrow \text{RINITV}$   
 $\text{RZVECV} \leftarrow \text{RTARGV}$   
 $\text{TDESIRE}_2 \leftarrow \text{DELLT}_4$

MOVE  $X(t_1)$ ,  $Y(t_1)$  AND  $t_0$  INTO THE CORRECT  
LOCATIONS FOR INPUT TO LAMBERT.  $\text{RZVECV}$   
IS USED FOR STORING THE SUCCESSIVE VALUES  
OF THE OFFSET VECTOR  $X(t_1)$  AND IS HERE  
INITIALIZED TO THE VALUE  $X_1(t_1)$ .

SET PUSH LIST  
POINTER TO  $\phi$

$u_{r1} = \frac{X(t_1) \text{ UNIT}}{\phi D_v}$   
 $\phi D_v = \text{MPAC}_v \text{ UNIT}(\text{RINIT}_v)$   
SCALED AT  $2^3$

$b$  IS ORTHOGONAL TO  
 $X(t_1)$  AND  $Y(t_1)$ .

$b = \frac{Y(t_1) \times X(t_1) \text{ UNIT}}{\text{UNIT}(\text{MPAC}_v \times \text{VINIT}_v)}$   
 $\text{UN}_v =$   
SCALED AT  $2^7$

$\cos \phi = \frac{u_{r1} \cdot Y(t_1) \text{ UNIT}}{\text{MPAC}_v \text{ UNIT}(\text{RTARGL}_v)}$   
SCALED AT  $2^3$

$\phi$  IS THE ANGLE BETWEEN THE  
INITIAL POSITION VECTOR  $X(t_1)$  AND  
THE TARGET VECTOR  $Y(t_1)$ .

CLEAR  
 $F_1(\text{NORMSW})$

INITIALIZE  $F_2$  PRIOR  
TO TEST THAT FOLLOWS.

TO NEXT SHEET

7 Reasons

1/1/68

1/1/68

1/1/68

1/1/68

11AP68

11AP68

11AP68

11AP68

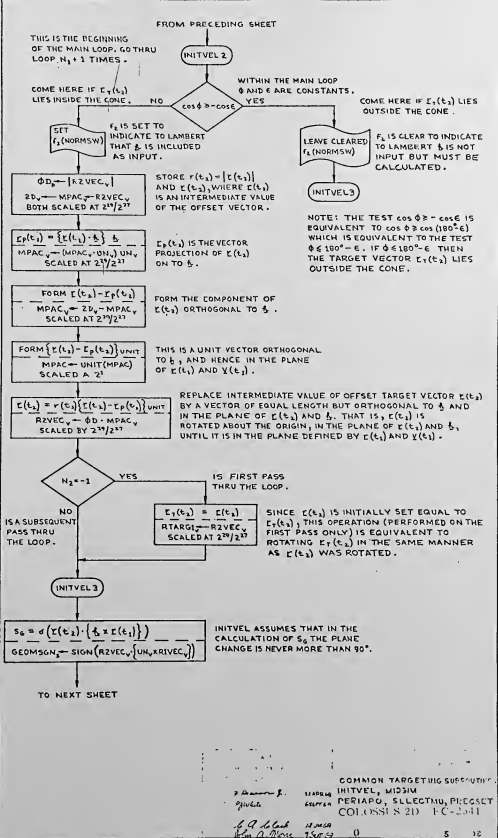
11AP68

COMMON TARGETING SUBROUTINES  
INITVEL, MIDGIM  
PERIAP0, SELECTNU, PRECSET  
COLOSSUS 2D FC-2641

0

4

12



X1 ← RTX1

RESTORE X1 PRIOR TO CALL TO LAMBERT.

LAMBERT  
CALCULATE  
INITIAL VELOCITY  
 $V_T(t_1)$   
FC3360

- LAMBERT INPUT:
- 1) R1VEC<sub>v</sub> =  $\mathbf{r}(t_1)$ , THE INITIAL POSITION VECTOR.
  - 2) R2VEC<sub>v</sub> =  $\mathbf{r}(t_2)$ , INTERMEDIATE VALUE OF THE OFFSET VECTOR.
  - 3) TDESIR<sub>d</sub> =  $t_2$ , DESIRED TRANSFER TIME.
  - 4) GEOMSON =  $S_2$ , A FLAG, IF POSITIVE  $\theta < 180^\circ$ ; IF NEGATIVE  $\theta > 180^\circ$ .
  - 5) VTARGET<sub>s</sub> =  $N_1$ , A FLAG, IF NON-ZERO  $V_T(t_1)$  IS NOT CALCULATED.
  - 6) GUESSW =  $f_1$ , A FLAG, IF SET  $\cot \gamma$  IS NOT INPUT.
  - 7) COGA =  $\cot \gamma$ , AN INITIAL GUESS IF  $f_1$  IS CLEAR.
  - 8) NORMSW =  $f_2$ , A FLAG, IF CLEAR  $\mathbf{u}$  IS CALCULATED.
  - 9) UN<sub>v</sub> =  $\mathbf{u}$ , UNIT VECTOR, NORMAL TO  $\mathbf{r}(t_1)$  AND  $\mathbf{Y}(t_1)$  IF  $f_2$  SET.
  - 10) X1<sub>s</sub> = INDEX REGISTER CONTAINING VALUE TO SELECT  $\mu$ -TABLE.
  - 11) ITERCTR = 2, MAXIMUM ITERATION COUNTER.
- LAMBERT OUTPUT:

- 1) VVEC<sub>v</sub> =  $V_T(t_2)$ , VELOCITY REQUIRED AT TIME  $t_1$  IN ORDER TO ARRIVE AT THE OFFSET POSITION  $\mathbf{r}(t_2)$  IN A CONIC MANNER AT TIME  $t_2$ .
- 2) VTARGET<sub>v</sub> =  $V_T(t_1)$ , VELOCITY AT THE OFFSET POSITION. IF  $N_1 = 0$  THIS VALUE IS CALCULATED BY LAMBERT AND IS SUBSEQUENTLY USED. IF  $N_1 \neq 0$  THIS VALUE IS NOT CALCULATED BY LAMBERT AND THE VALUE SUBSEQUENTLY USED IS THE OUTPUT OF INTEGRV<sub>s</sub>.
- 3) COGA =  $\cot \gamma$ , VALUE CONVERGED TO BY LAMBERT.
- 4) SOLNSW =  $f_3$ , A FLAG, IF CLEAR THE SOLUTION IS VALID.

CLEAR  
 $f_1$ (GUESSW)

$f_1$  IS CLEARED BECAUSE A VALUE OF  $\cot \gamma$  IS AVAILABLE NOW AS AN INITIAL GUESS TO LAMBERT ON THE NEXT PASS THRU THE LOOP.

VIPRIME<sub>v</sub> ← VVEC<sub>v</sub>  
SCALED AT  $2^{1/2}$

STORE THE VELOCITY  $V_T(t_2)$  IN ITS OUTPUT LOCATION. FOLLOWING THE LAST PASS THRU THE LOOP THIS VALUE WILL BE USED IN THE VELOCITY-TO-BE-GAINED EQUATION.

TEST THE ITERATION COUNT  
 $N_1$   
(VTARGET<sub>s</sub>) =  $\phi$

IF THE ITERATION COUNT IS  $\phi$ , THEN PROGRAM PREPARES TO RETURN AFTER A SINGLE CONIC CALCULATION.

INITVEL7  
SMB

WAKE UP THIS JOB

JOBSLEEP  
PUT THIS JOB TO SLEEP UNTIL INTEGRATION IS AVAILABLE  
FC8030

BUSY

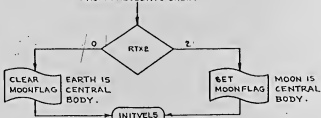
INTSTALL  
CHECK IF THE INTEGRATION ROUTINE IS BEING USED  
FC3350

IF INTEGRATION ROUTINE IS BEING USED PUT THIS ROUTINE TO SLEEP UNTIL INTEGRATION IS AVAILABLE. IF INTEGRATION ROUTINE IS NOT BEING USED RESERVE ITS USE FOR THIS ROUTINE BY SETTING THE FLAG INTFLAG 2.

THE INTEGRATION ROUTINE IS NOW RESERVED FOR THIS JOB.

TO NEXT SHEET

FROM PRECEDING SHEET



INITVELS

RCV<sub>v</sub> ← RIVEC<sub>v</sub> - RINIT<sub>v</sub>  
 VCV<sub>v</sub> ← VPRIME<sub>v</sub>  
 TET<sub>2</sub> ← INTIME<sub>2</sub>

SET UP  $\mathbf{r}(t_1)$ ,  $\mathbf{v}_r(t_1)$  AND  $t_1$  FOR INTEGRVS.

$t_2 = t_1 + t_2$   
 TDECI<sub>2</sub> ← INTIME<sub>2</sub> \* DELTA<sub>2</sub>  
 SCALED AT  $2^{18}$

TDECI IS THE TIME TO INTEGRATE TO, AND IS REQUIRED BY INTEGRVS.

CLEAR INTYPLG

IS CLEARED TO INDICATE TO INTEGRVS THAT PRECISION INTEGRATION BY THE ENCKE METHOD IS DESIRED, NOT CONIC INTEGRATION.

INTEGRVS  
 INTEGRATE STATE VECTOR  $\mathbf{r}(t_1)$ ,  $\mathbf{v}_r(t_1)$  UP TO TIME  $t_2$   
 FCS350

INTEGRVS INPUT:  
 1) RCV<sub>v</sub> =  $\mathbf{r}(t_1)$ , INITIAL POSITION VECTOR  
 2) VCV<sub>v</sub> =  $\mathbf{v}_r(t_1)$ , VELOCITY VECTOR THAT IS OUTPUT FROM THE LAMBERT SUBROUTINE.  
 3) TET =  $t_1$ , TIME OF VALIDITY OF STATE VECTOR.  
 4) TDECI =  $t_2$ , TIME TO INTEGRATE TO.

INTEGRVS OUTPUT:  
 1) RATT1 =  $\mathbf{r}'(t_2)$  } THESE ARE INTERMEDIATE VALUES OF  
 2) VATT1 =  $\mathbf{v}_r'(t_2)$  } THE TARGET STATE VECTOR RESULTING FROM A PRECISION INTEGRATION.

VTARGET<sub>v</sub> ← VATT1<sub>v</sub>  
 SCALED AT  $2^7/2^3$

SAVE THE INTERMEDIATE VALUE OF  $\mathbf{v}_r(t_2)$ .

$N_2 = N_2 + 1$   
 ITCTR<sub>2</sub> ← ITCTR<sub>2</sub> + 1

INCREMENT THE ITERATION COUNTER.

$N_2 = N_1$

YES

INITVEL 6  
 SHB

HAVE ITERATED A TOTAL OF  $N_2 + 1$  TIMES, USING  $N_2$  OFFSETS. NOW PREPARE TO EXIT.

NO

CONTINUE ITERATING

$\mathbf{r}(t_2) = \mathbf{r}(t_2) - \{ \mathbf{r}'(t_2) - \mathbf{v}_r(t_2) \}$   
 $\mathbf{r}2\mathbf{VEC}_v \leftarrow \mathbf{r}2\mathbf{VEC}_v - (\mathbf{RATT1}_v - \mathbf{RTARG1}_v)$   
 SCALED AT  $2^{11}/2^{17}$ .

COMPUTE A NEW INTERMEDIATE VALUE OF THE OFFSET TARGET VECTOR  $\mathbf{r}(t_2)$ , WHERE  $\mathbf{r}'(t_2)$  IS AN INTERMEDIATE VALUE RESULTING FROM A PRECISION INTEGRATION AND  $\mathbf{v}_r(t_2)$  IS THE TRUE TARGET VECTOR.

INITVEL 2  
 SHB

GO BACK TO THE BEGINNING OF THE LOOP.

J. B. ...  
 P. B. ...

15 APR 60  
 650000

COMMON TARGETING SUBROUTINE  
 INITVEL, MIDGIM  
 PERIAP, SELEGTM, DREGCT  
 COLOSSI S 2D FC-2611

L. A. ...  
 John A. ... 7 Sept 60

INITVEL 6

COME HERE WHEN  
FINISHED ITERATING.  
 $N_1 + 1$  TIMES.

RTARG<sub>v</sub> ← R2VEC<sub>v</sub>  
SCALED AT  $2^{17}/2^{17}$

STORE THE LAST COMPUTED VALUE OF THE  
OFFSET TARGET VECTOR  $\epsilon(t_2)$  IN ITS  
OUTPUT LOCATION.

INITVEL 7

WOULD COME HERE DIRECTLY IF  $N_1 = \phi$ . IN THIS  
CASE RTARG<sub>v</sub> STILL CONTAINS THE INPUT  
VALUE WHICH IS, FOR  $N_1 = \phi$ , THE OFFSET VECTOR.

$\Delta V = V_T(t_2) - V(t_1)$   
DELVEET3<sub>v</sub> ← VPRIME<sub>v</sub> - VINIT<sub>v</sub>  
SCALED AT  $2^{17}/2^5$

$\Delta V$  IS THE VELOCITY-TO-BE-GAINED.  
IT IS THE DIFFERENCE BETWEEN THE  
REQUIRED VELOCITY  $V_T(t_2)$  (THE OUTPUT  
OF LAMBERT) AND THE EXISTING  
VELOCITY  $V(t_1)$ .

VTPRIME<sub>v</sub> ← VTARGET<sub>v</sub>  
SCALED AT  $2^{17}/2^5$

STORE  $V_T(t_2)$ , THE FINAL VALUE OF THE  
FINAL PRECISION VELOCITY VECTOR, IN  
ITS OUTPUT LOCATION.

2

0

FOR OFF-NOMI-  
NAL MOON  
CENTERED  
SYSTEM.

FOR EARTH CENTERED SYSTEM  
OR NOMINAL MOON CENTERED  
SYSTEM.

SHIFT DATA TO BRING BINARY  
POINT BACK TO NOMINAL SCALING.  
SCALE RTARG<sub>v</sub> AT  $2^{17}$ , AND  
VTPRIME<sub>v</sub>, VPRIME<sub>v</sub>, DELVEET3<sub>v</sub>  
AT  $2^5$ .

DATA IS AT NOMINAL  
SCALING. NO SHIFTING  
IS REQUIRED.

INITVELX

GET PUSH LIST  
POINTER TO  $\phi D$

RTARD<sub>v</sub> ← RTARG<sub>v</sub>

CLEAR  
XDDELVFLG

NORMEX

$V_T(t_1), V_T(t_2), V_T(t_2)$   
 $\Delta V, V_T(t_2), CDT, t_2$

COMMON TARGETING SUBROUTINES  
INITVEL, MIDC-IM  
PERIAPD, SELECTMU, PRESET  
COLOSSUS 2D FC-2641

R. Hanson &  
P. White

16 APR 68

15 SEP 68

L. P. L. L. L.  
John D. P. P.

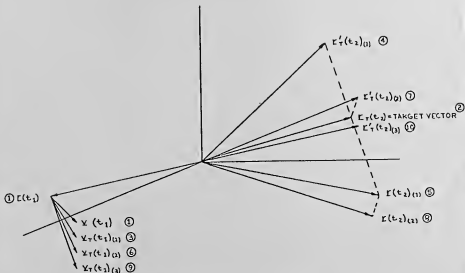
12 JUL 68

7 SEP 68

0

18

THE FOLLOWING IS A GEOMETRICAL REPRESENTATION OF WHAT OCCURS WHEN THREE PASSES ARE MADE THROUGH THE MAIN LOOP IN INITIAL. IT USES 2 OFFSETS AND 3 ITERATIONS ( $N_1 = 2$ ). THE SUBSCRIPTS OF (1), (2) AND (3) FOLLOWING THE VARIABLES REFER TO THE ITERATION NUMBER.



- ①  $E(t_1)$  IS THE GIVEN POSITION VECTOR,  $Y(t_1)$  IS THE GIVEN VELOCITY VECTOR.
  - ②  $E_T(t_2)$  IS THE GIVEN TARGET VECTOR. FOR COMPLETENESS AND CONSISTENCY IN USE OF SUBSCRIPTS THE TARGET VECTOR  $E_T(t_2)$  CAN BE CONSIDERED TO BE THE ZEROETH OFFSET VECTOR  $I(t_2)_{(0)}$ .
- ITERATION 1
- ③  $Y_T(t_2)_{(1)}$  IS CALCULATED BY LAMBERT USING  $E(t_1)$  FROM ① AND  $I(t_2)_{(0)} = E_T(t_2)$  FROM ②.
  - ④  $I^*(t_2)_{(1)}$  IS CALCULATED BY PRECISION INTEGRATION USING  $E(t_1)$  FROM ① AND  $Y_T(t_2)_{(1)}$  FROM ③.
  - ⑤  $I(t_2)_{(1)}$  IS THE OFFSET VECTOR RESULTING FROM SUBTRACTING THE MISS VECTOR BETWEEN  $I^*(t_2)_{(1)}$  FROM ④ AND  $E_T(t_2)$  FROM ② FROM THE OFFSET VECTOR  $E(t_2)_{(0)} = E_T(t_2)$  FROM ②.
- ITERATION 2
- ⑥  $Y_T(t_2)_{(2)}$  IS CALCULATED BY LAMBERT USING  $E(t_1)$  FROM ① AND  $I(t_2)_{(1)}$  FROM ⑤.
  - ⑦  $I^*(t_2)_{(2)}$  IS CALCULATED BY PRECISION INTEGRATION USING  $E(t_2)$  FROM ① AND  $Y_T(t_2)_{(2)}$  FROM ⑥.
  - ⑧  $I(t_2)_{(2)}$  IS THE OFFSET VECTOR RESULTING FROM SUBTRACTING THE MISS VECTOR BETWEEN  $I^*(t_2)_{(2)}$  FROM ⑦ AND  $E_T(t_2)$  FROM ② FROM THE OFFSET VECTOR  $E(t_2)_{(1)}$  FROM ⑤.
- ITERATION 3
- ⑨  $Y_T(t_2)_{(3)}$  IS CALCULATED BY LAMBERT USING  $E(t_2)$  FROM ① AND  $I(t_2)_{(2)}$  FROM ⑧.
  - ⑩  $I^*(t_2)_{(3)}$  IS CALCULATED BY PRECISION INTEGRATION USING  $E(t_2)$  FROM ① AND  $Y_T(t_2)_{(3)}$  FROM ⑨.
  - ⑪ THE ROUTINE NOW PREPARES TO EXIT. IT CALCULATES THE VELOCITY-TO-BE-GAINED AS THE DIFFERENCE  $Y_T(t_2)_{(3)} - Y(t_1)$ .
  - ⑫ THERE IS NO CALCULATION OF THE OFFSET VECTOR  $I(t_2)_{(3)}$  CORRESPONDING TO  $I^*(t_2)_{(3)}$ .
  - ⑬ THE FINAL OUTPUT VECTORS ARE:
    - 1)  $Y_T(t_2)_{(3)}$  FROM ⑩
    - 2)  $E(t_2)_{(3)}$  FROM ⑩
    - 3)  $E_T(t_2)_{(3)}$  FROM ⑩

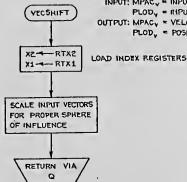
CEMACH TARGETING SUBROUTINE  
INITVEL, MISSMIS  
PERIAP, SLEETM, I, MISS  
COI, OS, S 2D TC 2 1

Revision 2  
Date  
L. P. Gind  
John A. Stone

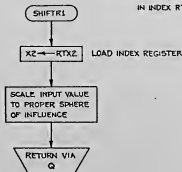
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PURPOSE: SUBROUTINE TO SCALE INPUT VECTORS TO PROPER SPHERE OF INFLUENCE

INPUT:  $MPAC_v$  = INPUT VELOCITY VECTOR  
 $PLOD_v$  = INPUT POSITION VECTOR  
 OUTPUT:  $MPAC_v$  = VELOCITY VECTOR  
 $PLOD_v$  = POSITION VECTOR



PURPOSE: SUBROUTINE TO SCALE INPUT DOUBLE PRECISION WORD TO SPHERE VALUE IN INDEX RTX2



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED ENTRANCE AND VALIDATION	
DEAN A.C. WILLIAMS INCH: <i>[Signature]</i> ADVISE: <i>[Signature]</i> DATE: <i>11/19/64</i> BY: <i>[Signature]</i>		3004500 20461 11/19/64 11/19/64	COMMON TARGETING SUBROUTINES BITVEL, MIDGIM PERIAMP, SELECTIMU, PRECSET COLOSSUS 21) FC-2641 0

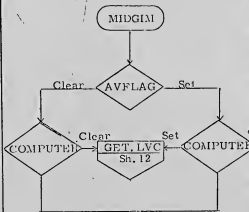
IF THE ACTIVE VEHICLE IS PERFORMING THIS COMPUTATION THIS ROUTINE COMPUTES THE POSITIVE MIDDLE GIMBAL ANGLE FOR THE ACTIVE VEHICLE ASSUMING THE X AXIS IS ALIGNED WITH THE AX IMPULSE THRUST DIRECTION. IF THE PASSIVE VEHICLE IS PERFORMING THIS COMPUTATION THIS ROUTINE TRANSFORMS THE INPUT VELOCITY VECTOR FROM INERTIAL COORDINATES TO LOCAL VERTICAL COORDINATES OF THE ACTIVE VEHICLE.

INPUT:

- 1) AVFLAG-A flag, is clear if CSM is active vehicle, is set if LM is active vehicle.
- 2) COMPUTER-A flag, is clear if LM is doing the computing, is set if CSM is doing the computing.
- 3)  $R_{INVT} = r$ , RADIUS VECTOR OF ACTIVE VEHICLE, IN METERS, AT  $2^{25}$ .
- 4)  $V_{INVT} = v$ , VELOCITY VECTOR OF ACTIVE VEHICLE, IN METERS/CSEC, AT  $2^7$ .
- 5)  $\Delta V = \Delta v$ , DELTA VELOCITY VECTOR OF ACTIVE VEHICLE IN INERTIAL COORDINATES, IN METERS/CSEC, AT  $2^7$ .

OUTPUT:

- 1) MGLVFLAG = A FLAG, IS CLEAR IF MIDDLE GIMBAL ANGLE WAS COMPUTED, IS SET IF DELTA VELOCITY VECTOR TRANSFORMED.
- 2)  $+MGA_D$  = MIDDLE GIMBAL ANGLE, IN REVOLUTIONS IN RANGE 0 TO 1, AT  $2^0$ .
- 3)  $DELVLVC_v = \Delta v_{LV}$ , DELTA VELOCITY VECTOR OF ACTIVE VEHICLE IN LOCAL VERTICAL COORDINATES, IN METERS/CSEC, AT  $2^7$ .



COME HERE IF THE ACTIVE VEHICLE IS PERFORMING THIS COMPUTATION.

GET +MGA

FORM  $\sin^{-1}(\Delta V_{UNIT} \cdot \frac{1}{2} \sin)$

$MPAC_D \rightarrow \sin^{-1}\left\{\text{UNIT}\left[\text{UNIT}\left(\frac{1}{2}\right)\right] \cdot (\text{REFSMMAT} + e)_v\right\}$   
SCALED AT  $2^0$

$\frac{1}{2} \sin$  IS THE UNIT VECTOR IN DIRECTION OF THE Y STABLE MEMBER AXIS.

TEST SIGN OF ANGLE.

NEGATIVE

POSITIVE

$MPAC_D \rightarrow MPAC_D + \text{HALFREV}_D + \text{HALFREV}_D$

CONVERT A NEGATIVE ANGLE TO A CORRESPONDING POSITIVE ANGLE BY ADDING ONE REVOLUTION.

$+MGA_D \rightarrow MPAC_D$   
SCALED AT  $2^0$

STORE MIDDLE GIMBAL ANGLE.

CLEAR MGLVFLAG

INDICATE MIDDLE GIMBAL ANGLE WAS COMPUTED.

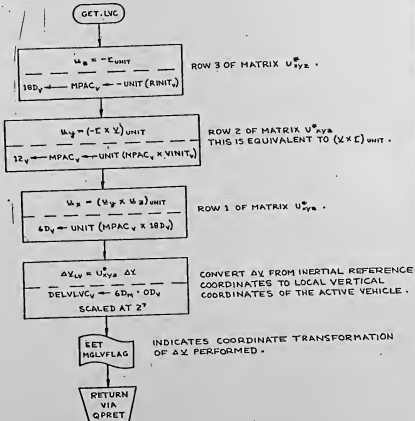
RETURN VIA QPRET

7. Location 2. 210000  
Pjshata 210000  
6. A. Clark 120000  
John A. Clark 9. 7. 60

COMMON TARGETING SUBROUTINES  
INITIAL, MIDGIM  
PERIAP, SELECTED, PASTER  
COMPUTES 2) 11



COME HERE IF THE PASSIVE  
VEHICLE IS PERFORMING  
THIS CALCULATION.



→ *Acronyms*  
*Pfwhite*

221012  
621018

*L. A. Cook*  
*John A. Bence*

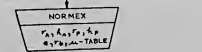
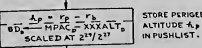
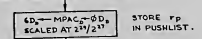
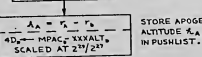
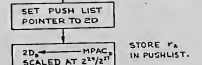
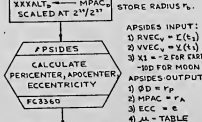
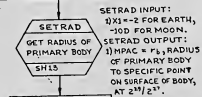
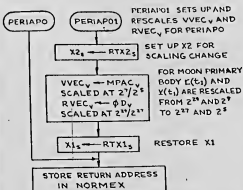
221012  
7/24/62

COMMON TARGETING SUBROUTINES  
INITVEL, MIDGTM  
PERIAPO, SELEGTMU, PRECSET  
COLOSSUS 2D FC-2611

0

12

18



THIS SUBROUTINE COMPUTES THE TWO BODY APOCENTER AND PERICENTER ALTITUDES, GIVEN (1) THE POSITION AND VELOCITY VECTORS FOR A POINT ON THE TRAJECTORY, AND (2) THE PRIMARY BODY INDICATOR.

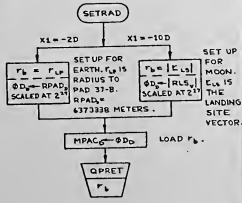
PERIAPD CALLED BY:  
 S30-1 (IN P30-P37), G51 (IN P32-P35, P72-P75), MANUPARM.

PERIAPD1 CALLED BY:  
 CS1 (IN P32-P35, P72-P75), P34-P35, P74-P75, P38-P39.

PERIAPD INPUT:  
 1)  $RVEC_V = X(t_1)$ , POSITION VECTOR TO POINT ON TRAJECTORY, IN METERS, AT  $2^{29}/2^{27}$ .  
 2)  $VVEC_V = Y(t_1)$ , VELOCITY VECTOR TO POINT ON TRAJECTORY, IN METERS/CSEC AT  $2^{29}/2^{27}$ .  
 3)  $X1_2$  = PRIMARY BODY INDICATOR IN INDEX REGISTER 1, -2 FOR EARTH, -10D FOR MOON.

PERIAPD1 INPUT:  
 1)  $\phi D_V = X(t_1)$ , IN METERS,  $2^{29}$ .  
 2)  $MPAC_V = Y(t_1)$ , IN METERS/CSEC, AT  $2^{27}$ .  
 3)  $RTX1_2$  = PRIMARY BODY INDICATOR, 15-2 FOR EARTH, -10D FOR MOON.  
 4)  $RTX2_2$  = VALVE USED FOR RESCALING  $X(t_1)$  AND  $Y(t_1)$  FOR OFF-NOMINAL SCALING, 15 0 FOR EARTH, 2 FOR MOON.

OUTPUT:  
 1)  $2D_b = r_A$ , RADIUS OF APOCENTER, IN METERS, AT  $2^{29}/2^{27}$ .  
 2)  $4D_b = A_A$ , APOCENTER ALTITUDE, IN METERS, AT  $2^{29}/2^{27}$ .  
 3)  $6D_b = r_p$ , RADIUS OF PERICENTER, IN METERS, AT  $2^{29}/2^{27}$ .  
 4)  $8D_b = A_p$ , PERICENTER ALTITUDE, IN METERS, AT  $2^{29}/2^{27}$ .  
 5)  $ECC = e$ , ECCENTRICITY, AT  $2^{27}$ .  
 6)  $XXXALT_b = r_b$ , RADIUS OF PRIMARY BODY, IN METERS, AT  $2^{29}/2^{27}$ .  
 7)  $\mu$  - TABLE FOR PRIMARY BODY.  
 8) PUSH LIST POINTER AT 10D.



COMMON TARGETING SUBROUTINES  
 INITVEL, MIDGIM  
 PERIAPD, SELECTMU, FREGSECT  
 (COLOSSUS 2D) FC-2511

6/3/68  
 2/2/68  
 0

THIS ROUTINE SETS UP VALUES OF  $\mu$  AND  $1/\sqrt{\mu}$  APPROPRIATE FOR EITHER EARTH OR MOON AS PRIMARY BODY AND DEPENDS ON CONDITION OF CMOONFLG.

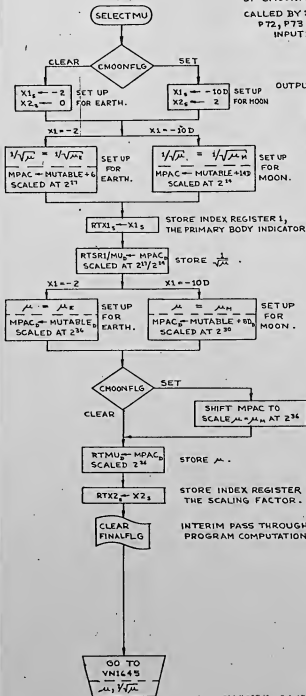
CALLED BY: P32, P33, P34, P35, P38, P39, P72, P73, P74, P75, P78, P79.

INPUT:

- 1) CMOONFLG = PERMANENT CSM STATE FLAG, IS CLEAR FOR EARTH PRIMARY BODY, IS SET FOR MOON.

OUTPUT:

- 1)  $RTMU_0 = \mu$ , AT  $2^{34}$ .  
 2)  $RTSR1/MU_0 = 1/\sqrt{\mu}$ , AT  $2^{17}/2^{14}$ .  
 3)  $RTX1_0$  = PRIMARY BODY INDICATOR, IS -2 FOR EARTH, -10D FOR MOON.  
 4)  $RTX2_0$  = SCALING FACTOR FOR NOMINAL/OFF-NOMINAL DATA, IS 0 FOR NOMINAL (EARTH), IS 2 FOR OFF-NOMINAL (MOON).



THIS GIVES  $\mu$  IDENTICAL SCALING FOR BOTH NOMINAL AND OFF-NOMINAL CASES.

COMMON TARGETING SUBROUTINES  
 INITVEL, MDGSM  
 PEPIAPC, SELECTMU, PRECSET  
 COLOSSUS 2D FC-2641

*Handwritten notes:*  
 P. ...  
 25070000  
 620718  
 G.P. Clark  
 G.M. ...  
 12/16/65  
 7:47:57

THIS ROUTINE PERFORMS A PRECISION UPDATE OF THE ACTIVE AND PASSIVE VEHICLES TO A SPECIFIED TIME.

CALLED BY: P34, P35, P39, PREC/TT, ADVANCE

INPUT:

1) TDEC1<sub>0</sub> = MPAC<sub>0</sub> = t<sub>2</sub>, TIME TO INTEGRATE TO, IN CSEC AT 2<sup>19</sup>.

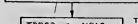
OUTPUT:

1) RACT3<sub>v</sub> = E(t<sub>2</sub>), POSITION VECTOR OF ACTIVE VEHICLE AT t<sub>2</sub>, IN METERS, AT 2<sup>19</sup>.

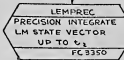
2) VACT3<sub>v</sub> = X(t<sub>2</sub>), VELOCITY VECTOR OF ACTIVE VEHICLE AT t<sub>2</sub>, IN METERS/CSEC, AT 2<sup>7</sup>.

3) RPASS3<sub>v</sub> = E(t<sub>2</sub>), POSITION VECTOR OF PASSIVE VEHICLE AT t<sub>2</sub>, IN METERS, AT 2<sup>19</sup>.

4) VPASS3<sub>v</sub> = X(t<sub>2</sub>), VELOCITY VECTOR OF PASSIVE VEHICLE AT t<sub>2</sub>, IN METERS/CSEC, AT 2<sup>7</sup>.



TEMPORARY STORAGE OF t<sub>2</sub>.



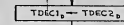
INPUT

1) RCV<sub>v</sub> = E(t<sub>1</sub>) 1) RATT<sub>v</sub> = E(t<sub>2</sub>)

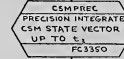
2) VCV<sub>v</sub> = X(t<sub>1</sub>) 2) VATT<sub>v</sub> = X(t<sub>2</sub>)

3) TET<sub>0</sub> = t<sub>1</sub> 3) TAT<sub>0</sub> = t<sub>2</sub>

4) TDEC1<sub>0</sub> = t<sub>1</sub>



SET UP t<sub>2</sub> FROM TEMPORARY STORAGE.



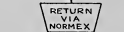
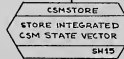
INPUT

1) RCV<sub>v</sub> = E(t<sub>1</sub>) 1) RATT<sub>v</sub> = E(t<sub>2</sub>)

2) VCV<sub>v</sub> = X(t<sub>1</sub>) 2) VATT<sub>v</sub> = X(t<sub>2</sub>)

3) TET<sub>0</sub> = t<sub>1</sub> 3) TAT<sub>0</sub> = t<sub>2</sub>

4) TDEC1<sub>0</sub> = t<sub>2</sub>



CLEAR



HERE IF STATE VECTOR BELONGS TO ACTIVE VEHICLE.



STORE THE INTEGRATED STATE VECTOR.



CLEAR



HERE IF STATE VECTOR BELONGS TO PASSIVE VEHICLE.



COMMON TARGETING SUBROUTINES:  
INITVEL, MFCIM  
PIRIAPO, SELECTIU, PRECSET  
COLOSSUS 2D FC-2641

7/20/68  
Pj/1/68

XXXXX  
6/27/68

4/1/68  
4/1/68

2/22/68  
4/1/68

0

15 18

GENERAL INFORMATION  
SUBROUTINES CALLED ON OTHER CHARTS

NAME	FLOW CHART NUMBER	DESCRIPTION	WHERE CALLED
LAMBERT	FCI350	CALCULATE INITIAL AND FINAL VELOCITIES GIVEN THE INITIAL AND FINAL POSITIONS AND TIME	INITVEL (SH 6)
INTSTALL	FCI350	RESERVE INTEGRATION ROUTINE FOR CALLER	INITVEL (SH 6)
INTEGRVS	FCI350	PERFORM PRECISION INTEGRATION ON STATE VECTOR	INITVEL (SH 7)
APSIDES	FCI350	COMPUTE PERICENTER, APOCENTER, ECCENTRICITY	PERIAPO (SH 13)
LEMPREC	FCI350	PERFORM PRECISION INTEGRATION ON LM STATE VECTOR	PRECSET (SH 15)
CSMPREC	FCI350	PERFORM PRECISION INTEGRATION ON CSM STATE VECTOR	PRECSET (SH 15)

FLAGS USED

NAME	MEANING		WHERE SET	WHERE CLEARED	WHERE TESTED
	SET	CLEAR			
MOONFLAG	MOON IS SPHERE OF INFLUENCE	EARTH IS SPHERE OF INFLUENCE	INITVEL (SH 7)	INITVEL (SH 7)	
GUESSW (f <sub>1</sub> )	NO STARTING VALUE FOR ITERATION	STARTING VALUE FOR ITERATION EXISTS	INITVEL (SH 4)	INITVEL (SH 6)	
FINALFLG	LAST PASS THROUGH RENDEZVOUS COMPUTATIONS	INTERIM PASS THROUGH RENDEZVOUS COMPUTATIONS		SELFCTMU (SH 14)	
AVFLAG	LM IS ACTIVE VEHICLE	CSM IS ACTIVE VEHICLE			PRECSET (SH 15)
INTYPFLG	CONIC INTEGRATION	ENCKE INTEGRATION		INITVEL (SH 7)	
MGLVFLAG	LOCAL VERTICAL COORDINATES COMPUTED	MIDDLE GIMBAL ANGLE COMPUTED	MIDGIM (SH 12)	MIDGIM (SH 11)	
NORMSW (f <sub>2</sub> )	UNIT NORMAL INPUT TO LAMBERT	LAMBERT COMPUTES ITS OWN UNIT NORMAL	INITVEL (SH 5)	INITVEL (SH 4)	

MIT INTEGRATION LAB CAMBRIDGE, MASS.		ANALYST CHECKED AND REVISION	
DESIGNER <i>A. J. Smith</i>	DRAWN <i>[Signature]</i>	CHECKED (NAME)	COMMON TARGETING SUBROUTINES INITVEL, MIDGIM PERIAPO, SELFCTMU, PRECSET COLOSSUS 2D FC-2641
APPROVED <i>G. D. Clark</i>	DATE 10/1/64	CHECKED (NAME)	0

AVEGFLAG	AVERAGEG (SERVICER) DESIRED	AVERAGEG (SERVICER) NOT DESIRED			INITVEL (SH 8)
CMOONFLG	CSM STATE VECTOR IN LUNAR SPHERE	CSM STATE VECTOR NOT IN LUNAR SPHERE			SELECTMU (SH 14)
GEOMSGN <sub>S</sub> (S <sub>C</sub> )	IS PLUS IF TRUE ANOMALY LESS THAN 180°	IS MINUS IF TRUE ANOMALY GREATER THAN 180°	INITVEL (SH 5)		
VTARGETAG <sub>S</sub>	IF NON-ZERO $\gamma_T(t_2)$ IS NOT CALCULATED	IF ZERO $\gamma_T(t_2)$ IS CALCULATED	INITVEL (SH 4)		INITVEL (SH 6, SH 7)
GUESSW (t <sub>1</sub> )	NO STARTING VALUE FOR ITERATION	STARTING VALUE FOR ITERATION EXISTS	INITVEL (SH 4)	INITVEL (SH 8)	

VARIABLES USED (BOTH PUSH LIST AND ERASABLE)

NAME	MEANING	SCALING	LOCATION
ITERCTR <sub>S</sub>	<sup>1</sup> MAX. LOOP CONTROL VALUE FOR LAMBERT ROUTINE	2 <sup>14</sup>	22D
TDECI <sub>D</sub>	t <sub>2</sub> , TIME TO INTEGRATE TO, IN CSEC	2 <sup>28</sup>	32D
TET <sub>D</sub>	t <sub>1</sub> , IN CSEC	2 <sup>28</sup>	E3, 1516
RCV <sub>V</sub>	$\underline{r}(t_1)$ , IN METERS	2 <sup>29</sup> /2 <sup>27</sup>	E3, 1534
VCV <sub>V</sub>	$\underline{v}_T(t_1)$ , IN METERS/CSEC	2 <sup>7</sup> /2 <sup>5</sup>	E3, 1542
RVEC <sub>V</sub>	$\underline{r}(t)$ , POSITION VECTOR, IN METERS	2 <sup>29</sup> /2 <sup>27</sup>	E5, 1654
R1VEC <sub>V</sub>	$\underline{r}(t_1)$ , IN METERS	2 <sup>29</sup>	E5, 1654
R2VEC <sub>V</sub>	$\underline{r}(t_2)$ , IN METERS	2 <sup>29</sup> /2 <sup>27</sup>	E5, 1662
TDESIRED <sub>D</sub>	t <sub>D</sub> , IN CSEC	2 <sup>28</sup>	E5, 1670
UN <sub>V</sub>	$\underline{h}$	2 <sup>1</sup>	E5, 1673
VTARGETAG <sub>S</sub>	IS THE NUMBER OF OFFSETS USED IN INITVEL ROUTINE	2 <sup>14</sup>	E5, 1701
VTARGET <sub>V</sub>	$\underline{v}_T(t_2)$	2 <sup>7</sup> /2 <sup>5</sup>	E5, 1702
VVEC <sub>V</sub>	$\underline{v}(t)$ , VELOCITY VECTOR, IN METERS/CSEC	2 <sup>7</sup> /2 <sup>5</sup>	E5, 1743
NORMEX <sub>S</sub>	RETURN ADDRESS OF PERIAPD AND PRECSET		E7, 1450
RTRN <sub>S</sub>	RETURN ADDRESS OF INITVEL		E7, 1452
TDEC2 <sub>D</sub>	TEMPORARY STORAGE OF TDECI	2 <sup>28</sup>	E7, 1560
XIINPUT <sub>S</sub>	TEMPORARY STORAGE OF XI		E7, 1564
ITCTR <sub>S</sub>	ITERATION COUNTER	2 <sup>14</sup>	E7, 1603
COZY <sub>D</sub>	COS (e)	2 <sup>2</sup>	E7, 1853

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARSIS RESEARCH AND NAVIGATION	
DRAWN <i>Ch. J. Smith</i> 12/16/64 CHECKED <i>Robert</i> 12/16/64 ANALYST DATE BY <i>R.P. Clark</i> 12/16/64 APPROVED <i>John A. Jones</i> 12/16/64		COMMON TARGETING SUBROUTINES INITVEL, MDDGM PERIAPD, SELECTMU, PRECSET COLOSSUS 2D FC-2611	

CONSTANTS USED

NAME	PHYSICAL MEANING	SCALING	COMPUTER VALUE
HALFREV <sub>D</sub>	0.5 REVOLUTIONS	2 <sup>0</sup>	1.0 B-1
EPSFOUR <sub>D</sub>	15/360 REVOLUTIONS (EQUALS 15°)	2 <sup>0</sup>	0.0416666666
RPAD <sub>D</sub>	STANDARD RADIUS OF PAD 37-B IN METERS, EQUALS 20,009,001.57 FT	2 <sup>29</sup>	8373338 B-29
MUTABLE <sub>D</sub>	$\mu_E$ IN M <sup>3</sup> /CSEC <sup>2</sup>	2 <sup>38</sup>	3.985032 E10 B-36
MUTABLE + 6D	$1/\sqrt{\mu_E}$ IN CSEC/M <sup>3/2</sup>	2 <sup>-17</sup>	0.50087529 E-5 B17
MUTABLE + 8D <sub>D</sub>	$\mu_M$ IN M <sup>3</sup> /CSEC <sup>2</sup>	2 <sup>30</sup>	4.902778 E8 B-30
MUTABLE + 14D <sub>D</sub>	$1/\sqrt{\mu_M}$ IN CSEC/M <sup>3/2</sup>	2 <sup>-14</sup>	0.45162595 E-4 B14

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ANALOG CALCULATING SUBROUTINES
DATE: 9-7-66 BY: R. J. ... APPROVED: C. P. ... FOR: ...	COMMON TARGETING SUBROUTINES INITVEL, MIDDIM FLRIAP, SELECTMU, PRECSET COLOSSUS 2D FC-2641
10/26/68 9/24/68	10/26/68 9/24/68

P37-RETURN TO EARTH

V2T100	Sh. 17
GAMDV10	Sh. 23
PREC100	Sh. 34
RTEVN	Sh. 28
P37	Sh. 3

Special Conventions:

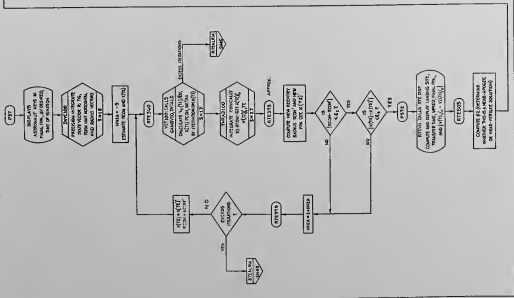
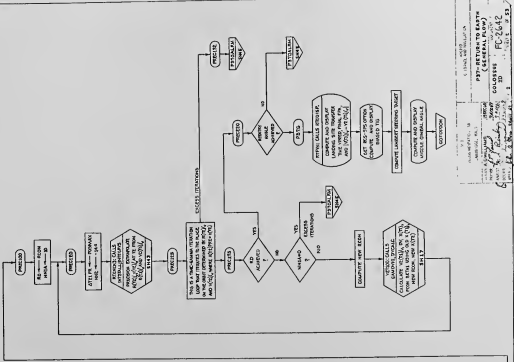
Because of the wide variety of situations which this program must handle, extensive use is made of floating point arithmetic. This involves normalization, with the shift count put into X1, X2, S1 or S2. An operation which normalizes a quantity Z and puts shift count into X1 is shown by  $\text{norm}_{X1}(Z)$ .

All quantities are double precision unless indicated in this manner: Subscript S for single precision, subscript T for triple, subscript V for vector.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>M. Connor</i> 12-2-67		P37 RETURN TO EARTH	
PRGRM <i>J. Laird</i> 12-4-69		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2642
DOCMR <i>R. B. ...</i> 12/1/69		REV 2	SHEET 1 OF 53
APPR'D <i>R. B. ...</i> 12/1/69			



COLLECTOR'S NAME: \_\_\_\_\_  
 COLLECTOR'S EMPLOYER: \_\_\_\_\_  
 COLLECTOR'S ADDRESS: \_\_\_\_\_  
 COLLECTOR'S PHONE: \_\_\_\_\_  
 COLLECTOR'S SIGNATURE: \_\_\_\_\_  
 DATE: \_\_\_\_\_  
 PC-2642



P37

P37 IS KEYS IN BY ASTRONAUT OR RECYCLED BY DSKY V32 ENTER AT MOST DISPLAYS.

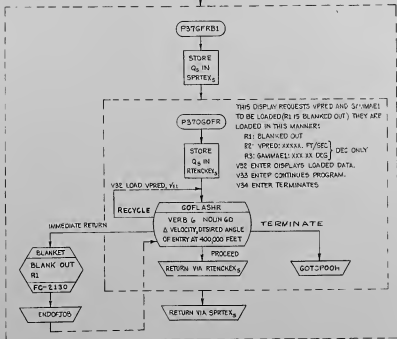
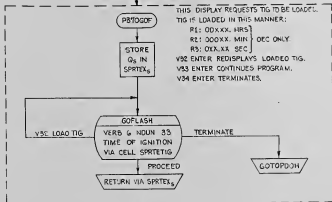
GROUP 4.0  
KILL GROUP  
4 RESTARTS

P37 IS NOT RESTARTABLE

ECSTEER ← OCT. 04000

1 @ 2<sup>8</sup> FOR P40: VALUE USED IN CROSS-PRODUCT STEERING FOR LAMBERT MANEUVER.

VPRED = 0; Y = 0  
GAMMAE1 ← ZEROVECS  
VPRED ← ZEROVECS



NEXT SHEET

P37 - RETURN TO EARTH  
(MAIN PROGRAM)

A.C. WILLIAMS

200046

9 AUG 69

7 AUG 69

COLDSO

2D

FC-2642

John A. M... 24/1/69

2

3

53

FROM PRECEDING SHEET

RTEDVD ← VPRED  
 RTEGAM2 ← GAMMAEL  
 CONICK2 ← IRTEB13  
 MAMAX1 ← CARTE

INVC100  
 CALCULATE R(T)<sub>0</sub>,  
 V(T)<sub>0</sub>, T1, P(T1), UR<sub>1</sub>,  
 UV<sub>1</sub>, UR<sub>1</sub>, R(T1), CPFA  
 SH 15

CLEAR SLOWFLG

RTEDVD

RTEDVD ← |RTEDVD|

R(T1) < KIRTE

SET SLOWFLG

POLY  
 MAMAX2 = COT  
 C1 · R(T1) + C2 · R(T1)<sup>2</sup>  
 + C3 · R(T1)<sup>3</sup>  
 FC-2100

T1 = 0  
 RCON = 6495000 @ 2<sup>28</sup>  
 NNIA = MORTB2B  
 RCON = KIRTE

IS KEVED-IN FLIGHT PATH ANGLE = 0?

IS RTEGAM2 = 0?

$Y(t_2) = COT(30^\circ - Y(t_2)_0)$   
 $X(t_2) = COT(1PTEB2 - RTEGAM20)$

RTEGAM2 = KEVED IN REENTRY ANGLE

IRTEB2 = 1/2 @ 80°

RTE550

RADIUS SMALL  
 K3 = 3° 28.5'

KIRTE = DEC. -06105

DOES TIC PUT CSM CLOSE TO EARTH?

KIRTE = DEC 7 x 10<sup>6</sup> @ 2<sup>29</sup>

KIRTE IS RADIUS USED TO DETERMINE WHICH ESTIMATE OF FLIGHT PATH ANGLE TO USE.

RADIUS LARGE

K4 = 5° 50'

KARTE = DEC. -11453

P37-RETURN TO EARTH (MAIN PROGRAM)

COLOSSUS 2D

FC-264E

VPRED = Δ VELOCITY DESIRED IN METERS/CSEC @ 2<sup>27</sup>  
 GAMMAEL = ANGLE OF REENTRY DESIRED, IN REVS @ 2° POSITIVE ABOVE HORIZON  
 IRTEB13 = DEC 2.0 @ 2<sup>14</sup>. THIS VALUE IS COMPLEMENTED AND LOADED INTO X1 TO OBTAIN THE PROPER IN-TABLE VALUES IN CONIC ROUTINES.  
 CARTE = -6.086643 x 10<sup>10</sup> @ 2<sup>28</sup>. MAJOR AXIS UPPER BOUND ON RETURN TRAJECTORIES.  
 IRTEB13 = 2 @ 2<sup>14</sup> IN METERS @ 2<sup>30</sup>.

INVC100 CALLS CSMPREC, WHICH CALCULATES POSITION AND VELOCITY VECTORS AT TIG. IF TIC PUTS THE CRAFT IN THE MOON'S SPHERE OF INFLUENCE, IT CALLS AN ALARM. THE ALARM GIVES THE ASTRONAUT THE OPTION OF TERMINATING OR RECYCLING, BY WHICH A NEW TIC MAY BE ENTERED. IF NO ALARM OCCURS, THE POSITION AND VELOCITY VECTORS AT TIG ARE EXAMINED TO DETERMINE WHETHER THEY ARE SO NEARLY COLLINEAR AS TO MAKE IT IMPOSSIBLE TO DETERMINE THE PLANE OF THE TRANSFER IF THEY ARE WITHIN 1.5 DEGREES, THE PLANE OF THE TRANSFER IS ARBITRARILY DEFINED SUCH THAT THE INCLINATION OF THE ORBIT AFTER THE MANEUVER WILL BE EQUAL TO THE ANGLE WHICH THE POSITION VECTOR AT TIG MAKES WITH THE EQUATORIAL.  $(UW_0 = (0,0,1) \times R(T1)_0$ )

INPUT: CSM STATE VECTOR  
 SPRTETIG = TIG = TIME OF IGNITION.  
 OUTPUT: R(T1)<sub>0</sub> = POSITION VECTOR AT TIG IN METERS @ 2<sup>29</sup> @ 2<sup>27</sup>  
 V(T1)<sub>0</sub> = VELOCITY VECTOR AT TIG IN METERS/CSEC @ 2<sup>27</sup> @ 2<sup>25</sup>  
 T1 = TIC  
 UR<sub>1</sub> = UNIT (R(T1)<sub>0</sub>) @ 2<sup>25</sup>  
 UV<sub>1</sub> = UNIT HORIZONTAL VECTOR @ 2<sup>21</sup>  
 CPFA = COSINE OF INITIAL FLIGHT PATH ANGLE @ 2<sup>21</sup>

POLY IS A POLYNOMIAL EVALUATOR: MA<sub>2</sub> = C<sub>0</sub> + C<sub>1</sub> P(T1) + C<sub>2</sub> P(T1)<sup>2</sup> + C<sub>3</sub> P(T1)<sup>3</sup>  
 INPUT: MPAC = R(T1) = |R(T1)<sub>0</sub>|  
 C<sub>0</sub> = DEC. 181000034.0 @ 2<sup>31</sup>  
 C<sub>1</sub> = DEC. 1.50785145 @ 2<sup>28</sup>  
 C<sub>2</sub> = DEC. -4.44935097 x 10<sup>-8</sup> @ 2<sup>-27</sup>  
 C<sub>3</sub> = DEC. 9.76938926 x 10<sup>-18</sup> @ 2<sup>-56</sup>  
 OUTPUT: MAMAX2 = MAJOR AXIS UPPER BOUND LIMIT ON RETURN TRAJECTORIES OF POSITIVE RADIAL COMPONENT IN METERS @ 2<sup>30</sup>

SIGN (NNIA) IS EQUIVALENT TO f<sub>1</sub> IN GSOP5. CSLOSSJ5 R-577.  
 T1 = COUNTER. FOR CONIC PHASE, NNIA < 0; F3H PRECISION, NNIA > 0.  
 RCON = RADIUS OF CONIC TRAJECTORY. (TEMPORARY ESTIMATE).  
 MORTB2B = DEC. 0.0  
 KIRTE = DEC. 6495000.0 @ 2<sup>29</sup>

NEXT SHEET

INTERCOMPARISON TABLE

A.C. WILLIAMS 2300000  
 911229  
 1/18/67

FROM PRECEDING SHEET

RTE360

ENTRANCE FROM RTE390

VET100

VET100

COMPUTE  
VE(T1)<sub>v</sub>, DV;  
X(T1), POON,  $\beta^1$   
SH17

CALLS: GAMDVIO  
XTILEM  
DVCALC

INPUT:

- 1)  $R(T1)$  = MAGNITUDE OF INITIAL POSITION VECTOR IN METERS @  $2^0$
- 2)  $RCO$  = MAGNITUDE OF FINAL POSITION VECTOR IN METERS @  $2^0$
- 3)  $V(T1)$ <sub>v</sub> = INITIAL VELOCITY VECTOR IN METERS/SEC @  $2^1$
- 4)  $RITOVVD$  =  $\Delta$  VELOCITY DESIRED IN METERS/SEC @  $2^1$
- 5)  $UR1$ <sub>v</sub> = UNIT INITIAL POSITION VECTOR @  $2^1$
- 6)  $UH$ <sub>v</sub> = UNIT HORIZONTAL VECTOR @  $2^1$
- 7)  $X(T2)$  = COT OF FINAL FLIGHT PATH ANGLE @  $2^0$
- 8)  $CFPA$  = COS OF INITIAL FLIGHT PATH ANGLE @  $2^1$
- 9)  $MA\ MAXI$  } TEMPORARY { LOWER
- 10)  $MA\ MAXE$  } TEMPORARY { UPPER } BOUND ON GAMDV ITERATOR  
IN METERS @  $2^{30}$
- 11)  $NNIA$  = CONIC ITERATION COUNTER. ( $NNIA < 0$  IMPLIES THIS IS CONIC PHASE)

OUTPUT:

- 1)  $VE(T1)$ <sub>v</sub> = POST-IMPULSE INITIAL VELOCITY VECTOR  
IN METERS/SEC @  $2^1$
- 2)  $DV$  = INITIAL DELTA V IN METERS/SEC @  $2^1$
- 3)  $X(T2)$  = COTAN OF INITIAL FPA (POST-IMPULSE) @  $2^0$
- 4)  $POON$  = SEMI-MAJOR RECTUM IN METERS @  $2^{25}$
- 5)  $BETA1$  =  $X(T2)^2$
- 6)  $MPAC = 0$ , NORMAL EXIT  
 $MPAC \neq 0$ , ALARM CODE OCT 605 - EXCESSIVE ITERATIONS  
IN GAMDVIO
- 7) ABORT EXIT TO P00000 : OCT 610

NEXT SHEET

A.C. WILLIAMS 1508660

J. J. L. 21009

P. R. L. 7/6/70

J. J. L. 7/6/70

P37 - RETURN TO EARTH  
(MAIN PROGRAM)

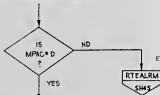
COLLOSSUS 2D

FC-2642

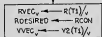
2

53

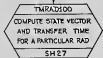
FROM PRECEDING SHEET



EXCESSIVE ITERATIONS IN GAMVOID.



PUT PST VARIABLES INTO LOCATIONS EXPECTED BY TIMERAD, THE CONIC SUBROUTINE CALLED BY TMRAD100.



INPUT: RVEC<sub>v</sub> INITIAL POSITION VECTOR IN METERS @ 2<sup>13</sup>  
 VVEC<sub>v</sub> INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2<sup>7</sup>  
 ROESIREQ/FINAL RAD. FOR WHICH TRANSFER TIME IS TO BE COMPUTED IN METERS @ 2<sup>29</sup>  
 OUTPUT: R(T2)/v<sub>v</sub> FINAL POSITION VECTOR IN METERS @ 2<sup>13</sup>  
 V(T2)/v<sub>v</sub> FINAL VELOCITY VECTOR IN METERS/CSEC @ 2<sup>7</sup>  
 T2 TRANSFER TIME TO FINAL RAD IN CSEC @ 2<sup>28</sup>



T2 = FINAL TIME



TAKE ASTRONAUT'S ENTRY ANGLE ?



COMPUTE FPA DESIRED (CENTER OF CORRIDOR)



USE ASTRONAUT'S ENTRY ANGLE



INPUT: x = |v(t2)/v|

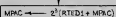
D<sub>1</sub> = D

D<sub>2</sub> = -4.876/D711 × 10<sup>-2</sup> @ 2<sup>-4</sup>

D<sub>3</sub> = DEC - 4.5415476 × 10<sup>-4</sup> @ 2<sup>11</sup>

D<sub>4</sub> = -1.4317675 × 10<sup>-6</sup> @ 2<sup>-10</sup>

OUTPUT: MPAC ← -D1 + D2X + D3X<sup>2</sup> + D4X<sup>3</sup> = GSOP X(t2)



RTED1 = PAD LOAD EQUIVALENT TO D1 ON PAGE 5.4-6 OF COLOSSUS GSOPS, R077



NEXT SHEET

NOTE PLACED IN 87

A.C. WILLIAMS

23DEC68

PST - RETURN TO EARTH  
(N'VIN PROGRAM)

911007

COLOSSUS 2D

FC-264C

9 April 69

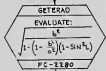
9 April 69

53

FROM PRECEDING SHEET

FLOOD  $\leftarrow$  MPAC - X(T2)  
ALPHAV  $\leftarrow$  UNIT(R(T2))

$X(t_2)_{ERR} @ 2'$



GETERAD:  
INPUT: ALPHAV + Z COMPONENT OF  $\frac{R(T2)_V}{|R(T2)_V|}$   
OUTPUT: ERADM, WHERE  $b^2 = 82XSC = 0.179450603 @ 2'^2$   
 $\left(1 - \frac{b^2}{a^2}\right) = EE = 6.6935116 \times 10^{-5} @ 2'$   
ERADM =  $P_1 = MPAC \cdot$  EARTH-RADIUS FOR  $R(T2)_V$   
IN METERS @  $2'$

FLOOD  $\leftarrow$  ERADM + ESRTE

RCOIN' ESRTE = DEC 12 1920.0 @  $2'^{2.5}$  = ENTRY ALTITUDE ABOVE FISCHER ELLIPSOID (EQUIVALENT TO 400,000 FT)



NO  
EPC2RTE =  $E_2 =$  DEC. 100. @  $2'^{2.5}$   
HAS THIS CONIC PORTION CONVERGED TO A SUITABLE RADIUS ?

YES

RTEST4



NO  
CHANGE IN  $X(T2)$  TOO LARGE  
EPC3RTE =  $E_3 =$  DEC. .001 @  $2'$ .  
WAS THE LAST CHANGE IN THE COTANGENT OF THE FINAL FLIGHT PATH ANGLE WITHIN AN ACCEPTABLE LIMIT ?

YES

RTEST5

NNIA  $\leftarrow$  NNIA + IRTETB8 INCREMENT COUNTER

PSITE SH3

CONIC SOLUTION ACHIEVED, PROCEED TO DISPLAY.

IS NNIA < 0 ?

NO-EXCESSIVE ITERATIONS

MPAC  $\leftarrow$  OCT6E2

NRTEB2B = DEC-8 @  $2'$

RTEALRM ALARM DISPLAY OCTAL CODE 605' EXCESSIVE ITERATIONS

SH45

605DPOOH FC-1019

SH3

TERMINATE RECYCLE

IS THIS THE FIRST TIME THROUGH ?

YES-FIRST TIME

RTEB50

NO-NOT FIRST TIME

RTEB55

$Dx(t_2) = X(t_2)_{ERR}$   
MPAC  $\leftarrow$  FLOOD

$$\frac{X(t_2) - X(t_1)}{X(t_2)_{ERR} - X(t_1)_{ERR}}$$
  
MPAC  $\leftarrow$  FLOOD  
RPRE2 - X(T2)  
NORM. (FLOOD - DRCON) @  $2'^{2.5}$

SLOPE ITERATION

NEXT SHEET

P27 - RETURN TO ENTH MAIN PROGRAM

A.C. WILLIAMS  
P. J. JARVIS  
J. J. JARVIS  
J. J. JARVIS

800058  
9A1487  
790115  
790115

COLOSS. 2D  
2

FC-26-42  
7  
53

FROM PRECEDING SHEET

RTE350

PLIGD	←	DX(t <sub>2</sub> )
RCON	=	RCONH
PLIGD	←	MPAC
RCON	←	PLDZD

IS  
TRIKE OVERFLOW  
?

PLOOD MAY = DRCON  $(x(t_2)_{err} = x(t_2)_{err})$ ,  
IN THAT CASE  $x(t_2)$ ,  $x(t_2)_{err}$  AND  $x(t_2)'$  ARE  
NOT UPDATED

YES  
RTE360  
SHE

NO

$x(t_2)_{err}$	←	$x(t_2)_{err}$
$x(t_2)'$	←	$x(t_2)'$
$x(t_2)$	←	$DX(t_2) + x(t_2)$
DRCON	←	PLOOD
RPRE	←	x(VE)
$x(t_2)$	←	PLIGD + x(t <sub>2</sub> )

SAVE LATEST FIGURES

RTE360  
SHE

APR 26 1964  
A.C. WILLIAMS  
A.C. WILLIAMS  
A.C. WILLIAMS  
A.C. WILLIAMS  
A.C. WILLIAMS

P37 - RETURN TO EARTH  
(MAIN PROGRAM)

COLOSSUM 2D FC-2642

P37E

RTENV  
COMPUTE LAT, LONG  
DISPLAY LAT, LONG  
AND OTHER DATA  
SH 2B

INPUT:  $V(T_2)/V_0$ ,  $R(T_2)/R_0$ ,  $V_2(T_1)/V_0$ ,  $V(T_1)/V_0$ ,  
 $UR_1/V_0$ ,  $UH_1/V_0$ ,  $SPRETIG$ ,  $TE$ .

OUTPUT: DISPLAY  
LATITUDE } AT 400,000 FT.  
LONGITUDE }  
DELTA TIME TO 400,000 FT  
VPEED: MAGNITUDE OF VELOCITY AT 400,000 FT  
GAMMA1: FLIGHT PATH ANGLE AT 400,000 FT  
DELTV: IMPULSIVE DELTA V

ASTRONAUT MAY APPROVE OF THESE CALCULATIONS AND  
PROCEED, OR DISAPPROVE AND EITHER TERMINATE  
OR RECYCLE.

RTE505

RCOH = RADIUS OF CONIC TRAJECTORY.  
PCOH IS CALCULATED IN DVALC.

$PCOH = \frac{a_2}{a_1 - a_2} =$  SEMI LATUS RECTUM  
 $BETA 1 = 1 + X(T_2)^2$  CALCULATED IN VET100

NO  
ENTRY NEAR  
PERIGEE  
YES  
ENTRY NEAR  
APOGEE

RTE510

$\beta_2 = -1$   
PHI2 ← -1RTE82

$\beta_2 = 1$   
PHI2 ← 1RTE82

(THIS  
OCCURS ONLY FOR NEARLY  
CIRCULAR ORBITS.)

RTE515

PREC100: PRECISION INTEGRATION SUBROUTINE  
CALLS: STEWIS, RTENV, PASH, TIMRND, VET100, INTALL  
COMPUTES & NUMERICALLY INTEGRATES A TRAJECTORY USING  
CONSTRAINTS DERIVED FROM THE CONIC INTEGRATION.

INPUT:  
1) RCOH = RCOH = FINAL RAD OF CONIC TRAJECTORY IN METERS @ 2<sup>13</sup>  
2) R(T<sub>2</sub>)/V<sub>0</sub> = R(T<sub>2</sub>) = PRE-RETURN POS. VECTOR IN METERS @ 2<sup>13</sup>  
3) V(T<sub>2</sub>)/V<sub>0</sub> = V(T<sub>2</sub>) = PRE-RETURN VELOCITY VECTOR IN M/SEC @ 2<sup>7</sup>  
4) T1 = T<sub>1</sub> = TIME OF PRE-RETURN STATE VECTOR IN CSEC @ 2<sup>10</sup>  
5) T12 = T<sub>12</sub> = TRANSFER TIME TO T<sub>2</sub>, THE FINAL POSITION TIME, IN CSEC @ 2<sup>10</sup>

- 6) R(T<sub>1</sub>) = MAGNITUDE OF R(T<sub>1</sub>)/V<sub>0</sub> IN METERS @ 2<sup>13</sup>
- 7) X(T<sub>2</sub>) = COTAN OF FINAL FLIGHT PATH ANGLE @ 2<sup>4</sup>
- 8) X(T<sub>1</sub>) = COTAN OF INITIAL FLIGHT PATH ANGLE @ 2<sup>5</sup>
- 9) R(TEDV) = DELTA VELOCITY DESIRED IN METERS/CSEC @ 2<sup>7</sup>
- 10) MAMAX1 = MA<sub>1</sub> = MAJOR AXIS LIMIT ON LOWER BOUND OF GAMMA ITERATOR IN METERS @ 2<sup>10</sup>
- 11) MAMAX2 = MA<sub>2</sub> = MAJOR AXIS LIMIT ON UPPER BOUND OF GAMMA ITERATOR IN METERS @ 2<sup>10</sup>
- 12) UR1/V<sub>0</sub> = U<sub>1</sub> = UNIT PRE-RETURN POSITION VECTOR @ 2<sup>1</sup>
- 13) UH1/V<sub>0</sub> = H<sub>1</sub> = UNIT HORIZONTAL VECTOR @ 2<sup>1</sup>
- 14) BETA1 =  $\beta_1 = 1 + X(T_2)^2$  @ 2<sup>4</sup>
- 15) PHI2 =  $\beta_2 =$  PERIGEE OR APOGEE @ 2<sup>2</sup>  
+1 = APOGEE -1 = PERIGEE

OUTPUT:

- 1) V(T<sub>1</sub>)/V<sub>0</sub> = V<sub>1</sub>(T<sub>1</sub>) = POST IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2<sup>7</sup>
- 2) R(T<sub>2</sub>)/V<sub>0</sub> = R(T<sub>2</sub>) = FINAL POSITION VECTOR IN METERS @ 2<sup>13</sup>
- 3) V(T<sub>2</sub>)/V<sub>0</sub> = V(T<sub>2</sub>) = FINAL VELOCITY VECTOR IN METERS/CSEC @ 2<sup>7</sup>
- 4) TE = T<sub>2</sub> = FINAL TIME IN CSEC @ 2<sup>10</sup>
- 5) MPIC = 0 FOR NORMAL EXIT  
MPIC = OCT613 OR OCT615 FOR ALARM EXIT.

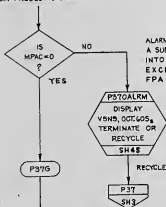
NEXT SHEET

V A. C. WILLIAMS  
11/1/68  
10/1/68  
10/1/68  
10/1/68

P37- RETURN TO EARTH  
(MAIN PROGRAM)  
650656 7/1/68  
10/1/68 2D FC-2642  
7/1/68 2 9 53



FROM PRECEDING SHEET



ALARM EXITS FROM PRECIO, AND GAMOVIO, A SUBROUTINE, LOAD G05 OR 613 OCT INTO MPAC: EXCESSIVE ITERATIONS OR FINAL FPA NOT REACHED.

P37OALRM CALLS GOFFLASH, WITH A VERB 5 NOUN 9, AND DISPLAYS OCTAL 605 OR 613 ALARM CODE. V34 ENTER TERMINATES PROGRAM V35 ENTER CONTINUES THE FLASH V32 ENTER RECYCLES P37.



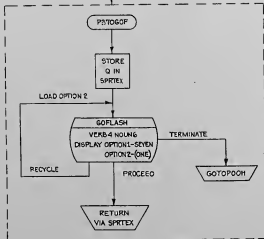
RTEVN CALLS RTEQIS: CALLS TMRADCO, AUGEWUGL AND LAT-LONG SUBROUTINES.

INPUTS:

$V(T_2)_0 = V(T_2)$ ;  $SPRTETIG = \text{MEYED-IN TIG}$ ;  $T_2 = \text{TEMPORARY TIME OF } V(T_2)$ ;  $R(T_2)_0 = R(T_2)$ ;  $UN_0 = UN$ ;  $V(T_1) = V(T_1)$ ;  $VE(T_1)_0 = VE(T_1)$ ;  $URU_0 = URU$

DISPLAY:

- 1) LAT(SPL) } LATITUDE AND LONGITUDE OF SPLASHDOWN.  
LONG(SPL) }
- 2) TSTD14 =  $T_2 - SPRTETIG$ ; OR  $L_2 - T_{10}$  = TRANSFER TIME TO 400,000 FT.
- 3)  $VPRED = |V(T_2)_0|$ , VELOCITY MAGNITUDE AT 400,000 FT.
- 4) GAMMAEL = FLIGHT PATH ANGLE.
- 5) DELTAV = CHANGE IN VELOCITY MAGNITUDE.



DISPLAY OPTION CODE, AND SPS OPTION  
OPTION 1 = SEVEN + RCS-SPS OPTION  
OPTION 2 = ONE = SPS OPTION (ASSUMED)

FOR SPS - PROCEED (OR LOAD RE WITH OCT 1)  
FOR RCS - LOAD OPTION 2 WITH OCT.00C.

SET PUSH LIST TO 0  
NEXT SHEET

INSTRUMENTATION  
 APPROVED BY: \_\_\_\_\_  
 DATE: \_\_\_\_\_  
 BY: \_\_\_\_\_  
 CHECKED BY: \_\_\_\_\_  
 DATE: \_\_\_\_\_

P37 - RETURN TO EARTH  
 (MAIN PROGRAM)

67-1060  
 51-10-17  
 51-10-17  
 51-10-17  
 51-10-17

COLORADO 2D FC-2642  
 2  
 10 53

FROM PRECEDING SHEET

DOES ASTRONAUT REQUIRE RCS ?  
 IRTB13 = E IN OPTION 2

YES  
 RCS OPTION

NO  
 GPS OPTION

P37Q

MPAC ← 2-MDOTRCS

MASS DECREMENTATION  
 FACTOR FOR RCS

$\frac{\Delta V}{V_c (SPS)}$   
 PLOOD ←  $NORM_{M1}(EMDOT)$   
 MPAC ←  $\frac{DV}{VCSFS}$

SAVE NORMALIZED  
 EMDOT, MASS  
 DECREMENTATION  
 FACTOR FOR SPS =  
 31.510396 @ 2<sup>5</sup>

IS  
 NJETSPLG  
 ON ?

2 JET RCS  
 BURN

MPAC ← 2-MPAC

4 JET RCS BURN

P37R

$\frac{\Delta V}{V_c (RCS)}$   
 PLOOD ←  $NORM_{M1}(MPAC)$   
 MPAC ←  $\frac{DV}{VCRCS}$

INPUT FOR POLY  
 SAVE WEIGHTED MDOTRCS

POLY  
 APPROXIMATE  
 $1 - e^{-\Delta V/V_c}$  BY A  
 QUADRATIC  
 POLYNOMIAL  
 FC-2100

INPUT: MPAC = DV/Vc

$$1 - e^{-\Delta V/V_c} = C_2(\Delta V/V_c)^2 + C_1(\Delta V/V_c) + C_0$$

WHERE  $C_2 = -.368281955 @ 2^{11}$   
 $C_1 = 0.379487897 @ 2^{11}$   
 $C_0 = 5.66240537 \times 10^{-4} @ 2^9$

OUTPUT IN MPAC

NEXT SHEET

A.C. WILLIAMS

6 JAN 65

*W. Williams*

7 JAN 65

*W. Williams*

10 DEC 65

*W. Williams*

7 APR 67

*W. Williams*

9 MAR 67

P37- RETURN TO EARTH  
 (MAIN PROGRAM)

COLDFUS 2D

FC-2642

2

11

53

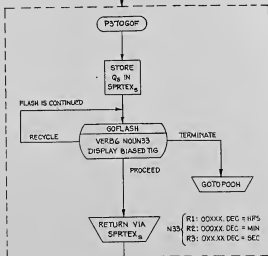
FROM PRECEDING SHEET

$$T_{10} = t_1 - C_T \Delta t_0$$

$$\text{WEIGHT} / (G_0 - C_S \text{UBST} + \text{MPAC} \cdot z - 129 - x_1) \cdot z - 129 - x_1$$

TIG ← T1

BIASED TIG



THIS DISPLAYS BIASED TIG, COMPUTED FROM KEYS IN TIG, AND THRUST PARAMETERS OF THRUST OPTION KEYS IN. ASTRONAUT SHOULD RECORD DATA AND KEY IN PROCEED. THERE IS NO GSOP OPTION FOR LOADING DATA.

CLEAR MARK COUNTERS (INITIALIZE FOR NEW USE OF RADAR)  
 NUMBER OF VHF MARKS INCORPORATED,  
 NUMBER OF RENDELVOUS MARKS TAKEN.

VHFONT<sub>0</sub> ← ZERO<sub>0</sub>  
 TRKMKCNT<sub>0</sub> ← ZERO<sub>0</sub>

RTENCK1  
 SET INTYPFLG,  
 CLEAR MOONFLAG  
 CALL INTEGRVS,  
 COMPUTE R(TZ)<sub>0</sub>, Tz  
 V(TZ)<sub>0</sub>, X1  
 SM42

RTENCK1: SETS INTYPFLG, MAKING THE INTEGRATION ROUTINE, INTEGRVS, DO CONIC INTEGRATION CLEARS MOONFLAG, INDICATING EARTH SPHERE OF INFLUENCE. LOADS THE INPUT INTO THE VARIABLES EXPECTED BY INTEGRVS, AND LOADS THE OUTPUT INTO VARIABLES EXPECTED BY PST.

INPUT: R(T1)<sub>0</sub>, V<sub>0</sub>(T1)<sub>0</sub>, T1, Tz  
 OUTPUT: R(TZ)<sub>0</sub> ← RATT<sub>0</sub> = POSITION VECTOR IN METERS @ 2<sup>05</sup>  
 V(TZ)<sub>0</sub> ← VATT<sub>0</sub> = VELOCITY VECTOR IN M/SEC @ 2<sup>07</sup>  
 Tz ← TAT = TIME IN\_CSEC @ 2<sup>08</sup>  
 X1 ← CONIC X1 FOR PROPER A-TABLE VALUES.

NEXT SHEET

P37- RETURN TO EARTH  
 (MAIN PROGRAM)

A.C. WILLIAMS

CHANGED

7/1/67

AND J. S. Brown

10/1/67

10/1/67

7/1/67

John A. ...

2

COLOSSUS 2D

FC-2642

2

12 53

FROM PRECEDING SHEET

$$K \cdot \text{UNIT} \begin{bmatrix} \dot{r}(t_2) \\ \dot{v}(t_2) \end{bmatrix} = -\text{UNIT} \begin{bmatrix} \dot{r}(t_1) \\ \dot{v}(t_1) \end{bmatrix} \cdot (U_{R1} \cos 7.5^\circ + U_{V1} \sin 7.5^\circ)$$

$$\text{MPAC} \leftarrow \text{UNIT} \begin{bmatrix} R(t_2) \\ V(t_2) \end{bmatrix} \cdot \begin{bmatrix} -(\cos 7.5^\circ U_{R1} + \sin 7.5^\circ U_{V1}) \\ \cos 7.5^\circ U_{R1} - \sin 7.5^\circ U_{V1} \end{bmatrix}$$

MCOS 7.5 = -.99144486 = MINUS COS 7.5°  
MSIN 7.5 = -.13082619 = MINUS SIN 7.5°

IS TARGET FOR LAMBERT STEERING  
SUFFICIENTLY FAR (22.5) FROM 180°  
TO KEEP LAMBERT STEERING  
FROM GLIDING SHIP OUT OF PLANE?

MCOS 22.5 = -.92387953  
@ 2°

YES

NO-NEW TARGET NEEDED: OBTAIN PROPER INPUTS FOR  
TIMETHET

IS PSEUDO-TARGET AFTER 180°?

NO

BEFORE 180°

?

YES

P3TV

P3TU

P3TV

$$\text{SINTH} = \sin(\text{THETA165})$$

$$\text{COSTH} = \cos(\text{THETA165})$$

THETA165 = 45.8333333 DEC  
165° IN REVS

$$\text{SINTH} = \sin(\text{THETA210})$$

$$\text{COSTH} = \cos(\text{THETA210})$$

THETA210 = 50.9333333 DEC  
210° IN REVS

PUSH PSEUDO-TARGET  
BACK TO 165°

PUSH PSEUDO-TARGET  
FORWARD TO 210°

SINTH = SIN @ 2°, WHERE @  
IS THE TRUE ANOMALY  
DIFFERENCE.  
COSTH = COS @, @ 2°

CLEAR  
RVSW

RVSW IS CLEARED TO ALLOW  
TIMETHET TO COMPUTE  $\dot{r}(t_2)$   
AND  $\dot{v}(t_2)$ .

$$\text{RVEC}_v \leftarrow \begin{bmatrix} R(t_1) \\ V(t_1) \end{bmatrix}_v$$

$$\text{VVEC}_v \leftarrow \begin{bmatrix} \dot{r}(t_1) \\ \dot{v}(t_1) \end{bmatrix}_v$$

INPUTS TO TIMETHET:  
 $\text{RVEC}_v = \dot{r}(t_1)$ , INITIAL POSITION VECTOR IN METERS @ 2°  
 $\text{VVEC}_v = \dot{v}(t_1)$ , INITIAL VELOCITY VECTOR IN METERS @ 2°

TIMETHET  
COMPUTE:  $t_{E1}$ ;  
 $\dot{r}(t_2)$ ;  $\dot{v}(t_2)$   
FC-2360

INPUT: RVEC; VVEC; XI = -2, INDEX VALUE FOR M-TABLE;  
SINTH; COSTH; RVSW, CLEARED.  
OUTPUT: TIMETHET COMPUTES TRANSFER TIME GIVEN THE INITIAL  
STATE VECTOR, AND THE DESIRED TRUE ANOMALY  
DIFFERENCE, @; AND, IN THIS CASE, THE FINAL STATE  
VECTOR,  $\dot{r}(t_2)$ , AND  $\dot{v}(t_2)$ , FOR LAMBERT STEERING.  
 $t_{E1}$  = TRANSFER TIME IN CSEC @ 2°  
PLOOD =  $\dot{r}(t_2)$  = FINAL POSITION VECTOR, IN METERS @ 2°  
MPAC =  $\dot{v}(t_2)$  = FINAL VELOCITY VECTOR

P3TW

NEXT SHEET

P37- RETURN TO EARTH  
(MAIN PROGRAM)

COLLOSSUS 2D

FC-2642

FROM PRECEDING SHEET

CLEAR  
XDELVFLG  
CLEAR  
NORMSW  
SET  
FINALFLG

INPUT TO P40, P41

XDELVFLG: LAMBERT (AIMPOINT) COMPUTATION  
NORMSW: LAMBERT MUST COMPUTE  
ITS OWN NORM.

THIS FLAG ALLOWS PROPER COMPUTATION OF MGA  
AND TERMINATION OF VN1645 BY V33 ENTER.

$t_e = t_{e0} + t_{e1}$   
RTARG ← PLOOD  
TPASS ← T + T1  
DEVSIN ←  $V_2(T) \sqrt{V_1 - V(T)}$

$I'(t_e)$   
 $t_e$   
INPUT FOR VN1645

P37WW

VN1645  
COMPUTE  $q_{max}$   
DISPLAY  
MKX CTRS, TIS  $q_{max}$   
FC-2720

KEYBOARD ENTRIES :  
V33 ENTER } TERMINATE  
V34 ENTER } P37  
V32 ENTER TRANSFERS  
TO PSTWW.

INPUT: DEVSIN  
FLAG: FINALFLG SET  
OUTPUT: MGA - MIDDLE GIMBAL ANGL.  
DISPLAY:  
VERB 16  
NOUN 45  
R1: MARKS: NOT MEANINGFUL  
R2: T1: TIME TO TIG (BIASED)  
XXBXX MIN/SEC.  
R3: MIDDLE GIMBAL ANGLE  
XXX.XX DEGS.  
IF REFSMMAT FLAG IS CLEAR,  
R3 = -.0000E.  
IF REFSMMAT FLAG IS SET,  
R3 WILL BE COMPUTED.

V32 recycles VN1645, asking  
for terminate or proceed  
response.

ASTROPHYSICAL OBSERVATORY  
UNIVERSITY OF ARIZONA

NAME: A.C. WILLIAMS  
ID NO: 91287  
TITLE: *Return to Earth*  
DATE: 1/11/68  
PROJECT: *Return to Earth*

P37 - RETURN TO EARTH  
(MAIN PROGRAM)

COLLEGE 2D

FC-2642

INVC100 CALLED BY MAINLINE PROGRAM AFTER RTE299

SAVE  
OPRET  
IN  
SPRTEX

TDEC1 ← SPRK2TIG STORE TIG IN LOCATION EXPECTED BY CSMPREC

CSMPREC  
PRECISION  
INTEGRATION OF  
 $R(T_1)$ ,  $V(T_1)$ ,  $T_1$   
AND  $P(T_1)$   
FC-2290

CSMPREC COMPUTES THE PRECISION STATE VECTOR FOR THE CSM AT TIG.  
INPUT:  
TDEC1 = TIG IN CSEC @ 2<sup>28</sup>  
(CURRENT CSM STATE VECTOR AND CURRENT TIME)  
OUTPUT:  
RATT =  $r(t_1)$ : POSITION VECTOR AT TIG IN METERS @ 2<sup>28</sup>  
VATT =  $v_1(t_1)$ : VELOCITY VECTOR AT TIG IN METERS/CSEC @ 2<sup>7</sup>  
TAT =  $T_{25}$ : TIME  $t_1$  IN CSEC @ 2<sup>28</sup>  
P(T1) = COORDINATE SYSTEM ORIGIN: EARTH: P(T1) = 0  
MOON: P(T1) = 2

$R(T_1)/_e$  ← RATT,  
 $V(T_1)/_e$  ← VATT,  
 $T_1$  ← TAT

PUT CSMPREC OUTPUT INTO PST LOCATIONS.

IS  
 $P(T_1) = 0$   
?  
YES  
NO  
EARTH'S SPHERE OF INFLUENCE ?  
MOON'S SPHERE

INVC109

MPAC ← OCT612

RTEALRM  
CALL PSTOALRM  
SHOW TIG PUTS  
CRAFT IN MOON  
SPHERE, RECYCLE  
OR TERMINATE  
SH45  
P37  
SH3

RTEALRM CALLS PSTOALRM WHICH DISPLAYS ALARM CODE 612, TIG PUTS CRAFT IN MOON'S SPHERE OF INFLUENCE. ASTRONAUT MAY RECYCLE PST OR TERMINATE RECYCLING PERMITS NEW TIG

$u_{r1} = \text{UNIT}(r(t_1))$   
 $u_{v1} = \text{UNIT}(v_1(t_1))$   
 $r(t_1) = |r(t_1)|$   
 $CFPA = u_{r1} \cdot u_{v1}$   
 $UR1/_e = \text{UNIT}(R(T_1)/_e)$   
 $UV1/_e = \text{UNIT}(V(T_1)/_e)$   
 $R(T_1) = |R(T_1)/_e|$   
 $CFPA = UR1/_e \cdot UV1/_e$

GOTOPOD TERMINATE  
SH3 RECYCLE

CFPA > 0 MEANS CRAFT IS BEFORE APOGEE AT TIG.  
CFPA < 0 MEANS CRAFT IS AFTER APOGEE AT TIG.  
CFPA = COSINE OF INITIAL FLIGHT PATH ANGLE (FPA)

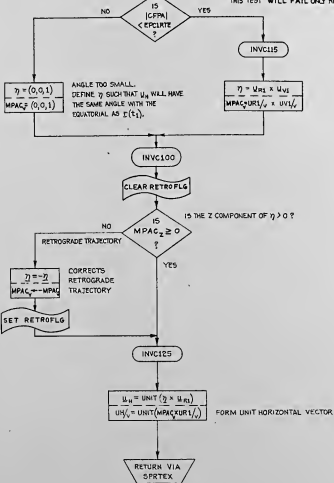
NEXT SHEET

A.C. WILLIAMS  
S. J. BRADY  
R. J. KEAR  
E. A. MANN

62ANNO  
912097  
601055J-2D  
FC-2642  
2 12 53  
P37 - RETURN TO EARTH (INVC100)

FROM PRECEDING SHEET

EPCLIRTE =  $e_1 = \text{DEC. } 99946 @ 2^1$   
 $e_2$  IS EQUAL  $\cos 1.5^\circ$ . QUESTION ASKS IF THE ANGLE  
 BETWEEN  $[t_1]$  AND  $\lambda_1(t_1)$  IS LESS THAN  $1.5^\circ$ .  
 THIS TEST WILL FAIL ONLY NEAR THE MOON.

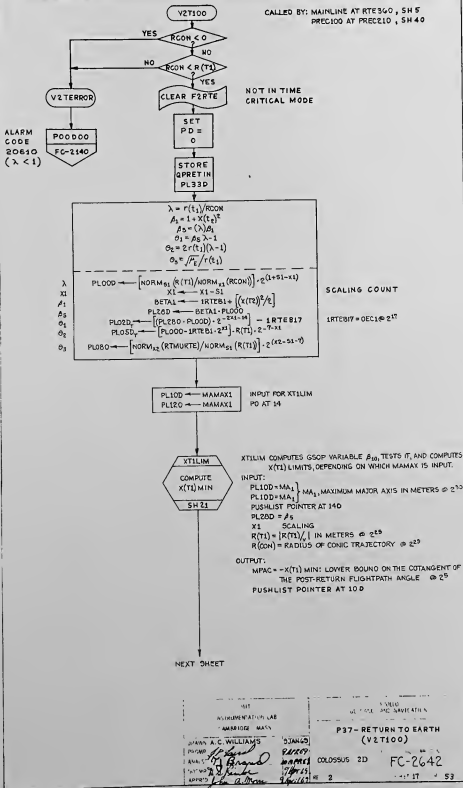


SPERRY A.C. WILLIAMS  
 311209  
 311209  
 311209  
 311209

P37 - RETURN TO EARTH  
 (INVC100)

COLOSSUS 2D FC-2642

CALLED BY: MAINLINE AT RTE340, SH 5  
PREC100 AT PREC10, SH 40







FROM PRECEDING SHEET

VZT150



GAMDV10 CALLS DVALC BY ITERATION, IT CALCULATES  $VZ(T1)_{\text{CAL}} = Y_z(t_1)$ ,  $DV = \Delta V$ ,  $X(T1) = X(t_1)$  AND  $PCON = P_{\text{CON}}$ .

INPUT:

PUSHLIST:

02D  $\theta_1 = \theta_5 \lambda - 1$   
 05D  $\theta_2 = 2r(t_1) \sqrt{\lambda - 1}$   
 08D  $\theta_3 = \sqrt{r_0} / r(t_1)$

10D  $X(t_1)_{\text{MIN}} = \text{LOWER BOUND ON INDEPENDENT VAR. } X(t_1)$

12D  $\Delta X(t_1)_{\text{MAX}} = \text{MAXIMUM } \Delta X(t_1)$

14D  $X(t_1)_{\text{MAX}} = \text{UPPER BOUND ON IND. VAR. } X(t_1)$

16D  $\Delta X(t_1) = \text{CHANGE IN } X(t_1)$

OTHER:

$V(T1)_{\text{CAL}} = Y(t_1) = \text{INITIAL, PRE-IGNITION VELOCITY VECTOR IN METERS/CSEC @ } 2^{\circ}$

RTEVD =  $\Delta V_0 = \text{KEYED-IN } \Delta \text{ VELOCITY DESIRED IN METERS/CSEC @ } 2^{\circ}$

$U(R1)_{\text{CAL}} = U_{R1} = \text{UNIT POSITION VECTOR AT } T_{10}$

$U_H = U_H = \text{UNIT HORIZONTAL VECTOR: } \text{UNIT}(\eta \times R(T1)_{\text{CAL}})$

$X(T1) = \text{COTANGENT OF INITIAL FLIGHT PATH ANGLE FROM THE VERTICAL.}$

PERTE = FLAG ON MEANS TIME CRITICAL MODE. FLAG OFF MEANS NOT IN TIME CRITICAL MODE.

OUTPUT:

$VZ(T1)_{\text{CAL}} = Y_z(t_1) = \text{POST-IMPULSE VELOCITY VECTOR IN METERS/CSEC @ } 2^{\circ}$

$DV = \Delta V = \text{CHANGE IN VELOCITY}$

$X(T1) = \text{COT OF INITIAL POST-RETURN FLIGHT PATH ANGLE FROM VERTICAL.}$

$PCON = P_{\text{CON}} = \text{SEMI-LATUS RECTUM IN METERS @ } 2^{\circ} \text{ @ } 2^{\circ}$

M/PAC ← RTEVD

IS THIS FUEL CRITICAL ?

YES

IS  
RTEVD=0  
?

NO

VZTIX

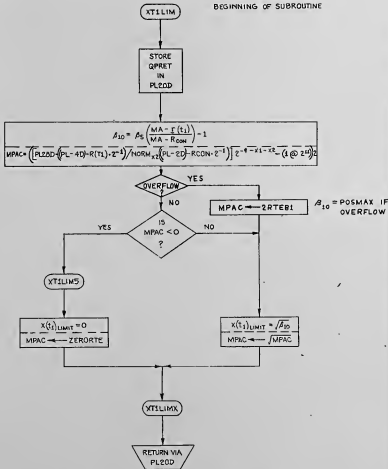
RETURN VIA  
33D<sub>b</sub>

NEXT SHEET

MIT 15, MEMPHIS, TENN. 38 MEMPHIS, TENN. DR. A.C. WILLIAMS 33 JAN 60 311009 311009 311009 311009	POST - RETURN TO EARTH (VZT100) COLOSSUS 2D FC-2642 REV 2 19 53
--	---



CALLED BY XT100 TWICE IN  
BEGINNING OF SUBROUTINE



XTILIM IS USED TWICE: ONCE USING MAMAX1 AND ONCE USING MAMAX2.  
WHEN MAMAX1 IS USED, XTILIM DETERMINES WHETHER THE PRESENT TRAJECTORY IS CLOSE TO PARABOLIC. IF IT IS, THE POST-IMPULSE FLIGHT PATH ANGLE IS NOT PERMITTED TO HAVE A NEGATIVE RADIAL COMPONENT.  
WHEN MAMAX2 IS USED, XTILIM DETERMINES WHETHER R(t1), THE ABSOLUTE VALUE OF THE POSITION VECTOR, IS GREATER THAN MAMAX2. IN THAT CASE, THE MAXIMUM RADIUS IS TAKEN TO BE R(t1) ITSELF. THE POST-IMPULSE PFA IS THEREFORE NOT PERMITTED TO HAVE A POSITIVE RADIAL COMPONENT.

M I  
 INSTRUCTIONS  
 APPROX 1967  
 BY A.C. WILLIAMS  
 9/1/67  
 BY J.P. BROWN  
 10/10/67  
 BY J. D. HENK  
 7/1/68  
 BY J. A. BROWN  
 9/20/68

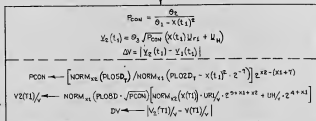
P37 - RETURN TO EARTH  
(XTSLIM)

COLOSSUS 2D

FC-2642

DV/CALC

STORE  
 QPRET  
 IN  
 PLS2D



PCDN = SEMI-LATUS RECTUM  
 IN METERS @  $2^{25}$   
 $V2(T1)/\sqrt{r_1} + Y_2(t_1)$  = POST-MIRAGE  
 INITIAL VELOCITY VECTOR  
 IN METERS/CSEC @  $2^7$   
 MAGNITUDE OF INITIAL  
 VELOCITY CHANGE  
 IN METERS/CSEC @  $2^7$

RETURN VIA  
 PLS2D

PCDN

PCDN SATISFIES THE EQUATION: 
$$PCDN = \frac{2r(t_1) \left( \frac{r(t_1)}{R_{CDW}} - 1 \right)}{\frac{(r(t_1))^2}{R_{CDW}^2} \left( 1 + (X(t_1))^2 \right) - \left( 1 + (X(t_1))^2 \right)^2}$$
 WHERE

$$\theta_2 = 2r(t_1) \left( \frac{r(t_1)}{R_{CDW}} - 1 \right)$$
 AND 
$$\theta_1 = \frac{(r(t_1))^2}{R_{CDW}^2} \left( 1 + (X(t_1))^2 \right) - 1$$
, WHERE  $r(t_1)$  = RADIUS

AT  $T_{R2}$ ;  $R_{CDW}$  = FINAL RADIUS AND  $X(t_2)$  = COTANGENT OF THE FINAL FLIGHT PATH ANGLE.  
 $X(T1)$  IS THE INDEPENDENT VARIABLE, EQUALING COTANGENT OF THE INITIAL FLIGHT PATH ANGLE.

13 JAN 67 10 48  
 AIRCDS VAL  
 STAFF AC WILLIAMS  
 NAME *W. J. Brown*  
 TITLE *W. J. Brown*  
 APPROVED *W. J. Brown*  
 SPECIAL *W. J. Brown*

P37 - RETURN TO EARTH  
 (DVCALL)

COLOSSUS 3D FC-2642

FC-2642

GAMOV10

STORE  
 QPRET  
 IN  
 PL81D

DV CALC  
 CALCULATE  
 VZ(T1), DV,  
 PCON  
 SHZ Z

DV CALC:  
 INPUT:  
 PUSHU2:  
 $OSD = \theta_2 = \left(1 + X(t_2)^2\right) \lambda^2 - 1$  WHERE  $\lambda = r(t_1)/R_{CON}$   
 $OSD = \theta_2 = 2r(t_1)(\lambda - 1)$   
 $OSD = \theta_2 = \sqrt{r(t_1)} / r(t_2)$   
 OTHER:  
 $V(t_1) V_0 = V_1(t_1)$  = PRE-IMPULSE VELOCITY VECTOR  
 IN METERS/CSEC @ 2<sup>7</sup>  
 $UR1/V_0 = U(t_1)$  = UNIT VECTOR @ 2<sup>1</sup>  
 $UH/V_0 = U_H$  = UNIT HORIZONTAL VECTOR @ 2<sup>1</sup>  
 $X(t_1)$  = COTANGENT OF THE POST IMPULSE  
 FLIGHT PATH ANGLE. @ 2<sup>9</sup>

OUTPUT:  
 $VZ(t_1) V_0 = V_2(t_1)$  = POST-IMPULSE VELOCITY VECTOR  
 IN METERS/CSEC @ 2<sup>7</sup>  
 $DV = \Delta V = |VZ(t_2) - VZ(t_1)|$  IN METERS/CSEC @ 2<sup>7</sup>  
 $PCON = R_{CON}$  = SEMI-LATUS RECTUM IN METERS @ 2<sup>28</sup>

DOES OPERATION  
 PL14D-PL10D CAUSE  
 OVERFLOW ?

DOES  $X(t_1)_{MAX} = X(t_1)_{MIN}$  CAUSE OVERFLOW ?

IS  
 PL14D-PL10D <  
 EPCORTE ?

IS  $X(t_1)_{MAX}$  WITHIN  $\epsilon_1$  OF  $X(t_1)_{MIN}$  ?  
 $EPCORTE = \epsilon_1 = 1/2^{16}$

RETURN VIA  
 PL81D

EXIT: BOUNDS OF  
 $X(t_1)$  CLOSE  
 TOGETHER

IS  
 PL14D-PL10D <  
 PL12D ?

IS THE DIFFERENCE BETWEEN THE BOUNDS  
 ON  $X(t_1)$  LESS THAN THE MAXIMUM  
 ALLOWABLE CHANGE IN  $X(t_1)$  ?  
 IF SO, LIMIT  $\Delta X(t_1)$ .

GAMOV15

$\Delta X(t_1) = \frac{1}{2} (X(t_1)_{MAX} - X(t_1)_{MIN}) \text{SIGN}(\Delta X(t_1))$   
 $PL12D \leftarrow \frac{1}{2} \text{SIGN}(PL12D)(PL14D - PL10D)$   
 LIMIT  $\Delta X(t_1)$

GAMOV20

NEXT SHEET

REVISIONS  
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P37- RETURN TO EARTH  
 (GAMOV10)

COLLOSSUS 2D FC-2642

FROM PRECEDING SHEET

$n_2 = 0$   
 INITIALIZE NNZ  
 $NNZ \leftarrow M144RTZ$  M144RTE - DEC-144 @ 2<sup>10</sup>

ENTRY FROM GAMDV65  
 START OF ITERATION LOOP

$n_2 \leftarrow n_2 + 1$   
 $NNZ \leftarrow NNZ + JRTZ B20$  INCREMENT LOOP COUNTER  
 (NNZ IS INCREMENTED TO ZERO)  
 $JRTZ B20 = 1 @ 2^{10}$

IS  $n_2 < 144$  ?  
 YES  
 NO

ALARM: EXCESSIVE  
 ITERATIONS  
 $MPAC \leftarrow OCT605$   
 CALLING ROUTINE TESTS MPAC.  
 NON-ZERO RESULTS IN ALARM  
 DISPLAY.

$VZTIX$   
 $SH20$

GAMDV30

$\Delta V' = \Delta V$   
 $X(t_1) = X(t_1)$   
 $X(t_2) = X(t_1) + \Delta X(t_1)$   
 $PL20D \leftarrow \Delta V$   
 $PL16D \leftarrow X(t_1)$   
 $X(t_2) \leftarrow X(t_1) + PL16D$

STORE OLD VALUES FOR COMPARISON WITH  
THOSE TO BE CALCULATED BY DV/CALC.

DV/CALC  
 CALCULATE  
 NEW  $VZ(T_1)/V_1$   
 DV AND PCOM  
 SH22

DV/CALC:  
 INPUT:  
 PUSHLIST:  $OSD = \theta_1$ ,  $OS0 = \theta_2$ ,  $OSD = \theta_3$   
 OTHER:  $V(T_1)/V_1 = Y_1(t_1)$ ;  $UR1/V_1 = V_{R1}$ ;  
 $UR2/V_1 = V_{R2}$ ;  
 $UR3/V_1 = V_{R3}$ ,  $X(T_1)$   
 OUTPUT:  
 $VZ(T_1) = Y_2(t_1)$ ,  $DV = \Delta V$ ,  $PCOM = PCOM$

NEXT SHEET

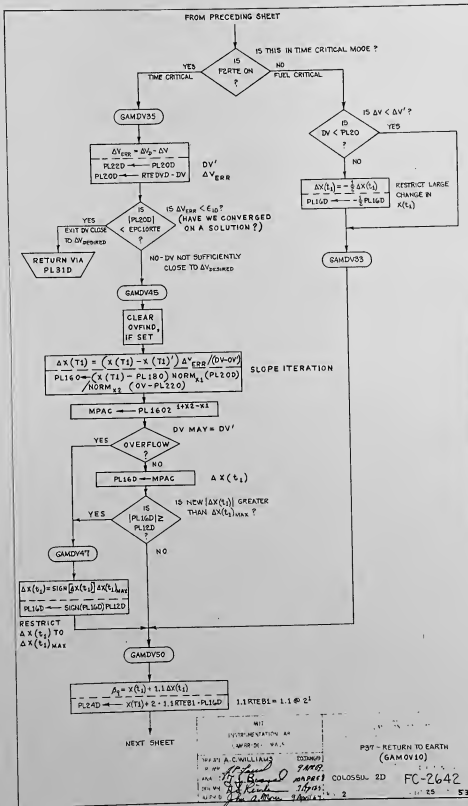
A.C. WILLIAMS  
 EDITORS:  
 JAMES  
 KANE  
 JAMES  
 JAMES  
 JAMES

PBT - RETURN TO EARTH  
 (GAMDV10)

COLOSSUS 2D FC-2642

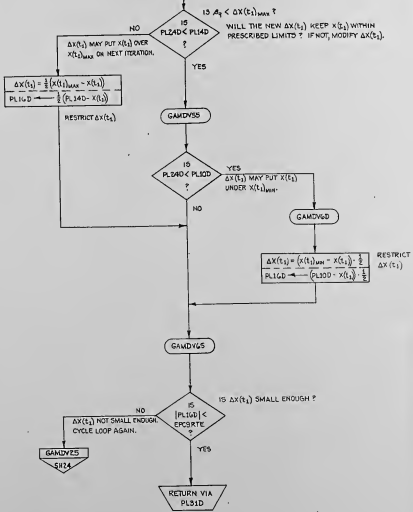
24 53

FROM PRECEDING SHEET





FROM PRECEDING SHEET



417  
 AND INTER. OF  
 AMERICA, MASS.  
 JERRY A. WILLIAMS  
 PRONO  
 REC'D  
 APR 2 1961  
 APR 2 1961

P37 - RETURN TO EARTH  
 (GAMDV10)  
 COLUSSUS 2D  
 FC-2642  
 26 53

TIME RADIUS CALLING SUBROUTINE

INPUT:

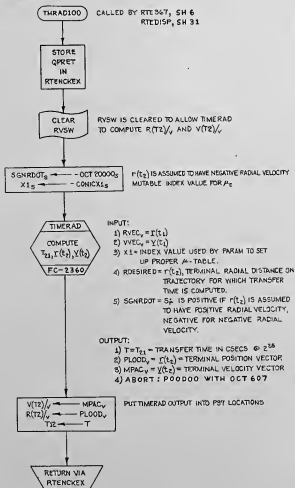
RVEC INITIAL POSITION VECTOR  
 VVEC INITIAL VELOCITY VECTOR  
 RDESIRD FINAL RADIIUS FOR WHICH TRANSFER  
 TIME IS TO BE COMPUTED

VECT. @  $2^{29}$  MTRS  
 VECE @  $2^7$  MTRS/CSEC  
 DR @  $2^{28}$  METERS

OUTPUT:

$R(t_2)/\sqrt{}$  FINAL POSITION VECTOR  
 $V(t_2)/\sqrt{}$  FINAL VELOCITY VECTOR  
 TIZ TRANSFER TIME TO FINAL RADIIUS  
 ABORT EXIT FOR NO SOLUTION :  
 P00000, WITH OCT 607

VECT. @  $2^{29}$  METERS  
 VECT. @  $2^7$  MTRS/CSEC  
 DR @  $2^{28}$  CSEC



P37 - RETURN TO EARTH  
(THRAD100)

A. C. WILLIAMS

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312603

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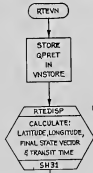
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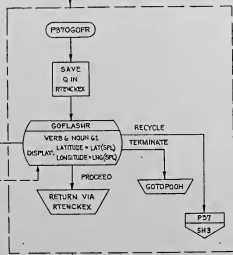
01-05505 2D

FC-2642

CALLED BY: P37E  
P37G



RTEDISP CALLS: THRADD00, A08XKUGL and LAT-LONGS  
 INPUT:  $V(T2)_0 = V(T2)$  FINAL VELOCITY VECTOR IN METERS/CSEC @ 2<sup>7</sup>  
 $R(T2)_0 = R(T2)$  FINAL POSITION VECTOR IN METERS @ 2<sup>29</sup>  
 $V(T1)_0 = V(T1)$  POST-IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2<sup>7</sup>  
 $V(T1)_1 = V(T1)$  PRE-IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2<sup>7</sup>  
 $UR(T1)_0 = U(T1)$  UNIT INITIAL POSITION VECTOR @ 2<sup>7</sup>  
 $UH(T1)_0 = U(T1)$  UNIT HORIZONTAL VECTOR AT T1 @ 2<sup>7</sup>  
 SPRTTIG = KEYS-IN-TIG IN CSEC @ 2<sup>28</sup>  
 TT = FINAL TIME IN CSEC @ 2<sup>28</sup>  
 OUTPUT: LATSPL = LATITUDE AT T2 IN REVS @ 2<sup>9</sup>  
 LINGSPL = LONGITUDE AT T2 IN REVS @ 2<sup>9</sup>  
 VPRED = MAGNITUDE OF VELOCITY AT 400,000 FT IN METERS/CSEC @ 2<sup>7</sup>  
 GAMMAE1 = FLIGHT PATH ANGLE @ 400,000 FT IN REVS AND ABOVE HORIZON @ 2<sup>9</sup>  
 T310T4 = TRANSIT TIME TO 400,000 FT, IN CSEC @ 2<sup>28</sup>  
 DELV10 = INITIAL VELOCITY CHANGE VECTOR IN LOCAL VERTICAL COORDINATES IN METERS/CSEC @ 2<sup>7</sup>



DISPLAY  
 R1: LATITUDE DEC XXX.XX DEG  
 R2: LONGITUDE DEC XXX.XX DEG  
 R3: BLANKED OUT



NEXT SHEET

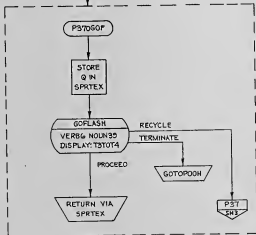
INSTRUMENTATION LAB  
 WASH DC, MASA  
 REPLY: A.C. WILLIAMS  
 9 AUG 62  
 11 APR 62  
 11 APR 62

P37-RETURN TO EARTH

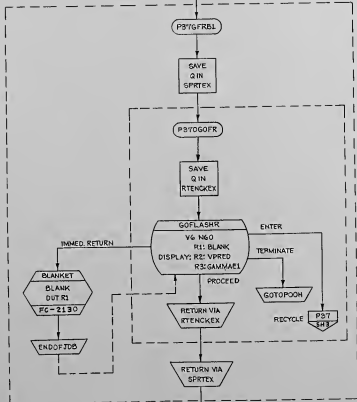
OK 0650P 2D FC-2642

FC-2642

FROM PRECEDING SHEET



DISPLAY:T3TOT4  
TRANSFER TIME  
TO 400,000 FT.  
R1: HRS: )  
O0XX  
R2: MIN: )  
O0XX  
R3: SEC: )  
OXXXX  
DECIMAL



NOTE: P37GFRB1  
INTERLOCKS WITH  
P37G06R IN THIS  
MANNER:  
IMMEDIATE RETURN  
FROM GOFLASHR IN  
P37G06R TO  
BLANKET WHICH IS  
CONTAINED IN  
P37GFRB1. ENDF-  
JOB RETURNS DIS-  
PLAY FOR  
ASTRONAUT RES-  
PONSE.

R1: BLANK  
R2: VPRE0 DEC XXXXX  
IN FT/SEC =  
VELOCITY MAG-  
NITUDE AT  
400,000 FT.  
R3: GAMMAE1  
DEC XXXXX IN  
DEGREES \* FLIGHT  
PATH ANGLE AT  
400,000 FT

NEXT SHEET

ACWILLIAMS  
230605  
210057  
209M17  
14/13  
9 April 67

P37 - RETURN TO EARTH  
(RTEVN)

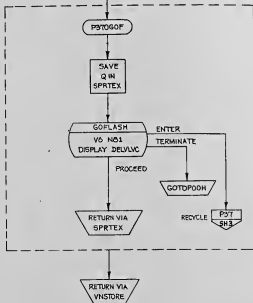
COLOSSUS 2D

FC-2642

2

29 53

FROM PRECEDING SHEET



DELTA V(LV) =  
DELV/LVC = DEC XXXX.X  
FT/SEC EACH COM-  
PONENT

MIT	
INSTRUMENTATION 14	
CAMP BRIDGE, MASS.	
FORM NO. A.C. WILLIAMS	24 JUN 62
REV. 100	9 11 62
ANAL. <i>John A. Williams</i>	9 11 62
DESIGN. <i>John A. Williams</i>	9 11 62
DATE. <i>John A. Williams</i>	9 11 62

PST - RETURN TO EARTH  
(RTEVN)

COLOSSUS 2D

FC-2642

30 53

RTDISP

STORE  
GPRET  
IN  
SPRTEX

$\Delta V_{LV} = (\Delta V \cdot U_{H_1}, 0, -\Delta V \cdot U_{V_1})$   
 $V_{PRED} \leftarrow |V(T_2)|_V$   
 $T_3TOT4 \leftarrow T_2 - SPRTETIG$   
 $GAMMAE1 \leftarrow \text{JRTERR} - \text{ACOS} [2 \text{UNIT}(R(T_2)_V) \cdot \text{UNIT}(V(T_2)_V)]$   
 $DELVLVC_V \leftarrow 2(U_{H_1} \cdot (V(T_2)_V - V(T_1)_V), 0, -U_{V_1} \cdot (V(T_2)_V - V(T_1)_V))$

VPRED = VELOCITY MAGNITUDE AT  
 400,000' IN M/CSEC @ 2<sup>17</sup>  
 T3TOT4 = TRANSFER TIME TO TIG  
 IN CSEC @ 2<sup>20</sup>  
 GAMMAE1: FPR AT 400,000 FT  
 REUS + HORZDM  
 DELVLVC: CHANGE IN VELOCITY VECTOR  
 Y=0 TO PREVENT OUT-OF-  
 PLANE MANEUVERS.

IS CURRENT ORBIT  
POSIGRADE ?  
YES: CLEAR  
NO: SET

DELVLVC<sub>K</sub> ← -DELVLVC<sub>K</sub>

MAKE DISPLAY OF DELVLVC CONSISTENT  
WITH STANDARD DEFINITION OF LOCAL  
VERTICAL

RTDIS

$|\Delta V|_V$   
 VGDISP ← DELVLVC<sub>V</sub>

IMPULSIVE ΔV

$RVEC_V \leftarrow R(T_2)_V$   
 $RDESIRED \leftarrow |R(T_2)_V| - 30480RTE$   
 $VVEC_V \leftarrow V(T_2)_V$

INPUT TO TMRAD100. 30480RTE = DEC30480 @ 2<sup>15</sup>

TMRAD100  
 COMPUTE STATE VECTOR  
 TRANSFER TIME FOR A  
 PARTICULAR RADIUS  
 SM 27

INPUT: RVEC: INITIAL POSITION VECTOR @ 2<sup>15</sup> METERS  
 VVEC: INITIAL VELOCITY VECTOR @ 2<sup>9</sup> M/CSEC  
 RDESIRED: FINAL RADIUS FOR WHICH TRANSFER  
 TIME IS TO BE COMPUTED.  
 OUTPUT: R(T<sub>2</sub>)<sub>V</sub>: FINAL POSITION VECTOR @ 2<sup>15</sup> METERS  
 V(T<sub>2</sub>)<sub>V</sub>: FINAL VELOCITY VECTOR @ 2<sup>9</sup> M/CSEC  
 T<sup>12</sup>: TRANSFER TIME TO FINAL RAD @ 2<sup>10</sup> CSEC

$FLOOD \leftarrow |V(T_2)|_V$   
 $FLOCD \leftarrow \text{ARCSIN} [\text{UNIT}(R(T_2)_V) \cdot \text{UNIT}(V(T_2)_V) \times 2]$

INPUT FOR AUGEKU8L

AUGEKU8L  
 COMPUTE  
 $\beta_e$   
 $T_e$   
 FC-2320 SHLS

INPUT:  $|V(T_2)|_V$   
 $|\text{ARCSIN}[\text{UNIT}(R(T_2)_V) \cdot \text{UNIT}(V(T_2)_V) \times 2]|$   
 OUTPUT: PHIE: RANGE TO TARGET = PL330  
 TE: TIME TO SPLASH = PL240  
 = MPAC 2<sup>18</sup>

NEXT SHEET

A. WILLIAMS  
 J. J. ...  
 ...  
 ...

P37 - RETURN TO EARTH  
 (RTDISP)

COLOSSUS 2D FC-2642

FROM PRECEDING SHEET

$$T_{LS} = t_0 + t_{22} + t_2$$

$$P_{LO2D} \leftarrow MPAC + T_{12} + T_2 \quad \text{TIME TO SPLASH-DOWN}$$

CHANGE IN RANGE ?

YES  $\neq 0$

NO  $= 0$

$P_{LO4D} \leftarrow P_{37RANGE}$  USE P37 RANGE FOR DISPLAY

RTD22

$$S_{\phi E} \leftarrow \sin(\phi_E)$$

$$C_{\phi E} \leftarrow \cos(\phi_E)$$

$$LNG(SPL) \leftarrow \sin(P_{LO4D})$$

$$LAT(SPL) \leftarrow \cos(P_{LO4D})$$

$$U_{12} = \text{UNIT} \left( (R(t_2) + Y(t_2)) \times R(t_2) \right)$$

$$U_{13} = U_{12} C_{\phi E} + U_{11} S_{\phi E}$$

$$P_{LO4D} \leftarrow \text{UNIT} \left( \text{UNIT}(R(t_2)) \times \text{UNIT}(V(t_2)) \times \text{UNIT}(R(t_2)) \times LNG(SPL) \right)$$

$$ALPHA_V \leftarrow P_{LO4D} + LAT(SPL) \times \text{UNIT}(R(t_2))$$

$$MPAC \leftarrow P_{LO2D}$$

$$T_{LS} = t_2 + t_{22} + t_0$$

$$S_{\phi E} = \sin(\phi_E)$$

$$C_{\phi E} = \cos(\phi_E)$$

$$U_{12} = \text{UNIT} \left( (R(t_2) + Y(t_2)) \times R(t_2) \right)$$

$$U_{13} = U_{12} C_{\phi E} + U_{11} S_{\phi E}$$

$$P_{LO2D} \leftarrow MPAC + T_{12} + T_2$$

$$LNG(SPL) \leftarrow \sin(P_{LO4D})$$

$$LAT(SPL) \leftarrow \cos(P_{LO4D})$$

$$P_{LO4D} \leftarrow \text{UNIT} \left( \text{UNIT}(R(t_2)) \times \text{UNIT}(V(t_2)) \times \text{UNIT}(R(t_2)) \times LNG(SPL) \right)$$

$$ALPHA_V \leftarrow P_{LO4D} + LAT(SPL) \times \text{UNIT}(R(t_2))$$

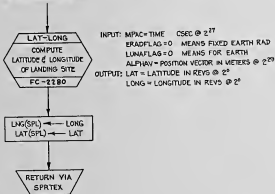
$$MPAC \leftarrow T_2 + T_{12} + T_2$$

CLEAR ERADFLAG LAT-LONG USES FIXED RADIUS

CLEAR LUNAFLAG LAT-LONG COMPUTES FOR EARTH

NEXT SHEET

FROM PRECEDING SHEET



811  
AERONAUTICAL  
LABORATORY, WPAFB, OHIO

FC-2280  
A.C. WILLIAMS  
S. J. BARNES  
J. A. BARNES

STANING  
SANCOS  
NADROS  
7 APR 68  
2 APR 68

P37-RETURN TO EARTH  
(RTEDISP)

COLOSAL 2D FC-2642

2 53 53



PREC100 CALLED BY MAINLINE FLOW AT RTE1515

STORE  
QPRET  
IN  
SPKRTX<sub>5</sub>

$\gamma_1 = 10$   
 $R_0 = RCON$   
 $f_1 = 1$   
NN1A ← QRTTE  
RD ← RCON

IN THIS PROGRAM, NN1A  
POSITIVE IS EQUIVALENT  
TO  $f_1$  SET.  $f_1$  SET MEANS  
THIS IS THE PRECISION  
PHASE.  
 $R_{CON}$  COMPUTED BY CONIC  
PHASE IS NOW HELD  
CONSTANT.

PREC120

ITERATION ENTRY  
FOR NEW  $V_2 (T_1)_{\gamma}$

$\Delta t_{12} = POSMAX$   
 $N_2 = 0$   
DT2:PR ← 2KTEB1  
NNZ ← MISKTE

NNZ IS INCREMENTED TOWARD 0.

RTECK3  
CALL INSTALL  
CLEAR INTYPFLG  
CLEAR MOONFLAG  
CALL INTEGRVS  
COMPUTE  $R(T_2)_{\gamma}$   
 $V(T_2)_{\gamma}$ ,  $T_2$ ,  $X_1$   
SH43

RTECK3 THIS ROUTINE TAKES THE VECTORS  $V_2(T_1)_{\gamma}$  PRODUCED  
BY VET100 AND  $R(T_1)_{\gamma}$  AND PRECISION INTEGRATES TO  $T_2$   
RTECK3 ENTERS THE INTEGRATION ROUTINE WITH  
INTYPFLG AND MOONFLAG CLEARED, FIRST CALLING  
INSTALL TO ENSURE THAT THE INTEGRATION ROUTINE  
IS NOT BEING USED. IT LOADS P37 VARIABLES INTO  
INPUT LOCATIONS USED BY THE INTEGRATION ROUTINE  
AND LOADS THE OUTPUT OF THE INTEGRATION ROUTINE  
INTO LOCATIONS USED BY P37

INPUT: 1  $R(T_1)_{\gamma}$  = INITIAL POSITION VECTOR IN METERS @  $2^{25}$   
2  $V_2(T_1)_{\gamma}$  = POST IMPULSE VELOCITY VECTOR  
IN METERS/CSEC @  $2^7$

3  $T_1$  = INITIAL TIME IN CSEC @  $2^{25}$

4  $T_2$  = FINAL TIME IN CSEC @  $2^{25}$

OUTPUT: 1  $R(T_2)_{\gamma}$  = FINAL POSITION VECTOR IN METERS @  $2^{25}$

2  $V(T_2)_{\gamma}$  = FINAL VELOCITY VECTOR IN METERS/CSEC @  $2^7$

MPAC =  $V(T_2)_{\gamma}$

3  $T_2$  = FINAL TIME IN CSEC @  $2^{25}$

4  $X_1 = CONICK1 = \mu$  - TABLE INDEX FOR EARTH.

5  $PLODD = R(T_2)_{\gamma}$

PREC125

SUB-ITERATION LOOP  
ENTRY (FOR "TIME-GAMMA" ITERATION  
ROUTINE)

NEXT SHEET

W11  
PRESENTATION LAB  
CAMBRIDGE, MASS.

253MCS  
28005

174W A.C. WILLIAMS  
DRAWN  
ANN: J. R. Boyd  
D 1100  
4700

2/20/65  
2/20/65  
2/20/65

P37 - RETURN TO EARTH  
(PREC100)

CLOSSUS 2D FC-2642

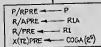
24 7 53

FROM PRECEDING SHEET

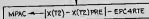


PARAM: COMPUTES CONIC PARAMETERS FOR THE ORBIT DETERMINED BY  $R(TZ)_{\text{PRE}}$ ,  $V(TZ)_{\text{PRE}}$  AT TZ (IT CALLS GEOM)

- INPUT: 1.  $P_{\text{LOOD}} = R(TZ)_{\text{PRE}}$   
 2.  $MPAC = V(TZ)_{\text{PRE}}$   
 3.  $X1 = -CONICX1 = -2$  FOR EARTH
- OUTPUT: 1.  $RLA = \phi_{\text{RA}}$ , RATIO OF  $|R(TZ)_{\text{PRE}}|$  TO SEMI-MAJOR AXIS @  $2^{\text{D}}$   
 2.  $P = P_{\text{RA}}$ , RATIO OF SEMI-LATUS RECTUM TO  $|R(TZ)_{\text{PRE}}|$  @  $2^{\text{D}}$   
 3.  $COGA = \cot \gamma$ , THE COTAN OF THE FLIGHT PATH ANGLE, MEASURED FROM THE VERTICAL @  $2^{\text{D}}$   
 4.  $R1 = \text{MAGNITUDE OF } R(TZ)_{\text{PRE}}$  IN METERS @  $2^{\text{D}}$



OUTPUTS OF PARAM ARE PUT INTO P37 LOCATIONS.



CALCULATION OF COGA MAY CAUSE OVERFLOW.



DOES  $X(TZ)_{\text{PRE}}$  COME WITHIN .00050° OF  $X(TZ)$ ? (FIGURE .00050° ROUNDED ON PAGE 5.9-9 OF R-577, SECTION 5 OF COLOSSUS 650P)  
 $X(TZ)$  IS TAKEN AS FIXED AFTER THE CONIC SECTION OF P37. THE RADIUS CAN VARY IN THE SEARCH FOR A PRECISION ORBIT AND TRANSFER TIME THAT ACHIEVE  $X(TZ)$ .



$\gamma_2 > 16^\circ$

EXCESSIVE ITERATIONS



ENTRANCE FROM PREC 175



ALARM: TOO MANY ITERATIONS



THE CODING FROM HERE TO THE LOOP BRANCH AFTER P37-174 MAY BE CONSIDERED A "TIME-GAMMA" SUBROUTINE.



$NN1A = \gamma_1$

IS THIS THE ELEVENTH ITERATION?

YES LAST CHANCE

ELEVENTH ITERATION

NOT ELEVENTH ITERATION

TO SHEET 36

NEXT SHEET

P37 - RETURN TO EARTH (PREC100)

A.C. WILLIAMS  
 J. B. Bingham  
 J. B. Bingham  
 J. B. Bingham

COLOSSUS 2D FC-2642

FROM PRECEDING SHEET

FROM SHEET 35

$$A_1 = \beta_1 P/R, \beta_2 = 1 - \beta_1 R/A$$

$$MPAC \leftarrow 1/RT(B_4 - \text{BETA1} \cdot R/APRC \cdot P/RPRE \cdot Z^2)$$

IS  $\beta_1 < 0$  ?  
 YES  
 NO  
 IS MPAC < 0 ?

PREC155

IF  $A_1$  IS LESS THAN ZERO, THEN  
 $X(T)$  WILL ONLY BE ACHIEVED  
 AT THE MAXIMUM FPA, IF AT ALL.

PREC160

$$\beta_4 = \frac{\beta_1}{Z^2 - \beta_1 \sqrt{A_1}}$$

$$MPAC \leftarrow \frac{\text{BETA1} \cdot P/RPRE}{\text{NORM}_{11}(1/RT(B_3 - 2P/11Z) \cdot MPAC)}$$

$$\beta_4 = 1/R/A$$

$$MPAC \leftarrow \frac{Z^{-4-11} \cdot 1/RT(B_1)}{\text{NORM}_{11}(R/APRC)}$$

PREC162

$$A_4 = \frac{R_0}{R_{PRE}}$$

$$RD \leftarrow \frac{R_{PRE}}{RD}$$

$$MPAC \leftarrow \frac{Z^{-1-11}}{\text{NORM}_{11}(R/PRE)}$$

SET  $R_{FINAL} = R_0$

PREC165

SET PUSH  
 LIST POINT-  
 ER TO ZERO

$$A_{12} = \beta_4 - 1$$

$$\text{PLOOD} \leftarrow MPAC$$

$$\text{BETA12} \leftarrow -(\text{PLOOD} - 1/RT(B_1))$$

STORE  $\beta_4$

THESE TWO TESTS PROVIDE FORTIMERAD TO COMPUTE A RETROGRADE  
 ORBIT IF THE LAST TIME INTEGRATION TOOK US PAST THE DESIRED  
 ANGLE OF REENTRY. THAT IS, TIMERAD IS PREVENTED FROM INTEGRA-  
 TING THROUGH ANOTHER REVOLUTION.

IS  $\text{BETA12} < 0$  ?  
 YES  
 NO

SIGN (BETA12) IS LOGICALLY EQUIVALENT  
 TO  $\beta_4$ , IN GSO'S COLOSSUS R-S7T PAGE S-4-45.  
 BEFORE PERIGEE ?

IS  $X(T)_{PRE} < 0$  ?  
 YES  
 NO - AFTER PERIGEE

$$\text{BETA12} \leftarrow -\text{BETA12}$$

NEXT SHEET

132400  
 21818  
 24217  
 24219  
 24219  
 24219

132400  
 21818  
 24217  
 24219  
 24219

132400  
 21818  
 24217  
 24219  
 24219

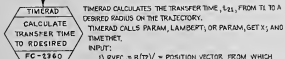
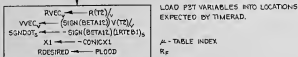
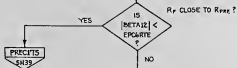
P37- RETURN TO EARTH  
 (PREC100)

COLLOSSUS 2D

FC-2642

53

FROM PRECEDING SHEET

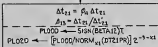


- INPUT:
- 1)  $RVEC = R(TC)/r_0$  = POSITION VECTOR FROM WHICH TRANSFER TIME TO THE RADIUS DESIRED WILL BE CALCULATED. IN METERS @  $2^{15}$
  - 2)  $VVEC = V(TC)/r_0$  = VELOCITY VECTOR CORRESPONDING TO  $R(TC)$ . IN METERS/SEC @  $2^7$
  - 3)  $X1 = -CONGX1$  FOR PROPER  $\mu$ -TABLE REFERENCE.
  - 4)  $RDESIED$  = RADIUS OF POINT ON THE TRAJECTORY IN METERS @  $2^{20}$
  - 5)  $SGNDOT = -OCT2000$ , IMPLIES THAT  $RDESIED$  HAS A NEGATIVE RADIAL VELOCITY.
  - 6)  $RVSW$  IS SET SO THAT THE NEW STATE VECTOR WILL NOT BE CALCULATED.

OUTPUT:

$T$  = TRANSFER TIME IN CSEC @  $2^{25}$

ABORT EXIT: P0000: OCT 607

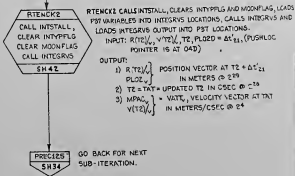
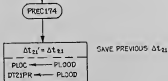
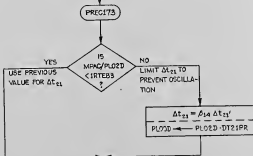
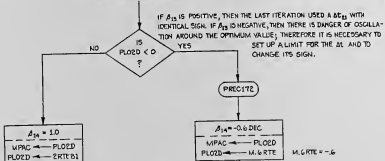


NEXT SHEET

A. WILLIAMS  
 J. B. SPANIEL  
 J. R. BROWN  
 23 JAN 62  
 744052  
 3/11/63  
 7/1/69

P37- RETURN TO EARTH  
 (PREC100)  
 COLLOSSUS 2D  
 FC-2642  
 2 37 53

FROM PRECEDING SHEET



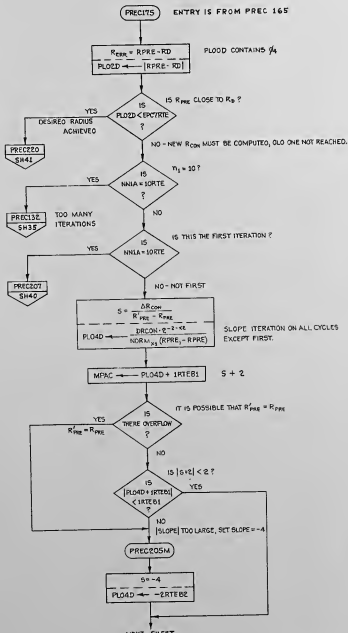
PST - RETURN TO EARTH  
 (PREC100)

302460J  
 704057  
 10 APR 67  
 7 27 45  
 9 APR 67

COLOSSUS 2D FC-2642

2

35 53



W11

303445  
 94207  
 94208  
 94209  
 94210

WILLIAMS  
 A.C. Williams  
 J. Brown  
 J. Brown  
 J. Brown

COL05555 2D  
 FC-2642

2  
 39 53

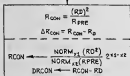
P87 - RETURN TO EARTH (PREC100)

FROM PRECEDING SHEET

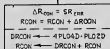
PREC206

PREC207

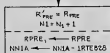
ENTRY FROM  
PREC 175



CRUDE ESTIMATE  
OF  $R_{CON}$  AND  
 $\Delta R_{CON}$  FOR FIRST  
THRU.



PREC210



STORE LAST RPRE FOR COMPARISON  
DECREMENT COUNTER  $n_1$



VT100 CALLS GAMDV10  
XTILIM  
DYCALC

INPUT: 1)  $R(T)_1$  = MAGNITUDE OF INITIAL POSITION VECTOR  
IN METERS @  $2^{50}$

2)  $R_{CON}$  = MAGNITUDE OF FINAL POSITION VECTOR  
IN METERS @  $2^{50}$

3)  $V(T)_1$  = INITIAL VELOCITY VECTOR IN METERS/SEC @  $2^7$

4)  $RTE1VD$  =  $\Delta$  VELOCITY DESIRED IN METERS/SEC @  $2^7$

5)  $UR1_1$  = UNIT INITIAL POSITION VECTOR @  $2^1$

6)  $UH_1$  = UNIT HORIZONTAL VECTOR @  $2^1$

7)  $X(T)_1$  = COTANGENT OF FINAL FLIGHT PATH ANGLE @  $2^0$

8)  $X(T)_1$  = COTANGENT OF INITIAL FLIGHT PATH ANGLE @  $2^0$

9)  $CPFA$  = COSINE OF INITIAL FLIGHT PATH ANGLE @  $2^1$

10)  $MAY(V1)$  TEMPORARY [LOWER] BOUND ON GAMDV

11)  $MAY(V1)$  TEMPORARY [UPPER] ITERATOR IN METERS @  $2^{10}$

12)  $PH12$  = PERDEG-ADDEG INDICATOR: -1 = PERDEG  
+1 = ADDEG

13)  $NN1A$  = PRECISION ITERATION COUNTER

( $NN1A > 0$  IMPLIES THIS IS PRECISION PHASE)

OUTPUT: 1)  $VE(T)_1$  = POST-IMPULSE VELOCITY VECTORS  
IN METERS/SEC @  $2^7$

2)  $DV_1$  = INITIAL DELTV IN METERS/SEC @  $2^0$

3)  $X(T)_1$  = COTAN OF INITIAL FPA (POST-IMPULSE) @  $2^0$

4)  $PC(1)$  = SLEW-LATUS RECTUM IN METERS @  $2^{10}$

5)  $BETAL = 1 + X(T)_1^2$  @  $2^1$

6)  $MPAC = 0$  NORMAL EXIT MODE

$MPAC \neq 0$ , ALARM CODE OCTGOS

EXCESSIVE ITERATIONS IN GAMDV10

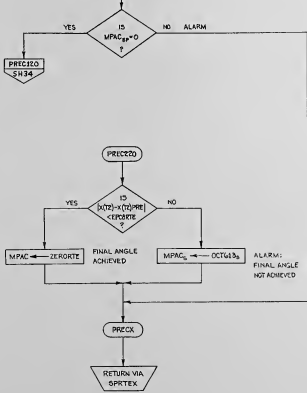
NEXT SHEET

MIT  
INSTR DIVISION  
CAMBRIDGE, MASS.  
SPENCER A. WILLIAMS  
PROB  
DATE: 10/1/61  
BY: J. B. Bond  
10/1/61  
10/1/61  
10/1/61

P37 - RETURN TO EARTH  
(PREC100)

COLOSSUS 2D FC-2642

FROM PRECEDING SHEET



P37-RETURN TO EARTH  
(PREC100)

BY: *[Signature]* DATE: *[Signature]*  
 CHECKED: *[Signature]* DATE: *[Signature]*  
 APPROVED: *[Signature]* DATE: *[Signature]*

2 FC-2642



RTENCK1

CALLED BY P87T

STORE  
QPRET  
IN  
RTENCKEXINSTALL  
STALL THIS JOB  
IF INTEGRATION  
IS BEING USED  
FC-2290 $r(t_1)$   
MPAC ←  $R(t_1)$ SET  
INTYPFLGDO CONIC INTEGRATION TO DEFINE  
PSEUDO TARGET FOR LAMBERT STEERING.RTENCK30  
SH43

RTENCK2

CALLED BY PREC174

STORE  
Q IN  
RTENCKEXINSTALL  
STALL THIS PROGRAM  
IF INTEGRATION  
IS BEING USED  
FC-2290CLEAR  
INTYPFLG

DO PRECISION INTEGRATION.

REV ←  $R(t_2)$   
VCV ←  $V(t_2)$   
TET ←  $T_2$   
MPAC ←  $T_2 + PLOC$ PUT P87 VARIABLES INTO LOCATIONS EXPECTED  
BY INTEGRVSMPAC =  $T_2$  + LAST QUANTITY IN PUSHLIST.  
(ADVANCES  $T_2$  BY  $\Delta t_{21}$ )RATHER THAN EXTRAPOLATE A NEW FINAL STATE VECTOR  
FROM  $R(t_1)$  AND  $V(t_1)$ , TIME IS SAVED BY EXTRAPOLATING  
THE NEW FINAL STATE VECTOR FROM THE OLD, USING ONLY A  
SMALL CHANGE IN  $T_2$ . I.E. STATE VECTOR AT  $T_2 + \Delta T_{21}$   
IS EXTRAPOLATED FROM STATE VECTOR AT  $T_2$ .RTENCK3D  
SH43

INSTRUMENTATION LAB	SP7860
100-13111 MASS.	740607
STAFF A.C. WILLIAMS	104781
TECHNICAL	740614
ANALYST <i>G. R. Brown</i>	740614
CHIEF OF OPS <i>G. R. Brown</i>	740614
APPROV. <i>G. R. Brown</i>	740614
	9 April 69

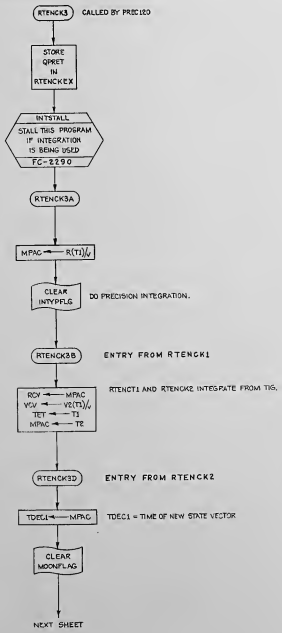
P87 - RETURN TO EARTH  
(RTENCK)

COLOSSUS 2D

FC-2642

42

53



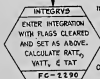
MIT  
 DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS  
 CAMBRIDGE MASS  
 JOHN A. WILLIAMS  
 1-60-11  
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P37- RETURN TO EARTH  
 (RTENCK)

COLOSSUS 2D

FC-2642

FROM PRECEDING SHEET



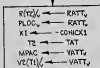
INTEGRVS

INPUT:

R0V<sub>0</sub>: POSITION VECTOR AT TET @ 2<sup>19</sup>  
V0V<sub>0</sub>: VELOCITY VECTOR AT TET @ 2<sup>7</sup>  
TET: TIME TO BE INTEGRATED FROM  
TDECI: TIME OF NEW STATE VECTOR @ 2<sup>10</sup>

OUTPUT:

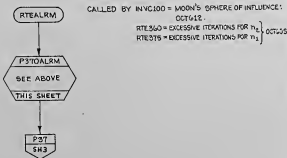
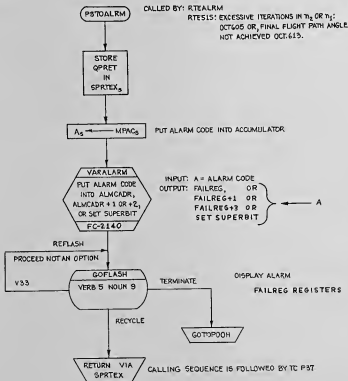
RATT<sub>1</sub>: POSITION VECTOR AT TDECI  
IN METERS @ 2<sup>19</sup>  
VATT<sub>1</sub>: VELOCITY VECTOR AT TDECI  
IN METERS/SEC @ 2<sup>7</sup>  
TAT: TDECI IN SEC @ 2<sup>10</sup>



-CONICK1 = J TABLE INDEX VALUE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		P37-RETURN TO EARTH (RTENCK)	
DR. A. C. WILLIAMS	SPENCER	COLOSSUS 2D	FC-2642
DR. J. P. BRAND	WAGNER		
DR. G. R. ...	...		
DR. ...	...		
APR 11 1968		2	44 53



A.C. WILLIAMS      3 FEB 68  
 J. Board      51 MAR 67  
 J. Board      20 APR 67  
 J. Board      2 APR 67  
 J. Board      2 APR 67

P37 - RETURN TO EARTH  
 (P370ALARM)

COLOSSUS 2D      FC-2642

2      45      53

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
ALPHA <sub>V</sub>	$\Gamma(t_2)$	INPUT TO GETERAD (UNIT $(RT2)_V$ )			
BETA <sub>1D</sub>	$\beta_1$	$1 + x(t_2)^2$			2 <sup>1</sup>
BETA <sub>2D</sub>	$\phi_4$	SIGN INDICATOR FOR TIMERAD			
CFPA <sub>D</sub>	$C_{FPA}$	COSINE OF PRE-RETURN FPA			2 <sup>1</sup>
COGA <sub>D</sub>	$x(t_2)_{PRE}$	OUTPUT OF PARAM. COT OF PRECISION ORBIT AT T2			2 <sup>5</sup>
CSTH <sub>D</sub>		INPUT TO TIMETHET COS OF 165° OR 210°			2 <sup>2</sup>
CONICK <sub>1S</sub>		CONIC <sub>A</sub> - TABLE INDEX			
DELVSIN <sub>D</sub>	$\sqrt{2}(t_1)$	$\sqrt{2}(t_1) - \sqrt{2}(t_1)$ INPUT TO VN2645	FT/SEC	M/CSEC	2 <sup>7</sup>
DRCON <sub>D</sub>	$\Delta R_{CON}$	RCON SLOPE ITERATOR	METERS	METERS	2 <sup>29</sup>
DT2IPR <sub>D</sub>	$\Delta t'_{21}$	PREVIOUS $\Delta t_{21}$	SECONDS	CSEC	2 <sup>28</sup>
DV <sub>D</sub>	$\Delta V$	TEMP ABSOLUTE VALUE OF $\Delta$ VELOCITY AT TIG	FT/SECOND	M/CSEC	2 <sup>7</sup>
ECSTER <sub>S</sub>		STEERING CONSTANT FOR LAMBERT STEERING	EQUALS 1 @ 2 <sup>1</sup>		2 <sup>2</sup>
ERADM <sub>D</sub>		RADIUS OF FISCHER ELLIPSOID FOR T2	METERS	METERS	2 <sup>29</sup>
GAMMAE <sub>1D</sub>		DISPLAY LOCATION FOR NOUN 60 - FINAL FPA	DEGREES	REVS	2 <sup>0</sup>
MAMA <sub>x1D</sub>	$MA_1$	MAJOR AXIS CLOSE TO PARABOLIC TRAJECTORY USED TO COMPUTE LOWER BOUND ON $x(t_1)$ , COT OF POST IMPULSE FPA	METERS	METERS	2 <sup>30</sup>
MAMA <sub>x2D</sub>	$MA_2$	MAXIMUM MAJOR AXIS USED FOR COMPUTING UPPER BOUND ON $x(t_1)$	METERS	METERS	2 <sup>30</sup>
NNIA <sub>D</sub>	$n_1$	COUNTER #1 FOR ITERATION			
SIGN(NNIA)	$f_1$	POSITIVE = PRECISION PHASE NEGATIVE = CONIC PHASE			
NN <sub>2D</sub>	$n_2$	COUNTER #2 FOR ITERATION			
P/RPRE <sub>D</sub>	$P/R_{PRE}$	RATIO OF SEMI-LATUS RECTUM TO $ (RT2)_V $			2 <sup>4</sup>
PCON <sub>D</sub>	$P_{CON}$	TEMPORARY SEMI-LATUS RECTUM	METERS	METERS	2 <sup>29</sup>
PHIE <sub>D</sub>	$\phi_E$	RANGE FROM 400,000 FT ENTRY ALTITUDE TO SPLASHDOWN	NAUTICAL MILES	METERS	2 <sup>29</sup>
PHI <sub>2D</sub>	$\phi_2$	PERIGEE-APOGEE INDICATOR: +1=APOGEE -1=PERIGEE			
*EMDOT	M	MASS DECREMENTATION FACTOR FOR CSM	LB/SEC	KG/CSEC	2 <sup>3</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		A9E11 C-7 RANGE AND VELOCITY	
DRAWN <i>A. J. [Signature]</i>		P37 RETURN TO EARTH	
PROG#	72006	DOC# (REV) (M)	
ANALYST	<i>A. J. [Signature]</i>	COLOSSUS 2D	FC-2642
DOC#	72006	SHEET 46 OF 53	
APPROV	<i>A. J. [Signature]</i>	REV 2	

## ERASABLE LOCATIONS USED (CONTINUED)

P37 RANGE		RANGE FROM 300 K FT TO SPLASH IF $\neq 0$ . IF = 0, USE AUGCKUGL COMPUTATION.	NAUTICAL MILES	REVS	$2^0$
P(T1) <sub>D</sub>	P(t <sub>1</sub> )	PRIMARY BODY AT TIG 1 - MOON 0 - EARTH			
R/APRE <sub>D</sub>	$\alpha R_{PRE}$	RATIO OF  R(T2)/V  TO SEMI-MAJOR AXIS			$2^6$
RATT <sub>V</sub>		RADIUS VECTOR OUTPUT OF INTEGRATION ROUTINES	METERS	METERS	$2^{20}$
RCON <sub>D</sub>	R <sub>VCON</sub>	TEMP FINAL RADIUS OF CONIC TRAJECTORY	METERS	METERS	$2^{20}$
RCV <sub>V</sub>		RADIUS VECTOR INPUT TO INTEGRVS	METERS	METERS	$2^{20}$
RD <sub>D</sub>	R <sub>D</sub>	FINAL RADIUS DESIRED	METERS	METERS	$2^{20}$
RDESIRED <sub>D</sub>	R <sub>P</sub>	TEMPORARY FINAL RADIUS	METERS	METERS	$2^{20}$
RPRE <sub>D</sub>	R <sub>PRE</sub>	TEMP FINAL RADIUS OF A PRECISION TRAJECTORY	METERS	METERS	$2^{20}$
RPRE <sub>D</sub>	x(t <sub>2</sub> ) R'PRE	LAST x(t <sub>2</sub> ) COT (FINAL FPA) (FOR CONIC) LAST R'PRE (FOR PRECISION)			$2^0$
RTARG <sub>D</sub>	$\tau(t_2)_D$	INPUT TO VN1645 RADIUS VECTOR AT FINAL TIME	METERS	METERS	$2^{20}$
RTEDVD <sub>D</sub>	$\Delta V_D$	$\Delta$ VELOCITY DESIRED	METERS/SEC	M/CSEC	$2^7$
RTEGAM2 <sub>D</sub>	$\tau(t_2)_D$	FINAL FPA DESIRED	DEGREES	REVS	$2^0$
RTENCKEX <sub>S</sub>		RETURN ADDRESS STORAGE			
RVEC <sub>V</sub>		INPUT TO CONIC SUBROUTINES (RADIUS VECTOR)	METERS	METERS	$2^{20}$
R(T1) <sub>D</sub>	r(t <sub>1</sub> )	RADIUS MAGNITUDE AT TIG	METERS	METERS	$2^{20}$
R(T1) <sub>V</sub>	r(t <sub>1</sub> )	RADIUS VECTOR AT TIG	METERS	METERS	$2^{20}$
R(T2) <sub>V</sub>	r(t <sub>2</sub> )	RADIUS VECTOR AT T <sub>2</sub>	METERS	METERS	$2^{20}$
SGNROOT <sub>S</sub>		INPUT TO TIMERA0 POSITIVE FOR POSITIVE RADICAL VELOCITY NEGATIVE FOR NEGATIVE RADICAL VELOCITY			
SNTH <sub>D</sub>		INPUT TO TIMETHET SINE OF 165° OT 210°			$2^1$
SPRTETIG <sub>D</sub>	T <sub>IG</sub>	TIME OF IGNITION	SECONDS	CSEC	$2^{20}$
SPRTXS <sub>S</sub>		RETURN ADDRESS STORAGE			
TAT <sub>D</sub>		TIME OF OUTPUT VECTORS OF CONIC SUBROUTINES	SECONDS	CSEC	$2^{20}$

P37  
RETURN TO EARTH

*a J. Smith* 12 NOV 68  
*J. P. Vane* 19 NOV 68  
*J. S. Vane* 20 NOV 68  
*J. S. Vane* 21 NOV 68  
*John A. Brown* 21 NOV 68

COLOSSUS 2D

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SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
POLY	2100	DOUBLE PRECISION POLYNOMIAL EVALUATOR	SH. 4, 6, 11
GETERAD	2280	COMPUTE EARTH RADIUS	SH. 7
TIMETHET	2360	COMPUTE TIME AND, IF RVSW IS CLEAR, STATE VECTOR TO A PARTICULAR ANGLE, THETA.	SH. 13
VN1645	2720	COMPUTE AND DISPLAY MIDDLE GIMBAL ANGLE	SH. 14
CSMPREC	2290	EXTRAPOLATE PRECISION STATE VECTOR TO TIME (IN THIS CASE, TIG)	SH. 13
TIMERAD	2360	COMPUTE TIME TO A PARTICULAR RADIUS	SH. 27, 37
AUGEKUGL	2650	COMPUTE RANGE FROM 400,000 FT ENTRY TO SPLASHDOWN	SH. 31
LAT-LONG	2280	GIVEN TIME AND STATE VECTOR AT THAT TIME COMPUTE LATITUDE AT THAT TIME	SH. 33
PARAM	2360	COMPUTE ORBITAL PARAMETERS FOR A GIVEN STATE VECTOR	SH. 35
INTSTALL	2290	STALL P37 IF INTEGRVS IS BEING USED	SH. 42, 43
INTEGRVS	2290	EXTRAPOLATE BY CONIC OR ENCKE METHOD FROM A STATE VECTOR TO A GIVEN TIME	SH. 44
VARALARM	2140	PUT ALARM CODE INTO A FAILREG REGISTER, OR SET SUPERBIT	SH. 45

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
RVSW	DO NOT COMPUTE FINAL STATE VECTOR IN TIME-THETA, TIMERAD	COMPUTE FINAL STATE VECTOR IN TIME-THETA, TIMERAD	SH. 37	SH. 13, 27	
XDELVFLG	EXTERNAL DELTA VG COMPUTATION	LAMBERT (AIM POINT) VG COMPUTATIONS		SH. 14	
NORMSW	UNIT NORMAL INPUT TO LAMBERT	LAMBERT COMPUTES ITS OWN UNIT NORMAL		SH. 14	
FINALFLG	LAST PASS THROUGH RENDEZVOUS PROGRAM COMPUTATIONS	INTERM PASS THROUGH RENDEZVOUS PROGRAM COMPUTATIONS	SH. 14		
F2RTE	IN TIME CRITICAL MODE	IN FUEL CRITICAL MODE	SH. 20	SH. 17	SH. 25
ERADFLAG	COMPUTE USING FISCHER ELLIPSOID	COMPUTE USING FIXED RADIUS		SH. 32	
LUNAFLEG	LUNAR LAT-LONG	EARTH LAT-LONG		SH. 32	
INTYFLEG	CONIC INTEGRATION	ENCKE INTEGRATION	SH. 42	SH. 42, 43	
MOONFLAG	MOON IS SPHERE OF INFLUENCE	EARTH IS SPHERE OF INFLUENCE		SH. 43	
NJETSFLG	2 JET RCS BURN	4 JET RCS BURN			SH. 11
RETROFLG	ORBIT RETROGRADE	ORBIT NOT RETROGRADE	SH. 16	SH. 16	SH. 31
SLOWFLG	COAST SLOWDOWN IS DESIRED	COAST SLOWDOWN IS NOT DESIRED	SH. 4	SH. 4	SH. 30

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10 APR 68

7 APR 68

2 APR 68

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TOEC <sub>1D</sub>		INPUT TO INTEGRVS: TIME TO BE INTEGRATED TO	SECONDS	CSEC	2 <sup>28</sup>
TE <sub>D</sub>	t <sub>c</sub>	TIME FROM ENTRY TO SPLASHDOWN	SECONDS	CSEC	2 <sup>28</sup>
TET <sub>D</sub>		TIME INPUT TO INTEGRVS	SECONDS	CSEC	2 <sup>28</sup>
TPASS <sub>4D</sub>		TIME INPUT TO S40.9	SECONDS	CSEC	2 <sup>28</sup>
TRKMKCNT <sub>S</sub>		TRACKING MARK COUNTER			
T <sub>1D</sub>	t <sub>1</sub>	INITIAL VECTOR TIME (TIG)	SECONDS	CSEC	2 <sup>28</sup>
T <sub>12D</sub>	t <sub>12</sub>	TRANSFER TIME TO FINAL RADIUS	SECONDS	CSEC	2 <sup>28</sup>
T <sub>2D</sub>	t <sub>2</sub>	TIME OF RE-ENTRY	SECONDS	CSEC	2 <sup>28</sup>
UH <sub>V</sub>	u <sub>H</sub>	UNIT HORIZONTAL VECTOR			
UR <sub>1V</sub>	u <sub>R1</sub>	UNIT RADIUS VECTOR AT t <sub>1</sub>			
UV <sub>1V</sub>	u <sub>V1</sub>	UNIT VELOCITY VECTOR AT t <sub>1</sub>			
V(T <sub>1</sub> ) <sub>V</sub>	v <sub>1</sub> (t <sub>1</sub> )	VELOCITY VECTOR AT t <sub>1</sub> (PRE-IMPULSE)	FT/SEC	M/CSEC	2 <sup>7</sup>
V2(T <sub>1</sub> ) <sub>V</sub>	v <sub>2</sub> (t <sub>1</sub> )	VELOCITY VECTOR AT t <sub>1</sub> (POST-IMPULSE)	FT/SEC	M/CSEC	2 <sup>7</sup>
V(T <sub>2</sub> ) <sub>V</sub>	v <sub>2</sub> (t <sub>2</sub> )	VELOCITY VECTOR AT t <sub>2</sub>	FT/SEC	M/CSEC	2 <sup>7</sup>
VHFMCNT <sub>S</sub>		VHFMARK COUNTER			
VNSTORE <sub>S</sub>		RETURN ADDRESS STORAGE			
VPRED <sub>D</sub>		1 EYED IN Δ DESIRED, OR FINAL VELOCITY	FT/SEC	M/CSEC	2 <sup>7</sup>
VVEC <sub>V</sub>		INPUT TO CONIC ROUTINES (V(T <sub>1</sub> ), v <sub>1</sub> )	FT/SEC	M/CSEC	2 <sup>7</sup>
WEIGHT <sub>GD</sub>		MASS OF VEHICLE	POUNDS	KG	2 <sup>16</sup>
X(T <sub>1</sub> ) <sub>D</sub>	x(t <sub>1</sub> )	COTAN INITIAL POST-IMPULSE FPA			2 <sup>5</sup>
X(T <sub>2</sub> ) <sub>D</sub>	x(t <sub>2</sub> )	COTAN (FINAL FPA)			2 <sup>0</sup>
X(T <sub>2</sub> )PRE <sub>D</sub>	x(t <sub>2</sub> )PRE	COTAN OF FINAL FPA OF PRECISION TRAJECTORY			2 <sup>0</sup>

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DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N33	GOFFLASH	R1 00XXX HRS R2 000XX MIN R3 0XX.XX SEC DEC ONLY TIG	SH. 3
V06N60	GOFFLASHR	R1 BLANKED OUT R2 VPRED XXXXX FT/SEC R3 GAMMAEI (FLIGHT PATH ANGLE) DEC ONLY $\Delta V$ DESIRED FINAL FPA DESIRED	SH. 3
V04N06	GOFFLASH	R1 OPTION CODE R2 ASSUMED OPTION R3 NOT USED OCTAL: RCS-SPS OPTION	SH. 10
V06N33	GOFFLASH	R1 00XXX. HRS R2 000XX. MIN R3 0XX.XX SEC DEC ONLY BIASED TIG	SH. 12
V06N61	GOFFLASHR	R1 XXX.XX R2 XXX.XX R3 BLANKED OUT LATITUDE } DEGREES LONGITUDE }	SH. 28
V06N30	GOFFLASH	R1 00XXX. HRS R2 000XX. MIN R3 0XX.XX SEC DECIMAL TRANSFER TIME	SH. 29
V06N60	GOFFLASHR	R1 BLANKED OUT R2 VPRED XXXXX FT/SEC R3 GAMMAEI XXX.XX DEGREES DEC ONLY PREDICTED V PREDICTED FINAL FPA	SH. 29
V06N81	GOFFLASH	R1 XXXX.X FT/SEC R2 XXXX.X FT/SEC R3 XXXX.X FT/SEC $\Delta V$ VECTOR	SH. 30
V05N09	GOFFLASH	R1 OCTAL ALARM CODE FROM MPAC, 00XXX, IN ONE REGISTER R2 R3	SH. 45

PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
RTEDI <sub>D</sub>	D <sub>1</sub>	X <sup>0</sup> COEFFICIENT IN COMPUTATION OF x(t <sub>2</sub> )	.2075330	1.6026937	2 <sup>3</sup>	

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
CSUBT <sub>P</sub>	C <sub>T</sub>	VALUE USED IN CALCULATING BIASED TIG	1/2	.5	2 <sup>0</sup>
C4RTE <sub>D</sub>	MAI	MAXIMUM MAJOR AXIS FOR RTI) V WITH NEGATIVE RADIAL COMPONENT	8. x 10 <sup>8</sup> METERS	8 x 10 <sup>8</sup> METERS	2 <sup>30</sup>
EPCIRTE <sub>D</sub>	$\epsilon_1$	VALUE USED TO TEST WHETHER RADIUS AND VELOCITY VECTORS ARE NEARLY COLINEAR	COS(1.5 <sup>0</sup> )	.99966	2 <sup>1</sup>

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## PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
EPC2RTE <sub>D</sub>	$\epsilon_2$	CRITERION USED TO DETERMINE WHETHER CONIC PORTION HAS CONVERGED TO A SUITABLE REENTRY RADIUS	100 METERS	100 METERS	$2^{24}$
EPC3RTE <sub>D</sub>	$\epsilon_2$	CRITERION USED TO DETERMINE WHETHER CONIC PORTION HAS CONVERGED TO A SUITABLE REENTRY ANGLE (ALTHOUGH THE TEST IS MADE ON THE COTANGENT OF THE ANGLE, IT IS EQUIVALENT TO .056°)	.001	.001	$2^0$
EPC4RTE <sub>D</sub>	$\epsilon_4$	CRITERION USED TO DETERMINE WHETHER PRECISION PORTION OF FINAL STATE VECTOR COMPUTATION HAS REACHED THE DESIRED REENTRY ANGLE (TEST MADE ON COTANGENT EQUIVALENT TO .00059°)	.00001	.00001	$2^0$
EPC6RTE <sub>D</sub>	$\epsilon_6$	CRITERION USED TO DETERMINE WHETHER FINAL STATE VECTOR COMPUTATION HAS ALREADY REACHED THE DESIRED REENTRY ANGLE	.000007	.000007	$2^1$
EPC7RTE <sub>D</sub>	$\epsilon_7$	CRITERION USED TO DETERMINE WHETHER PRECISION SECTION HAS CONVERGED UPON THE REENTRY RADIUS SELECTED IN CONIC PORTION	1000 METERS	1000 METERS	$2^{24}$
EPC8RTE <sub>D</sub>	$\epsilon_8$	CRITERION USED TO MAKE FINAL CHECK ON REENTRY ANGLE REACHED IN PRECISION PORTION (TEST ON COTANGENT, EQUIVALENT TO .116°)	.002	.002	$2^0$
EPC9RTE <sub>D</sub>	$\epsilon_9$	CRITERION USED TO DETERMINE IF GAMDV10 ITERATOR HAS REACHED A MINIMUM	$2^{-20}$	$2^{-20}$	$2^3$
EPC10RTE <sub>D</sub>	$\epsilon_{10}$	CRITERION USED TO DETERMINE WHETHER GAMDV10 ITERATOR HAS REACHED DESIRED $\Delta V$	0.01 M SEC	0.0001 M CNEC	$2^2$
E3RTE <sub>D</sub>	$E_3$	REENTRY ALTITUDE ABOVE FISCHER ELLIPSOID	121420 M	121420 M	$2^{21}$
K1RTE <sub>D</sub>	$K_1$	RADIUS USED TO DETERMINE WHICH ESTIMATE OF REENTRY ANGLE TO BE USED	$7.0 \times 10^8$ M	$7.0 \times 10^8$ M	$2^{21}$
K2RTE <sub>D</sub>	$K_2$	INITIAL ESTIMATE OF REENTRY RADIUS	$6.495 \times 10^8$ M	$64^*5000$ M	$2^{20}$
K3RTE <sub>D</sub>	$K_3$	INITIAL ESTIMATE OF COTANGENT OF REENTRY ANGLE (USED WHEN $ R(T) , V  < K_1$ (EQUIVALENT TO $-3^*29.5$ )	-.06105	-.06105	$2^0$

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PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
KARTE <sub>D</sub>	K <sub>4</sub>	INITIAL ESTIMATE OF COTANGENT OF REENTRY ANGLE USED WHEN $ R(T)/V  > K1$ (EQUIVALENT TO $-5^{\circ}58'$ )	-.10453	-.10453	2 <sup>0</sup>
MCOS7.5 <sub>D</sub>	-COS 7.5°	USED IN DETERMINING GSOP QUANTITY K	-.99144486	-.99144486	2 <sup>0</sup>
MCOS22.5 <sub>D</sub>	-COS 22.5°	CRITERION USED TO DETERMINE WHETHER TARGET FOR LAMBERT STEERING IS TOO CLOSE TO 180°	-.92387953	-.92387953	2 <sup>2</sup>
MDOTH <sub>D</sub>	m(SPS)	MASS DECREMENTATION FACTOR FOR SPS BURN	63.8 LB/SEC	.289391932 KG/CSEC	2 <sup>3</sup>
MDOTRCS <sub>D</sub>	m(RCS)	MASS DECREMENTATION FACTOR FOR RCS BURN	.16375 KG/SEC	.0016375 KG/CSEC	2 <sup>3</sup>
MSIN7.5 <sub>D</sub>	-SIN 7.5°	USED IN DETERMINING GSOP QUANTITY K	-.13052619	-.13052619	2 <sup>0</sup>
RTMURTE <sub>D</sub>	$\sqrt{\mu_E}$	SQUARE ROOT OF EARTH GRAVITATIONAL CONSTANT	19995050.1 M <sup>3/2</sup> /SEC	199650.501 M <sup>3/2</sup> /CSEC	2 <sup>10</sup>
THETA165 <sub>D</sub>	165°	165° - POSITION OF NEW TARGET FOR LAMBERT STEERING	165°	.458333333 REVS	2 <sup>0</sup>
THETA210 <sub>D</sub>	210°	210° - POSITION OF ALTERNATE NEW TARGET FOR LAMBERT STEERING	210°	.583333333 REVS	2 <sup>0</sup>
VCRCSD <sub>D</sub>	V <sub>C</sub> (RCS)	THRUST VELOCITY OF RCS JETS	2706.64 METERS/SEC	27.0664 METERS/CSEC	2 <sup>5</sup>
VCSPSD <sub>D</sub>	V <sub>C</sub> (SPS)	THRUST VELOCITY OF SPS ENGINE	3088.11 METERS/SEC	30.8811 METERS/CSEC	2 <sup>5</sup>
2RTEB1 <sub>D</sub>	POSMAX	INITIAL SETTING OF Δt <sub>21</sub>	377737777 OCT	377737777 OCT	2 <sup>0</sup>
3048ORTE <sub>D</sub>	30480	INPUT TO TIMERAD = $R(T)/V \times 30480$	30480 METERS	30480 METERS	2 <sup>20</sup>

THE FOLLOWING ARE INPUTS TO THE POLY SUBROUTINE, CALLED TO COMPUTE MAMAX2, XRG2', AND  $-\Delta v/v_0$ , IN THE ORDER THEY APPEAR. (ALL VALUES DP; NO AGC TAGS - POLY USES INDEXED ADDRESSING.)

C <sub>0</sub>	} COEFFICIENTS USED TO COMPUTE MA <sub>2</sub>	1.81000434 x 10 <sup>8</sup> M	181000434 M	2 <sup>31</sup>
C <sub>1</sub>		1.50785145	1.50785145	2 <sup>2</sup>
C <sub>2</sub>		-6.49983057 x 10 <sup>-9</sup>	-6.49983057	2 <sup>-27</sup>
C <sub>3</sub>		0.76938928 x 10 <sup>-18</sup>	0.76938928	2 <sup>-56</sup>

INSTRUMENT STATEMENT  
 AIR FORCE RESEARCH AND DEVELOPMENT COMMAND  
 WRIGHT-PATTERSON AIR FORCE BASE  
 OHIO 45433-6157  
 22 NOV 1964  
 210704Z  
 FC-2642  
 2  
 52 53

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
	D <sub>1</sub>	} COEFFICIENTS USED TO COMPUTE $x(T_2)^3$		0	
	D <sub>2</sub>		$-4.8760771 \times 10^{-4}$ S/M	$-4.8760771 \times 10^{-2}$ CSEC/M	2 <sup>-4</sup>
	D <sub>3</sub>		$4.5419476 \times 10^{-8}$ S <sup>2</sup> /M <sup>2</sup>	$4.5419476 \times 10^{-4}$ CSEC <sup>2</sup> /M <sup>2</sup>	2 <sup>11</sup>
	D <sub>4</sub>		$-1.4317675 \times 10^{-12}$ S <sup>3</sup> /M <sup>3</sup>	$-1.4317675 \times 10^{-8}$ CSEC <sup>3</sup> /M <sup>3</sup>	2 <sup>-18</sup>
-	C <sub>0</sub>	} COEFFICIENTS USED TO COMPUTE $(1-e^{-\Delta v/vc})$		$5.88240507 \times 10^{-4}$	2 <sup>3</sup>
-	C <sub>1</sub>			0.979487897	2 <sup>1</sup>
-	C <sub>2</sub>			-0.388281955	2 <sup>-1</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		P 37 RETURN TO EARTH
DRAWN <i>A. J. ...</i>	2 NOV 68	
DESIGN <i>S. H. ...</i>	2 JAN 69	
ANALYSIS <i>S. H. ...</i>	MIT COLLOSSUS 2D	FC-2642
DOCS: <i>S. H. ...</i>	9/10/68	
APPROVED <i>John A. ...</i>	9/10/68	53 53

P38 - P78 STABLE ORBIT RENDEZVOUS

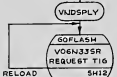
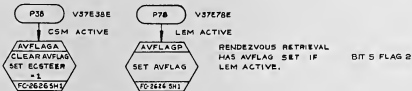
(PHASE 1 SOI STABLE ORBIT INITIATION (SOI)  
AND PHASE 3 STABLE ORBIT RENDEZVOUS (SOR))

P39 - P79 STABLE ORBIT MIDCOURSE (SOM)

EXTERNAL ENTRY POINT: PREC/TT (SH. 11)

MIT RETROPROPULSION LAB CAMBRIDGE, MASS.		APPLIED COSMICS AND NUCLEAR PHYSICS P38 - P78 STABLE ORBIT RENDEZVOUS	
DESIGN	<i>J. S. Ingalls</i>	4 APR 69	
DEVELOP	<i>J. S. Ingalls</i>	7 APR 69	
TEST	<i>W. J. ...</i>	14 APR 69	COLOSSUS IIA, FC-2644
OPERATION	<i>John A. ...</i>	17 APR 69	
REVIEW	<i>John A. ...</i>	17 APR 69	

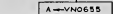




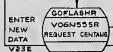
REQUEST TIG FOR SOI/SOR MANEUVER TO NEAREST .01 SEC

ASTRONAUT INPUTS:

R1 00XX HR6  
 R2 00XX MIN  
 R3 0XX.XX SEC



OUTPUT: TIG IN CSEC @ 2<sup>25</sup>



IMMEDIATE RETURN

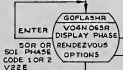
REQUEST TRANSFER CENTRAL ANGLE  $\phi$  BETWEEN TPI AND INTERCEPT (FROM PRE-TPI COMPUTATION)

ASTRONAUT INPUTS

R1 BLANK  
 R2 BLANK  
 R3 CENTANG-XXX.XX DEG

OUTPUT: CENTRAL ANGLE IN LOC CENTANG IN REVS @ 2<sup>1</sup>

GOTOPOOH TERMINATE



IMMEDIATE RETURN

PROGRAM LOADS R1 W/5 ASTRONAUT INPUTS R2

STABLE ORBIT R1 0000 @ 2<sup>14</sup>  
 1 = SOI PHASE R2 0000 @ 2<sup>14</sup>  
 2 = SOI PHASE R3 BLANK

GOTOPOOH TERMINATE

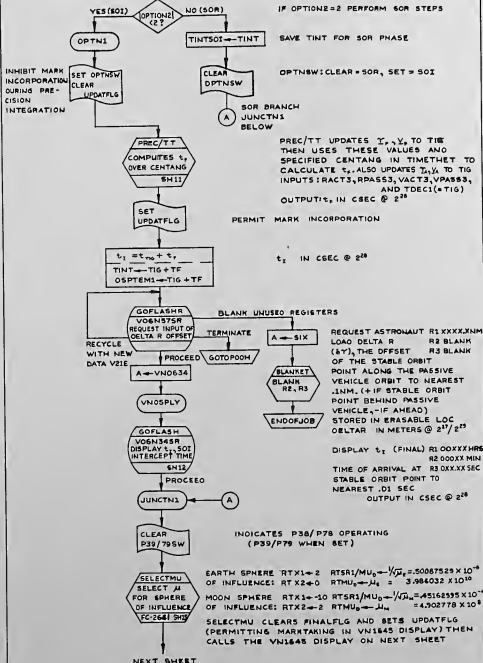


OUTPUT: 1 OR 2 IN LOC OPTION2

NEXT SHEET

INST. MODIFICATION AD DATE: 10/10/75 BY: J. J. [Signature] APPROVED: [Signature] [Signature] [Signature]	STABLE ORBIT RENDEZVOUS COLOSSUS IIA FC-2644 Rev 1
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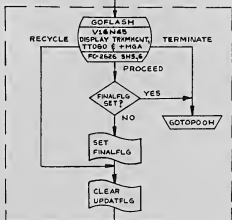
FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		FC-2644 CL-DANT AND NA-1047-C	
		P38-P78	
DRAWN: <i>[Signature]</i> CHECKED: <i>[Signature]</i> ANALYST: <i>[Signature]</i> DOCNR: <i>[Signature]</i> APP'D: <i>[Signature]</i>	SAPP'D: <i>[Signature]</i> DATE: <i>[Signature]</i> DATE: <i>[Signature]</i> DATE: <i>[Signature]</i>	STABLE ORBIT RENDEZVOUS COLOSSUS IIA FC-2644	
		SHEET 4 OF 15	



FROM PRECEEDING SHEET



VHF OPTICS  
 R1-MARK COUNT XXBXX  
 R2-TT0B0/TFI XKBXX (-=BEFORE TIG,  
 +=AFTER TIG)  
 IN MINUTES, SEC-  
 ONDS  
 R3-MIDDLE GIMBAL XXX.XX IN DEGREES  
 ANGLE AT TIG  
 -00001 IS DISPLAYED IN R3 UNTIL  
 FINALFLG IS SET (IMPLYING LAST PASS), THEN  
 A- R3 WILL DISPLAY -00002 IF THE CSM  
 IMU POSITIVE X-AXIS IS NOT ALIGNED  
 WITH THE THRUSTING DIRECTION  
 B- R3 WILL DISPLAY THE IMU POSITIVE  
 MIDDLE ANGLE WHEN THE IMU IS  
 ALIGNED

NOTE: DOTTED BOX CONTAINS SIMPLIFIED  
 FLOW OF V16N45 DETAILED VER-  
 SION IN FC-2626 SHS,6

RECYCLE



PREC/TT USES PRECSET TO RECOMPUTE  $X_1, Y_1, I_{x1}, Y_{x1}$  AT TIG, THEN OBTAINS NEW  $t_2$  USING  
 CENTANG IN TIMETHET.  $t_2$  WILL BE DIFFERENT  
 (SOI PASS) IF MARKS WERE TAKEN SINCE  
 PREC/TT FIRST USED

SEE SH 11 FOR INPUTS, OUTPUT IS  $t_2$  IN REVS @ 2<sup>14</sup>  
 RPA53 IN RVEC IN M @ 2<sup>20</sup>, 2<sup>16</sup>  
 VPASS3 IN VVEC IN M/CSEC @ 2<sup>21</sup>, 2<sup>17</sup>  
 CENTANG IN CSM, BNTH IN REVS @ 2<sup>1</sup>  
 UNIT LINE OF SIGHT IN ULOS } IN METERS @ 2<sup>1</sup>  
 UNIT NORMAL LOS IN UNRM } @ 2<sup>1</sup>

SOI BRANCH:  
 ORIGINAL  $t_2$  FOR SOI  $t_{20}$  PLUS  $t_2$  FROM  
 PREC/TT GIVES  $t_2$ , INTERCEPT TIME

(SOR) YES OPTNSH=0 (SOR)

NO (SOI)

OPTN2

TOEG10 ← TINT0

$$t_2 = t_1 + t_2$$

$$TINT_0 \leftarrow TINTSC0 + T_0$$



INPUT: PASSIVE STATE VECTOR  $I_1$ ;  $t_2$  IN  
 CSEC @ 2<sup>14</sup>  
 OUTPUT: RPA53, VPASS3 IN RATT, VATT  
 WITH STANDARD MOON/EARTH  
 SCALING

SOR BRANCH:

$t_2$  (SOI) +  $t_2$  (SOR) YIELDS  $t_2$  (SOR)  
 CONVERT  $t_2$  TO  $t_2$  USING  $I_{x1}, Y_{x1}$  AT  
 $t_2$  AND CIRCULAR APPROXIMATION  
 OUTPUT:  $t_2$  IN CSEC @ 2<sup>14</sup>

$$t_2 = \gamma_0 \cdot \gamma / |Y_{x1} X I_{x1}|$$

$$\text{DELT TIME}_0 \leftarrow \text{RATT DELTA} \cdot \text{RATT}_V \cdot X \cdot \text{RATT}_V$$

JUNCTN2

$$t_T = t_2 - t_2$$

$$\text{TARGET TIME}_0 \leftarrow \text{TINT}_1 - \text{DELT TIME}_0$$

TIME REQUIRED TO TRAVERSE  $t_T$  OFFSET  
 SUBTRACTED FROM INTERCEPT TIME (SOI OR SOR)  
 YIELDS TARGET TIME  $t_T$  IN CSEC @ 2<sup>14</sup>

MAINRTNE



45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100	ON LAB MASS. STABLE ORBIT RENDEZVOUS COLOSSUS IIA FC-2644 DIV 1
---	--

P38-778



OUTPUTS:  
 $RATT = \underline{r}_p(t_T), VATT = \underline{v}_p(t_T)$

STORE TIG IN CSEC @ 2<sup>18</sup>

EXIT FROM 53435.25

$$\underline{r}_T = \underline{r}_p(t_T)$$

INPUT:  $\underline{r}_p, \underline{v}_p$  AT  $t_T$  IN MPAC, VATT RESPECTIVELY;  
 TIG<sub>0</sub> IN INTIME;  $t_T$  IN TARGTIME;  $\underline{r}_A, \underline{v}_A$  AT  
 TIG IN RPASS3<sub>0</sub>, VPASS3<sub>0</sub> [FROM FIRST (SH4)  
 PREC/TT CALC]

INITVEL IS CALLED (WITH  $N_t = 2, \epsilon = 15^\circ$ ) BY 53435.25  
 TO COMPUTE A TRANSFER TRAJECTORY BETWEEN  
 THE INITIAL AND TERMINAL POINTS, THE INITIAL  
 AND TERMINAL VELOCITIES AND THE TOTAL  $\Delta V$   
 REQUIRED. CENTANG IS RETURNED IN ACTCENT<sub>0</sub>  
 AND  $t_p = t_t - t_{24}$  IS RETURNED IN DELT4<sub>0</sub>.  $\Delta V$   
 AT SOI TIG IS RETURNED IN DELVEET3, IN REFERENCE  
 X,Y,Z COMPONENTS, THEN CONVERTED  
 INTO LOCAL VERTICAL COORDINATES. OUTPUT IN  
 DELVLVC (STD. AGC POSITION, VELOCITY, TIME  
 SCALING THROUGHOUT)

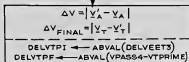
OUTPUT: RTARG ( $\underline{r}_p @ t_T$ ), VIPRIME ( $\underline{v}_A @ SOI$ );  
 VTPRIME ( $\underline{v}_A @ SOI$ ); DELVET3 ( $\Delta V @ SOI$ );  
 VPASS4 ( $\underline{v}_A @ SOI$ ); ACTCENT ( $\phi$ ); DELT4  
 ( $t_p$ ); DELVLVC ( $\Delta V @ SOI$ )

IF NOT FINAL PASS (RECYCLE @ PRIOR  
 VN1645), SET UPDATFLG, PERMITTING  
 STATE VECTOR UPDATE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		REF ID: CG 34861 ANT NAVCAP 21	
		P38-P78	
DRAWN <i>[Signature]</i>	DESIGNED <i>[Signature]</i>	STABLE ORBIT RENDEZVOUS	DOHWAT
PROGRAM <i>[Signature]</i>	17 May 67	COLOSSUS IIIA	FC-2644
FINAL <i>[Signature]</i>	16 May 67		
DOCNR <i>[Signature]</i>	17 May 67		
APPRO <i>[Signature]</i>	17 May 67	REV 4	SHEET 6 OF 15

FROM PRECEDING SHEET

MAINRTN1



COMPUTE VELOCITY DIFFERENTIAL AT BEGINNING ( $\Delta V$ ) AND END ( $\Delta V_{FINAL}$ ) OF TRANSFER TRAJECTORY

OD<sub>V</sub> ← RACT3  
MPAC<sub>V</sub> ← VIPRIME

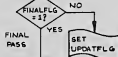


COMPUTE TRANSFER TRAJECTORY PERIGEE HEIGHT USING  $T_{A1}, Y_A$  AT TIG. RETURN PERIGEE HT. IN METERS @ 2<sup>29</sup> EARTH, 2<sup>27</sup> MOON

POSTTPI<sub>0</sub> ← H<sub>p0</sub>

SHIFT CONTENTS MPAC(H<sub>p</sub>) R1 AND STORE FOR NOUN 58 DISPLAY BELOW

H<sub>p</sub> IN METERS @ 2<sup>29</sup> IN EARTH COORD.  
IN METERS @ 2<sup>27</sup> IN MOON COORD.



ENABLE STATE VECTOR UPDATE

DSPLYS8



R1 XXXX.X PERIGEE ALT IN NM TO NEAREST .1NM  
R2 XXXX.X ΔV REQUIRED AT TIG  
R3 XXXX.X ΔV REQUIRED AT INTERCEPT

(R2, R3 TO NEAREST .1FPS)

DSPLYS1



COMPONENTS OF IMPULSIVE ΔV REQUIRED AT TIG IN LOCAL VERTICAL COORDINATES TO NEAREST .1FPS

R1 XXXX.X DELTA ΔVX (LV)  
R2 XXXX.X DELTA ΔVY (LV)  
R3 XXXX.X DELTA ΔVZ (LV)

LOCAL VERTICAL COORDINATE SYSTEM DEFINED AS:  
 $LX = (R \times V) \times R$  WHERE R IS ACTIVE VEHICLE GEOCENTRIC/SELENCENTRIC POSITION VECTOR AT TIG AND V IS ITS VELOCITY VECTOR  
 $LY = V \times R$   
 $LZ = -R$

CLEAR DELVFLG

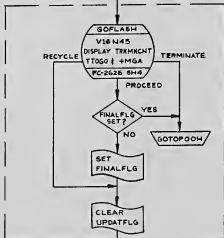
LAMBERT STEERING REQUIRED IN THRUSTING PROGRAM TO FOLLOW

NEXT SHEET

711	REV. 1
455 REUNIONATION LAB	01 21-11-1963
CAMPBELL WARE	
FC-26415M12	P38-P78
STABLE ORBIT RENDEZVOUS	
COLOSSUS IIA	FC-2644
REV. 1	REV. 1
	REV. 1

FROM PRECEDING SHEET

DELVBIN, ← DELVEETS,



STORE  $\Delta V_{P2}$  REF COORD

VHF OPTICS  
R1 MARK COUNT XXXXX  
R2 TTGO0/TPI XXXXX MIN/SEC  
(=BEFORE TIG, +AFTER  
TIG)  
R3 MIDDLE GIMBAL ANGLE XXX.XX  
AT TIG

-00001 IS DISPLAYED IN R3 UNTIL  
FINALFLG IS SET (IMPLYING LAST PASS),  
THEN

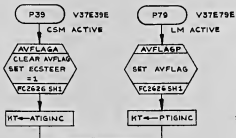
A - R3 WILL DISPLAY -00002 IF THE  
CSM IMU POSITIVE X-AXIS IS NOT  
ALIGNED WITH THE THRUSTING  
DIRECTION

B - R3 WILL DISPLAY THE IMU  
POSITIVE MIDDLE ANGLE WHEN  
THE IMU IS ALIGNED

NOTE: FOR FULL DETAILS OF VN1645  
SEE FC-2626

RE-ENTER  
ABOVE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P38-P78	
DRAWN <i>J. J. ...</i>	DATE <i>7 May 68</i>	STABLE ORBIT RENDEZVOUS DOCUMENT NO.	
PROGRAM <i>...</i>	BY <i>...</i>	COLOSSUS IIA FC-2644	
ANALYST <i>...</i>	DATE <i>7 May 68</i>		
DOCNO <i>...</i>	BY <i>...</i>		
APPROV <i>...</i>	DATE <i>...</i>	REV 1	SHEET 8 OF 16



SELECT PREPARATION TIME  
 <math>t^\*</math> FOR THRUST MANEUVER  
 PAO LOADED OR ASSIGNED  
 BY ASTRONAUT IN P27

BEGIN MIDCOURSE INITIAL CONDITIONS DISPLAY



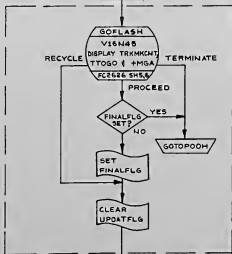
ALLOW MARKTAKING IN P20 AND  
 MARK INCORPORATION



P39/P79



LOADS VALUES OF  $\frac{1}{\mu}$  AND  $\mu$   
 INTO RTSR1/MU AND RTRNMU FOR EARTH  
 OR MOON SPHERE OF INFLUENCE ALSO  
 CLEARS FINALFLG AND SETS UPDATFLG  
 AND TRACKFLG



RECYCLE

TERMINATE

R1 XXBXX TRMKMCNT  
 R2 XXBXX TGOG  
 R3 XXXXX MGA

-0000 IS DISPLAYED IN R3 UNTIL  
 FINALFLG IS SET (IMPLYING LAST PASS),  
 THEN

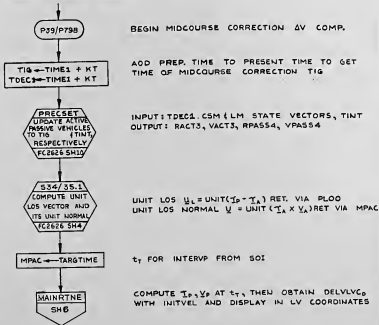
A - R3 WILL DISPLAY -0000 IF THE  
 CSM IMU POSITIVE X-AXIS IS NOT  
 ALIGNED WITH THE THRUSTING  
 DIRECTION

B - R3 WILL DISPLAY THE IMU  
 POSITIVE MIDDLE ANGLE WHEN  
 THE IMU IS ALIGNED

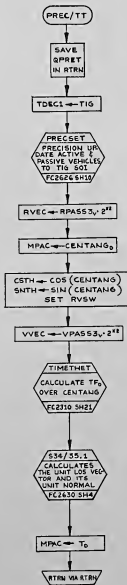
NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROX GUIDANCE AND NAVIGATION	
		P38-P78	
DESIGN P38, NR ANALYST DYCNR APPROV	<i>J. D. ...</i> <i>J. ...</i> <i>J. ...</i> <i>J. ...</i>	DATE 7 Nov 64 7 Nov 64 7 Nov 64	STABLE ORBIT RENDEZVOUS DOCUMENT # 11 COLOSSUS II FC-2644
		REV 1	SHEET 9 OF 15

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	AYOED D-D-AC, AND NAVIGATEC
PLAN <i>J. J. Horode</i> 10 APR 68	P38-P78
PROG <i>J. J. Horode</i> 17 May 68	STABLE ORBIT RENDEZVOUS
ANAL <i>J. J. Horode</i> 28 June 68	COLOSSUS IIA. RENDEZV. VC
DOCR <i>John A. Moore</i> 17 May 68	FC-2644
APPR <i>John A. Moore</i> 17 May 68	REV 1 SHEET 10 OF 15



UPDATES ACTIVE, PASSIVE VEHICLES TO TIG SOI; CALCULATES CENTANG OF PASSIVE VEHICLE BETWEEN TIG AND INTERCEPT; OBTAINS UNIT LOS VECTOR AND NORMAL UNIT VECTOR

STORE 501/50R TIME OF IGNITION (50M TIG OFFSET BY 57)

INPUT: TDEC1, CSM { LM STATE VECTORS  
OUTPUT: RACT<sub>3</sub>, VACT<sub>3</sub>, RPASS<sub>3</sub>, VPASS<sub>3</sub>,  
TDEC1, IN CSEC @ 2<sup>23</sup>, RACT, RPASS IN  
METERS @ 2<sup>23</sup>, VACT, VPASS IN M/CSEC @ 2<sup>7</sup>

RPASS3 IS SCALED ON X2 WHICH CONTAINS 0 FOR THE EARTH, 2 FOR THE MOON

OBTAIN TRANSFER CENTRAL ANGLE BETWEEN TIG AND TINT

CONVERT CENTANG TO SIN, COS FOR INPUT TO TIMETHET. SET RVSW TO INHIBIT STATE VECTOR CALCULATION IN TIMETHET. IN REVS @ 2<sup>5</sup>

SCALE VVEC 2<sup>7</sup> EARTH, 2<sup>5</sup> MOON.

GIVEN CENTANG OF PASSIVE VEHICLE BETWEEN TIG & TINT AND RPASS, VPASS AT TIG. CALCULATE TF TIME OF FLIGHT FOR 50R  
INPUT: RPASS3, VPASS3 IN METERS @ 2<sup>27</sup>/2<sup>23</sup> AND M/CSEC 2<sup>7</sup>/2<sup>3</sup>, RESPECTIVELY CENTANG CSMH & SNTH IN REVOLUTION @ 2<sup>5</sup>  
OUTPUT: t<sub>F</sub> IN CSEC @ 2<sup>23</sup>

LOS OF ACTIVE VEHICLE VIEWED FROM PASSIVE VEHICLE AT TIG

$$\begin{cases} U_L = \text{UNIT VEHICLE VIEWED} \\ U = \text{UNIT VEHICLE AT TIG} \end{cases}$$

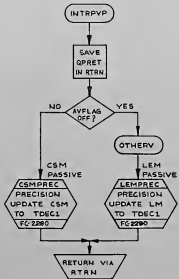
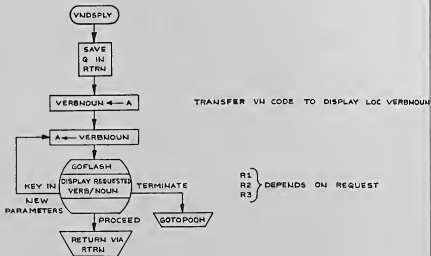
$$\begin{cases} U_L = (Y_L - Y_A) \\ U = (Y_A \times Y_A) \end{cases}$$

$$\begin{cases} OD_L = U \cdot LOS_V = -U_L \\ MPAC_V = U \cdot \text{UNRM}_V = -U \end{cases}$$

INPUT: RPASS3, RACT3, VACT3 STO. SCALING

U<sub>L</sub>, U ARE RETURNED VIA PUSH LIST LOC 00 AND MPAC, RESPECTIVELY, IN METERS @ 2<sup>5</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFRLC GUIDANCE AND NAV. DIV. P35-P78	
DRAWN BY <i>J. J. ...</i> CHECKED BY <i>J. J. ...</i> ANNOT. BY <i>J. J. ...</i> CALCD. BY <i>J. J. ...</i> APPROV. BY <i>J. J. ...</i>	SCANNED 7 Nov 64 17 Nov 64 17 Nov 64	STABLE ORBIT COLOSSUS II	RENDEZVOUS DOCUMENT NO FC-2644 REV 1 SHEET 11 OF 18



INPUT:  $t_2$  IN CSEC @ 2<sup>28</sup>  
 VEHICLES STATE VECTORS FOR LM, CSM  
 OUTPUT:  $Y_p, Y_b$  IN RATT, VATT AT  
 $t_2$  OR  $t_1$

STANDARD AGC SCALING

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION P38-P78	
DRAWN <i>H. G. Gagnier</i> CHECKED <i>J. J. Gagnier</i> ANALYST <i>J. J. Gagnier</i> DESIGNER <i>J. J. Gagnier</i> APPROVED <i>J. J. Gagnier</i>	304278 17 May 68 17 May 68 17 May 68 17 May 68	STABLE ORBIT RENDEZVOUS COLOSSUS IIA REV 4	DOCUMENT NO <b>FC-2644</b> SHEET 12 OF 18



SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
AVFLAG	FC-2626	CLEAR AVFLAG (CSM ACTIVE), SETS ECSTEER	SH. 3, 9
AVFLAGP	FC-2626	SETS AVFLAG	SH. 3, 9
P30FLGON	FC-2626	SETTRACK & UPDATFLG	SH. 3, 9
SELECTMU	FC-2630 SH. 15	SELECTS PROPER $1/\sqrt{\mu}$ , $\mu$ FOR EARTH/MOON SPHERE OF INFLUENCE	SH. 4, 9
S3435.25	FC-2630 SH. 9	PREPARES INPUTS FOR (AND CALLS) INITVEL, WHICH COMPUTES TRANSFER TRAJECTORY AND INITIAL AND TERMINAL VELOCITIES BEFORE, AND AFTER TRANSFER	SH. 6, 10
PERIAPO1	FC-2641	COMPUTES TRANSFER TRAJECTORY USING $R_A$ & $V_A$ AT TIG AND RETURNS $H_p$ , PERIGEE HEIGHT	SH. 7
CSPMPREC	FC-2290	PRECISION UPDATE CSM TO TDECI	SH. 12
LMPREC	FC-2290	PRECISION UPDATE LM TO TDECI	SH. 12
PRECSET	FC-2626	UPDATE PASSIVE VEHICLE TO TDECI	SH. 10, 11
S34/35.1	FC-2610	CALCULATES UNIT LOS AND UNIT NORMAL	SH. 11
TIMETHET	FC-2630	COMPUTES TIME OF FLIGHT OVER CENTANG	SH. 11

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
AVFLAG	LM ACTIVE VEHICLE	CSM ACTIVE VEHICLE	SH. 3	SH. 3	SH. 12
UPDATFLG	UPDATING ALLOWED	UPDATING DISALLOWED	SH. 3, 6, 7	SH. 7, 9	
TRACKFLG	TRACKING ALLOWED	TRACKING DISALLOWED	SH. 3		
OPTNSW	SOI PHASE OF P38	SOR PHASE OF P38	SH. 4	SH. 4	SH. 5
FINALFLG	LAST PASS	NOT LAST PASS	SH. 7, 9		SH. 5, 6, 7, 9
NDELVFLG	LAMBERT STEERING NOT REQUESTED	LAMBERT STEERING IN THRUSTING MANEUVER TO FOLLOW		SH. 7	
P39/795W	MIDCOURSE COMPUTATION	NOT MIDCOURSE	SH. 9		SH. 6, 8

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N33SR	GOFFLASH	R1 00XX HRS } R2 00XX MIN } REQUEST TIG R3 0XX.XX SEC }	SH. 3
V06N55SR	GOFFLASHR	R1 BLANK R2 BLANK R3 XXX.XX DEG.      REQUEST CENTANG, CENTRAL ANGLE OF TRANSFER	SH. 3
V04N06SR	GOFFLASHR	R1 00005 R2 0000X R3 BLANK      X = 1 FOR SOI X = 2 FOR SOR	SH. 3
V06N57SR	GOFFLASHR	R1 XXXX.X NM R2 BLANK R3 BLANK      STABLE ORBIT POINT OFFSET &r REQUEST	SH. 4
V06N34SR	GOFFLASH	R1 00XX HRS R2 000XX MIN R3 0XX.XX SEC      t <sub>1</sub> TIME OF INTERCEPT	SH. 4

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVAL GUIDANCE AND REGISTRATION	
DRAWN <i>[Signature]</i> 1 APR 68		P38 - P78	
CHKD <i>[Signature]</i> 7 MAY 68		STABLE ORBIT RENDEZVOUS	
ANAL ST <i>[Signature]</i> 17 MAY 68		DOCUMENT NO.	
DOING <i>[Signature]</i> 17 MAY 68		COLOSSUS IIA FC-2644	
APPROV <i>[Signature]</i> 17 MAY 68		SHEET 13 OF 15	

DISPLAYS (CONTINUED)

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V16N45	GOFLASH	R1 XXXXX R2 XXXXX TTOGO/TPI { TIME TO IGNITION/TIME FROM IGNITION IN MINUTES, SECONDS (MAXIMUM 60 B 80) IN DEGREES R3 MIDDLE GIMBAL ANGLE IN DEGREES	SH. 5, 6, 9
V06N58SR	GOFLASH	R1 0000.1 PERIGEE ALT. IN N. M. R2 0000.0 $\Delta V_{TIG}$ IN FPS } IN REFERENCE COORDINATES R3 0000.0 $\Delta V_{TPP}$ IN FPS	SH. 7
V06N81SR	GOFLASH	R1 0000.0 $\Delta VX$ R2 0000.0 $\Delta VY$ R3 0000.0 $\Delta VZ$ } IN LOCAL VERTICAL COORDINATES	SH. 7

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
OPTION1	5	STABLE ORBIT CODE			2 <sup>14</sup>
OPTION2	1 OR 2	PHASE 1 (SOI) OR PHASE 2 (SOR)			2 <sup>14</sup>
TINT	t <sub>i</sub>	TIME OF INTERCEPT FOR SOI	MIN B SEC	CSEC	2 <sup>28</sup>
TINTSOI	t <sub>i</sub>	SOI INTERCEPT TIME STORED FOR SOR-t <sub>iQ</sub> (SOR)		CSEC	2 <sup>28</sup>
TDEC1		STORAGE LOC FOR t <sub>i</sub> , t <sub>T</sub> FOR INTEGRATION		CSEC	2 <sup>28</sup>
T	t <sub>F</sub>	TIME OF FLIGHT, T <sub>IG</sub> TO t <sub>i</sub>		CSEC	2 <sup>28</sup>
DELTA R	$\delta r$	OFFSET OF STABLE ORBIT (INTERCEPT) POINT FROM PASSIVE VEHICLE	NM	METERS	2 <sup>29</sup>
DELTIME	$\delta t$	TIME TO TRAVERSE $\delta r$		CSEC	2 <sup>28</sup>
TARGETIME	t <sub>T</sub>	TIME ACTIVE VEHICLE REACHES STABLE ORBIT POINT		CSEC	2 <sup>28</sup>
INTIME	t <sub>IG</sub>	IGNITION TIME FOR S3435.25 (CALLS INITVEL)		CSEC	2 <sup>28</sup>
DELVTPI	$\Delta V$	MAGNITUDE OF $\Delta V$ REQUIRED FOR BURN	FPS	M/CSEC	2 <sup>7</sup>
DELVTTPF	$\Delta V_{FINAL}$	MAGNITUDE OF $\Delta V$ REQUIRED AT INTERCEPT	FPS	M/CSEC	2 <sup>7</sup>
POSTTPI	H <sub>p</sub>	MIN PERIGEE ALT.	NM	METERS	2 <sup>29</sup>
DELVSIN	$\Delta V$	VALUE OF VELOCITY INCREMENT IN REFERENCE INERTIAL COORDINATES FOR EXTERNAL $\Delta V$ BURNS	FPS	M/CSEC	2 <sup>7</sup>
KT	$\delta r$	STORAGE LOC FOR ATIGINC, PTIGINC (BELOW)		CSEC	2 <sup>28</sup>
ATIGINC	$\delta r$	ACTIVE } THRUST MANEUVER PASSIVE } PREP. TIME		CSEC	2 <sup>28</sup>
PTIGINC	$\delta r$				
VERBNOUN	VXXXNX	STORE VERBNOUN COMBINATIONS			2 <sup>14</sup>
TIG	t <sub>IG</sub>	IGNITION TIME FOR MANEUVER		CSEC	2 <sup>28</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		P38-P78 STABLE ORBIT RENDEZVOUS	
CHKD <i>[Signature]</i>	DATE <i>[Date]</i>	COLOSSUS IIA	DOCUMENT NO.
ANLST <i>[Signature]</i>	DATE <i>[Date]</i>	FC-2644	
CHKMR <i>[Signature]</i>	DATE <i>[Date]</i>		SHEET 14 OF 15
APPR <i>[Signature]</i>	DATE <i>[Date]</i>	REV 4	

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
MUTABLE	$\mu_e$ (MUE)	EARTH GRAVITATIONAL CONSTANT	$3.986032 \times 10^{10}$	$M^3/CSEC^2$	$2^{36}$
MUTABLE+6	$1/\sqrt{\mu_e}$	RECIPROCAL SQRT OF $\mu_e$	$.50087529 \times 10^{-5}$	$CSEC/M^{3/2}$	$2^{-17}$
MUTABLE+8	$\mu_M$ (MUM)	MOON GRAVITATIONAL CONSTANT	$4.902778 \times 10^8$	$M^3/CSEC^2$	$2^{30}$
MUTABLE+14	$1/\sqrt{\mu_M}$	RECIPROCAL SQRT OF $\mu_M$	$.45162595 \times 10^{-4}$	$CSEC/M^{3/2}$	$2^{-14}$

## PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
ATIGNC	6r	CSM PREP. TIME FOR MIDCOURSE MANEUVER PREPARATION				
PTIGNC	6r	LM PREP. TIME FOR MIDCOURSE MANEUVER PREPARATION				

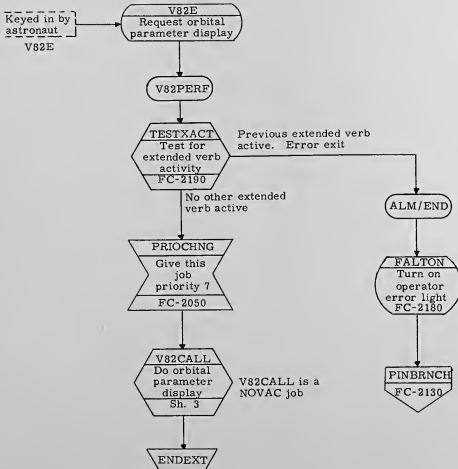
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		01084
P38-P78		
STABLE ORBIT RENDEZVOUS		
DRAWN <i>[Signature]</i> CHECKED <i>[Signature]</i> ANALYST <i>[Signature]</i> BY MR <i>[Signature]</i> DATE <i>[Signature]</i>	1 APR 69 7:30 AM 8:30 AM 7:45 AM 7:45 AM	COLOSSUS IIA FC-2644 REV 1 15 15

ORBITAL PARAMETERS DISPLAY

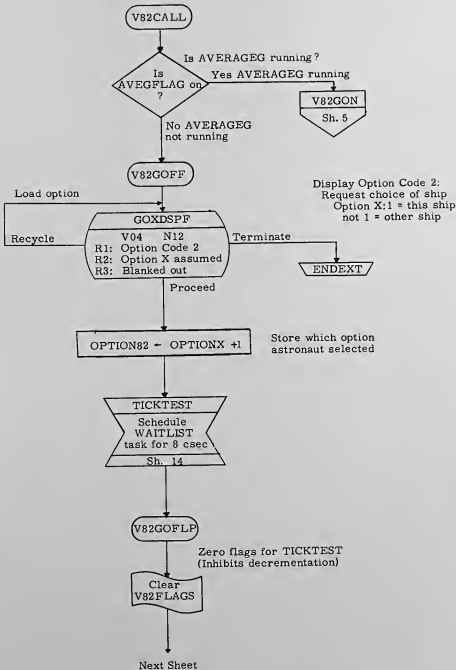
Major Subroutines and External Entry Points:

V82PERF:	Entry from Verb FAN	SH. 2
V82CALL:	Display and calling routine	SH. 3
TICKTEST:	TFF countdown mechanism	SH. 14
SR30.1:	Subroutine for calculating TFF and TPER	SH. 15

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Orbital Parameters Display	
DRAWN <i>J. Crocetta</i>	<i>B-3-69</i>		
PRGMR <i>J. Crocetta</i>	<i>8-29-69</i>		
ANALST		Colossus IIC	DOCUMENT NO. FC-2650
DOCMR <i>John M. Estlin 8/29/69</i>			
APPR'D <i>J.M. Estlin 8/29/69</i>		REV 1	SHEET 1 OF 25

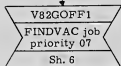


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. Conella</i>	<i>8-5-68</i>	Orbital Parameters Display
PRGMR	<i>T. Conella</i>	<i>8-29-68</i>	
ANALST			Colossus IIC
DOCMR	<i>Robert M. Suter</i>	<i>8/24/69</i>	DOCUMENT NO. FC-2650
APPR'D	<i>W. M. ...</i>	REV 1	SHEET 2 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. Conner</i>	Orbital Parameters Display	
PRGMR	<i>T. Craven</i>		
ANALST		Colossus IIC	DOCUMENT NO. FC-2650
DOCMR	<i>W. J. ...</i>	REV 1	SHEET 3 OF 25
APPR'D	<i>W. J. ...</i>		

From Preceding Sheet



Schedule computations as FINDVAC job

V82STALL

V82STALL holds progress of program until V82GOFF1, the state vector update subroutine has had a chance to set one of the flags in V82FLAGS

Is one of the bits of V82FLAGS set?

Yes, a flag on

No, no flag on

V82STALL

Delay job  
1 sec  
FC-2070

FLAGGON

Display: monitor

Apogee: R1 XXXX.X dec naut miles

Perigee: R2 XXXX.X dec naut miles

TFF: R3 XXBXX dec min. sec.

GOXDSPF

V16 N44  
R1: Apogee  
R2: Perigee  
R3: TFF

Terminate

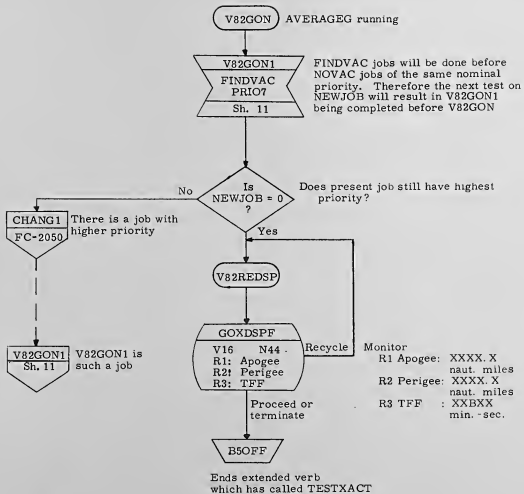
Proceed

Recycle

B5OFF

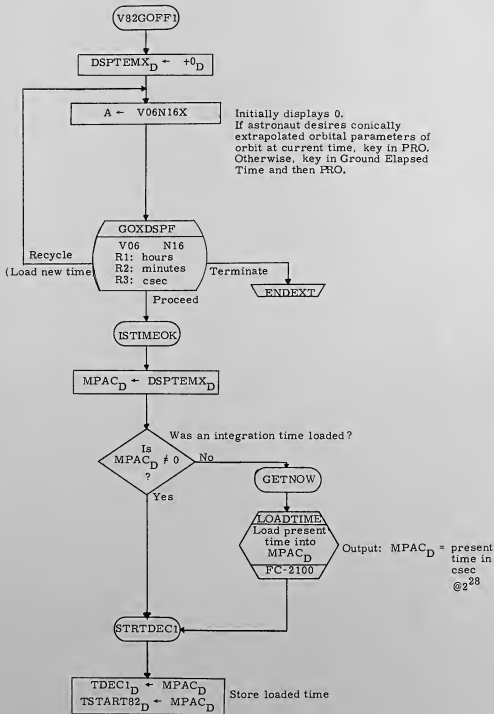
Ends extended verb which has called TESTXACT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: J. Carpenter		Orbital Parameters Display	
PRGMR: J. Cowell	8/24/69	DOCUMENT NO. FC-2650	
ANALST: J. Cowell	8/24/69	Colossus IIC	
DOCMR: J. Cowell	8/24/69	REV 1	SHEET 4 OF 25
APPR'D: J. Cowell	8/24/69		



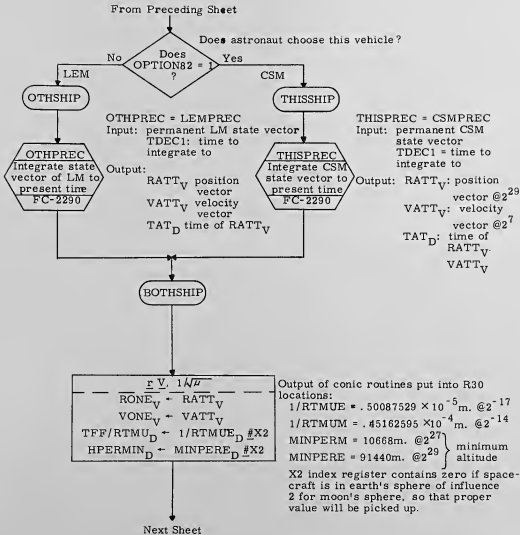
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J.C. Caputo</i>		Orbital Parameters Display	
PRGMR <i>J. Caputo</i>		DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2650
DOCMR <i>Robert M. Smith</i>		REV 1	SHEET 5 OF 25
APPR'D <i>W.M. Stewart</i>			



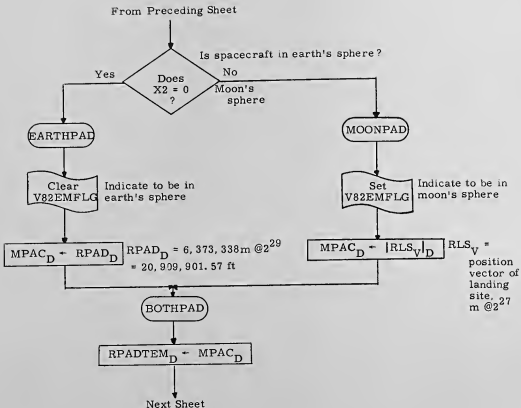


Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Curcio</i>	<i>10/1/69</i>	Orbital Parameters Display	
PRGMR <i>T. Curcio</i>	<i>8/29/69</i>	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR <i>John J. Pater</i>	<i>8/25/69</i>	REV 1	SHEET 6 OF 25
APPR'D <i>J. Curcio</i>	<i>8/29/69</i>		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	J. Coakley	Orbital Parameters Display	
PRGRM	T. Coakley	DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2650
DOCNR	APOLLO IIC SWS 11/25/69	REV	1
APPR'D	J.M. Frank	SHEET	7 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Cooper</i>		Orbital Parameters Display	
PRGMR <i>J. Cooper</i>		COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST		REV 1	SHEET 8 OF 25
DOCMR <i>Robert M. F. ...</i>			
APPR'D <i>[Signature]</i>			

From Preceding Sheet

SR30.1

Input:  $RONE_V$  = present position vector:

meters @  $2^{29}$

$VONE_V$  = present velocity vector:

m/csec @  $2^7$

V82EMFLG: Flag on = moon's sphere

Flag off = earth's sphere

$RPADTEM_D$  = radius of pad: meters

@  $2^{29}$

Output:  $HAPOX_D$  = apogee altitude above pad

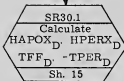
radius: meters @  $2^{29}$

$HPERX_D$  = perigee altitude above pad

radius: meters @  $2^{29}$

$TFF_D$  = time of free fall: csec @  $2^{28}$

- $TPER_D$  = time to perigee: csec @  $2^{28}$



Is POO running?

Is MODREG = 0?

Yes

No



SPLRET1

Entrance from SPLRET, with POO running

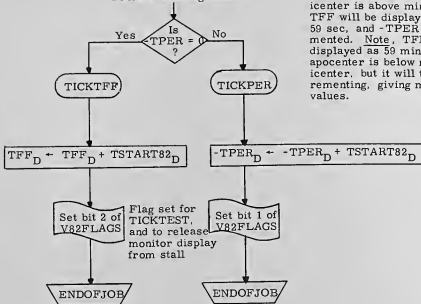
$TSTART82_D \leftarrow TIME2_D - TSTART82_D$

Time elapsed since TSTART82

Next Sheet

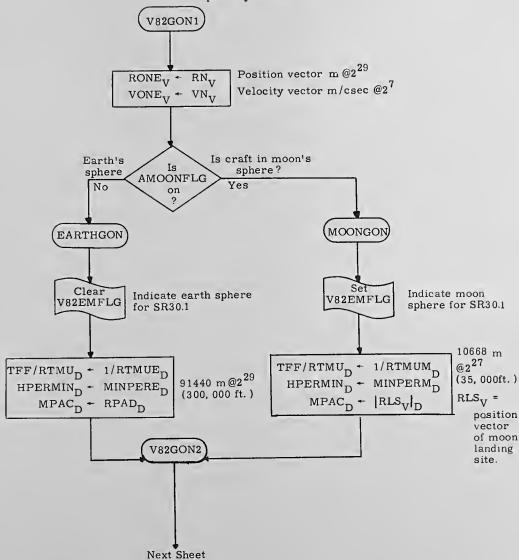
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. Cavallera</i>	8-29-68	Orbital Parameters Display
PRGMR	<i>J. Cavallera</i>	8-29-68	DOCUMENT NO.
ANALST			COLOSSUS IIC
DOCMT	<i>Robert M. Carter</i>	8/29/68	FC-2650
APPR'D	<i>[Signature]</i>	8/29/68	REV 1
			SHEET 19 OF 25

From Preceding Sheet



-TPER is set to zero when pericenter is above minimum. If so, TFF will be displayed as 59 min. 59 sec, and -TPER will be decremented. Note, TFF will also be displayed as 59 min. 59 sec when apocenter is below minimum pericenter, but it will then start decrementing, giving meaningless values.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. Conetta</i>	Orbital Parameters Display	
PRGMR	<i>T. Collier</i>	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR	<i>Refer to M. Conetta 8/25/62</i>		
APPR'D	<i>W. M. Conetta</i>	REV 1	SHEET 10 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J.C. Spicella		orbital Parameters Display	
PRGMR T. L. ...	7/24/68	DOCUMENT NO. FC-2650	
ANALST	8-29-68	COLOSSUS IIC	
DOCMR Robert M. ...	8/29/68	REV 1	
APPR'D G.M. ...	8/29/68	SHEET 11 OF 25	

From Preceding Sheet

RPADTEM ← MPAC<sub>D</sub>

SR30.1  
Calculate  
HAPOX<sub>D</sub>, HPERX<sub>D</sub>  
TFF<sub>D</sub>, TPER<sub>D</sub>  
Sh. 15

SR30.1

Input:

RONE<sub>V</sub> = position vector in  
meters @2<sup>29</sup>  
VONE<sub>V</sub> = velocity vector in  
meters/csec @2<sup>7</sup>  
RPADTEM = pad radius in  
meters @2<sup>29</sup>  
V82EMFLG on = moon.  
off = earth

Output:

HPERX<sub>D</sub> perigee height above  
pad radius @2<sup>29</sup>  
HAPOX<sub>D</sub> apogee height above  
pad radius @2<sup>29</sup>  
TFF<sub>D</sub> time of freefall  
- TPER<sub>D</sub> time to perigee } csec  
@2<sup>28</sup>

Is Major Mode 11 running?  
(earth orbit insertion monitor)

Is  
MODREG = 11  
?

No

Yes

V82GON3

Next Sheet

Is  
bit 5 of  
EXTVBACT  
= 0?

Does astronaut wish to  
terminate?

Yes

No

ENDEXT

DELAYJOB

Delay job  
1 sec

When AVERAGEG is running,  
computations are updated  
after 1 sec

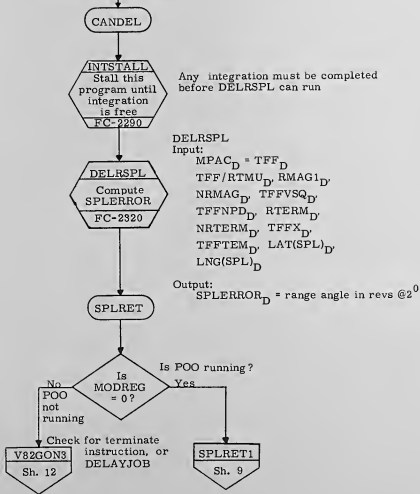
FC-2070

V82GON1

Sh. 11

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Orbital Parameters Display	
DRAWN: <i>S. C. ...</i>	<i>...</i>	COLOSSUS IIC	DOCUMENT NO.
PRGMR: <i>T. ...</i>	<i>...</i>		FC-2650
ANALST:			
DOCMR: <i>...</i>	<i>...</i>		
APPR'D: <i>...</i>		REV 1	SHEET 12 OF 25

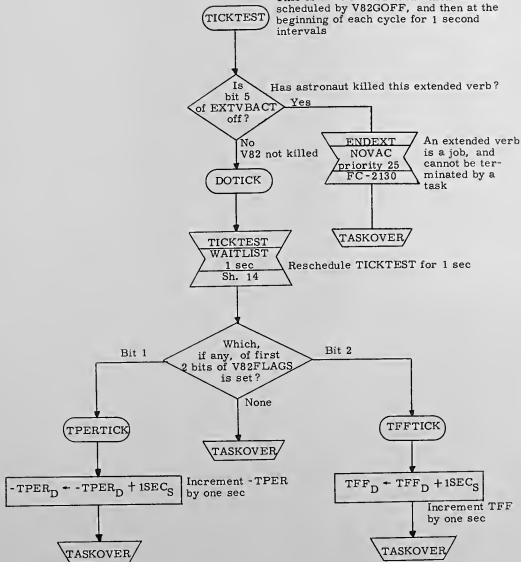
From Preceding Sheet



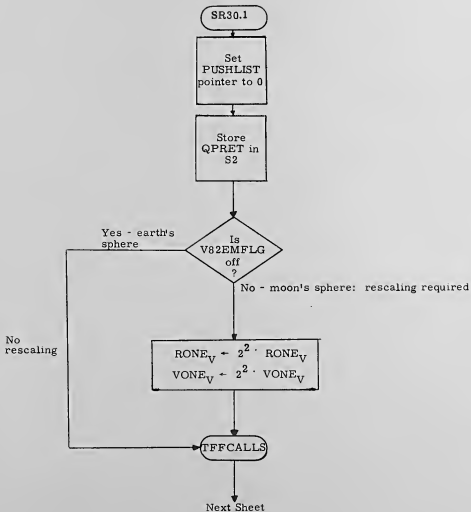
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>T. Coakley</i> 7/29/69		Orbital Parameters Display	
PRGMR <i>T. Coakley</i> 8/29/69		DOCUMENT NO. FC-2650	
ANALST		COLOSSUS IIC	
DOCMR <i>D. Williams, E. L. ...</i> 8/29/69		REV 1	
APPR'D <i>...</i> 7/29/69		SHEET 13 OF 25	



This is a WAITLIST task which is first scheduled by V82GOFF, and then at the beginning of each cycle for 1 second intervals

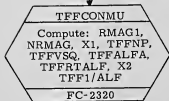


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. C. Costa</i>	<i>11/25/69</i>	Orbital Parameters Display	
PRGMR <i>J. Costello</i>	<i>8-29-69</i>	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR <i>Robert D. Fuler</i>	<i>8/27/69</i>		
APPR'D <i>DMT</i>	<i>8/27/69</i>	REV 1	SHEET 14 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		Orbital Parameters Display	
DRAWN <i>D. C. ...</i>	<i>2 Aug 69</i>	COLOSSUS IIC	DOCUMENT NO. FC-2650
PRGRM <i>T. ...</i>	<i>8-29-69</i>		
ANALST		REV 1	SHEET 15 OF 25
DOCNR <i>...</i>	<i>8/29/69</i>		
APPR'D <i>...</i>	<i>8/29/69</i>		

From Preceding Sheet



TFFCONMU:

Input:

RONE<sub>V</sub> = position vector in meters E@  
2<sup>29</sup> M@2<sup>27</sup>

VONE<sub>V</sub> = velocity vector in m/csec E@  
2<sup>7</sup> M@2<sup>5</sup>

TFF/RTMU =  $1/\sqrt{\mu}$  E@2<sup>-17</sup> M@2<sup>-14</sup>

Output:

RMAG<sub>1D</sub> = radius at time of RONE in  
meters E@2<sup>29</sup>, M@2<sup>27</sup>

NRMAG<sub>D</sub> = normalized RMAG, norm count  
in X<sub>1</sub> meters E@2<sup>29-NR</sup>  
M@2<sup>27-NR</sup>

NR = -X<sub>1</sub> = -norm count for NRMAG

TFFNP<sub>D</sub>: semilatus rectum, weighed by  
NR: meters E@2<sup>38-2NR</sup>  
M@2<sup>36-2NR</sup>

TFFVSQ<sub>D</sub>:  $\frac{V}{\sqrt{\mu}}$   $\frac{V}{\sqrt{\mu}}$  present velocity,  
normalized 1/meters E@2<sup>-20</sup>  
M@2<sup>-18</sup>

TFFALFA<sub>D</sub>: α weighed by NR, in 1/meters  
E@2<sup>-26 + NR</sup> M@2<sup>-24 + NR</sup>

TFFRTALF<sub>D</sub>:  $\sqrt{\alpha}$  normalized E@2<sup>-10-NA</sup>  
M@2<sup>-9-NA</sup>

X<sub>2</sub> = -NA, norm count for  $\sqrt{\alpha}$

TFF1/ALF<sub>D</sub> = signed, semi-major axis  
weighed by NA. In meters  
E@2<sup>+22 + 2NA</sup> M@2<sup>20 + 2NA</sup> M

VONE'<sub>V</sub> = VONE · TFF/RTMU in 1/(M 1/2)  
@2<sup>-10</sup>/2<sup>-9</sup>

TFFRP/RA:

Input:

TFFALFA<sub>D</sub> = α = (semi-major axis)<sup>-1</sup> in  
meters<sup>-1</sup> @2<sup>-26 + NR</sup>/2<sup>-24 + NR</sup>

TFFNP<sub>D</sub> = semi-latus rectum in meters  
@2<sup>38 - 2NR</sup>/2<sup>36 - 2NR</sup> X<sub>1</sub>, X<sub>2</sub>  
set by TFFCONMU

Output:

RPER<sub>D</sub> = perigee radius in meters @2<sup>29</sup>/2<sup>27</sup>

RAPO<sub>D</sub> = apogee radius in meters @2<sup>29</sup>/2<sup>27</sup>

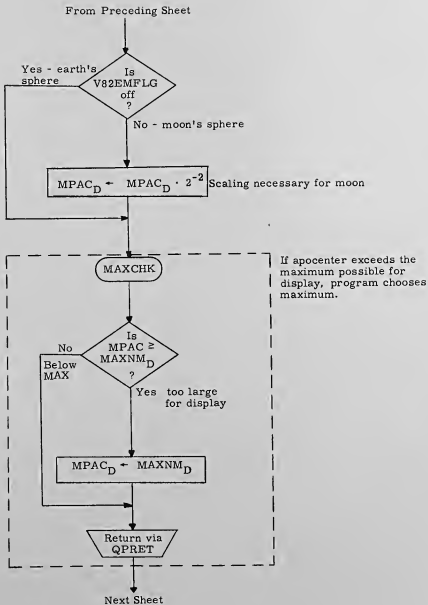


MPAC<sub>D</sub> + MPAC<sub>D</sub> - RPADTEM<sub>D</sub>

↓

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. C. Costa</i>	<i>1/24/69</i>	Orbital Parameter Display	
PRGRM <i>J. C. Costa</i>	<i>8-29-68</i>	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR <i>John F. Smith</i>	<i>8/25/69</i>		
APPR'D <i>J. C. Costa</i>	<i>1/24/69</i>	REV 1	SHEET 16 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Caprista</i>	<i>2/24/68</i>	Orbital Parameters Display	
PRGRM <i>J. Caprista</i>	<i>2/24/68</i>	COLOSSUS IIC	DOCUMENT NO.
ANALST			FC-2650
DOCNR <i>Roberts M. Smith 1/29/68</i>		REV 1	SHEET 17 OF 25
APPR'D <i>J. Caprista</i>			

From Preceding Sheet

STORHAPC

$HAPOX_D \leftarrow MPAC_D$   
 $MPAC_D \leftarrow RPER_D - RPADETM_D$   
 $MPAC + 4_D \leftarrow RPER_D - RPADETM_D$

Store into apocenter location: meters @  $2^{29}$   
 Prepare to store  $HPER_D$   
 Save for comparison with  $HPERMIN$

In earth's sphere?  
 Is  $V82EMFLG$  off?  
 Yes - earth's sphere

No - moon's sphere

$MPAC_D \leftarrow MPAC_D \cdot 2^{-2}$  Rescaling necessary

MAXCHK

Check for too large value

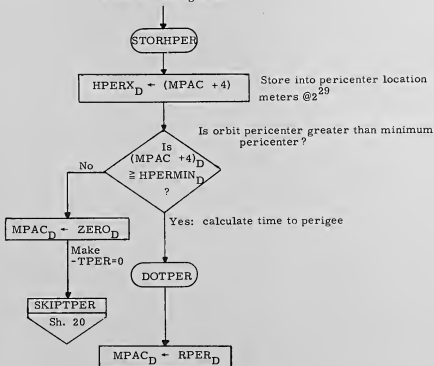
If pericenter exceeds the maximum possible for display, program chooses maximum

Sh. 17

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Conetta</i>	<i>8/25/69</i>	Orbital Parameters Display	
PRGMR <i>T. Conetta</i>	<i>8/25/69</i>	DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2650
DOCMP <i>Robert M. Esposito</i>	<i>8/29/69</i>	REV 1	SHEET 18 OF 25
APPR'D <i>William S. ...</i>	<i>8/29/69</i>		

From Preceding Sheet



CALCTPER

Input:

$RONE_V$  = position vectors in meters @ $2^{29}/2^{27}$

$VONE_V = \sqrt{1/\mu}$  csec/m<sup>2</sup> @ $2^{-10}/2^{-9}$

$RMAG_1_D = RONE_V D$  meters @ $2^{29}/2^{27}$

$MPAC_D = RPER_D$  = terminal radius length, meters @ $2^{29}/2^{27}$

$TFF/RTMU_D = 1/\sqrt{\mu}$  csec/m<sup>3/2</sup> @ $2^{-17}/2^{-14}$

$NRMAG_D = NORMX1 (RMAG)$  meters @ $2^{29} - X1 / 2^{27} - X1$

$X1$  = Norm factor for  $KMAG$

$TFFNP_D$  = semilatus rectum meters @ $2^{38} - 2X / 2^{36} - 2X$

$TFFALFA = a$  meters @ $2^{-26} + X1 / 2^{-24} + X1$

$TFFRTALF = \sqrt{a}$  meters<sup>1/2</sup> @ $2^{10} - X2 / 2^9 - X2$

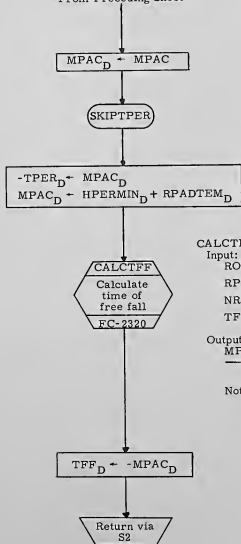
$TFF1/ALF$  = signed, semimajor axis, meters @ $2^{22} - 2x2 / 2^{20} - 2x2$

Output:

$MPAC_D$  = time to perigee in csec @ $2^{28}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. Cowley</i>	Orbital Parameters Display	
PRGMR	<i>T. Cullen</i>	DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2650
DOCMR	<i>Alfred D. Busey</i>	REV 1	SHEET 19 OF 25
APPR'D	<i>AMC</i>		

From Preceding Sheet



### CALCTFF

Input:

$RONE_V$ ,  $VONE_V$ ,  $RMAG1_D$ ,  $MPAC =$   
 $RPADETEM + HPERMIN$ ,  $TFF/RTMU_D$ ,  
 $NRMAG_D$ ,  $X1$ ,  $TFFNP_D$ ,  $TFFALFA_D$ ,  
 $TFFRTALF_D$ ,  $X2$ ,  $TFF1/ALF$

Output:

$MPAC_D = TFF =$  time of free-fall, in  
csec @  $2^{28}$

Note:

If the trajectory fails to reach  $HPERMIN +$   
 $RPADETEM$  (300,000 or 35,000) then TFF  
will be displayed as 59B59

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J.C. ...</i>	<i>...</i>	Orbital Parameters Display	
PRGMR <i>J.C. ...</i>	<i>...</i>	DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2650
DOCMR <i>Robert M. ...</i>	<i>...</i>	REV 1	SHEET 20 OF 25
APPR'D <i>...</i>	<i>...</i>		

DISPLAYS					
VERB NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED		
V04N12	GOXDSPF	R1: Option code 2 R2: Option 1 assumed R3: Blanked out	SH. 3		
V16N44	GOXDSPF	R1: XXXX. X naut miles apogee R2: XXXX. X naut miles perigee R3: XXBXX min, sec TFF	SH. 4, 5		
V06N16	GOXDSPF	R1: 00XXX. hours } time of event R2: 000XX. minutes } R3: 0XX. XX. seconds }	SH. 6		
FLAGS					
NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
AVERAGEFLAG	AVERAGEG running	AVERAGEG not running			SH. 3
Bit 5 or EXTVBACT	Do not terminate extended verb	Terminate extended verb			SH. 12, 14
AMOONFLG	In moon's sphere	In earth's sphere		SH. 11	
V82EMFLG	In moon's sphere	In earth's sphere	SH. 8, 11	SH. 8, 11	SH. 15, 17, 18
Bit 1 of V82FLAGS	TICKPER operating	TICKPER not operating	SH. 10	SH. 4	SH. 4, 14
Bit 2 of V82FLAG	TICKTFF	TICKTFF not operating	SH. 10	SH. 4	SH. 4, 14

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Cipriani</i>	<i>2/15/69</i>	Orbital Parameters Display	
PRGRM <i>T. G. ...</i>	<i>8249</i>	DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2650
DOCNR <i>APOLLO IIC 8/29/69</i>		REV 1	SHEET 21 OF 25
APPR'D <i>[Signature]</i>			



SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS		WHERE CALLED
SUBROUTINE NAME	FLOW CHART	DESCRIPTION
CALCTFF	2370	Calculates time of free fall to a particular radius
CALCTPER	2320	Calculates time of free fall to pericenter
DELAYJOB	2070	Delays a job for a particular time period
DELRSP	2320	Calculates error in splashdown between calculated and predicted
ENDEXT	2130	Ends an extended verb
FALTON	2130	Turns on operator error light
LOADTIME	2100	Loads present time into MPAC <sub>D</sub>
OTHPREC	2300	Update LM vector to a particular time
PRIORCHG	2050	Change calling job's priority
TESTXACT	2190	Test for extended verb activity
TFFCONMU	2320	Computes various parameters used in the TFF routines, and establishes them in the push list area
TFFRP/RA	2320	Calculates perigee and apogee radius for a given conic
THISPREC	2300	Update CSM state vector to a particular time
INTSTALL	2300	Stall calling program until integration is not in use. Then inhibit any other program from using integration until INTWAKE is called.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>JC Coxello</i>	Checked <i>Albright</i>	Orbital Parameters Display	
PRGMR <i>T. Coxello</i>	<i>8-29-68</i>	DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2650
DOCMR <i>John M. Coxello</i>	<i>8/29/68</i>		
APPR'D <i>JM Coxello</i>	<i>8/29/68</i>	REV 1	SHEET 22 OF 25

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
-TPER <sub>D</sub>	t <sub>PER</sub>	Negative of time from pericenter	min/sec	csec	2 <sup>28</sup>
HAPOX <sub>D</sub>	h <sub>a</sub>	Apocenter altitude	feet	meters	2 <sup>29</sup> / <sub>2</sub> 27
HPERMIN <sub>D</sub>		Minimum perigee	feet	meters	2 <sup>29</sup> / <sub>2</sub> 27
HPERX <sub>D</sub>	h <sub>p</sub>	Pericenter altitude	feet	meters	2 <sup>29</sup> / <sub>2</sub> 27
MODREG		Major mode indication			
NEWJOB		Points to coreset of active job of highest priority			
NRMAG <sub>D</sub>		Normalized RMAG	feet	meters	2 <sup>27</sup> + X1 / 2 <sup>24</sup> + X1 2
RAPO <sub>D</sub>		Apogee radius	feet	meters	2 <sup>29</sup> / <sub>2</sub> 27
RATT <sub>V</sub>		Radius vector output of integration	feet	meters	2 <sup>29</sup>
RLSV <sub>D</sub>	r <sub>LS</sub>	Lunar landing site radius	feet	meters	2 <sup>27</sup>
RMAG <sub>D</sub>	r	Magnitude of radius vector	feet	meters	2 <sup>27</sup> 2 <sup>29</sup>
RNV	r̄	Radius vector as given by AVERAGEG	feet	meters	2 <sup>29</sup>
RONE <sub>V</sub>	r̄	Radius vector input to integration	feet	meters	2 <sup>29</sup> / <sub>2</sub> 27
RPADTEM <sub>D</sub>		Location for storing pad radius	feet	meters	2 <sup>29</sup> / <sub>2</sub> 27

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Corliss	DATE 9/24/69	Orbital Parameters Display	
PRGMR J. Corliss	REV 2/2/69	DOCUMENT NO. FC-2650	
ANALST		COLOSSUS IIC	
DOCMR R. J. ...		REV 1	
APPRD R. J. ...		SHEET 23 OF 25	

ERASABLE LOCATIONS USED (CONTINUED)					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
RPER <sub>D</sub>	r <sub>p</sub>	Magnitude of pericenter	feet	meters	$2^{27}/2^{29}$
TFF <sub>D</sub>	t <sub>ff</sub>	Time of free fall to a certain altitude	seconds	csec	2 <sup>28</sup>
TFF/RTMU <sub>D</sub>	$1/\sqrt{\mu}$	Inverse of the square root of mu	sec/feet <sup>3/2</sup>	csec/m <sup>3/2</sup>	$2^{14}/2^{17}$
TFFALFA <sub>D</sub>		Inverse of the semimajor axis of a conic	1/feet	1/meters	$2^{-26} - X1/$ $2^{-24} - X1$
TFFNP <sub>D</sub>	p	Semilatus rectum, normalized	feet	meters	$2^{28} + X1/$ $2^{36} + X1/$
TFFRTALF <sub>D</sub>	$\sqrt{a}$	Square root of alpha	1/feet <sup>1/2</sup>	1/m	$2^{-10} - X1/$ $2^{-9} - X1$
TFFVVSQ <sub>D</sub>	(v <sup>1</sup> ) <sup>2</sup>	Velocity/ $\sqrt{\mu}$	1/feet <sup>1/2</sup>	1/m <sup>1/2</sup>	$2^{-20}/2^{-18}$
TFF1/ALF <sub>D</sub>		Signed, semi-major axis, weighted by X2	feet	meters	$2^{22} - 2 \cdot X2/$ $2^{20} - 2 \cdot X2$
TIME2 <sub>D</sub>		Timing registers	seconds	csec	2 <sup>28</sup>
TSTART8 <sub>D</sub>		Storage for TIME2 input	seconds	csec	2 <sup>28</sup>
TDEC1 <sub>D</sub>		Time to be integrated to	seconds	csec	2 <sup>28</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. S. ...</i>	Orbital Parameters Display	
PRGRM	<i>J. S. ...</i>	DOCUMENT NO.	
ANALST		COLOSSUS IIC	FC-2650
DOCNR	<i>Doc 2000-2000-2000</i>	REV 1	SHEET 24 of 25
APPR'D	<i>[Signature]</i>		

ERASABLE LOCATIONS USED (CONTINUED)					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC VALUE AND UNITS	AGC SCALING
VATTV		Velocity output of integration routines	feet/sec	meters/csec	$2^7$
VNV		Velocity vector, output of AVERAGEG	feet/sec	m/csec	$2^7$
VONEV		Velocity vector	feet/sec	m/csec	$2^7$
VONE'V		VONE	feet <sup>-1/2</sup>	m <sup>-1/2</sup>	$3 \cdot 10^2 \cdot 2^{-9}$

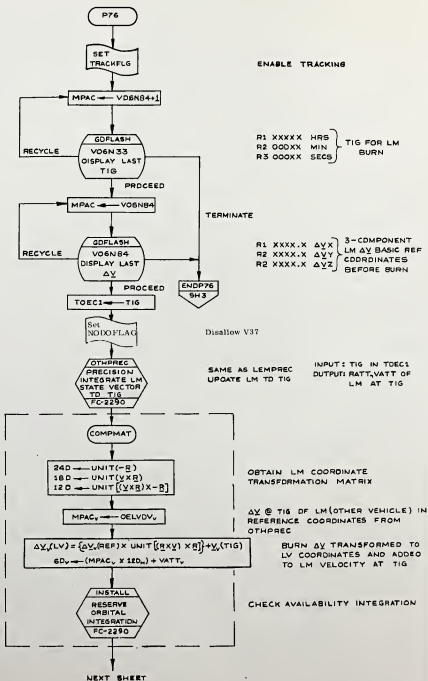
PROGRAM CONSTANTS					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
MAXNM		Maximum display value possible	9999.9 NM	01065 056038	$2^0$
MINPERE	r <sub>p</sub> MIN	300,000 ft reference alt for earth	300,000 ft	91440 meters	$2^9$
MINPERM	r <sub>p</sub> MIN	35,000 ft reference alt for moon	35,000 ft	1068 meters	$2^7$
RPAD		Standard pad radius	20910922 ft	6378338 meters	$2^{29}$
1/RTMUE	$1/\sqrt{\mu}_E$	Inverse of the square root of mu for earth	.0008427916 x10 <sup>-5</sup>	50087529 x10 <sup>-5</sup>	$2^{-17}$
1/RTMU	$1/\sqrt{\mu}_M$	Inverse of the square root of mu for moon	.0076599228 x10 <sup>-4</sup> sec/ft <sup>3/2</sup>	.45182595 x10 <sup>-4</sup> csec/m <sup>3/2</sup>	$2^{-14}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Corbett</i>	<i>12-7-69</i>	Orbital Parameters Display	
PRGMR <i>J. Corbett</i>	<i>12-7-69</i>		
ANALST		COLOSSUS IIC	DOCUMENT NO. FC-2650
DOCHR <i>(Signature)</i>	<i>12/10/69</i>	REV 1	SHEET 25 OF 25
APPR'D <i>(Signature)</i>			

P76 TARGET DELTA VELOCITY

P76 Sh. 2  
 COMPMAT SR. 2  
 P76SUB1 Sh. 3

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. J. ...</i>		P76 Target Delta V	
PRDWR <i>J. E. ...</i>		DOCUMENT NO.	
ANALST		COLLASSIS 20	FC-2670
DUCMR <i>...</i>		REV 2	SHEET 1 OF 8



ENABLE TRACKING

R1 XXXXX HRS } TIG FOR LM  
R2 000XX MIN } BURN  
R3 000XX SECS }

R1 XXXX.X ΔVX } 3-COMPONENT  
R2 XXXX.X ΔVY } LM ΔV BASIC REF  
R3 XXXX.X ΔVZ } COORDINATES  
BEFORE BURN

Disallow V37

SAME AS LEMPREC INPUT: TIG IN TOEC1  
UPDATE LM TO TIG OUTPUT: RATT,VATT OF  
LM AT TIG

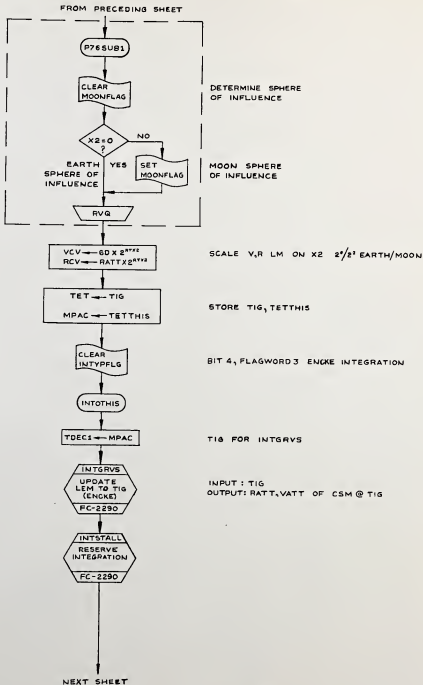
OBTAIN LM COORDINATE  
TRANSFORMATION MATRIX

ΔV @ TIG OF LM (OTHER VEHICLE) IN  
REFERENCE COORDINATES FROM  
OTHPREC

BURN ΔV TRANSFORMED TO  
LV COORDINATES AND ADDED  
TO LM VELOCITY AT TIG

CHECK AVAILABILITY INTEGRATION

27MAR68 16 APR 68 15 APR 68 15 APR 68	27MAR68 16 APR 68 15 APR 68 15 APR 68	TARGET DELTA V COLOSSUS 2D FC-2670 2 5
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P76  
TARGET DELTA V  
COLOSSUS 2D FC-2670  
2

4.0 [Signature]  
J.C. [Signature]  
[Signature]

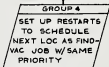
SIMARAS  
[Signature]  
24 May 67

3 6

FROM PRECEDING SHEET



SAVE CSM POSITION, VELOCITY, TIME INTEGRATED TO



BIT 7, FLAG 10 INTEGRATION ROUTINE TO BE RESTARTED



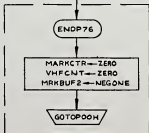
(SAME AS ATOPLEM)



RELINQUISH INTEGRATION ROUTINE



ALLOW V37



CLEAR COUNTERS

MIT INTEGRATION LAB CAMBRIDGE, MASS.		DATE: 12 May 64	
PROJECT: <i>Colossus</i>		P76	
DESIGNER: <i>J.C. Suck</i>	ENGINEER: <i>J.C. Suck</i>	TARGET DELTA V	
APPROVER: <i>John Suck</i>	DATE: <i>12 May 64</i>	COLOSSUS 2D	FC-2670
		REV: 2	REV: 4



## SUBROUTINES CALLED

SUBROUTINE NAME	WHERE FLOWED	DESCRIPTION	WHERE CALLED
OTHPREC	FC-2290	(SAME AS LEMPREC) PRECISION INTEGRATION OF LM	Sh. 2
INSTALL	FC-2290	RESERVES ORBITAL INTEGRATION	2
INTGRVS	FC-2290	ENKE UPDATE OF LEM TO TIG	3
MINIRECT	FC-2290	INITIALIZE NEW CONIC	4
ATOPOTH	FC-2290	MOVES LM STATE VECTOR TO PASSIVE STORAGE LOC	1
INTWAKE 0	FC-2290	RELEASES ORBITAL INTEGRATION ROUTINES	1

## FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
TRACKFLG	ENABLE MARKTAKING	INHIBIT MARKTAKING	Sh. 2		
MOONFLAG	MOON SPHERE OF INFLUENCE	EARTH SPHERE OF INFLUENCE	Sh. 5	Sh. 5	
INTYFLAG	ENKE INTEGRATION	CONIC INTEGRATION		Sh. 3	
REINTFLAG	RESTART INTEGRATION	DO NOT RESTART INTEGRATION	Sh. 4		
NODOFLAG	V>7 NOT PERMITTED	V>7 PERMITTED	Sh. 2	Sh. 4	

## VARIABLE ERASABLE LOCATIONS USED

AGC TAG	GPOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TDECI		STORAGE LOC FOR INTEGRATION TIME		CSEC	2 <sup>28</sup>
TIG		STORAGE LOC FOR IGNITION TIME		CSEC	2 <sup>28</sup>
DELVOV		ΔV OTHER VEHICLE (LM)		M CSEC	2 <sup>7</sup>
VCV		TEMPORARY CONIC VELOCITY		M CSEC	2 <sup>7</sup>
RCV		TEMPORARY CONIC POSITION		M	2 <sup>21</sup>
TET		TEMPORARY TIME OF STATE VECTOR		CSEC	2 <sup>28</sup>
TETHHS		TEMPORARY TIME OF CSM STATE VECTOR		CSEC	2 <sup>28</sup>
RRECT		TEMPORARY POSITION AT RECT TIME		M	2 <sup>20</sup>
MARKCTR		MARK COUNTER (USED BY R321)			1 <sup>0</sup>
VHFCNT		VHF MARK COUNTER			1 <sup>0</sup>
MRKBUF2		TEMP MARK COUNTER FOR R21			1 <sup>0</sup>
NEGONE		NEGATIVE 1			1 <sup>14</sup>

<p>MAY 1968          INSTRUMENTAL LAB          CAMBRIDGE MASS.</p> <p>3040          3000          2900          2800</p> <p><i>(Handwritten signatures and dates)</i></p>	<p>076</p> <p>TARGET DELTA V</p> <p>COLOSSUS 20          FC-2670</p>
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DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V00N84		DISPLAY LAST AV	Sh. 2
V00N33		DISPLAY LAST TIG	Sh. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		FIELD CERTAIN AND MEASUREMENT	
DRAWN: <i>Richard...</i>		P76 TARGET DELTA V	
REVISOR: <i>J.C. Carlson</i>	DATE: <i>10 May 68</i>	COLOSSUS 2D FC-2670	
DATE: <i>10 May 68</i>	BY: <i>J.C. Carlson</i>	REV 2	
APPROVED: <i>John H. ...</i>	DATE: <i>12 May 68</i>		

THRUST PROGRAMS (P40 AND P41)

Within this flowchart are the replacement sheets (Sh. 15, 51) to update the COLOSSUS 2C flowchart, FC-2680, Rev. 2, to the COLOSSUS 2D flowchart, FC-2680, Rev. 3

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P.T.E. P-41	
		THRUST PROGRAMS	
DRAWN		COLLOSSUS 2D	DOCUMENT NO. PX-2680
PROGRAM	<i>S.M. Gault</i>		
ANALYST		REV. 1	SHEET OF
DOCTR	<i>Robert M. Gault</i>		
APPROV	<i>Robert M. Gault</i>		

THRUST PROGRAMS (P40 AND P41)  
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

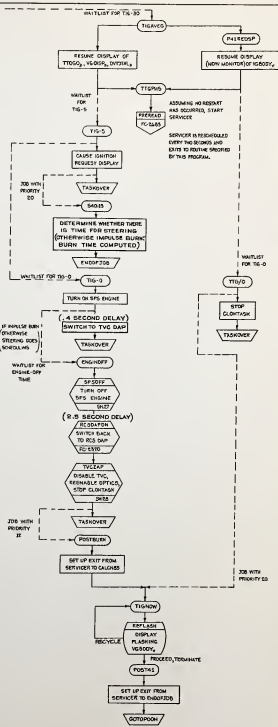
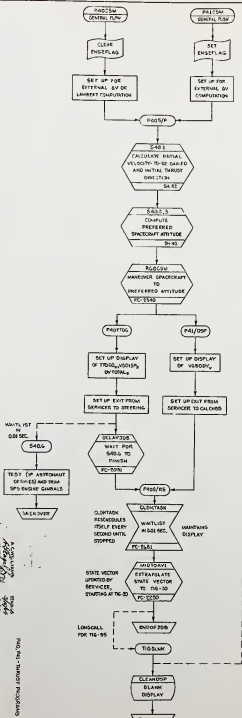
P40CSM:	HANDLES TIMING OF AN SPS MANEUVER INPUTS (FROM PRE-THRUST PROGRAMS): TIG <sub>D</sub> - TIME OF INITIATION OF MANEUVER, IN CSEC @ 2 <sup>28</sup> XDELVFLG - INDICATES WHETHER EXTERNAL ΔV OR LAMBERT MANEUVER	SH. 4									
IF EXTERNAL ΔV	<table border="0" style="border-left: 1px solid black; border-right: 1px solid black;"> <tr> <td style="padding-left: 10px;">DELVSIN<sub>V</sub> - DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES, IN M/CSEC @ 2<sup>7</sup></td> <td rowspan="3" style="font-size: 3em; padding: 0 10px;">}</td> <td rowspan="3"></td> </tr> <tr> <td style="padding-left: 10px;">WEIGHT/G<sub>D</sub> - MASS OF TOTAL VEHICLE (INCLUDING LM IF APPROPRIATE), IN KG @ 2<sup>16</sup></td> </tr> <tr> <td style="padding-left: 10px;">RTIG<sub>V</sub> - POSITION VECTOR AT TIME OF IGNITION IN REFERENCE COORDINATES, IN M @ 2<sup>29</sup></td> </tr> </table> <table border="0" style="border-left: 1px solid black; border-right: 1px solid black;"> <tr> <td style="padding-left: 10px;">VTIG<sub>V</sub> - VELOCITY VECTOR AT TIME OF IGNITION IN REFERENCE COORDINATES, IN M/CSEC @ 2<sup>7</sup></td> <td rowspan="2" style="font-size: 3em; padding: 0 10px;">}</td> <td rowspan="2"></td> </tr> <tr> <td style="padding-left: 10px;">OR</td> </tr> </table>	DELVSIN <sub>V</sub> - DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES, IN M/CSEC @ 2 <sup>7</sup>	}		WEIGHT/G <sub>D</sub> - MASS OF TOTAL VEHICLE (INCLUDING LM IF APPROPRIATE), IN KG @ 2 <sup>16</sup>	RTIG <sub>V</sub> - POSITION VECTOR AT TIME OF IGNITION IN REFERENCE COORDINATES, IN M @ 2 <sup>29</sup>	VTIG <sub>V</sub> - VELOCITY VECTOR AT TIME OF IGNITION IN REFERENCE COORDINATES, IN M/CSEC @ 2 <sup>7</sup>	}		OR	
DELVSIN <sub>V</sub> - DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES, IN M/CSEC @ 2 <sup>7</sup>	}										
WEIGHT/G <sub>D</sub> - MASS OF TOTAL VEHICLE (INCLUDING LM IF APPROPRIATE), IN KG @ 2 <sup>16</sup>											
RTIG <sub>V</sub> - POSITION VECTOR AT TIME OF IGNITION IN REFERENCE COORDINATES, IN M @ 2 <sup>29</sup>											
VTIG <sub>V</sub> - VELOCITY VECTOR AT TIME OF IGNITION IN REFERENCE COORDINATES, IN M/CSEC @ 2 <sup>7</sup>	}										
OR											
IF LAMBERT	<table border="0" style="border-left: 1px solid black; border-right: 1px solid black;"> <tr> <td style="padding-left: 10px;">ECSTEER - CROSS-PRODUCT STEERING CONSTANT @ 2<sup>3</sup></td> <td rowspan="3" style="font-size: 3em; padding: 0 10px;">}</td> <td rowspan="3"></td> </tr> <tr> <td style="padding-left: 10px;">RTARC<sub>V</sub> - AIMPOINT POSITION VECTOR IN REF. ERENCE COORDINATES, IN M @ 2<sup>29</sup></td> </tr> <tr> <td style="padding-left: 10px;">TPASS<sub>D</sub> - TIME OF ARRIVAL AT AIMPOINT IN CSEC @ 2<sup>28</sup></td> </tr> </table>	ECSTEER - CROSS-PRODUCT STEERING CONSTANT @ 2 <sup>3</sup>	}		RTARC <sub>V</sub> - AIMPOINT POSITION VECTOR IN REF. ERENCE COORDINATES, IN M @ 2 <sup>29</sup>	TPASS <sub>D</sub> - TIME OF ARRIVAL AT AIMPOINT IN CSEC @ 2 <sup>28</sup>					
ECSTEER - CROSS-PRODUCT STEERING CONSTANT @ 2 <sup>3</sup>	}										
RTARC <sub>V</sub> - AIMPOINT POSITION VECTOR IN REF. ERENCE COORDINATES, IN M @ 2 <sup>29</sup>											
TPASS <sub>D</sub> - TIME OF ARRIVAL AT AIMPOINT IN CSEC @ 2 <sup>28</sup>											
P41CSM:	HANDLES TIMING OF AN RCS MANEUVER INPUTS (FROM PRE-THRUST PROGRAMS): ALL THOSE FOR P40 (EXTERNAL ΔV CASE), AS WELL AS NJETSPLG - INDICATES 3- OR 4- JET BURN	SH. 5									
SETMINDB:	SETS MINIMUM DEADBAND	SH. 7									
TIGBLNK:	BLANKS DISPLAY (AT TIG-35)	SH. 14									
TIGAVEG:	RESUMES DISPLAY; STARTS AVERAGEG ROUTINE (AT TIG-30)	SH. 15									
TIG-5	SCHEDULES IGNITION (AT TIG-5), CAUSES V99 FLASH (IGNITION ENABLE REQUEST)	SH. 16									
S40.13	DETERMINES WHETHER LONG (STEERING) OR SHORT (IMPULSE) BURN; IF SHORT, COMPUTES BURN TIME	SH. 17									
TIG-0	STARTS IGNITION	SH. 20									
IGNITION:	TURNS ON SPS ENGINE, SETS UP TVC DAP; IF SHORT BURN, SCHEDULES ENGINE CUTOFF	SH. 20									
ENGINEOFF:	SETS UP ENGINE CUTOFF AND RETURN TO RCS DAP	SH. 24									
SETMAXDB:	SETS MAXIMUM DEADBAND	SH. 25									
SPSOFF:	TURNS OFF SPS ENGINE; DOES TVC UPDATES	SH. 27									
TVCZAP:	DISABLES THRUST VECTOR CONTROL	SH. 28									
POSTBURN:	DOES FINAL DISPLAY	SH. 29									
P40RCS:	CLEANS UP AFTER-BURN DETAILS	SH. 29									
TIGNOW:	LETS ASTRONAUT DO SMALL VELOCITY CHANGE CORRECTION	SH. 30									
POST41:	ENDS PROGRAM	SH. 30									
TIG/0:	ENDS DISPLAY; SETS UP END OF PROGRAM	SH. 31									

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P40, P41-THRUST PROGRAMS	
DRAWN A.C. WILLIAMS	15NOV62	COLOSSUS II D	DOCUMENT NO. FC-2600
PROGRAM <i>[Signature]</i>	<i>[Signature]</i>		
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DOCAB <i>[Signature]</i>	<i>[Signature]</i>		
APPROV <i>[Signature]</i>	<i>[Signature]</i>		
19 MAR 61		REV 3	PAGE 1 OF 59

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS (CONTINUED):

S40.1:	CALCULATES INITIAL VELOCITY-TO-BE-GAINED AND INITIAL THRUST DIRECTION	SH.32
AGAIN:	CALCULATES REQUIRED VELOCITY AND VELOCITY CHANGE FOR A MANEUVER BEGINNING AT A GIVEN TIME	SH.38
S40.2,3:	COMPUTES PREFERRED SPACECRAFT ATTITUDE	SH.40
S40.6:	TESTS (IF REQUIRED) AND TRIMS SPS ENGINE GIMBALS	SH.44
PR40.6	RESTART ENTRY TO S40.6	SH.44

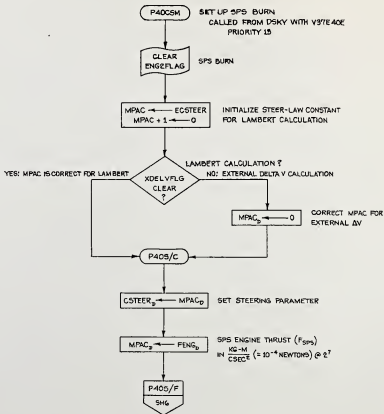
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROX GEO. IN. AND NAV. INST. LA	
DRAWN A. C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PREPARED <i>A. C. Williams</i>	15NOV68	COLLOSSUS II D	FC-2680
ANALYST <i>A. C. Williams</i>	11/1/68		
DOCUMENTED <i>A. C. Williams</i>	3/1/69		
APPROVED <i>A. C. Williams</i>	7/26/68	REV 3	2 of 58



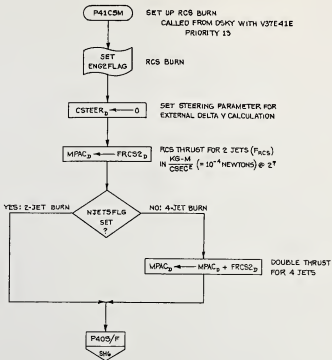
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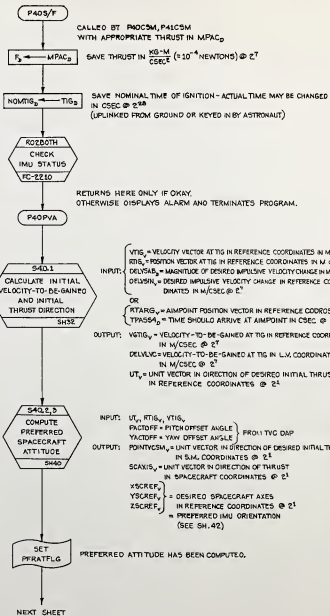


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		P40, P41 - THRUST PROGRAMS	
DRAWN A.C. WILLIAMS	1700CSM	DOCUMENT NO.	FC-2680
PROG: <i>W. J. Williams</i>	<i>2/11/67</i>	COLOSSUS ID	
ANALYST: <i>W. J. Williams</i>	<i>2/11/67</i>		
DOC: <i>W. J. Williams</i>	<i>2/11/67</i>		
APP'D: <i>W. J. Williams</i>	<i>2/11/67</i>		



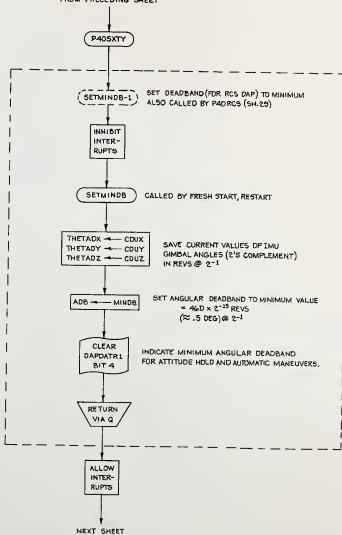
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DRAWN A.C. WILLIAMS	DATE 3/1/68	ANALYST R. J. GIBLIN	DATE 3/1/68
APPROV. J. H. BROWN	DATE 3/1/68	APPROV. J. H. BROWN	DATE 3/1/68
COLLOSSUS IID		FC-2680	
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DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROGRAM <i>W.C.</i>	INSTRUM <i>W.C.</i>	EQUATION NO. <i>1000</i>	
ANALYST <i>W.C. Williams</i>	DATE <i>10/1/68</i>	COLOSSUS <input checked="" type="checkbox"/>	FC-2680
DOCK <i>W.C. Williams</i>	APPV <i>W.C. Williams</i>	REV <i>3</i>	SHEET 6 OF 8

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARJELLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PROGRAM P40, P41 - THRUST PROGRAMS	
PROGRAM <i>4/26/61</i>	DOC# 2661	ANALYST <i>L. G. Chubb</i>	COLLOSSUS II DOCUMENT NO. FC-2680
DOCS <i>4/26/61</i>	APPR <i>4/26/61</i>	REV 2	SHEET 7 OF 58

FROM PRECEDING SHEET



INPUT: SCAXIS<sub>v</sub> = AXIS (IN SPACECRAFT COORDINATES)  
TO BE ALIGNED @ 2°  
POINTVCSM<sub>v</sub> = DIRECTION (IN S.M.COORDINATES) OF  
DESIRED ALIGNMENT @ 2°  
BAXISFLG = 0 (SET BY FRESHSTART AND RESET  
EVERY TIME RGOCSM RUNS)  
INDICATES THAT ROUTINE IS TO ALIGN  
ONE VECTOR RATHER THAN 3 AXES.

NBRCYCL5 ← -1

INITIALIZE VARIABLE TO BEGIN  
S40.9 (VELOCITY-TO-BE-GAINED CALCULATION)

SET  
TIMRFLAG

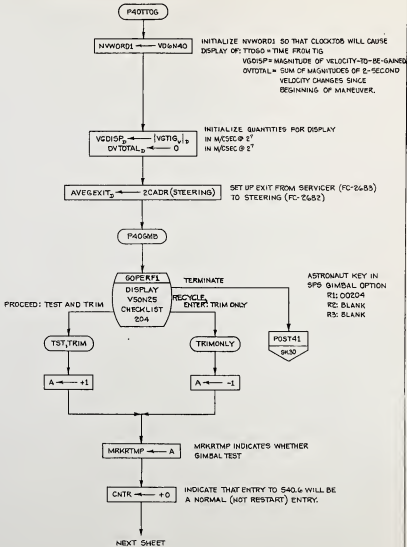
CLOCKTASK OPERATING

P40: SPS

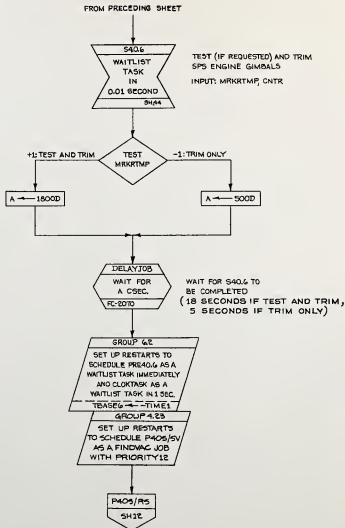
P41: RCS



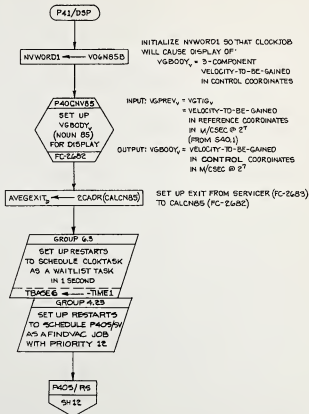
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DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
FROM <i>FC-2340</i>	DATE <i>1/10/68</i>	DOCUMENT NO.	
ANALYST <i>FC-2340</i>	BY <i>FC-2340</i>	COLLOSSUS II D   FC-2680	
DOCS <i>FC-2340</i>	DATE <i>1/10/68</i>	REV 0	
APPROV <i>FC-2340</i>	DATE <i>1/10/68</i>	UNIT 8 W 58	



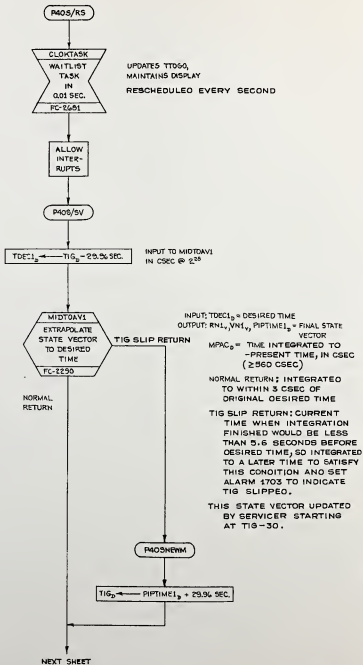
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DRAWN A.C. WILLIAMS FROM <i>[Signature]</i> ANALYST <i>[Signature]</i> CHECKED BY <i>[Signature]</i> APPROVED BY <i>[Signature]</i>	P40, P41 - THRUST PROGRAMS COLLOSSUS II O DOCUMENT NO. FC-2680 REV 3



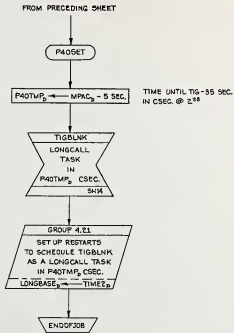
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DRAWN: A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROGRAM: <i>FC-207D</i>	DATE: <i>3/1/69</i>	COLLOSSUS ID: <i>FC-2680</i>	DOCUMENT NO.
ANALYST: <i>John D. ...</i>	DATE: <i>3/1/69</i>	FC-2680	
BOOKED: <i>John D. ...</i>	DATE: <i>3/1/69</i>	SHEET 10 OF 58	
APPROVED: <i>John D. ...</i>	DATE: <i>3/1/69</i>		



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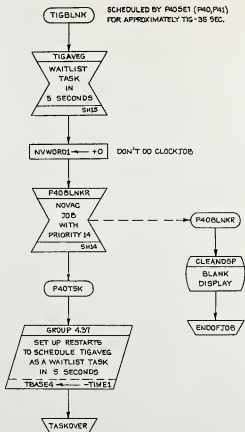


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROGR <i>FC-2680</i>	SCALE <i>1/4"</i>	COLLOSSUS ID	
ANALYST <i>John Williams</i>	<i>Willet</i>	DOT UNIT IN: FC-2680	
DOCUMENTED <i>John Williams</i>	<i>Willet</i>	SHEET NO. OF 58	
APPROV <i>John D. Brown</i>	REV 3		

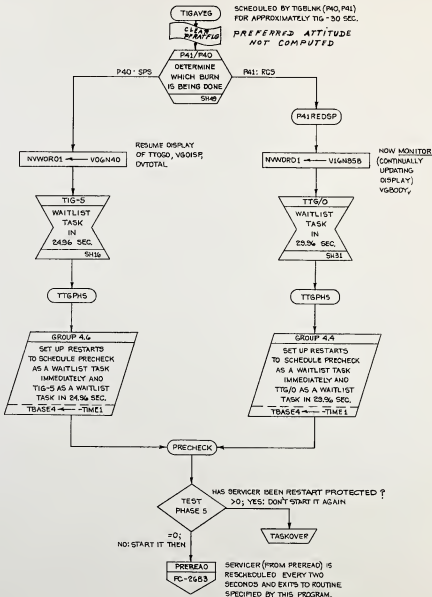


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DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROGRAM <i>P40</i>	DATE <i>1/10/68</i>	DOCUMENT NO.	
ANALYST <i>A.C. Williams</i>	<i>1/10/68</i>	COLLOSSUS II D	FC-2680
DOCUMENT NO. <i>FC-2680</i>	DATE <i>1/10/68</i>	REV B	SHEET 13 OF 58

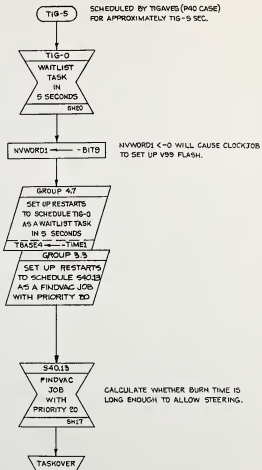




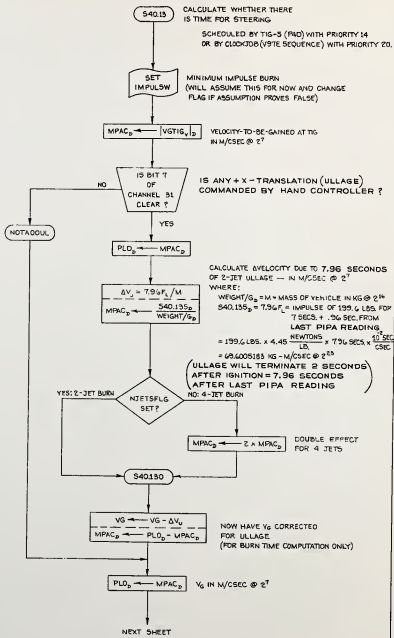
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DRAWN A.C. WILLIAMS		PROJECT P40, P41 - THRUST PROGRAMS	
PROW <i>A.C. Williams</i>	DESIGN <i>A.C. Williams</i>	DOCUMENT NO. COLOSSUS IID      FC-2680	SHEET 14 OF 58
ANALYST <i>A.C. Williams</i>	ANALYST <i>A.C. Williams</i>		
DOCK <i>A.C. Williams</i>	DOCK <i>A.C. Williams</i>		
APPROV <i>A.C. Williams</i>	APPROV <i>A.C. Williams</i>		



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DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
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ANALYST <i>[Signature]</i>	3042	COLOSSUS IID FC-2680	
DOCS <i>[Signature]</i>	11/17	REV 5	
APPROV <i>[Signature]</i>	12/22/64	SER 15 OF 58	



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DRANN A.C. WILLIAMS		PMO, P41-THRUST PROGRAMS	
PREPARED	11/16/68	COLOSSUS II D	DOCUMENT NO.
ANALYST	11/16/68	FC-2680	
DOCNO	11/16/68		
APPROVED	11/16/68		



INSTRUMENTATION AB CAMPBELL MASS.		P40, P41 - THRUST PROGRAMS
JEFFERY A.C. WILLIAMS 11-20-64 ANALYST DTIC UPPD	1000790 3/0/64 11/1/64 7/5/64 12/1/64	COLLOSSUS II D FC-2680 3

FROM PRECEDING SHEET

$$T_1 = V_0 - \frac{K_1}{M}$$

$$MPAC_0 \leftarrow PLO_0 - \frac{KIVAL_0}{WEIGHT/G_0}$$

INTERMEDIATE RESULT RELATING  $V_0$  AND  $\Delta$  VELOCITY DUE TO 1 SEC. OF SPS THRUST IN M/CSEC @ 2<sup>7</sup>  
 $KIVAL_0$  = SPS IMPULSE AFTER 1 SEC. OF THRUST (= KEVAL<sub>0</sub>) FOR A 1 KG VEHICLE.  
 IN KG-M/CSEC @ 2<sup>23</sup>  
 $WEIGHT/G_0$  = MASS OF VEHICLE IN KG @ 2<sup>18</sup>

BURN TIME < 1 SECOND ?  
 $MPAC_0 < -0?$

S40.131  
 SH19

PL2<sub>0</sub> ← MPAC<sub>0</sub> SAVE T<sub>1</sub>

$$T_2 = \frac{5FIMP}{M - 3.5M}$$

$$PLA_0 \leftarrow \frac{FANG_0 \times 5SECONDO_0 \times 2^{-2}}{WEIGHT/G_0 - 3.5SECONDO_0 \times EMDOT_0}$$

CALCULATE  $\Delta$  VELOCITY DUE TO 5 SECS. OF SPS THRUST, IN M/CSEC @ 2<sup>7</sup>

WHERE:  
 $FANG_0$  = THRUST IN KG-M/CSEC @ 2<sup>7</sup>  
 (PAD LOADED)  
 $WEIGHT/G_0$  = MASS OF VEHICLE IN KG @ 2<sup>14</sup>  
 $EMDOT_0$  = RATE OF MASS DECREASE DURING BURN  
 IN KG/CSEC @ 2<sup>3</sup>  
 $5SECONDO_0$  = 500 CSEC @ 2<sup>24</sup>  
 $3.5SECONDO_0$  = 350 CSEC @ 2<sup>19</sup>  
 $2^{-2}$  = MEAN BURN TIME FOR 1-6 SECONDS  
 $2^{-2}$  FACTOR IS FOR SCALING.

BURN TIME < 6 SECS ?  
 $PL2_0 < PLA_0$  ?

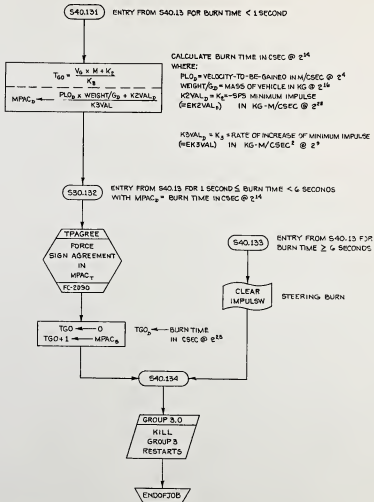
$$MPAC_0 \leftarrow 1SECONDO_0 + \frac{PL2_0}{PLA_0} \times 5SECONDO_0$$

CALCULATE BURN TIME BY EXTRAPOLATION IN CSEC @ 2<sup>14</sup>  
 WHERE:  
 $1SECONDO_0 = 100CSEC @ 2^8$

S40.133  
 SH19

S40.132  
 SH19

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PRICE	2/19/67	DOCUMENT NO.	FC-2680
ANALYST	3/1/67	CHECKED BY	COLLINS
SOCIAL	3/1/67	DATE	3/1/67
APPROV	12/1/67	SHEET NO.	OF 58



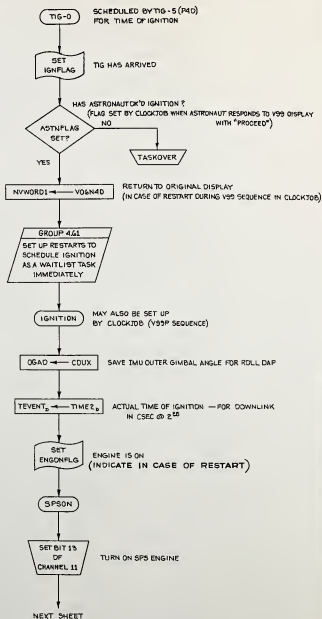
NOTE: BURN TIME COMPUTATIONS (ABOVE) FOLLOW THE EMPIRICALLY DERIVED EXPRESSION FOR IMPULSE :

FOR 0 SEC. <  $\Delta t$  < 1 SEC:  $MV_0 = -K_2 + K_3 \Delta t$

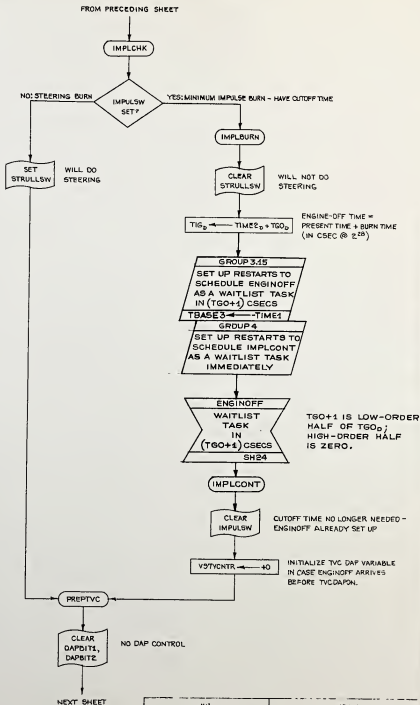
FOR 1 SEC. <  $\Delta t$  < 6 SEC:  $MV_0 = K_1 + F_{IMP}(\Delta t - 1 \text{ SEC})$

[  $K_1, K_2, K_3, F_{IMP}$   
 STORED IN ERASABLE  
 MEMORY ]

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFOSL CONTRACT AND DEV. # 47-115	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROG# 487-2-1-1	3/20/68	DOCUMENT #	
ANALYST P. J. HULL	3/11/68	COLOSSUS II D	FC-2680
DOCS# 487-2-1-1-1	3/11/68	3-17-68	
APPROV. J. A. WOOD	3/11/68	15 58	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRANN, A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROGRAM	2/20/68	COLLOSSUS IID	DOCUMENT NO
ANALYST	2/20/68		FC-2680
DOCUMENTED BY	3/2/69		REV B
APPROVED	3/2/69		REV B



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT D40, P41 - THRUST PROGRAM	
DRAWN A.C. WILLIAMS	DATE 1/15/64	ANALYST J. J. COLOSSUS	REV 3
DOC# 100-100-100-100	APPROV'd [Signature]	PROJECT NO. FC-2680	SHEET 21 OF 58



FROM PRECEDING SHEET

TSLOC<sub>0</sub> ← 2CADR (TSIDLOC)<sub>0</sub>

NO DAP USING TIMES COUNTER -  
TSRPT WILL GO TO IDLING ROUTINE

GROUP 4.3  
SET UP RESTARTS TO  
SCHEDULE DOTVCON  
AS A WAITLIST TASK  
IN 0.4 SECOND  
TBASE4 ← TIME1

FIXDELAY  
WAIT  
0.4 SECOND  
FC-2040

WAIT FOR THRUST BUILDUP

DOTVCON

TVCPHASE ← -1  
TVCXPHS ← +0

RESTART INITIALIZATION PHASE OF TVC DAP  
NOT INTO TVCEXEC YET

SET DAPBIT1  
CLEAR DAPBIT2

TVC DAP IN CONTROL

GROUP 4.3  
SET UP RESTARTS TO  
SCHEDULE CLKTASK  
AS A WAITLIST TASK  
IN 1 SECOND

ERRBTMP ← ERROR1  
ERRBTMP+1 ← ERROR2

SAVE PITCH<sub>1</sub> YAW ATTITUDE ERRORS  
FROM RCS DAP FOR USE IN  
INITIALIZING TVC DAP IN REV5 @ 2<sup>-1</sup>

GROUP 4.5  
SET UP RESTARTS TO  
SCHEDULE DOSTRULL  
AS A WAITLIST TASK  
IN 1.6 SECONDS  
TBASE4 ← TIME1

TVC DAP WOULD BE  
RESTARTED ANYWAY

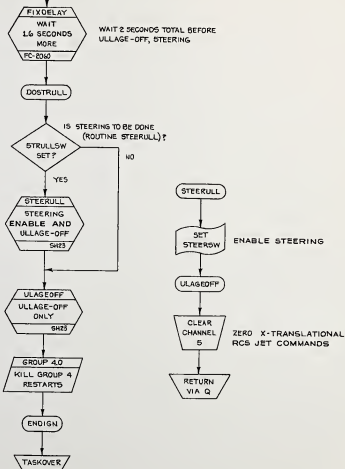
TVC DAPON  
TSRPT TASK  
WITHIN 0.01 SEC  
FC-2490

SETS UP TVC DAP

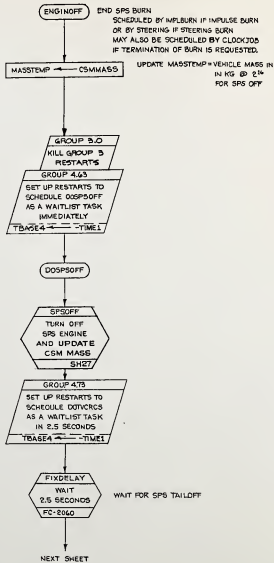
NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
BRANN A. C. WILLIAMS		PAO, IMJ - THRUST PROGRAMS	
PROGRAM	3/1/67	COLLOSSUS II D	DOCUMENT NO:
ANALYST	3/1/67		FC-2680
DOCK	3/1/67	REV 5	SHEET 22 OF 58

FROM PRECEDING SHEET

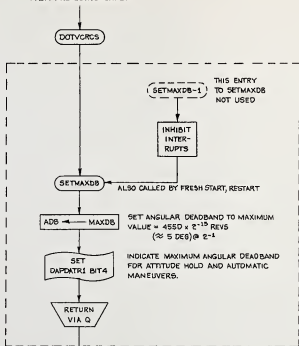


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		48-110 GUIDE 1 AND 2A - 11	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
TOLMAN R. S. [Signature]		DOCTILE	
ANALYST [Signature]		2/26/57	
DOC# 44-2000-11-20022		3/1/57	
APPRO'D [Signature]		17-266-1	
		CON OISSUS II D	
		FC-2680	
		MAY 23 1958	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS 100765		P40, P41 - THRUST PROGRAMS	
PCB# 4/10/64	4/10/64	COLUSSUS IID	FC-2680
ANALYST 4/10/64	4/10/64		REV 3
DO 4/10/64	4/10/64		
APPROV 4/10/64	4/10/64		
		FC-2680	
		SHEET 24 OF 58	

FROM PRECEDING SHEET



RCS DAPON  
SET UP  
RCS DAP  
FC-2370

NO MORE TVC DAP CONTROL

MASS/PROP  
UPDATE  
FILTER GAINS  
AND WEIGHT/G  
FOR RCS DAP  
FC-2430

TVCZAP  
DISABLE TVC,  
RENEWABLE OPTICS,  
DISABLE  
CLOCKTASK  
SHZB

NEXT SHEET

MIT DOCUMENTATION CENTER LAMARIBL, MASS.	
DRAWN A.C. WILLIAMS	280748
PROJ. A.S. 2/8/68	2068
ANALYST A.S. 2/8/68	2068
DATE 2/8/68	2068
APPROV. [Signature]	17 2068

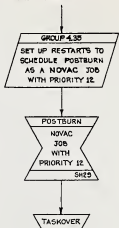
P40, P41-THRUST PROGRAMS

COLOSSUS II D FC-2680

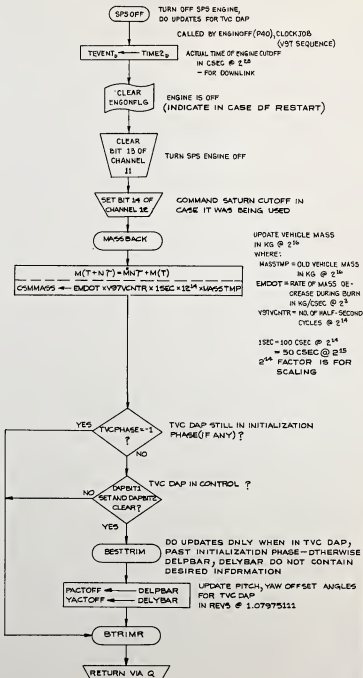
4.3

25 58

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		GROUP GUIDANCE AND NAVIGATION	
DRAWN BY A.C. WILLIAMS		PROJECTS	
PROGRAM	NOVAC	P40, P41 - THRUST PROGRAMS	
ANALYST	Edwin D. ...	DRAWING NO.	
DOOR	...	COLOSSUS II D : FC-2680	
APPROVED	John D. ...	REV. 26	



SPS OFF

TURN OFF SPS ENGINE,  
DO UPDATES FOR TVC DAP

CALLED BY ENGINOFF(P40), CLOCKJOB  
(VST SEQUENCE)

TEVENT ← TIMEZ

ACTUAL TIME OF ENGINE CUTOFF  
IN CSEC @ 2<sup>14</sup>  
- FOR DOWNLINK

CLEAR ENGINFLG

ENGINE IS OFF  
(INDICATE IN CASE OF RESTART)

CLEAR  
BIT 13 OF  
CHANNEL 11

TURN SPS ENGINE OFF

SET BIT 14 OF  
CHANNEL 12

COMMAND SATURN CUTOFF IN  
CASE IT WAS BEING USED

MASSBACK

UPDATE VEHICLE MASS  
IN KG @ 2<sup>16</sup>

WHERE:

MASSTMP = OLD VEHICLE MASS  
IN KG @ 2<sup>16</sup>

EMDOT = RATE OF MASS DE-  
CREASE DURING BURN  
IN KG/CSEC @ 2<sup>14</sup>

VSTVCTR = NO. OF HALF-SECOND  
CYCLES @ 2<sup>14</sup>

1SEC = 100 CSEC @ 2<sup>14</sup>

= 50 CSEC @ 2<sup>15</sup>

2<sup>14</sup> FACTOR IS FOR  
SCALING

$$M(T+\Delta T) = MNT + M(T)$$

$$CSMMASS \leftarrow EMDOT \times VSTVCTR \times 156C \times 12^{14} \times MASSTMP$$

YES  
TVCPHASE ← 1

TVCPHASE ← 1  
TVCPHASE STILL IN INITIALIZATION  
PHASE (IF ANY)?

NO

NO  
DAPMT1  
SET AND DAPMT2  
CLEAR?

TVCPHASE IN CONTROL?

BESTRIM

DO UPDATES ONLY WHEN IN TVC DAP;  
PAST INITIALIZATION PHASE - OTHERWISE  
DELPBAR, DELYBAR DO NOT CONTAIN  
DESIRED INFORMATION

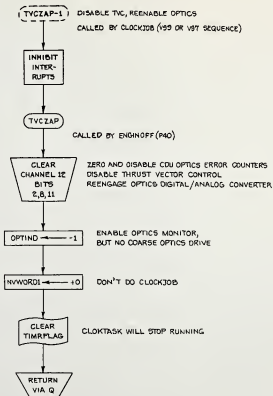
FACTOFF ← DELPBAR  
YACTOFF ← DELYBAR

UPDATE PITCH, YAW OFFSET ANGLES  
FOR TVC DAP  
IN REVS @ 1.07975111

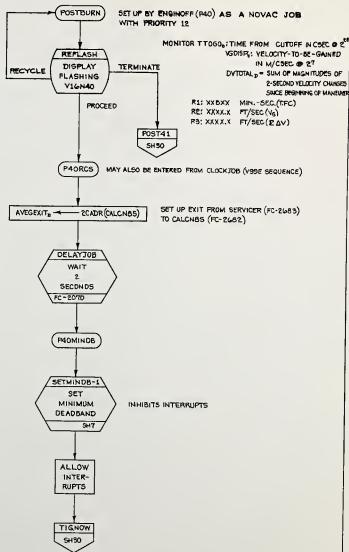
BTRIMR

RETURN VIA Q

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GROUND AND VA. LAB.	
DRAWN BY: A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
CHECKED BY: [Signature]		COLUSSUS ID	
DATE: [Date]		FC-2680	
APPROVED BY: [Signature]		REV B	

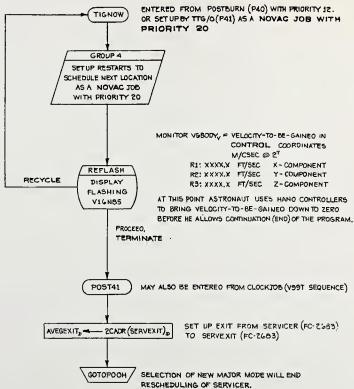


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		#P40-0 SUBRANSI AND NAVSATIONP	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROG# 2799	2799	G.D. JAMES W.	
ANALYST [Signature]	3/11/68	COLDSSUS ID FC-2680	
DOCTR [Signature]	3/11/68	REV 2	
APPROV [Signature]	3/11/68	SHEET 25 OF 58	

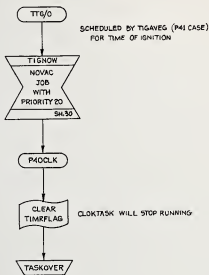


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS	300C7LS	P40, P41 - THRUST PROGRAMS	
PROGRAM <i>Ad Engoff</i>	<i>3/16/68</i>	DOCUMENT NO.	
ANALYST <i>P. J. White</i>	<i>1/16/68</i>	COLOSSUM II D	FC-2680
DOCTR <i>Ad Engoff</i>	<i>1/16/68</i>	REV B	SHEET 25 OF 58
APPROV <i>A. J. ...</i>	<i>1/16/68</i>		

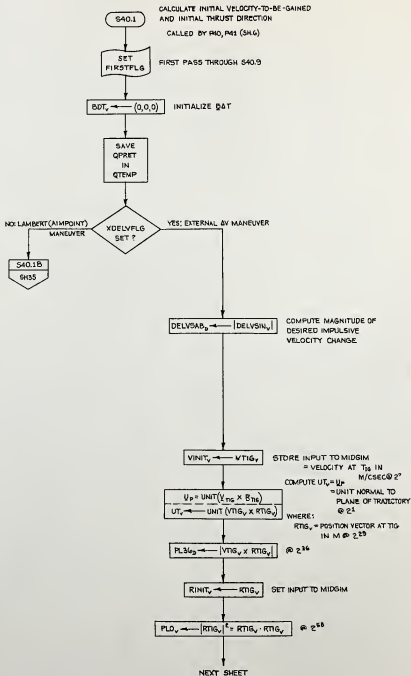




MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AP-110 GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
FORM 300	30003A	DOCUMENT NO.	
ANALYST <i>E. J. ...</i>	<i>...</i>	FC-2680	
DOCS <i>...</i>	<i>...</i>	REV B	
APPROV <i>John A. ...</i>	<i>...</i>	JAN 50 14 58	



MIT		APPROVED	
INSTRUMENTATION LAB		CREATION AND REVISION	
CAMBRIDGE MASS.		P40, P41 - THRUST PROGRAMS	
DRAWN A.C. WILLIAMS	3000765		
PREP <i>AS Eng 89</i>	<i>2/1/69</i>		
ANAL <i>John J. Hall</i>	<i>2/1/69</i>		
DESIGN <i>John M. Stewart</i>	<i>2/12/69</i>	COLLOSSUS IID	FC-268J
APPROV <i>John A. Moore</i>	<i>12/22/68</i>	11-3	31 58



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS	300CT68	P40, P41 - THRUST PROGRAMS	
PROG'D BY <i>[Signature]</i>	1/10/69	DESIGNED BY	
ANALYSIS BY <i>[Signature]</i>	5/2/69	COLLOSSUS ID	FC-2680
DOCUMENTED BY <i>[Signature]</i>	5/2/69	REV 5	
APPROVED BY <i>[Signature]</i>	5/2/69		

FROM PRECEDING SHEET

$$\frac{\theta_T}{2} = \frac{1}{2} \frac{V_{T0}}{c} + \frac{1}{2} \frac{V_{T0}}{2c} \times \frac{V_{T0} \times \sqrt{2} \times |dY|_{U_0} \times M}{|d_{me}|^2 \times F}$$

$$PL14_p \leftarrow \text{THETA}_{DN_p} \times PL20_p \times DELVSAD_p \times \text{WEIGHT}/S_p$$

$$PLQ_p \leftarrow F_p$$

CALCULATE  $\frac{\theta_T}{2}$  = ONE-HALF THE ESTIMATED CENTRAL ANGLE TRAVELED DURING MANEUVER IN REVS @ 2°  
(SEE GSOP SECT. 5 FIGURE 3.3-7)

WHERE:

THETA<sub>DN</sub> =  $\frac{1}{2} \times \frac{1}{c} \times \frac{1}{2c} \times 2^2$   
(FOR CONVERSION OF RAD'S TO REVS)  
DELVSAD<sub>p</sub> = MAGNITUDE OF DESIRED IMPULSIVE VELOCITY CHANGE IN M/CSEC @ 2°  
WEIGHT/S<sub>p</sub> = MASS OF VEHICLE IN KG @ 2<sup>16</sup>  
F<sub>p</sub> = NOMINAL THRUST IN  $\frac{KG-M}{CSEC \times 10^4}$  NEWTON @ 2°  
(SET BY P40 OR P44)

$$\frac{(\Delta Y \cdot U_p)}{PLQ_p} \leftarrow (\text{DELVSIN}_p \cdot U_p) \times U_p \times 2^2$$

CALCULATE OUT-OF-PLANE COMPONENT IN M/CSEC @ 2°

WHERE: DELVSIN<sub>p</sub> = DESIRED IMPULSIVE VELOCITY CHANGE IN M/CSEC @ 2° IN REFERENCE COORDINATES  
U<sub>p</sub> = UNIT NORMAL TO PLANE OF TRAJECTORY @ 2°  
2° FACTOR IS FOR SCALING.

$$\frac{\Delta Y_p}{PLQ_p} \leftarrow \frac{\Delta Y - (\Delta Y \cdot U_p) U_p}{\text{DELVSIN}_p - PLQ_p}$$

CALCULATE  $\Delta Y_p$  = IN-PLANE COMPONENT OF DESIRED VELOCITY CHANGE IN M/SEC @ 2° IN REFERENCE COORDINATES

$$\frac{1}{2} \dot{V}_p(T_{02}) = \left[ \cos\left(\frac{\theta_1}{2}\right) \text{UNIT}(\Delta Y_p) + \sin\left(\frac{\theta_1}{2}\right) \text{UNIT}(\Delta Y_p \cdot U_p) \right] \Delta Y_p + (\Delta Y \cdot U_p) U_p$$

$$VGTIG_p \leftarrow \left[ \cos(PL14_p) \text{UNIT}(PLQ_p) + \sin(PL14_p) \text{UNIT}(PLQ_p \times U_p) \right] |PLQ_p| \times 2^2 + PLQ_p$$

CALCULATE VELOCITY-TO-BE-GAINED AT TIME OF IGNITION IN M/CSEC @ 2° IN REFERENCE COORDINATES WHERE 2° FACTOR IS FOR SCALING

ROTATE IN-PLANE COMPONENT BY  $\frac{\theta_1}{2}$  (TO COMPENSATE FOR FINITE DURATION OF BURN) AND ADD THE OUT-OF-PLANE COMPONENT

$$\frac{U_{T02}}{UT_p} \leftarrow \frac{\text{UNIT}(V_p(T_{02}))}{\text{UNIT}(VGTIG_p)}$$

UNIT VECTOR IN THE DIRECTION OF DESIRED INITIAL THRUST IN REFERENCE COORDINATES @ 2°

$$PLQ_{02} \leftarrow VGTIG_p$$

INPUT TO MIDGIM IN M/CSEC @ 2° IN REFERENCE COORDINATES

SET  
AVPLAS

INPUT TO MIDGIM INDICATING THAT IT IS TO CONVERT A VECTOR FROM REFERENCE TO LOCAL VERTICAL COORDINATES.

NEXT SHEET

MIT  
AERONAUTICAL LAB  
CAMBRIDGE, MASS.

DAVID A. WILLIAMS  
T. W. S. ZELDEN  
APR 2 1969  
APR 2 1969

110750  
11/1/69  
11/1/69

P40, P41 - THRUST PROGRAMS

COLLUSUS IID

FC-2680

11 33 58

FROM PRECEDING SHEET



INPUT: AVFLAG (INDICATING SUBROUTINE OPTION)  
COMPUTER (ALWAYS SET IN COLOSSUS - INDICATES  
CGC (NOT LGC) COMPUTER)

PLD<sub>v</sub> = VECTOR IN REFERENCE COORDINATES

RINIT<sub>v</sub> = POSITION VECTOR FOR SAME TIME AS PLD<sub>v</sub>  
IN REFERENCE COORDINATES IN M @  $t^0$

VINIT<sub>v</sub> = VELOCITY VECTOR FOR SAME TIME AS PLD<sub>v</sub>  
IN REFERENCE COORDINATES IN M/SEC @  $t^0$

OUTPUT: MSLVFLAG (INDICATING WHICH SUBROUTINE OPTION  
WAS USED; IN THIS CASE, SET)

DELVLV<sub>v</sub> = VECTOR IN LOCAL VERTICAL COORDINATES  
(CONVERTED FROM PLD<sub>v</sub>)

∴ HERE, DELVLV<sub>v</sub> = VELOCITY-TO-BE-GAINED AT TIME OF IGNITION  
IN M/SEC @  $t^0$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		44-1110 GIBBONS* AND NAVIGATION	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROF. S. Zeldin	SHEET 4	DOCUMENT NO.	
ANALYST E. J. Sullivan	7/11/69	COLOSSUS II D	FC-2680
DESIGNED by Alan S. Brown	3/2/68	REV 3	SEP 64 14 58
APPROVED by G. A. Brown	12/22/68		

S40.18 LAMBERT BRANCH OF S40.1

TDECI<sub>1</sub> ← TIG<sub>1</sub> - TWOOT<sub>1</sub>  
 DELTA<sub>1</sub> ← TPA554<sub>1</sub> - TDECI<sub>1</sub>

SET UP INPUTS TO AGAIN:  
 TDECI<sub>2</sub> = TWO SECONDS BEFORE TIME OF IGNITION  
 IN CSEC @ 2<sup>28</sup>  
 WHERE TWOOT = 200 CSEC @ 2<sup>28</sup>  
 DELTA<sub>2</sub> = TIME FROM TDECI<sub>2</sub> UNTIL TIME AMPPOINT  
 IS TO BE REACHED  
 IN CSEC @ 2<sup>28</sup>  
 WHERE TPA554<sub>2</sub> = TIME THAT AMPPOINT IS TO BE  
 REACHED IN CSEC @ 2<sup>28</sup>

AGAIN  
 CALCULATE  
 REQUIRED VELOCITY  
 AND A VELOCITY  
 FOR MANEUVER BEGINNING  
 AT DESIRED TIME  
 5H.30

INPUT: TDECI<sub>1</sub>, DELTA<sub>1</sub>, RTARG<sub>v</sub> = AMPPOINT POSITION VECTOR  
 IN REFERENCE COORDINATES  
 IN M @ 2<sup>29</sup>

OUTPUT: VPRIME<sub>v</sub> = INITIAL VELOCITY REQUIRED FOR  
 MANEUVER AT TDECI<sub>1</sub>,  
 IN M/SEC @ 2<sup>27</sup>

RINIT<sub>v</sub>, RTIG<sub>v</sub> = POSITION VECTOR AT TDECI<sub>1</sub> IN M @ 2<sup>29</sup>  
 IN REFERENCE COORDINATES

VINIT<sub>v</sub>, VTIG<sub>v</sub> = VELOCITY VECTOR AT TDECI<sub>1</sub>, IN M/CSEC @ 2<sup>27</sup>  
 IN REFERENCE COORDINATES

DELVEET<sub>3</sub> = CHANGE IN VELOCITY REQUIRED FOR  
 MANEUVER AT TDECI<sub>1</sub>, IN M/CSEC @ 2<sup>27</sup>  
 IN BASIC REFERENCE COORDINATES

UT<sub>v</sub> ← VPRIME<sub>v</sub>

TEMPORARY STORAGE FOR V<sub>0</sub> (T<sub>12</sub>-2)  
 IN M/CSEC @ 2<sup>27</sup>

TDECI<sub>2</sub> ← TIG<sub>2</sub>  
 DELTA<sub>2</sub> ← TPA554<sub>2</sub> - TDECI<sub>2</sub>

SET UP INPUTS TO AGAIN (IN CSEC @ 2<sup>28</sup>)  
 WHERE TDECI<sub>2</sub> = TIME OF IGNITION THIS TIME.

AGAIN  
 CALCULATE  
 REQUIRED VELOCITY  
 AND A VELOCITY  
 FOR MANEUVER BEGINNING  
 AT DESIRED TIME  
 5H.30

INPUT: TDECI<sub>2</sub>, DELTA<sub>2</sub>, RTARG<sub>v</sub>

OUTPUT: VPRIME<sub>v</sub>,  
 RINIT<sub>v</sub>, RTIG<sub>v</sub>,  
 VINIT<sub>v</sub>, VTIG<sub>v</sub>,  
 DELVEET<sub>3</sub>

PLD<sub>v</sub> ← DELVEET<sub>3</sub>  
 VGTIG<sub>v</sub> ← DELVEET<sub>3</sub>

SAVE REQUIRED VELOCITY CHANGE AT TIG  
 IN PLD<sub>v</sub> AS INPUT TO MIDGM  
 AND IN VGTIG<sub>v</sub> FOR FUTURE REFERENCE  
 IN REFERENCE COORDINATES IN M/CSEC @ 2<sup>27</sup>

NEXT SHEET

WILL INSTRUCTIONS BY WAF-02 44.5. A.C. WILLIAMS S. Kelly 1/16/69 1/1/69 1/1/69 1/1/69	310700 4069 1/1/69 1/1/69 1/1/69
---	--

P40, P41 = THRUST PROGRAMS

COL0550 2 D

FC-2680

3

35

58

FROM PRECEDING SHEET

SET  
AVFLAG

INPUT TO MIDGIM INDICATING THAT IT IS  
TO CONVERT A VECTOR FROM REFERENCE  
TO LOCAL VERTICAL COORDINATES.

MIDGIM  
CONVERT VECTOR  
FROM REFERENCE  
TO LOCAL VERTICAL  
COORDINATES  
FC-2630

INPUT: AVFLAG (INDICATING SUBROUTINE OPTION)  
COMPUTER (ALWAYS SET IN COLOSSUS - INDICATES  
CSC COMPUTER)  
 $PLO_v$  = VECTOR IN REFERENCE COORDINATES  
 $RINT_v$  = POSITION VECTOR FOR SAME TIME AS  $PLO_v$   
IN REFERENCE COORDINATES IN  $M @ 2^8$   
 $VINT_v$  = VELOCITY VECTOR FOR SAME TIME AS  $PLO_v$   
IN REFERENCE COORDINATES IN  $M/SEC @ 2^7$   
OUTPUT: MGLVFLAG (INDICATING WHICH SUBROUTINE OPTION  
WAS USED; IN THIS CASE, SET)  
 $DELVLV_v$  = VECTOR IN LOCAL VERTICAL  
COORDINATES (CONVERTED FROM  $PLO_v$ )  
∴ HERE,  $DELVLV_v$  = VELOCITY - TO BE GAINED AT  
TIME OF IGNITION  
IN  $M/SEC @ 2^7$

CALCUT

MPAC<sub>v</sub> ← RTIG<sub>v</sub>

INPUT TO CALCGRAV:  
POSITION VECTOR AT DESIRED TIME  
IN REFERENCE COORDINATES IN  $M @ 2^8$

CALCGRAV  
CALCULATE  
GRAVITATIONAL  
ACCELERATION  
FC-2683

INPUT: MPAC<sub>v</sub> = POSITION VECTOR  
OUTPUT: MPAG<sub>v</sub> =  $GDTI/R_v = \frac{1}{2} g$  THE DIFFERENCE IN VELOCITY DUE TO  
GRAVITATIONAL ACCELERATION,  
AT SPECIFIED POSITION, OVER 2 SECONDS  
IN REFERENCE COORDINATES IN  $M/SEC @ 2^7$

$$CB = C \left( \frac{V_x(T_{IG}) - V_x(T_{IG} - 2) - 2 \times \frac{1}{2} G(T_{IG}) \Delta T}{2 \text{ SECS}} \right)$$

$$PLIZ \leftarrow CSTEER \left( \frac{V_{I\text{PRIME}_v} - UT_v - 2 \times GDTI/R_v}{200CS_2} \right) \times 2^2$$

CALCULATE CB = INTERMEDIATE RESULT  
IN REFERENCE COORDINATES  
IN  $M/SEC^2 @ 2^5$

WHERE:

$V_{I\text{PRIME}_v} = V_x(T_{IG})$  = REQUIRED VELOCITY  
AT TIG  
IN  $M/SEC @ 2^7$   
 $UT_v = V_x(T_{IG} - 2)$  = REQUIRED VELOCITY  
AT TIG - 2  
IN  $M/SEC @ 2^7$   
 $200CS_2 = 200 \text{ CSEC} @ 2^{12}$   
 $CSTEER = \text{STEER-LAW CONSTANT} @ 2^2$   
(SET BY P40, P41)  
 $2^2$  FACTOR IS FOR SCALING.

NEXT SHEET

NET INSTRUMENTATION LAB CAMBRIDGE, MASS.		47010C GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS ... 3/10/49		P40, P41 - THRUST PROGRAMS	
PRGMA S. P. ... 3/10/49		DOCUMENT NO.	
ANALYST ... 3/10/49		COLOSSUS II D	
CHECKED ... 3/10/49		FC-2680	
APPROVED ... 3/10/49		REV 36 ... 58	

FROM PRECEDING SHEET

$$Q = CB - (\text{UNIT}(Y_2(T_{10})) \cdot CB) \text{UNIT}(Y_2(T_{10}))$$

$$PL1Z_v \leftarrow PL1Z_v - (\text{UNIT}(VGTIG_v) \cdot PL1Z_v) \text{UNIT}(VGTIG_v) \times Z^4$$

CALCULATE Q = INTERMEDIATE RESULT  
IN REFERENCE COORDINATES  
IN M/CSEC @  $Z^{-5}$

WHERE:

VGTIG<sub>v</sub> = VELOCITY-TD-BE GAINED AT TIG  
IN REFERENCE COORDINATES  
IN M/CSEC @  $Z^7$   
 $Z^4$  FACTOR IS FOR SCALING.

$$V_{T0} = \text{UNIT} \left[ \sqrt{\left(\frac{F_D}{M}\right)^2 - (Q)^2} \text{UNIT}(Y_2(T_{10})) + Q \right]$$

$$UT_v \leftarrow \text{UNIT} \left[ \sqrt{\left(\frac{F_D \times Z^{-4}}{\text{WEIGHT}/G_0}\right)^2 - (PL1Z_v)^2} \text{UNIT}(VGTIG_v) \times Z^4 + PL1Z_v \right]$$

CALCULATE

V<sub>T0</sub> = UNIT VECTOR IN DIRECTION OF  
DESIRED INITIAL THRUST  
@  $Z^4$  (IN REFERENCE COORDINATES)

WHERE:

F<sub>D</sub> = ENGINE THRUST IN KG-M/CSEC<sup>2</sup>  
( $10^{-6}$  NEWTONS) @  $Z^7$   
(FROM P40 OR P41)  
WEIGHT/G<sub>0</sub> = MASS OF VEHICLE  
IN KG @  $Z^{10}$   
 $Z^{-4}$ ,  $Z^4$  FACTORS ARE FOR SCALING

RETURN  
VIA QTEMP

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROGRAM 5-22-64	INDEXED 3/10/64	REVISED BY W	
ANALYST Peter J. Heller	WILLIAMS	COLOSSUS II D	FC-2680
DOCSM <del>WILLIAMS</del> SEBASTIAN 3/17/64			57 • 58
APPROVED <del>WILLIAMS</del> 1/20/64 69	REV 3		



AGAIN CALLED BY 540.18 (5H.34), ALSO BY P51 (7C-2660)

SAVE QPRT IN QTEMP1

INTEGRATE STATE VECTOR TO DESIRED TIME  
FC-2280

INPUT: TDEC1<sub>0</sub> = DESIRED TIME IN CSEC @ 2<sup>23</sup>  
OUTPUT: RATT<sub>v</sub> = POSITION VECTOR AT DESIRED TIME IN REFERENCE COORDINATES, IN M @ 2<sup>25</sup>  
VATT<sub>v</sub> = VELOCITY VECTOR AT DESIRED TIME IN REFERENCE COORDINATES, IN M/CSEC @ 2<sup>7</sup>  
TAT<sub>0</sub> = ACTUAL TIME INTEGRATED TO, IN CSEC @ 2<sup>20</sup> (≈ TDEC1<sub>0</sub>)  
X1 = -2 IF IN EARTH SPHERE OF INFLUENCE, -10 IF IN MOON SPHERE OF INFLUENCE, 2 IF IN MOON SPHERE OF INFLUENCE.

RTX2 ← X2  
RTX1 ← X1

SAVE INDEX REGISTER VALUES FOR INITVEL.

RTIG<sub>v</sub> ← RATT<sub>v</sub>  
RINIT<sub>v</sub> ← RATT<sub>v</sub>  
VTIG<sub>v</sub> ← VATT<sub>v</sub>  
VINIT<sub>v</sub> ← VATT<sub>v</sub>

SET UP OUTPUT STATE VECTOR, INPUTS TO INITVEL = STATE VECTOR AT TDEC1<sub>0</sub>

PLD<sub>0</sub> ← 0

SET UP INPUT FOR INITVEL  
PLD<sub>0</sub> = NO. OF ITERATIONS - 1  
(0 INDICATES LAMBERT SOLUTION ONLY, NOT PRECISION)

MPAC<sub>0</sub> ← EPA(45)H<sub>0</sub>

INITIALIZE MPAC<sub>0</sub> TO 45°

IS ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS IN THE RANGE SUCH THAT TARGET VECTOR SHOULD BE ROTATED INTO THE POSITION-VELOCITY PLANE?

YES

NORMSW SET ?

NO

IF NOT, CORRECT MPAC<sub>0</sub> TO 10°  
DECREASE THE RANGE SO THAT ANGLE WILL REMAIN OUTSIDE IT DURING THE BURN

MPAC<sub>0</sub> ← EPA(10)H<sub>0</sub>

LEAVE THE RANGE LARGE SO THAT ANGLE WILL REMAIN INSIDE IT DURING THE BURN

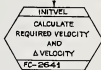
PLD<sub>0</sub> ← MPAC<sub>0</sub>

SET ε (IN REVS AT 2°) SUCH THAT: IF ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS IS WITHIN ε OF 1/2 REV (180°), INITVEL WILL ROTATE THE TARGET VECTOR INTO THE POSITION-VELOCITY PLANE

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		GROUP GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROGRAM 5-2-67		COLLOSSUS II D	
ANALYST J. G. HULL		FC-2680	
DOCUMENT 49-271-2000-1126		REV 2	
APPROVED J. G. HULL		SHEET 35 OF 38	

FROM PRECEDING SHEET



INPUT: RINIT<sub>v</sub> = INITIAL POSITION VECTOR IN REFERENCE COORDINATES  
IN M @ 2<sup>25</sup>  
VINIT<sub>v</sub> = INITIAL VELOCITY VECTOR IN REFERENCE COORDINATES  
IN M/CSEC @ 2<sup>7</sup>  
RTARG<sub>v</sub> = OFFSET TARGET VECTOR IN REFERENCE COORDINATES  
IN M @ 2<sup>25</sup>  
DELTA<sub>t</sub> = TIME OF FLIGHT FROM RINIT<sub>v</sub> TO RTARG<sub>v</sub> IN CSEC @ 2<sup>8</sup>  
PLD<sub>0</sub> = NO. OF ITERATIONS - 1 (0 INDICATES LAMBERT)  
PLD<sub>0</sub> = ANGLE ε (IN REVS @ 2<sup>20</sup>) WHICH DETERMINES  
SITUATION IN WHICH TARGET VECTOR  
MUST BE ROTATED  
RTX1 = -ε IF IN EARTH SPHERE OF INFLUENCE,  
-10 IF IN MOON SPHERE OF INFLUENCE,  
RTX2 = 0 IF IN EARTH SPHERE OF INFLUENCE,  
2 IF IN MOON SPHERE OF INFLUENCE.  
OUTPUT: VPRIME<sub>v</sub> = INITIAL VELOCITY REQUIRED FOR MANEUVER  
IN REFERENCE COORDINATES  
IN M/CSEC @ 2<sup>7</sup>  
VTRIME<sub>v</sub> = FINAL VELOCITY (AT RTARG<sub>v</sub>) AFTER MANEUVER  
IN REFERENCE COORDINATES  
IN M/CSEC @ 2<sup>7</sup>  
DELVEET<sub>v</sub> = INITIAL CHANGE IN VELOCITY REQUIRED FOR  
MANEUVER  
IN REFERENCE COORDINATES  
IN M/CSEC @ 2<sup>7</sup>



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPELL GUIDANCE AND NAVIGATION	
SPAWN A.C. WILLIAMS		ANDREW	PRO, P41 - THRUST PROGRAMS
FRANK J. ZELTZER	WILLIAMS		000,000 1/2 W.
ANALYST	WILLIAMS	COLORSUS II	FC-2680
DOCS	WILLIAMS		REV 30 58
APPROV	WILLIAMS		

S40.2.3

COMPUTE PREFERRED SPACECRAFT ATTITUDE  
CALLED BY P40, P41

$$\begin{matrix} U_D = [\text{REFSMMAT}] U_{TD} \\ \text{POINTYSM}_D \leftarrow \text{REFSMMAT}_M \cdot U_{TD} \times 2^1 \end{matrix}$$

CONVERT INITIAL THRUST DIRECTION VECTOR  
TO STABLE MEMBER COORDINATES @ 2<sup>1</sup>

WHERE:

REFSMMAT<sub>M</sub> = TRANSFORMATION MATRIX  
BETWEEN REFERENCE  
AND S.M. COORDINATE  
SYSTEMS  
@ 2<sup>1</sup>U<sub>TD</sub> = U<sub>TD</sub> = UNIT VECTOR IN DIRECTION OF  
DESIRED INITIAL THRUST  
IN REFERENCE COORDINATES  
@ 2<sup>1</sup> (FROM S40.1)2<sup>1</sup> FACTOR IS FOR SCALING.SAVE  
QPRET  
IN  
QTEMP

YES: SPS BURN (P40)

NO: RCS BURN (P41)

ENSEFLAG  
CLEAR  
?S40.2.3B  
SH45O, COS(Y+Y<sub>0</sub>), SIN(Y+Y<sub>0</sub>),  
COS(P+P<sub>0</sub>), SIN(P+P<sub>0</sub>)PLD<sub>D</sub> ← 0PL2<sub>D</sub> ← COS(FACTOFF × TRIMSCLD × 2<sup>1</sup> + YBIAS<sub>D</sub>)PL4<sub>D</sub> ← SIN(FACTOFF × TRIMSCLD × 2<sup>1</sup> + YBIAS<sub>D</sub>)PL6<sub>D</sub> ← COS(FACTOFF × TRIMSCLD × 2<sup>1</sup> + PBIAS<sub>D</sub>)PL8<sub>D</sub> ← SIN(FACTOFF × TRIMSCLD × 2<sup>1</sup> + PBIAS<sub>D</sub>)ZSCREF<sub>D</sub> ← SIN(FACTOFF × TRIMSCLD × 2<sup>1</sup> + PBIAS<sub>D</sub>)CALCULATE INTERMEDIATE RESULTS @ 2<sup>1</sup>

WHERE:

FACTOFF = Y = YAW OFFSET ANGLE IN REVS @ 1.07975111

FACTOFF = P = PITCH OFFSET ANGLE IN REVS @ 1.07975111

TRIMSCLD = SCALING CONSTANT FOR FACTOFF, FACTOFF

= 1.07975111 @ 2<sup>1</sup>YBIAS<sub>D</sub> = Y<sub>0</sub> = YAW MECHANICAL BIAS ANGLE= +0.95° IN REVS @ 2<sup>0</sup>PBIAS<sub>D</sub> = P<sub>0</sub> = PITCH MECHANICAL BIASANGLE = -2.15° IN REVS @ 2<sup>0</sup>2<sup>1</sup> FACTOR IS FOR SCALING

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED BY SUSPICITANT AND UNCLASSIFIED	
DRAWN A.C. WILLIAMS PROGRAM S. J. BARRY ANALYST P. J. HARRIS DOCS. P. J. HARRIS APPROVED P. J. HARRIS		P40, P41 - THRUST PROGRAMS COLLOSSUS IID FC-2680	
REV 3		REV 3	

FROM PRECEDING SHEET

$$\begin{aligned} Z_{sc(sc)} &= (\cos(P+P_s) \cos(Y+Y_s) - \cos(P+P_s) \sin(Y+Y_s) \sin(P+P_s)) \\ Y_{sc(sc)} &= (\sin(Y+Y_s), \cos(Y+Y_s), 0) \\ X_{sc(sc)} &= (-\sin(P+P_s) \cos(Y+Y_s), \sin(P+P_s) \sin(Y+Y_s), \cos(P+P_s)) \\ XSCREF_v &\leftarrow (PLA_{0y} \times PL2_y \times Z^1 - PLA_{0z} \times PLA_{0y} \times Z^1, PLA_{0z}) \\ YSCREF_v &\leftarrow (PLA_{0z}, PLA_{0z}, PLA_{0z}) \\ ZSCREF_v &\leftarrow (-ZSCREF_{0y} \times PL2_y \times Z^1, ZSCREF_{0y} \times PLA_{0z} \times Z^1, PLA_{0z}) \end{aligned}$$

$$\text{CALCULATE } [M]^T = \begin{bmatrix} X_{sc(sc)} \\ Y_{sc(sc)} \\ Z_{sc(sc)} \end{bmatrix}$$

GIVING SPACECRAFT AXES IN ENGINE BELL COORDINATES @ 2<sup>1</sup> WHERE  $[M] = \begin{bmatrix} X_{eb(sc)} \\ Y_{eb(sc)} \\ Z_{eb(sc)} \end{bmatrix}$  GIVES ENGINE BELL AXES IN SPACECRAFT COORDINATES

$$\begin{aligned} X_{eb(sc)} &= (\cos(P+P_s) \cos(Y+Y_s), \sin(Y+Y_s), -\sin(P+P_s) \cos(Y+Y_s)) \\ SCAXIS_v &\leftarrow (XSCREF_v, YSCREF_v, ZSCREF_v) \end{aligned}$$

CALCULATE UNIT VECTOR IN DIRECTION OF ENGINE BELL (X AXIS OF ENGINE BELL COORDINATE SYSTEM) IN SPACECRAFT COORDINATES @ 2<sup>1</sup> (FOR RUDCSM)

$$\begin{aligned} \delta_{ref(sc)} &= U_{TD} \\ PLO_v &= U_{TV} \end{aligned}$$

$$\begin{aligned} Y_{eb(sc)} &= U_{TD} \times \text{UNIT}(B(T_{0z})) \\ PL6_v &= \text{UNIT}(PLO_v \times \text{UNIT}(RTIS)) \end{aligned}$$

INITIALIZE VALUE OF  $Y_{eb(sc)}$  - MAY BE CHANGED BY TSTRXUT

$$PL3_{0z} \leftarrow |PLO_v \times \text{UNIT}(RTIG)|$$

INPUT TO TSTRXUT @ 2<sup>2</sup>



INPUT:  $PL3_{0z} = |U_{TD} \times \text{UNIT}(R(T_{0z}))|$   
OUTPUT: IF  $U_{TD}, R(T_{0z})$  NOT COLLINEAR:

$$Y_{eb(sc)} = MPAC_v \times PL6_v = \text{UNIT}(U_{TD} \times \text{UNIT}(B(T_{0z})))$$

IF  $U_{TD}, R(T_{0z})$  COLLINEAR:

$$Y_{eb(sc)} = MPAC_v \times PL6_v = \text{UNIT}(U_{TD} + \text{UNIT}(R(T_{0z})) + \frac{1}{2} \text{UNIT}(Y(T_{0z})))$$

CALCULATE

$$[M] = \begin{bmatrix} X_{eb(sc)} \\ Y_{eb(sc)} \\ Z_{eb(sc)} \end{bmatrix}$$

GIVING DESIRED ENGINE BELL COORDINATE AXES IN REFERENCE COORDINATES @ 2<sup>1</sup>

$$\begin{aligned} Z_{eb(sc)} &= X_{eb(sc)} \times Y_{eb(sc)} \\ PL12_v &= PLO_v \times MPAC_v \times Z^1 \end{aligned}$$

Z<sup>1</sup> FACTOR IS FOR SCALING

NEXT SHEET

PAO, P11 - THRUST PROGRAMS

A.C. WILLIAMS 4/2/68

NO FC 2.30

FROM PRECEDING SHEET

$$\begin{aligned} \sum_{EB(NP)}^T \sum_{SC(NP)} &= \sum_{SC(EB)} \times [M_N] \\ Y_{EB(NP)} &= Y_{SC(NP)} = Y_{SC(EB)} \times [M_N] \\ \sum_{EB(NP)}^T \sum_{SC(NP)} &= \sum_{SC(EB)} \times [M_N] \end{aligned}$$


---


$$\begin{aligned} XSCREF_v &\leftarrow XSCREF_v \times \begin{bmatrix} PL6_v \\ PL6_v \\ PL12_v \end{bmatrix} \times r^2 \\ YSCREF_v &\leftarrow YSCREF_v \times \begin{bmatrix} PL6_v \\ PL6_v \\ PL12_v \end{bmatrix} \times r^2 \\ ZSCREF_v &\leftarrow ZSCREF_v \times \begin{bmatrix} PL6_v \\ PL6_v \\ PL12_v \end{bmatrix} \times r^2 \end{aligned}$$

CALCULATE

$$\begin{bmatrix} X_{SC(NP)} \\ Y_{SC(NP)} \\ Z_{SC(NP)} \end{bmatrix} = [M] \times [M_N]$$

GIVING DESIRED SPACECRAFT AXES  
IN REFERENCE COORDINATES

@  $r^2$

WHERE  $r^2$  FACTOR IS FOR SCALING

NOTE: THESE AXES ALSO GIVE  
THE PREFERRED IMU  
ALIGNMENT, IN CASE  
ASTRONAUT CHOOSES  
TO REALIGN IMU (P52)

RETURN  
VIA QTEMP

NOTE: THE COMPUTATION ABOVE IS DERIVABLE FROM THE EQUATION:

$$[M_{EB(NP)}] = [M_{EB(SC)}] \times [M_{SC(NP)}]$$

$$[M_{EB(NP)}] \text{ AND } [M_{EB(SC)}] \text{ ARE KNOWN,}$$

$$\text{SO } [M_{SC(NP)}] = [M_{EB(SC)}] \times [M_{EB(NP)}]$$

$$= [M_{EB(SC)}]^T \times [M_{EB(NP)}]$$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APR 10 1968 PHO, P41 - THRUST PROGRAMS	
BY RAY A.C. WILLIAMS	ANALYST	FC-2680	42 58
PREP. C. J. [Signature]	ANALYST [Signature]	COLLOSSUS IID	
DATE: [Signature]	APPROV. [Signature]		
APPROV. [Signature]			

S402, 5B

ENTERED FROM S402,3  
FOR RCS BURN (P41)SCAXIS<sub>v</sub> ← UNITX<sub>v</sub>SET OUTPUT SCAXIS<sub>v</sub> = UNIT VECTOR IN THRUST DIRECTION  
IN SPACECRAFT COORDINATES @ 2<sup>1</sup>  
WHERE UNITX<sub>v</sub> = (1, 0, 0) @ 2<sup>1</sup>
$$\frac{Y_{SC}(nr)}{XSCREF_v} \leftarrow \frac{U_{TD}}{U_{TV}}$$
$$\frac{Y_{SC}(nr)}{PLG_v} \leftarrow \frac{\text{UNIT}(U_{TD} \times R(T_{14}))}{\text{UNIT}(U_{TV} \times RTIG_v)}$$
INITIALIZE VALUE WHICH  
MAY BE CHANGED BY  
TSTRKUTPL36<sub>0</sub> ← |U<sub>TV</sub> × RTIG<sub>v</sub>|INPUT TO TSTRKUT  
@ 2<sup>30</sup>

TSTRKUT

ARE U<sub>TV</sub> AND RTIG<sub>v</sub> COLLINEAR?  
PL36 = 0?

NO

YES

MPAC<sub>v</sub> ← PLG<sub>v</sub>

BADVECTOR

$$Y_{SC}(nr) \leftarrow \text{UNIT}(U_{TV} \times (\text{UNIT}(RTIG_v) + \frac{1}{2} \text{UNIT}(U_{TD}))$$
  
$$MPAC_v \leftarrow \text{UNIT}(U_{TV} \times (\text{UNIT}(RTIG_v) + \frac{1}{2} \text{UNIT}(U_{TD}))$$
  
$$PLG_v \leftarrow \text{UNIT}(U_{TV} \times (\text{UNIT}(RTIG_v) + \frac{1}{2} \text{UNIT}(U_{TD}))$$
RETURN VIA  
QPRETYSCREF<sub>v</sub> ← MPAC<sub>v</sub>
$$\frac{Z_{SC}(nr)}{ZSCREF_v} \leftarrow \frac{Z_{SC}(nr)}{Y_{SC}(nr)} \times \frac{Y_{SC}(nr)}{XSCREF_v} \times \frac{XSCREF_v}{MPAC_v}$$
RETURN VIA  
QTEMP

CALCULATE

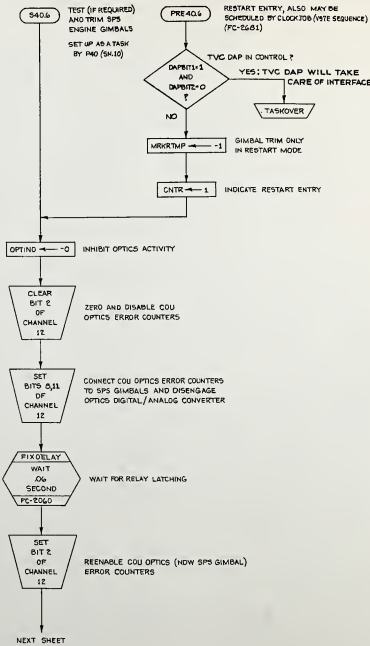
$$\left[ \begin{array}{l} Y_{SC}(nr) \\ Y_{SC}(nr) \\ Z_{SC}(nr) \end{array} \right]$$
GIVING PREFERRED  
SPACECRAFT AXES  
IN REFERENCE  
COORDINATES  
@ 2<sup>1</sup>  
(SEE NOTE S442)DOCUMENTATION CENTER  
LAURENCE WALKERBY A.C. WILLIAMS (SNOW) 5/1/64  
S. E. ELDON 4/1/64  
Peter J. Hall 3/1/64  
Colossus 41-3812A 3/12/64  
John D. Brown 11/1/64

PHO, P41 - THRUST PROGRAMS

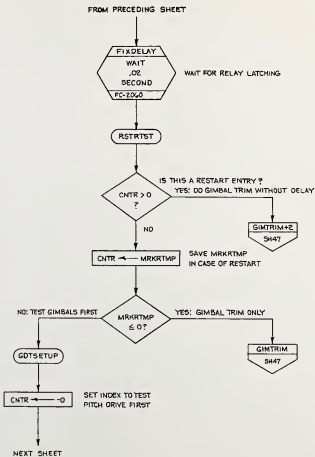
COLLOSSUS IID

FC-2680

43 58



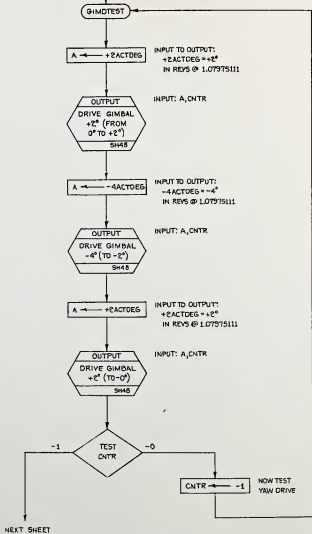
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED OPTICS AND NAVIGATION	
DESIGN: A.C. WILLIAMS	SKETCH:	P40, P41 - THRUST PROGRAMS	
FROM: <i>2/10/61</i>	<i>2/10/61</i>	CALL NUMBER	
ANALYST: <i>2/10/61</i>	<i>2/10/61</i>	COLOSSUS IID	FC-2680
DOCUMENT: <i>2/10/61</i>	<i>2/10/61</i>	REV 3	REV 3



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED GUIDANCE AND NAVIGATION
DRAWN A. C. WILLIAMS PROGRAM <i>AD 1/2/69</i> ANALYST <i>AD 1/2/69</i> DOCNR <i>AD 1/2/69</i> APPROV <i>AD 1/2/69</i>	P40, P41 - THRUST PROGRAMS COLOSSUS IID DOCUMENT NO. FC-2680 REV 3

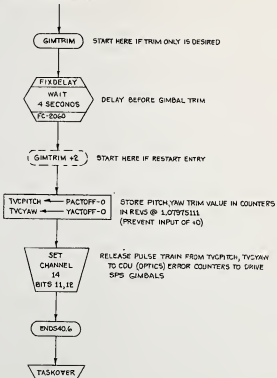


FROM PRECEDING SHEET

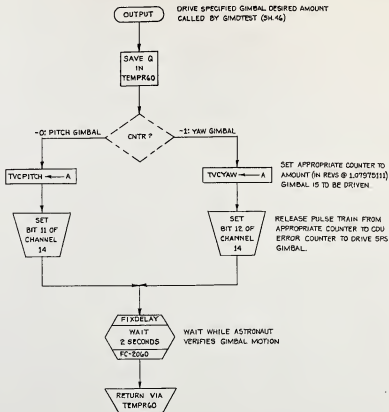


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AEREO GUIDANCE AND NAVIGATION	
DRAWN A. C. WILLIAMS		PROJECT RQ-1 - THRUST PROGRAMS	
PROC'D <i>AB</i>	5/11/57	COLOSSUS	DOCUMENT NO.
ANAL'Z <i>AB</i>	5/15/57	FC-2680	
DOC'D <i>AB</i>	5/15/57		
APP'D <i>AB</i>	5/15/57		
		SHEET 46 OF 58	

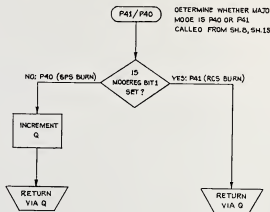
FROM PRECEDING SHEET



NIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. C. WILLIAMS		PING, P41 - THRUST PROGRAMS	
CHECKED <i>[Signature]</i>		DOCUMENT NO.	
ANALYST <i>[Signature]</i>		COLOSSUS 3	
APPROVED <i>[Signature]</i>		FC-2680	
DATE <i>[Date]</i>		SHEET 47 OF 50	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC QUINCY AND NAVIGATION	
DRAWN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PROGRAM <i>APR 68</i>	SNOWSO	DOCUMENT NO.	
ANALYSIS <i>APR 68</i>		COLOSSUS II D	FC-2680
DESIGN <i>APR 68</i>		REV 3	REV 48 58
APPROVED <i>APR 68</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS PROGRAM <i>3/1/62</i> ANALYST <i>John P. ...</i> CHECKED <i>John P. ...</i> APPROVED <i>John P. ...</i>	P40, P41 - THRUST PROGRAMS COLLOSSUS II D BY <i>3</i>
	DOC. IDENT. NO. <b>FC-2680</b> 4-11-65 58

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
CALCGRAV	2683	CALCULATE GRAVITATIONAL ACCELERATION	SH. 36
CLOKTASK	2681	UPDATE TT0GO, MAINTAIN DISPLAY	SH. 12
INITVEL	2641	CALCULATE VELOCITY AND $\Delta$ VELOCITY REQUIRED FOR MANEUVER	SH. 39
MASSPROP	2430	UPDATE MASS PROPERTIES FOR DAPS (& FILTER GAIN VALUES FOR TVC DAP)	SH. 25
MIDGIM	2630	OPTION USED HERE: CONVERT VECTOR FROM REFERENCE COORDINATES TO LOCAL VERTICAL COORDINATES	SH. 34, 36
MIDTOAV1	2290	EXTRAPOLATE STATE VECTOR TO DESIRED TIME	SH. 12
PREREAD	2683	SET UP SERVICER, WHICH UPDATES STATE VECTOR DURING BURN	SH. 15
P40CNV85	2682	SET UP NOUN 85 (VGBODY <sub>V</sub> ) FOR DISPLAY	SH. 11
RCSADAPON	2370	SET UP RCS DAP (HENCE DISCONTINUE ANY OTHER-HERE, TVC DAP)	SH. 25
R02BOTH	2210	CHECK IMU STATUS (AND TERMINATE PROGRAM IF NOT OK)	SH. 6
R60CSM	2340	PERFORM SPACECRAFT ATTITUDE MANEUVER	SH. 8
THISPREC (- CSMPREC)	2290	PRECISION UPDATE OF STATE VECTOR TO DESIRED TIME	SH. 38
TPAGREE	2090	FORCE SIGN AGREEMENT IN TRIPLE-PRECISION MPAC	SH. 19
TVCADAPON	2430	SET UP TVC DAP	SH. 22

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
ASTNFLAG FLAGWRD7 BIT 12	ASTRONAUT HAS OKAYED IGNITION	ASTRONAUT HAS NOT OKAYED IGNITION			SH. 20
AVFLAG FLAGWRD2 BIT 5	WHEN USED IN COLOSSUS AS INPUT TO MIDGIM: MIDGIM IS TO CONVERT A VECTOR FROM REFERENCE COORDINATES TO LOCAL VERTICAL COORDINATES	MIDGIM IS TO COMPUTE MIDDLE GIMBAL ANGLE	SH. 33, 36		
COMPUTER FLAGWRD3 BIT 8	COMPUTER IS CGC	COMPUTER IS LGC		FRESH START AND RESTART	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DEAN A.C. WILLIAMS		P40, P41 - THRUST PROGRAMS	
PREPARED <i>[Signature]</i>	UNIVERSITY	1	DOCUMENT NO.
ANALYST <i>[Signature]</i>	WILLIAMS	COLOSSUS IID	FC-2680
DRAWN <i>[Signature]</i>	SCOTT		SHEET 50 OF 68
APPROVED <i>[Signature]</i>	12544	REV B	

FLAGS (CONTINUED)

NAME				WHERE SET	WHERE (CLEARED)	WHERE TESTED	
DAPBIT1 FLAGWRD6 BIT 15	BOTH SET	DAPBIT1-1	DAPBIT1=0	BOTH CLEAR	SH. 22	SH. 21	SH. 27, 44
DAPBIT2 FLAGWRD6 BIT 14		DAPBIT2=0	DAPBIT2=1			SH. 21, 22	SH. 27, 44
		SATURN DAP IN CONTROL	TVC DAP IN CONTROL	RCS NO DAP IN CONTROL			
		<u>MEANING WHEN SET</u>		<u>MEANING WHEN CLEAR</u>			
DAPDATR1 BIT 4	ANGULAR DEADBAND IS MAXIMUM	ANGULAR DEADBAND IS MINIMUM		SH. 25	SH. 7		
ENQONFLG FLAGWRD5 BIT 7	SPS ENGINE IS ON	SPS ENGINE IS OFF		SH. 20	SH. 27		
ENG2FLAG FLAGWRD2 BIT 11	RCS BURN	SPS BURN		SH. 5	SH. 4	SH. 40	
FIRSTFLG FLAGWRD2 BIT 7	FIRST PASS THROUGH ROUTINE S40.9	LATER THAN FIRST PASS THROUGH S40.9		SH. 32			
IGNFLAG FLAGWRD7 BIT 13	TIME OF IGNITION HAS ARRIVED	TIME OF IGNITION HAS NOT ARRIVED		SH. 20			
IMPULSW FLAGWRD2 BIT 9	MINIMUM IMPULSE BURN - CUTOFF TIME IS KNOWN	STEERING BURN - CUTOFF TIME NOT DETERMINED		SH. 17	SH. 19, 21	SH. 21	
NJETSFLG FLAGWRD1 BIT 15	2-JET RCS BURN	4-JET RCS BURN				SH. 5, 17	
NORMSW FLAGWRD7 BIT 10	ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS IS SUCH THAT TARGET VECTOR NEED NOT BE ROTATED INTO THE POSITION-VELOCITY PLANE.	ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS IS SUCH THAT TARGET VECTOR MUST BE ROTATED INTO THE POSITION-VELOCITY PLANE.				SH. 38	
PFRAF1FLG FLAGWRD2 BIT 4	PREFERRED ATTITUDE HAS BEEN COMPUTED	PREFERRED ATTITUDE NOT COMPUTED		SH. 6	SH. 15		
STEERSW FLAGWRD2 BIT 11	STEERING IS TO BE DONE	STEERING WILL NOT BE DONE		SH. 23			
STRCLLSW FLAGWRD6 BIT 13	DO ROUTINE STEERULL (STEERING IS TO BE DONE)	DO ONLY ROUTINE ULAGBOFF (NO STEERING)		SH. 21	SH. 21	SH. 23	
TIMRFLAG FLAGWRD7 BIT 11	CLOKTASK OPERATING	CLOKTASK NOT OPERATING		SH. 8	SH. 28, 31		
XDELVFLG FLAGWRD2 BIT 8	EXTERNAL DELTA V MANEUVER	LAMBERT (AIMPOINT) MANEUVER				SH. 4, 32	
3AXISFLG FLAGWRD5 BIT 6	DESIRED MANEUVER SPECIFIED BY 3 AXES	DESIRED MANEUVER SPECIFIED BY ONE ALIGNMENT AXIS			ASSUMED CLEAR SH. 8		

M-1  
INSTRUMENTATION LOG  
APPROPRIATE MARKS

DATE: 12/12/68  
BY: A.C. WILLIAMS  
CHECKED: [Signature]  
TITLE: [Signature]  
PROJECT: COLOSSUS IIC  
FC-2680  
PAGE 41 - THRUST PROGRAM  
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## CHANNEL BITS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
CHANNEL 5 BITS 8-1	RCS JETS CONTROLLING X-TRANSLATION, PITCH AND YAW ROTATION ARE FIRING	RCS JETS CONTROLLING X-TRANSLATION, PITCH AND YAW ROTATION ARE NOT FIRING		SH. 23	
CHANNEL 11 BIT 13	SPS ENGINE ON	SPS ENGINE OFF	SH. 20	SH. 27	
CHANNEL 12 BIT 2	OPTICS CDU ERROR COUNTERS ENABLED	OPTICS CDU ERROR COUNTERS CLEARED AND DISABLED	SH. 44	SH. 28, SH. 44	
CHANNEL 12 BIT 8	OPTICS CDU ERROR COUNTERS CONNECTED TO SPS GIMBALS	OPTICS CDU ERROR COUNTERS DISCONNECTED FROM SPS GIMBALS	SH. 44	SH. 28	
CHANNEL 12 BIT 11	OPTICS DIGITAL/ANALOG CONVERTER DISENGAGED	OPTICS DIGITAL/ANALOG CONVERTER ENGAGED	SH. 44	SH. 28	
CHANNEL 12 BIT 14	S I V B CUTOFF COMMANDED	S I V B CUTOFF NOT COMMANDED	SH. 27		
CHANNEL 14 BIT 11	PULSE TRAIN RELEASED FROM TVCPITCH	PULSE TRAIN FROM TVCPITCH INHIBITED	SH. 47, SH. 48	AUTOMATIC WHEN PULSE TRAIN ENDED	
CHANNEL 14 BIT 12	PULSE TRAIN RELEASED FROM TVCYAW	PULSE TRAIN FROM TVCYAW INHIBITED	SH. 47, SH. 48	AUTOMATIC WHEN PULSE TRAIN ENDED	
CHANNEL 31 BIT 7	*X-TRANSLATION IS NOT COMMANDED BY TRANSLATIONAL HAND CONTROLLER	*X-TRANSLATION IS COMMANDED BY TRANSLATIONAL HAND CONTROLLER			SH. 17

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P40, P41 - THRUST PROGRAMS	
DESIGN: <i>J. J. ...</i>	BY: <i>J. J. ...</i>	COLOSSUS ID: <i>FC-2680</i>	DOCUMENT NO.
ANALYST: <i>John ...</i>	BY: <i>John ...</i>		FC-2680
DOCS: <i>John ...</i>	BY: <i>John ...</i>		
APPROV: <i>John ...</i>	BY: <i>John ...</i>	REV 3	SHEET 52 OF 58

## DISPLAYS

VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V50N25	PLEASE PERFORM FLASHING	R1-00204 CHECKLIST CODE - SPS GIMBAL TRIM	SH. 9
V16N40	FLASHING MONITOR	R1. XXXXX MIN-SEC TTOGO-TIME FROM TIC R2: XXXX.X FT/SEC VGDISP-VELOCITY-TO-BE-GAINED (MAGNITUDE) R3 XXXX.X FT/SEC DVTOTAL-SUM OF MAGNITUDES OF TWO-SECOND VELOCITY CHANGES SINCE BEGINNING OF THE MANEUVER	SH. 29
V16N85	FLASHING MONITOR	R1: XXXX.X FT/SEC VGBODY <sub>v</sub> - VELOCITY-TO-BE-GAINED R2 XXXX.X FT/SEC IN CONTROL COORDINATES R3- XXXX.X FT/SEC (X, Y, Z COMPONENTS)	SH. 30

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
A DB		ANGULAR DEADBAND FOR AUTOPILOT	DEGREES	REVS	2 <sup>-1</sup>
A VEEXIT <sub>D</sub>		VARIABLE ADDRESS OF EXIT FROM SERVICER (FC#2683)			
BDT <sub>V</sub>	BAT	INTERMEDIATE QUANTITY IN STEERING COMPUTATIONS, EQUAL TO $(\dot{V}_R - G\dot{M}T)$ IN REFERENCE COORDINATES	M/SEC <sup>2</sup>	M/CSEC <sup>2</sup>	2 <sup>7</sup>
CDUX		OUTER IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-1</sup>
CDUY		INNER IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-1</sup>
CDUZ		MIDDLE IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 <sup>-1</sup>
CNTR		USED HERE TO INDICATE WHETHER ENTRY TO S40.6 IS A RESTART ENTRY AND TO INDICATE PASS THROUGH TESTING PORTION OF S40.6			
CSMMASS		CSM VEHICLE MASS	KG	KG	2 <sup>16</sup>
CSTEER <sub>D</sub>	C	CROSS PRODUCT STEERING CONSTANT			2 <sup>2</sup>
DELLT <sub>D</sub>		LENGTH OF TIME TO REACH TARGET	SEC	CSEC	2 <sup>28</sup>
DELPBAR		TVC PITCH OFFSET-TRACKER-FILTER OUTPUT	DEGREES	REVS	1.07975111
DELVEET <sub>V</sub>		CHANGE IN VELOCITY REQUIRED FOR A MANEUVER, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
DELVLVC <sub>V</sub>	$\Delta V_{LV}$	VELOCITY-TO-BE-GAINED AT TIME OF IGNITION, IN TIME-OF-IGNITION LOCAL VERTICAL COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>

MIT INSTRUMENTATION LAB		COLOSSUS II D	
CAMPSIDE MASS.		R40, P41 - THRUST PROGRAMS	
OPRAN A.C. WILLIAMS	15NOV67		
PRGRM <i>see page 2</i>	2/16/67		
ANALYST <i>John A. Williams</i>	3/1/67	COLOSSUS II D	FC-2680
DOCOR <i>John A. Williams</i>	3/1/67		
APPR'D <i>John A. Williams</i>	17 MAR 67		



ERASABLE LOCATIONS USED (CONTINUED)					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
DELYBAR		TVC YAW OFFSET-TRACKER-FILTER OUTPUT	DEGREES	REVS	1.07975111
DELYSAB <sub>D</sub>	$V_{L.V}$	MAGNITUDE OF VELOCITY - TO-BE-GAINED AT TIME OF IGNITION	M/SEC	M/CSEC	2 <sup>7</sup>
DELSIN <sub>V</sub>	$V$	DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
DVTOTAL <sub>D</sub>		SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE THE BEGINNING OF THE MANEUVER (FOR DISPLAY)	M/SEC	M/CSEC	2 <sup>7</sup>
ERRBTMP		TEMPORARY STORAGE FOR ERROR <sub>Y</sub> (BELOW) - USED BY TVC DAP	DEGREES	REVS	2 <sup>-1</sup>
ERRBTMP-1		TEMPORARY STORAGE FOR ERROR <sub>Z</sub> (BELOW) - USED BY TVC DAP	DEGREES	REVS	2 <sup>-1</sup>
ERROR <sub>Y</sub>		PITCH ATTITUDE ERROR (CONTROL COORDS.) - FROM RCS DAP	DEGREES	REVS	2 <sup>-1</sup>
ERROR <sub>Z</sub>		YAW ATTITUDE ERROR (CONTROL COORDS.) - FROM RCS DAP	DEGREES	REVS	2 <sup>-1</sup>
$F_D$	$F$	NOMINAL THRUST (USED IN CENTRAL ANGLE COMPUTATION)	POUNDS OR NEWTONS	KG-M/CSEC <sup>2</sup>	2 <sup>7</sup>
GDT1/2 <sub>V</sub>	(1/2)GAT	1/2 THE DIFFERENCE IN VELOCITY DUE TO GRAVITATIONAL ACCELERATION AT A SPECIFIED POINT OVER A 2-SECOND INTERVAL, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
MASSTMP		TEMPORARY STORAGE FOR UPDATED CSM VEHICLE MASS	KG	KG	2 <sup>16</sup>
MODREG		MAJOR MODE, OR PROGRAM, NUMBER			
MRKRTMP		USED HERE TO INDICATE TO S40, 8 WHETHER ENGINE GIMBALS ARE TO BE TESTED, OR ONLY TRIMMED			
NBRCYCLS	$N$	USED TO INDICATE WHETHER S40, 8 IS TO BEGIN ANEW, AND IF NOT, THE NUMBER OF 2-SECOND CYCLES SINCE S40, 8 WAS LAST STARTED			2 <sup>14</sup>
NOMTI <sub>G</sub> <sub>D</sub>		NOMINAL TIME OF IGNITION (ACTUAL TIME OF IGNITION MAY BE CHANGED)	SEC	CSEC	2 <sup>28</sup>
NVWORD1		USED TO INDICATE TO CLOCK TASK WHETHER ANY DISPLAY IS TO BE DONE (BY CLOCKJOB) AND IF SO, WHICH ONE			
OGAD		OUTER IMU GIMBAL ANGLE FOR ROLL DAP	DEGREES	REVS	2 <sup>-1</sup>
OPTIND		INDICATES WHAT, IF ANY, OPTICS ACTIVITY IS TO BE ALLOWED			
PACTOFF PHASES		PITCH OFFSET ANGLE	DEGREES	REVS	1.07975111
PIPTIME <sub>1</sub> <sub>D</sub>		INDICATES WHETHER CERTAIN ROUTINES ARE TO BE RESTARTED AND, IF SO, AT WHAT POINT			
		TIME CORRESPONDING TO SOME UPDATED STATE VECTOR	SECS	CSECS	2 <sup>28</sup>

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4-40-61  
4-40-61

PGM. P41-THRUST PROGRAMS

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## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSPS SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
POINTVCSM <sub>V</sub>	$\underline{U}_D$	UNIT VECTOR IN DIRECTION IN WHICH ANOTHER VECTOR ASSOCIATED WITH THE SPACECRAFT IS TO BE ALIGNED IN THIS CASE, IN THE DIRECTION OF INITIAL THRUST, IN STABLE MEMBER COORDINATES			2 <sup>1</sup>
RATT <sub>V</sub>	R(T)	POSITION VECTOR, IN REFERENCE COORDINATES, COMPUTED BY INTEGRATION ROUTINE FOR A SPECIFIED TIME	M	M	2 <sup>20</sup>
REFSMMAT <sub>M</sub>	[REFSMMAT]	TRANSFORMATION MATRIX FOR CONVERSION BETWEEN REFERENCE AND STABLE MEMBER COORDINATE SYSTEMS			2 <sup>1</sup>
RINIT <sub>V</sub>		POSITION VECTOR AT A SPECIFIED TIME, IN REFERENCE COORDINATES	M	M	2 <sup>20</sup>
RTARG <sub>V</sub>	$\underline{R}(T_2)$	AIMPOINT POSITION VECTOR, IN REFERENCE COORDINATES	M	M	2 <sup>20</sup>
RTIG <sub>V</sub>	$\underline{R}(T_{IG})$	POSITION VECTOR AT TIME OF IGNITION, IN REFERENCE COORDINATES	M	M	2 <sup>20</sup>
RTXI		TEMPORARY STORAGE FOR INDEX REGISTER 1, INDICATES WHETHER REFERENCE COORDINATE SYSTEM IS CENTERED AT EARTH OR MOON, BY VALUE OF -2 OR -10, RESPECTIVELY			
RTX2		TEMPORARY STORAGE FOR INDEX REGISTER 2, INDICATES WHETHER REFERENCE COORDINATE SYSTEM IS CENTERED AT EARTH OR MOON, BY VALUE OF 0 OR 2, RESPECTIVELY			
SCAXIS <sub>V</sub>		UNIT VECTOR (IN THIS CASE, IN DIRECTION OF THRUST) IN SPACECRAFT COORDINATES, TO BE ALIGNED WITH ANOTHER VECTOR			2 <sup>1</sup>
TDEC <sub>D</sub>	T	SPECIFIED TIME CORRESPONDING TO STATE VECTOR TO BE COMPUTED	SECS	CSECS	2 <sup>28</sup>
TEVENT <sub>D</sub>		ACTUAL TIME OF RELEVANT EVENT, FOR DOWNLINK	SECS	CSECS	2 <sup>28</sup>
TGO <sub>D</sub>	T <sub>GO</sub>	TIME UNTIL ENGINE CUTOFF (IF KNOWN)	SECS	CSECS	2 <sup>28</sup>
THETA <sub>DX</sub>		SNAPSHOT OF OUTER IMU GIMBAL ANGLE	DEGREES	REVS	2 <sup>-1</sup>
THETA <sub>DY</sub>		SNAPSHOT OF INNER IMU GIMBAL ANGLE	DEGREES	REVS	2 <sup>-1</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		P40, P41 - THRUST PROGRAMS	
DESIGNER A.C. WILLIAMS	DATE 3/10/69	COLLOSSUS	II D FC-2680
APP'D Peter M. Sullivan	DATE 3/10/69	REV 3	55 58

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
THETADZ		SNAPSHOT OF MIDDLE IMU GIMBAL ANGLE	DEGREES	REVS	$2^{-1}$
TIG <sub>D</sub>	T <sub>IG</sub>	TIME OF IGNITION OR OF CUTOFF, WHICHEVER IS RELEVANT	SECS	CSECS	$2^{28}$
TIME1		LOW-ORDER HALF OF TIME <sub>2,D</sub> -CURRENT TIME	SECS	CSECS	$2^{28}$
TIME <sub>2,D</sub>		CURRENT TIME	SECS	CSECS	$2^{28}$
TPASS <sub>4,D</sub>	T <sub>2</sub>	TIME OF ARRIVAL AT TARGET	SECS	CSECS	$2^{28}$
TVCXPHS		USED TO INDICATE WHICH AREA IN THE TVC EXECUTIVE IS TO BE RESTARTED			
TVCPHASE		USED TO INDICATE WHICH AREA IN THE TVC DAP IS TO BE RESTARTED			
TVCPITCH		ANGLE THROUGH WHICH SPS ENGINE PITCH GIMBAL IS TO BE DRIVEN	DEGREES	REVS	1.07975111
TVCYAW		ANGLE THROUGH WHICH SPS ENGINE YAW GIMBAL IS TO BE DRIVEN	DEGREES	REVS	1.07975111
UT <sub>V</sub>	<u>U</u> <sub>TD</sub>	UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST, IN REFERENCE COORDINATES			$2^1$
VATT <sub>V</sub>	V(T)	VELOCITY VECTOR, IN REFERENCE COORDINATES, COMPUTED BY INTEGRATION ROUTINE FOR A SPECIFIED TIME	M/SEC	M/CSEC	$2^7$
VGBODY <sub>V</sub>		VELOCITY-TO-BE-GAINED IN CONTROL COORDINATES	M/SEC	M/CSEC	$2^7$
VGDISP <sub>D</sub>		MAGNITUDE OF VELOCITY-TO-BE-GAINED (FOR DISPLAY)	M/SEC	M/CSEC	$2^7$
VGPREV <sub>V</sub>	<u>V</u> <sub>G</sub>	LAST COMPUTED VELOCITY-TO-BE-GAINED, IN REFERENCE COORDINATES	M/SEC	M/CSEC	$2^7$
VGTIG <sub>V</sub>	<u>V</u> <sub>G(T<sub>IG</sub>)</sub>	VELOCITY-TO-BE-GAINED AT TIME OF IGNITION, IN REFERENCE COORDINATES	M/SEC	M/CSEC	$2^7$
VINIT <sub>V</sub>		VELOCITY VECTOR AT A SPECIFIED TIME, IN REFERENCE COORDINATES	M/SEC	M/CSEC	$2^7$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		PMQ #1-THRUST PROGRAMS	
DESIGN A. C. MULLINGS	12/2/68		
FROM <i>[Signature]</i>	12/12/68		
ANALYST <i>[Signature]</i>	12/11/68	COLOSSUS II D	DOCUMENT NO. FC-2680
DOCSN <i>[Signature]</i>	12/11/68		
APPROV <i>[Signature]</i>	12/11/68	REV 3	SHEET 26 OF 28

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
VIPRME <sub>V</sub>	$\underline{V}_R$	VELOCITY REQUIRED AT BEGINNING OF A MANEUVER, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
VTIG <sub>V</sub>	$\underline{V}(T_{IG})$	VELOCITY VECTOR AT TIME OF IGNITION, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
V97VCNTR		USED BY TVC DAP TO COUNT NUMBER OF HALF-SECOND INTERVALS			2 <sup>14</sup>
WEIGHT/G <sub>D</sub>	M	MASS OF VEHICLE (INCLUDING LM IF APPROPRIATE)	KG	KG	2 <sup>16</sup>
XSCREF <sub>V</sub>	$\underline{X}_{SC}(RF)$	SPACECRAFT X AXIS IN REFERENCE COORDINATES			2 <sup>1</sup>
YACTOFF		YAW OFFSET ANGLE	DEGREES	REVS	1.07878111
YSCREF <sub>V</sub>	$\underline{Y}_{SC}(RF)$	SPACECRAFT Y AXIS IN REFERENCE COORDINATES			2 <sup>1</sup>
ZSCREF <sub>V</sub>	$\underline{Z}_{SC}(RF)$	SPACECRAFT Z AXIS IN REFERENCE COORDINATES			2 <sup>1</sup>

## PROGRAM CONSTANTS

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
EP4(10)H <sub>D</sub>	10 <sup>0</sup>	POSSIBLE VALUE FOR MINIMUM ANGLE BETWEEN INITIAL AND FINAL POSITION VECTORS SUFFICIENT TO DEFINE A PLANE OF FLIGHT	10 DEGREES	.027777777 REV	2 <sup>0</sup>
EP4(45)H <sub>D</sub>	45 <sup>0</sup>	POSSIBLE VALUE FOR MINIMUM ANGLE BETWEEN INITIAL AND FINAL POSITION VECTORS SUFFICIENT TO DEFINE A PLANE OF FLIGHT	45 DEGREES	.125 REV	2 <sup>0</sup>
FENG <sub>D</sub>	F <sub>SPS</sub>	SPS ENGINE THRUST (USED IN CENTRAL ANGLE COMPUTATION FOR P40)	20500 LBS	9.1168544 KG-M/CSEC <sup>2</sup>	2 <sup>7</sup>
FRCS2 <sub>D</sub>	F <sub>RCS</sub>	RCS THRUST FOR 2 JETS (USED IN CENTRAL ANGLE COMPUTATION FOR P41)	199.6 (COS 10) LBS	.087437837 KG-M/CSEC <sup>2</sup>	2 <sup>7</sup>
MAXDB		MAXIMUM VALUE FOR ANGULAR DEADBAND (FOR AUTOPILOT)	4.998779 DEGREES	455 x 2 <sup>-15</sup> REVS	2 <sup>-1</sup>
MINDB		MINIMUM VALUE FOR ANGULAR DEADBAND (FOR AUTOPILOT)	.505371 DEGREES	46 x 2 <sup>-15</sup> REVS	2 <sup>-1</sup>

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ATMOSPHERIC ACTION LAB		
DESIGNER <i>L. J. Meyer</i>	DATE <i>3/19/67</i>	FC-2630 II D 57 - 58
CHECKER <i>J. J. Meyer</i>	DATE <i>3/19/67</i>	
ANALYST <i>John A. Hill</i>	DATE <i>3/19/67</i>	
DESIGNER <i>John A. Hill</i>	DATE <i>3/19/67</i>	
APPV. <i>John A. Hill</i>	DATE <i>3/19/67</i>	
COLO'SSUS		

## PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
PBIAS <sub>D</sub>	P <sub>O</sub>	BIAS IN FITCH OFFSET ANGLE	-2.15 DEGREES	-.0059722222 REV	2 <sup>0</sup>
S40.135 <sub>D</sub>	7.98F <sub>L</sub>	IMPULSE OF ULLAGE THRUST DUE TO 2-JET BURN FOR 7.98 SECONDS	1588.818 LB-SEC	89.6005183 KG-M/CSEC	2 <sup>23</sup>
TRIMSICAL <sub>D</sub>		SCALING FACTOR FOR SPS ENGINE GIMBAL OFFSET ANGLES	1.07975111	1.07975111	2 <sup>1</sup>
YBIAS <sub>D</sub>	Y <sub>O</sub>	BIAS IN YAW OFFSET ANGLE	+0.95 DEGREES	+ .00263888888 REV	2 <sup>0</sup>
-2ACTDEG		AMOUNT OF ROTATION USED IN TESTING ENGINE GIMBALS	+1.9928 DEGS	+0.00553583 REV	1.07975111
-4ACTDEG		AMOUNT OF ROTATION USED IN TESTING ENGINE GIMBALS (MUST BE -2 x +2ACTDEG (ABOVE))	-3.9856 DEGS	-.01107166 REV	1.07975111

## PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
ECSTEER	EC	CROSS-PRODUCT STEERING CONSTANT, USED FOR LAMBERT MANEUVER - UPDATED BY PRE-THRUST PROGRAMS - USUALLY THE VALUE REMAINS 1.0, BUT MAY BE CHANGED TO .5 OR ANY VALUE FROM -4.0 TO +4.0	1.0	1.0	2 <sup>2</sup>	10000
EMDOT	M	RATE OF MASS DECREASE DURING SPS BURN			2 <sup>3</sup>	
K1VAL <sub>D</sub> (=EK1VAL <sub>D</sub> )	K <sub>1</sub>	1-SECOND SPS IMPULSE	LB-SEC	KG-M/CSEC	2 <sup>23</sup>	
FANG <sub>D</sub>	F <sub>IMP</sub>	EFFECTIVE THRUST DURING 1-6 SECOND INTERVAL OF BURN (USED IN IMPULSIVE BURN TIME COMPUTATIONS)	POUNDS OR NEWTONS	KG-M/CSEC <sup>2</sup>	2 <sup>7</sup>	
K2VAL <sub>D</sub> (=EK2VAL <sub>D</sub> )	K <sub>2</sub>	-SPS MINIMUM IMPULSE	LB-SEC	KG-M/CSEC	2 <sup>23</sup>	
K3VAL (=EK3VAL)	K <sub>3</sub>	EFFECTIVE THRUST DURING 0-1 SECOND INTERVAL OF BURN (USED IN IMPULSIVE BURN TIME COMPUTATIONS)	LB-SEC/SEC	KG-M/CSEC <sup>2</sup>	2 <sup>9</sup>	

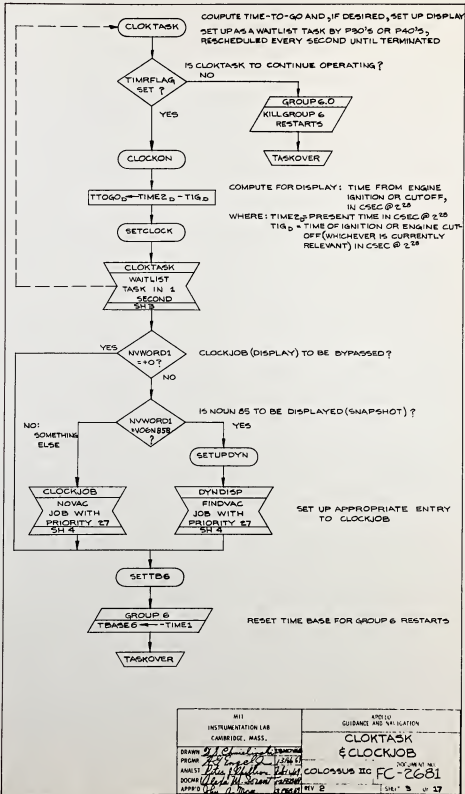
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED GUIDANCE AND NAVIGATION	
DRAWN <i>L. D. Moore</i> 1/10/69		P40, P41 - THRUST PROGRAMS	
PROGRAM <i>SPS</i>	ANALYST <i>John S. White</i> 1/11/69	COLLOSSUS IID	DOCUM AT NO. FC-2680
DOCMAN <i>John M. Sargent</i> 1/11/69	APPROV <i>John A. Moore</i> 1/11/69	REV 3	UNIT 58 OF 68

## CLOKTASK AND CLOCKJOB

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS:		
CLOKTASK:	COMPUTES TIME-TO-GO AND, IF DESIRED, SETS UP DISPLAY	SH. 3
CLOCKJOB:	UPDATES TRIGONOMETRIC FUNCTIONS OF IMU GIMBAL ANGLES AND CAUSES DESIRED DISPLAY	SH. 4
DYNDISP:	SETS UP VELOCITY-TO-BE-GAINED FOR NOUN 85 DISPLAY AND DISPLAYS IT	SH. 4
V99T:	TERMINATES PROGRAM (FROM TERMINATE RESPONSE TO V99 FLASH)	SH. 5
V99P:	SETS UP IGNITION OF SPS ENGINE (FROM PROCEED RESPONSE TO V99 FLASH)	SH. 6
V99E:	BYPASSES SPS BURN, JUMPING TO RCS TRIM PORTION OF PROGRAM (FROM ENTER RESPONSE TO V99 FLASH)	SH. 7
V97T:	ENDS SPS BURN, THEN SETS UP TERMINATION OF PROGRAM (FROM TERMINATE RESPONSE TO V97 FLASH)	SH. 8
V97P:	ALLOWS SPS BURN TO CONTINUE 2 SECONDS MORE BEFORE AGAIN TESTING FOR THRUST FAILURE (FROM PROCEED RESPONSE TO V97 FLASH)	SH. 10
V97E:	URNS OFF SPS ENGINE, SETS UP RE-IGNITION (FROM ENTER RESPONSE TO V97 FLASH)	SH. 11

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ANPOLO GUIDANCE AND NAVIGATION	
		CLOKTASK & CLOCKJOB	
DRAWN <i>J. H. Smith</i>	DOCTORS		
PREPARED <i>J. H. Smith</i>	11/26/62		
ANALYST <i>J. H. Smith</i>	11/26/62	COLOSSUS IC	DOCUMENT NO.
SKETCHED <i>J. H. Smith</i>	11/26/62		FC-2681
APPROVED <i>J. H. Smith</i>	11/26/62	REV 2	SHEET 1 OF 17

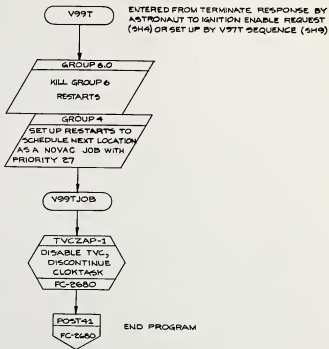




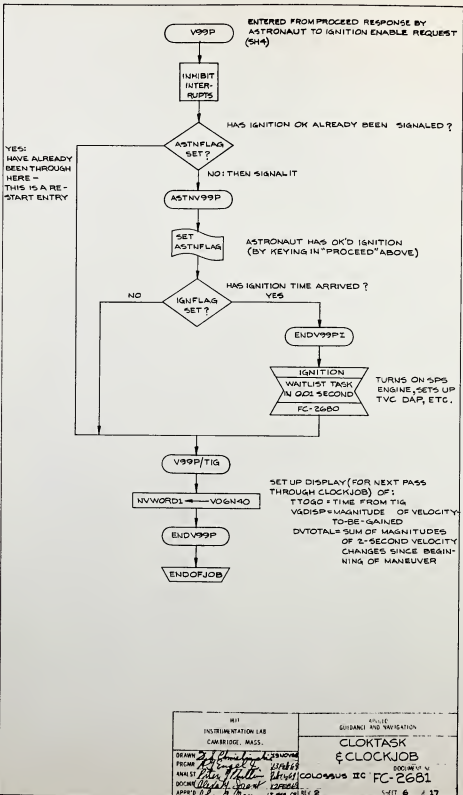
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROLO GUIDANCE AND SIMULATION	
DRAWN <i>[Signature]</i>		CLOKTASK & CLOKJOB	
PREPARED <i>[Signature]</i>		NOV. 1961	
ANALYST <i>[Signature]</i>		COLOSSUS IIC FC-2681	
DOCTOR <i>[Signature]</i>		REV 2	
APPROVED <i>[Signature]</i>		SER. 3 OF 17	







MIT 77-011 IN TERMINATION 122 LAMBRIDGE, MASS.	PROJECT CLOKTASK & CLOCKJOB I. NO. 11 COLLOSSUS II FC-2681 REV. 2 5 - 17
APPROVED BY: <i>[Signature]</i> BY: <i>[Signature]</i> DATE: <i>[Signature]</i> AUTHORITY: <i>[Signature]</i>	APPROVED BY: <i>[Signature]</i> DATE: <i>[Signature]</i> AUTHORITY: <i>[Signature]</i>



V99E

ENTERED FROM ENTER RESPONSE (BY ASTRO-NAUT) TO IGNITION ENABLE REQUEST (SH4)

GROUP 6.0  
KILL GROUP 6  
RESTARTS

GROUP 4  
SET UP RESTARTS TO  
SCHEDULE NEXT LOCATION  
AS A NOVAC JOB  
WITH PRIORITY 27

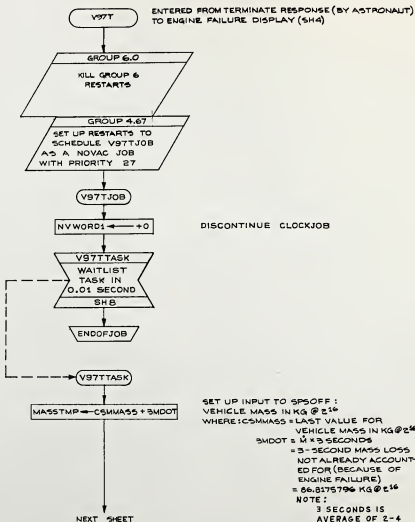
V99EJOB

TVCTAP-  
DISABLE TVC,  
DISCONTINUE  
CLOCKTASK  
FC-2680

PNORCS  
FC-2680

DO MANUAL (RCS) Δ V TRIM

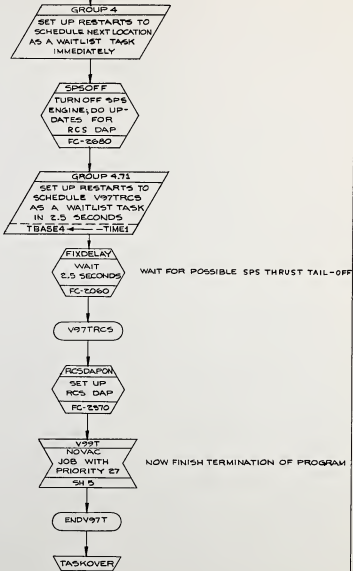
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLICATION GUIDANCE AND CALIBRATION
DRAWN <i>[Signature]</i> <del>REMOVED</del>		<b>CLOCKTASK &amp; CLOCKJOB</b> DOCUMENT # COLOSSUS IIC : FC-2681 SHEET 7 OF 17
PROGRAM	<i>[Signature]</i> <del>REMOVED</del>	
ANALYST	<i>[Signature]</i> <del>REMOVED</del>	
APPROVED	<i>[Signature]</i> <del>REMOVED</del>	



SET UP INPUT TO SP5OFF:  
VEHICLE MASS IN KG @ 2<sup>16</sup>  
WHERE: CSMMASS = LAST VALUE FOR  
VEHICLE MASS IN KG @ 2<sup>16</sup>  
3MDOT =  $\frac{1}{2} \times 3$  SECONDS  
= 3 - SECOND MASS LOSS  
NOT ALREADY ACCOUNT-  
ED FOR (BECAUSE OF  
ENGINE FAILURE)  
= 66.8175796 KG @ 2<sup>16</sup>  
NOTE:  
3 SECONDS IS  
AVERAGE OF 2-4  
SECOND LOW-THRUST  
DETECTION PERIOD

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DRAWN <i>J. J. Chubb</i>		CLOCKTASK & CLOCKJOB	
FRONT <i>J. J. Chubb</i>		DOCUMENT NO.	
ANALYST <i>John A. Chubb</i>		FC-2681	
DOCKMAN <i>John A. Chubb</i>		SHEET 6 OF 17	
APPROV <i>John A. Chubb</i>		REV 2	

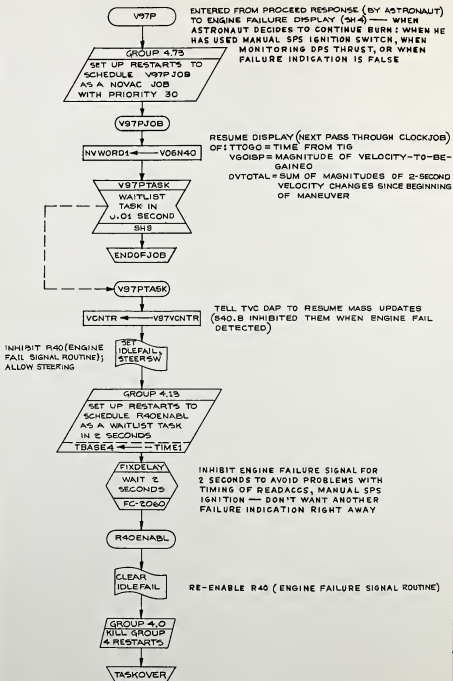
FROM PRECEDING SHEET



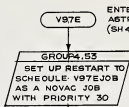
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		CLOCKTASK CLOCKJOB	
PREPARED <i>[Signature]</i>		FC-2681	
ANALYST <i>[Signature]</i>		NOV 1959	
BY <i>[Signature]</i>		COLLOSSUS IIC	
APPROVED <i>[Signature]</i>		REV 2	

17 228.64

9 17



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
CLOCKTASK & CLOCKJOB	
DRAWN BY <i>[Signature]</i> FROM <i>[Signature]</i> ANALYST <i>[Signature]</i> DESIGNER <i>[Signature]</i> APPROV <i>[Signature]</i>	DOCUMENT NO. COLOSSUS IIC FC-2681 SHEET 10 OF 37



ENTERED FROM ENTER RESPONSE (BY  
ASTRONAUT) TO ENGINE FAILURE DISPLAY  
(SH 4)

RESUME DISPLAY (NEXT PASS  
THROUGH CLOCKJOB) OF:  
TTGO = TIME FROM TIG (WILL SHOW :  
59 MIN 59 SEC)  
VSDISP = MAGNITUDE OF VELOCITY -  
TO BE GAINED  
OVTOTAL = SUM OF MAGNITUDES  
OF 2- SECONDS VELOCITY CHANGES  
SINCE THE BEGINNING OF THE MANEUVER

SET TIME OF IGNITION (TIG<sub>0</sub>) LESS THAN  
-19 X 2<sup>14</sup> CSEC (≈ -51.9 MIN) @ 2<sup>28</sup>. THIS  
VALUE WILL INSURE THAT TIME - FROM -TIG  
COMPUTED BY CLOKTASK WILL BE SO  
GREAT THAT IT WILL BE DISPLAYED AS THE  
MAXIMUM :  
+59 MIN 59 SEC

SET UP INPUT TO SPOFF : VEHICLE  
MASS IN KG @ 2<sup>10</sup> WHERE :  
CSMMASS = LAST VALUE FOR VEHICLE  
MASS IN KG @ 2<sup>16</sup>  
3MDOT = M X 3 SECONDS  
= 3 - SECOND MASS LOSS  
NOT ALREADY ACCOUNTED FOR  
(BECAUSE MASS UPDATES STOPPED  
WHEN ENGINE FAILURE DETECTED)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> PREP BY <i>[Signature]</i> ANALYST BY <i>[Signature]</i> APPROVED <i>[Signature]</i>		CLOKTASK & CLOCKJOB COLLOSSUS IIC DOCUMENT NO <b>FC-2681</b>	
		SHEET 11 OF 17	



FROM PRECEDING SHEET

SPSOFF97

SPSOFF  
TURN OFF  
SPS ENGINE, DO  
UPDATES FOR  
RCS DAP  
FC-2660

GROUP 4.11  
SET UP RESTARTS TO  
SCHEDULE V97E40.6  
AS A WAITLIST TASK  
IN 2.5 SECONDS

FIXDELAY  
WAIT 2.5  
SECONDS  
FC-2060

WAIT FOR POSSIBLE SPS THRUST TAILOFF

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		CLOCKTASK & CLOCKJOB	
PROGRAM <i>[Signature]</i>		DOCUMENT NO.	
ANALYST <i>[Signature]</i>		COLOSSUS IIC FC-2681	
DOCKMAN <i>[Signature]</i>		REV 2	
APPROV'D <i>[Signature]</i>		SHEET 12 OF 17	

FROM PRECEDING SHEET

V97E40.6

PRE40.6

WAITLIST  
TASK IN  
0.01 SECOND  
FC-2680

RESTART ENTRY TO S40.6  
WILL DO SP5 ENGINE GIMBAL TRIM ONLY

RCS DAPON  
SET UP  
RCS DAP  
FC-2570

GROUP 6.2

SET UP RESTARTS TO  
SCHEDULE PRE40.6  
AS A WAITLIST TASK  
IMMEDIATELY AND  
CLOCKTASK AS A  
WAITLIST TASK IN 1  
SECOND

PRE40.6 MUST BE RESTARTED,  
SINCE TYC DAP IS NOT IN  
CONTROL, WILL NOT TAKE  
CARE OF INTERFACE

GROUP 4

SET UP RESTARTS TO  
SCHEDULE NEXT LOCATION  
AS A WAITLIST TASK  
IMMEDIATELY

QUICKIGN

SET UP SITUATION FOR V99P SEQUENCE  
TO CAUSE IGNITION (ANOTHER TRY):  
[ THE SITUATION IS PARALLEL TO THAT  
OF A LATE IGNITION ]

CLEAR  
ASTN FLAG  
SET  
IGNFLAG

ASTRONAUT HAS NOT YET OK'D (NEW)  
IGNITION  
IGNITION TIME HAS ARRIVED  
(PROCEED RESPONSE TO V99 FLASH)  
WILL BRING IMMEDIATE IGNITION

FIXDELAY  
WAIT  
0.3 SECOND  
FC-2060

ALLOW TIME FOR S40.6 (PRE40.6)  
TO BE EXECUTED

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APP'D (-FRONT AND WAITLIST)
DRAWN <i>[Signature]</i>		CLOCKTASK FCLOCKJOB FC-2681 REV 2
FROM <i>[Signature]</i>		
ANALYST <i>[Signature]</i>		
DOCKED <i>[Signature]</i>		
APPROV'D <i>[Signature]</i>		
COLLOSSUS IIC		EXCISE SHEET 19 of 27

FROM PRECEDING SHEET

V99FLASH

NVWORD1 ← -BIT9

SET INDICATOR NEGATIVE TO CAUSE  
V99 FLASH (IGNITION ENABLE  
REQUEST) NEXT TIME THROUGH  
CLOCKJOB

GROUP 4.77

SET UP RESTARTS TO  
SCHEDULE TIG-0 AS A  
WAITLIST TASK  
IMMEDIATELY  
TBASE4 ← TIME1

GROUP 5.3

SET UP RESTARTS TO  
SCHEDULE S40.13  
AS A FINDVAC JOB WITH  
PRIORITY 20

S40.13

FINDVAC  
JOB WITH  
PRIORITY 20  
FC-2680

DETERMINES LENGTH OF IMPULSIVE  
BURN.  
(ULLAGE ALLOWANCE WILL BE  
INCORRECT THIS TIME, UNLESS  
THERE IS NO ULLAGE)

ENDV97E

TASKOVER

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ARD:IG GUIDANCE AND NAVIGATION
DRAWN <i>[Signature]</i>	CLOCKTASK
PREPARED <i>[Signature]</i>	CLOCKJOB
ANALYST <i>[Signature]</i>	DOCUMENT NO
DOCKED <i>[Signature]</i>	COLOSSUS IIC FC-2681
APPROVED <i>[Signature]</i>	SHEET 24 OF 27

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
IGNITION	2680	TURNS ON SPS ENGINE; SETS UP TVC DAP	SH. 8 SH. 4
POST41	2680	TERMINATES PROGRAM	SH. 5
PRE40.6	2680	TRIMS SPS ENGINE GIMBALS	SH. 13
P40CNV85	2682	PREPARES VELOCITY-TO-BE-GAINED FOR NOUN 85 DISPLAY	SH. 4
P40RCS	2680	RCS TRIM PORTION OF P40	SH. 7
QUICTRIG	2270	COMPUTES TRIGONOMETRIC FUNCTIONS OF THREE ANGLES GIVEN	SH. 4
RCS DAPON	2370	SETS UP RCS DAP	SH. 9 SH. 13
SPSOFF	2680	TURNS OFF SPS ENGINE. DOES UPDATES FOR RCS DAP	SH. 9 SH. 12
S40.13	2680	DETERMINES LENGTH OF IMPULSIVE BURN	SH 14
TVCZAP-1	2680	DISABLES THRUST VECTOR CONTROL; DISCONTINUES CLOKTASK	SH. 5 SH. 7

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
ASTNFLAG FLAGWRD7 BIT 12	ASTRONAUT HAS OKAYED IGNITION	ASTRONAUT HAS NOT OKAYED IGNITION	SH.6	SH.13	SH.6
IDLEFAIL FLAGWRD1 BIT 6	INHIBIT R40 (ENGINE FAIL SIGNAL ROUTINE)	ENABLE R40 (ENGINE FAIL SIGNAL ROUTINE)	SH.10	SH.10	
IGNFLAG FLAGWRD7 BIT 13	IGNITION TIME HAS ARRIVED	IGNITION TIME HAS NOT ARRIVED	SH.13		SH.6
STEERSW FLAGWRD2 BIT 11	STEERING TO BE DONE	NO STEERING TO BE DONE	SH.10		
TMRFLAG FLAGWRD7 BIT 11	CLOKTASK TO CONTINUE	CLOKTASK NOT TO RUN			SH.3

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED GUIDANCE AND NAVIGATION
CLOKTASK & CLOCKJOB	
DRAWN <i>[Signature]</i> 30 OCT 68 PREPARED <i>[Signature]</i> 28 OCT 68 ANALYSIS <i>[Signature]</i> 28 OCT 68 CHECKED <i>[Signature]</i> 28 OCT 68 APPROVED <i>[Signature]</i> 11 NOV 68	COLLOSSUS IIC FC-2681 REV 2 SHEET 15 OF 17

## DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V68N40	NORMAL	R1: XXRX MIN-SEC TIOGO = TIME FROM TIG R2: XXXX X FT/SEC VGDISP = MAGNITUDE OF VELOCITY-TO-BE-GAINED R3: XXXX X FT/SEC DVTTOTAL = SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE BEGINNING OF MANEUVER	SH. 4
V68N85	NORMAL	R1: XXXX X FT/SEC } R2: XXXX X FT/SEC } 3 COMPONENTS OF R3: XXXX X FT/SEC } VGBODY <sub>v</sub> = VELOCITY-TO-BE GAINED IN CONTROL COORDINATES	SH. 4
V16N85	MONITOR	SAME AS ABOVE	SH. 4
V98N40	FLASHING, PLEASE PERFORM: IGNITION ENABLE	REGISTERS SAME AS FOR NOUN 40 DISPLAY ABOVE	SH. 4
V97N40	FLASHING, PLEASE PERFORM: RESPONSE TO THRUST FAILURE	REGISTERS SAME AS FOR NOUN 40 DISPLAY ABOVE	SH. 4

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
CDUSPOTX		FIRST ANGLE INPUT TO QUICTRIG - IN 2'S COMPLEMENT	DEGREES	REVS	2 <sup>-1</sup>
CDUSPOTY		SECOND ANGLE INPUT TO QUICTRIG - IN 2'S COMPLEMENT	DEGREES	REVS	2 <sup>-1</sup>
CDUSPOTZ		THIRD ANGLE INPUT TO QUICTRIG - IN 2'S COMPLEMENT	DEGREES	REVS	2 <sup>-1</sup>
CDUX		OUTER IMU GIMBAL ANGLE IN 2'S COMPLEMENT	DEGREES	REVS	2 <sup>-1</sup>
CDUY		INNER IMU GIMBAL ANGLE IN 2'S COMPLEMENT	DEGREES	REVS	2 <sup>-1</sup>
CDUZ		MIDDLE IMU GIMBAL ANGLE IN 2'S COMPLEMENT	DEGREES	REVS	2 <sup>-1</sup>
COSCDUX		COSINE OF FIRST ANGLE INPUT TO QUICTRIG			2 <sup>1</sup>
COSCDUY		COSINE OF SECOND ANGLE INPUT TO QUICTRIG			2 <sup>1</sup>
COSCDUZ		COSINE OF THIRD ANGLE INPUT TO QUICTRIG			2 <sup>1</sup>
CSMMASS		MASS OF CSM	KG	KG	2 <sup>16</sup>
DVTTOTAL		SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE BEGINNING OF MANEUVER	M/SEC	M/CSEC	2 <sup>16</sup>
MASSTMP		TEMPORARY UPDATED VERSION OF CSMMASS (ABOVE)	KG	KG	2 <sup>16</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
CLOKTASK & CLOCKJOB			
DRAWN: <i>[Signature]</i>	22 OCT 67	DOCUMENT NO.	
PROJ: <i>[Signature]</i>	11/26/67	COLOSSUS IIC	FC-2681
ANALYST: <i>[Signature]</i>	11/26/67		
DOCNO: <i>[Signature]</i>	11/26/67		
APPR: <i>[Signature]</i>	11/26/67	REV 2	SHEET 16 OF 17

## ERASABLE DEFINITIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
WORD1		INDICATES WHETHER ANY DISPLAY IS TO BE SET UP BY CLOCKJOB AND, IF SO, WHICH ONE			
SINC0UX		SINE OF FIRST ANGLE INPUT TO QUICTRIG			$2^1$
SINC0UY		SINE OF SECOND ANGLE INPUT TO QUICTRIG			$2^1$
SINC0UZ		SINE OF THIRD ANGLE INPUT TO QUICTRIG			$2^1$
TBASE6		LOW ORDER HALF OF TIME FROM WHICH GROUP 6 WAITLIST TASK RESTART $\Delta$ 'S ARE MEASURED	SEC	CSEC	$2^{14}$
TIG <sub>D</sub>	T <sub>IG</sub>	TIME OF ENGINE IGNITION OR CUTOFF, WHICHEVER IS CURRENTLY RELEVANT	SEC	CSEC	$2^{20}$
TIME <sub>D</sub> <sup>2</sup> = (TIME2) (TIME1)		PRESENT TIME	SEC	CSEC	$2^{28}$
TT0G0 <sub>D</sub>		TIME FROM TIG (ABOVE)	SEC	CSEC	$2^{26}$
VGBODY <sub>V</sub>		VELOCITY TO-BE-GAINED IN CONTROL COORDINATES (DISPLAYED AS NOUN 85)	M/SEC	M'CSEC	$2^7$
VGDISP <sub>D</sub>		MAGNITUDE OF VELOCITY TO-BE-GAINED (DISPLAYED AS PART OF NOUN 40)	M/SEC	M'CSEC	$2^7$
VGPREV <sub>V</sub>	V <sub>G</sub>	VELOCITY TO-BE-GAINED IN REFERENCE COORDINATES	M/SEC	M'CSEC	$2^7$

## PROGRAM CONSTANTS

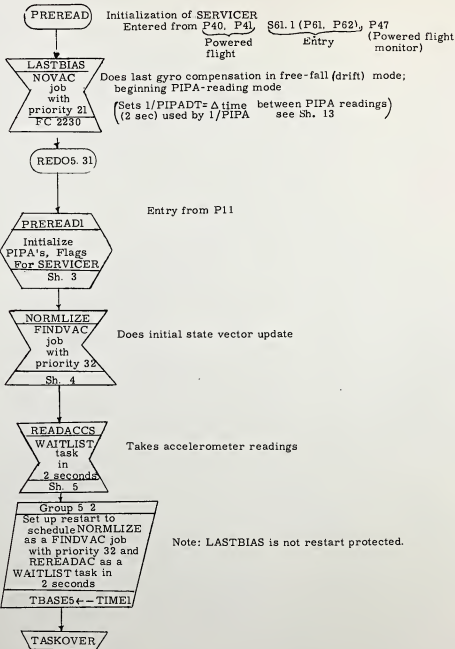
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
3M0DOT	M x 3 SEC	3-SECOND MASS LOSS DUE TO SPS BURN	86.8175796 KG	86.8175796 KG	$2^{16}$

REC INFORMATION LIAISON TELETYPE UNIT		GUPDAY 2 11 68 CLOUTASK 4 2 2 2 2 2
3-11 3-12 3-13 3-14 3-15	30078 12061 10199 12062 12063	COLDSBUS EC EC-7 52 2 2

SERVICER

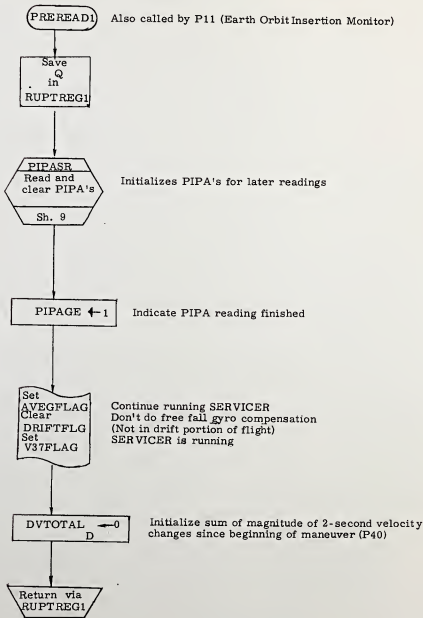
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS		
PREREAD:	Initializes SERVICER	Sh. 2
PREREAD1:	Zero PIPA's	Sh. 3
NORMLIZE:	Does Initial State Vector Update	Sh. 4
READACCS:	Reads Accelerometers, Sets up SERVICER; Reschedules Itself Every 2 Seconds Until Stopped	Sh. 5
PIPASR:	Reads PIPA Counters	Sh. 9
REREADAC:	Possible Restart Entry to READACCS - In Case Accelerometers Must Be Reread	Sh. 13
QUIKREAD:	Takes Quick Accelerometer Readings for Downlink Telemetry	Sh. 15
SERVICER:	Checks $\Delta$ Velocity Values Read In, Does Permanent State Vector Update Using Sensed $\Delta$ Velocity	Sh. 16
CALCRVG:	Computes New State Vector	Sh. 20
CALCGRAV:	Calculates Gravitational Acceleration at Specified Position	Sh. 22
AVGEND:	Final Exit from SERVICER: Performs Transition to Coasting Flight Routines	Sh. 25
SERVEXIT:	Common End of SERVICER Routines	Sh. 27

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
PRGRM	<i>R. Engel</i>	<i>4/24/69</i>	
ANALST	<i>R. Engel</i>	<i>4/24/69</i>	COLOSSUS 2D
DOCNR			DOCUMENT NO. FC-2683
APPR'D	<i>John C. Estlin</i>	<i>4/24/69</i>	REV 1
			SHEET 1 OF 31

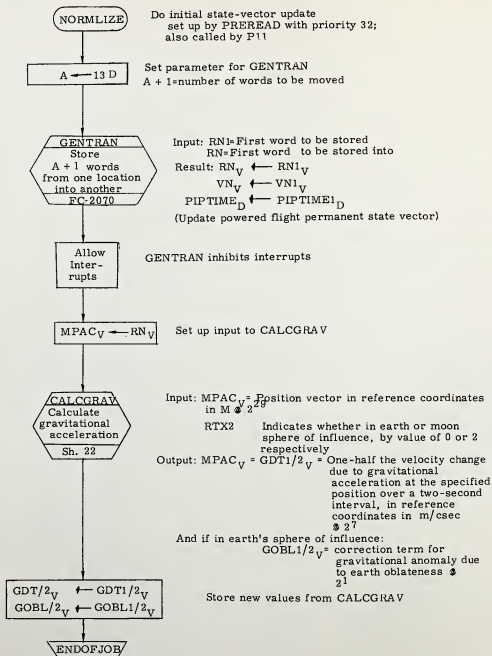


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. W. Smith</i> 5/27/69		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2683
ANALST <i>A. L. Engel</i> 11/10/69			
DOCMR		REV 1	SHEET 2 OF 3
APPR'D <i>Robert M. Carter</i> 11/11/69			

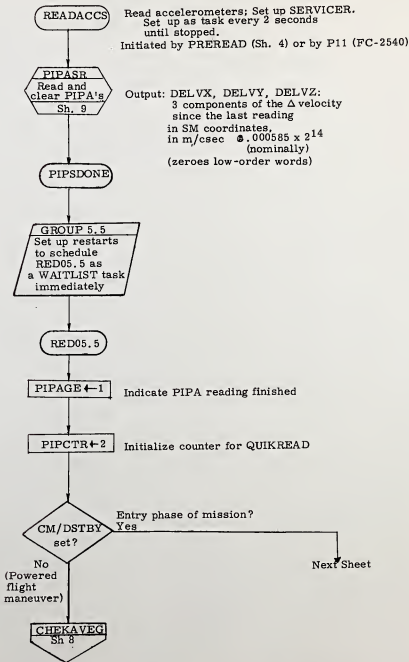




MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>L. Winkler</i>	<i>8/19/69</i>	COLOSSUS 2D	DOCUMENT NO. FC-2683
PRGRM			
ANALST <i>Al. Engel</i>	<i>11/19/69</i>		
DOCMR			
APPR'D <i>Robert M. East</i>	<i>11/19/69</i>	REV 1	SHEET 3 OF 37



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>L. Weisich</i>	<i>7/16/62</i>	COLOSSUS 2D	DOCUMENT NO.
PRGRM			FC-2683
ANALST <i>AL Engel</i>	<i>11/10/62</i>		
DOCNR			
APPR'D <i>Robert M. Estlin</i>	<i>11/10/62</i>	REV 1	SHEET 4 OF 37



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>B. W. White</i>	<i>11/16/69</i>	COLOSSUS 2D	DOCUMENT NO.
PRGMR			FC-2683
ANALST <i>A. L. Engle</i>	<i>11/16/69</i>		
DOCNR			
APPR'D <i>Robert M. Engle</i>	<i>11/16/69</i>	REV 1 1	SHEET 5 OF 37

From Preceding Sheet

GROUP 6  
TBASE6 ← -(PIPTIME1 + 1)

PIPTIME1 + 1 is low-order half of PIPTIME<sub>D</sub> = time of last PIPA reading

AOG/PIP ← AOG  
AIG/PIP ← AIG  
AMG/PIP ← AMG

Save for entry DAP:  
Latest snapshot (taken by entry DAP at 100 ms intervals) of:  
IMU gimbal angles (2's complement) in revs @ 2<sup>-1</sup>

ROLL/PIP ← ROLL/180  
ALFA/PIP ← ALFA/180  
BETA/PIP ← BETA/180

Corresponding Euler angles for CM attitude in revs @ 2<sup>-1</sup>

No  
CMDAPARM set?

Entry firings and calculations allowed?

Yes

QUIKREAD  
WAITLIST  
task in  
0.5 second  
Sh. 15

Takes new PIPA reading for Downlink telemetry

XOLDBUF ← XPIPBUF  
YOLDBUF ← YPIPBUF  
ZOLDBUF ← ZPIPBUF  
XPIPBUF ← DELVX  
YPIPBUF ← DLEVY  
ZPIPBUF ← DELVZ

But first save the current ones from PIPASR

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>L. Welch</i>	<i>5/22/69</i>		
PRGMR			
ANALST <i>J.L. Engel</i>	<i>11/14/69</i>	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D <i>Robert M. Engle</i>	<i>11/14/69</i>	REV 1	SHEET <sup>B</sup> OF 31

From Preceding Sheet

NOSAVPIP

CM/GYMDT ← 5

Update time delay for entry,  
DAP restart to 5 csec @ 2<sup>74</sup>

SETJTAG  
WAITLIST  
task  
in  
1.2 seconds  
FC-2780

Initiates entry ROLLDAP

GROUP 1.3

Set up restarts to  
schedule SETJTAG as  
a WAITLIST task in  
1.2 seconds  
TBASE1 ← -TIME1

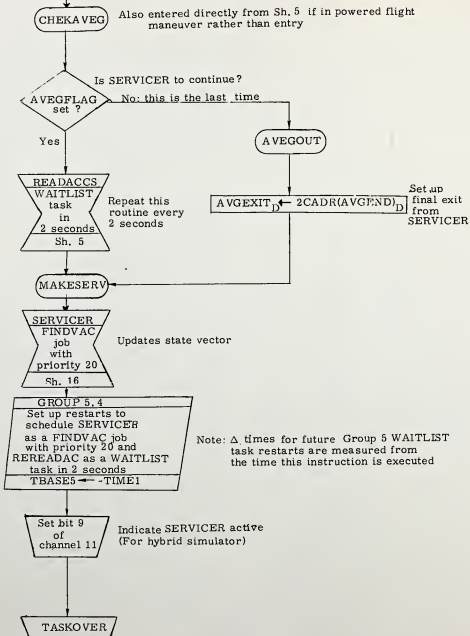
GROUP 5.37

Set up restarts to  
schedule CHEKA VEG  
as a WAITLIST task  
immediately

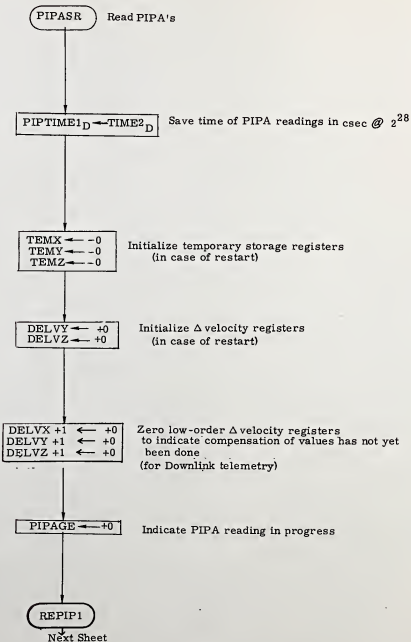
Next Sheet

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		SERVICER	
DRAWN <i>L. Welch</i>	<i>8/2/69</i>	COLOSSUS 2D	DOCUMENT NO.
PRGRM			FC-2683
ANALST <i>A. Engel</i>	<i>11/10/69</i>	REV 1	SHEET 7 OF 37
DOCMR			
APPR'D <i>R. G. ...</i>	<i>11/10/69</i>		

From Preceding Sheet



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		SERVICER	
DRAWN	<i>[Signature]</i>	COLOSSUS 2D	DOCUMENT NO. FC-2683
PRGMR	<i>[Signature]</i>		
ANALST	<i>Al Engel</i>		
DOCMR			
APPR'D	<i>[Signature]</i>	REV 1	SHEET 8 OF 34



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>L. Welch</i>	<i>4/14/68</i>	COLOSSUS 2D	DOCUMENT NO. FC-2683
PRGRM			
ANALST <i>Al Engel</i>	<i>4/14/68</i>		
DOCMR			
APPR'D <i>Robert M. Estlin</i>	<i>4/14/68</i>	REV 1	SHEET 9 OF 37

From Preceding Sheet

TEMX ← -PIPA X  
 TEMY ← -PIPA Y

Temporary storage  
 of X and Y PIPA  
 readings

DEL VX ← PIPAX  
 DEL VY ← PIPAY

Final storage  
 of X and Y PIPA  
 readings

PIPA X ← -0  
 PIPA Y ← -0

Clear X and Y  
 PIPA counters

REPIP3

Next Sheet

Set  $DEL V_D = [(DEL VX)_D, (DEL VY)_D, (DEL VZ)_D]$   
 $= \Delta V$   
 = Change in velocity  
 since last reading  
 in stable member coordinates  
 in m/csec @  $0.000585 \times 2^{14}$   
 (Nominally)

Where:

PIPA X = X-component of  $\Delta V$   
 $\int_{t-2}^t \text{secs } A_x dt$   
 Where  $t=2$

PIPA Y = Y-component of  $\Delta V$   
 $\int_{t-2}^t \text{secs } A_y dt$   
 Where  $t=2$

PIPA Z = Z-component of  $\Delta V$   
 $\int_{t-2}^t \text{secs } A_z dt$   
 Where  $t=2$   
 All in SM coordinates  
 in m/csec @  $0.000585 \times 2^{14}$   
 (Nominally)

Note: Scaling of  $\Delta V$  increments,  
 as measured by PIPA's, is  
 inaccurate due to bias and  
 scale factor errors in the  
 hardware. These errors  
 are compensated for (making  
 scale factor accurate and  
 removing bias) in 1/PIPA  
 (See Sh. 17)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Smith</i> <i>1/14/69</i>		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2683
ANALST <i>H. Engel</i> <i>1/14/69</i>			
DOCMR			
APPR'D <i>R. M. Smith</i> <i>1/14/69</i>	REV 1	SHEET 10 OF 37	



From Preceding Sheet

TEMZ ← - PIPAZ Temporary storage  
of Z PIPA reading

A ↔ PIPAZ

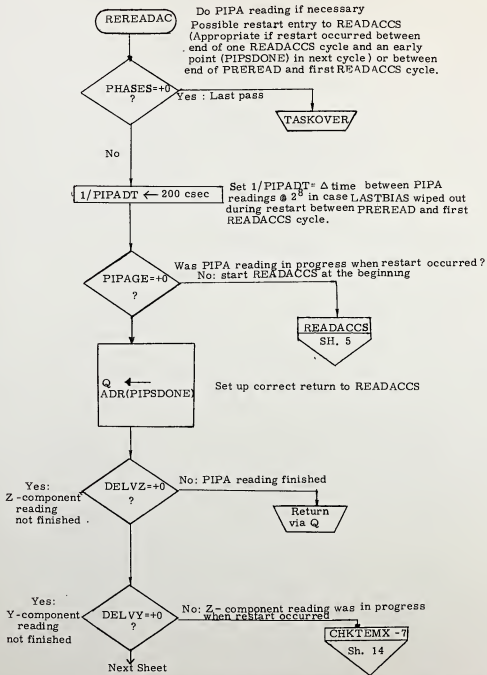
PIPAZ ← -0 Clear Z PIPA counter

DOLDEVZ

DELVZ ← A Final storage of  
Z PIPA reading

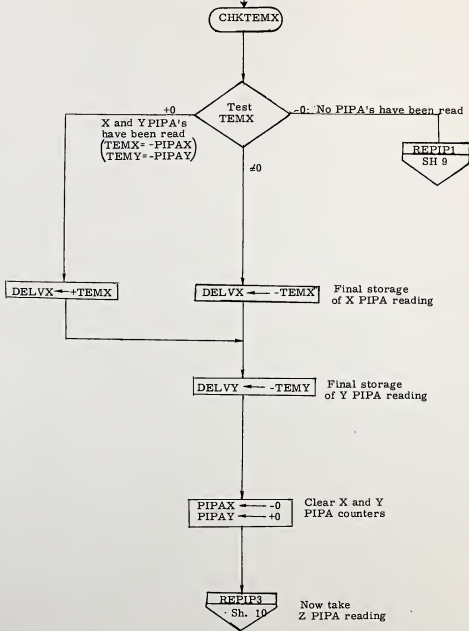
Return  
via Q

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Watch</i> 11/14/69		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2683
ANALST <i>Mc Engel</i>	11/14/69		
DOCNR		REV 1	SHEET 11 OF 37
APPR'D <i>Robert M. Carter</i>	11/14/69		

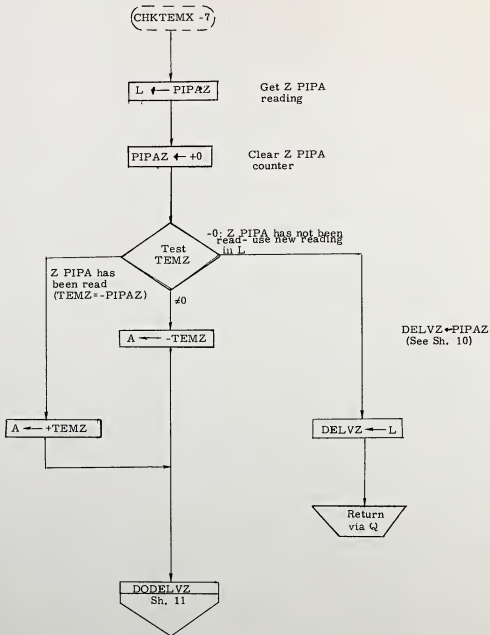


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		SERVICER	
DRAWN	<i>S. W. White</i>	<i>5/24/69</i>	
PRGMR			
ANALST	<i>Al Engel</i>	<i>11/10/69</i>	COLOSSUS 2D
DOCMR			DOCUMENT NO. FC-2683
APPR'D	<i>Robert M. Eustace</i>	<i>11/11/69</i>	REV 1
			SHEET 12 OF 37

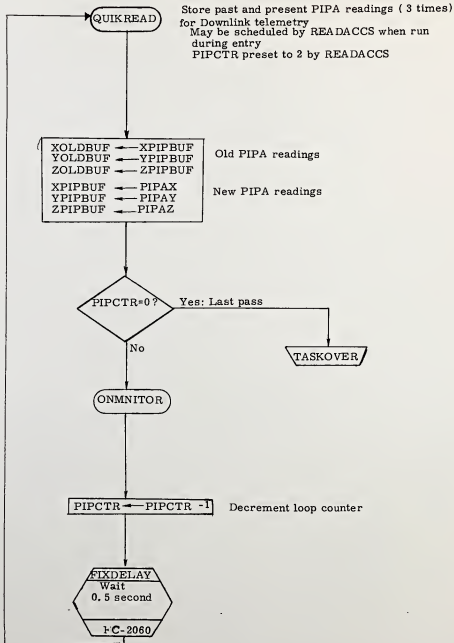
From Preceding Sheet



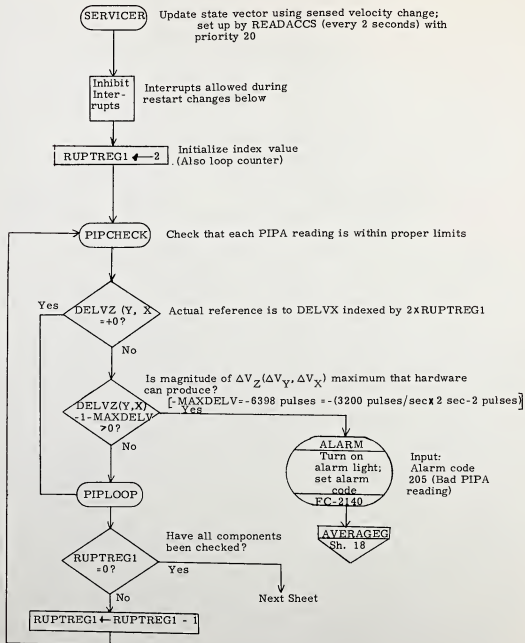
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. W. White</i> <i>1/10/69</i>		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2683
ANALST <i>DL Engel</i> <i>1/10/69</i>			
DOCHR		REV 1	SHEET 13 OF 37
APPR'D <i>Robert C. Eng...</i> <i>1/10/69</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN	<i>L. W. ...</i>		
PRGMR	<i>...</i>		
ANALYST	<i>Al Engel</i>	COLOSSUS 2D	DOCUMENT NO. PC-2683
DOCNR			
APPR'D	<i>Robert M. ...</i>	REV 1	SHEET 14 OF 31

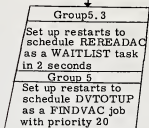


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>C. Welch</i>	<i>8/24/62</i>	COLOSSUS 2D	DOCUMENT ID. I-C-2060
PRGRM			
ANALST <i>Al. Engel</i>	<i>8/1/62</i>		
DOCNR			
APPR'D <i>Robert D. ...</i>	<i>8/1/62</i>	REV 1	SHEET 15 OF 37



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. W. White</i> 1/14/69		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>AE Engel</i>	1/14/69		FC-2683
DOCMR		REV 1	SHEET 16 OF 37
APPR'D <i>Robert M. Esch</i>	1/14/69		

From Preceding Sheet



Input: DELVX, DELVY, DELVZ = 3 components of  
 $\Delta$  velocity as  
read from PIPA's  
in SM coordinates

Nominally in m/csec @  $.000585 \times 2^{14}$   
1/PIPADT =  $\Delta$  time between PIPA  
readings  
in csec @  $2^8$   
(Set by LASTBIAS and/or  
REREADAC) See Sh. 2, Sh. 12

Output:  $DELV_V = (DELVX_D, DELVY_D, DELVZ_D)$

= velocity change vector ( $\Delta V$ )  
corrected for scale  
factor, bias errors  
in PIPA's,

Actually in m/csec @  $.000585 \times 2^{14}$

Note: 1/PIPA is not restart  
protected.

Drag less than .05g?

Update  $TTE_D$  = negative time of  
free fall from latest  
PIPA reading  
in csec @  $2^{28}$

Where:  $TTE2_D$  = negative absolute time  
of arrival at EMS  
altitude in csec @  $2^{28}$

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>L. Leitch</i>	<i>1/17/68</i>	COLOSSUS 2D	DOCUMENT NO. FC-2683
PRGMR			
ANALST <i>AC Engel</i>	<i>11/1/69</i>		
DCMR			
APPR'D <i>Robert M. Carter</i>	<i>11/1/69</i>	REV 1	SHEET 11 OF 37

From Preceding Sheet

$$DVTOTAL_D \leftarrow DVTOTAL_D + KPI1 \times |DEL V_V|$$

Update DVTOTAL<sub>D</sub> = sum of the magnitudes of 2-second velocity changes since beginning of the maneuver in m/csec @2

Where KPI1 = .000585 x 2<sup>7</sup>  
scaling factor for DEL V<sub>V</sub>

AVERAGEG

Group 5, 3

Set up restarts to schedule REREADAC. as a WAITLIST task in 2 seconds

Group 5

Set up restarts to schedule next location as a FINDVAC job with priority 20

Input: DEL V<sub>V</sub> = 2-second velocity change in SM coordinates in m/csec @ .000585 x 2<sup>14</sup>

RN<sub>V</sub> = Old position vector in reference coordinates in m @ 2<sup>29</sup>

VN<sub>V</sub> = Old velocity vector in reference coordinates in m/csec @ 2<sup>7</sup>

GDT/2<sub>V</sub> = 1/2 the change in velocity due to gravitational acceleration at RN<sub>V</sub> over an interval of 2-secs. in reference coordinates, in m/csec @ 2<sup>7</sup>

RTX2 - Indicates whether in earth or moon sphere of influence, by value of 0 or 2, respectively

Output: DELVREF<sub>V</sub> = Sensed velocity change in reference coordinates in m/csec @ 2<sup>7</sup>

RN1<sub>V</sub> = Updated position vector in reference coordinates in m @ 2<sup>29</sup>

VN1<sub>V</sub> = Updated velocity vector in reference coordinates in m/csec @ 2<sup>7</sup>

GDT1/2<sub>V</sub> = 1/2 the change in velocity due to gravitational acceleration at RN1<sub>V</sub> over an interval of 2 secs in reference coordinates, in m/csec @ 2<sup>7</sup>

And if in earth's sphere of influence:

GOBL1/2<sub>V</sub> = Gravitational anomaly due to earth oblateness @ 2<sup>1</sup>

CALCRVG

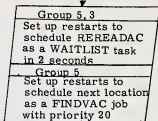
Update state vector  
Sh. 20

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN	<i>R. Wick</i>	<i>5/27/69</i>	
PRGMR			
ANALYST	<i>Al Engel</i>	<i>11/10/69</i>	COLOSSUS 2D
DOCMR			DOCUMENT NO. DC-2083
APPR'D	<i>Robert M. Estlin</i>	<i>11/10/69</i>	REV 1
			SHEET 18 OF 37

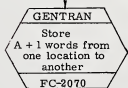


From Preceding Sheet



A ← 25D

Set parameter for GENTRAN:  
A + 1 = number of words to be moved

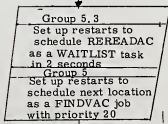


Input: RN1 = First word to be stored  
 RN = First word to be stored into  
 Result:  $RN_V \leftarrow RN1_V$   
 $VN_V \leftarrow VN1_V$   
 $PIPTIME_D \leftarrow PIPTIME1_D$   
 $GDT/2_V \leftarrow GDT1/2_V$   
 $GOBL/2_V \leftarrow GOBL1/2_V$   
 (Update powered flight permanent state vector)  
 -in reference coordinates

ENDCOPY

Allow  
Interrupts

GENTRAN inhibits interrupts



Location specified  
in AVGEXIT<sub>D</sub>

AVGEXIT<sub>D</sub> Set by program using SERVICER:  
 STEERING (FC 2682) Set by P40 (SPS Thrust)  
 CALCN85 (FC 2682) Set by P40, P41 (Thrust)  
 CM/POSE (FC 2775) Set by P62 (Entry)  
 CALCN83 (FC 2700) Set by P47 (Thrust Monitor)  
 VHHDOT (FC 2540) Set by P11 (Earth Orbit)  
 Insertion Monitor)  
 AVGEND (Sh. 25) Set by READACCS in final pass  
 SERVEXIT (Sh. 27) Common end of this routine

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>R. Walsh</i> 8/24/68		COLOSSUS 2D	DOCUMENT NO.
PRGMR			FC-1143
ANALST <i>Al Engel</i> 11/10/68			
DOCMR			
APPR'D <i>R. M. Evans</i> 11/14/68		REV 1	SHEET 19 OF 37

CALCRVG

Update state vector

$$\frac{\Delta V_{REF}}{DEL V_{REF}} = \frac{\Delta V_{SM} [REFSMMAT]_M}{KPIPI \times DEL V_{SM} \times REF SMMAT_M \times 2^1}$$

Convert  $\Delta V$  sensed into reference coordinates in m/csec @  $2^7$

Where:  $DEL V_{SM} = \Delta V$  in SM coordinates in m/csec @  $2^{14}$   
 $KPIPI = .000585 \times 2^{14}$   
 $DEL V_{REF}$  = Transformation for conversion between SM and reference coords @  $2^1$   
 $REFSMMAT_M =$  Transformation for conversion between SM and reference coords @  $2^1$   
 $2^1$  factor is for scaling

$$PL0_V \leftarrow 1/2 DELVREF_V$$

Save intermediate results:

$1/2 \Delta V$  (in reference coords, in m/csec @  $2^7$

in reference coords

$$PL6_V \leftarrow GDT/2_V + DELVREF_V$$

$1/2 G(T)\Delta T + 1/2 \Delta V$  in m/csec @  $2^7$

Compute new position vector in reference coords, in m @  $2^{29}$

Where:  $RN_V =$  Old position vector in reference coordinates in m @  $2^{29}$

$VN_V =$  Old velocity vector in reference coordinates in m/csec @  $2^7$

$GDT/2_V = 1/2$  the

velocity change due to gravitation acceleration at  $RN_V$  over a 2-second interval in reference coordinates in m/csec @  $2^7$

$2SEC(22)_D = 200$  csec @  $2^{22}$

$$\frac{R(T+\Delta T)}{MPAC_V} = \frac{R(T) + \Delta T V(T) + G(T) \Delta T/2 + \Delta V/2}{RN_V + 2SEC(22)_D \left[ \frac{VN_V + GDT/2_V + 1/2 DELVREF_V}{D} \right]}$$

Save Q PRET in PL 31

$$RN1_V \leftarrow MPAC_V$$

Save new position vector

Next Sheet

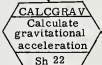
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>W. L. ...</i>			
PRGMR			
ANALST <i>Al Engel</i>	<i>11/10/69</i>	COLOSSUS 2D	DOCUMENT NO. F.C-2683
DOCMR			
APPR'D <i>Robert M. ...</i>	<i>11/11/69</i>	REV 1	SHEET 20 OF 37

From Preceding Sheet

Input: MPAC<sub>V</sub> = Position vector in reference coordinates in m @2<sup>29</sup>  
 RTX2 - Indicates whether in earth or moon sphere of influence, by value of 0 or 2, respectively

Output: MPAC<sub>V</sub> = GDT1/2<sub>V</sub> = 1/2 the change in velocity due to gravitational acceleration at the specified position over a 2-second interval in reference coordinates in m/csec @2<sup>7</sup>

And if in earth's sphere of influence:  
 GOBL1/2<sub>V</sub> = Gravitational anomaly due to earth oblateness @2<sup>1</sup>



Compute new velocity vector in reference coords, in m/csec @2<sup>1</sup>

Where: VN<sub>V</sub> = Old velocity vector in reference coordinates in m/csec @2<sup>7</sup>

$$V(T+\Delta T) = V(T) + \frac{G(T+\Delta T) + G(T)}{2} \Delta T + \Delta V$$

$$VN1_V \leftarrow VN_V + MPAC_V + PL6_V + PL0_V$$

PL6<sub>V</sub> } Intermediate results saved above  
 PL0<sub>V</sub> }

Return via PL31

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>R. Welch</i>	<i>gdy/ks</i>	COLOSSUS 2D	DOCUMENT NO.
PRGMR			PL-4835
ANALST <i>Al Engel</i>	<i>11/1/69</i>		
DOCNR			
APPR'D <i>R. DeM. Egan</i>	<i>11/1/69</i>	REV 1	SHEET 21 OF 37

CALCGRAV

Calculate gravitational acceleration  
at position given in MPAC<sub>V</sub> (in reference  
coordinates in m @<sup>29</sup>)

$$\frac{U_R = \text{UNIT}(B)}{\text{UNIT}(MPAC_V)} \leftarrow \text{UNIT}(MPAC_V)$$
  
PLX<sub>V</sub> ← UNIT(MPAC<sub>V</sub>)

Get unit vector in direction of position vector  
in reference coordinates @2<sup>1</sup>

Note: PLX refers to location in pushlist  
to which pointer (PUSHLOC) refers  
when this routine is called

$$R^2 = B \cdot B$$
  
PL34<sub>D</sub> ← MPAC<sub>V</sub> · MPAC<sub>V</sub>

R<sup>2</sup> is saved (in m<sup>2</sup> @2<sup>58</sup>),

X1 ← -RTX2

Save RTX2 = Indicator of earth or moon  
sphere of influence  
by value of 0 or 2 respectively

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Welch</i> 5/20/68		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALYST <i>de Engel</i>	5/10/68		FC-2683
DOCMR		REV 1	SHEET 22 OF 37
APPR'D <i>R. M. Egan</i>	5/10/68		

From Preceding Sheet

No: Moon

$X1 = 0?$

In earth's sphere of influence?

Yes: must make correction for earth oblateness

$$\cos \phi = \frac{U_R \cdot U_Z}{PLX_D \leftarrow PLX_V \cdot UNITW_V}$$

Compute  $\cos \phi$  at  $2^1$

Where:  $\phi$  = angle between position vector and earth polar axis

$UNITW_V = U_Z$  = Unit vector in direction of Z = Earth rotation vector (Polar axis)

in reference coordinates @  $2^0$

$$\frac{-R^2}{4E} G_B = 3/2 J_{2E} (R_E/R)^2 \left[ (1 - 5 \cos^2 \phi) U_R + 2 \cos \phi U_Z \right]$$

$$GOBL/2_V \leftarrow 20J_D \frac{RESQ_D}{PL34_D} (DP1/20_D - PLX_D^2) UNITR_V + 2J_D \frac{RESQ_D}{PL34_D} PLX_D UNITW_V$$

Compute gravitational anomaly due to earth oblateness @  $2^1$  (Reference coords)

Where:  $20J_D = 20 \times 3/2 J_{2E} @ 2^1$

Where  $J_{2E} = .10823067 \times 10^{-2}$

$2J_D = 2 \times 3/2 J_{2E} @ 2^1$  = 2nd harmonic of earth's potential function

$RESQ_D = R_E^2$  = Square of equatorial radius of the earth =  $40.6808943 \times 10^{12} m^2 @ 2^0$

$DP1/20_D = .05 = 1/20$

$$PLX_V \leftarrow UNITR_V + GOBL/2_V$$

When in earth sphere of influence, must correct for earth oblateness by adding in  $G_B$  (@  $2^1$ )

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Wicks</i> <i>5/10/69</i>		SERVICER	
PRGMR	ANALYST <i>Al Engel</i> <i>5/10/69</i>	COLOSSUS 2D	DOCUMENT NO. FC-2883
DOCNR	APPR'D <i>Robert M. Eng...</i> <i>11/11/69</i>	REV 1	SHEET 23 OF 37

From Preceding Sheet

ITISMOON

-2: Moon

0: Earth

Test  
X 1

$$\frac{1/2 G \Delta T - 1/2 \left( \frac{\mu_M}{R^2} U_R \right) \Delta T}{MPAC_V \left( \frac{MUDT(M)_D}{(PL36)_D} \right) \times PLX_V \times 2^{-21}}$$

$$\frac{1/2 G \Delta T - 1/2 \left( \frac{\mu_E}{R^2} U_R + \frac{G_B}{R} \right) \Delta T}{MPAC_V \left( \frac{MUDT(E)_D}{(PL36)_D} \right) \times PLX_V \times 2^{-21}}$$

Compute  $1/2 G \Delta T$

=  $1/2$  the  $\Delta$  velocity due to gravitational acceleration  
(at specified position) over 2 seconds  
in reference coordinates in m/csec @  $2^7$

Where:

$$- MUDT(M)_D = - \mu_M \Delta T$$

$$= - \left( .4902778 \times 10^9 \frac{m^3}{csec^2} \right) \times (200csec) @ 2^{44}$$

$$- MUDT(E)_D = - \mu_E \Delta T$$

$$= - \left( .398603225 \times 10^{11} \frac{m^3}{csec^2} \right) \times (200csec) @ 2^{44}$$

$2^{-21}$  factor is for scaling

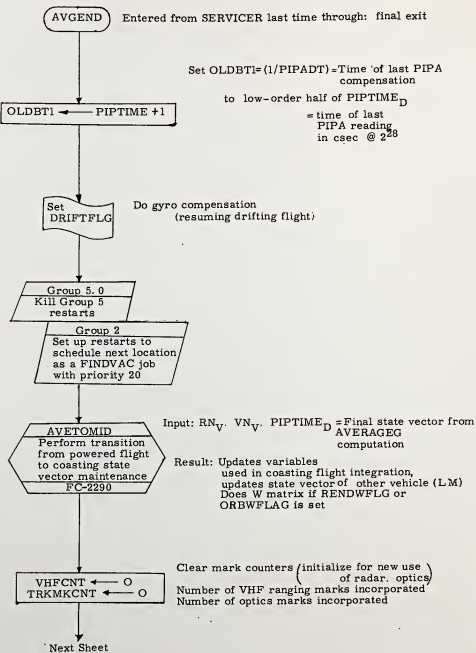
$$GDT1/2_V \leftarrow MPAC_V$$

Store new value for  $1/2 G \Delta T$

Return

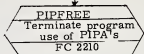
via QPRET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>R. White</i>	<i>8/2/68</i>		
PRGMR			
ANALST <i>A. Engel</i>	<i>11/16/68</i>	COLOSSUS 2D	DOCUMENT NO.
DOCMR			FC-2683
APPR'D <i>R. ...</i>	<i>11/16/68</i>	REV 1	SHEET 24 OF 31



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>R. D. L. Co</i>	<i>8/2/68</i>	COLOSSUS 2D	DOCUMENT NO. FC-2683
PRGMR			
ANALST <i>Al Engel</i>	<i>11/10/68</i>		
DOCMR			
APPR'D <i>Robert M. Eng...</i>	<i>11/11/68</i>	REV 1	SHEET 25 of 37

From Preceding Sheet



MRKBUF2 ← -BIT 9

Invalidate mark buffer



Indicate SERVICER no longer active

Clear  
CM/DSTBY  
V37FLAG

Entry DAP not activated  
SERVICER not running

RNDVZFLG  
set ?

P20 (Rendezvous navigation) running ?

No

Yes: Set up restarts for P20

Group 1.11  
Set up restarts to  
schedule PKUP20 as  
a FINDVAC job  
with priority 10

Group 2.13  
Set up restarts to  
schedule REDOR22  
as a FINDVAC job  
with priority 10

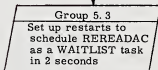
CANV37

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>L. V. ...</i>	<i>...</i>	COLOSSUS 2D	DOCUMENT NO. PC-2883
PRGMR			
ANALST <i>A. Engel</i>	<i>11/10/69</i>		
DOCNR			
APPR'D <i>Robert M. ...</i>	<i>11/11/69</i>	REV 1	SHEET 26 OF 37



SERVEXIT

Common end of SERVICER routines



ENDOFJOB

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN	<i>L. Welch</i> 7/6/69		
PRGMR			
ANALST	<i>AL Engel</i> 11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D	<i>Robert M. Suter</i> 11/11/69	REV 1	SHEET 27 OF 37

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

Subroutine Name	Flow Chart	Description	Where Called
ALARM	2140	Turns on alarm light; sets alarm code	Sh. 16
AVETOMID	2290	Performs transition from powered flight to coasting flight maintenance of state vector; updates state vector of other vehicle (LM); extrapolates W matrix if REND or ORB W flag is set (uses CSM state)	Sh. 25
CALCN83	2700	Updates total $\Delta V$ for noun 83 display and inertial V, rate of change of V, altitude above pad for noun 62 display	Sh. 19
CALCN85	2682	Updates velocity-to-be-gained for noun 85	Sh. 19
CM/POSE	2775	Return point to re-entry control	Sh. 19
GENTRAN	2070	Transfers a string of data words from one location to another	Sh. 4, 19
LASTBIAS	2230	Does last gyro compensation in free fall mode	Sh. 2
PIPFREE	2210	Terminates program use of PIPA'S	Sh. 26
SETJTAG	2780	Initiates entry ROLL/DAP	Sh. 7
STEERING	2682	Updates velocity-to-be-gained, computes steering rate commands for TVC DAP, and time-to-SFS-cutoff	Sh. 19
VHHDOT	2540	Updates and displays inertial V, rate of change of V, altitude above pad (Noun 62)	Sh. 19
I/PIPA	2230	Does PIPA compensation and powered flight gyro compensation; corrects sensed $\Delta V$ values for scale-factor, bias errors	Sh. 17

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. W. White</i>		SERVICER	
PRGRM	<i>11/10/69</i>	COLOSSUS 2D	DOCUMENT NO. FC-2683
ANALST	<i>Al Engel</i>		
DOCMR			
APPR'D	<i>Robert M. Eng...</i>	REV 1	SHEET 28 OF 37

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
AVEFLAG FLAGWRD1 BIT1	SERVICER to continue running	SERVICER to stop running	Sh. 3		Sh. 8
CMDAPARM FLAGWRD6 BIT12	Entry firings and calculations allowed	Entry firings and calculations inhibited			Sh. 6
CM/DSTBY FLAGWRD6 BIT2	Entry DAP activated	Entry DAP not activated		Sh. 26	Sh. 5
DRIFTFLG FLAGWRD2	Drifting flight: Gyro compensation done	Not drifting: No free fall gyro compensation done	Sh. 25	Sh. 3	
RNDVZFLG FLAGWRD0 BIT7	P20 running	P20 not running			Sh. 26
V37FLAG FLAGWRD7 BIT6	SERVICER running	SERVICER not running	Sh. 3	Sh. 26	
05GWSW FLAGWRD6 BIT3	Drag over . 05g	Drag under . 05g			Sh. 17
CHANNEL BITS					
CHANNEL BIT	EFFECT WHEN SET	EFFECT WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
CHANNEL 11 BIT 9	SERVICER active (For hybrid simulator)	SERVICER not active (For hybrid simulator)	Sh. 8	Sh. 26	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
SERVICER			
DRAWN <i>Ch. L. Litch</i>	<i>11/12/69</i>		
PRGMR			
ANALST <i>AL Engel</i>	<i>11/12/69</i>	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D <i>Robert M. Eng...</i>	<i>11/12/69</i>	REV 1	SHEET 29 OF 37

## DISPLAYS

Verh No	Type of Display	Description of Each Register	Where Executed
	ALARM	Alarm light on; R1, R2, R3 not affected	Sh. 16

## ERASABLE LOCATIONS USED

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
AIG		Snapshot of inner IMU gimbal angle (2's complement)	degrees	revs	2 <sup>-1</sup>
AIG/PIP		Value of AIG (above) at time of last PIPA reading (used by entry DAP)	degrees	revs	2 <sup>-1</sup>
ALFA/PIP		Value of ALFA/180 (below) at time of last PIPA reading (used by entry DAP)	degrees	revs	2 <sup>-1</sup>
ALFA/180		Third Euler angle for CM attitude	degrees	revs	2 <sup>-1</sup>
AMG		Snapshot of middle IMU gimbal angle (2's complement)	degrees	revs	2 <sup>-1</sup>
AMG/PIP		Value of AMG (above) at time of last PIPA reading (used by entry DAP)	degrees	revs	2 <sup>-1</sup>
AOG		Snapshot of outer IMU gimbal angle (2's complement)	degrees	revs	2 <sup>-1</sup>
AOG/PIP		Value of AOG (above) at time of last PIPA reading (used by entry DAP)	degrees	revs	2 <sup>-1</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION SERVICER	
DRAWN <i>L. Welch</i>	<i>1/2/69</i>		
PRGMR			
ANALST <i>W. Engel</i>	<i>11/1/69</i>	COLOSSUS 2D	DOCUMENT NO. FC-2583
DOCMR			
APPR'D <i>Robert M. Eng...</i>	<i>11/1/69</i>	REV 1	SHEET 30 OF 37

## ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
AVGEXITD		2CADR of location which begins routine to run after SERVICER	degrees	revs	$2^{-1}$
BETA/PIP		Value of BETA/180 (below) at time of last PIPA reading (used by entry DAP)	degrees	revs	$2^{-1}$
BETA/180		Second Euler angle for CM attitude	m/sec	m/csec	$2^7$
DELVREFV	$\Delta V_{REF}$	Sensed velocity change in reference coordinates	m/sec	m/csec	.000585 $\times 2^{1\frac{1}{2}}$
DELV	$\Delta V$	Sensed velocity change in stable member coordinates	m/sec	m/csec	.000585 $\times 2^{1\frac{1}{2}}$
DELVXD	$\Delta V_X$	X-component of sensed velocity change in SM coordinates	m/sec	m/csec	.000585 $\times 2^{1\frac{1}{2}}$
DELVYD	$\Delta V_Y$	Y-component of sensed velocity change in SM coordinates	m/sec	m/csec	.000585 $\times 2^{1\frac{1}{2}}$
DELVZD	$\Delta V_Z$	Z-component of sensed velocity change in SM coordinates	m/sec	m/csec	.000585 $\times 2^{1\frac{1}{2}}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>P. W. Sch</i> <i>1/1/69</i>		SERVICER	
PRGRM		COLOSSUS 2D	DOCUMENT NO. FC-2683
ANALST <i>H. Engel</i>	<i>1/1/69</i>		
DOCNR			
APPR'D <i>P. W. Sch</i>	<i>M. E. ...</i>	REV 1	SHEET 31 OF 37

## ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
DVTOTALD					
GDT/2 <sub>V</sub>	$1/2 \underline{G} (T) \Delta T$	Sum of the magnitudes of 2-second velocity changes since beginning of the maneuver 1/2 The change in velocity due to gravitational acceleration over a 2-second interval, in reference coordinates	m/sec m/sec	m/csec m/csec	2 <sup>7</sup> 2 <sup>7</sup>
GDTI/2 <sub>V</sub>	$1/2 \underline{G}(T+\Delta T)X \Delta T$	Temporary storage for updated version of GDT/2 <sub>V</sub> (above)	m/sec	m/csec	2 <sup>7</sup>
GOBL/2 <sub>V</sub>	$\frac{-R^2}{\mu E} \underline{G}_B (T)$	Correction term (in reference coordinates) for gravitational anomaly due to earth oblateness - satisfies the equation: $\underline{G}(\text{at } \underline{R}) = \frac{\mu E}{R^2} \text{ UNIT } (\underline{R}) + \underline{G}_B$			2 <sup>1</sup>
GOBLI/2 <sub>V</sub>	$\frac{-R^2}{\mu E} \underline{G}_B (T+\Delta T)$	Temporary storage for updated version of GOBL/2 <sub>V</sub> (above)			2 <sup>1</sup>
MRKBUF2		Temporary storage for marks used in rendezvous tracking; invalid if negative			
OLDBT1 =1/PIPADT PHASE5		Δ Time between PIPA readings or time of last PIPA compensation Indicates whether certain routines are to be restarted and, if so, at what point	sec	csec	2 <sup>8</sup> or 2 <sup>14</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Leitch</i> 10/60		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>Al Engel</i> 11/19/61			FC-2883
DOCMR		REV 1	SHEET 32 OF 37
APPR'D <i>Robert M. Engle</i> 11/19/61			

## ERASABLE LOCATIONS USED (CONTINUED)

AGC - Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
PIPAGE		Indicates whether or not PIPA reading is in progress, by value of 0 or 1, respectively	m/sec	m/csec	.000585 x 2 <sup>14</sup>
PIPAX		Counter accumulating X-component velocity change (in SM coordinates) since last reading	m/sec	m/csec	.000585 x 2 <sup>14</sup>
PIPAY		Counter accumulating Y-component velocity change (in SM coordinates) since last reading	m/sec	m/csec	.000585 x 2 <sup>14</sup>
PIPAZ		Counter accumulating Z-component velocity change (in SM coordinates) since last reading	m/sec	m/csec	.000585 x 2 <sup>14</sup>
PIPTIME <sub>D</sub>		Time of last PIPA reading	sec	csec	2 <sup>28</sup>
PIPTIME <sub>1D</sub>		Temporary updated version of PIPTIME <sub>D</sub> (above)	sec	csec	2 <sup>28</sup>
REFSMMAT <sub>M</sub>	[REFSMMAT]	Transformation matrix for conversion between SM and reference coordinate systems			2 <sup>1</sup>
RN <sub>V</sub>	R(T)	Position vector in reference coordinates	m	m	2 <sup>29</sup>
RN <sub>1V</sub>	R(T+ΔT)	Temporary updated version of RN <sub>V</sub> (above)	m	m	2 <sup>29</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>R. L. DeLoe</i>	<i>7/1/68</i>	COLLOSSUS 2D	
PRGMR			DOCUMENT NO. FC-2683
ANALST <i>H. Engel</i>	<i>11/1/68</i>		
DOCMR			
APPR'D <i>Robert M. Egan</i>	<i>11/11/69</i>	REV 1	SHEET 33 OF 37

## ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
ROLL/PIP		Value of ROLL/180 (below) at time of last PIPA reading (used by entry DAP)	degrees	revs	$2^{-1}$
ROLL/180 RTX2		First Euler angle for CM attitude	degrees	revs	$2^{-1}$
TEMX		Indicator of whether vehicle is in earth or moon sphere of influence, by value of 0 or 2, respectively	m/sec	m/csec	$-.000585 \times 2^{14}$
TEMY		Temporary storage for PIPA reading (PIPAX above)	m/sec	m/csec	$-.000585 \times 2^{14}$
TEMZ		Temporary storage for PIPA reading (PIPAY above)	m/sec	m/csec	$-.000585 \times 2^{14}$
TIME2 <sub>D</sub> = (TIME2) (TIME1)		Temporary storage for PIPA reading (PIPAZ above)	sec	csec	$2^{28}$
TRKMKCNT		Present time			
TTE <sub>D</sub>	- T FF	Number of optics marks incorporated	seconds	csec	$2^{28}$
TTE <sub>2D</sub>		Negative of time of free fall from latest PIPA reading	seconds	csec	$2^{28}$
		Negative of absolute time of arrival at EMS altitude	seconds	csec	$2^{28}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		SERVICER	
DRAWN <i>L. W. White</i>	<i>g/tp</i>		
PRGMR			
ANALST <i>Al Engel</i>	<i>10/1/68</i>	COLOSSUS 2D	DOCUMENT NO. PC-2683
DOCMR			
APPR'D <i>R. J. ...</i>	<i>11/11/68</i>	REV 1	SHEET 34 OF 37



## ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSOP symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
UNITR-V	$\underline{U}_R$	Unit vector in direction of position vector (in reference coordinates)			$2^1$
VHFCNT		Number of VHF ranging marks incorporated			
VN <sub>V</sub>	$\underline{V}(T)$	Velocity vector in reference coordinates	m/sec	m/csec	$2^7$
VN <sub>1-V</sub>	$\underline{V}(T+\Delta T)$	Temporary updated version of VN <sub>V</sub> (above)	m/sec	m/csec	$2^7$
XOLDBUF		Old PIPAX (see above) reading for Downlink telemetry	m/sec	m/csec	.000585 x $2^{14}$
XPIPBUF		New PIPAX (see above) reading for Downlink telemetry	m/sec	m/csec	.000585 x $2^{14}$
YOLDBUF		Old PIPAY (see above) reading for Downlink telemetry	m/sec	m/csec	.000585 x $2^{14}$
YPIPBUF		New PIPAY (see above) reading for Downlink telemetry	m/sec	m/csec	.000585 x $2^{14}$
ZOLDBUF		Old PIPAZ (see above) reading for Downlink telemetry	m/sec	m/csec	.000585 x $2^{14}$
ZPIPBUF		New PIPAZ (see above) reading for Downlink telemetry	m/sec	m/csec	.000585 x $2^{14}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>B. Welch</i> 11/1/68		SERVICER	
PROGRAM	<i>11/1/68</i>	COLOSSUS 2D	DOCUMENT NO.
ANALYST <i>H. Engel</i>	<i>11/1/68</i>		FC-2883
DOCNR		REV 1	SHEET 35 OF 37
APPROV <i>B. Welch</i>			

PROGRAM CONSTANTS

AGC Tag	CSOP Symbol	Meaning	Engineering Value and Units	AGC Value And Units	AGC Scaling
KPIP1		Scaling factor for converting $\Delta V$ sensed to nominal velocity scaling	$.000585 \times 2^7$	$.000585 \times 2^7$	$2^0$
-MAXDELV		-(Maximum $\Delta V$ component hardware can sense - 2)	-6398 Pulses	-6398 Pulses	$2^{14}$
-MUDT(E) <sub>D</sub>	$-A_E \Delta T$	-(Earth gravitational constant) x (2 seconds)	$-.79720645 \times 10^{15}$ m <sup>3</sup> /sec	$-.79720645 \times 10^{13}$ m <sup>3</sup> /csec	$2^{44}$
-MUDT(M) <sub>D</sub>	$-A_M \Delta T$	-(Moon gravitational constant) x (2 seconds)	$-.9805556 \times 10^{13}$ m <sup>3</sup> /sec	$-.9805556 \times 10^{11}$ m <sup>3</sup> /csec	$2^{44}$
RESQ <sub>D</sub>	$R_E^2$	Square of equatorial radius of the earth	$40.6809913 \times 10^{12}$ m <sup>2</sup>	$40.6809913 \times 10^{12}$ m <sup>2</sup>	$2^{59}$
2J <sub>D</sub>	$2 \times (3/2 J_{2E})$	2 x 3/2 x the 2nd harmonic of earth's potential function	$3.2469201 \times 10^{-3}$ x $10^{-3}$	3.2469201	$2^{-1}$
20J <sub>D</sub>	$20 \times (3/2 J_{2E})$	20 x 3/2 x the 2nd harmonic of earth's potential function	$3.2469201 \times 10^{-2}$	$3.2469201 \times 10^{-2}$	$2^{-1}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. Welch</i> 8/14/62		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>Al Engel</i> 11/10/62			FC-2683
DOCMR		APPR'D <i>Robert M. Engle</i> 11/10/62	SHEET 36 OF 37
REV 1			

PROGRAM CONSTANTS (CONTINUED)

AGC Tag	GSOP Tag	Meaning	Engineering Value And Units	AGC Value And Units	AGC Scaling	Octal Value
UNITW V	I Z	Unit vector in the direction of earth rotation vector (Z) in reference coordinates	-3.32402568949 x 10 <sup>-6</sup> 4.18407084553 x 10 <sup>-5</sup> 9.399999998 x 10 <sup>-1</sup>	Same	2 <sup>0</sup>	77777 76203 00000 25740 37777 37777

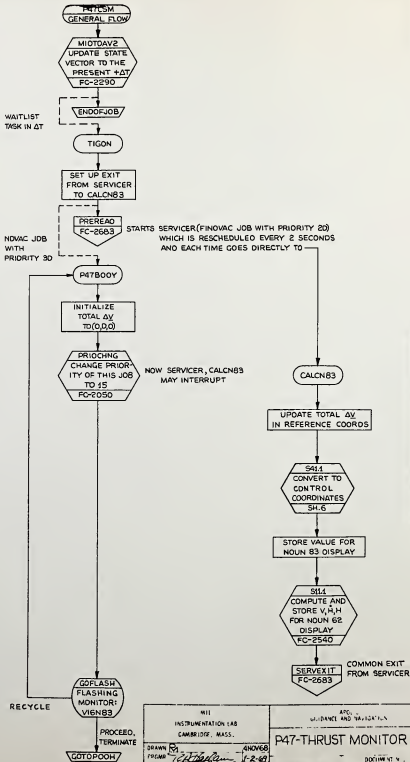
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>R. W. Welch</i> 1/24/69		SERVICER	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST <i>H. Engel</i> 11/14/68			FC-2683
DOCMR		REV 1	SHEET 31 OF 31
APPR'D <i>R. W. Welch</i>			

P47 - THRUST MONITOR

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS		
P47CSM:	SETS UP MONITOR OF VELOCITY CHANGE, USED DURING NON-GNCS CONTROLLED MANEUVERS	SH. 3
TIGON:	STARTS AVERAGE G MAINTENANCE OF STATE VECTOR	SH. 4
P47BODY:	INITIALIZES AND DISPLAYS VELOCITY CHANGE	SH. 5
CALCN83:	UPDATES VALUES FOR NOUN 83 (A, V IN CONTROL COORDINATES) AND NOUN 82 (V, H, R) DISPLAYS	SH. 6
S41.1:	CONVERTS VECTOR FROM REFERENCE TO CONTROL COORDINATES	SH. 8

THE ENCLOSED REPLACEMENT SHEETS (SH. 4, 5) WILL UPDATE THE COLOSSUS II FLOWCHART FC-2700, REV. 1, TO COLOSSUS IIC, FC-2700, REV. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		P47 THRUST MONITOR	
DESIGN	<i>P. J. ...</i>	30 DEC 68	
ANALYSIS	<i>P. J. ...</i>	1-2-69	
DOCNR	<i>P. J. ...</i>	1-2-69	
APPROV	<i>P. J. ...</i>	REV 2	
		COLOSSUS IIC	FC-2700
			SHEET 1 OF 10



MIL  
INSTRUMENTATION LAB  
CAMBRIDGE, MASS.

DRAWN *[Signature]* 4NOV68  
 POCM *[Signature]* 1-2-69  
 ANALYST *[Signature]* 1-2-69  
 DCNM *[Signature]* 1-2-69  
 APPROV *[Signature]* 1-2-69

APC  
GUIDANCE AND NAVIGATION

**P47-THRUST MONITOR**

COLOSSUS IIC

DOC# FC-2700

REV 2

SEP 2 1970

P47CSM

MONITORS VELOCITY CHANGE DURING MANEUVERS  
NOT UNDER GNCS CONTROL  
CALLED VIA OSKY BY V37E47E  
(FINDVAC JOB WITH PRIORITY 13)

RQ2507H  
CHECK  
IMU STATUS  
FC-2210

RETURNS HERE ONLY IF OKAY —  
OTHERWISE DISPLAYS ALARM AND TERMINATES PROGRAM

MIDDAV2  
UPDATE  
STATE VECTOR  
FC-2290

OUTPUT:  $RN1_v$  = POSITION VECTOR IN REFERENCE  
COORDINATES IN M @ 2<sup>29</sup>  
 $VN1_v$  = VELOCITY VECTOR IN REFERENCE  
COORDINATES IN M/CSEC @ 2<sup>7</sup>  
 $PIPTIME1_0$  = TIME CORRESPONDING TO  $RN1_v, VN1_v$   
IN CSEC @ 2<sup>28</sup>  
(A LITTLE PAST THE PRESENT TIME)  
 $MPAC_0$  = TIME INTEGRATED TO ( $PIPTIME1_0$ ) - PRESENT TIME  
IN CSEC @ 2<sup>18</sup>

P40TMP ← (MPAC + 1)

SAVE THIS ΔT

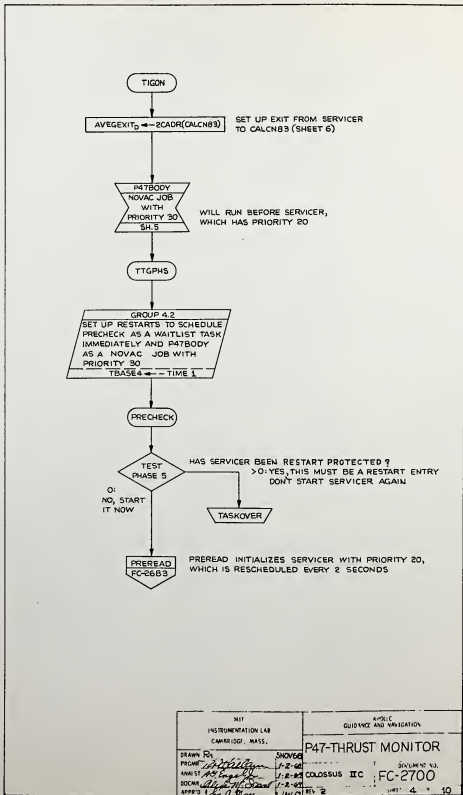
TIGON  
WAITLIST  
TASK IN  
(MPAC + 1) CSEC  
SH.4

GROUP 4.57  
SET UP RESTARTS TO  
SCHEDULE TIGON AS  
A WAITLIST TASK IN  
(P40TMP) CSEC  
TBASE4 ← -TIME 1

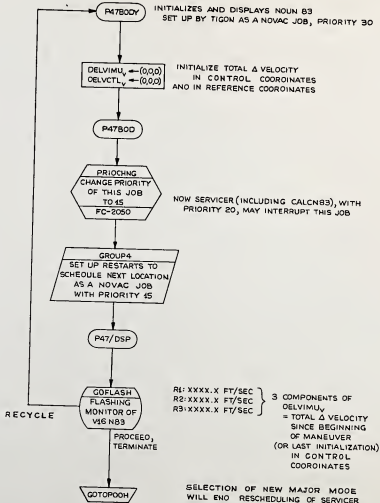
MPAC + 1 IS LOW-ORDER HALF  
OF MPAC<sub>0</sub>  
HIGH-ORDER HALF SHOULD  
BE ZERO

ENDOFJOB

INSTRUMENTATION LAB		P47-THRUST MONITOR	
DRAWN BY <i>[Signature]</i>		DESIGNED BY <i>[Signature]</i>	
DATE	1-2-69	DATE	1-2-69
APPROVED BY <i>[Signature]</i>	1-2-69	APPROVED BY <i>[Signature]</i>	1-2-69
COLOSSUS IIC		FC-2700	
REV 2		REV 2	
3		10	

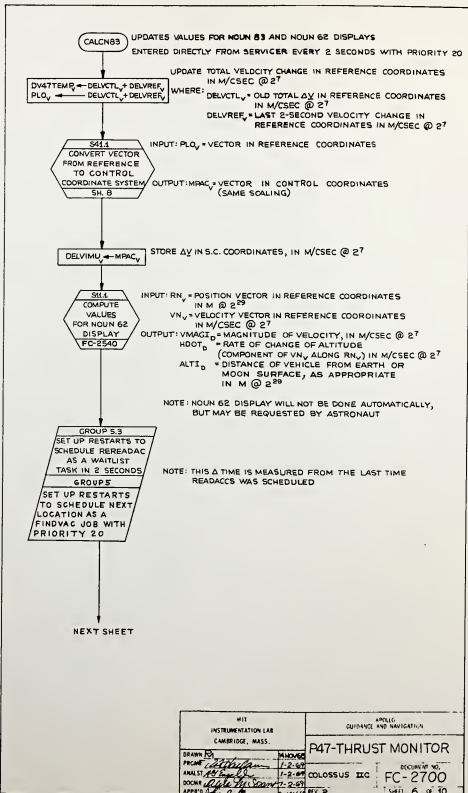


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AERONAUTICAL GUIDANCE AND NAVIGATION	
DRAWN BY: <i>[Signature]</i>		P47-THRUST MONITOR	
PREPARED BY: <i>[Signature]</i>	1-2-66	DESIGNED BY:	
ANALYST: <i>[Signature]</i>	1-2-66	COLLOSSUS IIC	FC-2700
DOCMAN: <i>[Signature]</i>	1-2-66	REV 2	SHEET 4 OF 10
APPROVED: <i>[Signature]</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ATHEL GUIDANCE AND NAVIGATION	
DRAWN BY: <i>[Signature]</i>		P47-THRUST MONITOR	
PROJECT: <i>[Signature]</i>	DATE: <i>[Signature]</i>	COLLOSUS IIC	FORM NO. FC-2700
DOCK: <i>[Signature]</i>	DATE: <i>[Signature]</i>	SIV 2	S 1 20
APPRO: <i>[Signature]</i>	DATE: <i>[Signature]</i>		





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARC/LIG GUIDANCE AND NAVIGATION	
DRAWN BY <i>[Signature]</i>		P47-THRUST MONITOR	
FRGME <i>[Signature]</i>	AN/MSR	DOCUMENT NO.	
ANALYST <i>[Signature]</i>	1-2-63	COLOSSUS IIC	FC-2700
DOCWR <i>[Signature]</i>	7-2-63	SHEET 6 OF 10	
APPROV <i>[Signature]</i>	1 JAN 64	REV B	

FROM PRECEDING SHEET

A ← 5

SET PARAMETER FOR GENTRAN  
A+1 = NUMBER OF WORDS TO BE MOVED



INPUT: DV47TEMP = FIRST WORD TO BE STORED  
DELVCTL = FIRST WORD TO BE STORED INTO

RESULT: DELVCTL ← DV47TEMP,  
(STORE UPDATED VERSION OF TOTAL ΔV  
IN REFERENCE COORDINATES, IN M/CSEC @ 27)

SERVXT

SERVXIT  
FC-26B3

COMMON EXIT FROM SERVICER

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY <i>W. S. ...</i>		P47-THRUST MONITOR	
DESIGN <i>W. S. ...</i>	MINOR 1-2-69	COLLOSSUS IIC	
ANALYST <i>W. S. ...</i>	1-2-69	FC-2700	
CLIENT <i>W. S. ...</i>	1-2-69	REV 7 10	
APPROVED <i>W. S. ...</i>	2-10-69	REV B	

S41.1

CONVERTS VECTOR FROM REFERENCE TO CONTROL COORDINATES  
ENTERED WITH INPUT VECTOR IN PL<sub>x</sub>, SCALED AT 2<sup>Y</sup>  
(WHERE PUSHLOC POINTS TO PL<sub>x</sub>(Y+6))

SAVE  
QIPRET  
IN  
QTEMP



OUTPUT: SINCOUX, COSCOUX  
SINCUDY, COSCUDY  
SINCUDZ, COSCUDZ } @ 2<sup>1</sup>

CONVERT INPUT VECTOR TO S.M. COORDINATES @ 2<sup>Y+1</sup>

MPAC<sub>v</sub> ← REFSMMAT<sub>x</sub> \* PL<sub>x</sub>

WHERE REFSMMAT<sub>x</sub> = TRANSFORMATION MATRIX FOR  
CONVERSION BETWEEN REFERENCE  
AND STABLE MEMBER COORDINATE  
SYSTEMS @ 2<sup>1</sup>



INPUT: SINCOUX, COSCOUX  
SINCUDY, COSCUDY  
SINCUDZ, COSCUDZ  
MPAC<sub>v</sub> = VECTOR IN S.M. COORDINATES

OUTPUT: MPAC<sub>v</sub> = VECTOR IN N.B. COORDINATES  
(SAME SCALING)

MPAC<sub>v</sub> ← 10 \* 2<sup>2</sup> \* QUADROT<sub>M</sub> \* MPAC<sub>v</sub>

CONVERT VECTOR TO CONTROL COORDINATES  
@ 2<sup>Y</sup>

WHERE: QUADROT<sub>M</sub> = TRANSFORMATION MATRIX FOR  
CONVERSION BETWEEN  
NAV. BASE AND CONTROL  
COORDINATE SYSTEMS @ 10

10, 2<sup>2</sup> FACTORS ARE FOR SCALING

RETURN VIA  
QTEMP

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY <i>[Signature]</i> (SHOWS)		P47-THRUST MONITOR	
PREPARED BY <i>[Signature]</i> 1-2-68	ANALYST <i>[Signature]</i> 1-8-68	COLOSSUS IIC	DOCUMENT NO. FC-2700
DOCUMENT NO. <i>[Signature]</i> 1-8-68	APPROVED BY <i>[Signature]</i> 1-8-68	REV 2	SHEET 8 OF 10

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
CDUTRIG	2270	UPDATES TRIGONOMETRIC FUNCTIONS OF IMU GMBAL ANGLES	SH. 8
GENTRAN	2070	MOVE GIVEN NUMBER OF WORDS FROM ONE LOCATION INTO ANOTHER	SH. 7
MIDTOAV2	2290	UPDATE STATE VECTOR TO A LITTLE PAST PRESENT TIME	SH. 3
PREREAD	2663	STARTS SERVICER, WHICH MAINTAINS STATE VECTOR DURING A MANEUVER	SH. 4
PRIOCHNG	2050	CHANGES PRIORITY OF THE CURRENT JOB	SH. 5
R02BOTH	2210	CHECKS THAT IMU IS ON, HAS KNOWN ORIENTATION (AND TERMINATES PROGRAM IF NOT)	SH. 3
SERVEXIT	2663	COMMON END OF SERVICER ROUTINES	SH. 7
S11.1	2540	COMPUTES MAGNITUDE OF VELOCITY, ALTITUDE AND ALTITUDE CHANGE RATE FOR NOUN 82 DISPLAY	SH. 6
SMNBa	2270	CONVERTS GIVEN VECTOR FROM STABLE MEMBER TO NAVIGATION BASE COORDINATES	SH. 8

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V16NS3	FLASHING MONITOR	R1: XXXX. X FT/SEC R2: XXXX. X FT/SEC R3: XXXX. X FT/SEC	SH. 5

3 COMPONENTS OF DELVIMU<sub>y</sub>  
= TOTAL ΔV  
SENSED SINCE BEGINNING OF MANEUVER (OR LAST INITIALIZATION IN CONTROL COORDINATES)

ERASABLE LOCATIONS USED

AGC TAG	OSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
ALTI <sub>D</sub>	H	DISTANCE OF VEHICLE FROM EARTH OR MOON SURFACE, AS APPROPRIATE	M	M	2 <sup>28</sup>
AVEGEXIT <sub>D</sub>		VARIABLE 2CADR ADDRESS OF EXIT FROM SERVICER (FC-2683)			
COSCDUX		COSE OF OUTER IMU GIMBAL ANGLE			2 <sup>1</sup>
COSCDLY		COSE OF INNER IMU GIMBAL ANGLE			2 <sup>1</sup>
COSCDUZ		COSE OF MIDDLE IMU GIMBAL ANGLE			2 <sup>1</sup>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P 47	
		THRUST MONITOR	
DRAWN <i>[Signature]</i>	BOOTH	JULY 1969	
PREPARED <i>[Signature]</i>	1-2-69	COLLOSSUS IIC	
ANALYST <i>[Signature]</i>	1-2-69	FC-2700	
DOCTR <i>[Signature]</i>	1-2-69	SHEET 9 OF 10	
APPRO'D <i>[Signature]</i>	2-16-69	REV B	

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
DELVCTL <sub>V</sub>		TOTAL $\Delta V$ SENSED SINCE BEGINNING OF MANEUVER (OR SINCE LAST INITIALIZATION) IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
DELVIMU <sub>V</sub>		TOTAL $\Delta V$ SENSED SINCE BEGINNING OF MANEUVER (OR SINCE LAST INITIALIZATION) IN CONTROL COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
DELVREF <sub>V</sub>	$\Delta V$ -REF	SENSED 2-SECOND VELOCITY CHANGE IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
DV47TEMP <sub>V</sub>		TEMPORARY UPDATED VERSION OF DELVCTL <sub>V</sub> (ABOVE) FOR COPY CYCLE	M/SEC	M/CSEC	2 <sup>7</sup>
HDO <sub>T</sub>	$\dot{H}$	RATE OF CHANGE OF ALTITUDE (ABOVE LAUNCH PAD)	M/SEC	M/CSEC	2 <sup>7</sup>
PHASES		INDICATES WHETHER CERTAIN ROUTINES ARE TO BE RE-STARTED AND, IF SO, AT WHAT POINT			
PIPTIME <sub>D</sub>		TIME OF LAST ACCELEROMETER READING (CORRESPONDS TO RN <sub>V</sub> , VN <sub>V</sub> )	SEC	CSEC	2 <sup>28</sup>
REFSMAT <sub>M</sub>	(REFSMAT)	TRANSFORMATION MATRIX FOR CONVERSION BETWEEN REFERENCE AND STABLE MEMBER COORDINATE SYSTEMS			2 <sup>1</sup>
RN <sub>V</sub>	$\underline{R}$	POSITION VECTOR IN REFERENCE COORDINATES	M	M	2 <sup>28</sup>
RNI <sub>V</sub>		TEMPORARY UPDATED VERSION OF RN <sub>V</sub> (ABOVE)	M	M	2 <sup>28</sup>
SINCDUX		SINE OF OUTER IMU GIMBAL ANGLE			2 <sup>1</sup>
SINCDUY		SINE OF INNER IMU GIMBAL ANGLE			2 <sup>1</sup>
SINCDUZ		SINE OF MIDDLE IMU GIMBAL ANGLE			2 <sup>1</sup>
V <sub>MAGI</sub> <sub>D</sub>	$\underline{V}$	INERTIAL VELOCITY (MAGNITUDE)	M/SEC	M/CSEC	2 <sup>7</sup>
VN <sub>V</sub>	$\underline{V}$	VELOCITY VECTOR IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 <sup>7</sup>
VNI <sub>V</sub>		TEMPORARY UPDATED VERSION OF VN <sub>V</sub> (ABOVE)	M/SEC	M/CSEC	2 <sup>7</sup>

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING AND AGC VALUE	AGC SCALING
QUADROT <sub>M</sub>		TRANSFORMATION MATRIX FOR CONVERSION BETWEEN NAVIGATION BASE AND CONTROL COORDINATE SYSTEMS (A 1.25 DEGREE ROTATION)	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & .99200 & -.12620 \\ 0 & .12620 & .99200 \end{bmatrix}$	10

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
P47 THRUST MONITOR			
DRAWN <i>A. J. Smith</i>	300028	PROGRAM <i>A. J. Smith</i>	7-2-67
ANALYST <i>A. J. Smith</i>	7-2-67	DOCS <i>A. J. Smith</i>	7-2-67
APPROV <i>A. J. Smith</i>	7-2-67	COLOSSUS IIC	DOCUMENT NO. FC-2700
	REV 2		SHEET 10 OF 10

PS2: IMU REALIGNMENT

ENCLOSED ARE REPLACEMENT SHEETS (SH. 1, 23) TO UPDATE  
THE COLOSSUS II FLOWCHART FC-2720, REV. 0, TO THE  
COLOSSUS IIC FLOWCHART FC-2730, REV. 1.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARND GUIDANCE AND NAVIGATION	
		PS2 IMU REALIGNMENT	
DRAWN	PLAUS 02	DOCUMENT NO.	
FKCHR		FC-2720	
ANALYST		REV 1	
DOCNR	G.S. NALLY	SHEET 0	
APPROVED	<i>[Signature]</i>		



UPDATING BY MARKS NOT ALLOWED  
TRACKING NOT ALLOWED

DO IMU STATUS CHECK

IS PREFERRED ORIENTATION FLAG SET ?

IS PFRATFLG SET ?

P52A

A ← 3

SET LGC ASSUMED OPTION TO 00003

A ← 1

SET LGC ASSUMED OPTION TO 00001

OPTION2 ← A

P52B

KEY IN V22 AND ENTER DESIRED ORIENTATION CODE

ENTER

PROCEED



- R1=00005=OPTION CODE FOR ASSUMED IMU ORIENTATION SELECTION.
  - R2=OPTION ASSUMED BY THE LGC.
  - 1.= PREFERRED-SELECTED BY PREVIOUSLY OPERATED PROGRAM AS OPTIMUM ORIENTATION FOR SELECTED MANEUVER.
  - 2.= NOMINAL-ORIENTATION BASED ON RADIUS AND VELOCITY VECTORS AT SELECTED TIME.
  - 3.= REFSMMAT-ORIENTATION CURRENTLY STORED IN LGC.
  - 4.= LANDING-ORIENTATION BASED ON LANDING SITE LOCATION AND CSM ANGULAR MOMENTUM AT NOMINAL LANDING TIME.
  - R3= BLANK.
- OPTION ASSUMED BY LGC

WHAT TYPE OF ORIENTATION ?

3- REFSMMAT

1- PREFERRED

P52C  
SH5

SKIP COARSE ALIGN NOT NECESSARY FOR DRIFT CORRECTION OF REFSMMAT- FINE ALIGN ONLY

0 OR 2  
L.S OR NOMINAL

NEXT SHEET

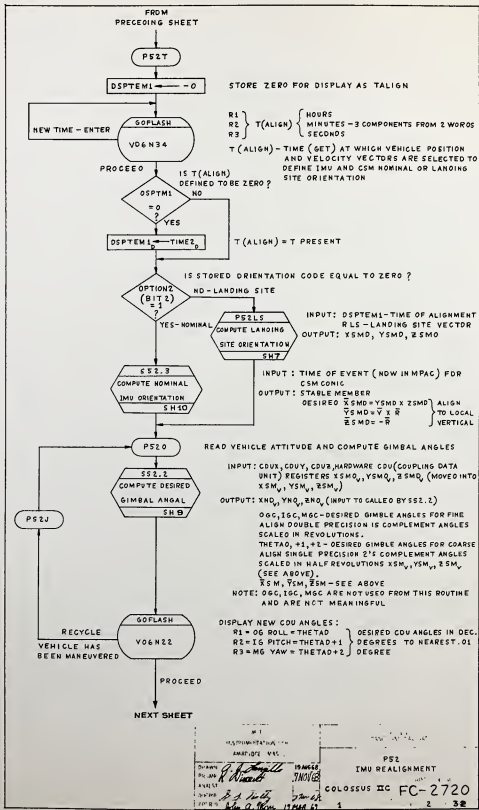
P52J  
SH2

SELECT PREFERRED IMU ORIENTATION FOR GIMBAL ANGLE COMPUTATION PREVIOUSLY CALCULATED MANEUVER. THIS ORIENTATION MUST BE CALCULATED AND STORED BY A PREVIOUSLY SELECTED PROGRAM

19 AUG 68  
74304  
R. M. ...  
J. B. ...  
J. ...

P52  
IMU REALIGNMENT

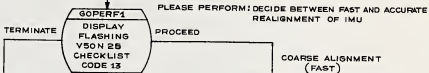
COLOSSUS IIC FC-2720



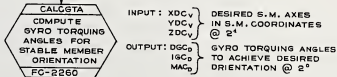
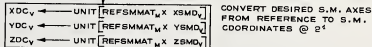


FROM PRECEDING SHEET

COARSTYP



GYCRS GYRO TORQUING (ACCURATE)



CLEAR DRIFTFLG, REFSMFLG NO GYRO COMPENSATION TO BE DONE REFSMMAT MATRIX INVALID

GODSPR DISPLAY V16N20 MONITOR IMU GIMBAL ANGLES : R1: XXX.XX DEG. OUTER GIMBAL ANGLE (CDUX) R2: XXX.XX DEG. INNER GIMBAL ANGLE (CDUY) R3: XXX.XX DEG. MIDDLE GIMBAL ANGLE (CDUZ)

NEXT SHEET

INT

INT. SECURITY DIVISION, AIR

CAMPBELL, WASH.

DATE: 10/10/68

BY: S. NALLY

APPROVED: S. NALLY 19MAG

APPROVED: John A. Jones 19MAG

PS2 IMU REALIGNMENT

COLOSSUS IIC FC-2720

3 - 32

FROM PRECEDING SHEET



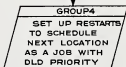
INPUT:  $OGC_0, IGC_0, MSC_0$   
CONTAIN DESIRED TORQUING ANGLES



BAD RETURN



GOOD RETURN



INPUT:  $X1 = \text{ECAOR}(\text{MATRIX TO BE TRANSFERRED})$   
 $X2 = \text{ECAOR}(\text{MATRIX TO BE STORED INTO})$

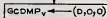
RESULT:  $\text{REFSMAT}_M \leftarrow \begin{matrix} \text{XSMD}_V \\ \text{YSMD}_V \\ \text{ZSMD}_V \end{matrix}$



NO PREFERRED ATTITUDE COMPUTED



REFSMAT MATRIX IS AGAIN VALID



INITIALIZE PARAMETER FOR GYRO COMPENSATION

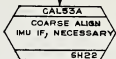


GYRO COMPENSATION TO BE DONE



UNIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		P52 IMU REALIGNMENT	
DRAWN BY: <i>[Signature]</i> CHECKED BY: <i>[Signature]</i> DATE: <i>[Date]</i> APPROVED BY: <i>[Signature]</i>	APPROVED BY: <i>[Signature]</i> DATE: <i>[Date]</i> APPROVED BY: <i>[Signature]</i>	COLOSSUS III FC-2720	DOCUMENT NO. 11-4-32

(P52J+3)



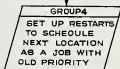
INPUT: COUX, COUY, COUZ, THETA<sub>D</sub>, +1, +2  
FOR IMUCOARS  
OUTPUT: REFSMMAT = (XSM<sub>V</sub>, YSM<sub>V</sub>, ZSM<sub>V</sub>)  
REFSMMAT = PRESENT IMU ORIENTATION

CAL53RET

SET REFSMFLG

REFSMMAT IS GOOD

P52C



REQUEST PLEASE PERFORM CELESTIAL  
BODY ACQUISITION  
R1=.00015 - PLEASE PERFORM STAR  
ACQUISITION  
R2 = BLANK  
R3 = BLANK

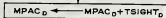
ENTER



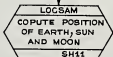
PROCEED



INPUT: COMPUTER CLOCK  
OUTPUT: MPAC<sub>0</sub> - TIME 2, TIME 1



TIME OF SIGHTING

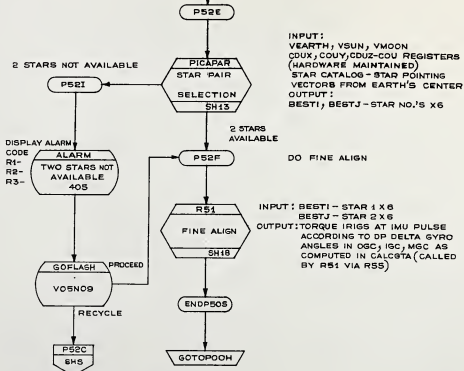


INPUT: MPAC<sub>0</sub> - TIME OF SIGHTING  
OUTPUT: VEARTH, VSUN, VMOON

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	REVISED DATE: 11-1-64 BY: J. H. ...
DRAWN BY: <i>[Signature]</i> CHECKED BY: <i>[Signature]</i> DATE: <i>[Date]</i> SCALE: <i>[Scale]</i> MATERIAL: <i>[Material]</i> QUANTITY: <i>[Quantity]</i> SPECIAL INSTRUCTIONS: <i>[Notes]</i>	P52 IMU REALIGNMENT COLLOSSUS IIC FC-2720 5 32

FROM PRECEDING SHEET



VEHICLE HAS BEEN MANEUVERED

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS		APPLE CALCOMP AND NAVICAT 4	
REVISION BY: <i>S. Nally</i> DATE: <i>12/11/68</i>		P52 IMU REALIGNMENT	
COLLOSSUS IIC FC-2720		DOCUMENT NO. 6 32	

PS2LS  
LANDING SITE ORIENTATION

DISPLAY THE LANDING SITE LATITUDE, LONGITUDE  
AND ALTITUDE COMPUTE THE LANDING SITE  
ORIENTATION FOR PS2 OR PS4.  
INPUT: OSPTM1 - TIME OF ALIGNMENT  
RLS - LANDING SITE VECTOR IN MOON FIXED  
COORDINATES  
OUTPUT: XSMO, YSMO, ZSMO

QMAJ ← QPRET

SET  
LUNAFLAG

LUNAR LAT AND LONG

TSIGHT ← OSPTM1

TIME IS ALIGNMENT

SET  
ERADFLAG

USE FIXED RADIUS

$OD_V \leftarrow RLS_V$   
 $6D \leftarrow TSIGHT_0$

LANDING SITE VECTOR  
TIME OF ALIGNMENT

RP → TO → R  
CONVERT TO BASIC  
REFERENCE SYSTEM  
FC-2283

CONVERT RP (VECTOR IN PLANETARY COORDINATE SYSTEM  
MOON FIXED) TO R (SAME VECTOR IN BASIC  
REF. SYSTEM)

INPUT: MPAC - NON ZERO = MOON

0 - 50 - RP VECTOR

6 - 70 - TIME

OUTPUT: MPAC, -R VECTOR B17 FOR MOON

ALPHA<sub>V</sub> ← MPAC<sub>V</sub>  
MPAC<sub>DP</sub> ← TSIGHT

R VECTOR B29

TIME OF ALIGNMENT

LAT-LONG  
CONVERT R VECTOR  
TO LAT, LONG, ALT  
FC-2280

CONVERT RAD VECTOR AT GIVEN TIME TO LAT, LONG, AND ALT

INPUT: ALPHA - POSITION VECTOR

MPAC<sub>DP</sub> - TIME

ERADFLAG, LUNAFLAG

OUTPUT: LAT - LATITUDE

LONG - LONGITUDE

ALT - ALTITUDE

LLASRD  
STORE ALT  
AND LONG  
FC-2590

STORE IN LOCATIONS FOR NBS DISPLAY

INPUT: ALT<sub>DP</sub>, LONG<sub>DP</sub>

OUTPUT: LANDLAT<sub>DP</sub>, LANDLONG<sub>DP</sub>

NOTE: LAT AND LANDLAT ARE THE SAME

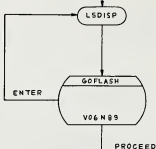
NEXT SHEET

PS2  
IMU REALIGNMENT  
GLOUSSUS IIC FC-2720  
20 AUG 68  
71  
19 MAR 69  
1

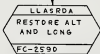
7

30

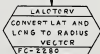
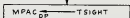
FROM  
PRECEDING SHEET



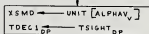
DISPLAY STORED LANDING SITE COORDINATES  
R1 - LAT - LATITUDE OF LANDING SITE IN DEG TO  
NEAREST .001 DEG  
R2 - LONG/2 - LONGITUDE OF LANDING SITE  
DIVIDED BY 2 IN DEG TO NEAREST  
.001 DEG PLUS 15 EAST  
R3 - ALT - ALTITUDE ABOVE MEAN LUNAR RADIUS  
ZERO



INPUT: LANDALT<sub>DP</sub>, LANDLONG<sub>DP</sub>  
OUTPUT: ALT, LONG



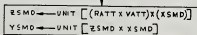
CONVERT LAT, LONG, ALT AT A GIVEN TIME TO  
RADIUS VECTOR  
INPUT: LAT, LONG, ALT, (MPAC<sub>DP</sub> - TIME)  
ERADFLAG, LUNAFAG  
OUTPUT: ALPHA<sub>V</sub> - R



LANDING SITE X UNIT VECTOR



INPUT: TDECI  
OUTPUT: RATT - POSITION VECTOR  
VATT - VELOCITY VECTOR



LANDING SITE Z UNIT VECTOR  
LANDING SITE Y UNIT VECTOR



21 AUG 68  
PS2  
IMU REALIGNMENT  
COLOSSUS IIC FC-2770  
1 8 32

*John A. Brown*  
14 MAR 68

SS2.2  
COMPUTE DESIRED GIMBAL ANGLES

QMAJ ← QPRET

CDU TRIG  
SINES, COSINES OF  
CDU COUNTERS  
FC-2270

CALCSMSC  
COMPUTE NAV.  
BASE WORDS  
SH25

X1 = 180  
S1 = 60

SS2.2.A

$XNB_v = \text{UNIT} [XNB_x \text{ REFSMMAT}]$   
 $YNB_v = \text{UNIT} [YNB_x \text{ REFSMMAT}]$   
 $ZNB_v = \text{UNIT} [ZNB_x \text{ REFSMMAT}]$

SS2.2.1

X1 = -CADR(XSMD)  
X2 = -CADR(XSM)

MATMOVE  
MOVE XSMD,YSMD,  
ZSMD INTO XSM,  
YSM, ZSM  
SH27

CALCSA  
COMPUTE GIMBAL  
ANGLES  
FC-2260

RETURN  
VIA QMAT

COMPUTES THE GIMBAL ANGLES FOR DESIRED STABLE MEMBER AND PRESENT VEHICLE  
INPUT: CDUX, CDUY, CDUZ - OUTER, INNER, MIDDLE GIMBAL ANGLES XSMD,YSMD,ZSMD - STABLE MEMBER DESIRED IN BASIC COORDS  
OUTPUT: THETAD, +1, +2 - 2'S COMP. SP. VALUES OF THE GIMBAL ANGLES IN REVOLUTIONS  
SAVE Q IN QMAT

INPUT: CDUX, CDUY, CDUZ  
OUTPUT: SINCDOX, SINCDOY, SINCDOZ  
COSCOUX, COSCOUY, COSCDUZ

INPUT: SINCDOX, SINCDOY, SINCDOZ  
COSCOUX, COSCOUY, COSCDUZ  
OUTPUT: XNB, YNB, ZNB - DIRECTIONS OF THE X, Y, Z AXES OF THE NAV.  
BASE (= SPACE CRAFT) COORDINATE SYSTEM IN STABLE MEMBER COORDINATE SYSTEM

18 WORD MATRIX  
6 WORD VECTORS

DIRECTIONS OF THE X, Y, Z AXES OF THE PRESENT NAV. BASE COORDINATE SYSTEM IN BASIC REFERENCE COORDINATE SYSTEM

INPUT TO MATMOVE

INPUT: X1, X2  
OUTPUT: MOVE MATRIX FROM X1 LOCATION TO X2 LOCATION

INPUT: XNB<sub>v</sub>, YNB<sub>v</sub>, ZNB<sub>v</sub> - PRESENT NAV. BASE COORDS - UNIT VECTOR  
XSM<sub>v</sub>, YSM<sub>v</sub>, ZSM<sub>v</sub> - DESIRED IMU ORIENTATION - UNIT VECTOR  
OUTPUT: THETAD, +1, +2 - SINGLE PRECISION 2'S COMPLEMENT VALUES OF DESIRED GIMBAL ANGLES

INSTRUMENTS DIVISION  
NAVIGATIONAL AID  
FC-2270

PS2  
IMU REALIGNMENT

DRAPP: *[Signature]* 21AUG68  
TECH: *[Signature]* 21AUG68  
ANAL: *[Signature]*  
ADVIS: *[Signature]* 15AUG68

COLOSSUS IIC FC-2720

SS2.3

QMAJ ← QPRET

TDEC1 ← MPAC<sub>p</sub>

CSDMPREC  
INTEGRATE  
STATE VECTOR  
FC-2720

ZSMD ← UNIT [-RATT]  
YSMD ← UNIT [VATT X RATT]  
XSMD ← UNIT [YSMD X ZSMD]

RETURN VIA  
QMAJ

COMPUTES NOMINAL ORIENTATION BASED ON  $\vec{R}$  AND  $\vec{V}$   
(POSITION AND VELOCITY VECTORS)

INPUT: TIG (IN MPAC) - TIME OF IGNITION

OUTPUT: XSMD<sub>v</sub>, YSMD<sub>v</sub>, ZSMD<sub>v</sub> - DESIRED GIMBAL AXES  
IN BASIC REFERENCE COORDINATES

TIME OF IGNITION (IF KNOWN) OR CURRENT TIME

INPUT: TDEC1 - TIME OF INTEGRATION

OUTPUT: RATT<sub>v</sub>, VATT<sub>v</sub> - POSITION AND VELOCITY  
VECTORS

DESIRED GIMBAL AXES

ZSMD = UNIT R

YSMD = UNIT (V+P)

XSMD = UNIT (YSMD X ZSMD)

FC-2720

REVISIONS

DATE

BY

APPROVED

1

IMU REALIGNMENT

COLOSSUS IIC FC-2720

10 3E



COMPUTES INPUTS FOR PICAPAR AND PLANET  
INPUT: TIME IN MPAC<sub>0</sub>

MOON = EARTH  
OUTPUT: VSUN = 1 (RES-REM) = -1 (RES)  
VEARTH = -1 (REM+RATT) = -1 (RATT)  
VMOON = -1 (RATT) = 1 (REM-RATT)  
CEARTH = COS 5° = COS (SIN (RE/RATT)+5)  
CMOON = COS (SIN (CRM/RATT)+5) = COS 5  
CSUN = COS 15 = COS 15  
VEL/C = VSUN X ECLIPOL + VATT/C = SAME

LOCSAM  
550

QMAJ ← Q  
TSIGHT ← A

LSPOS  
LOCATE SUN  
AND MOON  
FC-2286

INPUT: TIME IN MPAC<sub>0</sub>  
OUTPUT: VMOON - MPAC - POSITION VECTOR OF THE MOON  
VSUN - 2D - POSITION VECTOR OF THE SUN

VMOON ← MPAC  
VSUN ← 2D  
TDEC1<sub>0</sub> ← TSIGHT<sub>0</sub>

POSITION VECTOR OF MOON  
POSITION VECTOR OF SUN  
TIME OF INTEGRATION

CSMCONIC  
INTEGRATE  
STATE VECTOR  
FC-2290

INPUT: TDEC1 (TIME OF INTEGRATION)  
OUTPUT: RATT<sub>V</sub> - POSITION VECTOR  
VATT<sub>V</sub> - VELOCITY VECTOR

IS  
EARTH  
PRIMARY  
?

YES

NO

EARTCNTR  
5H12

MOONCNTR

VSUN ← UNIT [VSUN-VMOON]  
VEARTH ← UNIT [VMOON+RATT]  
VMOON ← UNIT [RATT]  
MPAC<sub>0</sub> ← REURB<sub>0</sub>

R<sub>M</sub> (EQUATORIAL RADIUS (1738040 METERS)  
OF MOON)

OCCOS  
COMPUTE COSINE  
OF ANGLE OF  
OCCULTATION  
5H12

INPUT: MPAC<sub>0</sub> - R<sub>M</sub>  
OUTPUT: MPAC = (COS (ARCSIN (R<sub>M</sub>/36) - 5))

CMOON ← MPAC  
CEARTH ← CSS5  
MPAC<sub>V</sub> ← VSUN<sub>V</sub>

COSINE 5°

NEXT SHEET

P 52

IMU REALIGNMENT

COLOSSUS IC FC-2720

11 32

FROM PRECEDING SHEET

ENDSAM

VEL/C ← MPAC<sub>v</sub> X ECLIPOL<sub>v</sub>  
 VEL/C ← VATT X 1/C + VEL/C  
 CSUN<sub>D</sub> ← CSSUN<sub>D</sub>

RETURN VIA  
QMAJ

EARTCNTR

VMOON ← UNIT[VMOON-RATT]  
 VEARTH ← UNIT[RATT]  
 MPAC<sub>D</sub> ← RSUBE<sub>D</sub>

RATT = POSITION VECTOR OF CM W.R.T. MOON  
 VATT = VELOCITY VECTOR OF CM W.R.T. MOON  
 R<sub>E</sub> = RADIUS OF EARTH  
 R<sub>M</sub> = RADIUS OF MOON  
 ECLIPOL = POLE OF ECLIPTIC SCALED BY TANGENTIAL  
 VELOCITY OF EARTH W.R.T. SUN OVER THE  
 VELOCITY OF LIGHT  
 R<sub>EM</sub> = POSITION OF MOON W.R.T. EARTH  
 R<sub>ES</sub> = POSITION OF SUN W.R.T. EARTH  
 C = VELOCITY OF LIGHT

R<sub>E</sub> - EQUATORIAL RADIUS (6 3 7 8 1 6 6 METERS) OF EARTH

OCCOS

COMPUTE COSINE OF ANGLE OF OCCULTATION

MPAC<sub>D</sub> ← MPAC<sub>D</sub>/36D  
 MPAC ← ARCSIN(MPAC) + 5 DEGREES  
 MPAC ← COS(MPAC)

COS (ARCSIN(MPAC/36) + 5)

RETURN  
VIA Q

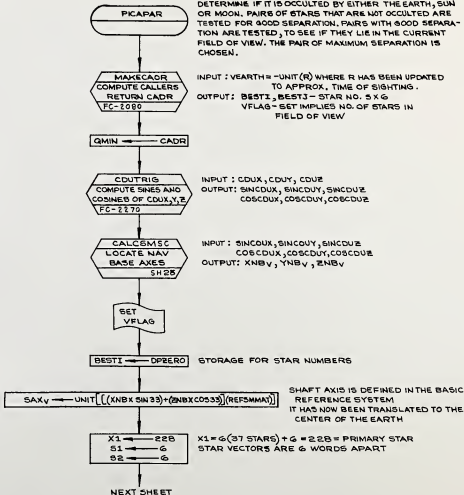
CEARTH ← MPAC  
 CMOON ← CSS5  
 VSUN ← UNIT[VSUN]

ENDSAM

SH48

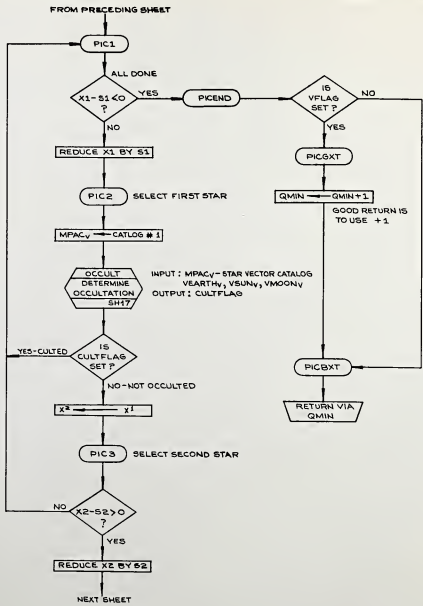
WPT INSTRUMENT NO. 88 MODEL NO. 7A-5 DRAWN <i>J. J. Kelly</i> SCALE <i>1/2" = 100'</i> REVISED CHECKED <i>J. J. Kelly</i> APPROVED <i>J. J. Kelly</i>	DATE 12/15/61 P52 IMU REALIGNMENT COLUSSUS IC FC-2720 12 32
--	--

THIS PROGRAM READS THE IMU, CDUS AND COMPUTES THE VEHICLE ORIENTATION WITH RESPECT TO INERTIAL SPACE. IT THEN COMPUTES THE SHAFT AXIS WITH RESPECT TO REFERENCE INERTIA. EACH STAR IN THE CATALOG IS TESTED TO DETERMINE IF IT IS OCCULTED BY EITHER THE EARTH, SUN OR MOON. PAIRS OF STARS THAT ARE NOT OCCULTED ARE TESTED FOR GOOD SEPARATION. PAIRS WITH GOOD SEPARATION ARE TESTED, TO SEE IF THEY LIE IN THE CURRENT FIELD OF VIEW. THE PAIR OF MAXIMUM SEPARATION IS CHOSEN.



UNIT	27
VERIFICATION AS	27
CAMPID. 04 5.	
DRAWN <i>J. J. Scott</i>	
PCBAM <i>R. D. Scott</i>	
ANALYST	
DESIGNER <i>J. J. Scott</i>	27-12
APPROV. <i>J. J. Scott</i>	170045

P52	
IMU REALIGNMENT	
COLOSSUS IIC	FC-2720
REV 1	SHEET 13 OF 32



W-1		FORM 1 (REV. 1-63)	
EXPERIMENTAL DATA		P52	
CALCULATED RESULTS		IMU REALIGNMENT	
DRAWN	<i>J. W. Scott</i>	SCALE	
PREP'D	<i>J. W. Scott</i>	DATE	NOV 68
ANALYST		PROJECT	COLOSSUS IIC FC-2720
DESIGNED	<i>J. A. Kelly</i>	REVISED	NOV 68
APPROVED	<i>J. A. Kelly</i>	REVISED	NOV 68

FROM PRECEDING SHEET

PIC 4

MPAC ← CATLOG, 2

OCCULT  
DETERMINE  
OCCULTATION  
SH 17

INPUT: MPAC - STAR VECTOR CATALOG  
VEARTHY, VSUNV, YMCONV  
OUTPUT: CULTFLAG

IS  
CULTFLAG  
SET?

YES

NO

MPAC ← (CATLOG, 1 - CATLOG, 2) - C5566

$$C5566 = (\cos 76^\circ) / 4$$

IS SEPARATION LESS THAN 76°?

YES

IS  
MPAC < 0?

NO

MPAC ← MPAC + C556640

$$C556640 = (\cos 30^\circ) / 4$$

IS SEPARATION GREATER THAN 30°?

YES

IS  
MPAC > 0?

NO

MPAC ← (CATLOG, 1 - SAX) - C5533

$$C5533 = (\cos 38^\circ) / 4$$

IS STAR 1 BEYOND 38° OF SHAFT AXIS?

IS  
MPAC < 0?

YES

PIC 1  
SH 14

NO

MPAC ← (CATLOG, 2 - SAX) - C5533

IS STAR 2 WITHIN 38° OF SHAFT AXIS?

IS  
MPAC > 0?

YES

NEXT SHEET

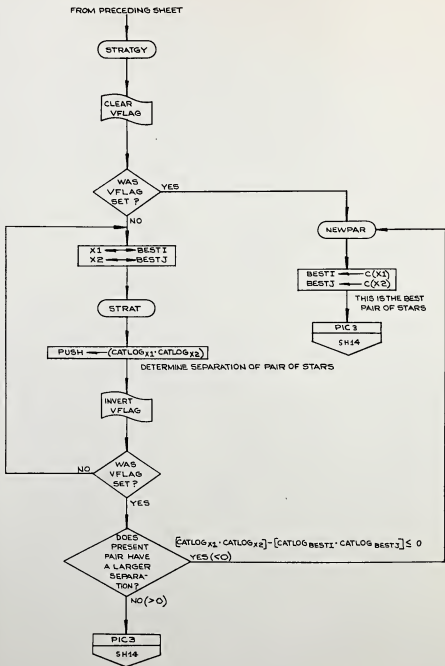
NO - GET ANOTHER  
STAR

PIC 3  
SH 14

GET ANOTHER  
2ND STAR

DATE	10 AUG 1963
TIME	17:00
BY	<i>[Signature]</i>
CHKD	<i>[Signature]</i>
APPD	<i>[Signature]</i>

PROJECT	PS2
TITLE	IMU REALIGNMENT
NO.	COLOSSUS IIC
REV.	FC-2720
DATE	15 32



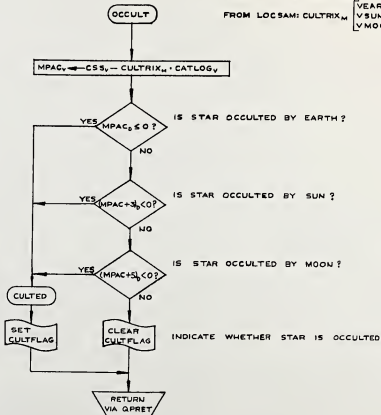
INFORMATION TO  
 FILE NO. 30436  
 12/18/68  
 J. S. Judd  
 John A. Wilson  
 12/20/68

P52  
 IMU REALIGNMENT  
 COLOSSUS IIC FC-2720  
 15 32

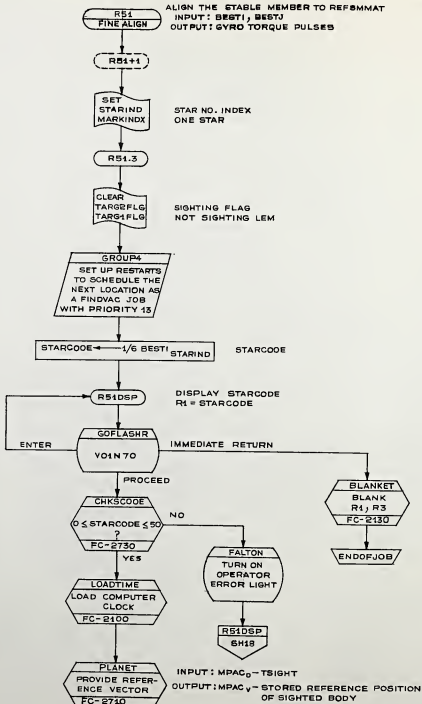
INPUT: STAR VECTOR (CATLOG<sub>v</sub>)

FROM LOCSAM: CULTRIX<sub>M</sub>

VEARTH<sub>v</sub>  
VSUN<sub>v</sub>  
VMOON<sub>v</sub> @ 2'



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN E. LAVERGNE		P52 IMU REALIGNMENT	
CHKD S. WALLY	DESIGNED	DOCUMENT NO.	
ANALYST	APPROVED	COLUSSUS IIC	FC-2720
DESIGNED G. S. WALLY	APPROVED	REV 1	SHEET 27 OF 32



MIL INSTRUMENTATION LAB CAMBRIDGE, MASS.	48013 "LIMACS" AND NAVIGATION
TO: <i>P.M. Smith</i>	P52 IMU REALIGNMENT
FROM: <i>S. J. ...</i>	DOCUMENT NO.
ANALYST: <i>G.S. NALLY</i>	COLOSSUS IIC FC-2720
DATE: <i>12/11/61</i>	REV 1
APPROVED: <i>John A. ...</i>	148 32



FROM PRECEDING SHEET



NO - SECOND STAR

YES - FIRST STAR

R51ST

STARSAN1<sub>v</sub> ← MPAC<sub>v</sub>

STARSAN2<sub>v</sub> ← MPAC<sub>v</sub>

STORED DIRECTION OF SECOND BODY (INPUT FOR R52)

STORED DIRECTION OF 1ST BODY (INPUT FOR R52)



YES

NO (P52)

R51B

R56  
BACKUP SIGHTING ROUTINE  
FC-2730

INPUT: TARGIFLG - NOT SIGHTING LEM  
TARG2FLG - SIGHTING FLAG  
MARKINDX - ONE STAR  
STARIND - INDEX TO BEST1 OR BEST2  
OUTPUT: DRIVE SHAFT AND TRUNNION CDUS

R52  
AUTO OPTICS POSITIONING ROUTINE  
FC-2730

R51A

SXTSM  
COMPUTE LOS VECTOR  
FC-2730

INPUT: DRIVE SHAFT AND TRUNNION CDUS  
OUTPUT: MPAC<sub>v</sub> - DIRECTION VECTOR

STARSAN2<sub>v</sub> ← MPAC<sub>v</sub>

OBSERVED DIRECTION OF STAR

MKRELEAS  
ZERO MARKSTAT  
FC-2240

MPAC<sub>D</sub> ← TSIGHT

PLANET  
PROVIDE REFERENCE VECTOR  
FC-2710

INPUT: MPAC<sub>D</sub> - TSIGHT  
OUTPUT: MPAC<sub>v</sub> - STORED REFERENCE POSITION OF SIGHTED BODY

NEXT SHEET

WEL INSTRUMENTATION LAB CAMBRIDGE, MASS.		P52 IMU REALIGNMENT	
DRAWN <i>J. J. Kelly</i>	CHECKED <i>J. J. Kelly</i>	ANALYST <i>J. J. Kelly</i>	DATE 17 MAR 67
COLOSSUS IIC		FC-2720	
REV 1		REV 1	

FROM PRECEDING SHEET

IS STARIND SET?

YES - FIRST STAR

NO - SECOND STAR

STARAD<sub>v</sub> ← UNIT (REFSMAT X MPAC<sub>v</sub>)

STORED DIRECTION OF SECOND STAR

R51.4

STORED DIRECTION OF FIRST STAR

PLANVEC<sub>v</sub> ← UNIT (REFSMAT X MPAC<sub>v</sub>)  
STARSAV1<sub>v</sub> ← STARSAV2<sub>v</sub>  
STARIND ← D

R51.3

SH18

G<sub>Dv</sub> ← STARSAV2<sub>v</sub>  
12<sub>Dv</sub> ← STARSAV1<sub>v</sub>  
STARAD + G<sub>v</sub> ← PLANVEC<sub>v</sub>

SECOND OBSERVED STAR  
FIRST OBSERVED STAR  
STORED DIRECTION OF 1ST STAR

CHKS DATA  
CHECK VALIDITY  
OF SIGHTINGS  
FC-2710

INPUT : STARAD<sub>v</sub>, STARAD + G<sub>v</sub> - CATALOGED STAR VECTORS  
G<sub>Dv</sub>, 12<sub>Dv</sub> - OBSERVED STAR VECTORS  
OUTPUT: FREEFLAG, VO6N05

ARE SIGHTINGS VALID?

NO  
IS FREEFLAG SET?

YES

COMPUTE COORDINATES OF ONE COORDINATE SYSTEM REFERRED TO ANOTHER (DESIRED REFERRED TO PRESENT, IN THIS CASE)

INPUT : STARAD<sub>v</sub>, STARAD + G<sub>v</sub> - DESIRED (2 BODIES SYSTEM A)  
G<sub>Dv</sub>, 12<sub>Dv</sub> - PRESENT (± BODIES SYSTEM B)  
NOTE: SYSTEM A + B ARE THE SAME FOR THIS USE OF AXISGEN  
OUTPUT: XDC<sub>v</sub>, YDC<sub>v</sub>, ZDC<sub>v</sub>

AXISGEN  
COORDINATE  
TRANSFORMATION  
FC-2720

R55  
GYRO TORQUE  
S726

INPUT : XDC<sub>v</sub>, YDC<sub>v</sub>, ZDC<sub>v</sub>  
OUTPUT : TORQUE (IRIGS ACCORDING TO DP DELTA GYRD ANGLES IN OGC, 16C, MGC AS COMPUTED IN CALCGTA

CLEAR  
PFRATFLG

PREFERRED ATTITUDE IS NOT COMPUTED

NEXT SHEET

UNIT INSTRUMENTATION I CAMBRIDGE, MASS		P52 IMU REALIGNMENT	
DRAWN PDCME INVENT REV BY REV'D	<i>J.P. Jager</i> <i>R. Dubois</i>  <i>J.P. Jager</i> <i>J.P. Jager</i>	CHECKED JNNVH  DATE 19 06 64	COLLOSSUS IIC FC-2720 20 - 32

FROM PRECEDING SHEET

R81K

GOPERF1  
V50N25  
R1=00014  
R2=BLANK  
R3=BLANK

REQUEST PLEASE PERFORM FINE ALIGN

R1 = 00014

R2 = BLANK

R3 = BLANK

ENTER

PROCEED

ENDP505  
SH6

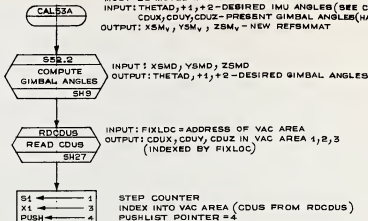
EXIT

P52C  
SH5

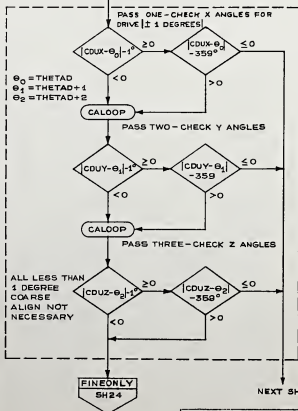
ASTRONAUT WANTS TO RECYCLE

001 INSTRUMENTAL APPROVED BY <i>John A. Kelly</i> 12/11/67 1314819	P52 IMU REALIGNMENT COLOSSUS IIC FC-2720 1
---	---

CALLED BY PS2 TO COARSE ALIGN THE IMU IF ANY GIMBAL MUST BE MOVED MORE THAN 1 DEGREE  
 INPUT: THETAD,+1,+2-DESIRED IMU ANGLES (SEE CALCGA)  
 CDUX,CDUY,CDUZ-PRESENT GIMBAL ANGLES(HARDWARE)  
 OUTPUT: XSMV, YSMV, ZSMV-NEW REFSMMAT



**CALOOP** CHECK TO SEE THAT ALL CDUS ARE WITHIN 1 DEGREE OF DESIRED VALUE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARPA GUIDANCE AND NAVIGATION	
DRAWN: <i>[Signature]</i>		PS2 IMU REALIGNMENT	
PREPARED: <i>[Signature]</i>		DOCUMENT NO.	
ANALYST: <i>[Signature]</i>		COLOSSUS IIc FC-2720	
DESIGNED: G.S. NALLY		SHEET 22 OF 32	
APPROVED: <i>[Signature]</i>		REV 1	

FROM PRECEDING SHEET

COARFINE

GROUP4  
 SET UP-RESTARTS  
 TO SCHEDULE NEXT  
 LOCATION AS A  
 JOB WITH OLD  
 PRIORITY

INPUT: THETAD,  
 THETAD +1,  
 THETAD+2  
 (DESIRED IMU  
 GIMBAL ANGLES)

COARBUS  
 PERFORM  
 DESIRED  
 ALIGNMENT  
 FC-2710

SETH/PDT  
 SET 1/PIPADT  
 TO  
 TIME1  
 FC-2710

GCOMP<sub>v</sub> ← (0,0,0)

SET  
 DRIFTFLG

NEXT SHEET

MIT INSTRUMENTATION LAB "AMBIENT" WALL	A-1.0 LIBRARY AND QUALIFICATION P52 IMU REALIGNMENT
DRAWN <i>[Signature]</i> CHECKED <i>[Signature]</i> ANALYST <i>[Signature]</i> NAME G. S. NALLY APPROV. <i>[Signature]</i>	COLLOSSUS IIC FC-2720 DATE 23 * 32

FROM  
PRECEDING SHEET

FINEONLY

X1 ← -CADR (XSM)  
X2 ← -CADR (REFSMMAT)

FOR MATMOVE

MATMOVE  
MOVE XSM, YSM,  
ZSM INTO  
REFSMMAT  
SH27

NORMAL OR PREFERRED ORIENTATION  
INTO REFSMMAT  
(REFSMFLG WILL BE SET UPON  
RETURN TO PS2)

CAL53RET  
SH5

V-1 INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC CLIMBANT AND NAVIGATION	
DRAWN <i>[Signature]</i>		PS2 IMU REALIGNMENT	
CHECKED <i>[Signature]</i>		DOCUMENT NO.	
ANALYST <i>[Signature]</i>		COLOSSUS IIC: FC-2720	
DYN MIC <i>[Signature]</i>		SHEET 24 OF 32	
APPROVED <i>[Signature]</i>		REV 1	

CALCSMEC  
COMPUTE NAV. BASE AXES

CALL BY PICAPAR, SS 2.2  
INPUT: SINC1DX, SINC1DY, SINC1DZ, COSC1DX, COSC1DY, COSC1DZ - SINES, COSINES OF OUTER, INNER, MIDDLE GIMBAL ANGLES  
OUTPUT: XNB<sub>v</sub>, YNB<sub>v</sub>, ZNB<sub>v</sub> - CONSIDER THESE THREE VECTORS AS THE TRANSFORMATION MATRIX  
[SMNB] = Q<sub>3</sub>Q<sub>2</sub>Q<sub>1</sub> STABLE MEMBER TO NAV BASE WHERE:

$$XNB_v = Z \begin{bmatrix} (\text{COSC1DY})(\text{COSC1DZ}) \\ (\text{SINC1DZ})/2 \\ -(\text{SINC1DY})(\text{COSC1DZ}) \end{bmatrix}$$

$$Q_1 = \begin{bmatrix} \text{COSC1DY} & 0 & -\text{SINC1DY} \\ 0 & 1 & 0 \\ \text{SINC1DY} & 0 & \text{COSC1DY} \end{bmatrix} \quad (\text{INNER})$$

$$ZNB_v = Z \begin{bmatrix} 2(\text{COSC1DY})(\text{SINC1DX})(\text{SINC1DZ}) + (\text{COSC1DX})(\text{SINC1DY}) \\ -(\text{SINC1DX})(\text{COSC1DZ}) \\ (\text{COSC1DX})(\text{COSC1DY}) \\ -2(\text{SINC1DX})(\text{SINC1DZ})(\text{SINC1DY}) \end{bmatrix}$$

$$Q_2 = \begin{bmatrix} \text{COSC1DZ} & \text{SINC1DZ} & 0 \\ -\text{SINC1DZ} & \text{COSC1DZ} & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (\text{MIDDLE})$$

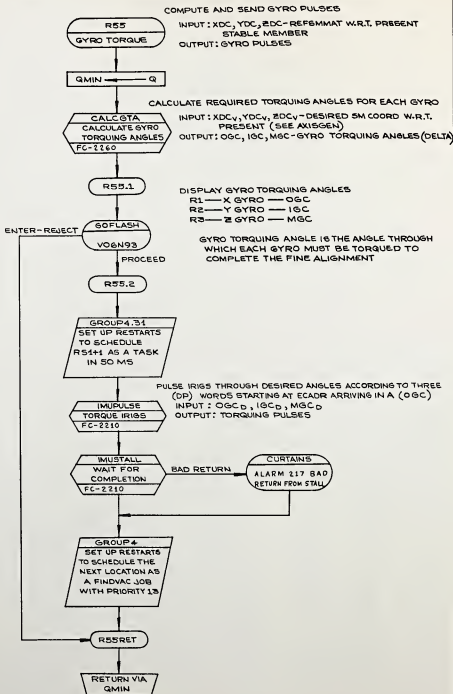
$$YNB_v = Z \begin{bmatrix} ZNB_v \times XNB_v \end{bmatrix}$$

$$Q_3 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \text{COSC1DX} & \text{SINC1DX} \\ 0 & -\text{SINC1DX} & \text{COSC1DX} \end{bmatrix} \quad (\text{OUTER})$$

RETURN VIA  
QPRET

REVISED 1965  
MAY 1965  
P52  
IMU REALIGNMENT  
COLOSSUS IIC FC-2720  
25 32

REVISED BY: *[Signature]* 30464M  
DATE: *[Signature]* 7/20/65  
APPROVED BY: *[Signature]* 12/20/65



COMPUTE AND SEND GYRO PULSES

R55  
GYRO TORQUE

INPUT: XDC, YDC, ZDC - REFEMMAT W.R.T. PRESENT  
STABLE MEMBER  
OUTPUT: GYRO PULSES

QMIN ← Q

CALCQTA  
CALCULATE GYRO  
TORQUING ANGLES  
FC-2260

CALCULATE REQUIRED TORQUING ANGLES FOR EACH GYRO  
INPUT: XDC<sub>v</sub>, YDC<sub>v</sub>, ZDC<sub>v</sub> - DESIRED SM COORD W.R.T.  
PRESENT (SEE AXISGEN)  
OUTPUT: OG<sub>C</sub>, IG<sub>C</sub>, MG<sub>C</sub> - GYRO TORQUING ANGLES (DELTA)

R55.1

DISPLAY GYRO TORQUING ANGLES

R1 — X GYRO — OG<sub>C</sub>  
R2 — Y GYRO — IG<sub>C</sub>  
R3 — Z GYRO — MG<sub>C</sub>

GOFFLASH  
VO6N93

GYRO TORQUING ANGLE IS THE ANGLE THROUGH  
WHICH EACH GYRO MUST BE TORQUED TO  
COMPLETE THE FINE ALIGNMENT

R55.2

GROUP 4.31  
SET UP RESTARTS  
TO SCHEDULE  
R544 AS A TASK  
IN 50 MS

PULSE IRIGS THROUGH DESIRED ANGLES ACCORDING TO THREE  
(DP) WORDS STARTING AT ECADR ARRIVING IN A (OGC)

IMIPULSE  
TORQUE IRIGS  
FC-2210

INPUT: OG<sub>C</sub><sub>D</sub>, IG<sub>C</sub><sub>D</sub>, MG<sub>C</sub><sub>D</sub>  
OUTPUT: TORQUING PULSES

IMUSTALL  
WAIT FOR  
COMPLETION  
FC-2210

BAD RETURN

CURTAINS  
ALARM 217 BAD  
RETURN FROM STALL

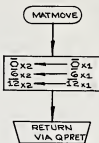
GROUP 4  
SET UP RESTARTS  
TO SCHEDULE THE  
NEXT LOCATION AS  
A FINDVAC JOB  
WITH PRIORITY 13

R55RET

RETURN VIA  
QMIN

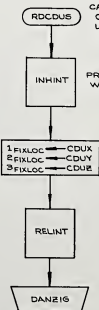
<p>WORK ORDER NO. _____          DATE _____          TIME _____          BY: <i>J. J. [illegible]</i>          APPROVED BY: <i>J. J. [illegible]</i>          DATE: _____</p>	<p>ISSUED BY: _____          DATE: _____          TIME: _____          BY: _____          APPROVED BY: _____          DATE: _____</p>
<p>COLOSSUS IIC FC-2720</p>	





INPUT : ADDRESS OF MATRIX TO BE MOVED  
 IN INDEX REG. NO #1  
 ADDRESS WHERE MATRIX IS TO BE MOVED  
 IN INDEX REG. NO #2

NOTE : ADDRESSES ARE COMPLEMENTED FOR  
 THE SUBTRACTIVE INDEXING LOGIC OF THE  
 INTERPRETER



CALLED BY CALSSA (BY RTB CALL) TO READ  
 CDU'S INTO VAC AREA WHOSE ADDRESS IS  
 LOCATED IN FIXLOC

PREVENT CDU'S FROM CHANGING  
 WHILE READING

434PT  
 434PT  
 434PT  
 434PT  
 434PT  
 434PT

P52  
 IMU REALIGNMENT

COLOSSUS IIC FC-2720

27 32

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
R02BOTH	EC-2210	IMU STATUS CHECK	SH. 1
LOADTIME	FC-2100	LOAD COMPUTER CLOCK	SH. 5, 18
RP-TO-R	FC-2283	CONVERT VECTOR FROM PLANETARY COORDINATE TO BASIC REFERENCE SYSTEM	SH. 7
LAT-LONG	FC-2280	CONVERT R VECTOR TO LAT, LONG AND ALT	SH. 7
LLASRD	FC-2590	STORE ALTITUDE AND LONGITUDE	SH. 7
LLASRDA	FC-2590	RESTORE ALTITUDE AND LONGITUDE	SH. 8
LALOTORV	FC-2280	CONVERT LATITUDE AND LONGITUDE TO RADIUS VECTOR	SH. 8
CSMPREC	FC-2200	PERFORM ORBIT INTEGRATION	SH. 8, 10
CDUTRIG	FC-2270	COMPUTES SINES, COSINES OF CDU, X, Y, Z	SH. 9, 13
CALCGA	FC-2260	COMPUTE GIMBAL ANGLES	SH. 9
CSMCONIC	FC-2290	INTEGRATE STATE VECTOR	SH. 11
LSPOS	FC-2286	LOCATE SUN AND MOON	SH. 11
MAKECADR	FC-2080	COMPUTE CALLERS RETURN ADDRESS	SH. 13
PLANET	FC-2710	PROVIDE REFERENCE VECTOR	SH. 18, 19
BLANKET	FC-2130	CLEAR R1, R2	SH. 18
CHKSCODE	FC-2730	CHECK STARCODE	SH. 18
RS6	FC-2730	BACKUP SIGHTING ROUTINE	SH. 18
RS2	FC-2730	AUTO OPTICS POSITIONING ROUTINE	SH. 19
SXTSM	FC-2730	COMPUTE LOS VECTOR	SH. 19
MKRELEAS	FC-2240	ZERO MARKSTAR	SH. 19
CHKSDATA	FC-2710	CHECK VALIDITY OF SIGHTINGS	SH. 20
AXISGEN	FC-2260	COORDINATE TRANSFORMATION	SH. 20
IMUCOARS	FC-2210	PERFORM COARSE ALIGNMENT	SH. 23
IMUSTALL	FC-2210	WAIT FOR COMPLETION	SH. 23, 26
IMUFIN20	FC-2210	RETURN TO FINE ALIGNMODE	SH. 23
SET1/PDT	FC-2710	SET 1/PIPADT TO TIME1	SH. 23
CALCGTA	FC-2260	CALCULATE GYRO TORQUING ANGLES	SH. 26
IMPULSE	FC-2210	TORQUE IRIGS	SH. 26

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
UPDATFLG	UPDATING BY MARKS ALLOWED	UPDATING BY MARKS NOT ALLOWED		SH. 1	
TRACKFLG	TRACKING ALLOWED	TRACKING NOT ALLOWED		SH. 1	
REFSMFLG	REFSMMAT GOOD	REFSMMAT NO GOOD	SH. 4, 5	SH. 3	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> 8 JAN 68		P52 IMU REALIGNMENT	
PERFORMED <i>[Signature]</i> 14 MAR 68	ANALYST <i>[Signature]</i>	DOCUMENT NO.	
DOCWR <i>[Signature]</i> 14 MAR 68	APPROVED <i>[Signature]</i> 14 MAR 68	COLOSSUS IIC	FC-2720
	REV 1	SHEET	28M 32

FLAGS (CONTINUED)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
LUNAF LG	LUNAR LAT-LONG	EARTH LAT-LONG	SH. 7		
ERADFLG	EARTH - COMPUTE FISCHER ELLIPSOID MOON - USE FIXED RADIUS	EARTH + USE FIXED. RADIUS MOON - USE RCS FOR LUNAR RADIUS	SH. 7		
VFLAG	LESS THAN TWO STARS IN FIELD OF VIEW	TWO STARS IN FIELD OF VIEW	SH. 13, 16	SH. 16	SH. 14, 16
CULTFLG	STAR OCCULTED	STAR NOT OCCULTED	SH. 17	SH. 17	SH. 14, 15
TARG2FLG	SIGHTING LANDMARK	SIGHTING STAR	SH. 18		
TARG1FLG	SIGHTING LEM	NOT SIGHTING LEM	SH. 18		
REEFLG	SIGHTINGS ARE VALID	SIGHTING ANGLE EXCEEDS TOLERANCE			SH. 20
PFRATFLG	PREFERRED ATTITUDE COMPUTED	PREFERRED ATTITUDE NOT COMPUTED		SH. 4, 20	
DRIFTFLG	TRUPT CALLS GYRO COMPENSATION	TRUPT DOES NO GYRO COMPENSATION	SH. 4, 23		
STARIND	SECOND STAR	FIRST STAR	SH. 18		SH. 19, 20
MARKINDX	ONE STAR		SH. 18		

DISPLAYS

VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V04N06	FLASHING PLEASE PERFORM	R1 = 00005: OPTION CODE FOR ASSUMED IMU R2 = OPTION ASSUMED BY THE LGC R3 = BLANK	SH. 1
V06N34	FLASHING	R1 = T(ALIGN) - HRS R2 = T(ALIGN) - MIN R3 = T(ALIGN) - SEC	SH. 2
V06N22	FLASHING	R1 = OG ROLL R2 = IG PITCH R3 = MG YAW	SH. 2
V50N25	PLEASE PERFORM	R1 = 00015: PLEASE PERFORM STAR ACQUISITION R2 = BLANK R3 = BLANK	SH. 5
V05N09	FLASHING	ALARM 405 - TWO STARS NOT AVAILABLE	SH. 6
V06N89	FLASHING	R1 = LAT R2 = LONG/2 R3 = ALT	SH. 8
V01N70	FLASHING	R1 = STARCODE	SH. 18
V50N25	PLEASE PERFORM	R1 = 00014: PLEASE PERFORM FINE ALIGN R2 = BLANK R3 = BLANK	SH. 21
V50N25	PLEASE PERFORM	R1 = 00013: DECIDE BETWEEN COARSE ALIGN AND GYRO TORQUING R2 = BLANK R3 = BLANK	SH. 3
V16N20	MONITOR	R1 = OUTER GIMBAL ANGLE - DEG R2 = INNER GIMBAL ANGLE - DEG R3 = MIDDLE GIMBAL ANGLE - DEG	SH. 3

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		G04441 AND 401 271A	
DRAWN <i>9/1/68</i>		P52 IMU REALIGNMENT	
PROGRAM <i>15</i>		COLOSSUS IIC	
ANALYST		FC-2720	
DESIGNER <i>G.S. NALLY</i>		29 32	
APPROVED <i>A. D. ...</i>			

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
OPTION2		ORIENTATION CODE			
DSPTM1		DISPLAY WORD			
TIME2		PRESENT TIME			
TSIGHT		TIME OF SIGHTING	CENTISECONDS		B-28
ALPHAV <sub>v</sub>	R	RADIUS VECTOR			1/2 UNIT VECTOR
XSMO		STABLE MEMBER DESIRED COORDINATES X-ROW			1/2 UNIT VECTOR
YSMD-		STABLE MEMBER DESIRED COORDINATES Y-ROW			1/2 UNIT VECTOR
ZSMO		STABLE MEMBER DESIRED COORDINATES Z-ROW			1/2 UNIT VECTOR
VATT		CONIC VELOCITY VECTOR			
RATT		CONIC POSITION VECTOR			
TDEC1		PRESENT TIME			
VEARTH	$\vec{u}_E$	UNIT VECTOR SPECIFYING LINE OF SIGHT TO EARTH			1/2 UNIT VECTOR
VSUN	$\vec{u}_S$	UNIT VECTOR SPECIFYING LINE OF SIGHT TO SUN			1/2 UNIT VECTOR
VMOON	$\vec{u}_M$	UNIT VECTOR SPECIFYING LINE OF SIGHT TO MOON			1/2 UNIT VECTOR
VEL/C		ABERRATION CORRECTION			
CEARTH					
CSUN					
CMOON					
BESTI		STAR NUMBER TIMES 6	INTEGER	REVS	1
BESTJ		STAR NUMBER TIMES 6	INTEGER	REVS	1
XNB <sub>v</sub>	$X_{NB}$	PRESENT NAV BASE X COORDINATE			1/2 UNIT VECTOR
YNB	$Y_{NB}$	PRESENT NAV BASE Y COORDINATE			1/2 UNIT VECTOR
ZNB	$Z_{NB}$	PRESENT NAV BASE Z COORDINATE			1/2 UNIT VECTOR
REFSMMAT	REFSMMAT				1/2 UNIT VECTOR
SAX		SHAFT AXIS			1/2 UNIT VECTOR
STARCODE					
STARSV1		STAR NO 1 UNIT VECTOR			
STARSV2		STAR NO 2 UNIT VECTOR			

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	AVSEC CORONA AND NAV CAPS
FORM 1 REV 1 G. S. NALLY APR 68	PS2 IMU REALIGNMENT REV 1 COLLOSSUS IIC FC-2720 30 32

## ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
MODREG					
STARAD					
PLANVEC		REFERENCE VECTOR			
STARAD#		SIGHTED DIRECTION OF 2ND BODY			
THETAD		GIMBAL ANGLES			
CDUX					
CDUY					
CDUZ					
SINCDUX					
SINCDUY					
SINCDUZ					
COSCDUX					
COSCDUY					
COSCDUZ					
MARKSTAT					
XSM	X <sub>SM</sub>	STABLE MEMBER DESIRED COORDINATE X-ROW			1/2 UNIT VECTOR
YSM	Y <sub>SM</sub>	STABLE MEMBER DESIRED COORDINATE Y-ROW			1/2 UNIT VECTOR
ZSM	Z <sub>SM</sub>	STABLE MEMBER DESIRED COORDINATE Z-ROW			1/2 UNIT VECTOR
QMIN					

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
DEG359				359 <sup>0</sup>	
DEGREE1				1 <sup>0</sup>	
SIN33		SINE 32 <sup>0</sup> 31'23.10"		.5376381241	
COS33		COSINE 32 <sup>0</sup> 31'23.19"		.8431756920	
CSS66		COSINE 76 <sup>0</sup> /4		.060480472	
CSS6640		(COSINE 76 <sup>0</sup> - COSINE 30 <sup>0</sup> )/4		-.15602587	
CSS33		(COSINE 38 <sup>0</sup> )/4		.197002688	
CSS5		(COSINE 5 <sup>0</sup> )/4		.2480475	
CSSUN		(COSINE 15 <sup>0</sup> )/4		.24148	
RSUBM	R <sub>M</sub>	RADIUS OF MOON		1738090 METERS	

WIT ILLUMINATION LA. I AMPLITUDE MASS.	PS 2 IMU REALIGNMENT
a of <i>[Signature]</i> JAMES G. S. NALLY	COLLOSSUS IIC FC-2720 31 32

## PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
RSUBE	$R_E$	RADIUS OF EARTH		6378166 METERS	
1/C		1/SPEED OF LIGHT		.000042699 M/CS	
ECLIPOL		POLE OF THE ECLIPTIC X MEAN VELOCITY OF EARTH + SPEED OF LIGHT		0, -.00007896, .00018209 VECTOR	
TSIGHT1		TIME DELAY TO STAR SIGHTINGS		240 SECS	

MIT INFORMATION LAB CAMBRIDGE, MASS.		ADDED GUIDANCE AND NOTES	
DRAWN <i>[Signature]</i> - JAMES		P52 IMU REALIGNMENT	
PREPARED <i>[Signature]</i> - R. MAHER		TREATMENT NO.	
ANALYST		COLOSSUS II C	
DESIGN <i>[Signature]</i> - G.S. NALLY		FC-2720	
APPROVED <i>[Signature]</i> - JAMES		REV 1	
		REV 32 - 32	

R52, R53, R56

R52	Sh. 2
ADVOBB	Sh. 5
SR52.1	Sh. 6
ROTA	Sh. 10
R53	Sh. 11
CHKSCODE	Sh. 12
SXTSM	Sh. 13
R56	Sh. 14

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>2 - [unclear] 11/16/64</i>		R52, R53, R56	
PGRGR <i>Shannon 11/16/64</i>		DOCUMENT NO.	
ANALYST		COI ORSUS 211	FC-2730
DOCWR <i>[unclear] 11/16/64</i>		REV 3	SHEET 1 OF 1
APPR <i>[unclear] 11/16/64</i>			

POINT THE STAR LOS OF THE OPTICS AT A STAR OR LANDMARK  
 DEFINED BY THE PROGRAM OR BY DSKY INPUT  
 POINT THE STAR LOS OF THE OPTICS AT THE LM DURING RENDEZVOUS  
 TRACKING OPERATION

OO THE TRACKING ATTITUDE ROUTINE (R61) EVERY 16 SEC.  
 DURING RENDEZVOUS TRACKING OPERATIONS  
 INPUT : PRESET BY CALLER-TARG1FLG, TARG2FLG, RNDVZFLG,  
 TRACKFLG, MARKINDX, STARCODE  
 THROUGH DSKY-LAT-LONG, ALT OF LANDMARK,  
 STARCODE  
 OUTPUT: DRIVE SHAFT AND TRUNNION CDUS

R52  
 AUTOOPTICS POSITIONING ROUTINE

SAVQR52 ← QPRET

CLEAR  
 ADVTRK NOT ADVANCED GROUND TRACK

R52VRB

DESOPTT ← CDUT  
 DESOPTS ← CDJS  
 OPTIND ← 0

CLEAR  
 R52FLAG V51 NOT INITIATED

R52A

SET  
 TRUNFLAG DRIVING OF TRUNNION ALLOWED

IS THE LM TARGET FLAG SET?  
 YES-LM → R52HA SH4

NO → CLEAR  
 TERMIFLG DO NOT TERMINATE R52

R52C

IS OPTICS MODE IN AGC?  
 NO-MANUAL → R52M SH3

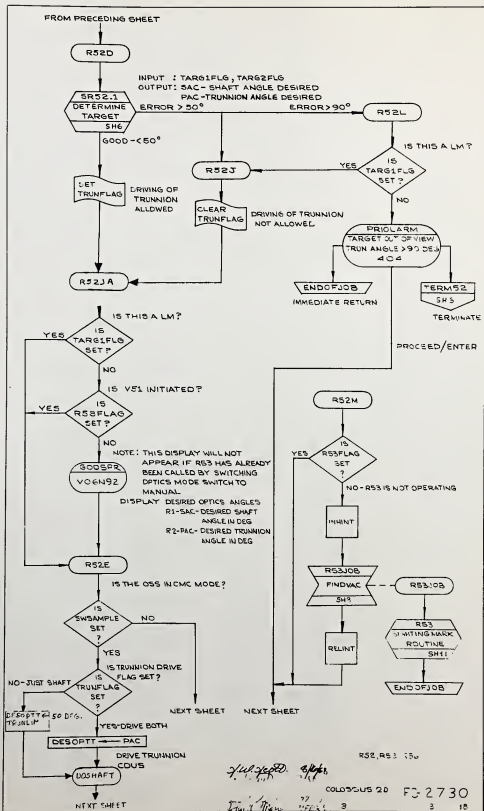
IS  
 SWSAMPLE  
 > 0  
 YES-AGC → NEXT SHEET

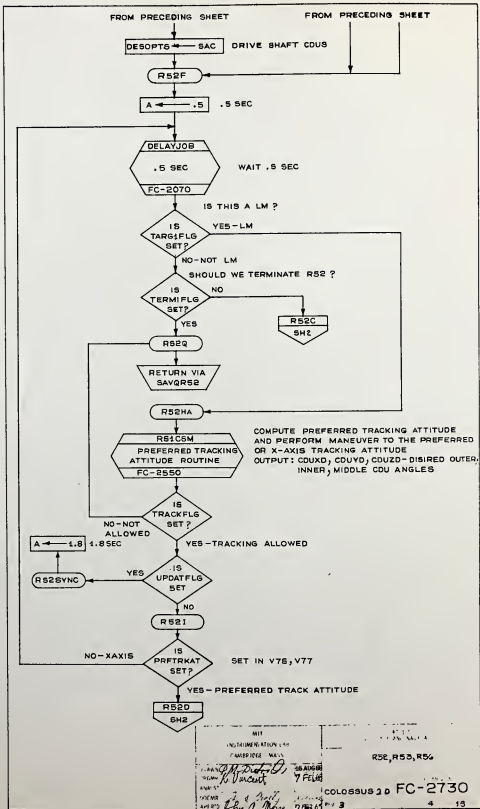
R52, R53, R56

COLUMBUS 20 FC-2730

2 18





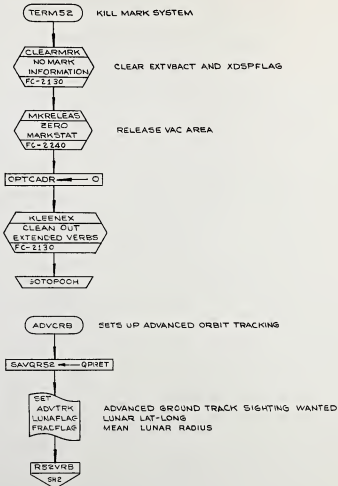


MIT  
 COLUSSUS 30 FC-2730

7 AUG 68  
 7 FEB 69

COLOSSUS 30 FC-2730

4 15

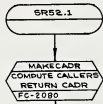


R52, R 53, R56

*J. W. ...* 15 AUG 66  
*...* 71  
*...* 3  
 2 FEB 67

COLOSSUS 2D FC-2730  
 3 5 19

TARG1 AND TARG2 FLAG ARE LOOKED AT TO DETERMINE IF TARGET IS LEM, STAR OR LANDMARK. A REFERENCE SIGHTING VECTOR IS OBTAINED AND TRANSFORMED INTO STABLE MEMBER COORDINATES. FINALLY A TRUNNION ANGLE TEST IS MADE.



INPUT: TARG1FLG, TARG2FLG  
 NOTE: IF TARG1FLG=1, TARGET IS LM; IF BOTH=0, TARGET IS STAR;  
 IF TARG1FLG=0 AND TARG2FLG=1, TARGET IS LANDMARK  
 OUTPUT: SAC - SHAFT ANGLE DESIRED  
 PAC - TRUNNION ANGLE DESIRED

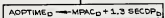
INPUT : CALLERS CADR SAVED BY  
 OUTPUT: CADR IN A REG



CALLERS CAOR



INPUT : COMPUTER CLOCK  
 OUTPUT: MPAC<sub>D</sub> - TIME2, TIME1



PRESENT TIME PLUS 2.4 SECONDS

IN CASE OF LEM OR LMK THE PRESENT TIME PLUS 2 SECONDS IS SAVED IN AOPTIME



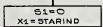
YES, THE TARGET IS THE LEM



YES, THE TARGET IS LANDMARK



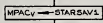
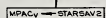
NO - TARGET IS A STAR



IF TARGET IS A STAR, VECTOR IS OBTAINED FROM THE CATALOG



NO - BESTJ



NEXT SHEET

R52, R 53, R56

1.4.1968  
 2.1.1968  
 27m-41  
 7.1968

COLOSSUS 20 FC-2730

FROM PRECEDING SHEET

COMS2 TRANSFORMS THE REFERENCE SIGHTING VECTOR INTO SM COORDS

STARV ← UNIT [REFSMMAT \* MPACV]

READ IMU - CDU5

CDUTRIS  
SINES, COSINES  
OF CDU COUNTERS  
FC-2270

INPUT : CDUX, CDUY, CDUZ  
OUTPUT : SINCDUX, SINCDUY, SINCDUZ  
COSCDUX, COSCDUY, COSCDUZ

CALCSXA  
COMPUTE THE SEX-  
TANT SHAFT AND  
TRUNNION ANGLES  
FC-2250

INPUT : STARV - STAR VECTOR REFERRED TO PRESENT SM COORDS  
SINCDUY, Z, X ; COSCDUY, Z, X  
OUTPUT : SAC - SEXTANT SHAFT ANGLE  
PAC - SEXTANT TRUNNION ANGLE

NC - CELESTIAL  
BODY IS  
OCCLUDED

IS  
CULTFLAG  
CLEAR?

CHECK 50 DEG +20 VS 36 +90

Y  
RUNDB

IS THE ANGLE GREATER THAN +50 DEG?

IS PACD  
-20 TRDNG  
YES

IS THE ANGLE LESS THAN -20 DEG?

IS PACD  
-20 DESEAIN  
YES

ERSEEB

GMIN ← GMIN + 1

CRSEEB

GMIN ← GMIN + 2

CRSEFL

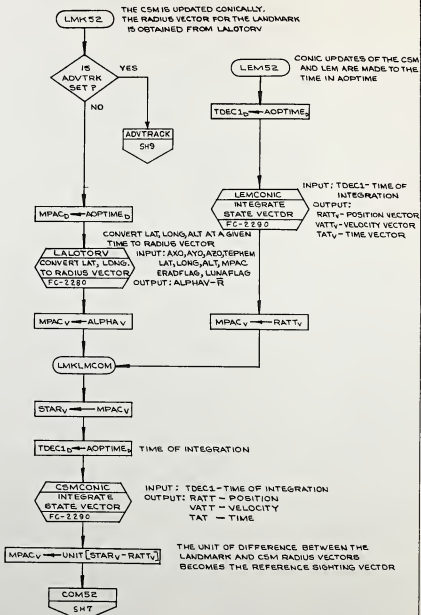
A ← GMIN

RETURN VIA  
SWCALL

R52, R53, R56

COLOSSUS 20 FC-2730

7 15

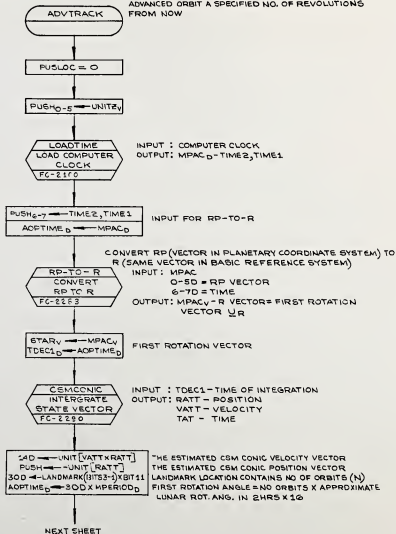


R52, R53, R56

COLOSSUS 20 FC-2730

6 15

CALLED BY SR52.1  
 USED TO COMPUTE AN OPTICS LOS VECTOR TO A POINT ON  
 THE GROUND  
 TRACK 60 DEGREES FORWARD OF THE LOCAL VERTICAL OF AN  
 ADVANCED ORBIT A SPECIFIED NO. OF REVOLUTIONS  
 FROM NOW



R52, R53, R56

COLOSSUS 20 FC-2730

3 3 18

FROM PRECEDING SHEET

ROTATE THE LOCAL VERTICAL VECTOR ABOUT THE POLAR AXIS OF THE MOON TO ACCOUNT FOR LUNAR ROTATION

INPUT : PUSH<sub>0-5</sub> = -UNIT (RATT)

STAR<sub>V</sub> = FIRST ROTATION VECTOR  $\underline{U}_R$

ADPTIME = ANGLE THROUGH WHICH MOON ROTATES IN ONE NOMINAL LUNAR - ORBITAL PERIOD K NO OF ORBITS - (A = A<sub>M</sub>N)

OUTPUT : PUSH<sub>0-5</sub>

ROTA  
ROTATE VERTIC-  
CLE VECTOR  
SH 10

STAR → 24D  
ADPTIME<sub>D</sub> → DF1/6<sub>D</sub> - ADPTIME<sub>D</sub>

2ND ROTATION VECTOR  
2ND ROTATION ANGLE = 60° - A

ROTATE VECTOR ABOUT THE NORMAL TO THE CSM ORBITAL PLANE TO ATTAIN DESIRED 60° ANGLE

INPUT : STAR = LOS VECTOR

ADPTIME = 60° - FIRST ROTATION ANGLE - (A =  $\frac{\pi}{3} - A$ )

OUTPUT : PUSH<sub>0-5</sub>

ROTA  
ROTATE VECTOR TO  
ORBITAL PLANE  
SH 10

STAR<sub>V</sub> ← PUSH<sub>0-5</sub>

DESIRED LINE OF SIGHT VECTOR  $\underline{U}_{LOS}$

COM52  
SH 6

INPUT : ADPTIME = ROTATION ANGLE - (A)

STAR = ROTATION VECTOR - ( $\underline{U}_R$ )

PUSH<sub>0-5</sub> = LOS VECTOR - ( $\underline{U}_{LOS}$ )

OUTPUT : PUSH<sub>0-5</sub> = FINAL DESIRED LINE OF SIGHT VECTOR ( $\underline{U}_{LOS}$ )

ROTA

PUSH<sub>6,7</sub> → -(SIN(ADPTIME) X STAR)  
PUSH<sub>6-11</sub> → 1/2 SIN(ADPTIME) X (STAR X LOS)  
PUSH<sub>12-17</sub> → 1/2 (STAR · LOS) STAR  
PUSH<sub>18-19</sub> → 1/2 COS(ADPTIME)  
PUSH<sub>0-5</sub> → UNIT [LOS - 1/2 (STAR · LOS) STAR + 1/2 COS(ADPTIME) + 1/2 SIN(ADPTIME) (STAR X LOS) + 1/2 (STAR · LOS) STAR]

ROTATE THE VECTOR  $\underline{U}_{LOS}$  ABOUT  $\underline{U}_R$  THROUGH THE ANGLE A BY

$\underline{U}_{LOS} = (1 - \cos A) (\underline{U}_R \cdot \underline{U}_{LOS}) \underline{U}_R + \underline{U}_{LOS} \cos A + \underline{U}_R \times \underline{U}_{LOS} \sin A$

RETURN VIA  
QPRET

R52, R53, R56

COLUSSUS 20 FC-2730

10 18



R53  
SIGHTING MARK ROUTINE

PURPOSE IS TO PERFORM A SATISFACTORY NUMBER OF OPTICAL SIGHTING MARKS FOR THE REQUESTING PROGRAM(OR ROUTINE)

INPUT : TARG&FLG - TARGET FLAG - STAR OR LANDMARK  
MARKINDX - NO. OF MARKS WANTED  
STARIND - INDEX TO BESTI OR WESTJ

OUTPUT: R53FLAG  
TER1FLG

R53EXIT → QPRET SAVE RETURN

SET  
R53FLAG

SET SIGHTING MARK FLAG INDICATES THAT A VS1 REQUEST TO PLEASE MARK HAS BEEN INITIATED

R53A

A ← MARKINDX(BITS-1)

NO OF MARKS

SXTMARK  
RESERVE VAC  
AREA AND SCHEDULE  
MKVBS1 JOB  
FC-2240

INPUT : BIT 3-1 OF A: NO OF MARKS REQUESTED  
OUTPUT: MARKSTAT = MARK VALUE AND VAC AREA ADDRESS  
QPRET = VAC AREA POINTER VALUE  
VAC AREA WORD 1 : 0

OPTSTALL  
WAIT FOR MARK  
TO FINISH  
FC-2210

CURTAINS  
ALARM  
00217  
FC-2140

RELEASE VAC AREA  
O(MARKSTAT) →  
MARKSTAT - 1

HAVE ANY MARKS BEEN DONE?

QPRET (MARKSTAT) = NUMBER OF MARKS ACTUALLY PERFORMED  
(MKVBS1)

R53B

IS CALLING PROGRAM P22 OR P23?

CHECKMM  
CHECK  
MOOREG  
FC-2630

YES - BYPASS DISPLAY

NO - DISPLAY

NEXT SHEET

R53C1

A ← 40

CLEANDSP  
BLANK  
DISPLAY  
REGISTERS  
FC-2150

NEXT SHEET

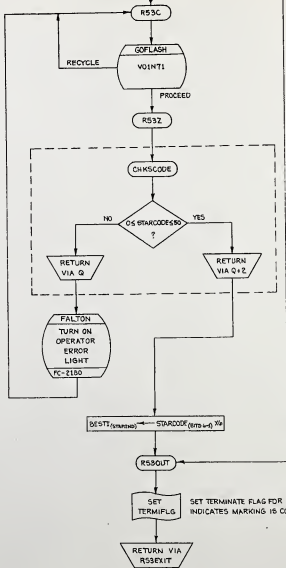
R52, R53, R56

*W. Madison*  
*2/2/53*  
81248  
514  
17011  
7 FEB 53

COLOSSUS 20 FC-2730

11 18

FROM PRECEDING SHEET



REQUEST RESPONSE AND DISPLAY  
OF CELESTIAL BODY CODE  
V0INT1  
R1 - D00XX - CELESTIAL BODY CODE  
R2 - BLANK  
R3 - BLANK  
CELESTIAL BODY CODE  
00 - PLANET  
01/45 - STAR FROM CELESTIAL  
BODY CODE LIST

46 - SUN  
47 - EARTH  
50 - MOON

OBTAIN STAR VECTOR  
FROM STORED EPHEMERIS.

BY  
"REVISIONS"  
APPROVED, DATE  
BY A.C. WILLIAMS  
BY R. D. [unclear]  
CHECKED  
DATE

EPH500  
JUL 68  
2784  
7865

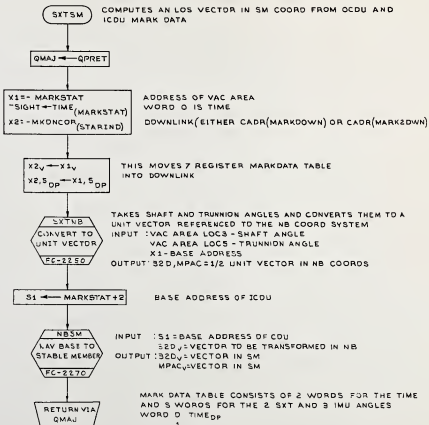
R52, R53, R56

COLOSSUS 2D

FC-2730

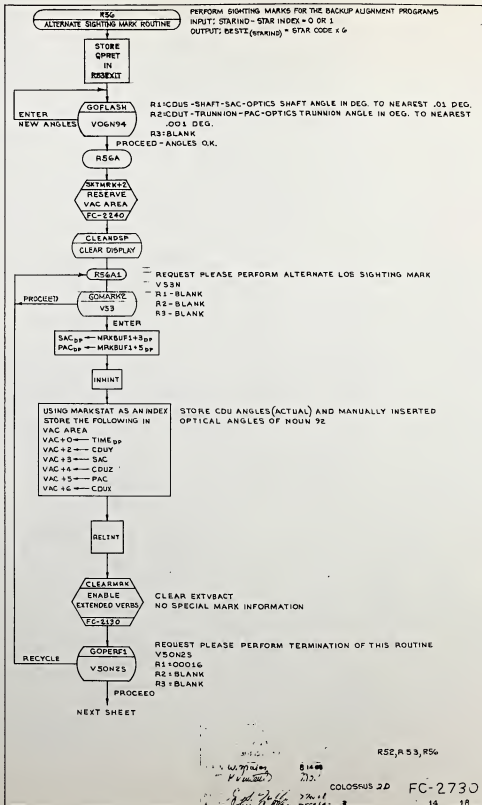
3

12 10



R52, R53, R56

W. J. M. 81348  
 M. J. M. 81348  
 20633115 2D FC-273D  
 2  
 12 15



FROM PRECEDING SHEET



A.C.WILLIAMS SPEDLO  
in view of 11/1/1

R52, R53, R5G

COLOSSUS 2D

FC-2730

G.P. NALLY 2/1/1  
for R. B. 7/5/1

3

15 16

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
R61CSM	FC-2550	PREFERRED TRACKING ATTITUDE	SH. 4
CLEARMRK	FC-2130	NO MARK INFORMATION	SH. 5, 14
MKRELEAS	FC-2240	ZERO MARKSTAT	SH. 5
KLEENEX	FC-2130	CLEAN OUT EXTENDED VERBS	SH. 5
MAKECADR	FC-2080	COMPUTE CALLERS RETURN CADR	SH. 6
LOADTIME	FC-2100	LOAD COMPUTER CLOCK	SH. 6
CDUTRIG	FC-2270	SINES, COSINES OF CIDU COUNTERS	SH. 7
CALCSCA	FC-2250	COMPUTE THE SEXTANT SHAFT AND TRUNNION ANGLES	SH. 7
LALOTORV	FC-2280	CONVERT LAT, LONG TO RADIUS VECTOR	SH. 8
LEMCONIC	FC-2290	INTEGRATE STATE VECTOR	SH. 8
CSMCONIC	FC-2290	INTEGRATE STATE VECTOR	SH. 8, 9
LOADTIME	FC-2100	LOAD COMPUTER CLOCK	SH. 9
RP-TO-R	FC-2283	CONVERT RP TO R	SH. 9
SXTMARK	FC-2240	RESERVE VAC AREA AND SCHEDULE MKVB51 JOB	SH. 11, 14
OPTSTALL	FC-2210	WAIT FOR MARK TO FINISH	SH. 11
CHECKMM	FC-2030	CHECK MODREG	SH. 11
SXTNB	FC-2250	CONVERT TO UNIT VECTOR	SH. 13
NBSM	FC-2270	NAV BASE TO STABLE MEMBER	SH. 13

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		R52, R53, R56
DRAWN <i>J. C. Clark</i> CHECKED <i>R. J. Jones</i> DATE <i>2-7-69</i> APPROVED <i>G. S. NALLY</i> <i>John D. Moore</i>	27-10 308A69 REV 3	COLLOSSUS 3D FC-2730 16 18

FLAGS						
NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED	
ADVTRK	ADVANCE GROUND TRACK WANTED	NOT ADVANCED GROUND TRACK	SH. 5	SH. 2	SH. 8	
TRUNFLAG	DRIVING OF TRUNNION ALLOWED	DRIVING OF TRUNNION NOT ALLOWED	SH. 2, 3	SH. 3	SH. 3	
TERMMFLG	TERMINATE R52	DO NOT TERMINATE R52		SH. 2, 12	SH. 4	
R53FLAG	V51 INITIATED	V51 NOT INITIATED	SH. 11		SH. 3	
TARG1FLG	SIGHTING LEM	NOT SIGHTING LEM			SH. 3, 4, 6	
TRACKFLG	TRACKING ALLOWED	TRACKING NOT ALLOWED			SH. 4	
UPDATFLG	UPDATING BY MARKS ALLOWED	UPDATING BY MARKS NOT ALLOWED			SH. 4	
LUNAFLAG	LUNAR LAT-LONG	EARTH LAT-LONG	SH. 5			
ERRADFLAG	USE FIXED RADII S	USE RLS FOR LUNAR RADIUS	SH. 5			
TARG2FLG	SIGHTING LANDMARK	SIGHTING STAR			SH. 6	
CULTFLAG	STAR OCCULTED	STAR NOT OCCULTED			SH. 7	

DISPLAYS			
VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
		PROLARM - TARGET OUT OF VIEW - 404	SH. 3
		CURTAINS - ALARM 217	SH. 11
V01N71	FLASHING	RESPONSE AND DISPLAY OF CELESTIAL BODY CODE R1 - CELESTIAL BODY CODE R2 - BLANK R3 - BLANK	SH. 12
V53	PLEASE PERFORM	PLEASE PERFORM ALTERNATE LOS SIGHTING MARK R1 - BLANK R2 - BLANK R3 - BLANK	SH. 14
V06N94	FLASHING	R1 - CDUS - SHAFT R2 - CDUT - TRUNNION R3 - BLANK	SH. 14
V50N25	PLEASE PERFORM	PLEASE PERFORM TERMINATION OF THIS ROUTINE R1 - 00016 R2 - BLANK R3 - BLANK	SH. 14

R52, R53, R56

*J. S. Chumbley*  
R. D. Ward

G. S. NALLY 2749  
John A. Beck 316249

COLOSSUS 20 FC-2730

37 18

## ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
CDUT		OPTICS TRUNNION ANGLE	DEGREES	REVS	2 <sup>-3</sup>
CDUS		OPTICS SHAFT ANGLE	DEGREES	REVS	2 <sup>-1</sup>
DESOPTT		DISPLAY NOUN FOR TRUNNION ANGLE	DEGREES	REVS	2 <sup>-1</sup>
DESOPTS		DISPLAY NOUN FOR SHAFT ANGLE	DEGREES	REVS	2 <sup>+1</sup>
STARSAV2		STAR2 UNIT VECTOR			2 <sup>1</sup>
STARSAV1		STAR1 UNIT VECTOR			2 <sup>1</sup>
RATT <sub>V</sub>		CONIC POSITION VECTOR	M	M	2 <sup>29</sup>
VATT <sub>V</sub>		CONIC VELOCITY VECTOR	M/SEC	M/CSEC	2 <sup>7</sup>
TAT <sub>D</sub>		TIME OF RATT <sub>V</sub> , VATT <sub>V</sub>	SEC	CSEC	2 <sup>28</sup>
ALPHAV <sub>V</sub>		RADIUS VECTOR	M	M	2 <sup>20</sup>
LANDMARK		NO OF REVOLUTIONS			
AOPTIME		TEMPORARY			
STAR <sub>V</sub>		TEMPORARY			
STARIND		STAR INDICATOR			
TDECI <sub>D</sub>		TIME VARIABLE	SEC	CSEC	2 <sup>28</sup>
TSIGHT <sub>D</sub>		TIME OF SIGHTING	SEC	CSEC	2 <sup>28</sup>
CDUX		OUTER IMU GIMBAL ANGLE	DEGREES	REVS	2 <sup>-1</sup>
CDUY		INNER IMU GIMBAL ANGLE	DEGREES	REVS	2 <sup>-1</sup>
CDUZ		MIDDLE IMU GIMBAL ANGLE	DEGREES	REVS	2 <sup>-1</sup>

## PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
38TRDEG		50° TO 85° ANGLE CHECK	80 DEGS	.16666667 REV	2 <sup>-2</sup>
20DEGSMN		65° TO 90° ANGLE CHECK	-38 DEGS	-.1098 REV	2 <sup>-2</sup>
MPERIOD		LUNAR ANGULAR ROTATION IN 2 HOURS	1.071432 DEGS	.0029762 REV	2 <sup>-4</sup>
DP1/6		1/6 REVOLUTION = 60°	60 DEGS	.16666666 REV	2 <sup>0</sup>
TRUNLIM		MAXIMUM TRUNNION = 50°	50 DEGS		

WFP  
 ASD INFORMATION LAB  
 W-01-2 MASS.  
 37 JAN 69  
 R52, R53, R56  
 CALOSSUS 2.0 FC-2730  
 G.S. MALLY 2 707  
 Jan 11 1969 3 56 63



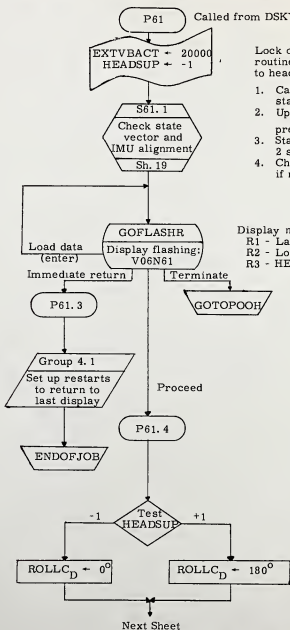
P60's - ENTRY PROGRAMS

P61	Maneuver to CM/SM separation attitude	Sh. 2
P62	CM/SM separation and pre-entry maneuver	Sh. 6
WAKEP62	Schedule P63	Sh. 9
P63	Entry initialization	Sh. 10
P64	Post .05G entry mode	Sh. 12
P65	Up control entry mode	Sh. 13
P66	Ballistic entry mode	Sh. 15
P67	Final entry mode	Sh. 16
P67.1	Final entry display (N67)	Sh. 17
P67.2	Calculation for N67 display	Sh. 18
S61.1	Check for proper IMU alignment and ensure that AVERAGEG is started	Sh. 19
S61.1C	Start AVERAGEG	Sh. 20
S61.1A	Check entry IMU alignment	Sh. 21
S61.2	Calculation for N60, N63 displays	Sh. 22
DISPTARG	Range estimator	Sh. 28
P62.3	Compute desired entry attitude	Sh. 30

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>J. Conzola</i>		P60's	
PRCMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 1 OF 35
APPR'D			

P61: Maneuver to CM/SM Separation Attitude



Lock out extended verbs (protect TFF routines from V82) Set HEADSUP flag to head down (lift up)

1. Call R02 check REFSMMAT & IMU status. Set IMUSE flag
2. Update state vectors  $V_{N_V}$ ,  $R_{N_V}$ , to present time + a small tolerance
3. Start AVERAGEG as part of servicer 2 sec. update sequence
4. Check IMU alignment and do alarm if not satisfactory (10 sec display)

Display noun 61:

- R1 - Latitude (splash) xxx.xx deg  
 R2 - Longitude (splash) xxx.xx deg  
 R3 - HEADSUP: +1 = heads up (lift down)  
 -1 = heads down (lift up)

If HEADSUP = +1,  
 command 180° roll (lift down)  
 If HEADSUP = -1,  
 command 0° roll (lift up)

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	J. Conetta	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCNR		REV 1	SHEET 2 OF 35
APPR'D			

From Preceding Sheet

AGIN, MON

EXTVBACT  
+ 2000<sub>8</sub>

Lock out extended verbs

NEWRVN

MM<sub>D</sub> + PIPTIME<sub>D</sub>

Temporary storage for test below

STARTEN

Calculate  
initial target  
vector

FC-2770

Input: PIPTIME<sub>D</sub> from AVERAGEG, LAT(SPL)<sub>D</sub>  
LNG(SPL)<sub>D</sub>

Output: RTINIT<sub>V</sub> - initial target vector (at PIPTIME)  
RTEAST<sub>V</sub> - eastward component of RTINIT<sub>V</sub>  
RTNORM<sub>V</sub> - normal component of RTINIT<sub>V</sub>  
RT<sub>V</sub> - target vector at estimated impact time  
TIME/RTO<sub>D</sub> - time of initial target vector

flagword 6  
bit 3

Clear  
.05GSW

Enable TICKTTE (FC-2683) to decrement TTE

RONE<sub>V</sub> + RN<sub>V</sub>  
URONE<sub>V</sub> + Unit(RN<sub>V</sub>)  
VONE<sub>V</sub> - VN<sub>V</sub>

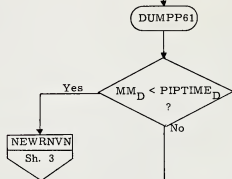
UNI<sub>V</sub> = Unit[VONE<sub>V</sub> × URONE<sub>V</sub>]

Next Sheet

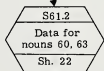
# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: J. Cicco <i>J. Cicco</i>		P60's	
PROGRAM		COLOSSUS 2D	DOCUMENT NO.
ANALYST			FC-2760
DOCWR		REV 1	SHEET 3 OF 35
APPR'D			

From Preceding Sheet



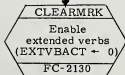
If PIPTIME has been updated, it means that AVERAGEG has run, so above calculations are invalid and must be redone using new state vector



Input: RONE<sub>V</sub>, VONE<sub>V</sub>, URONE<sub>V</sub>, UNL<sub>V</sub>,  
UNITW<sub>V</sub>, EMSALT

Output: GMAX = maximum predicted deceleration during entry (in g's)  
 VPRED = predicted inertial velocity at 400,000 ft  
 GAMMAEI = predicted flight path angle (°) at 400,000 ft  
 RTOGO = range from EMS altitude to splash  
 VIC = predicted inertial velocity at EMS altitude  
 TTE = time to go from present position to EMS altitude (EMS altitude = altitude at .05g  
 G. value = 284,643 ft orbital entry  
 = 297,431 ft lunar entry)

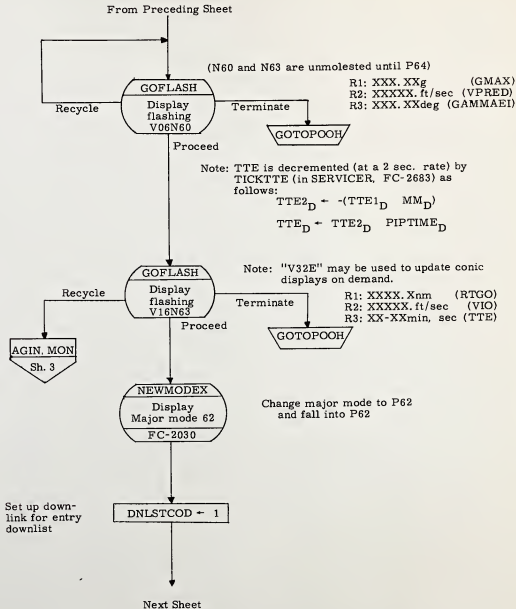
} noun 60  
 } noun 63



Next Sheet

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: J. Curcio		P60's	
PRGRM		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2760
DCCHR		REV 1	SHEET 4 OF 35
APPR'D			



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Corbett</i>		P60's	
PRGMR		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2760
DOCMR		REV 1	SHEET 5 OF 35
APPR'D			

From Preceding Sheet

Flow in from P61 or by DSKY request

P62

CM/SM separation and pre-entry maneuver

If entered from DSKY, start AVERAGEG also

S51.1

Check state vector and IMU alignment

Sh. 19

POSEXIT ← CADR(P62.3)

Set CM/POSE exit address to calculate desired .05g gimbal angles, but without display via ENTRYVN.

CM/DAPIC

Start entry DAP in idle mode

FC-2780

Start calculations of body rates for entry DAP  
Disable entry display: ENTRYDSP flag cleared

P62.2

AVERAGEG ← 2CADR(CM/POSE)

Put CM/POSE in SERVICER 2 sec. update sequence for calculation of body attitude following AVERAGEG routine. Remains active until end of entry.

Enter

GOPERF1R

Display flashing V50N25 checklist 41

Terminate

GOTOPOOH

Immediate return

P61.3

Group 4.1

Restart at last display

R1 = 00041 (CM-SM separation request)  
R2 }  
R3 } Blank

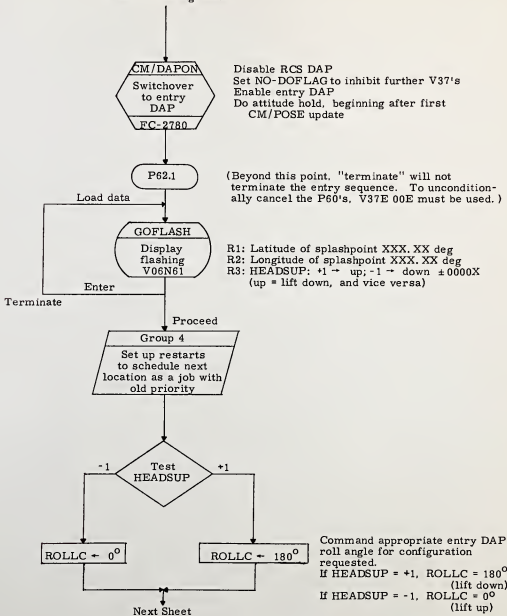
Next Sheet

ENDOFJOB

**PRELIMINARY**

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	J.C. ...	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 6 OF 35
APPR'D			

From Preceding Sheet



# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>SCM/010</i>		P60's	
PRGMR		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2760
DOCMR		REV 1	SHEET 7 of 35
APPR'D			

From Preceding Sheet

ALFACOM ← ALFAPAD  
BETACOM ← 0°

Pitch command } command nominal entry  
Yaw command } attitude  
(ALFAPAD is pad loaded hypersonic trim  
angle of attack commensurate with  
expected L/D. (L/D = .28; ALFAPAD =  
-18.5°))

P63FLAG ← 1

Enable entry DAP to call WAKEP62 in order  
to go on to P63 (was set to -1 by CM/DAPON)

ENTRYVN ← V06N22

Set up entry display; executed in re-entry  
control (OVERNOUT) to display desired  
CDU angles.

Set  
ENTRYDSP

Set flagword 6 bit 13 to  
enable entry display

Test  
CMDAPMOD

+0, -1

If  $|\alpha| < 45^\circ$ , go directly to P63,  
since maneuver to entry  
attitude is complete, or nearly  
so. (CMDAPMOD is set by entry  
DAP: -0 if  $|\alpha| > 135^\circ$

-1 if  $135^\circ \geq |\alpha| \geq 45^\circ$

-0 if  $|\alpha| < 45^\circ$

-1 if in atmosphere)

-0, +1

Wait for entry DAP to  
schedule P63 when  
maneuver to entry  
attitude is complete

P63.1

Group 4.0  
Kill Group 4  
restarts

P63

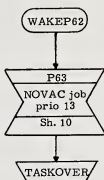
Sh. 10

ENDOFJOB

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Conroy</i>		P60's	
PRGMR	<i>W. Squire</i>	DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2760
DOCMR		REV 1	SHEET 8 OF 35
APPR'D			



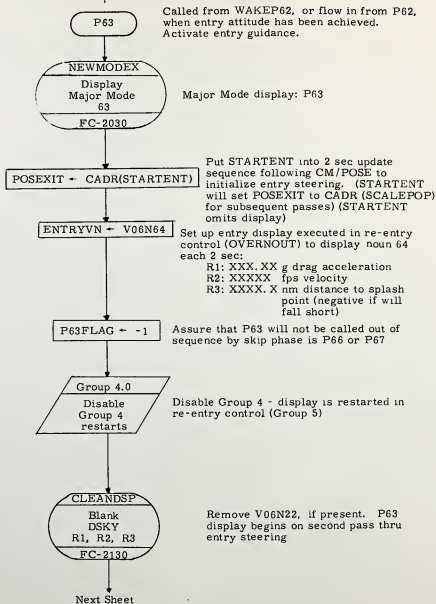


Called from entry DAP at transition from  $|a| > 45^\circ$  to  $|a| < 45^\circ$  if P63 flag = +0 (P63 flag must first become +1 which it does when  $|a| > 45^\circ$ ) (See FC-2780)

Schedule P63

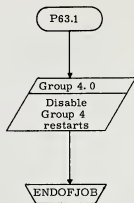
# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>Sciacca</i>		P60's	
PRGMR	<i>Sept 67</i>	COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 9 OF 35
APPR'D			



# PRELIMINARY

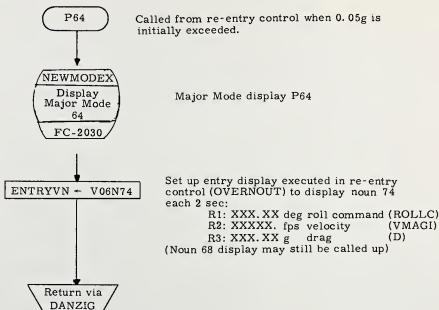
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Coombs</i>	<i>25019</i>	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 10 OF 35



Disable Group 4 - display is restarted  
in re-entry control (Group 5)

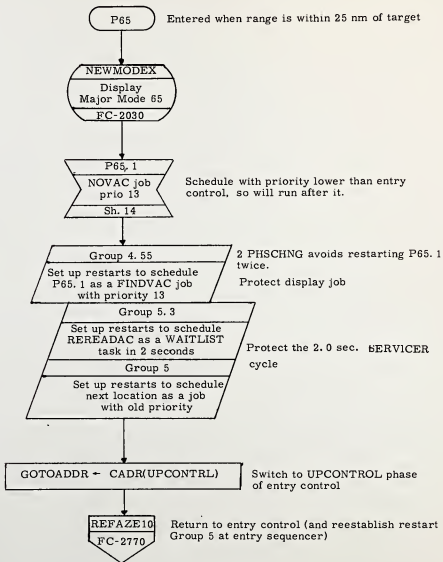
# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Cinotta</i>		P60's	
PRGMR	<i>S. Horner</i>	DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2760
DOCMR		REV 1	SHEET 11 OF 35
APPR'D			



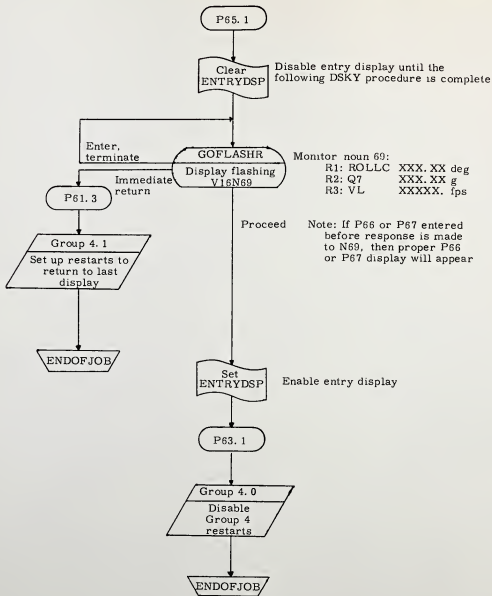
# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Covatta</i>	<i>entry + 7</i>	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 12 OF 35
APPR'D			



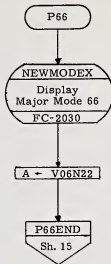
# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. C. ...</i>		P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 13 OF 35
APPR'D			



# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <u>J. Conolly</u> <u>2 Sept 66</u>		P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 14 OF 35
APPR'D			



Entered when drag <Q7

Set up entry display to display desired gimbals angles (noun 22)

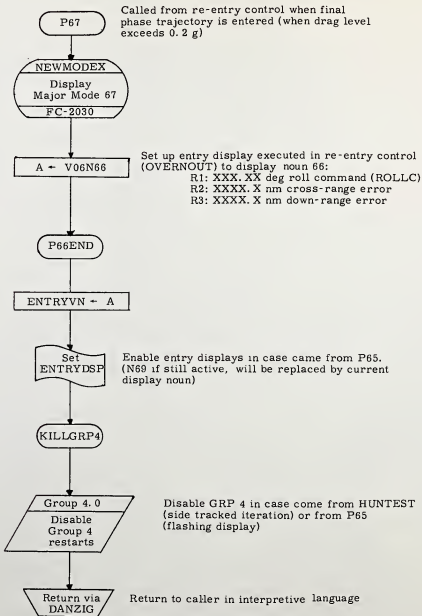
R1: XXX.XX deg

R2: XXX.XX deg

R3: XXX.XX deg

# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>S. C. M. 10/68</i>	<i>5-50-68</i>	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 15 OF 35
APPR'D			



# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Cavatita</i>		P60's	
PRGMR	<i>ASG:V</i>	DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2760
DOCMR		REV 1	SHEET 16 OF 35
APPR'D			



P67. 1

Called from STEEROFF (reentry control) when relative velocity first becomes less than 1000 ft/s. Establish final entry display

GOF LASH

Display flashing V16N67

R1 = RTGO = range to go to target (positive if gone past) XXXX.X nm  
 R2 = LAT = latitude of present position (+ is north) XXX.XX deg  
 R3 = LONG = longitude of present position (+ is east) XXX.XX deg

Proceed or terminate Terminate entry steering and entry DAP at crew option

Inhibit inter-rupts

Clear CM/DSTBY  
 Clear GYMDIFSW

(FLAGWRD6, bits 2, 1)  
 Turn off entry DAP at next DAP update

Enable inter-rupts

AVEGEXIT<sub>D</sub> = 2CADR(SERVEXIT)

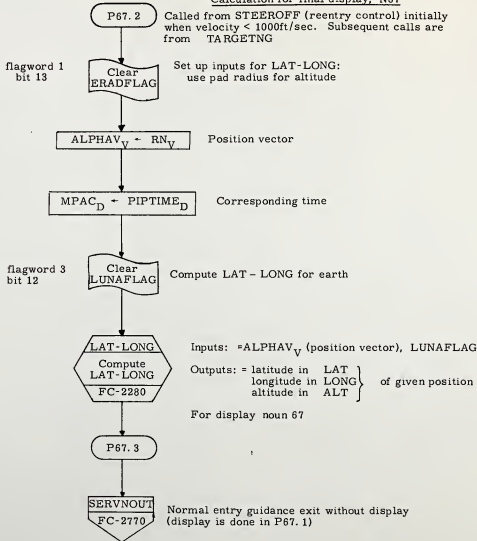
Disconnect entry programs from AVERAGEG/ SERVICER cycle

GOTOPOOH

PRELIMINARY

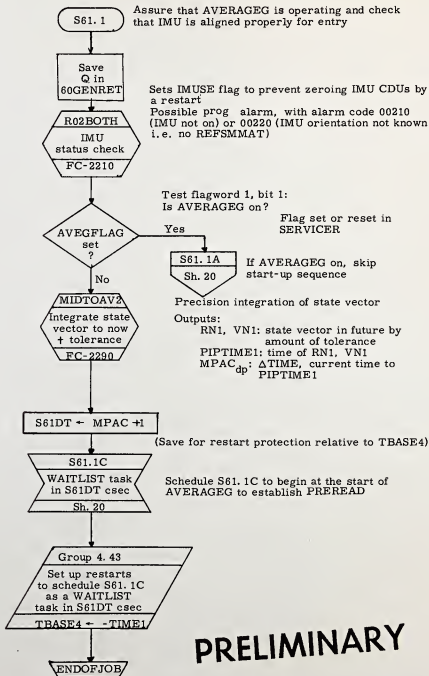
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. C. ...</i>		P60's	
PRGMR		DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 17 OF 35

Calculation for final display, N67



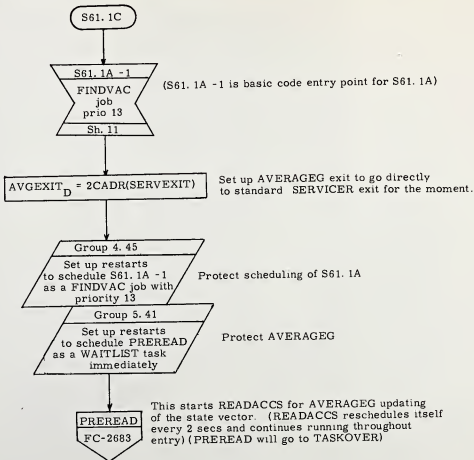
# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Ciaglia</i> <i>4 Sept 68</i>		P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 18 OF 35
APPR'D			



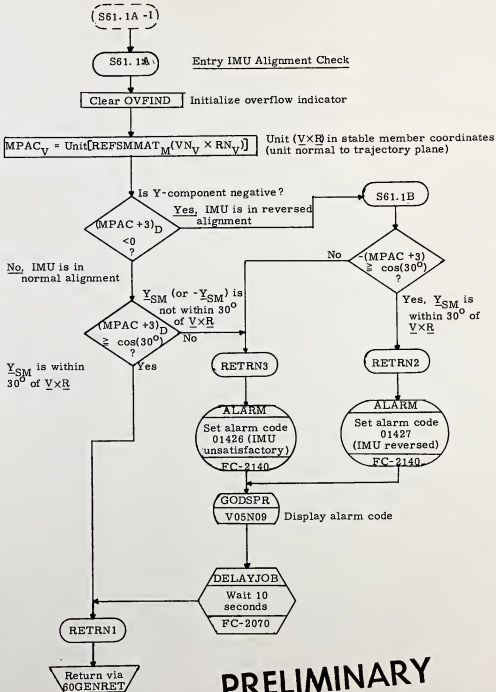
**PRELIMINARY**

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. C. ...</i>	<i>...</i>	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCNR		REV 1	SHEET 19 OF 35
APPR'D			



# PRELIMINARY

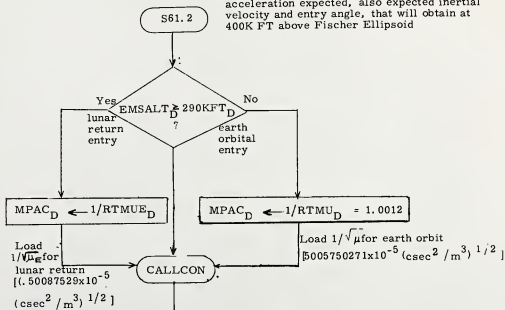
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P60's	
DRAWN	J. O'Connell	PRGMR	ASPR
ANALST		DOCMR	
APPR'D		REV 1	
		COLOSSUS 2D	DOCUMENT NO. FC-2760
		SHEET 20 OF 35	



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. C. ...</i>	P60's	
PRGRM		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCNR		REV 1	SHEET 21 OF 35
APPR'D			

Noun 60 and Noun 63 Calculation Subroutine  
 Calculate entry display (noun 60) of maximum  
 acceleration expected, also expected inertial  
 velocity and entry angle, that will obtain at  
 400K FT above Fischer Ellipsoid



TFFCNIC  
 Compute conic parameters  
 FC-2320

Input: MPAC<sub>D</sub> } 1/√A for earth  
 RONE<sub>v</sub> } Saved from SERVICED by NEWNRVIN (P61)  
 URONE<sub>v</sub> }  
 VONE<sub>v</sub> }  
 UNL<sub>v</sub> }  
 Conic parameters in pushlist (for use by TFF subroutines)

MPAC<sub>D</sub> ← RTBIAL<sub>D</sub>

First guess at terminal radius (R<sub>h</sub>) at nominal EMS altitude  
 RTRIAL<sub>D</sub> = RPAD + nominal 0.05Q  
 altitude = 20,909,901.57 ft + 284,643 ft = 21,194,545 ft

CALCTFF  
 Calculate time of free fall  
 FC-2320

Input: terminal radius (MPAC<sub>D</sub>) (R<sub>h</sub>)  
 Conic parameters in pushlist (from TFFCONIC)  
 Output: NRTERM = normalized R<sub>h</sub>  
 TFFX = α Z<sup>2</sup> or 1/α Z<sup>2</sup>  
 TFFTEM = PZ | Z | or P/Z  
 P / α SGN (Q<sub>0</sub> + R<sub>0</sub>/Z)

Next Sheet

PRELIMINARY

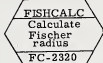
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P60'S	
DRAWN	<i>L. Goldstone 4/1/60</i>	COLOSSUS 2D	DOCUMENT NO. FC-2180
PRGMR			
ANALST		REV 1	SHEET 22 of 35
DOCMR			
APPR'D			

From Preceding Sheet



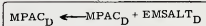
Input: NRTERM } From CALCTFF  
TFFX }  
TFFTEM }  
NRMAG } From TFFCONIC

Output: MPAC = sin (δf), where (δf) is transfer  
CDELFF/2 = angle from present to  
cos (δf) EMS altitude.



Input: MPAC<sub>D</sub> = sin (δf), UNIV = unit (V<sub>0</sub> × R<sub>0</sub>)  
CDELFF/2 = cos (δf)

Output: MPAC<sub>D</sub> = ERADM = Radius of earth  
(R<sub>e</sub>) at latitude of estimated terminal  
radius (R<sub>h</sub>)



Corrected estimate of terminal  
radius (R<sub>h</sub>)

EMSALT<sub>D</sub> = 284, 643 ft (pad loaded,  
earth orbital)

EMSALT<sub>D</sub> = 297, 431 ft (pad loaded,  
lunar return)



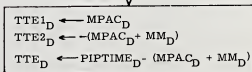
Input: MPAC<sub>D</sub> = terminal radius (R<sub>h</sub>)

Output: MPAC<sub>D</sub> = time of flight to EMS  
altitude from present position.

NRTERM = normalized R<sub>h</sub>

TFFX = αZ<sup>2</sup> or  $\frac{1}{\alpha Z^2}$

TFFTEM = PZ | Z | or  $\frac{P}{Z} \text{SGN} \left( Q_0 + \frac{R_0}{2} \right)$



Time till entry (.05g) stored positive  
Negative for N63 display



Input: NRTERM } From CALCTFF  
TFFX }  
TFFTEM }  
NRMAG } From TFFCONIC

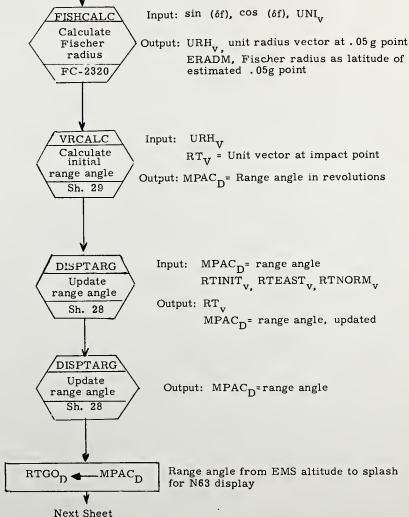
Output: MPAC<sub>D</sub> = sin (δf)  
CDELFF/2 = cos (δf)

Next Sheet

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>L. G. Johnson</i> 7/2/69	P60'S	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR		REV 1	SHEET 23 OF 35
APPR'D			

From Preceding Sheet



# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. J. Johnson</i>	<i>9/1/68</i>	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 24 OF 35
APPR'D			



From Preceding Sheet

VGAMCALC  
 Calculate  
 velocity  
 magnitude and  
 flight path  
 angle  
 FC-2320

Input: NRTERM (from CALCTFF)  
 Conic parameters in Pushlist from  
 TFFCONIC

Output:  $PDL_{0D}$  = terminal velocity ( $V_h$ )  
 $MPAC_D$  = flight path angle ( $\delta_e$ )  
 (relative to horizontal)

$$V_{EMS} = V_h + \frac{-1,510,000}{V_h \cdot \delta_e}$$

Predicted inertial velocity at EMS  
 altitude for N63 display  
 (compensated to account for  
 atmospheric drag)

$$V_{10D} \leftarrow PL_{0D} + \frac{VEMSCON_D}{PL_{0D} \cdot MPAC_D}$$

Obtain  $V_g$  at 300,000 feet altitude  
 for use in GMAX algorithm

$$MPAC_D \leftarrow ERADM_D + 300KFT_D$$

ERADM = earth radius at EMS  
 latitude (from FISHCAL)

$$RTERM_D \leftarrow MPAC_D$$

PREVGAM  
 Calculate  
 velocity  
 magnitude and  
 flight path  
 angle  
 FC-2320

Input:  $MPAC_D = R_h$   
 Conic parameters in Pushlist  
 TFFCONIC

Output:  $PL_{0D}$  = terminal velocity ( $V_h$ )  
 $MPAC_D$  = flight path angle ( $\delta_e$ )

Calculation of maximum G for display (noun 60)

$$PL_{2D} \leftarrow MPAC_D$$

Predicted flight path angle at  
 300,000 feet ( $\delta_e$ )

Next Sheet

# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Gilbert</i>	<i>9/10/62</i>	P60's	
PRGRM		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 25 OF 35
APPR'D			

From Preceding Sheet

$$V^2 = \left( \frac{V_h - 36,000}{20,000} \right)^2$$


---


$$PL0_D \leftarrow \left( \frac{PL0_D - 36KFT/S_D}{20KFT/S_D} \right)^2$$

$$G_{MAX} = \frac{4(r_e - 6.05 - 2.4V^2)}{1 + 4.8V^2} + 10$$


---


$$MPAC_D \leftarrow \frac{KR2_D [PL2_D + (-6.05DEG)_D] + (KR1_D \cdot PL0_D)] + KR3_D}{DP2(-4)_D + (PL0_D/KR4_D)}$$

Is  
MPAC<sub>D</sub> ≥ 0  
?

No

Prevent negative value

Yes

$$MPAC_D \leftarrow +0$$

$$GMAX_D \leftarrow MPAC_D$$

GMAX's for N60 display

Next Sheet

# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>L. J. Johnson</i> 1/12/68		P60'S	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 26 OF 35
APPR'O			

From Preceding Sheet

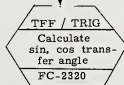
$$MPAC_D = ERADM_D + 400KF T_D$$

First guess of terminal radius at 400,000 ft  
 $ERADM_D$  = earth radius at EMS latitude ( from FISHCALC )



Input:  $MPAC_D$  = terminal radius  
 Conic parameters in Pushlist from TFFCONIC

Output: NRTERM, TFFX, TFFTEM



Input: NRTERM } From CALCTFF  
 TFFX }  
 TFFTEM }  
 NRMAG From TFFCONIC

Output:  $MPAC_D = \sin(\delta f)$  where  $(\delta f)$  is the transfer angle  
 $CDEL F/2 = \cos(\delta f)$  from present position to 400,000 ft



Input:  $MPAC_D = \sin(\delta f)$   
 $CDEL F/2 = \cos(\delta f)$   
 $UNI_V = \text{unit } V_o \times R.$

Output:  $MPAC$  = radius of earth at latitude of 400,000 ft. Terminal radius =  $ERADM$

Next Sheet

# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. Goldstone</i> 2/2/68	P60'S	
PRGMR		COLLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV	
APPR'D			SHEET 27 OF 35

From Preceding Sheet

$$MPAC_D \leftarrow MPAC_D + 400KFT_D$$

Corrected estimate of radius  
at 400,000 feet

$$X2 \leftarrow RTGO$$

Save range angle from EMS attitude  
(high order half) for Downlink

$$RTERM_D \leftarrow MPAC_D$$

PREVGAM  
Calculate velocity  
magnitude and  
flight path angle  
at 400KFT  
FC-2320

Input:  $MPAC_D$  = terminal radius conic  
parameters in Pushlist from TFFCONIC

Output:  $MPAC_D$  = flight path angle at  
400,000 ft ( $\delta_e$ )

$PDL0_D$  = velocity 400,000 ft ( $V_h$ )

$$MPAC_D \leftarrow MPAC_D$$

GAMMAEI is negative for entry

Next Sheet

# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>J. Johnson 7/1/68</i>	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR		REV 1	SHEET 20 OF 35
APPR'D			

From Preceding Sheet

MPAC +1 ← X 2

From packed word for Downlink:  
put RTGO ( high - word ) into low-word  
of GAMMAEI

2

GAMMAEI ← MPAC<sub>D</sub>

Flight path angle at 400,000 ft for N60  
Downlink quantity:  
high-word =  $\gamma_e$   
low-word = range to go

VPRED<sub>D</sub> ← PLO<sub>D</sub>

Conic velocity at 400,000 ft for  
noun 60 display

P61. 1  
Sh. 4

Note: Effect of RTGO in low-word  
GAMMAEI on DSKY is  
negligible ( $\approx 0.005$  deg)

# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Johnson 7/6/62</i>		P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCMR		REV 1	SHEET 29 OF 35
APPR'D			

DISPTARG

Range estimator

Save QPRET  
in  
60GENRET $C(MPAC_D) =$  range angle estimate

$$DTEAROT = KT_{\theta_1} \theta + t_{ff}$$

$$KT_{\theta_1} = 1100$$

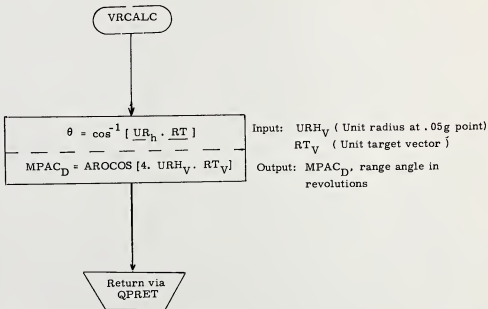
$$DTEAROT_D \leftarrow KTETA1_D \cdot MPAC_D + TTE1_D$$

TTE =  $t_{ff}$  = time of free fall
 EARROT2  
 Locate predicted  
 impact point  
 FC-2250

 Input:  $DTEAROT_D$  (estimated flight time)  
 $RTINIT_V$   $RTEAST_V$   $RTNORM_V$ ,  
 $TIME/RTO_D$ 
Output:  $RT_V$ , predicted target vector
 VRCALC  
 Calculate  
 range angle  
 Sh. 29
Input:  $URH_V$ ,  $RT_V$ Output:  $MPAC_D$ , range angle in revolutionsReturn via  
60GENRET

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. Goldstone</i>	<i>8/14/68</i>	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 30 OF 35



# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P60's	
DRAWN <i>L. Goldstone</i> 7/27/63			
PRGRM		COLOSSUS 2D	DOCUMENT NO.
ANALST			FC-2760
DOCRR			
APPR'D		REV 1	SHEET 31 OF 35

P62.3

If ENTRYDSP = 0, omit entry display ( ENTRYVN )

If ENTRYDSP = 1, do entry display ( ENTRYVN )

QPRET ←  
CADR  
[ENDEXIT]

S62.3

1. Compute desired gimbal angles for entry attitude
2. Generate desired body triad for trimmed flight with respect to relative velocity

YNB<sub>V</sub> = desired body Y axis in reference coordinatesUYA/2<sub>V</sub> = normal to trajectory plane in reference coordinates from CM/POSE

$$YNB_V \leftarrow UYA/2_V \cdot \cos(\text{ROLLC}_D) + UZA/2_V \cdot \sin(\text{ROLLC}_D)$$

ROLLC<sub>D</sub> = roll commandUZA/2<sub>V</sub> = trajectory triad Z axis in reference coordinates (from CM/POSE)

$$XNB_V \leftarrow UXA/2_V \cdot \cos(\text{ALFAPAD}) + (YNB_V \times UXA/2_V) \cdot \sin(\text{ALFAPAD})$$

UXA/2<sub>V</sub> = trajectory triad X axis in reference coordinates from (from CM/POSE)

ALFAPAD = pad loaded pitch trim angle

$$ZNB_V \leftarrow XNB_V \times YNB_V$$

Z axis to complete the triad

Next Sheet

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. G. ...</i> 7/17/69		P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 32 OF 35



From Preceding Sheet

$XSM_v \leftarrow REFSMMAT_v$   
 $YSM_v \leftarrow REFSMMAT_v + 6D_v$   
 $ZSM_v \leftarrow REFSMMAT_v + 12D_v$

Reference coordinate system to stable member transformation matrix, for use by CALCGA

Clear  
CPHIFLAG

Clear flagword 0, bit 15:

CPHIFLAG causes CALCGA to store resulting angles in  $tp$  in CPHI

CALCGA  
Calculate  
desired  
gimbal angle (g)  
FC-2260

Inputs:  $XNB_v$ ,  $VNB_v$ ,  $ZNB_v$ ,  $XSM_v$ ,  $YSM_v$ ,  $ZXM_v$

Outputs: 3 gimbal angles in MPAC, MPAC +1 and MPAC +2 also in CPHI, +2

From CALCGA

Return via  
QPRET

# PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. J. J. / 1/7/62</i>		P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2780
ANALST			
DOCWR		REV 1	SHEET 33 OF 35
APPR'D			

SUBROUTINES CALLED WHICH ARE  
FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
ALARM	FC-2140	Set alarm code	Sh. 21
CALCGA	FC-2260	Calculate desired gimbal angle (s)	Sh. 33
CALCTFF	FC-2320	Calculate time of free fall	Sh. 22, 23, 27
CLEANDSP	FC-2130	Blank DSKY	Sh. 10
CLEARMRK	FC-2130	Enable extended verbs	Sh. 4
CM/DAPIC	FC-2780	Start entry DAP	Sh. 6
CM/DAPON	FC-2780	Enable entry DAP	Sh. 7
DELAYJOB	FC-2070	Delay job specified time	Sh. 21
EARROT2	FC-2250	Locate predicted impact point	Sh. 30
FISHCALC	FC-2320	Calculate Fischer radius	Sh. 23, 24, 27
LAT-LONG	FC-2280	Compute latitude and longitude	Sh. 18
MIDTOAV2	FC-2290	Precision integration of state vector	Sh. 19
NEWMODEX	FC-2030	Change major mode	Sh. 5, 10, 12, 13, 15, 16
PREREAD	FC-2683	Start READACCS	Sh. 20
PREVGAM	FC-2320	Calculate velocity magnitude and flight path angle	Sh. 25, 28
REFAZE10	FC-2770	Entry control	Sh. 13
R02BOTH	FC-2210	IMU status check	Sh. 19
SERVNOUT	FC-2770	Normal entry guidance exit without display	Sh. 18
STARTEN1	FC-2770	Calculate initial target vector	Sh. 3
TEFCONIC	FC-2320	Compute conic parameters	Sh. 22
TFF/TRIG	FC-2320	Calculate sin and cosine of transfer angle	Sh. 23, 27
VGAMCALC	FC-2320	Calculate velocity magnitude and flight path angle	Sh. 25

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. DeWaters</i> 4/21/69		P60's	
PRGMR _____		DOCUMENT NO.	
ANALST _____		COLOSSUS 2D	FC-2760
DOCMR _____		REV 1	SHEET 34 OF 35

PRELIMINARY

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
AVEGFLAG Flagword 1 bit 1	AVERAGE(SERVICER) to continue	AVERAGE(SERVICER) to cease			Sh. 19
CM/DSTBY Flagword 6 bit 2	Entry DAP activated	Entry DAP not activated		Sh. 17	
CPHIFLAG Flagword 0 bit 15	Output of CALCGA is CPHIX	Output of CALCGA is THETAD		Sh. 33	
ENTRY DSP Flagword 6 bit 13	Do entry display via ENTRY VN	Omit entry display	Sh. 8, 14, 16	Sh. 14	
ERADFLAG Flagword 1 bit 13	Earth: compute Fischer ellipsoid radius Moon: use fixed radius	Earth: use fixed radius Moon: use RLS for lunar radius		Sh. 18	
GYMDIFSW Flagword 6 bit 1	CDU differences and body rates computed	CDU differences and body rates not computed		Sh. 17	
LUNAFLAG Flagword 3 bit 12	Lunar LAT-LONG	Earth LAT-LONG		Sh. 18	
.05GSW Flagword 6 bit 3	Drag over .05G	Drag less than .05G		Sh. 3	

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	<i>L. Caldwell</i>	P60's	
PRGMR	<i>Spice</i>	DOCUMENT NO.	
ANALST		COLOSSUS 2D	FC-2760
DOCMR		REV 1	SHEET 35 of 35
APPR'D			

REENTRY CONTROL

CM/POSE	BODY ATTITUDE DETERMINATION FOR ENTRY DAP	SH. 3
STARTENT	ENTRY INITIALIZATION	SH. 6
STARTEN1	INITIAL TARGETING	SH. 7
SCALEPOP	ENTRY CONTROL	SH. 8
TARGETING	UPDATE TARGET VECTOR	SH. 9
INITROLL	HOLD EARLY ROLL ATTITUDES	SH. 12
HUNTEST	CALCULATE STARTING CONDITIONS FOR UPCONTRL	SH. 13
UPCONTRL	ROLL CONTROL DURING SEMI-CIRCULAR PHASE OF ENTRY	SH. 19
KEP	INITIALIZE P66	SH. 24
KEP2	MONITOR DRAG	SH. 24
PREFINAL	INITIALIZE P67	SH. 25
PREDICT3	FINAL SUB-ORBITAL CONTROL	SH. 25
ENEXIT OVERNOUT }	DISPLAY ENTRYVN AND EXIT	SH. 31
SERVNOUT	EXIT FROM SERVICER CYCLE	SH. 31

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARJIS GUIDANCE AND NAVIGATION	
		REENTRY CONTROL	
DRAWN <i>J. D. Hunt</i>			DOCUMENT NO.
PCWR		COLOSSUS IIC	FC-2770
ANALYST			
DOCMB			
APPR'D		REV	SHEET 4 OF 31



CM BODY ATTITUDE DETERMINATION FOR ENTRY DAP  
(REF. GSOP CH 3.4)

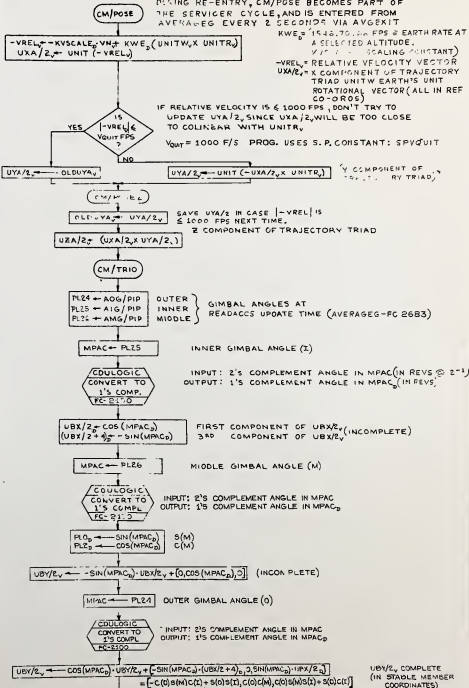
DURING RE-ENTRY, CM/POSE BECOMES PART OF THE SERVICE CYCLE, AND IS ENTERED FROM AVERAGE EVERY 2 SECONDS VIA AVXGKIT

$KWE = 1948.70 \times 10^6$  FPS<sup>2</sup> EARTH RATE AT A SELECTED ALTITUDE.  
 $VIT =$  SCALING CONSTANT

$-VREL =$  RELATIVE VELOCITY VECTOR  
 $UXA/2 = X$  COMPONENT OF TRAJECTORY TRIAD UNIT W EARTH'S UNIT ROTATIONAL VECTOR (ALL IN REF CO-ORDS)

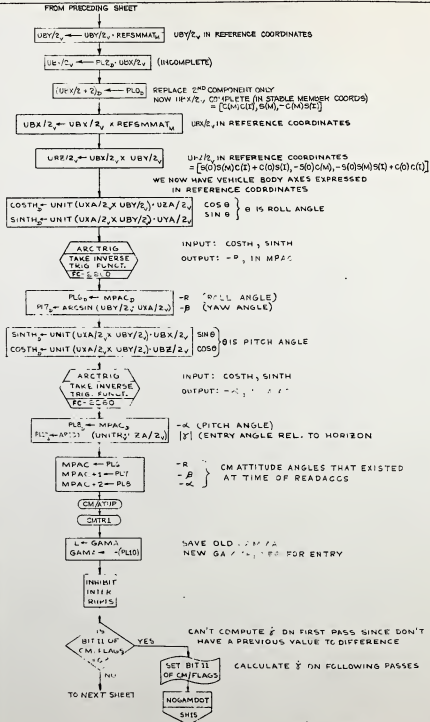
IF RELATIVE VELOCITY IS  $\leq 1000$  FPS, DON'T TRY TO UPDATE  $UYA/2$ , SINCE  $UYA/2$  WILL BE TOO CLOSE TO COLINEAR WITH UNIT.

$V_{OUT} = 1000$  F/S PROG. USES S.P. CONSTANT: SPYQUIT



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	
DRAWN <i>D. J. [Signature]</i>	DATE
PRGMR	
ANALST	
DOCHR	
APPR'D	

APOLLO GUIDANCE AND NAVIGATION	
REENTRY CONTROL	
COLLUS S IIC	DOCUMENT NO.
REV	30-01170
	SHEET 3 OF 31



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>9.9. Longille</i>		REENTRY CONTROL	
PROGRAM		DOCUMENT NO.	
ANALYST		70	
DOCTR		REV	SHEET 4 OF 31
APPRO			

FROM PRECEDING SHEET

GAMDOT

$$\dot{\gamma} = \gamma(\dot{\gamma}) - \delta(t-T)/T$$

$$\text{GAMDOT} \leftarrow \text{TCD} \cdot (\text{GAMA} - 1)$$

SINCE UPDATE OCCURS EACH  $T = 2$  SEC,  $\Delta \gamma \approx 2 \dot{\gamma}$ .  
FOR  $\dot{\gamma}$  TO BE COMPATIBLE WITH BODY RATES WHICH  
ARE UPDATED EACH  $t = .1$  SEC, SAVE GAMDOT =  $\gamma \Delta X / T$   
IF  $\dot{\gamma} < .5$  DEG/SEC, IGNORE AND SET TO ZERO AS A FLAG  
FOR DAP

IF  $|\text{GAMDOT}| < .5$  DEG/SEC?

YES

NOGAMDOT

GAMDOT ← 0

CORRECT ATTITUDE ANGLES  
FOR CHANGES SINCE  
READACC TIME

(MPAC ← ROLL Z FROM ABOVE; ROLL/DIP IS  
ROLL INCREMENT SINCE LAST PIPA UPDATE)  
IN THESE TWO CALCULATIONS, THE RESULTS  
ARE PUT INTO THE RANGE ± 180° BY  
ROUTINE CORANGOV

$$\text{TEMPROLL} = \text{ROLL}/180 - (\text{MPAC}/\text{ROLL}/\text{PIP})$$

$$\text{TEMPALFA} = \text{ALFA}/180 - ((\text{MPAC}+2)/\text{ALFA}/\text{PIP})$$

$$\text{MPAC} + 2 = -\infty$$

$$\text{MPAC} + 1 = -\beta \text{ (IGNORE OVERFLOW, IF ANY)}$$

CMTR 2

$$\text{TEMPBETA} = \text{BETA}/180 - ((\text{MPAC}+1)/\text{BETA}/\text{PIP})$$

GROUP 5

SET UP RESTARTS TO SCHEDULE REDOPOSE  
AS A JOB WITH THE SAME PRIORITY

REDOPOSE

$$\text{ROLL}/180 \leftarrow \text{TEMPROLL} \quad R (R(11))$$

$$\text{ALFA}/180 \leftarrow \text{TEMPALFA} \quad \alpha (A(11))$$

$$\text{BETA}/180 \leftarrow \text{TEMPBETA} \quad \beta (B(11))$$

UPDATED CM ATTITUDES  
RELATIVE TO TRAJECTORY TRIAD  
(INPUTS FOR ENTRY DAP)

ALL  
INTER-  
RUPT

CM/POSE 3

$$\text{VMAG}_2 \leftarrow \text{ABVAL}(\text{VN}_1)$$

VELOCITY MAGNITUDE (FOR DISPLAY 40UN 64)

GO  
DDPF  
LD  
ST

P62

P62.3  
FC-276C

P63  
STARTENT  
SH.6

P63-P67

SCALEPOP  
SH.8

EXIT MAY POINT TO ONE OF THE FOLLOWING:

- STARTENT: INITIALIZES ENTRY CONTROL AND CHANGES POSEXIT TO "SCALEPOP". (USED ONCE AT COMPLETION OF PITCHOVER MANEUVER TO BEGIN ENTRY CONTROL.)
- SCALEPOP: STARTING POINT FOR ALL PHASES OF ENTRY CONTROL.

NOTE:

11CUN22 MAY BE DISPLAYED  
MANUALLY. AFTER CREW ACCEPTS  
1161. ENTRYDSP FLAG IS SET AND  
11CUN22 IS DISPLAYED  
AUTOMATICALLY

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DRAWN PRGMR ANALYST DOCHR APPROV		REENTRY CONTROL	
DATE: 12/15/68		DOCUMENT NO. FC 2770	
REV		SHEET 5 OF 31	



ENTRY INITIALIZATION

REFERENCES:  
GSDP, SECT. 5.7

FOLLOWS CM/POSE AFTER P63 HAS  
SET POSEXIT=CADR (STARTENT)



INITIALIZE SWITCHES

- ENRDYDSP - ENABLE ENTRY DISPLAYS
- GONEPAST\* - OMIT LATERAL CALCULATIONS
- RELVELSW - TARGETING USES INERTIAL VELOCITY
- EGSW - NDT IN FINAL PHASE
- NOSWITCH - ALLOW LATERAL SWITCH OF ROLL ANGLE
- HIND - DON'T ITERATE HUNTEST AFTER RANGER
- INRLSW - HOLD INITIAL ROLL ATTITUDE UNTIL .05g EXCEEDED
- LATSW - DOWNLIFT NDT INHIBITED
- .05GSW - DRAG < .05g

\* GONEPAST IS INITIALLY SET TO OMIT LATERAL STEERING. THUS ROLL WILL REMAIN 0 OR 180° AS DEFINED BY HEADSUP UNTIL DNSET OF .05g (P64)

[USE PAD LOAD] FINAL PHASE L/D

[USE PAD LOAD] MAXIMUM L/D (MINIMUM ACTUAL VEHICLE L/D)

L/D FOR MIN. ROLL ANGLE WHEN LATERAL STEERING IS DESIRED

LATERAL SWITCHING SLOPE = LATSLOPE = 1/24  
MINIMUM DRAG FOR UPCONTROL = Q7F = 6 FP55  
UPCONTROL FACTOR, INITIAL VALUE = PDSMAX<sub>D</sub> = 1 - 2<sup>-18</sup>

INITIAL L/D COMMAND: ROLL = 0°, OR ROLL = 180°

INITIALIZE TARGET AT PRESENT TIME

OUTPUT: RTINIT<sub>2</sub> - INITIAL TARGET VECTOR

RT<sub>v</sub> - TARGET VECTOR { RTEAST<sub>v</sub>, RTNORM<sub>v</sub>}

THETA - RANGE ANGLE (ALL VECTORS IN REF. COORD.)

LATANG<sub>2</sub> = LATERAL RANGE AT TARGET

K2ROLL<sub>2</sub> = INDICATOR FOR LATERAL SWITCH OF ROLL COMMAND

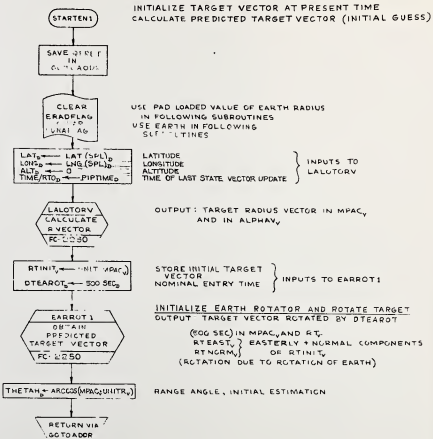
Q2<sub>2</sub> = COMPONENT OF FINAL PHASE RANGE (LIFT DEPENDENT)

SET FOR INITIAL ENTRY PHASE (SEE SCALEPOP SH8) HEREAFTR, SCALEPOP TO FOLLOW CM/POSE IN SERVICER SEQUENCE

OMIT ENTRY DISPLAY ON INITIAL PASS AND EXIT

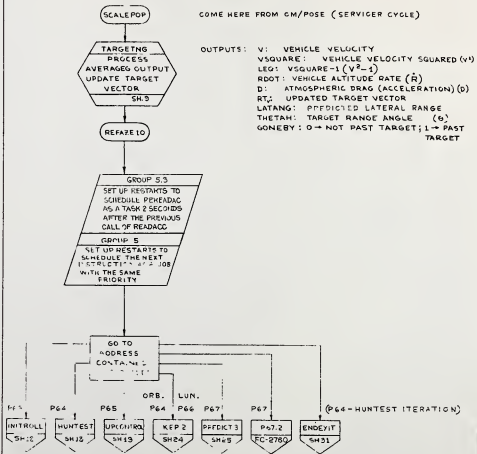
REENTRY CONTROL COLOSSUS IIC DOCUMENT NO. FC-2770 SHEET 6 OF 31	REENTRY CONTROL DOCUMENT NO. FC-2770 SHEET 6 OF 31
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## INITIAL TARGETING



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DRAWN PAGE#		REENTRY CONTROL	
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DOCHR		IIC FC 2770	
APPRO'D		SHEET 7 OF 31	

ENTRY CONTROL

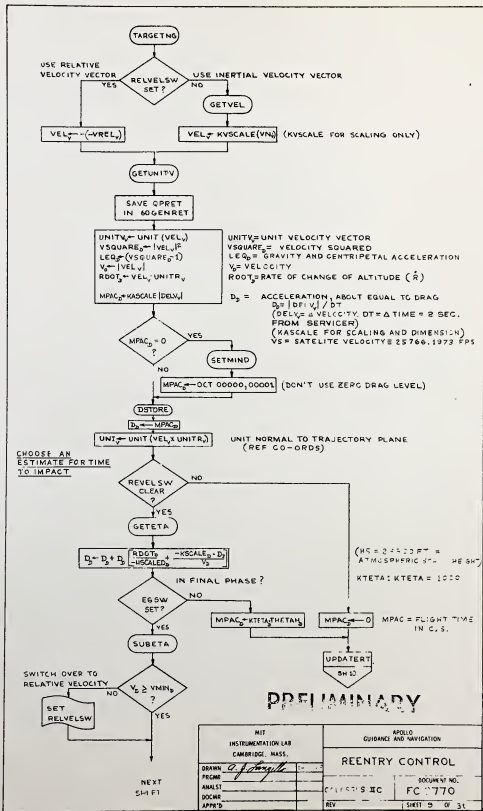


COME HERE FROM GM/POSE (SERVICER CYCLE)

OUTPUTS: V: VEHICLE VELOCITY  
 VSQUARE: VEHICLE VELOCITY SQUARED (V<sup>2</sup>)  
 LEG: VSQUARE-1 (V<sup>2</sup>-1)  
 RDOT: VEHICLE ALTITUDE RATE (R)  
 D: ATMOSPHERIC DRAG (ACCELERATION) (D)  
 RT: UPDATED TARGET VECTOR  
 LATANG: PREDICTED LATERAL RANGE  
 THETAM: TARGET RANGE ANGLE (θ)  
 GONEBY: 0 = NOT PAST TARGET; 1 = PAST TARGET

INITROLL: HOLOS EARLY ROLL ATTITUDES  
 HUNTEST: CHECKS IF ESTIMATED RANGE AT NOMINAL L/D IS LESS THAN DESIRED RANGE  
 UPCHIRL: CONTROLS ROLL DURING SEMI-CIRCULAR PHASE OF ENTRY  
 KEP 2: MONITORS DRAG  
 PREDICT3: FINAL SUB-ORBITAL CONTROL  
 P67.2: MAINTAINS LAST COMPUTED ROLL ANGLE  
 ENDEYIT: EXIT

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DRAWN: <i>[Signature]</i>		REENTRY CONTROL	
PRCHR: <i>[Signature]</i>	SCALE: _____	DOCUMENT NO.	
ANALST: _____	_____	FC 2770	
DOCHR: _____	_____	SHEET 8 OF 31	
APPR'D: _____	_____	REV: _____	



FROM PRECEDING SHEET

SUBETAR

KT1: ~ R<sub>E</sub>

MPAC<sub>2</sub> ←  $\frac{KT1 \cdot \text{THETAH}_2}{V_2}$

KT1 = EARTH RADIUS R<sub>E</sub> X SCALE FRACTION.  
RESULT IS TIME IN CSEC.  
(R<sub>E</sub> = 21, 202, 900 Ft)

UPDATERT

DTEAROT<sub>2</sub> ← MPAC<sub>2</sub> + PIPTIME<sub>2</sub> - TIME/RTD

PREDICTED IMPACT TIME:  
Δ TIME SINCE RTINIT<sub>2</sub> WAS ESTABLISHED

EARROT2  
PREDICT  
TARGET  
VECTOR  
FC-2250

INPUT: RTINIT<sub>2</sub>, DTEAROT<sub>2</sub>  $\left\{ \begin{array}{l} \text{RTNORM}_2 \\ \text{RTBAST}_2 \end{array} \right.$   
OUTPUT: RT<sub>2</sub> - PREDICTED TARGET VECTOR  
AT IMPACT TIME (DTEAROT<sub>2</sub>)  
(ALSO IN MPAC<sub>2</sub>)

LATANG<sub>2</sub> ← MPAC<sub>2</sub> · UNI<sub>2</sub>

LATERAL RANGE

CLEAR  
GONEBY

IS  
(RT<sub>2</sub> X UNIT<sub>2</sub>)  
· UNI<sub>2</sub> < 0 ?  
NO, NOT PAST TARGET YES, PAST TARGET

SET  
GONEBY

SETANGLE

IS  
 $1 - \text{RT}_2 \cdot \text{UNIT}_2$   
≤ ε<sup>2</sup> ?  
NO YES

RANGE ANGLE THETAH  
(ASSUMES THETAH < 180 DEG)

TINYTHET

THETAH = TARGET RANGE.

MPAC<sub>2</sub> ←  $\arccos(\text{RT}_2 \cdot \text{UNIT}_2)$

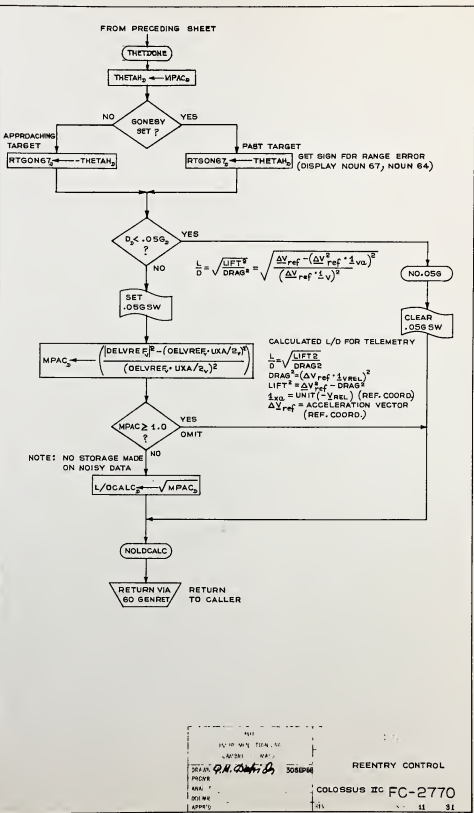
MPAC<sub>2</sub> ←  $\arccos \sqrt{2(1 - \text{RT}_2 \cdot \text{UNIT}_2)}$

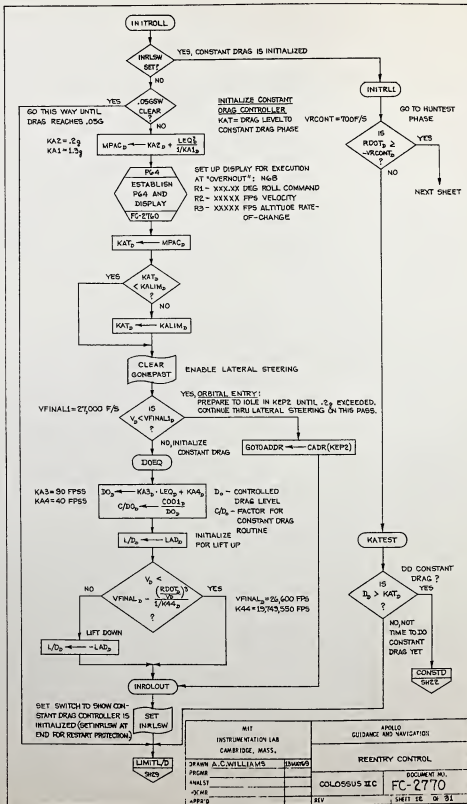
FOR COSINE VERY CLOSE TO 1,  
USE THIS SMALL ANGLE  
APPROXIMATION FOR GREATER  
PRECISION:

$\theta = \sqrt{2 - 2X}$   
WHERE X = COS(θ)

NEXT SHEET

TRACK PREPARE ANALYST SCHED APPROV	REENTRY CONTROL COLLOSSUS IIC FC-2770 10 31
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CHECKED  
DATE  
APP'D

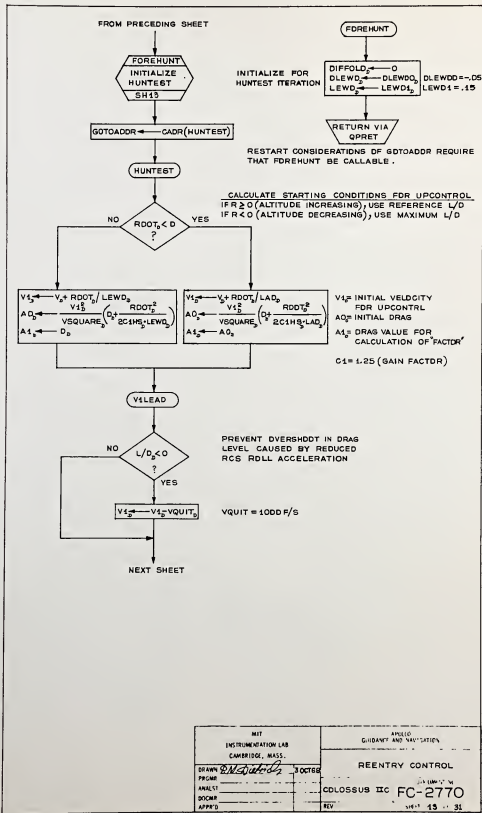
APOLLO  
GUIDANCE AND NAVIGATION

REENTRY CONTROL

COLLOSSUS IIC

DOCUMENT NO.  
FC-2770

SHEET 22 OF 31





FROM PRECEDING SHEET

HUNTEST1

$$ALP_2 \leftarrow \frac{A O_2 2 C_1 H S_D}{V_1^2 L E W D_2}$$

$$FACT1_D \leftarrow \frac{V_1}{V_2}$$

$$FACT2_D \leftarrow \frac{1 - ALP_2}{ALP_2 (ALP_2 - 1)}$$

$$VL \leftarrow FACT1_D \left( 1 - \sqrt{FACT2_D Q_7 + ALP_2} \right)$$

$$GAMMAL1_2 \leftarrow \frac{LEW D_2 (V_1^2 - VL^2)}{VL^3}$$

CALCULATE EXIT CONDITIONS FOR UPCONTROL  
IF GRAVITY AND CENTRIPETAL ACCEL. NEGLIGIBLE

$$\alpha = \frac{R C_1 A_2 H S}{V_1^2 L / D} ALP$$

$$F_1 = \frac{1 - \alpha}{V_1} FACT1$$

$$F_2 = \frac{\alpha (\alpha - 1)}{A_0} FACT2$$

$$V = F_1 \left( 1 - \sqrt{Q_7 F_2 + \alpha} \right)$$

$$V_{L1} = \frac{L/D (V_1 - V_2)}{V_0}$$

INTERMEDIATE FACTORS  
FOR CALCULATION OF  
VL AND GAMMAL1

VL = EXIT VELOCITY  
FOR UPCONTROL

GAMMAL1 = FLIGHT PATH ANGLE  
AT EXIT VELOCITY ("SIMPLE" VALUE)

VLMIN = 18.000 F/S  
VL < VLMIN ?

YES

FINAL  
SH25

EXIT VELOCITY LOW  
GO TO FINAL PHASE

NO

$$VBARSD \leftarrow VL^2$$

VL > 1 ?

IS VL > SATELLITE VELOCITY ?

YES

BECDNSTD  
SH22

EXIT VELOCITY HIGH, (> SATELLITE  
VELOCITY); GO TO CONSTANT  
DRAG ROUTINE TO REDUCE  
VELOCITY

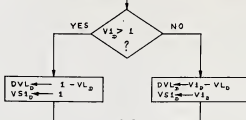
NO

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		FIELD GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> 3 OCT 66		REENTRY CONTROL	
PROGRAM		DOCUMENT NO.	
ANALYST		CDLOSSUS IIC	FC-2770
DOCMP			
APPRO'D		REV	11/11 44 11 31

FROM  
PRECEDING SHEET

CALCULATE FLIGHT PATH ANGLE (ALTITUDE RATE)  
CONVERTED FOR NEGLECTED ACCELERATIONS



$DVL_D$  = VELOCITY CHANGE FOR WHICH THE CORRECTION FOR GRAVITY AND CENTRIFUGAL ACCELERATION IS APPLIED  
 $VSI_D$  = SMALLER OF 1 OR  $V_{1D}$ , USED TO LIMIT THE CORRECTION

GETDHOOK

$$OHOOK_D \leftarrow \frac{(1 - VSI_D)^2}{FACT_2} - ALP_D$$

$$AHOOKOV_D \leftarrow \frac{DHOOK_D}{Q_7_D} - CHOOK_D$$

$$MPAC_D \leftarrow GAMMAL_D \frac{(AHOOKOV_D + 1) CHI_D (DVL_D)^2}{DHOOK_D VBAR_S_D}$$

$OHOOK_D$  = DRAG AT VELOCITY  $VSI$   
(COMPUTATION USES OHOOKYQ7 ROUTINE)  
 $AHOOKOV_D$  =  $AHOOKOV_L$   
 $AHOOK_D$  = SLOPE FOR ASSUMED LINEAR DENSITY VARIATION  
 $MPAC_D$  = CORRECTED VALUE OF FLIGHT PATH ANGLE AT EXIT VELOCITY  $VL$  FOR UPCONTROL  
 $CHI_D$  = 1 (CONSIDER THAT  $q$  IS PART OF SYMBOL  $CHI$ )  
 $CHOOK_D$  = .25



CALCULATE NEW EXIT CONDITIONS (VL ANO Q7) FOR  $MPAC_D = 0$   
(PREVIOUS EXIT CONDITIONS CANNOT BE REACHED, SINCE GRAVITY TOO LARGE)

NEGAMA

$$VL_2 \leftarrow VL_D + \frac{1}{3} VL_D, MPAC_D \leftarrow \left( \frac{1}{3} LEWD_2 - \frac{CHI_D DVL_D (AHOOKOV_D + \frac{1}{3})}{DHOOK_D VL_D} \right)$$

$$Q_7_D \leftarrow \left[ \left( 1 - \frac{VL_D}{FACT_1} \right)^2 - ALP_D \right] / FACT_2$$

$$VBAR_S_D \leftarrow (VL_2)^2$$

$$MPAC_D \leftarrow 0$$

$VL_2$  = EXIT VELOCITY  
 $Q_7_D$  = EXIT DRAG LEVEL MINIMUM DRAG FOR UPCONTROL (COMPUTATION USES OHOOKYQ7 ROUTINE)  
 $MPAC_D$  = EXIT FLIGHT PATH ANGLE

HUNTEST3

GAMMAL\_D ← MPAC\_D

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		A9.1.1 CIRCUITRY AND VL. JATLAS	
DRAWN <i>G. J. Long</i> 110876P		REENTRY CONTROL	
PRICAR	ANAL ST	COLOSSUS IIC	FC-2770
DOCAR	APPR	REV	15 11 31

FROM  
PRECEDING SHEET

$$\text{GAMMAL}_2 \leftarrow \text{GAMMAL}_1 + Q10 (\text{GAMMAL}_2 - \text{GAMMAL}_1)$$

USE WEIGHTED AVERAGE FOR UP-RANGE

Q10 = .5  
C12: HS/RE  
KC3: -1/RE

RANGER

Q3 = .07 NM / FPS  
Q5 = 7050 NM / FPS  
Q6 = .0349 RAD

RANGE ERROR CALCULATION

(QUANTITIES ARE ALL EFFECTIVELY IN  
REVS AT 2°)  
TRUNCATED COSINE SERIES (APPROXIMATION)

$$\text{COSG}/2_2 \leftarrow 1 - \frac{(\text{GAMMAL}_2)^2}{2}$$

$$\text{ASKEP}_2 \leftarrow 2 \sin^{-1} \left( \frac{\text{VBAR}_5 \text{ COSG}/2_2 \text{ GAMMAL}_2}{\sqrt{(\text{VBAR}_5^2 - \text{VBAR}_2^2) \text{ COSG}^2 + \frac{1}{4} Q_3^2}} \right)$$

KEPLER RANGE = ASKEP<sub>2</sub>

$$\text{ASPI}_2 \leftarrow Q_3 \text{VL}_2 + Q_2$$

FINAL PHASE RANGE = ASPI<sub>2</sub>

$$\text{ASPUP}_2 \leftarrow - \left( \frac{\text{C12}_2}{\text{GAMMAL}_2} \right) \text{LOG} \left( \frac{Q_7 \cdot \text{V1}_2^2}{\text{A0}_2 \cdot \text{VBAR}_2^2} \right)$$

UP PHASE RANGE = ASPUP<sub>2</sub>

$$\text{ASPDWN}_2 \leftarrow \frac{\text{V}_2 \cdot \text{RDOT}_2}{\text{A0}_2 \cdot \text{LAD}_2} \text{KC3}_2$$

RANGE TO PULLOUT = ASPDWN<sub>2</sub>

$$\text{ASP3}_2 \leftarrow Q_5 (\text{Q6}_2 - \text{GAMMAL}_2)$$

GAMMA CORRECTION = ASP3<sub>2</sub>

ASPS (TM) ← ASKEP<sub>2</sub>  
ASPS (TM) + 1 ← ASPI<sub>2</sub>  
ASPS (TM) + 2 ← ASPUP<sub>2</sub>  
ASPS (TM) + 3 ← ASPDWN<sub>2</sub>  
ASPS (TM) + 4 ← ASP3<sub>2</sub>

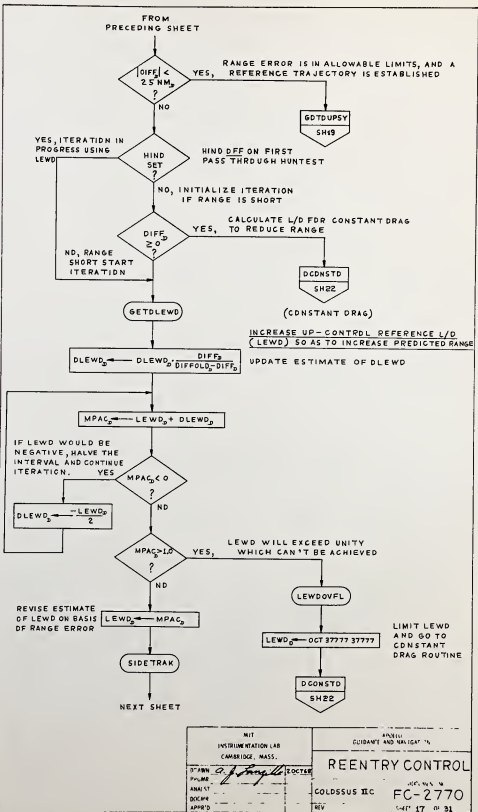
HIGH ORDER HALF  
FOR DOWN TELEMETRY

$$\text{DIFF}_2 \leftarrow \text{ASPS}_2 + \text{ASPDWN}_2 + \text{ASPUP}_2 + \text{ASPI}_2 + \text{ASKEP}_2 - \text{THETA}_2$$

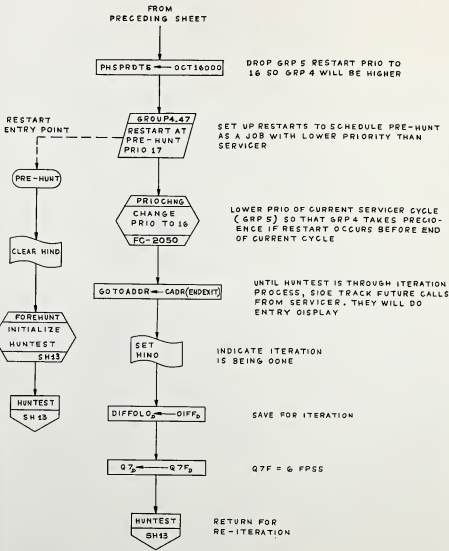
DIFF<sub>2</sub> = PREDICTED RANGE - DESIRED RANGE  
(THETA CALCULATED IN TARGETING)

NEXT SHEET

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DRAWN PROGRAM ANALYST DPCMR APPROV		REENTRY CONTROL	
5/10/68		FC-2770	
		REV 16 (P. 31)	



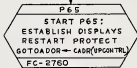
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		REENTRY CONTROL	
FORM <i>9.1 Sample</i> DOCKET		COLDSSUS IIC	
ANALYST	DOC#	REV	FC-2770
APPROV			400.000.00 4-17 17 01 91



DIVISION OF RESEARCH AND DEVELOPMENT CAMBRIDGE MASS		REENTRY CONTROL	
OPERN <i>[Signature]</i> 2 OCT 68	ANALST	COLLOSSUS IIC	FC-2770
CORR'S	APPR'D	REV	UNIT 10 31

GO TO UPSY

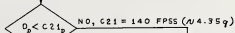
INITIALIZE P65



ESTABLISH FLASHING DISPLAY N69 UNDER GRP4

UPCONTROL

REFERENCE TRAJECTORY FOUND TO STEER VEHICLE ON TRAJECTORY TO EDGE OF ATMOSPHERE. TRAJECTORY CALCULATED AS FUNCTION OF DRAG ( $D_0$ )



SET NOSWITCH

TO PREVENT LOSS OF RANGING CAPABILITY, SUPPRESS LATERAL SWITCH AT HIGH DRAG

IS VELOCITY TOO HIGH FOR REFERENCE ?



DOWNCNTL

REDUCE VELOCITY :

FLY CONSTANT DRAG AS THOUGH L/D WERE THE MAXIMUM, LAD

GO TO BALLISTIC PHASE



KEP SH24

CLEAR OVFL INDICATOR FOR CONSTO

$$PLO_D \rightarrow LAO_D + K2D_0 [RDOT - LAO_D (V_{1v}^2 - V_v^2)]$$

$$MPAC_D \rightarrow \frac{AO_D - VSQUARE_P - (V_{1v} V_v)^2 LAD_D}{V_{1v}^2 2C1HS_D}$$

COMPONENTS OF DESIRED L/D  
MPAC = D REF

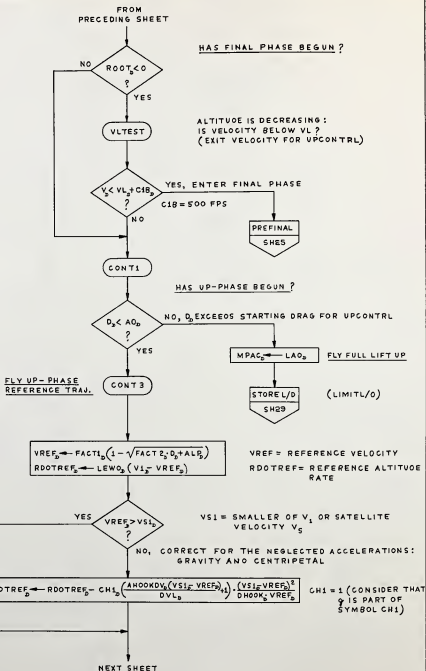
CONSTDI SH22

K2D : C17 = -.001

NEXT SHEET

MAINTAIN CONSTANT DRAG

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<i>Q. J. Smith</i> 14 OCT 68 ANALYST SUPERVISOR APPROVED		<b>REENTRY CONTROL</b> COLOSSUS IIC FC-2770 10/10/68 10 OF 31	



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	
DRAWN FORM ANALY SCALE DATE	APPROV 14 OCT 68

AERIE GUIDANCE AND NAVIGATION	
REENTRY CONTROL	
DOCUMENT NO. COLOSSUS IIC	FC-2770
REV	SHEET 20 OF 31

FROM PRECEDING SHEET

CONTINUE

YES  $D_0 < Q7MIN_D$  ?

DON'T UPDATE FACTOR IF  
DRAG IS TOO LOW (< Q7MIN FT./SEC)  
Q7MIN = 40 FPS

NO

$$FACTOR \leftarrow \frac{D_0 - Q7D}{A1_0 - Q7D}$$

FACTOR IN L/D CALCULATION

( $A_1 =$  EITHER  $A_0$  OR  $D$ , COMPUTED  
IN HUNTEST)

UPCNTRL3

$$PLD_D \leftarrow \frac{FACTOR_D}{-1/KB2_D} \left[ \frac{FACTOR_D (RDOT_D - RDOTREF_D)}{1/KB1_D} + V_D - VREF_D \right]$$

( $\Delta L/D = PLD_D$ )

$KB1 = 3.4$   
 $KB2 = .0034$  } OPTIMIZED GAINS

OVERFLOW ?

YES,  $|\Delta L/D| \geq 16$  ( $\Delta L/D$  IS NOW SCALED  $2^{-4}$ )

GOMAX L/D  
SH29

(QUICK EXIT FOR OVERFLOW)

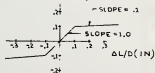
NO

YES  $|PLD_D| < 0.1$  ?

$\Delta L/D = PDL$  OOD  
LIMIT GAINS  
FOR LARGE  
COMMANDS:

$$PLD_D \leftarrow [1 + 1(|PLD_D| - 1)] \text{SIGN}(PLD_D)$$

L/D (OUT)



NEAT 1

$$MPAC_D \leftarrow LEWD_D + PLD_D$$

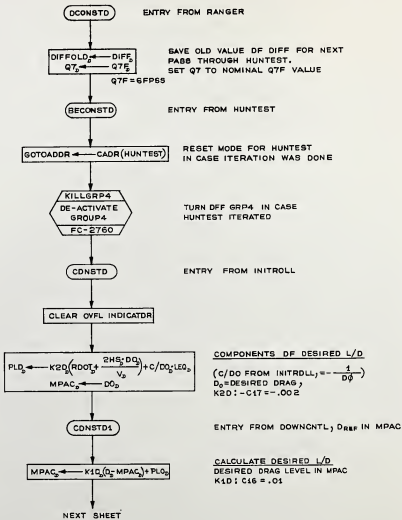
$L/D = L/D_{REF} + \Delta L/D$  (OOD RESCALED TO  $2^2$  BEFORE  
ADDITION)

NEGTESTS  
SH29

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DRAWN <i>G. J. ...</i>		REENTRY CONTROL	
FIGNR	DATE	COLLUSUS IIC	DOCUMENT NO.
ANALST			FC 770
DOCNR		REV	SHEET 21 OF 31

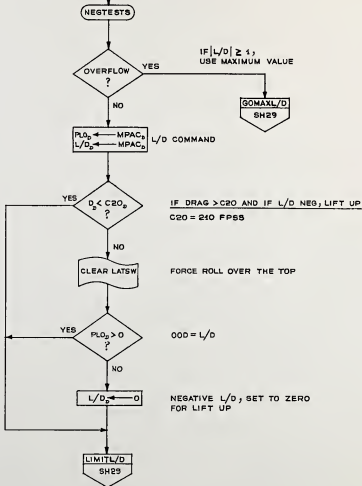


CONSTANT DRAG ROUTINE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARTICLE CLEANSING AND NAVIGATION	
DRAWN BY: <i>M. C. D. [Signature]</i> PROGRAM: 40CT68 ANALYST: DOC NO: APP'D:		REENTRY CONTROL DOCUMENT NO. <b>COLOSSUS II FC-2770</b> REV: SHEET 22 OF 31	

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFELC ORDNANCE AND NAVIGATION	
DRAWN <i>P.M. [Signature]</i> 1 OCT 66		REENTRY CONTROL	
PROGRAM		COLOSSUS IC	DOCUMENT NO.
ANALYST			FC-2770
DESIGNER			
APPROVED		REV	SHEET 23 OF 31

INITIALIZE P66

KEP

NOTE: SET ENTRYVDP  
FLAG IN CASE  
CAME FROM  
P65. DISABLE  
GRP4.



LUNAR ENTRY: COME HERE FROM UPCONTROL  
(P65) AND DO 3 AXIS ALTITUDE HOLD TO TRIM  
IF  $D < .05g$  ALSO ROLL  $C = 0$  IF  $D < .05g$ .  
OTHERWISE MAINTAIN SAME ROLLC..

SET UP KEPLER PHASE  
ENTRY DISPLAYS

N22  
R1: XXX.XX DEG } DESIRED  
R2: XXX.XX DEG } GIMBAL  
R3: XXX.XX DEG } ANGLES  
COMPUTED BY S62.3 (FC-2760)

SET VARIABLE ADDRESS TO  
KEPLER PHASE

DRBITAL ENTRY: COME HERE FROM INITROLL  
IN P64 AND HOLD CONSTANT L/D UNTIL DRAS  
GREAT ENOUGH TO ENTER FINAL PHASE.

Q7FKMIN =  
Q7F + KDMIN = 6.5 FPSS

ENTER  
FINAL PHASE

FOR ENTRY DAP

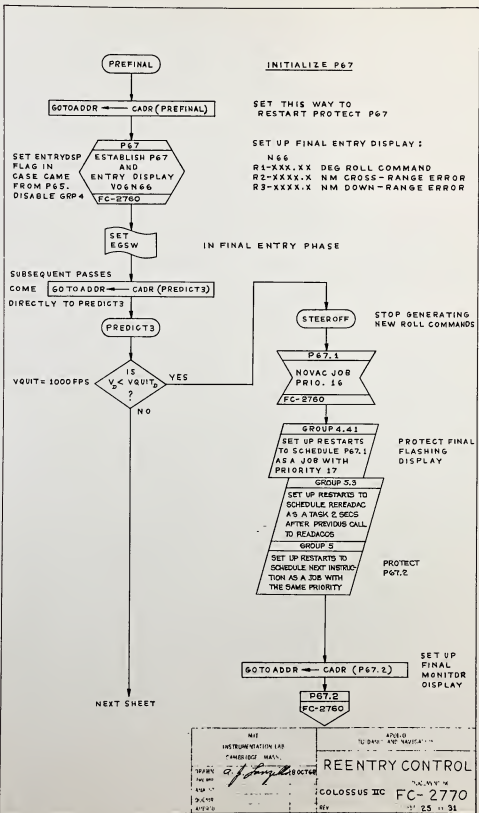
IF  $D < .05g$ ,  
SET ROLL COMMAND  
TO 0; OTHERWISE LEAVE IT  
ALONE. (FOR BACK-UP  
PROCEDURES)

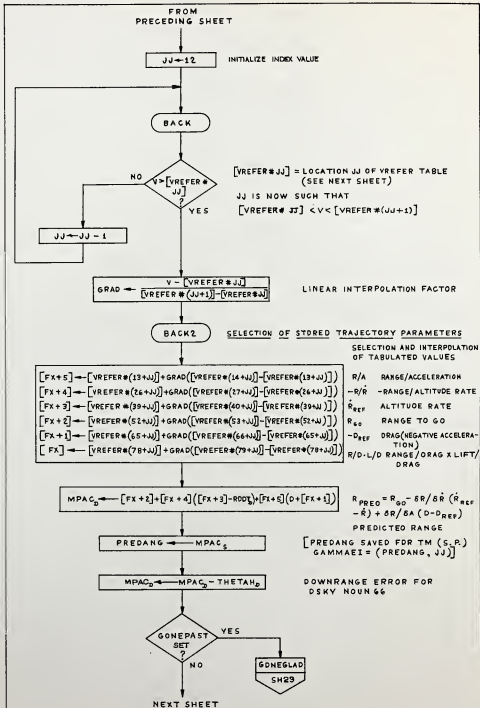
(CAUSE S62.3 TO EXIT TO ENDEXIT,  
AS SHOWN BELOW)

OUTPUT:

CPH1,+1,+2 DESIRED GIMBAL ANGLES  
FOR NGUN 22 DISPLAY VIA  
ENTRYVYN

M/S INSTRUMENTATION LAB CAMBRIDGE MASS.	APPROVED GUIDANCE AND NAVIGATION
DRAWN PFCBR ANALYST DOCMR APPRD	REENTRY CONTROL COLOSSUS IIC FC-2770 REV 24 OF 31





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ARPA GUIDANCE AND NAVIGATION
DRAWN <i>[Signature]</i> 8 OCT 54 PROGRAM ANALYST DOCUMR APPR'D	<b>REENTRY CONTROL</b> DOCUMENT NO. <b>COLOSSUS IIC FC-2770</b> REV.      SHEET 26 OF 31

Vref FPS	dR/dD NM/FPS	-dR/dR NM/FPS	Rref FPS	R togo NM	-Dref FPS	dR/dL/D NM
VREFER: 994	VREFER+13 = .0346	VREFER+26 = -.00357	VREFER+31	VREFER+32	VREFER+35	VREFER+78
2103	-.05551	-.003582	-719	37.7	-41.15	12.20
6295	-.09034	-.007039	-684	25.6	-60.0	21.82
8531	-.1410	-.01446	-609	46.3	-81.5	93.86
10101	-.2379	-.02479	-493	75.4	-93.9	187.44
VREFER+6: 14 014	-.3305	-.03391	-416	99.9	-98.5	282.2
15 951	-.3765	-.05129	-322	170.9	-118.7	329.4
18 357	-.4954	-.09882	-414	210.3	-125.2	466.5
20829	-.6489	-.1935	-744	244.8	-120.4	682.7
23090	-2.021	-2.175	-927	344.3	-95.4	980.5
23500	-3.354	-3.044	-820	504.8	-28.1	1385
VREFER+12: 35000	-3.354	-3.044	-820	794.3	-6.4	1508

THIS TABLE IS STORED SEQUENTIALLY BEGINNING AT LOCATIN "VREFER"

Vref = VELOCITY, THE INDEPENDENT VARIABLE

dR/dD = CHANGE IN RANGE VS CHANGE IN ATMOSPHERIC DRAG

-dR/dR = CHANGE IN RANGE VS. CHANGE IN ALTITUDE RATE (NEGATED)

Rref = ALTITUDE RATE OF REFERENCE TRAJECTORY

R togo = RANGE TO 5G OF REFERENCE TRAJECTORY

-Dref = ATMOSPHERIC DRAG OF REFERENCE TRAJECTORY

dR/dL/D = CHANGE IN RANGE VS. CHANGE IN LIFT/DRAG

LOCATIONS VREFER - VREFER + 12

LOCATIONS VREFER -13 - VREFER + 25

LOCATIONS VREFER +24 - VREFER + 38

LOCATIONS VREFER +39 - VREFER + 51

LOCATIONS VREFER +52 - VREFER + 64

LOCATIONS VREFER +65 - VREFER + 77

LOCATIONS VREFER +78 - VREFER + 90

SELECTION OF THE TABULATED VALUES IS BY INDEXING. AN INDEX PARAMETER "JJ" IS SET TO THE LOCATION OF THE APPROPRIATE VELOCITY VALUE. THE LOCATION OF THE CORRESPONDING dR/dD IS JJ+13; OF -dR/dR IS JJ+26, ETC.

FOR INSTANCE: IF V = 14001, JJ = 6 SINCE VREFER = 13104. THEN dR/dD = dR/dD - dR/dD + 13 = 14001 - 13104 = 897

-dR/dR = VREFER + 24 = 6 = -.06139; Rref = VREFER + 39 = 1 = 352; R togo = VREFER + 52 = 6 = 170.9

Dref = VREFER + 45 = 6 = -118.7; AND dR/dL/D = VREFER + 78 = 6 = 329.4

IN PRACTICE, V GENERALLY FALLS BETWEEN TWO TABULATED VALUES. LINEAR INTERPOLATION IS THEN USED IN THE TABLE FOR EACH OF THE PARAMETERS.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRWNR PGWRN ANALST DOCWR APPRV	<i>O. J. ...</i>	REENTRY CONTROL	
		COLCASSUS IIC	DOCUMENT NO. FC 2770
		REV	SHEET 27 OF 31

FROM  
PRECEDING SHEET

GONEBY  
SET ?

YES

SET  
GONEPAST

LATCH THE FLAG ON

HAYDHRNG

DNRNGERR<sub>2</sub> ← MAXRNG<sub>2</sub>

MAXRNG YIELDS  
9999.9 NM ON  
DSKY

DNRNGERR<sub>0</sub> ← MPAC<sub>0</sub>

GONEGLAD  
SH29

MPAC<sub>0</sub> ←  $(4 - \text{DNRNGERR}_2) / \text{FX}_2$

|MPAC<sub>0</sub>| ≥ 1.0 ?

YES<sub>2</sub>, |DNRNGERR<sub>2</sub>| ≥ FX/4

FX = R/D · L/D REFERENCE  
USE MAXIMUM L/D  
(NOTE: AT THIS POINT,  
FX<sub>1</sub> CONTAINS +0)

MPAC<sub>0</sub> ← LOD<sub>0</sub> + MPAC<sub>0</sub>

|MPAC<sub>0</sub>| ≥ 1.0 ?

YES<sub>1</sub>, |L/D| ≥ 1.0

GOMAXL/D  
SH29

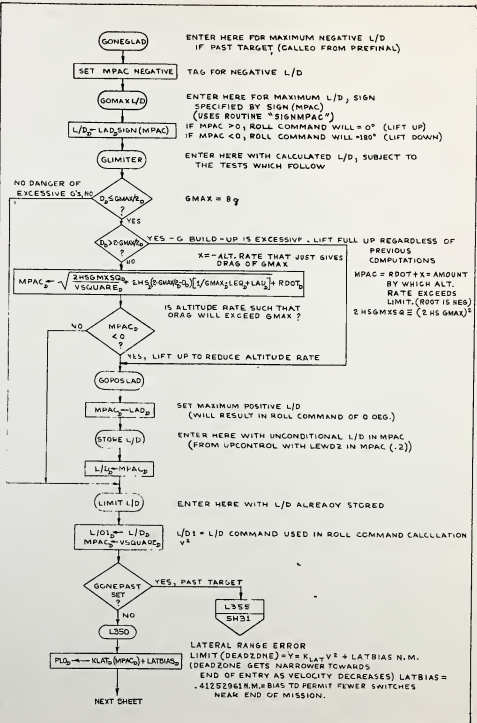
L/D<sub>0</sub> ← MPAC<sub>0</sub>

L/D = LOD + 4 (THETA - PRDANG) / FX

GLIMITER  
SH29

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	
DRAWN PFCMD ANALYT DYN MR APPROV	<i>S. J. Campbell</i> 3 OCT 64

MIT DYNAMICS AND MECHANICS	
REENTRY CONTROL	
COLOSSUS IIC	DOCUMENT NO. FC-2770
REV	SHEET 20 OF 31

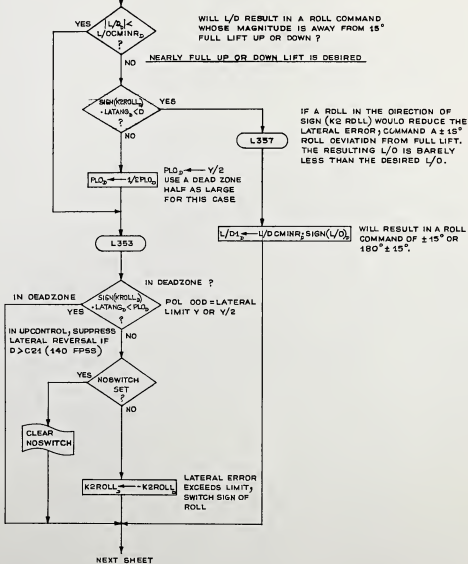


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
REENTRY CONTROL			
DRAWN PROGRAM ANALYST DOCTR APP'D	<i>A. J. Angelle</i> JUL 65	CCLOSSUS IIC	DOCUMENT NO. FC 2770
		REV	SHEET 29 OF 31



FROM PRECEDING SHEET

LATERAL LOGIC



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT CONTROL AND NAVIGATION	
DRAWN <i>J.M. [Signature]</i> 8 OCT 58		REENTRY CONTROL	
PROGRAM		DESIGNER NO.	
ANALYST		COLOSSUS IC	FC-2770
DOCUM		REV	SHEET 30 OF 31
APPROV			



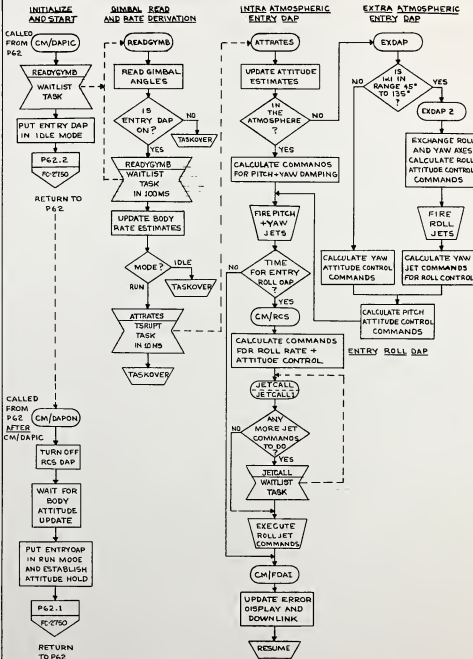
ENTRY DIGITAL AUTOPILOT

CM/DAPIC	ENTRY DAP START ROUTINE	SH. 4
CM/DAPON	RCS DAP ENTRY TO DAP CHANGEOVER ROUTINE	SH. 5
READGYMB	READ GIMBAL ANGLES	SH. 6
ATTRATES	INTRA-ATMOSPHERIC DAP	SH. 9
EXDAP	EXTRA-ATMOSPHERIC DAP	SH. 11
CM/RCS	ENTRY ROLL DAP	SH. 14
CM/FDAI	FDAI ERROR DISPLAY AND DOWNLINK	SH. 20
BIASEDZ	ATTITUDE/RATE DEAD ZONE TEST	SH. 21
3DDZ	3 DEGREE ATTITUDE DEADZONE TEST	SH. 21
4D/SDZ	4 DEGREE/SEC RATE DEADZONE TEST	SH. 21
2D/SDZ	2 DEGREE/SEC RATE DEADZONE TEST	SH. 22
FLUSHJET	TURN OFF ALL RCS JETS	SH. 23
RATEAVG	AVERAGE RATE ROUTINE	SH. 23
ANGOVCOR	ANGLE OVERFLOW CORRECTION ROUTINE	SH. 23
SETJTAG	ENABLE ENTRY ROLL DAP	SH. 24

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARJEO GUIDANCE AND NAVIGATION	
DRAWN A.C.WILLIAMS		ENTRY DIGITAL AUTOPILOT	
PERFORM	AMAYO	COLOSSUS II C	DOCUMENT NO. FC-2780
ANALYST		REV	SHEET 1 OF 24
POOR			
APPROV			

## ENTRY DIGITAL AUTOPILOT — OVERALL VIEW

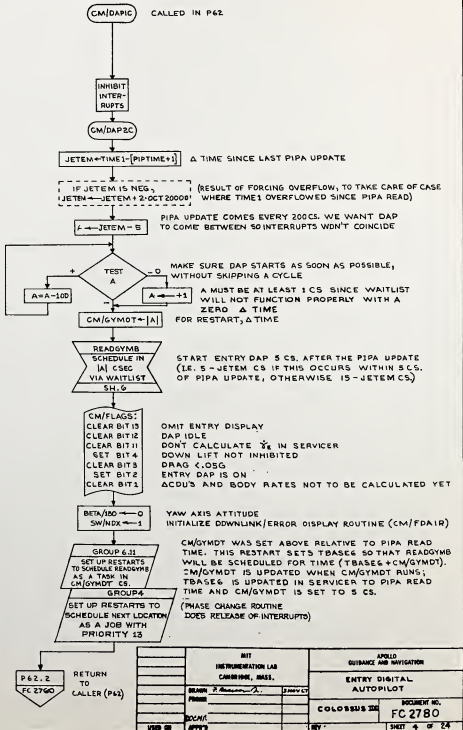


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>P. R. ...</i>		ENTRY DIGITAL AUTOPILOT	
PROGRAM		DOCUMENT NO.	
DATE		COLOSSUS II G FC 2780	
USED ON		REV SHEET 8 OF 24	



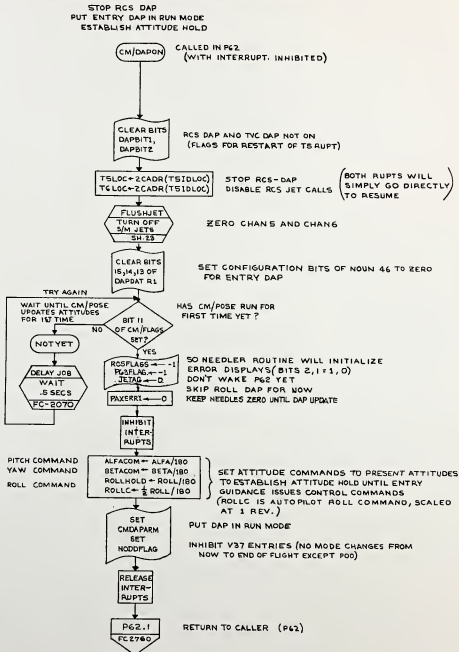
# ENTRY DAP START ROUTINE

START ENTRY DAP IN IDLE MODE  
TO INITIALIZE ATTITUDES AND RATES



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
SERIAL: 2-100000-1		ENTRY DIGITAL AUTOPILOT	
FORM:	REV:	COLOSSUS III	DOCUMENT NO. FC 2780
USED ON:	APP'D:	REV:	SHEET 4 of 24

## RCS DAP TO ENTRY DAP CHANGE-OVER ROUTINE



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		ENTRY DIGITAL AUTOPILOT
DESIGNED BY <i>J. H. ...</i>	7 JAN 67	
POWER		
DESIGN		COLOSSUS 300
USED ON	APPS	DOCUMENT NO. <b>FC2780</b>
	REV	SHEET 5 OF 24

ENTRY OAP  
 READ GIMBAL ANGLES  
 CALCULATE RATES

READGYMB

SCHEDULED INITIALLY IN CM/DAPIC, (SH. 4)  
 RESCHEDULES SELF EVERY 100 MS THEREAFTER  
 UNTIL TURN-OFF

CM/GYMTOT ← CM/GYMDT+100 UPDATE RESTART & TIME BY 100 MS (GROUP 6)

BIT 6  
 OF IMDES 33  
 CLEAR?

IMU OK?

IDLE ENTRY OAP - ATTITUDES + RATES  
 NOT AVAILABLE

READGYMB

- DELAOG → AOG - COUX  
 AOG → COUX  
 - DELAIG → AIG - COUY  
 AIG → COUY  
 - DELAMG → AMG - COUZ  
 AMG → COUZ

READ GIMBAL ANGLES

- Δ OUTER GIMBAL ANGLE  
 OUTER GIMBAL ANGLE  
 (φ)  
 - Δ INNER GIMBAL ANGLE  
 INNER GIMBAL ANGLE  
 (θ)  
 - Δ MIDDLE GIMBAL ANGLE  
 MIDDLE GIMBAL ANGLE  
 (ψ)

OCBRATE?

OAP OFF  
 0,0  
 0,1

TEST  
 CM/DSTBY,  
 SYMDIFSW

1ST PASS  
 FOLLOWING IDLE

CM/GYMIC

SET  
 GYMDIFSW

JETAG → 0

OLDELQ → 0

OLDELQ → 0

OLDELR → 0

GAMDOT → 0

A ← +0

FLUSHJET  
 TURN OFF  
 JETS  
 SH.23

GROUPS 0  
 KILL GROUP 4  
 RESTARTS

TASKOVER

DO BODY  
 RATE  
 CALCULATIONS

A ← +1

DOBRATE

JETEM ← A

READGYMB

WAITLIST TASK  
 IN 100 MS

SH. 6

TEST  
 JETEM

> 0

BODYRATE

COSM → COS(AMG)

SINO → SIN(AOG)

SINOCOSM → SINO-COSM

COSO → COS(AOG)

COSOCOSM → COSO-COSM

COS ψ  
 SIN φ  
 COS ψ SIN φ  
 COS φ  
 COS φ COS ψ

ELEMENTS OF TRANSFORMATION MATRIX  
 FOR CALCULATING BODY RATES  
 FROM GIMBAL ANGLES  
 SCALED AT 2°

NEXT SHEET

CLEAR  
 GYMDIFSW

INDICATES ENTRY  
 OAP IS IDLING

FLUSHJET

TURN OFF  
 JETS

SH.23

CAN'T PROVIDE  
 CONTROL WITHOUT  
 RATES, SO STOP  
 JETS

DO BODY  
 RATES ON  
 NEXT PASS

SKIP ROLL DAP, DON'T HAVE RATES

ROLL  
 PITCH  
 YAW  
 ψ, θ

SKIP BODY RATE CALCULATIONS

SKIP BODY RATE CALCULATIONS

TASKOVER  
 END OF IDLE  
 END OF PASS 1

IMU NO GOOD, OR ONLY  
 ONE GOOD READING SINCE  
 IDLE, SO CAN'T CALCULATE  
 RATES

ENTRY DIGITAL  
 AUTOPILOT

COLOSSUS  
 IC

FC-2780

6 - 24



**CALCULATION OF RATES IN BODY CO-ORDS.**

FROM PRECEDING SHEET

$JETEM \leftarrow (-\sin\psi - \text{DELAG}) \cdot (\cos\psi \cos\theta - \text{DELAG})$       $\Delta \text{ PITCH} = \dot{\psi} \sin\phi + \dot{\theta} \cos\psi \cos\phi$   
 $A \leftarrow \text{OLDELQ}$      **SAVE FOR NEXT CYCLE**  
 $\text{OLDELQ} \leftarrow JETEM$

**RATEAVG**  
 COMPUTE  
 AVERAGE  
 RATE  
 SH.23

INPUT: A, OLD  $\Delta$  PITCH VALUE     IN REVS AT  $2^{-1}$   
 JETEM, NEW  $\Delta$  PITCH VALUE  
 OUTPUT: A, = AVERAGE RATE

$GREL \leftarrow A$

PITCH AXIS ANGULAR RATE     IN REVS/SEC AT  $10 \cdot 2^{-1}$   
 (1 E. REVS/.1 SEC AT 180 DEG.)

$JETEM \leftarrow (-\cos\psi - \text{DELAG}) \cdot (\sin\psi \cos\theta - \text{DELAG})$       $\Delta \text{ YAW} = \dot{\psi} \cos\phi - \dot{\theta} \cos\psi \sin\phi$   
 $A \leftarrow \text{OLDELR}$      **SAVE FOR NEXT CYCLE**  
 $\text{OLDELR} \leftarrow JETEM$

**RATEAVG**  
 COMPUTE  
 AVERAGE  
 RATE  
 SH.25

YAW AXIS ANGULAR RATE     IN REVS/SEC AT  $2^{-1} \cdot 10$

$\text{SINM} \leftarrow \sin(\text{AMG})$

$\sin\psi$  (NEEDED TO COMPUTE ROLL RATE)

$JETEM \leftarrow (-\text{DELAG} \cdot \text{SINM} - \text{DELAG})$       $\Delta \text{ ROLL} = \dot{\phi} + \dot{\theta} \sin\psi$   
 $A \leftarrow \text{OLDELP}$      **SAVE FOR NEXT CYCLE**  
 $\text{OLDELP} \leftarrow JETEM$

**RATEAVG**  
 COMPUTE  
 AVERAGE  
 RATE  
 SH.25

ROLL AXIS ANGULAR RATE     IN REV/SEC AT  $2^{-1} \cdot 10$

$\text{PREL} \leftarrow A$

YES  
 GAMDOT  
 = 0?

GAMMA IS ANGLE BETWEEN S/C VELOCITY VECTOR  
 AND THE LOCAL HORIZON. GAMDOT IS THE  
 CHANGE IN THIS ANGLE, CALCULATED IN CM  
 BODY ATTITUDE ROUTINE (FC 2770)

NO ( $\neq 0$ )

$JETEM + 1 \leftarrow -\text{GAMDOT} \cdot \sin(\text{ROLL}/180)$   
 $\text{PREL} \leftarrow \text{PREL} + \text{SINTRIM} \cdot (JETEM + 1)$   
 $\text{GREL} \leftarrow \text{GREL} + \text{GAMDOT} \cdot \cos(\text{ROLL}/180)$   
 $\text{RREL} \leftarrow \text{RREL} - \text{COSTRIM} \cdot (JETEM + 1)$

$p = p - \sin\alpha \sin R \dot{\gamma}_E$   
 $q = q - \cos R \dot{\gamma}_E$   
 $r = r + \cos\alpha \sin R \dot{\gamma}_E$

ROLL/GO = ROLL AXIS ATTITUDE  
 SINTRIM =  $-\sin\alpha$   
 COSTRIM =  $\cos\alpha$

WHERE  $\alpha$  IS THE TRIM ANGLE  
 NOMINAL VALUE,  $-20^\circ$

NOGAMDOT

IS DAP ARMED?  
 YES, GO ON  
 NO, TERMINATE  
 CMDAPARM  
 SET?

TASKOVER

TO NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
BLANK		ENTRY DIGITAL AUTOPILOT	
FORM	REVISED	COLOSSUS IIC	DOCUMENT NO. FC 2780
USED ON	APP'D	REV	SHEET 7 OF 24

FROM PRECEDING SHEET



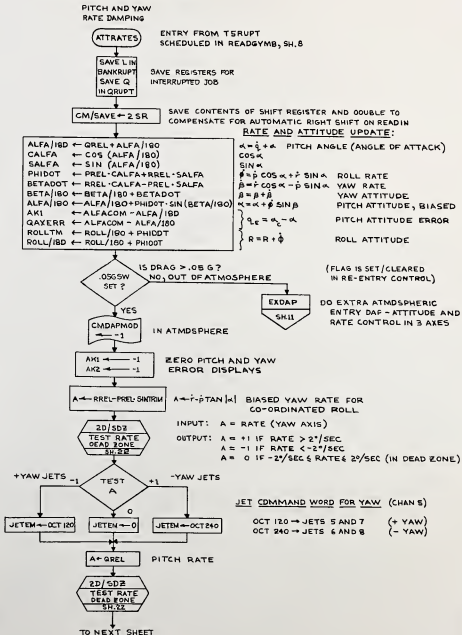
SCHEDULE CALCULATION OF ATTITUDES, AND  
CALCULATION AND EXECUTION OF JET COMMANDS



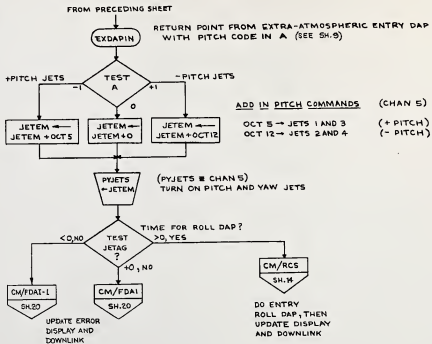
END OF ATTITUDE  
AND RATE CALCULATIONS

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
			ENTRY DIGITAL AUTOPILOT	
	DESIGN <i>P. R. ...</i>	DATE	DOCUMENT NO.	
	FROM		FC 2780	
	BY		COLOSSUS INC	
ISSUED ON	APPROVED	REV	SHEET 8 OF 24	

# INTRA ATMOSPHERIC DAP

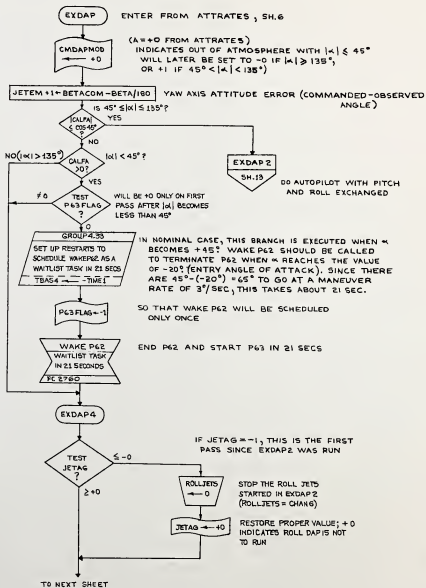


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY: <i>[Signature]</i>		ENTRY DIGITAL AUTOPILOT	
PROGRAM: _____		DOCUMENT NO. COLOSSUS 200 FC2780	
DESIGN: _____		REV	
USER OR APPR: _____		SHEET 8 OF 24	

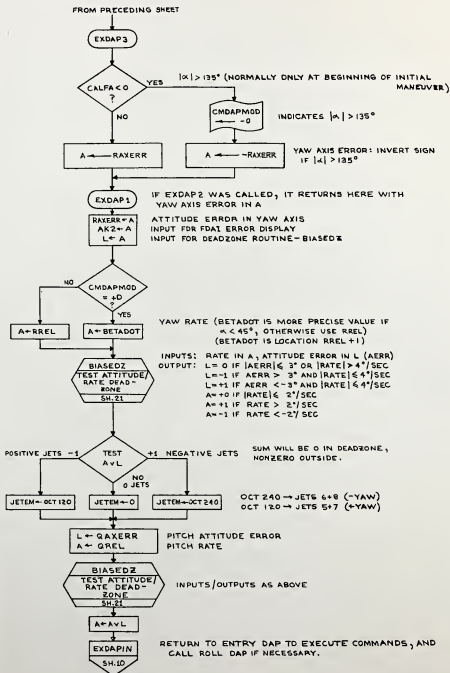


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN ? <i>Reams</i>		ENTRY DIGITAL AUTOPILOT	
PROJ	SHOVCT	DOCUMENT NO.	
DOC#		COLOSSUS ICG	FC 2780
USED ON	APP#	REV	SHEET 10 OF 14

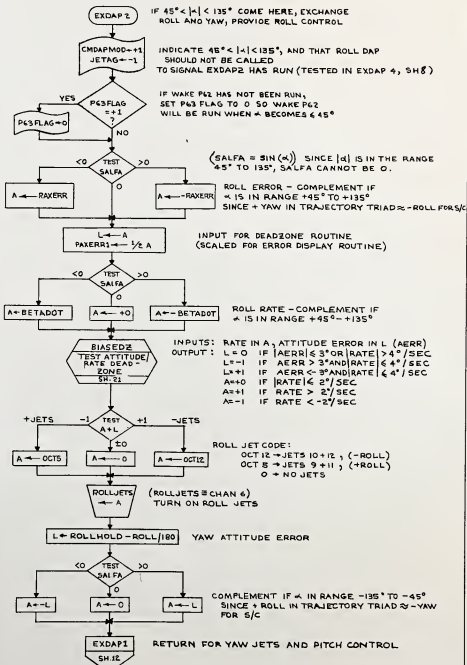
EXTRA ATMOSPHERIC DAP



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>R. R. ...</i>		ENTRY DIGITAL AUTOPILOT	
PROB: <i>...</i>		DOCUMENT NO. FC 2780	
USED ON: <i>...</i>		REV: <i>...</i>	
APPRO: <i>...</i>		SHEET 11 OF 24	

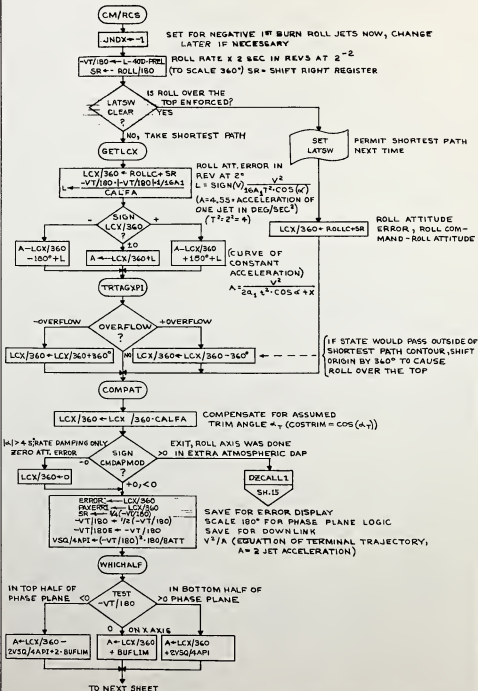


MIT		APOLLO	
INSTRUMENTATION LAB		GUIDANCE AND NAVIGATION	
CAMBRIDGE, MASS.		ENTRY DIGITAL	
DRAWN: <i>Richard Thompson</i>		AUTAPILOT	
PROGRAM: <i>FC2780</i>		INCIDENT NO.	
DESIGN: <i>FC2780</i>		FC2780	
CHECKED: <i>FC2780</i>		SHEET NO. OF 24	
APPROVED: <i>FC2780</i>		REV	



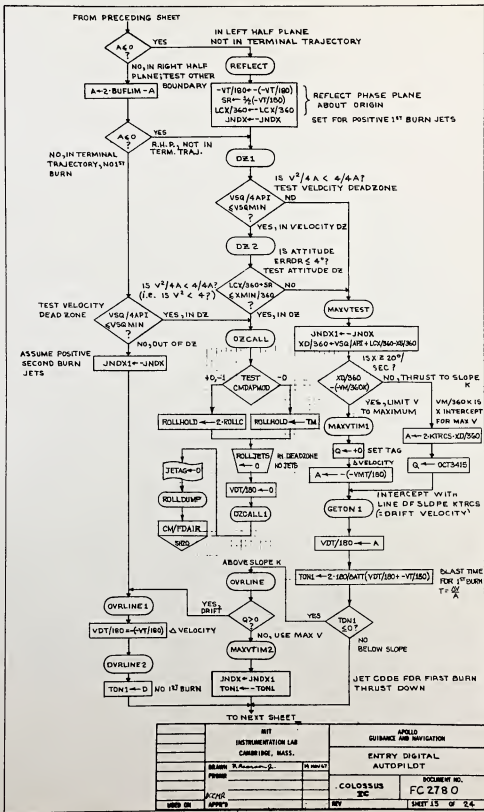
	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED GUIDANCE AND NAVIGATION
	DESIGN BY <u>                    </u>	ENTRY DIGITAL AUTOPILOT
	PROJECT <u>                    </u>	COLOSSUS S/C
	USED ON <u>                    </u>	DOCUMENT NO. FC 2780
	APPROVED <u>                    </u>	REV <u>                    </u>
		SHEET 15 OF 24

ENTRY ROLL DAP



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
BR/WH FORM		ENTRY DIGITAL AUTOPILOT	
RZM/r		COLOMBUS EC	DOCUMENT NO. FC 2780
USED ON	APPROV'D	REV	SHEET 14 OF 24





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DEVELOPER R. R. ...		ENTRY DIGITAL AUTOPILOT	
DESIGNER R. R. ...	APPROVED R. R. ...	COLOSSUS IC	DOCUMENT NO. FC 2780
USED ON APPROVED	REV	SHEET 15 OF 24	

FROM PRECEDING SHEET

GETON2

TON2 ← IB0/BATT · 4(VDT/IB0)

SECOND BURN TIME  $T = \frac{\Delta V}{A}$  (TIME FROM INTERCEPT OF PARABOLA TO ORIGIN)

YES  
TON2 < 0 ?

TON2 ← -TON2  
JNDZ1 ← JNDZ  
THRUST  
OTHER  
WAY

GETOFF

$XD/360 \leftarrow -(VDT/IB0) \cdot TON2$  Δ ANGLE DURING SECOND BURN (TEMP STORAGE)

YES, DON'T TRY  
TO DIVIDE  
VDT/IB0  
= 0 ?

$L \leftarrow TON1 (-VT/IB0 - VDT/IB0) + XD/360 + LCX/360$   
 $A \leftarrow 0$   
 $A \cdot L \leftarrow \frac{A \cdot L}{VDT/IB0}$

DRIFT TIME  
 $t_d = \frac{2X - t_1(V + V_0) - t_2 V_0}{2V_0}$   
RESULT IN A REMAINDER IN L,  
IN CS. SCALED AT 400

NO, DIVIDE  
OVERFLOW  
A = 0 ?

TOFFOVFL

A ← 2JETT

INCS. AT  $2^{14}$   
LONG ENOUGH TO  
ASSURE DRIFT  
FOR FULL 2 SEC.

YES  
DIVIDE WILL NOT OVERFLOW SINCE THE RESULT  
WAS ZERO, THE REMAINDER IN L IS NOW EQUAL  
TO THE ORIGINAL NUMERATOR

GETOFF2

$2JETT = 400$  AT  $2^{14} = 1$  AT  $\frac{2^{14}}{400}$   
DIVISION FOR REAL TIME  
RESULTS IN CS. SCALED AT  $2^{14}$

$A \leftarrow 2JETT \left( \frac{L}{VDT/IB0} \right)$

TIMSCAL

TOFF ← A

NEXT SHEET

ENTRY DIGITAL  
AUTO PILOT

COLOSSUS

FC-2780

REV - C

16 x 24

FROM PRECEDING SHEET

TON1 ← TON1 · 4JETT  
TON2 ← TON2 · 4JETT

TON1, TON2 COMPUTED IN CS. SCALED AT 400 AND FOR 4 JETS  
4JETTS 2 AT 2<sup>14</sup>/400, SO NOW: 2 JET TIME IN CS. AT 2<sup>14</sup>

JETAG ← +0  
SWJNDX ← H

SO ROLL DAP WILL NOT RUN AGAIN UNTIL SERVICER RESETS THE FLAG TO + INITIALIZE DOWN LINK ROUTINE (CM/FDAIR) TO START AT THE TOP OF THE LIST

TIMETST

TUSED → TUSED + TIME1 - 203CS

TUSED ← OLD TI (FROM SETJTAG), NOW CONTAINS Δ TIME - 203CS.

IF TUSED IS NEG,  
TUSED ← -TUSED + 2 · OCT20000

RESULT OF FORCING OVERFLOW (SEE SH4 FOR FURTHER EXPLANATION)

TOO SHORT,  
SUPPRESS 1ST BURN

TON1 ≤ 2CS. ?

YES  
NO

TEST JNDX ?

-1  
0  
+1

T1BITS ← OCT 5

T1BITS ← 0

T1BITS ← OCT 12

JET CODE FOR OCT 12 → JETS 10 AND 12 (-ROLL)  
1ST BURN (CHAN 6)  
OCT 5 → JETS 9 AND 11 (+ROLL)

TIMETST1

TUSED → TUSED + TON1

TIME REMAINING IN 2 SEC PERIOD AFTER FIRST BURN

TON1 ← -1

SKIP 1ST BURN

TUSED > 0 ?

YES, TON1 TOO LONG FOR 1 CYCLE

NO

TIMETST5

TON1 ← 0

(A TIME OF 0 MEANS THE BURN OR DRIFT PERIOD EXTENDS TO THE END OF THE 2 SEC. ROLL DAP CYCLE TIME)

A ← -1

(A NEGATIVE TIME MEANS SKIP THE BURN OR DRIFT PERIOD ENTIRELY AND GO ON TO THE NEXT (IF ANY) AT ONCE)

TOO SHDRT, SUPPRESS QUIESCENT PERIOD

TOFFS ≤ 2CS. ?

YES  
NO

TIMETST2

TUSED → TUSED + TOFF

TIME REMAINING IN 2 SEC PERIOD AFTER DRIFT TIME

TOFF ← -1

SKIP DRIFT PERIOD

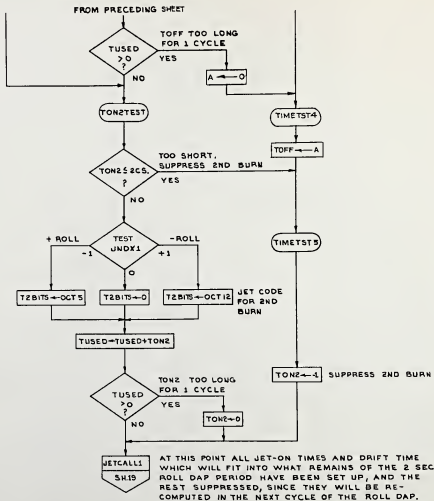
NEXT SHEET

ENTRY DIGITAL  
AUTO PILOT

COLOSSUS  
IC

FC-2780

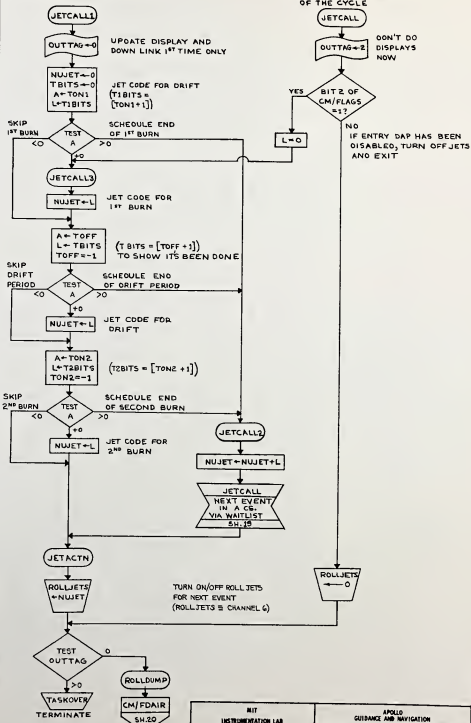
17 24



0770 01-29-60 24-PP 99-PP 49-PP	8668 ENTRY DIGITAL AUTOPILOT COLOSSUS IC FC-2780 24
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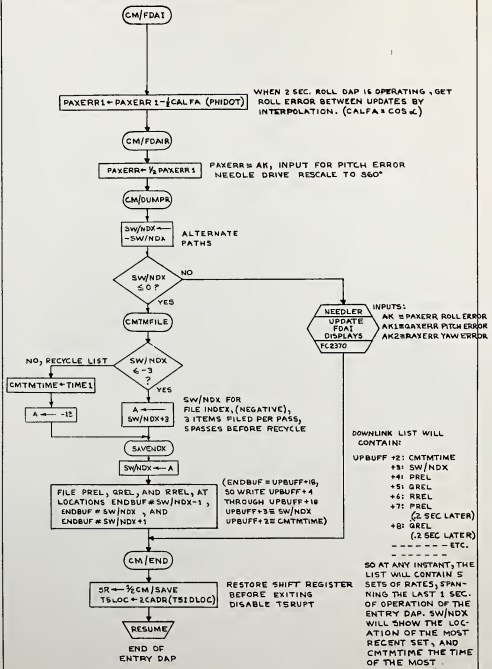
FIRST PASS OF THE CYCLE

SUBSEQUENT PASSES OF THE CYCLE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
BLAKE R. Cameron, Jr. 12/19/67		ENTRY DIGITAL AUTOPILOT	
FORM		COLOSSUS	DOCUMENT NO. FC 278 O
DATE		36	
USED ON	APPRO	REV	SHEET 15 OF 24

# FDAI ERROR DISPLAY AND DOWNLINK



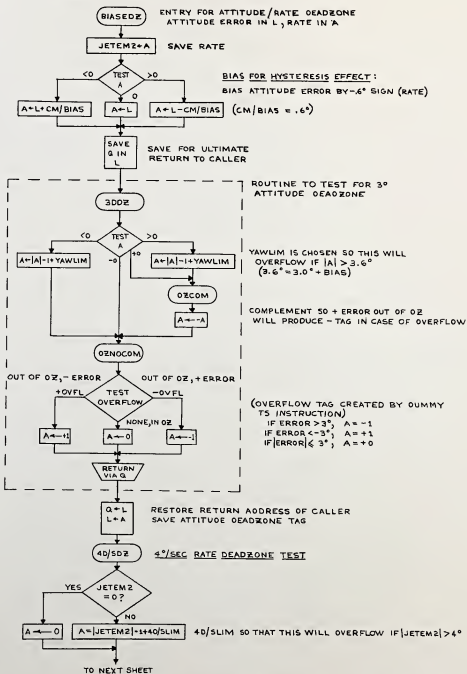
DOWNLINK LIST WILL CONTAIN:

UPBUFF +2: CMT/TIME  
 +3: SW/NDX  
 +4: PREL  
 +5: QREL  
 +6: RREL  
 +7: PREL  
 (2 SEC LATER)  
 +8: QREL  
 (2 SEC LATER)  
 ----- ETC.

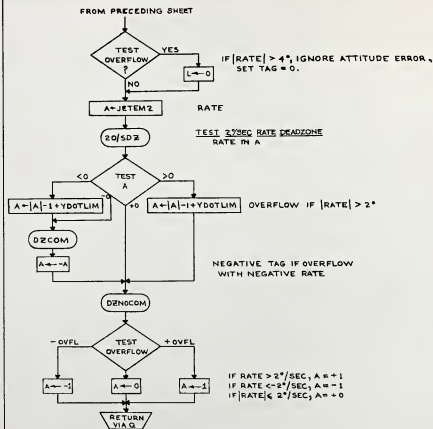
SO AT ANY INSTANT, THE LIST WILL CONTAIN 5 SETS OF RATES, SPANNING THE LAST 1 SEC. OF OPERATION OF THE ENTRY DAP. SW/NDX WILL SHOW THE LOCATION OF THE MOST RECENT SET, AND CMT/TIME THE TIME OF THE MOST RECENT SET.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
REVISION: <i>J. Roman</i>		ENTRY DIGITAL AUTOPILOT	
PROJECT: <i>STANU</i>		DOCUMENT NO. <b>FC 2780</b>	
DRAWN: _____		COLOSSUS <b>2A</b>	
CHECKED: _____		REV _____	
USED ON: <i>APPS</i>		SHEET 20 OF 24	

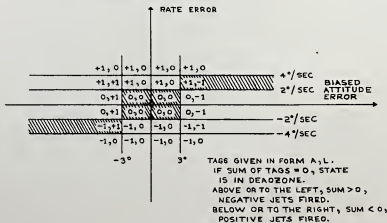
### DEADZONE TEST ROUTINE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>G. J. [Signature]</i>		ENTRY DIGITAL AUTOPILOT	
PROBN		DOCUMENT NO.	
DCM		COLLOSSUS IC	
APP'D		FC2780	
USED ON		REV	
		SHEET 21 OF 24	



PHASE PLANE LOGIC



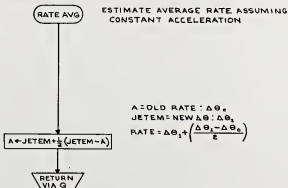
	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
	SEARCH <i>P. P. ...</i>		ENTRY DIGITAL AUTOPILOT	
	FORM		COLOSSUS INC	DOCUMENT NO. FC 2780
USED ON	APPROV		REV	SHEET 22 OF 24



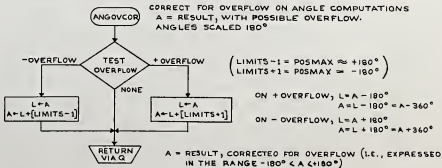
### JET TURN OFF ROUTINE



### AVERAGE RATE ROUTINE

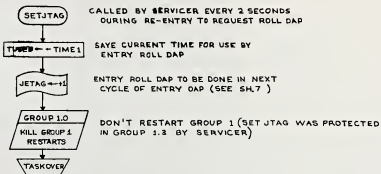


### ANGLE OVERFLOW CORRECTION ROUTINE



	RIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
		ENTRY DIGITAL AUTOPILOT	
DRAWN BY <i>J. Brown</i>	Checked	COLOSSUS I/C	DOCUMENT NO. FC2780
DATE			
USED ON	APPS	REV	SHEET 23 OF 24

ROUTINE TO ENABLE  
ENTRY ROLL DAP



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
			ENTRY DIGITAL AUTOPILOT	
	DESIGN <i>F. Cannon</i>	DATE 24 NOV 67		
	POWER			
	PCMR		COLOSSUS 316	DOCUMENT NO. FC 2780
USED BY	APPROV		REV	SHEET 24 OF 24

12 DECEMBER 1969

ACCOMP	FC-2300	Orbital Integration ENTRY 9			
ACROLL	FC-2400	RCS DAP Jet Selection Logic ENTRY 5			
ACTIVE	FC-2626	P32, P72--CSI CALLED 16			
	FC-2627	P33, P73--CDH CALLED 2			
ACTLIM	FC-2440	TVC DAP ENTRY 16			
	FC-2440	TVC DAP ENTRY 16			
ADVANCE	FC-2626	P32, P72--CSI ENTRY 9			
	FC-2627	P33, P73--CDH CALLED 2			
ADVORB	FC-2590	P22 Orbital Navigation CALLED 7			
	FC-2730	R52, R53, R56 ENTRY 5			
ADVTRK	FC-2070	Service Routines	C-6		
	FC-2730	R52, R53, R56 S-5	C-2		T-8
AGAIN	FC-2620	P30, P31 CALLED 7			
	FC-2680	Thrust Programs (P40, P41) ENTRY 38			
ALARM	FC-2627	P33, P73--CDH CALLED 3			
	FC-2020	Fresh Start and Restart CALLED 20,32			
	FC-2140	Alarm and Abort ENTRY 4			
	FC-2200	T4RUPT CALLED 6,15,16,29,32,33,41,42			
	FC-2235	IMU Extended Verbs (V40, V41, V42) CALLED 6,7			
	FC-2683	Servicer CALLED 16			
	FC-2760	P60's Entry Programs CALLED 21			
ALARM2	FC-2140	Alarm and Abort ENTRY 4			
ALARMS	FC-2545	P17/P77--TPI Search Programs ENTRY 13			
ALPLT	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 16			
ALPLT1	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 16			
ALLOOP	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 15			
ALM/END	FC-2370	DAP Interface and Service Routines CALLED 2,6,10			
	FC-2450	Stroke Test Package CALLED 1			
	FC-2605	Navigation Extended Verbs CALLED 2,6			
	FC-2235	IMU Extended Verbs (V40, V41, V42) CALLED 2,3,4,6,8			
ALMXTA	FC-2626	P32, P72--CSI ENTRY 22			
ALWAYS	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 20			
AMBGUPDT	FC-2370	DAP Interface and Service Routines ENTRY 25			
	FC-2380	DAP Interface Initialization and Phase I CALLED 4,8			
	FC-2460	Roll Autopilot CALLED 8			
AMONFLG	FC-2290	Integration Initialization S-20	C-20		T-17,18
	FC-2540	P11 Earth Orbit Insertation Monitor			T-18
	FC-2070	Service Routines	C-6		
	FC-2650	Orbital Parameters Display			T-8,11
	FC-2650	Orbital Parameters Display			T-11
APSESW	FC-2310	Conic Subroutines S-24	C-24		
	FC-2020	Fresh Start and Restart S-6			
APSIDZS	FC-2310	Conic Subroutines ENTRY 38			
	FC-2641	Common Targeting Subroutines CALLED 13			
ASTNPLAG	FC-2020	Fresh Start and Restart	C-26,6		
	FC-2680	Thrust Programs (P40, P41)			T-20
	FC-2681	Clocktask and Clockjob S-6	C-13		T-6
ATERJOB	FC-2540	P11 Earth Orbit Insertation Monitor ENTRY 10			
ATOPCSN	FG-2290	Integration Initialization ENTRY 5			
	FC-2300	Orbital Integration CALLED 33,38			
	FC-2290	Integration Initialization ENTRY 5			
	FC-2300	Orbital Integration CALLED 33,38			
ATOPOTF	FC-2670	P76 Target Delta V Program CALLED 4			
ATTCHPLG	FC-2370	DAP Interface and Service Routines S-13			C-13
	FC-2070	Service Routines	C-6		
ANGEKUGL	FC-2320	TPFConics ENTRY 15			
	FC-2642	P37 Return To Earth CALLED 31			
AVAPLAGA	FC-2644	P38/P78: P39/P79 CALLED 3,9			

AVEGFLAG	FC-2020	Fresh Start and Restart	C-34,6	
	FC-2650	Orbital Parameters Display		T-3,4
	FC-2650	Orbital Parameters Display		T-3
	FC-2683	Servicer S-3	T-8	
	FC-2760	P60's Entry Programs		T-19
AVEMIDSW	FC-2290	Integration Initialization S-16		
	FC-2070	Service Routines	C-6	
AVETOMID	FC-2290	Integration Initialization ENTRY 16		
	FC-2683	Servicer CALLED 25		
AVFLAG	FC-2545	P17/P77--TPI Search Programs S-4	C-4	T-3,4,8
	FC-2620	P30, P31 S-B		
	FC-2626	P32, P72--CSI S-2	C-2	
	FC-2627	P33, P73--CDH S-1	C-1	
	FC-2070	Service Routines	C-6	
	FC-2630	P34/P74 TPI Targeting S-2	C-2	
	FC-2640	P35-P75 TPM Targeting S-1	C-1	
	FC-2641	Common Targeting Subroutines		T-15
	FC-2644	P38/P78; P39/P79 S-3	C-3	
	FC-2680	Thrust Programs (P40, P41) S-33,36		T-12
AVFLAGA	FC-2545	P17/P77--TPI Search Programs CALLED 3		
	FC-2627	P33, P73--CDH CALLED 1		
	FC-2630	P34/P74 TPI Targeting CALLED 2		
	FC-2640	P35-P75 TPM Targeting CALLED 1		
AVFLAGP	FC-2545	P17/P77--TPI Search Programs CALLED 3		
	FC-2626	P32, P72--CSI ENTRY 2		
	FC-2627	P33, P73--CDH CALLED 1		
	FC-2630	P34/P74 TPI Targeting CALLED 2		
	FC-2640	P35-P75 TPM Targeting CALLED 1		
	FC-2644	P38/P78; P39/P79 CALLED 3,9		
AVGEND	FC-2683	Servicer ENTRY 25		
AVWHIDSW	FC-2300	Orbital Integration	C-40	
AXISGEN	FC-2720	P52 IMU Realignment Program CALLED 20		
AZMTHCGI	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 34		
A-PCHK	FC-2290	Integration Initialization CALLED 21		
	FC-2300	Orbital Integration ENTRY 38		
BADEND	FC-2550	P20 Rendezvous Navigation CALLED 34		
BALLOUT	FC-2060	Waitlist CALLED 13		
	FC-2140	Alarm and Abort ENTRY 5		
	FC-2240	SXTMARK CALLED 1		
	FC-2242	R57 Optics Calibration Routine CALLED 2		
BANKCALL	FC-2080	Inter-bank Communication ENTRY 1		
BANKJUMP	FC-2080	Inter-bank Communication ENTRY 2		
BDF2Z	FC-2400	RCS DAP Jet Selection Logic ENTRY 11		
BDROLL	FC-2400	RCS DAP Jet Selection Logic ENTRY 7		
BIGTIME	FC-2310	Conic Subroutines ENTRY 21		
BLANKET	FC-2360	R64 (R05)--S-Band Antenna CALLED 5		
	FC-2590	P22 Orbital Navigation CALLED 3,6,16		
	FC-2600	P23 Cislunar Midcourse Navigation CALLED 12		
	FC-2626	P32, P72--CSI CALLED 2		
	FC-2190	Extended Verbs CALLED 5		
	FC-2242	R57 Optics Calibration Routine CALLED 3,4		
	FC-2720	P52 IMU Realignment Program CALLED 18		
BVECTORS	FC-2550	P20 Rendezvous Navigation ENTRY 39		
	FC-2590	P22 Orbital Navigation CALLED 15		
CA+ECE	FC-2200	T4RUPT CALLED 43		
CALCGA	FC-2720	P52 IMU Realignment Program CALLED 9		
	FC-2760	P60's Entry Programs CALLED 33		
CALCGRAV	FC-2680	Thrust Programs (P40, P41) CALLED 36		
	FC-2683	Servicer ENTRY 22		
CALCGTA	FC-2540	P11 Earth Orbit Insertation Monitor CALLED 13		

FC-2720 P52 IMU Realignment Program CALLED 26  
 CALCMAN2 FC-2350 Maneuver Calculations and Steering S-9  
 FC-2070 Service Routines C-6  
 CALCMAN3 FC-2350 Maneuver Calculations and Steering S-9  
 CALCN83 FC-2683 Servicer CALLED 19  
 FC-2700 P47 Thrust Monitor ENTRY 6  
 CALCN85 FC-2683 Servicer CALLED 19  
 CALCRVG FC-2683 Servicer ENTRY 20  
 CALCSCA FC-2730 R52, R53, R56 CALLED 7  
 CALCSMSC FC-2720 P52 IMU Realignment Program ENTRY 25  
 CALCTFP FC-2650 Orbital Parameters Display CALLED 20  
 FC-2650 Orbital Parameters Display CALLED 20  
 FC-2760 P60's Entry Programs CALLED 22,23,27  
 CALCTPER FC-2320 TPFConics ENTRY 5  
 FC-2650 Orbital Parameters Display CALLED 19  
 FC-2650 Orbital Parameters Display CALLED 19  
 CAL53A FC-2720 P52 IMU Realignment Program ENTRY 22  
 CCSHOLE FC-2140 Alarm and Abort ENTRY 5  
 CDHMRV FC-2626 P32, P72--CSI CALLED 16  
 FC-2627 P33, P73--CDH ENTRY 5  
 CDIVE FC-2200 T4RUP ENTRY 4  
 CDUINC FC-2100 RTB Op Codes ENTRY 10  
 CDULOGIC FC-2350 Maneuver Calculations and Steering CALLED 22  
 FC-2100 RTB Op Codes ENTRY 3  
 CDUTOC5M FC-2340 R60 Attitude Maneuver CALLED 5  
 CDUTODCM FC-2340 R60 Attitude Maneuver CALLED 5  
 FC-2350 Maneuver Calculations and Steering ENTRY 22  
 CDUTRIG FC-2325 Rendezvous Parameters Displays CALLED 4  
 FC-2540 P11 Earth Orbit Insertion Monitor CALLED 13  
 FC-2550 P20 Rendezvous Navigation CALLED 13,14  
 FC-2700 P47 Thrust Monitor CALLED 8  
 FC-2720 P52 IMU Realignment Program CALLED 9,13  
 FC-2730 R52, R53, R56 CALLED 7  
 CHAZPOGC FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 33  
 CHECKCTF FC-2310 Conic Subroutines ENTRY 19  
 CHECKG FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 39  
 CHECKMM FC-2605 Navigation Extended Verbs CALLED 6  
 FC-2030 Phase Table Maintenance ENTRY 3  
 FC-2240 SIXMARK CALLED 2,8  
 FC-2730 R52, R53, R56 CALLED 11  
 CHKCOMED FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 13  
 CHKPOOH FC-2330 R62 Crew Defined Maneuver (V49) CALLED 2  
 FC-2340 R64 (R05)--S-Band Antenna CALLED 2  
 FC-2361 V89 (R63) CALLED 2  
 FC-2190 Extended Verbs CALLED 2  
 CHKSCOD% FC-2720 P52 IMU Realignment Program CALLED 18  
 FC-2730 R52, R53, R56 ENTRY 12  
 CHKSDATA FC-2720 P52 IMU Realignment Program CALLED 20  
 CKMID7 FC-2300 Orbital Integration ENTRY 36  
 CKROPTVP FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 26  
 CLEARNDSP FC-2760 P60's Entry Programs CALLED 10  
 CLEARNRK FC-2020 Fresh Start and Restart CALLED 24,36  
 FC-7240 SIXMARK CALLED 8  
 FC-2730 R52, R53, R56 CALLED 5,14  
 FC-2760 P60's Entry Programs CALLED 4  
 CLOCKJOB FC-2681 Clotask and Clockjob ENTRY 4  
 CLOKTASK FC-2626 P32, P72--CSI CALLED 23  
 FC-2680 Thrust Programs (P40, P41) CALLED 12  
 FC-2681 Clotask and Clockjob ENTRY 3  
 CHDAPARM FC-2070 Service Routines C-6

C-10

T-10

	FC-2683	Servicer	T-6		
	FC-2780	CM Entry Digital Autopilot S-5		T-7	
CNDSOHT	FC-2430	TVC Start-up, Executive, and Service Routines	ENTRY 21		
CMOONFLG	FC-2290	Integration Initialization S-5,18	C-5,18	T-5	
	FC-2550	P20 Rendezvous Navigation		T-35	
	FC-2590	P22 Orbital Navigation	T-4,19,20,22, 23,24,25,30		
	FC-2600	P23 Cislunar Midcourse Navigation			T-11,12,17
	FC-2630	P34/P74 TPI Targeting		T-14	
	FC-2641	Common Targeting Subroutines		T-14	
CM/DAPIC	FC-2760	P60's Entry Programs CALLED 6			
CM/DAPON	FC-2760	P60's Entry Programs CALLED 7			
CM/DSTBY	FC-2070	Service Routines	C-6		
	FC-2683	Servicer	C-26	T-5	
	FC-2760	P60's Entry Programs	C-17		
	FC-2780	CM Entry Digital Autopilot		T-6	
CM/POSE	FC-2683	Servicer CALLED 19			
CNTWUP30	FC-2620	P30, P31 ENTRY 6			
CNTSCHK	FC-2120	AGC Block Two Selfcheck ENTRY 7			
COALIGN	FC-2530	Prelaunch Initialization and Gyro Compassing	ENTRY 36		
COGAPLAG	FC-2310	Conic Subroutines S-22	C-22,33		
	FC-2070	Service Routines	C-6		
COMPMAT	FC-2670	P76 Target Delta V Program ENTRY 2			
COMPPTG	FC-2620	P30, P31 CALLED 5,10			
	FC-2626	P32, P72--CSI ENTRY 22			
COMPUTER	FC-2070	Service Routines	C-6		
COMPYER	FC-2530	Prelaunch Initialization and Gyro Compassing	ENTRY 26		
CPHIPLAG	FC-2070	Service Routines	C-6		
	FC-2760	P60's Entry Programs	C-33		
CREWMANU	FC-2330	R62 Crew Defined Maneuver (V49) ENTRY 2			
CFS61.1	FC-2550	P20 Rendezvous Navigation ENTRY 11			
CSI/A	FC-2626	P32, P72--CSI ENTRY 11			
CSMCONIC	FC-2290	Integration Initialization ENTRY 7			
	FC-2360	R64 (R05)--S-Band Antenna CALLED 3			
	FC-2361	R89 (R63) CALLED 4			
	FC-2545	P17/P77--TPI Search Programs CALLED 4,5			
	FC-2590	P22 Orbital Navigation CALLED 3			
	FC-2190	Extended Verbs CALLED 3,4			
	FC-2720	P52 IMU Realignment Program CALLED 11			
	FC-2730	R52, R53, R56 CALLED 8,9			
CSMPREC	FC-2290	Integration Initialization ENTRY 6			
	FC-2325	Rendezvous Parameters Displays CALLED 7			
	FC-2590	P22 Orbital Navigation CALLED 19			
	FC-2641	Common Targeting Subroutines CALLED 15			
	FC-2647	P37 Return To Earth CALLED 15			
	FC-2644	P38/P78: P39/P79 CALLED 12			
	FC-2720	P52 IMU Realignment Program CALLED 8,10			
CSMSTORE	FC-2545	P17/P77--TPI Search Programs CALLED 4			
	FC-2641	Common Targeting Subroutines ENTRY 15			
CULTFLAG	FC-2070	Service Routines	C-6		
	FC-2720	P52 IMU Realignment Program S-17			
	FC-2730	R52, R53, R56	C-17	T-14,15	
			T-7		
CURTAINS	FC-2140	Alarms and Abort ENTRY 4			
C33TEST	FC-2200	T4RUPT ENTRY 38			
DAPBIT1	FC-2370	DAP Interface and Service Routines S-5	C-3,4	T-2,6,25	
	FC-2430	TVC Start-up, Executive, and Service Routines			T-10
	FC-2450	Stroke Test Package	T-1		
	FC-2540	P11 Earth Orbit Insertation Monitor S-19	C-6	T-10	
	FC-2020	Fresh Start and Restart	C-21	T-20,21,30	
	FC-2680	Thrust Programs (P40, P41) S-22	C-5	T-27,44	
	FC-2780	CM Entry Digital Autopilot			

DAPBIT2	FC-2370	DAP Interface and Service Routines S-4,5		T-6,25
	FC-2430	TVC Start-up, Executive, and Service Routines		
	FC-2450	Stroke Test Package	T-1	
	FC-2540	P11 Parth Orbit Insertion Monitor S-19		T-10
	FC-2020	Fresh Start and Restart	C-6	T-20,21,30
	FC-2680	Thrust Programs (P40, P41)	C-21,22	T-27,44
	FC-2780	CM Entry Digital Autopilot	C-5	
DAPDATR1	FC-2680	Thrust Programs (P40, P41) S-25	C-7	
DAPPDISP	FC-2370	DAP Interface and Service Routines ENTRY 6		
DAPINIT	FC-2430	TVC Start-up, Executive, and Service Routines ENTRY 9		
DCMTOCODU	FC-2340	R60 Attitude Maneuver CALLED 7		
	FC-2350	Maneuver Calculations and Steering ENTRY 20		
DELAYJOB	FC-2325	Rendezvous Parameters Displays CALLED 3		
	FC-2360	R64 (R05)--S-Band Antenna CALLED 5		
	FC-2550	P20 Rendezvous Navigation CALLED 31		
	FC-2626	P32, P72--CSI CALLED 6		
	FC-2020	Fresh Start and Restart CALLED 31		
	FC-2070	Service Routines ENTRY 8		
	FC-2190	Extended Verbs CALLED 5		
	FC-2650	Orbital Parameters Display CALLED 12		
	FC-2650	Orbital Parameters Display CALLED 12		
	FC-2760	P60's Entry Programs CALLED 21		
DELCOMP	FC-2340	R60 Attitude Maneuver CALLED 6,7		
	FC-2350	Maneuver Calculations and Steering ENTRY 16		
DELRSP	FC-2320	TFPConics ENTRY 13		
	FC-2650	Orbital Parameters Display CALLED 13		
	FC-2650	Orbital Parameters Display CALLED 13		
DELTIME	FC-2310	Conic Subroutines ENTRY 25		
DIFEQ*0	FC-2300	Orbital Integration ENTRY 27		
DIFEQ*1	FC-2300	Orbital Integration ENTRY 27		
DIFEQ*2	FC-2300	Orbital Integration ENTRY 32		
DIMOFLAG	FC-2290	Integration Initialization S-4,16	C-3,6,7,8,19	
	FC-2300	Orbital Integration	C-37	T-9,12,32
	FC-2550	P20 Rendezvous Navigation S-4,21	C-7	
	FC-2580	P21 Ground Track Determination		C-3,4
	FC-2590	P22 Orbital Navigation S-10,18	C-11,18	
	FC-2600	P23 Cislunar Midcourse Navigation S-15		C-14
	FC-2070	Service Routines	C-6	
DISDVLVC	FC-2626	P32, P72--CSI ENTRY 8		
DISPLA	FC-2630	P34/P74 TPI Targeting ENTRY 15		
DISPMGA	FC-2620	P30, P31 ENTRY 5		
DISPTARG	FC-2760	P60's Entry Programs ENTRY 28		
DIVIDE	FC-2660	P23 Cislunar Midcourse Navigation ENTRY 22		
DLT2-1	FC-2060	Waitlist ENTRY 10		
DMENFLG	FC-2590	P22 Orbital Navigation S-15	C-12,26	T-13,18
	FC-2600	P23 Cislunar Midcourse Navigation		C-11
	FC-2610	Measurement Incorporation		T-3,5,8,9,12
	FC-2070	Service Routines	C-6	
DNTHFAST	FC-2200	T4RUPT ENTRY 42		
DOFSTART	FC-2020	Fresh Start and Restart ENTRY 3		
DOW..	FC-2300	Orbital Integration ENTRY 41		
DOW..1	FC-2300	Orbital Integration ENTRY 42		
DOWENT2	FC-2070	Service Routines ENTRY 4		
DOWNFLAG	FC-2070	Service Routines ENTRY 4		
DPADD	FC-2370	DAP Interface and Service Routines ENTRY 26		
DPDPTPLG	FC-2070	Service Routines	C-6	
	FC-2200	T4RUPT	C-31,32	
	FC-2220	P06 GWCS Power Down		C-3
	FC-2683	Servicer S-25	C-3	
	FC-2720	P52 IMU Realignment Program S-4,23		

	FC-2060	Waitlist		T-25	
DSKYFLAG	FC-2070	Service Routines	C-6		
	FC-2150	Keypurt and Uprupt S-4			
	FC-2200	T4RUPT		T-4	
DSPOUTSB	FC-2200	T4RUPT ENTRY 47			
DSPTAB*1	FC-2070	Service Routines S-13	C-13		
DYNDISP	FC-2681	Cloktask and Clockjob ENTRY 4			
D6OR9FLG	FC-2290	Integraton Initialization		C-3,16	
	FC-2300	Orbital Integration			T-33
	FC-2550	P20 Rendezvous Navigation		C-7	
	FC-2590	P22 Orbital Navigation S-10,18		C-11,18	
	FC-2600	P23 Cislunar Midcourse Navigation			C-14
	FC-2070	Service Routines	C-6		
ERROT*2	FC-2760	P60's Entry Programs CALLED 30			
EARTH*	FC-2530	Prelaunch Initialization and Gyro Compassing			ENTRY 38
EARTH*+3	FC-2530	Prelaunch Initialization and Gyro Compassing			ENTRY 38
	FC-2540	P11 Earth Orbit Insertation Monitor CALLED 5			
EARTH*+	FC-2530	Prelaunch Initialization and Gyro Compassing			ENTRY 37
ECSTEER	FC-2626	P32, P72--CSI S-2			
EGSW	FC-2070	Service Routines	C-6		
	FC-2770	Reentry Control S-25	C-6		T-9
ENABL2	FC-2430	TVC Start-up, Executive, and Service Routines			ENTRY 20
ENATMA	FC-2370	DAP Interface and Service Routines			ENTRY 18
ENDEXT	FC-2650	Orbital Parameters Display CALLED 14			
	FC-2650	Orbital Parameters Display CALLED 14			
ENDMARK	FC-2242	R57 Optics Calibration Routine CALLED 5			
ENDNON	FC-2200	T4RUPT ENTRY 35			
ENGINOFF	FC-2630	P34/P74 TPI Targeting			ENTRY 24
ENGNONFLG	FC-2020	Fresh Start and Restart		C-26,6	T-20
	FC-2680	Thrust Programs (P40, P41) S-20		C-27	
ENG2FLAG	FC-2070	Service Routines	C-6		
	FC-2680	Thrust Programs (P40, P41) S-5		C-4	T-40
ENTRYDSP	FC-2070	Service Routines	C-6		
	FC-2760	P60's Entry Programs S-8,14,16		C-14	
ERADFLAG	FC-2320	TFFConics		C-14	
	FC-2540	P11 Earth Orbit Insertation Monitor			C-7
	FC-2580	P21 Ground Track Determination		C-5	
	FC-2590	P22 Orbital Navigation S-4			
	FC-2600	P23 Cislunar Midcourse Navigation S-16			
	FC-2070	Service Routines	C-6		
	FC-2642	P37 Return to Earth		C-32	
	FC-2720	P52 IMU Realignsment Program S-7			
	FC-2730	R52, R53, R56 S-5			
	FC-2760	P60's Entry Programs		C-18	
	FC-2770	Reentry Control	C-7		
ERASCALC	FC-2530	Prelaunch Initialization and Gyro Compassing			ENTRY 42
ERRORLIM	FC-2440	TVC DAP ENTRY 15			
	FC-2440	TVC DAP ENTRY 11,15			
ERTHRVSE	FC-2530	Prelaunch Initialization and Gyro Compassing			ENTRY 41
ESTIMS	FC-2530	Prelaunch Initialization and Gyro Compassing			ENTRY 11
ETPIFLAG	FC-2070	Service Routines	C-6		
	FC-2630	P34/P74 TPI Targeting S-3		C-3	T-3,4,7
EXDAPOFF	FC-2530	Prelaunch Initialization and Gyro Compassing			ENTRY 31
EXRSPT	FC-2430	TVC Start-up, Executive, and Service Routines			ENTRY 22
EXTVBAC*	FC-2325	Rendezvous Parameters Displays S-5			T-3,5
	FC-2070	Service Routines	C-12		
	FC-2650	Orbital Parameters Display			T-12,14
FALTON	FC-2325	Rendezvous Parameters Displays CALLED 2			
	FC-2330	R62 Crew Defined Maneuver (V49) CALLED 2			
	FC-2360	R64 (R05)--S-Band Antenna CALLED 2			



	FC-2361	V89 (R63) CALLED 2		
	FC-2550	P20 Rendezvous Navigation CALLED 17		
	FC-2600	P23 Cislunar Midcourse Navigation CALLED 5		
	FC-2605	Navigation Extended Verbs CALLED 2,6		
	FC-2020	Fresh Start and Restart CALLED 33		
	FC-2190	Extended Verbs CALLED 2		
	FC-2235	IMU Extended Verbs (V40, V41, V42) CALLED 6		
	FC-2650	Orbital Parameters Display CALLED 2		
	FC-2650	Orbital Parameters Display CALLED 2		
	FC-2290	Integration Initialization CALLED 18		
FAZAB5	FC-2300	Orbital Integration ENTRY 28		
FRF3	FC-2626	P32, P72--CSI S-7		T-3,6
FINALFLG	FC-2627	P33, P73--CDH		T-4
	FC-2070	Service Routines	C-6	
	FC-2630	P34/P74 TPI Targeting		T-16
	FC-2641	Common Targeting Subroutines		C-14
	FC-2642	P37 Return To Earth S-14		
	FC-2644	P38/P78; P39/P79 S-7,9		T-5,6,7,9
FINETIME	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 40		
	FC-2220	P06 GNCS Power Down CALLED 7		
FIRSTFLC	FC-2070	Service Routines	C-6	
FIRSTFLG	FC-2680	Thrust Programs (P40, P41) S-32		
FISHCALC	FC-2320	TFPCOnics ENTRY 12		
	FC-2760	P60's Entry Programs CALLED 23,24,27		
FIXDELAY	FC-2060	Waitlist ENTRY 10		
FRESFLAG	FC-2070	Service Routines	C-6	
FRESHDAP	FC-2380	DAP Interface Initialization and Phase I ENTRY 6		
FWDFLTR	FC-2440	TVC DAP ENTRY 4		
	FC-2440	TVC DAP ENTRY 4		
FYPX	FC-2120	AGC Block Two Selfcheck ENTRY 10		
F2RTP	FC-2070	Service Routines	C-6	
	FC-2642	P37 Return To Earth S-20	C-17	
GAMCOMP	FC-2300	Orbital Integration ENTRY 23		
GAMDIPS4	FC-2070	Service Routines	C-6	
GAMDV10	FC-2642	P37 Return To Earth ENTRY 23		
GENTPAN	FC-2550	P20 Rendezvous Navigation CALLED 18,20		
	FC-2020	Fresh Start and Restart CALLED 28		
	FC-2070	Service Routines ENTRY 11		
	FC-2240	SXTMARK CALLED 5		
	FC-2683	Servicer CALLED 4,19		
	FC-2700	P47 Thrust Monitor CALLED 7		
GEOM	FC-2310	Conic Subroutines ENTRY 34		
GETEPAD	FC-2320	TFPCOnics CALLED 12		
	FC-2600	P23 Cislunar Midcourse Navigation CALLED 18		
	FC-2642	P37 Return To Earth CALLED 7		
GET-LVC	FC-2641	Common Targeting Subroutines ENTRY 12		
GET+MGA	FC-2620	P30, P31 CALLED 5,9		
	FC-2626	P32, P72--CSI CALLED 6		
	FC-2641	Common Targeting Subroutines ENTRY 11		
GETUM	FC-2550	P20 Rendezvous Navigation ENTRY 38		
	FC-2590	P22 Orbital Navigation CALLED 12		
GETX	FC-2310	Conic Subroutines ENTRY 26		
GLOCKMON	FC-2200	T4RUPT ENTRY 43		
G10KPA10	FC-2020	Fresh Start and Restart		T-26,6
GOESTIMS	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 5		
GOINT	FC-2630	P34/P74 TPI Targeting ENTRY 14		
GONEBY	FC-2070	Service Routines	C-6	
	FC-2770	Reentry Control S-10	C-10	T-11,28
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	FC-2770	Reentry Control S-6,28	C-12	T-26,29

GOODEND	FC-2550	P20 Rendezvous Navigation CALLED	34			
GOPERFI	FC-2220	P06 GNCS Power Down CALLED	3			
GOPIN	FC-2310	DAP Interface and Service Routines	ENTRY	3		
GOPROG	FC-2020	Fresh Start and Restart	ENTRY	13		
GOPROG2	FC-2020	Fresh Start and Restart	ENTRY	20		
GOTOPOOH	FC-2020	Fresh Start and Restart	ENTRY	24		
GRBRKFLG	FC-2070	Service Routines		C-6		
GTSPCSSI	FC-2530	Prelaunch Initialization and Gyro Compassing	ENTRY	2		
GUESSW	FC-2010	Conic Subroutines		T-11,16		
	FC-2070	Service Routines		C-6		
	FC-2641	Common Targeting Subroutines	S-4		C-6	
GYMDIFSW	FC-2070	Service Routines		C-6		
	FC-2760	P60's Entry Programs		C-17		
	FC-2780	CM Entry Digital Autopilot	S-6		C-6	T-6
HACK	FC-2440	TVC DAP CALLED	2,10			
	FC-2440	TVC DAP CALLED	1,6			
	FC-2450	Stroke Test Package	ENTRY	2		
HACKWLST	FC-2450	Stroke Test Package	ENTRY	2		
HAVEGUS*	FC-2641	Common Targeting Subroutines	ENTRY	4		
	FC-2641	Common Targeting Subroutines	ENTRY	4		
HIENFRGY	FC-2310	Conic Subroutines	ENTRY	21		
WIND	FC-2070	Service Routines		C-6		
	FC-2770	Reentry Control	S-18		C-6,18	T-17
HOBIZ	FC-2600	P23 Cislunar Midcourse Navigation	ENTRY	18		
.05GSW	FC-2020	Fresh Start and Restart	S-6			
	FC-2683	Servicer		T-17		
	FC-2760	P60's Entry Programs		C-3		
	FC-2770	Reentry Control	S-11		C-6,11	T-12,24
	FC-2780	CM Entry Digital Autopilot			C-4	T-9
IBNKCALL	FC-2080	Inter-bank Communication	ENTRY	4		
IDLEFAIL	FC-2020	Fresh Start and Restart			C-26,6	
	FC-2681	Cloktask and Clockjob	S-10		C-10	
IGNFLAG	FC-2020	Fresh Start and Restart			C-25,6	
	FC-2680	Thrust Programs (P40, P41)	S-20			
	FC-2681	Cloktask and Clockjob	S-13			T-6
IGNITION	FC-2630	P34/P74 TPI Targeting	ENTRY	20		
	FC-2681	Cloktask and Clockjob	CALLED	6		
IMPULSW	FC-2020	Fresh Start and Restart	S-26		C-6	
	FC-2680	Thrust Programs (P40, P41)	S-17		C-19,21	T-21
IMURAD	FC-2200	T4RUPT CALLED	35			
IMUCAGE	FC-2200	T4RUPT	ENTRY	31		
IMUCOARS	FC-2235	IMU Extended Verbs (V40, V41, V42)	CALLED	5		
	FC-2720	P52 IMU Realignment Program	CALLED	23		
IMUFINE*	FC-2235	IMU Extended Verbs (V40, V41, V42)	CALLED	9		
IMUFINEK	FC-2235	IMU Extended Verbs (V40, V41, V42)	ENTRY	8		
IMUFINE20	FC-2720	P52 IMU Realignment Program	CALLED	23		
IMUMON	FC-2200	T4RUPT	ENTRY	25		
IMUOP	FC-2200	T4RUPT	ENTRY	32		
IMPULSE	FC-2235	IMU Extended Verbs (V40, V41, V42)	CALLED	9		
	FC-2720	P52 IMU Realignment Program	CALLED	26		
IMUSE	FC-2550	P20 Rendezvous Navigation			C-8	
	FC-2020	Fresh Start and Restart			C-37,6	
	FC-2220	P06 GNCS Power Down			C-3	
IMUSEFLA	FC-2200	T4RUPT		C-32		T-34,35
IMUSTALL	FC-2235	IMU Extended Verbs (V40, V41, V42)	CALLED	3,5,9		
	FC-2720	P52 IMU Realignment Program	CALLED	23,26		
IMUSTLLG	FC-2530	Prelaunch Initialization and Gyro Compassing	ENTRY	36		
IMUZERO	FC-2235	IMU Extended Verbs (V40, V41, V42)	CALLED	3		
INCORFLG	FC-2550	P20 Rendezvous Navigation	S-22,24		C-28	T-24,27,28
	FC-2590	P22 Orbital Navigation	S-14		C-17	T-17

	FC-2070	Service Routines	C-6	
INCRP1	FC-2550	P20 Rendezvous Navigation	CALLED 26	
	FC-2590	P22 Orbital Navigation	CALLED 15	
	FC-2600	P23 Cislunar Midcourse Navigation	CALLED 11	
	FC-2610	Measurement Incorporation	ENTRY 3	
INCRP2	FC-2550	P20 Rendezvous Navigation	CALLED 27	
	FC-2590	P22 Orbital Navigation	CALLED 16	
	FC-2600	P23 Cislunar Midcourse Navigation	CALLED 12	
	FC-2610	Measurement Incorporation	ENTRY 9	
INCRCDUS	FC-2100	RTB Op Codes	ENTRY 9	
INFINFLG	FC-2310	Conic Subroutines	S-29	C-29
	FC-2070	Service Routines		C-6
INFINITY	FC-2310	Conic Subroutines	ENTRY 29	
INITIALW	FC-2550	P20 Rendezvous Navigation	ENTRY 36	
INITSUR	FC-2020	Fresh Start and Restart	ENTRY 25	
INITV	FC-2310	Conic Subroutines	ENTRY 20	
INITVEL	FC-2545	P17/P77--TPI Search Programs	CALLED 8	
	FC-2630	P34/P74 TPI Targeting	CALLED 12	
	FC-2641	Common Targeting Subroutines	ENTRY 4	
	FC-2680	Thrust Programs (P40, P41)	CALLED 39	
INRLSW	FC-2070	Service Routines		C-6
	FC-2770	Reentry Control	S-12	C-6
INSTALL	FC-2580	P21 Ground Track Determination	CALLED 3	T-12
	FC-2610	Measurement Incorporation	CALLED 7	
INTEGRV	FC-2580	P21 Ground Track Determination	CALLED 4	
INTEGRV	FC-2290	Integration Initialization	ENTRY 8	
	FC-2550	P20 Rendezvous Navigation	CALLED 4,5,21,22	
	FC-2580	P21 Ground Track Determination	CALLED 4	
	FC-2590	P22 Orbital Navigation	CALLED 12	
	FC-2600	P23 Cislunar Midcourse Navigation	CALLED 15	
INTEGRV5	FC-2290	Integration Initialization	ENTRY 8	
	FC-2325	Rendezvous Parameters Displays	CALLED 9	
	FC-2630	P34/P74 TPI Targeting	CALLED 15	
	FC-2641	Common Targeting Subroutines	CALLED 7	
	FC-2642	P37 Return To Earth	CALLED 44	
INTEGRV7	FC-2290	Integration Initialization	ENTRY 8	
	FC-2300	Orbital Integration	CALLED 35	
INTPLAG	FC-2290	Integration Initialization	S-11	C-13
	FC-2020	Fresh Start and Restart		C-18,20,6
INTGRATE	FC-2300	Orbital Integration	ENTRY 8	
INTGRV5	FC-2670	P76 Target Delta V Program	CALLED 3	
INTINT	FC-2626	P32, P72--CSI	CALLED 3,15,16	
	FC-2627	P33, P73--CDH	CALLED 2	
	FC-2630	P34/P74 TPI Targeting	ENTRY 14	
INTINT2C	FC-2626	P32, P72--CSI	ENTRY 15	
INTINT3P	FC-2627	P33, P73--CDH	ENTRY 2	
INTRPVP	FC-2644	P38/P78; P39/P79	ENTRY 12	
INTSTALL	FC-2290	Integration Initialization	ENTRY 10	
	FC-2325	Rendezvous Parameters Displays	CALLED 8,9,10	
	FC-2550	P20 Rendezvous Navigation	CALLED 7,9	
	FC-2590	P22 Orbital Navigation	CALLED 10,18	
	FC-2600	P23 Cislunar Midcourse Navigation	CALLED 14	
	FC-2605	Navigation Extended Verbs	CALLED 3	
	FC-2020	Fresh Start and Restart	CALLED 35	
	FC-2641	Common Targeting Subroutines	CALLED 6	
	FC-2642	P37 Return To Earth	CALLED 42,43	
	FC-2650	Orbital Parameters Display	CALLED 13	
	FC-2650	Orbital Parameters Display	CALLED 13	
	FC-2670	P76 Target Delta V Program	CALLED 2,3	
INTWAKE	FC-2290	Integration Initialization	ENTRY 12	

	FC-2300	Orbital Integration CALLED 40			
	FC-2320	TPFConics CALLED 14			
	FC-2605	Navigation Extended Verbs CALLED 4			
	FC-2610	Measurement Incorporation CALLED 12			
INTWAKDO	FC-2290	Integration Initialization ENTRY 12			
	FC-2670	P76 Target Delta V Program CALLED 4			
INTWAKFU	FC-2290	Integration Initialization ENTRY 14			
INTWAKEO	FC-2320	TPFConics CALLED 14			
INTYPLFG	FC-2290	Integration Initialization S-7	C-3,6,20	T-8	
	FC-2325	Rendezvous Parameters Displays S-8,9	C-8,9		
	FC-2550	P20 Rendezvous Navigation	C-7		
	FC-2580	P21 Ground Track Determination	C-4		
	FC-2590	P22 Orbital Navigation	C-10,18		
	FC-2600	P23 Cislunar Midcourse Navigation	C-14		
	FC-2070	Service Routines	C-6		
	FC-2630	P34/P74 TPI Targeting S-14	C-14		
	FC-2641	Common Targeting Subroutines	C-7		
	FC-2642	P37 Return To Earth S-42	C-42,43		
	FC-2670	P76 Target Delta V Program	C-3		
ISWCALL	FC-2080	Inter-bank Communication ENTRY 4			
ISWBETEN	FC-2080	Inter-bank Communication ENTRY 4			
IIEPATOR	FC-2310	Conic Subroutines ENTRY 36			
ITSWICH	FC-2545	P17/P77--TPI Search Programs S-10	C-7	T-10	
	FC-2627	P33, P73--CDH S-4			
	FC-2070	Service Routines	C-6		
	FC-2630	P34/P74 TPI Targeting S-3	C-3,4	T-4,7	
ITURNOM	FC-2200	T4RUPT ENTRY 29			
JETSLECT	FC-2380	DAP Interface Initialization and Phase I CALLED 2			
	FC-2390	RCS DAP Phase 2 CALLED 11			
	FC-2400	RCS DAP Jet Selection Logic ENTRY 1			
	FC-2460	Roll Autopilot CALLED 2			
JOBSLEEP	FC-2290	Integration Initialization CALLED 10			
JOBWAKE	FC-2290	Integration Initialization CALLED 13			
	FC-2670	P76 Target Delta V Program CALLED 10			
JSWITCH	FC-2300	Orbital Integration S-33	C-8	T-8,27	
	FC-2070	Service Routines	C-6		
KALCMAN3	FC-2340	R60 Attitude Maneuver CALLED 4			
KEPLERN	FC-2300	Orbital Integration CALLED 31			
	FC-2310	Conic Subroutines ENTRY 4			
KEPPREP	FC-2290	Integration Initialization CALLED 9			
	FC-2300	Orbital Integration ENTRY 29			
KEYCOM	FC-2150	Keyrupt and Uprupt ENTRY 4			
	FC-2240	SXTMARK CALLED 4			
KEYRUPT1	FC-2150	Keyrupt and Uprupt ENTRY 3			
KFLAG	FC-2545	P17/P77--TPI Search Programs S-4,5	C-4,5	T-5,6,7,10,11	
	FC-2070	Service Routines	C-6		
KLEENEX	FC-2550	P20 Rendezvous Navigation CALLED 18			
	FC-2240	SXTMARK CALLED 8			
	FC-2730	R52, R53, R56 CALLED 5			
KMATEIX	FC-2390	RCS DAP Phase 2 CALLED 6			
KNOWNPLG	FC-2590	P22 Orbital Navigation S-6	C-6	T-7,13	
	FC-2070	Service Routines	C-6		
LALOTOVY	FC-2320	TPFConics CALLED 14			
	FC-2540	P11 Earth Orbit Insertation Monitor CALLED			
	FC-2590	P22 Orbital Navigation CALLED 23			
	FC-2600	P23 Cislunar Midcourse Navigation CALLED 16			
	FC-2720	P52 IMU Realignment Program CALLED 8			
	FC-2730	R52, R53, R56 CALLED 8			
LAMBERT	FC-2310	Conic Subroutines ENTRY 14			
	FC-2641	Common Targeting Subroutines CALLED 6			

LAMENTER	FC-2310	Conic Subroutines ENTRY	35	
LASTBIAS	FC-2683	Servicer CALLED	2	
LATAZCHK	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY	47	
LATSW	FC-2070	Service Routines	C-6	
	FC-2770	Reentry Control S-6	C-23	
	FC-2780	CM Entry Digital Autopilot S-4,14		T-14
LAT-LONG	FC-2580	P21 Ground Track Determination CALLED	5	
	FC-2590	P22 Orbital Navigation CALLED	7,20	
	FC-2642	P37 Return To Earth CALLED	33	
	FC-2720	P52 IMU Realignment Program CALLED	7	
	FC-2760	P60's Entry Programs CALLED	18	
LFMCONIC	FC-2361	V89 (R63) CALLED	4	
	FC-2545	P17/P77--TPI Search Programs CALLED	3,8	
	FC-2190	Extended Verbs CALLED	4	
	FC-2730	R52, R53, R56 CALLED	8	
LFMPREC	FC-2290	Integration Initialization ENTRY	6	
	FC-2325	Rendezvous Parameters Displays CALLED	7,10	
	FC-2641	Common Targeting Subroutines CALLED	15	
LFMSTOFF	FC-2545	P17/P77--TPI Search Programs CALLED	3	
	FC-2641	Common Targeting Subroutines ENTRY	15	
LFTPLGON	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY	33	
LINUS	FC-2340	R60 Attitude Maneuver CALLED	8	
LINVEL	FC-2300	Orbital Integration CALLED	44	
LIVINGO	FC-2550	P20 Rendezvous Navigation ENTRY	1	
	FC-2580	P21 Ground Track Determination ENTRY	1	
	FC-2605	Navigation Extended Verbs ENTRY	1	
LITFLSWR	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY	46	
LLASRD	FC-2720	P52 IMU Realignment Program CALLED	7	
LLASRDA	FC-2720	P52 IMU Realignment Program CALLED	8	
LMOONPLG	FC-2290	Integration Initialization S-5	C-5	T-5
	FC-2550	P20 Rendezvous Navigation		T-35
LMPREC	FC-2644	P38/P78; P39/P79 CALLED	12	
LCADCOFF	FC-2430	TVC Start-up, Executive, and Service Routines ENTRY	31	
LCADTIME	FC-2290	Integration Initialization CALLED	3,19	
	FC-2300	Orbital Integration CALLED	36	
	FC-2360	R64 (R05)--S-Band antenna CALLED	3	
	FC-2361	V89 (R63) CALLED	3	
	FC-2550	P20 Rendezvous Navigation CALLED	3,11,19,20	
	FC-2580	P21 Ground Track Determination CALLED	5	
	FC-2590	P22 Orbital Navigation CALLED	3,7	
	FC-2600	P23 Cislunar Midcourse Navigation CALLED	7	
	FC-2100	RTB Op Codes ENTRY	2	
	FC-2190	Extended Verbs CALLED	3	
	FC-2631	R36 (V90) CALLED	3	
	FC-2640	P35-P75 TPM Targeting CALLED	1	
	FC-2650	Orbital Parameters Display CALLED	6	
	FC-2650	Orbital Parameters Display CALLED	6	
	FC-2720	P52 IMU Realignment Program CALLED	5,18	
	FC-2730	R52, R53, R56 CALLED	6,9	
LOCSAY	FC-2720	P52 IMU Realignment Program ENTRY	11	
LCD SAYPT	FC-2150	Keypurt and Uprupt CALLED	3,5	
LOMAT	FC-2620	P30, P31 CALLED	3	
	FC-2630	P34/P74 TPI Targeting ENTRY	14,15	
LONGCALL	FC-2060	Waitlist ENTRY	21	
LOWMERRY	FC-2600	P23 Cislunar MidCourse Navigation ENTRY	5	
LSP0S	FC-2300	Orbital Integration CALLED	11	
	FC-2720	P52 IMU Realignment Program CALLED	11	
LUMPOS	FC-2300	Orbital Integration CALLED	45	
LUNAPLAG	FC-2580	P21 Ground Track Determination S-4	C-4	
	FC-2590	P22 Orbital Navigation S-4,20,22,24	C-4,20,22,24	

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 FC-2642 P37 Return To Earth C-32  
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 FC-2760 P60's Entry Programs C-18  
 FC-2770 Reentry Control C-7  
 LUNAPLG FC-2720 P52 IMU Realignment Program S-7  
 LUNPOS FC-2360 R64 (R05)--S-Band Antenna CALLED 3  
 FC-2600 P23 Cislunar Midcourse Navigation CALLED 15  
 FC-2190 Extended Verbs CALLED 3  
 MAINRTNE FC-2644 P38/P78; P39/P79 ENTRY 6  
 MAKECADR FC-2340 R60 Attitude Maneuver CALLED 2  
 FC-2550 P20 Rendezvous Navigation CALLED 10  
 FC-2080 Inter-bank Communication ENTRY 2  
 FC-2670 P76 Target Delta V Program CALLED 10  
 FC-2720 P52 IMU Realignment Program CALLED 13  
 FC-2730 R52, R53, R56 CALLED 6  
 MARKCON FC-2240 SXTMARK ENTRY 5  
 \*ARKDIP FC-2240 SXTMARK ENTRY 9  
 MARKDISP FC-2240 SXTMARK CALLED 5  
 FC-2242 R57 Optics Calibration Routine ENTRY 4  
 MARKINDX FC-2720 P52 IMU Realignment Program S-18  
 MARKIT FC-2240 SXTMARK ENTRY 9  
 MARKR0PT FC-2240 SXTMARK ENTRY 4  
 MARK2 FC-2240 SXTMARK ENTRY 6  
 MASSPROP FC-2370 DAP Interface and Service Routines CALLED 9  
 FC-2430 TVC Start-up, Executive, and Service Routines ENTRY 23  
 FC-2020 Fresh Start and Restart CALLED 31  
 FC-2680 Thrust Programs (P40, P41) CALLED 25  
 MATMOVE FC-2720 P52 IMU Realignment Program ENTRY 27  
 MATRXJOB FC-2540 P11 Earth Orbit Insertion Monitor ENTRY 7  
 MAXCHK FC-2620 P30, P31 CALLED 4,8  
 MAXDBPLG FC-2370 DAP Interface and Service Routines S-8 C-8  
 FC-2020 Fresh Start and Restart C-6 T-25  
 MGLVFLAG FC-2070 Service Routines C-6  
 FC-2641 Common Targeting Subroutines S-12 C-11  
 MIDAVPLG FC-2290 Integration Initialization S-20  
 FC-2300 Orbital Integration C-40 T-32  
 FC-2070 Service Routines C-6  
 MIDFLAG FC-2300 Orbital Integration S-3 C-3 T-6,10,38,41  
 FC-2070 Service Routines C-6  
 MIDGIM FC-2620 P30, P31 CALLED 8  
 FC-2680 Thrust Programs (P40, P41) CALLED 34,36  
 MIDTOAV1 FC-2290 Integration Initialization ENTRY 19  
 FC-2680 Thrust Programs (P40, P41) CALLED 12  
 MIDTOAV2 FC-2290 Integration Initialization ENTRY 19  
 FC-2700 P47 Thrust Monitor CALLED 3  
 FC-2760 P60's Entry Programs CALLED 19  
 MID1FLAG FC-2290 Integration Initialization S-19 C-19  
 FC-2300 Orbital Integration T-36  
 FC-2070 Service Routines C-6  
 MINIRECT FC-2290 Integration Initialization CALLED 17  
 FC-2300 Orbital Integration ENTRY 43  
 FC-2670 P76 Target Delta V Program CALLED 4  
 MKOVFLAG FC-2070 Service Routines C-6  
 MKREJECT FC-2240 SXTMARK ENTRY 7  
 MKRELEAS FC-2590 P22 Orbital Navigation CALLED 9  
 FC-2240 SXTMARK ENTRY 3  
 FC-2720 P52 IMU Realignment Program CALLED 19  
 FC-2730 R52, R53, R56 CALLED 5

MKRLEES	FC-2550	P20 Rendezvous Navigation	CALLED 7		
MKBV51	FC-2240	SIXMARK ENTRY	8		
MNDSPLAG	FC-2020	Fresh Start and Restart	CALLED 21		
MOONFLAG	FC-2290	Integration Initialization	S-5,14,21	C-5,14	T-5,8
	FC-2300	Orbital Integration	S-44	C-44	T-11,13,15,19
				31,40,41,44	
				45	
MOONFLAG	FC-2325	Rendezvous Parameters Displays	S-8,9	C-8,9	
	FC-2580	P21 Ground Track Determination	S-4	C-3	
	FC-2070	Service Routines		C-6	
	FC-2630	P34/P74 TPI Targeting	S-14	C-14	
	FC-2641	Common Targeting Subroutines	S-7	C-7	
	FC-2642	P37 Return To Earth		C-43	
	FC-2670	P76 Target Delta V Program	S-3	C-3	
MOONTHIS	FC-2325	Rendezvous Parameters Displays			T-8,9
	FC-2610	Measurement Incorporation			T-10
MOVEACSM	FC-2610	Measurement Incorporation	CALLED 11		
MOVEALEM	FC-2610	Measurement Incorporation	CALLED 11		
MOVEPCSM	FC-2610	Measurement Incorporation	CALLED 10		
MOVEPLEM	FC-2610	Measurement Incorporation	CALLED 10		
MF.KLEAN	FC-2020	Fresh Start and Restart	ENTRY 7		
MRKIDFLG	FC-2070	Service Routines		C-6	
MRKNVFLG	FC-2070	Service Routines		C-6	
MRUPTFLG	FC-2070	Service Routines		C-6	
MVAI^FLG	FC-2070	Service Routines		C-6	
MXM3	FC-2340	B60 Attitude Maneuver	CALLED 6,7		
	FC-2350	Maneuver Calculations and Steering	ENTRY 25		
NBDONLY	FC-2060	Waitlist	CALLED 20		
NBSM	FC-2550	P20 Rendezvous Navigation	CALLED 38		
	FC-2730	B52, B53, B56	CALLED 13		
NEEDFLG	FC-2380	DAP Interface Initialization and Phase I			T-5
NEPDLER	FC-2370	DAP Interface and Service Routines	ENTRY 20		
	FC-2380	DAP Interface Initialization and Phase I	CALLED 5		
	FC-2430	TVC Start-up, Executive, and Service Routines	CALLED 7,11		
	FC-2460	Roll Autopilot	CALLED 5		
	FC-2540	P11 Earth Orbit Insertation Monitor	CALLED 4,16,17,20,21		
NEEDLES3	FC-2370	DAP Interface and Service Routines	ENTRY 21		
NEPDLFLG	FC-2370	DAP Interface and Service Routines	S-19	C-18	
	FC-2070	Service Routines		C-6	
	FC-2680	Thrust Programs (P40, P41)	S-12,13	C-12	
NFGP	FC-2310	Conic Subroutines	ENTRY 21		
NFWIPLG	FC-2290	Integration Initialization	S-8		
	FC-2300	Orbital Integration		C-6	T-6
	FC-2070	Service Routines		C-6	
NFWM^ODPA	FC-2020	Fresh Start and Restart	CALLED 42		
	FC-2030	Phase Table Maintenance	ENTRY 2		
NLW^M^ODFX	FC-2540	P11 Earth Orbit Insertation Monitor	CALLED 4		
	FC-2030	Phase Table Maintenance	ENTRY 2		
	FC-2760	P60's Ftry Programs	CALLED 5,10,12,13,15,16		
NBWPHASE	FC-2030	Phase Table Maintenance	ENTRY 4		
NEWSTATEB	FC-2310	Conic Subroutines	ENTRY 35		
NEW^COL	FC-2370	Orbital Integration	ENTRY 35		
NJETS^FLG	FC-2370	DAP Interface and Service Routines	S-15	C-15	
	FC-2070	Service Routines		C-6	
	FC-2642	P37 Return To Earth			T-11
	FC-2680	Thrust Programs (P40, P41)			T-5,17
NOACY	FC-2400	RCS DAP Jet Selection Logic	ENTRY 8		
NOATTOFF	FC-2200	T4RUPT Called	34,35		
NOBDZ	FC-2400	RCS DAP Jet Selection Logic	ENTRY 6		
NODO^LA^S	FC-2290	Integration Initialization	S-3	C-4	

	FC-2020	Fresh Start and Restart		C-37,6	T-32
	FC-2140	Alarm and Abort	C-12		
	FC-2220	P06 GNCS Power Down S-2	C-6		
	FC-2670	P76 Target Delta V Program S-2		C-4	
	FC-2780	CM Entry Digital Autopilot S-5			
NODOPO1	FC-2540	P11 Earth Orbit Insertation Monitor S-4			
NOEBANK	FC-2120	AGC Block Two Selfcheck ENTRY 6			
NOEHOR	FC-2070	Service Routines	C-6		
NORPHOR	FC-2600	P23 Cislunar Midcourse Navigation S-6		C-6	T-22
NORMLIZE	FC-2540	P11 Earth Orbit Insertation Monitor CALLED 9			
	FC-2683	Service ENTRY 4			
NORNSW	FC-2310	Conic Subroutines	C-33		T-34
	FC-2620	P30, P31	C-7		
	FC-2070	Service Routines	C-6		
	FC-2641	Common Targeting Subroutines S-5		C-4	
	FC-2642	P37 Return To Earth	C-14		
	FC-2680	Thrust Programs (P40, P41)			T-38
NORMUNI"	FC-2100	RTB Op Codes ENTRY 15			
NORMUNK1	FC-2100	RTB Op Codes ENTRY 15			
NOSWITCH4	FC-2070	Service Routines	C-6		
	FC-2770	Reentry Control S-19	C-6,30,31		T-30
NO2Y	FC-2400	RCS DAP Jet Selection Logic ENTRY 10			
NEMIDFLG	FC-2070	Service Routines	C-6		
NFMNVFLC	FC-2070	Service Routines	C-6		
NFUPTFLG	FC-2070	Service Routines	C-6		
NWAITFLG	FC-2070	Service Routines	C-6		
N22ORN17	FC-2370	DAP Interface and Service Routines S-19		C-19	
	FC-2380	DAP Interface Initialization and Phase I			T-5
	FC-2070	Service Routines	C-6		
OPTMODES	FC-2070	Service Routines S-13			
OPTMON	FC-2200	T4RUPT ENTRY 11			
OPTNSW	FC-2070	Service Routines	C-6		
	FC-2644	P38/P78; P39/P79 S-4	C-4		T-5
OPTSTALL	FC-2730	R52, R53, R56 CALLED 11			
OPTTEST	FC-2200	T4RUPT ENTRY 6			
ORBRFLAG	FC-2290	Integration Initialization		C-14	T-4,16
	FC-2300	Orbital Integration	C-37		
	FC-2550	P20 Rendezvous Navigation		C-22	
	FC-2590	P22 Orbital Navigation		C-39	T-11,18
	FC-2600	P23 Cislunar Midcourse Navigation S-15			T-14,15
	FC-2605	Navigation Extended Verbs		C-5,7	
	FC-2070	Service Routines	C-6		
OPDERSW	FC-2310	Conic Subroutines			T-36,37
	FC-2070	Service Routines	C-6		
ORIGCHNG	FC-2300	Orbital Integration ENTRY 44			
OTHPREC	FC-2631	R36 (V90) CALLED 4			
	FC-2650	Orbital Parameters Display CALLED 7			
	FC-2650	Orbital Parameters Display CALLED 7			
	FC-2670	P76 Target Delta V Program CALLED 2			
OVERPFIX	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 36			
PARAM	FC-2310	Conic Subroutines ENTRY 33			
	FC-2642	P37 Return To Earth CALLED 35			
PASSIVE	FC-2626	P32, P73--CSI CALLED 3			
	FC-2627	P33, P73--CDR CALLED 2			
PCOPY	FC-2430	TVC Start-up, Executive, and Service Routines CALLED 19			
	FC-2440	TVC DAP ENTRY 8			
	FC-2440	TVC DAP ENTRY 8			
PDSPFLAG	FC-2340	R60 Attitude Maneuver S-8			T-4,8
	FC-2550	P20 Rendezvous Navigation S-10		C-10	T-34
	FC-2070	Service Routines	C-6		



PERIAPO FC-2545 P17/P77--TPI Search Programs CALLED 9  
 FC-2626 P32, P72--CSI CALLED 13  
 FC-2641 Common Targeting Subroutines ENTRY 13  
 PFRIAPOI FC-2620 P30, P31 CALLED 4,8  
 PFERIAPO1 FC-2626 P32, P72--CSI CALLED 16  
 FC-2630 P34/P74 TPI Targeting CALLED 5  
 FC-2641 Common Targeting Subroutines ENTRY 13  
 FC-2644 P38/P78; P39/P79 CALLED 7  
 PPAILOK FC-2200 T4RUPT CALLED 37  
 PFRATPLG FC-2070 Service Routines C-6  
 FC-2680 Thrust Programs (P40, P41) S-6  
 FC-2720 P52 IMU Realignment Program C-4,20  
 PHASCHNG FC-2030 Phase Table Maintenance ENTRY 5  
 PICAPAR FC-2720 P52 IMU Realignment Program ENTRY 13  
 PINRRFLG FC-2070 Service Routines C-6  
 PINRRWCH FC-2370 DAP Interface and Service Routines CALLED 3  
 FC-2605 Navigation Extended Verbs CALLED 2,6,7  
 PIPACHK FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 6  
 PIPASR FC-2683 Servicer ENTRY 9  
 PIPATASK FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 7  
 PIPFAIL FC-2200 T4RUPT ENTRY 41  
 PIPFREE FC-2683 Servicer CALLED 26  
 PIJOB8R FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 8  
 PITCHDAP FC-2440 TVC DAP ENTRY 2  
 FC-2440 TVC DAP ENTRY 2  
 PITCHTIM FC-2400 RCS DAP Jet Selection Logic ENTRY 11  
 PLANET FC-2720 P52 IMU Realignment Program CALLED 18,19  
 POINTAKS FC-2600 P23 Cislunar Midcourse Navigation ENTRY 13  
 POLY FC-2310 Conic Subroutines CALLED 25,28  
 FC-2642 P37 Return To Earth CALLED 4,6,11  
 PCODOO FC-2300 Orbital Integration CALLED 22  
 FC-2060 Waitlist CALLED 9  
 FC-2140 Alarm and Abort ENTRY 5  
 POOFLAG FC-2290 Integration Initialization S-3 T-5  
 FC-2300 Orbital Integration  
 FC-2020 Fresh Start and Restart C-26,6  
 POOKLEAN FC-2020 Fresh Start and Restart ENTRY 7  
 POSN17C FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 36  
 POSTAND FC-2220 P06 GNCS Power Down ENTRY 4  
 POSTBURN FC-2630 P34/P74 TPI Targeting ENTRY 29  
 POSTJUMP FC-2080 Inter-bank Communication ENTRY 2  
 POST41 FC-2630 P34/P74 TPI Targeting ENTRY 30  
 FC-2681 Cloktask and Clockjob CALLED 5  
 POWRSEFS FC-2540 P11 Earth Orbit Insertation Monitor CALLED 11  
 PRECIPLG FC-2300 Orbital Integration C-40 T-5  
 FC-2070 Service Routines C-6  
 FC-2290 Integration Initialization S-4,6,8 C-4  
 PRECOMP FC-2440 TVC DAP ENTRY 7  
 FC-2440 TVC DAP ENTRY 7  
 PREC/TT FC-2644 P38/P78; P39/P79 ENTRY 11  
 PRECSET FC-2626 P32, P72--CSI CALLED 9  
 FC-2630 P34/P74 TPI Targeting CALLED 4  
 FC-2640 P35-P75 TPM Targeting CALLED 1  
 FC-2641 Common Targeting Subroutines ENTRY 15  
 FC-2644 P38/P78; P39/P79 CALLED 10,11  
 PREC100 FC-2642 P37 Return To Earth ENTRY 34  
 PREREAD FC-2680 Thrust Programs (P40, P41) CALLED 15  
 FC-2683 Servicer ENTRY 2  
 FC-2700 P47 Thrust Monitor CALLED 4  
 FC-2760 P60's Entry Programs CALLED 20

PREHEAD1 FC-2540 P11 Earth Orbit Insertation Monitor CALLED 4  
 FC-2683 Servicer ENTRY 3  
 PRESWTCH FC-2430 TVC Start-up, Executive, and Service Routines ENTRY 28  
 PREVGAM FC-2320 TFPConics ENTRY 11  
 FC-2760 P60's Entry Programs CALLED 25,28  
 PRB40.6 FC-2680 Thrust Programs (P40, P41) ENTRY 44  
 FC-2681 Cloktask and Clockjob CALLED 13  
 PFPTRKAT FC-2361 V89 (R63) S-3 C-3 T-5  
 FC-2550 P20 Rendezvous Navigation S-3  
 FC-2070 Service Routines C-6  
 FC-2190 Extended Verbs S-3 C-3 T-5  
 PPIOCHNG FC-2340 R60 Attitude Maneuver CALLED 8  
 FC-2370 DAP Interface and Service Routines CALLED 6  
 FC-2550 P20 Rendezvous Navigation CALLED 6,19,31  
 FC-2650 Orbital Parameters Display CALLED 2  
 FC-2650 Orbital Parameters Display CALLED 2  
 FC-2700 P47 Thrust Monitor CALLED 5  
 PRIODFLG FC-2070 Service Routines C-6  
 PRIODSPR FC-2140 Alarm and Abort CALLED 10  
 PFIOLAPM FC-2140 Alarm and Abort ENTRY 3  
 PPOCKEY FC-2200 T4RUPT CALLED 5  
 PROG20 FC-2550 P20 Rendezvous Navigation ENTRY 3  
 PROG21 FC-2580 P21 Ground Track Determination ENTRY 2  
 PPOG22 FC-2590 P22 Orbital Navigation ENTRY 2  
 PROGS2 FC-2720 P52 IMU Realignment Program ENTRY 1  
 PRONVFLG FC-2070 Service Routines C-6  
 PROUT FC-2530 Prelaunch Initialization and Gyro Compasing ENTRY 37  
 FC-2540 P11 Earth Orbit Insertation Monitor CALLED 5  
 PTOACSM FC-2290 Integration Initialization ENTRY 5  
 PTOALEM FC-2290 Integration Initialization ENTRY 5  
 PULSEIMU FC-2100 RT8 Op Codes ENTRY 12  
 P11 FC-2540 P11 Earth Orbit Insertation Monitor ENTRY 3  
 P17 FC-2545 P17/P77--TPI Search Programs ENTRY 3  
 P17.1 FC-2545 P17/P77--TPI Search Programs ENTRY 3  
 P17.2 FC-2545 P17/P77--TPI Search Programs ENTRY 5  
 P17.3 FC-2545 P17/P77--TPI Search Programs ENTRY 12  
 P20FLGON FC-2545 P17/P77--TPI Search Programs CALLED 3  
 FC-2627 P33, P73--CDH CALLED 1  
 FC-2630 P34/P74 TPI Targeting CALLED 2  
 FC-2640 P35-P75 TPM Targeting CALLED 6  
 FC-2644 P38/P78; P39/P79 CALLED 3,9  
 P21FLAG FC-2580 P21 Ground Track Determination S-4  
 FC-2020 Fresh Start and Restart C-8,26,6  
 P22MKFLG FC-2590 P22 Orbital Navigation S-9 C-4  
 FC-2070 Service Routines C-6  
 P22SUBP9 FC-2600 P23 Cislunar Midcourse Navigation CALLED 6  
 P23 FC-2600 P23 Cislunar Midcourse Navigation ENTRY 3  
 P3XORP7X FC-2626 P32, P72--CSI ENTRY 23  
 P30 FC-2620 P30, P31 ENTRY 2  
 P30/P31 FC-2620 P30, P31 ENTRY 2  
 P31 FC-2620 P30, P31 ENTRY 7  
 P32 FC-2626 P32, P72--CSI ENTRY 2  
 P33 FC-2627 P33, P73--CDH ENTRY 1  
 P34 FC-2630 P34/P74 TPI Targeting ENTRY 2  
 P35 FC-2640 P35-P75 TPM Targeting ENTRY 1  
 P37 FC-2642 P37 Return To Earth ENTRY 3  
 P38 FC-2644 P38/P78; P39/P79 ENTRY 3  
 P39 FC-2644 P38/P78; P39/P79 ENTRY 9  
 P39/79SW FC-2070 Service Routines C-6  
 FC-2644 P38/P78; P39/P79 S-9 T-6,8

P40CNV85	FC-2680 Thrust Programs (P40, P41) CALLED 11			
	FC-2681 Cloktask and Clockjob CALLED 4			
P40CSM	FC-2630 P34/P74 TPI Targeting ENTRY 4			
P40RCS	FC-2630 P34/P74 TPI Targeting ENTRY 29			
	FC-2681 Cloktask and Clockjob CALLED 7			
P41CSM	FC-2630 P34/P74 TPI Targeting ENTRY 5			
P47BODY	FC-2700 P47 Thrust Monitor ENTRY 5			
P47CSM	FC-2700 P47 Thrust Monitor ENTRY 3			
P52LS	FC-2720 P52 IMU Realignment Program ENTRY 7			
P61	FC-2760 P60's Entry Programs ENTRY 2			
P62	FC-2760 P60's Entry Programs ENTRY 6			
P62.3	FC-2760 P60's Entry Programs ENTRY 30			
P63	FC-2760 P60's Entry Programs ENTRY 10			
P64	FC-2760 P60's Entry Programs ENTRY 12			
P65	FC-2760 P60's Entry Programs ENTRY 13			
P66	FC-2760 P60's Entry Programs ENTRY 15			
P67	FC-2760 P60's Entry Programs ENTRY 16			
P67.1	FC-2760 P60's Entry Programs ENTRY 17			
P67.2	FC-2760 P60's Entry Programs ENTRY 18			
P72	FC-2626 P32, P72--CSI ENTRY 2			
P73	FC-2627 P33, P73--CDH ENTRY 1			
P74	FC-2630 P34/P74 TPI Targeting ENTRY 2			
P75	FC-2640 P35-P75 TFM Targeting ENTRY 1			
P76	FC-2670 P76 Target Delta V Program ENTRY 2			
P76SUB1	FC-2670 P76 Target Delta V Program ENTRY 3			
P77	FC-2645 P17/P77--TPI Search Programs ENTRY 3			
P78	FC-2644 P38/P78; P39/P79 ENTRY 3			
P79	FC-2644 P38/P78; P39/P79 ENTRY 9			
*NBSM	FC-2325 Rendezvous Parameters Displays CALLED 5			
*SMNB*	FC-2360 R64 (R06)--S-Band Antenna CALLED 4			
	FC-2550 P20 Rendezvous Navigation CALLED 4			
	FC-2100 Extended Verbs CALLED 4			
	FC-2700 P47 Thrust Monitor CALLED 8			
QUICTRIG	FC-2681 Cloktask and Clockjob CALLED 4			
QUIKDSP	FC-2200 T4RUPT ENTRY 46			
QUIKSPAD	FC-2683 Servicer ENTRY 15			
QUI?FLAG	FC-2300 Orbital Integration		T-3	
	FC-2070 Service Routines	C-6		
	FC-2290 Integration Initialization		C-3	T-3
RADSTALL	FC-2550 P20 Rendezvous Navigation CALLED 32			
RANGERD	FC-2550 P20 Rendezvous Navigation ENTRY 32			
RATELIM	FC-2460 Roll Autopilot ENTRY 4			
RCSATT	FC-2370 DAP Interface and Service Routines CALLED 4			
	FC-2380 DAP Interface Initialization and Phase I ENTRY 2			
	FC-2390 RCS DAP Phase 2 CALLED 2,3			
	FC-2400 RCS DAP Jet Selection Logic CALLED 16			
RCSDAP04	FC-2370 DAP Interface and Service Routines ENTRY 4			
	FC-2380 DAP Interface Initialization and Phase I CALLED 2			
	FC-2460 Roll Autopilot CALLED 2			
	FC-2020 Fresh Start and Restart CALLED 31			
	FC-2680 Thrust Programs (P40, P41) CALLED 25			
	FC-2681 Cloktask and Clockjob CALLED 9,13			
RCSDAPUP	FC-2370 DAP Interface and Service Routines ENTRY 4			
RCSPLAGS	FC-2350 Maneuver Calculations and Steering S-10		C-26	
	FC-2380 DAP Interface Initialization and Phase I S-2,3,8,5			C-8,5
	FC-2400 RCS DAP Jet Selection Logic S-17		C-16	T-17
	FC-2540 P11 Earth Orbit Insertation Monitor S-4,17,20			
RCSUP	FC-2380 DAP Interface Initialization and Phase I ENTRY 2			
RCDUS	FC-2720 P52 IMU Realignment Program ENTRY 27			
READACCS	FC-2683 Servicer ENTRY 5			

READCDUX	FC-2340	R60 Attitude Maneuver CALLED 5			
	FC-2350	Maneuver Calculations and Steering ENTRY 24			
RFPADPIPS	FC-2100	RT8 Op Codes ENTRY 4			
RECT.1	FC-2600	P23 Cislunar Midcourse Navigation ENTRY 17			
RECTIFY	FC-2300	Orbital Integration ENTRY 43			
	FC-2610	Measurement Incorporation CALLED 11			
	FC-2290	Integration Initialization CALLED 8,9			
RECTIFY+	FC-2290	Integration Initialization CALLED 14			
RECTOUT	FC-2300	Orbital Integration ENTRY 40			
	FC-2290	Integration Initialization CALLED 9			
REDO	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 31			
REDORCS	FC-2380	DAP Interface Initialization and Phase I ENTRY 2			
REDOSAT	FC-2370	DAP Interface and Service Routines CALLED 5			
	FC-2540	P11 Earth Orbit Insertation Monitor ENTRY 20			
REDOTVC	FC-2430	TVC Start-up, Executive, and Service Routines ENTRY 18			
REEFLG	FC-2720	P52 IMU Realignment Program			T-20
REFFAZE10	FC-2760	P60's Entry Program CALLED 13			
REFSMFLG	FC-2540	P11 Earth Orbit Insertation Monitor S-8			T-6,31
	FC-2550	P20 Rendezvous Navigation			T-4
	FC-2600	P23 Cislunar Midcourse Navigation			
	FC-2620	P30, P31	T-5,9		
	FC-2626	P32, P72--CSI		T-6	
	FC-2200	T4RUPT C-32,33			
	FC-2220	P06 GNCS Power Down C-3			
	FC-2720	P52 IMU Realignment Program S-4,5 C-3			
REINTFLG	FC-2300	Orbital Integration S-33,38			
	FC-2610	Measurement Incorporation S-7			
	FC-2020	Fresh Start and Restart C-20,6			
	FC-2140	Alarm and Abort C-12			
	FC-2290	Integration Initialization C-13			T-10,12
	FC-2670	P76 Target Delta V Program S-4			
RELDSP	FC-2020	Fresh Start and Restart CALLED 32,37,42			
RELVELSW	FC-2070	Service Routines C-6			
	FC-2770	Reentry Control S-9 C-6		T-9	
RENDWFLG	FC-2300	Orbital Integration C-37			
	FC-2550	P20 Rendezvous Navigation S-23			T-4,21,23
	FC-2590	P22 Orbital Navigation C-3,11			
	FC-2600	P23 Cislunar Midcourse Navigation C-6			
	FC-2605	Navigation Extended Verbs C-5,7			
	FC-2070	Service Routines C-6			
	FC-2290	Integration Initialization C-14			T-4,16
REPLACER	FC-2400	RCS DAP Jet Selection Logic ENTRY 19			
RFPPLACEY	FC-2400	RCS DAP Jet Selection Logic ENTRY 19			
REP11	FC-2540	P11 Earth Orbit Insertation Monitor ENTRY 6			
REREADAC	FC-2683	Servicer ENTRY 12			
RESETX2	FC-2310	Conic Subroutines ENTRY 30			
RFSTARTS	FC-2020	Fresh Start and Restart ENTRY 43			
RETROFLG	FC-2070	Service Routines C-6			
	FC-2642	P37 Return To Earth S-16 C-16			T-31
RLI*TEST	FC-2440	TVC DAP ENTRY 15			
	FC-2440	TVC DAP ENTRY 15			
RNDREFDR	FC-2200	T4RUPT CALLED 31,32			
RNDVZFLG	FC-2550	P20 Rendezvous Navigation S-3 C-8			T-8,17
	FC-2590	P22 Orbital Navigation C-3			
	FC-2600	P23 Cislunar Midcourse Navigation C-3			
	FC-2020	Fresh Start and Restart C-37,6			T-37,39,39
	FC-2200	T4RUPT C-33			
	FC-2220	P06 GNCS Power Down C-3			
	FC-2683	Servicer T-26			
RNGSCFLG	FC-2070	Service Routines C-6			

ROLDDAP	FC-2430	TVC Start-up, Executive, and Service Routines	CALLLED 11	
	FC-2460	Roll Autopilot	ENTRY 1	
ROLLTIMF	FC-2400	RCS DAP Jet Selection Logic	ENTRY 9	
ROTA	FC-2730	R52, R53, R56	ENTRY 10	
ROTATE	FC-2626	P32, P72--CSI	ENTRY 9	
ROUTINESB	FC-2070	Service Routines	ENTRY 12	
RPOFLAG	FC-2070	Service Routines		C-6
RPQFLAG	FC-2300	Orbital Integration S-22		T-44
	FC-2290	Integration Initialization	S-8	
RP-TO-R	FC-2300	Orbital Integration	CALLLED 20	
	FC-2590	P22 Orbital Navigation	CALLLED 7, 14	
	FC-2290	Integration Initialization	CALLLED 21	
	FC-2720	P52 IMU Realignment Program	CALLLED 7	
	FC-2730	R52, R53, R56	CALLLED 9	
RTEVN	FC-2642	P37 Return To Earth	ENTRY 28	
RVCON	FC-2290	Integration Initialization	ENTRY 9	
RVSU	FC-2310	Conic Subroutines		T-22
	FC-2545	P17/P77--TPI Search Programs	S-6	
	FC-2626	F32, P72--CSI	S-13,14	
	FC-2627	P33, P73--CDM		C-8
	FC-2630	P34/P74 TPI Targeting	S-4	
	FC-2070	Service Routines		C-6
	FC-2642	P37 Return To Earth	S-37	C-13,27
R-TO-PP	FC-2300	Orbital Integration	CALLLED 15	
	FC-2590	P22 Orbital Navigation	CALLLED 13,21	
R02BOTH	FC-2360	R64 (R05)--S-Band Antenna	CALLLED 3	
	FC-2361	V89 (R63)	CALLLED 2	
	FC-2550	P20 Rendezvous Navigation	CALLLED 3	
	FC-2590	P22 Orbital Navigation	CALLLED 3	
	FC-2190	Extended Verbs	CALLLED 2,3	
	FC-2640	Thrust Programs (P40, P41)	CALLLED 6	
	FC-2700	P47 Thrust Monitor	CALLLED 3	
	FC-2720	P52 IMU Realignment Program	CALLLED 1	
	FC-2760	P40's Entry Programs	CALLLED 19	
R21MARK	FC-2550	P20 Rendezvous Navigation	S-18	C-18
	FC-2020	Fresh Start and Restart		C-8,36,6
R22	FC-2550	P20 Rendezvous Navigation	ENTRY 19	
R22CAFLG	FC-2070	Service Routines		C-6
R23CSM	FC-2550	P20 Rendezvous Navigation	ENTRY 18	
R23FLG	FC-2550	P20 Rendezvous Navigation	S-17	C-17
	FC-2070	Service Routines		C-6
R23.55	FC-2600	P23 Cislunar Midcourse Navigation	ENTRY 10	
R31PLAG	FC-2325	Rendezvous Parameters Displays	S-2	C-2
	FC-2070	Service Routines		C-6
R36	FC-2631	R36 (V90)	ENTRY 3	
R51	FC-2720	P52 IMU Realignment Program	ENTRY 18	
R52	FC-2550	P20 Rendezvous Navigation	CALLLED 7	
	FC-2590	P22 Orbital Navigation	CALLLED 4	
	FC-2600	P23 Cislunar Midcourse Navigation	CALLLED 8	
	FC-2720	P52 IMU Realignment Program	CALLLED 19	
	FC-2730	R52, R53, R56	ENTRY 2	
R53	FC-2600	P23 Cislunar Midcourse Navigation	CALLLED 4	
	FC-2730	R52, R53, R56	ENTRY 11	
R53FLAG	FC-2070	Service Routines		C-6
	FC-2730	R52, R53, R56	S-11	T-3
R55	FC-2720	P52 IMU Realignment Program	ENTRY 26	
R56	FC-2720	P52 IMU Realignment Program	CALLLED 19	
	FC-2730	R52, R53, R56	ENTRY 14	
R57	FC-2600	P23 Cislunar Midcourse Navigation	CALLLED 4,8	
	FC-2242	P57 Optics Calibration Routine	ENTRY 2	

R57FLAG	FC-2600	P23 Cislunar Midcourse Navigation S-8	C-3,9	T-8
	FC-2070	Service Routines	C-6	
R60CSM	FC-2330	R62 Crew Defined Maneuver (V49) CALLED 3		
	FC-2340	R60 Attitude Maneuver ENTRY 2		
	FC-2361	V89 (R63) CALLED 3		
	FC-2550	P20 Rendezvous Navigation CALLED 10		
	FC-2600	P23 Cislunar Midcourse Navigation CALLED 8		
	FC-2190	Extended Verbs CALLED 3		
	FC-2680	Thrust Programs (P40, P41) CALLED 8		
R60FLAG	FC-2070	Service Routines	C-6	
R61CSM	FC-2550	P20 Rendezvous Navigation ENTRY 10		
	FC-2730	R52, R53, R56 CALLED 4		
R62DISP	FC-2330	R62 Crew Defined Maneuver (V49) ENTRY 3		
R63	FC-2361	V89 (R63) ENTRY 4		
	FC-2550	P20 Rendezvous Navigation CALLED 11		
	FC-2190	Extended Verbs ENTRY 4		
SATSTICK	FC-2540	P11 Earth Orbit Insertation Monitor ENTRY 21		
SATSTKON	FC-2370	DAP Interface and Service Routines ENTRY 5		
	FC-2540	P11 Earth Orbit Insertation Monitor ENTRY 19		
SAVSECLG	FC-2600	P23 Cislunar Midcourse Navigation S-9	C-4	T-5,6
	FC-2070	Service Routines	C-6	
SBANDANT	FC-2360	R64 (R05)--S-Band Antenna ENTRY 3		
SCALPREP	FC-2220	P06 GNCS Power Down ENTRY 7		
SCNDSOL	FC-2626	P32, P72--CSI ENTRY 21		
SELECTMU	FC-2626	P32, P72--CSI CALLED 2		
	FC-2627	P33, P73--CDH CALLED 1		
	FC-2630	P34/P74 TPI Targeting ENTRY 17		
	FC-2640	P35-P75 TPM Targeting CALLED 1		
	FC-2641	Common Targeting Subroutines ENTRY 14		
	FC-2644	P38/P78; P39/P79 CALLED 4,9		
SELFCHK	FC-2080	Inter-bank Communication ENTRY 3		
	FC-2120	AGC Block Two Selfcheck ENTRY 2		
SERVEXIT	FC-2683	Servicer ENTRY 27		
	FC-2700	P47 Thrust Monitor CALLED 7		
SERVICER	FC-2683	Servicer ENTRY 16		
SERVNOUT	FC-2760	P60's Entry Programs CALLED 18		
SETCOARS	FC-2200	T4RUPT CALLED 43		
SETGWLST	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 14		
SFTINTG	FC-2600	P23 Cislunar Midcourse Navigation ENTRY 14		
SFTISSW	FC-2200	T4RUPT ENTRY 30		
SETJTAG	FC-2683	Servicer CALLED 7		
SFTMAXDB	FC-2370	DAP Interface and Service Routines ENTRY 24		
	FC-2630	P34/P74 TPI Targeting ENTRY 25		
	FC-2020	Fresh Start and Restart CALLED 25		
SETMINDB	FC-2370	DAP Interface and Service Routines ENTRY 24		
	FC-2630	P34/P74 TPI Targeting ENTRY 7		
	FC-2020	Fresh Start and Restart CALLED 25		
SETRE	FC-2590	P22 Orbital Navigation CALLED 24		
SFTT5	FC-2380	DAP Interface Initialization and Phase I ENTRY 2		
SFTVOARS	FC-2020	Fresh Start and Restart CALLED 19		
SET1/PDT	FC-2720	P52 IMU Realignment Program CALLED 23		
SGNAGPER	FC-2300	Orbital Integration CALLED 4		
	FC-2100	RTB Op Codes ENTRY 5		
	FC-2631	R36 (V90) CALLED 6		
SHIPTR1	FC-2641	Common Targeting Subroutines ENTRY 10		
SHORTNP	FC-2220	P06 GNCS Power Down CALLED 5		
SHOW	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 25		
SIGNMPAC	FC-2300	Orbital Integration CALLED 5		
	FC-2320	TFPConics CALLED 9		
	FC-2350	Maneuver Calculations and Steering CALLED 7,16,17,18,19,20		

	FC-2100	RTB Op Codes	ENTFY 14			
SKIPVHP	FC-2550	P20 Rendezvous Navigation		C-32		T-34
	FC-2020	Fresh Start and Restart	S-8	C-6		
SIAPV	FC-2020	Fresh Start and Restart	ENTRY 2			
SLOPESW	FC-2310	Conic Subroutines	S-10,14	C-36		T-12,18,36
	FC-2070	Service Routines		C-6		
SLOWFLG	FC-2070	Service Routines		C-6		
	FC-2642	P37 Return To Earth	S-4	C-4		T-20
SMALLNP	FC-2370	DAP Interface and Service Routines	ENTRY 28			
	FC-2390	RCS DAP Phase 2	CALLED 10			
SMCDURES	FC-2550	P20 Rendezvous Navigation	CALLED 13			
SOLNSW	FC-2310	Conic Subroutines	S-12,19,21,23	C-10,14,24		
	FC-2070	Service Routines		C-6		
SCMERRRP	FC-2530	Prelaunch Initialization and Gyro Compassing	ENTRY 37			
SOMERR2	FC-2530	Prelaunch Initialization and Gyro Compassing	ENTRY 37			
SCPTION	FC-2120	AGC Block Two Selfcheck	ENTRY 13			
SOUPCPLG	FC-2550	P20 Rendezvous Navigation	S-33	C-20		T-24,26,27,
					29,30	
SOURCFLG	FC-2070	Service Routines		C-6		
SPCOS	FC-2110	Single Precision Subroutines	ENTRY 2			
SPSIN	FC-2110	Single Precision Subroutines	ENTRY 2			
SPSOPF	FC-2630	P34/P74 TPI Targeting	ENTRY 27			
	FC-2020	Fresh Start and Restart	CALLED 30			
	FC-2681	Cloktask and Clockjob	CALLED 9,12			
3P30.1	FC-2650	Orbital Parameters Display	ENTRY 15			
	FC-2650	Orbital Parameters Display	ENTRY 15			
SR52.1	FC-2730	R52, P53, R56	ENTRY 6			
STARLISH	FC-2370	DAP Interface and Service Routines	ENTRY 2			
STARIND	FC-2720	P52 IMU Realignment Program	S-18			T-19,20
STARTEM1	FC-2760	P60's Pnry Programs	CALLED 3			
STARTSB2	FC-2020	Fresh Start and Restart	ENTRY 8			
STAR*SUB	FC-2020	Fresh Start and Restart	ENTRY 8			
STAR*SW	FC-2020	Fresh Start and Restart	ENTRY 2			
STATEFLG	FC-2300	Orbital Inteqration	S-37	C-3,38		T-38
	FC-2550	P20 Rendezvous Navigation	S-7			
	FC-2590	P22 Orbital Navigation	S-10,18			
	FC-2600	P23 Cislunar Midcourse Navigation	S-14			
	FC-2070	Service Routines		C-6		
	FC-2140	Alarm and Abort		C-12		
	FC-2290	Integration Initialization	S-3	C-3		
STATINT	FC-2290	Integration Initialization	ENTRY 3			
STATINT1	FC-2290	Integration Initialization	ENTFY 3			
STEERING	FC-2683	Servicer	CALLED 19			
STERSW	FC-2020	Fresh Start and Restart		C-26,6		
	FC-2680	Thrust Programs (P40, P41)	S-23			
	FC-2681	Cloktask and Clockjob	S-10			
STICKCHK	FC-2370	DAP Interface and Service Routines	ENTRY 23			
	FC-2390	RCS DAP Phase 2	CALLED 3,5			
	FC-2540	P11 Earth Orbit Insertion Monitor	CALLED 21			
STIK*LAG	FC-2370	DAP Interface and Service Routines				C-18
	FC-2390	RCS DAP Phase 2	S-3			
	FC-2020	Fresh Start and Restart		C-36,6		
	FC-2070	Service Routines		C-6		
STOPPAT5	FC-2350	Maneuver Calculations and Steering	ENTRY 26			
	FC-2370	DAP Interface and Service Routines	CALLED 11			
	FC-2550	P20 Rendezvous Navigation	CALLED 9			
	FC-2020	Fresh Start and Restart	CALLED 21,25			
STPKTST1	FC-2450	Stroke Test Package	ENTRY 1			
STROKON	FC-2450	Stroke Test Package	ENTRY 1			
STRULLSW	FC-2020	Fresh Start and Restart		C-26,6		

	FC-2680	Thrust Programs (P40, P41)	S-21	C-21	T-23
STSHOSUM	FC-2120	AGC Block Two Selfcheck	ENTRY 7		
SUPDACAL	FC-2080	Inter-bank Communication	ENTRY 3		
	FC-2120	AGC Block Two Selfcheck	CALLED 9		
SUPERBSW	FC-2080	Inter-bank Communication	ENTRY 2		
SURFFLAG	FC-2290	Integration Initialization			T-4,5,18 T-8,9,10
	FC-2325	Rendezvous Parameters Displays			
SVDWN1	FC-2290	Integration Initialization	CALLED 5		
	FC-2610	Measurement Incorporation	CALLED 11		
SVDWN2	FC-2290	Integration Initialization	CALLED 5		
	FC-2610	Measurement Incorporation	CALLED 11		
SWCALL	FC-2080	Inter-bank Communication	ENTRY 1		
SWICHOVR	FC-2370	DAP Interface and Service Routines	CALLED 2		
	FC-2430	TVC Start-up, Executive, and Service Routines	ENTRY 28		
SWRPTURN	FC-2080	Inter-bank Communication	ENTRY 1		
SWTOVEF	FC-2430	TVC Start-up, Executive, and Service Routines	S-29		C-3
	FC-2070	Fresh Start and Restart		C-25,6	
	FC-2070	Service Routines		C-6	
SXTMARK	FC-2730	R52, R53, R56	CALLED 11,14		
SXTN8	FC-2325	Rendezvous Parameters Displays	CALLED 6		
	FC-2550	P20 Rendezvous Navigation	CALLED 38		
	FC-2730	R52, R53, R56	CALLED 13		
SXTSM	FC-2720	P52 IMU Realignment Program	CALLED 19		
	FC-2730	R52, R53, R56	ENTRY 13		
SYSTEST	FC-2530	Prelaunch Initialization and Gyro Compassing	ENTRY 31		
S11-1	FC-2540	P11 Earth Orbit Insertation Monitor	ENTRY 18		
	FC-2700	P47 Thrust Monitor	CALLED 6		
S17-1	FC-2545	P17/P77--TPI Search Programs	ENTRY 3		
S17-2	FC-2545	P17/P77--TPI Search Programs	ENTRY 6		
S22-1	FC-2590	P22 Orbital Navigation	ENTRY 9		
S30-1	FC-2620	P30, P31	ENTRY 2		
S31-1	FC-2620	P30, P31	ENTRY 7		
S32-1F1	FC-2626	P32, P72--CSI		C-11,21	T-12
	FC-2070	Service Routines		C-6	
S32-1F2	FC-2626	P32, P72--CSI	S-11,21	C-18	T-18
	FC-2070	Service Routines		C-6	
S32-1F3A	FC-2626	P32, P72--CSI	S-18,19	C-11,21	T-12,18,21
	FC-2070	Service Routines		C-6	
S32-1F3B	FC-2070	Service Routines		C-6	
S32/33-X	FC-2626	P32, P72--CSI	ENTRY 8		
S32/33-1	FC-2626	P32, P72--CSI	ENTRY 5		
	FC-2627	P33, P73--CDH	CALLED 4		
S32-1F3D	FC-2626	P32, P72--CSI	S-11,19	C-18,21	T-12,18,21
S33/34-1	FC-2627	P33, P73--CDH	CALLED 3		
	FC-2630	P34/P74	TPI Targeting	ENTRY 6	
S33-34-1	FC-2630	P34/P74	TPI Targeting	ENTRY 6	
S34/35-1	FC-2630	P34/P74	TPI Targeting	ENTRY 6	
	FC-2640	P35-P75	TPM Targeting	CALLED 1	
	FC-2644	P38/P78; P39/P79	CALLED 11		
S34/35-2	FC-2630	P34/P74	TPI Targeting	ENTRY 11	
	FC-2640	P35-P75	TPM Targeting	CALLED 2	
S34/35-3	FC-2630	P34/P74	TPI Targeting	ENTRY 13	
S34/35-4	FC-2630	P34/P74	TPI Targeting	ENTRY 16	
S34/35-5	FC-2630	P34/P74	TPI Targeting	ENTRY 16	
	FC-2640	P35-P75	TPM Targeting	CALLED 2	
S3435-25	FC-2630	P34/P74	TPI Targeting	ENTRY 11	
	FC-2644	P38/P78; P39/P79	CALLED 6,10		
S40-1	FC-2680	Thrust Programs (P40, P41)	ENTRY 32		
S40-13	FC-2630	P34/P74	TPI Targeting	ENTRY 17	
	FC-2681	Cloktask and Clockjob	CALLED 14		



540.14	FC-2370	DAP Interface and Service Routines ENTRY 17		
	FC-2380	DAP Interface Initialization and Phase I CALLED 6		
	FC-2460	Roll Autopilot CALLED 6		
540.15	FC-2370	DAP Interface and Service Routines ENTRY 17		
	FC-2430	TVC Start-up, Executive, and Service Routines CALLED 4,12,29		
540.2,3	FC-2680	Thrust Programs (P40, P41) ENTRY 40		
540.6	FC-2680	Thrust Programs (P40, P41) ENTRY 44		
541.1	FC-2700	P47 Thrust Monitor ENTRY 8		
541.2	FC-2370	DAP Interface and Service Routines ENTRY 13		
	FC-2380	DAP Interface Initialization and Phase I CALLED 6		
	FC-2460	Roll Autopilot CALLED 6		
S50	FC-2720	P52 IMU Realignment Program ENTRY 11		
S52.2	FC-2720	P52 IMU Realignment Program ENTRY 9		
S52.3	FC-2720	P52 IMU Realignment Program ENTRY 10		
S61.1	FC-2760	P60's Entry Programs ENTRY 19		
S61.1A	FC-2760	P60's Entry Programs ENTRY 21		
S61.1C	FC-2760	P60's Entry Programs ENTRY 20		
S61.2	FC-2760	P60's Entry Programs ENTRY 22		
TARGDRVE	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 43		
TAR C1PLG	FC-2340	R60 Attitude Maneuver		T-8
	FC-2550	P20 Rendezvous Navigation S-6		
	FC-2590	P22 Orbital Navigation	C-7	
	FC-2600	P23 Cislunar Midcourse Navigation		C-3
	FC-2020	Fresh Start and Restart	C-38,6	
	FC-2720	P52 IMU Realignment Program S-18		
	FC-2730	R52, R53, R56		T-3,4,6
TARG2PLG	FC-2590	P22 Orbital Navigation S-7		
	FC-2600	P23 Cislunar Midcourse Navigation		C-3
	FC-2070	Service Routines	C-6	
	FC-2720	P52 IMU Realignment Program S-18		
	FC-2730	R52, R53, R56		T-6
TAR/EREP	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 45		
TASKOVER	FC-2060	Waitlist ENTRY 18		
TERMIFLG	FC-2070	Service Routines	C-6	
TERMINFL	FC-2730	R52, R53, R56	C-2,12	T-4
TESTLOOP	FC-2290	Integration Initialization CALLED 8		
	FC-2300	Orbital Integration ENTRY 3		
TESTXACT	FC-2325	Rendezvous Parameters Displays CALLED 2		
	FC-2330	R62 Crew Defined Maneuver (V49) CALLED 2		
	FC-2360	R64 (R05)--S-Band Antenna CALLED 2		
	FC-2361	V89 (R63) CALLED 2		
	FC-2370	DAP Interface and Service Routines CALLED 6,10		
	FC-2605	Navigation Extended Verbs CALLED 2		
	FC-2190	Extended Verbs CALLED 2		
	FC-2235	IMU Extended Verbs (V40, V41, V42) CALLED 4,6,8		
	FC-2631	R36 (V90) CALLED 2		
	FC-2650	Orbital Parameters Display CALLED 2		
	FC-2650	Orbital Parameters Display CALLED 2		
TFPCONIC	FC-2320	TFPConics ENTRY 3		
	FC-2760	P60's Entry Programs CALLED 22		
TFPCONMU	FC-2320	TFPConics ENTRY 3		
	FC-2650	Orbital Parameters Display CALLED 16		
	FC-2650	Orbital Parameters Display CALLED 16		
TFPRP/RA	FC-2320	TFPConics ENTRY 4		
	FC-2650	Orbital Parameters Display CALLED 16		
	FC-2650	Orbital Parameters Display CALLED 16		
TFP/TRIG	FC-2320	TFPConics ENTRY 11		
	FC-2760	P60's Entry Programs CALLED 23,27		
TFPSW	FC-2320	TFPConics S-5	C-5	T-5
	FC-2070	Service Routines	C-6	

THISPRFC FC-2620 P30, P31 CALLED 3  
 FC-2631 R36 (V90) CALLED 4  
 FC-2650 Orbital Parameters Display CALLED 7  
 FC-2650 Orbital Parameters Display CALLED 7  
 FC-2680 Thrust Programs (P40, P41) CALLED 38  
 TICKTEST FC-2650 Orbital Parameters Display ENTRY 14  
 FC-2650 Orbital Parameters Display ENTRY 14  
 TIGAVEG FC-2630 P34/P74 TPI Targeting ENTRY 15  
 TIGBLNK FC-2630 P34/P74 TPI Targeting ENTRY 14  
 TIGNOW FC-2630 P34/P74 TPI Targeting ENTRY 30  
 TIGON FC-2700 P47 Thrust Monitor ENTRY 4  
 TIG-0 FC-2630 P34/P74 TPI Targeting ENTRY 20  
 TIG-5 FC-2630 P34/P74 TPI Targeting ENTRY 16  
 TIMERAD FC-2310 Conic Subroutines ENTRY 23  
 FC-2642 P37 Return To Earth CALLED 27,37  
 TIMFRFLG FC-2620 P30, P31 S-6,10 C-6,10  
 TIMESTEP FC-2300 Orbital Integration ENTRY 6  
 TIMETHET FC-2310 Conic Subroutines ENTRY 22  
 FC-2545 P17/P77--TPI Search Programs CALLED 7  
 FC-2626 P32, P72--CSI CALLED 13,14  
 FC-2627 P33, P73--CDH CALLED 5  
 FC-2630 P34/P74 TPI Targeting CALLED 5  
 FC-2642 P37 Return To Earth CALLED 13  
 FC-2644 P38/P78; P39/P79 CALLED 11  
 TIMFLAG FC-2681 Cloktask and Clockjob T-3  
 TIMRFLAG FC-2020 Fresh Start and Restart C-26,6  
 FC-2680 Thrust Programs (P40, P41) S-8 C-28,31  
 TLM FC-2200 T4RUPT ENTRY 28  
 TNONTEST FC-2200 T4RUPT ENTRY 33  
 TORQNF FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 25  
 TPAGREE FC-2220 P06, GNCS Power Down CALLED 5,6  
 FC-2680 Thrust Programs (P40, P41) CALLED 19  
 TRACKFLG FC-2340 R60 Attitude Maneuver T-8  
 FC-2545 P17/P77--TPI Search Programs S-3  
 FC-2550 P20 Rendezvous Navigation S-3 C-8 T-6,8,17,31  
 FC-2620 P30, P31 S-2,7  
 FC-2626 P32, P72--CSI S-2  
 FC-2627 P33, P73--CDH S-1  
 FC-2020 Fresh Start and Restart S-39 C-38,6  
 FC-2200 T4RUPT C-32,33  
 FC-2220 P06, GNCS Power Down C-3  
 FC-2630 P34/P74 TPI Targeting S-2  
 FC-2640 P35-P75 TPM Targeting S-1  
 FC-2644 P38/P78; P39/P79 S-3  
 FC-2670 P76 Target Delta V Program S-2  
 FC-2720 P52 IMU Realignment Program C-1  
 FC-2730 R52, R53, R56 T-4  
 TPANSANG FC-2545 P17/P77--TPI Search Programs ENTRY 14  
 TPANSF1 FC-2100 RTB Op Codes ENTRY 13  
 TPANSF2 FC-2100 RTB Op Codes ENTRY 13  
 TPFALLOF FC-2550 P20 Rendezvous Navigation CALLED 33  
 FC-2605 Navigation Extended Verbs CALLED 7  
 FC-2070 Service Routines ENTRY 13  
 TPFALLOF FC-2550 P20 Rendezvous Navigation CALLED 32  
 FC-2070 Service Routines ENTRY 13  
 TPMOJFLG FC-2070 Service Routines C-6  
 TRUNFLAG FC-2070 Service Routines C-6  
 FC-2730 R52, R53, R56 S-2,3 C-3 T-3  
 TTG/0 FC-2630 P34/P74 TPI Targeting ENTRY 31  
 TVCDAPON FC-2430 TVC Start-up, Executive, and Service Routines ENTRY I

	FC-2680	Thrust Programs (P40, P41) CALLED 22		
TVCEXEC	FC-2430	TVC Start-up, Executive, and Service Routines ENTRY 10		
TVCINIT1	FC-2430	TVC Start-up, Executive, and Service Routines ENTRY 2		
TVCZAP	FC-2020	Fresh Start and Restart CALLED 31		
	FC-2630	P34/P74 TPI Targeting ENTRY 28		
TVCZAP-1	FC-2681	Cloktask and Clockjob CALLED 5,7		
TWIDDLE	FC-2060	Waitlist ENTRY 9		
T3RUPT	FC-2060	Waitlist ENTRY 16		
T4RUPT	FC-2200	T4RUPT ENTRY 3		
T5IDLOC	FC-2380	DAP Interface Initialization and Phase I ENTRY 2		
	FC-2020	Fresh Start and Restart ENTRY 17		
T5PHASE	FC-2460	Roll Autopilot CALLED 2		
T5PHASE2	FC-2380	DAP Interface Initialization and Phase I CALLED 2		
	FC-2390	RCS DAP Phase 2 ENTRY 2		
T6SETUP	FC-2400	RCS DAP Jet Selection Logic ENTRY 15		
T6START	FC-2380	DAP Interface Initialization and Phase I CALLED 7		
	FC-2400	RCS DAP Jet Selection Logic ENTRY 17		
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