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

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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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INSTRUMENTATION LABORATORY

E-2456
(Rev. 1)

APOLLO GUIDANCE AND NAVIGATION FLOW CHARTS

PROGRAM COLOSSUS 2D COMANCHE 72

DECEMBER 1969

MIT INSTRUMENTATION LABORATORY
CAMBRIDGE 39, MASSACHUSETTS

ACKNOWLEDGEMENT

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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).

Jack C. Reed
Group Leader
APOLLO Documentation

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FRESH START AND RESTART

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DOFSTART	3	SOFTWARE FRESH START
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POOKLEAN	7	SUBROUTINE FOR MAKING GROUPS 1, 3, 4, 5, 6 INACTIVE
V37KLEAN	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
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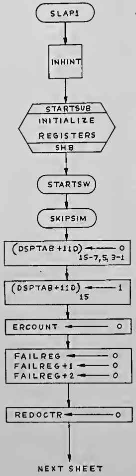
LIST OF REVISIONS

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	
DRAWN L. Alldstone	9/3/69	FRESH START & RESTART	
PROGMR			
ANALST P. Rye	9-9-69	COLOSSUS II-D	DOCUMENT NO. FC-2020
DOCMR [signature]	9-8-69		
APPR'D [signature]	9-9-69	REV 3	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 (GIMBAL 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

DRAWN 26NOV68
1-23-69

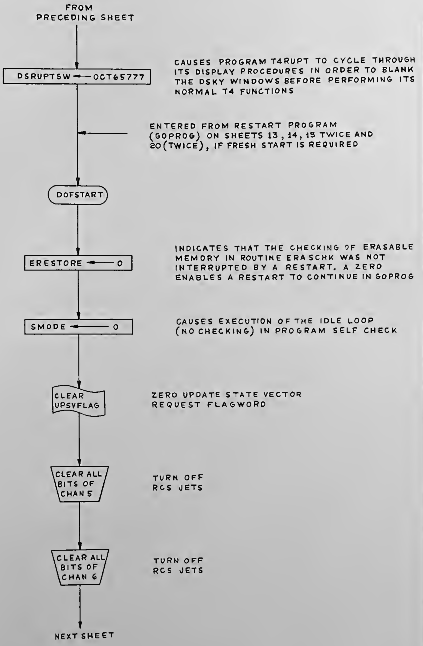
FRESH START AND RESTART

COLOSSUS II-D

REV 3

FC-2020

2 50



26NOV68
23JAN69
C G Beck 1-23-69
John A. Moore 23JAN69

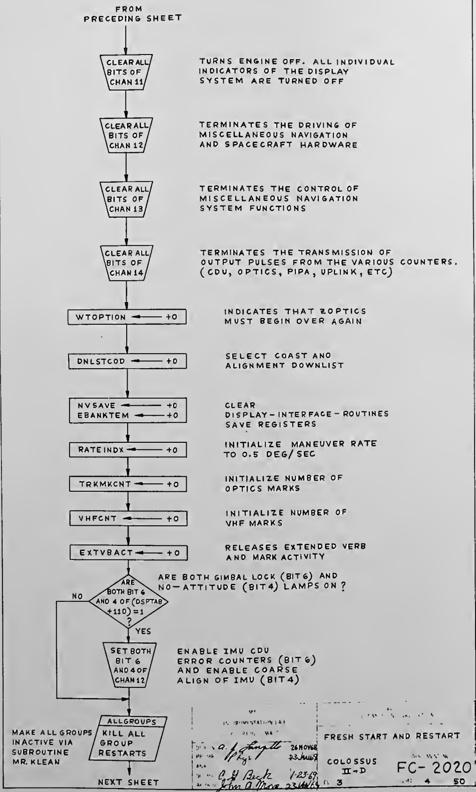
FRESH START AND RESTART

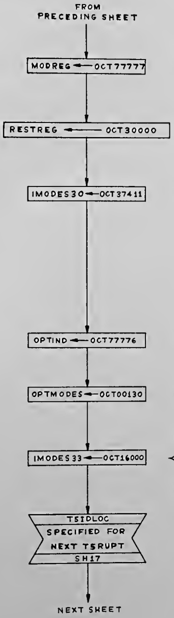
COLOSSUS II-D

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
DNLSTCOD ← +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 (DSPTAB +11D) = 1 ?
ARE BOTH GIMBAL LOCK (BIT 6) AND NO-ATTITUDE (BIT 4) LAMPS ON ?
NO
YES
SET BOTH BIT 6 AND 4 OF CHAN 12
ENABLE IMU CDU ERROR COUNTERS (BIT 6) AND ENABLE COARSE ALIGN OF IMU (BIT 4)
ALLGROUPS
KILL ALL GROUP RESTARTS
MAKE ALL GROUPS INACTIVE VIA SUBROUTINE MR. KLEAN
NEXT SHEET
FRESH START AND RESTART
COLOSSUS II-D
FC-2020
26 NOV 68
23 JAN 69
C. J. Beck 1-23-69
John A. Moore 23 JAN 69
3
4
50



CAUSES MAJOR MODE DISPLAY WINDOW TO BE BLANKED

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

FRESH START IMU INITIALIZATION PROGRAM T4RUPT WILL PROCESS THE CONTENTS OF IMODES30

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

FRESH START OPTICS INITIALIZATION. PROGRAM T4RUPT WILL PROCESS THE CONTENTS OF OPTMODES

INITIALIZATION OF BITS USED FOR VARIOUS HARDWARE DATA. A ONE IN THE FOLLOWING BIT-POSITIONS INDICATE:

BIT 13 - NO ACCELERATION - FAIL INDICATION
BIT 12 - NO TELEMETRY ENDPULSE REJECTED
BIT 11 - NO EXCESSIVE UPLINK BIT RATE

INACTIVATE DIGITAL AUTO PILOTS (DAP IS IN IDLE STATE). TIME5 WAS SET IN STARTSUB TO OVERFLOW IN 40 MS.

MIT INSTRUMENTATION LAB CAMBRIDGE MASS

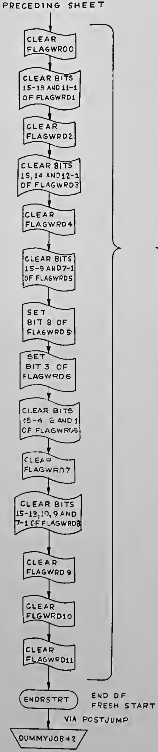
DRAWN A. J. Forsyth 27NOV68
PROGMR 23JAN69
ANALYST
DOCMR C. H. Beck 1-23-69
APPR'D John A. Moore 23JAN69

FRESH START AND RESTART

COLOSSUS II-D

REV 3

FC-2020



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 FLAGWRD5 WHICH IS SET TO ONE. ALSO BIT 12 (NODOP01) OF FLAGWRD1, BIT 13 (REFSMMAT FLAG) OF FLAGWRD3, BITS 12 (CMOONFLG), 11 (LMOONFLG) AND 8 (SURFFLAG) OF FLAGWRD8 WHICH REMAIN INTACT

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

APSESW FLAG

DRAG OVER 0.05G

.05GSW FLAG

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

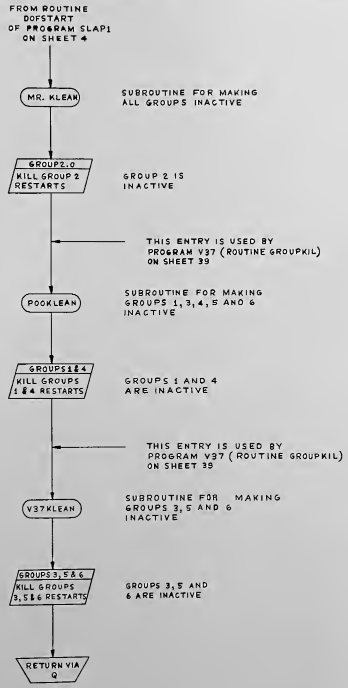
FRESH START AND RESTART

COLOSSUS II-D

FC-2020

REV 3

27NOV68 · 1-23-69 · 28JAN69



CAMBRIDGE MASS

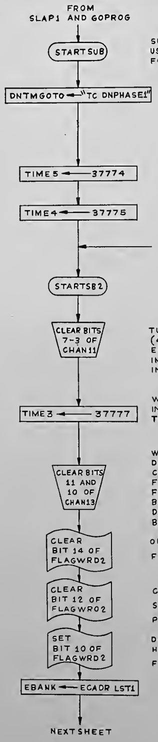
DRAWN A. J. Fangillo 2 DEC
CHKD ... 23 JAN
APPR C. H. Beck 1-23 62
APPR John A. Moore 23 ...

FRESH START AND RESTART

COLOSSUS II-D

FC-2020

REV 3 7 50



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

INITIALIZES PROGRAM DOWN TELEMETRY

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

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)

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.

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

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

OPTION TWO FOR MARKRUPT

FLAG R21MARK

CALCULATE BASE VECTOR DURING 1ST PASS THROUGH P21

STEERING OMITTED

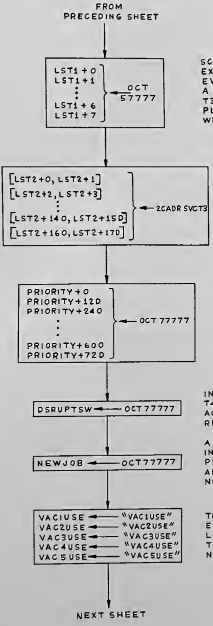
P21FLAG

DISREGARD RADAR READ BECAUSE OF SOFTWARE OR HARDWARE RESTART

FLAG SKIPVHF

LST1 AND LST2 ARE IN EBANK 3

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Langill 3 DEC 68 PRGMR P. Rye 23 JAN 69 ANALST DOCMR C. J. Beck 1-23-69 APPR'D John A. Moore 23 JAN 69	FRESH START AND RESTART COLOSSUS II-D FC-2020 REV 3 SHEET 8 OF 50



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. T3RUPT WILL PLACE OCT 17777 (OCT 57777 PLUS OCT 37777) INTO COUNTER TIME3 WHICH WILL RESULT IN 81.93 SECONDS

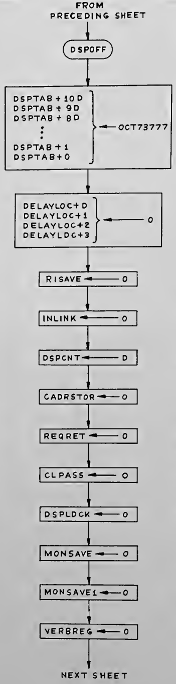
T3RUPT WILL CAUSE THE EXECUTION OF TASK SVCT3 WHOSE COMPLETE ADDRESS IS IN THE ADDRESS LIST LST2. TASK SVCT3 CHECKS GYRO DRIFT AND COMPENSATES IF NECESSARY AND RESUMES INTERRUPTED ROUTINE VIA TASKOVER

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

INITIALIZES T4RUPT. SEQUENCE OF T4RUPT 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



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 CCS 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+0 FOLLOWED BY DSPTAB+10, +9, ETC

INDICATES THAT NO JOB IS USING ENDIDLE (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

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 REQUIST (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

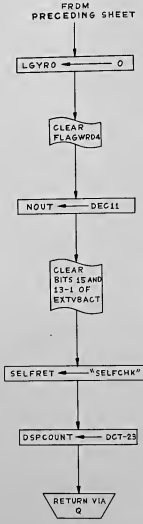
INDICATES TO PROGRAM MODE SWITCHING ROUTINES THAT NO JOB IS IN THE DORMANT STATE AWAITING THE COMPLETION OF A RADAR MODE SWITCH. THE SYSTEM IS PREPARED TO PUT A JOB REQUESTING A MODE CHANGE INTO A DORMANT STATE UNTIL THE SWITCH HAS BEEN COMPLETED. SEE NOTE BELOW

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



INDICATES THE GYROS ARE AVAILABLE TO BE PULSED

TURNS OFF INTERFACE DISPLAYS

INDICATES TO PROGRAM T4RUPT THAT THERE ARE ELEVEN CHANGES IN THE DSPTAB REGISTER TABLE (ELEVEN RELAY CODES TO BE TRANSMITTED VIA CHANNEL 10, I.E. OUT 0)

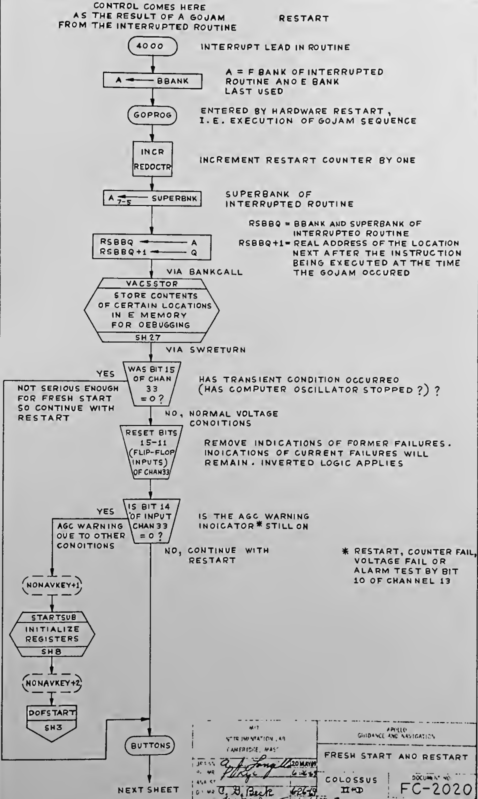
CLEAR EXTENDED VERB AND MARK ACTIVITY. LEAVE EXTENDED VERB RESTART FLAG (BIT 14) INTACT. IT INHIBITS OTHER EXTENDED VERB ACTIVITY AFTER AN R62 OR R63 RESTART

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

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

END OF SUBROUTINE STARTSUB

MIT INSTRUMENTATION LAB CAMBRIDGE MASS	APOLLO GUIDANCE AND NAVIGATION
DRAWN 2 DEC68	FRESH START AND RESTART
PRGMR 23 JAN 69	COLOSSUS II-D — DOCUMENT NO. FC-2020
ANALST	
DOCMR 1-23-69	
APPR'D 23 JAN 69	REV 3 — SHEET 12 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS

APOLLO GUIDANCE AND NAVIGATION

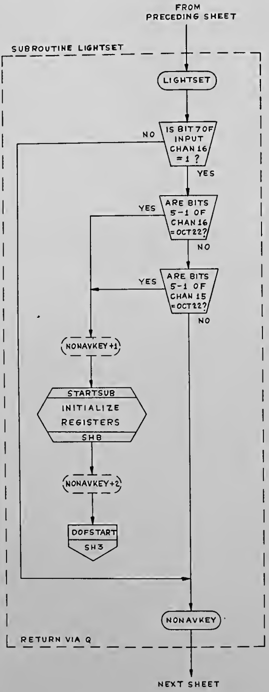
FRESH START AND RESTART

COLOSSUS II-D

REV 3

DOCUMENT NO FC-2020

SHEET 13 OF 50



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 PANAL DSKY ERROR LIGHT RESET BUTTON BEEN DEPRESSED ?

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

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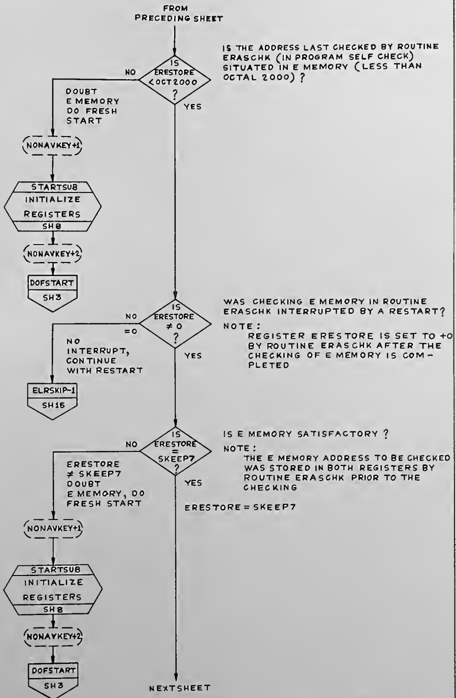
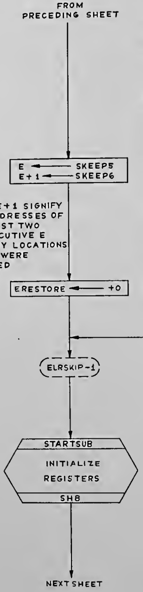
DRAWN G. J. Langille 22MAR67	FRESH START AND RESTART
PRGMR P. Reys 6-24-69	COLOSSUS II+D
ANALST	DOCUMENT NO. FC-2020
DOCMR C. W. Beck 6-26-69	REV 3
APPR'D Alida M. Frank 6/26/69	SHEET 14 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	FRESH START AND RESTART
COLOSSUS II-D	DOCUMENT NO. FC-2020
REV 3	SHEET 15 OF 50



PRIOR TO CHECKING E MEMORY LOCATIONS E AND E+1, THE ORIGIONAL 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 ORIGIONAL CONTENTS. SINCE ROUTINE ERASCHK WAS INTERRUPTED BY A RESTART, THE LAST TWO CONSECUTIVE E MEMORY LOCATIONS DID NOT HAVE THEIR ORIGIONAL 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 ≦ E ≦ OCT 1776
IN E BANK 0

OR OCT 1400 ≦ E ≦ OCT 1776
IN E BANK 1, 3, 4, 5, 6 OR 7

OR OCT 1400 ≦ E ≦ OCT 1772
IN E BANK 2

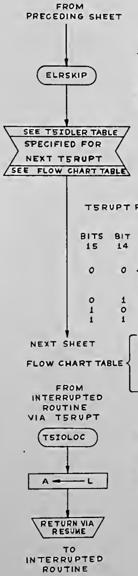
NOTE:
E AND E+1 SIGNIFY THE ADDRESSES OF THE LAST TWO CONSECUTIVE E MEMORY LOCATIONS WHICH WERE CHECKED

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

ENTER HERE FROM PRECEDING SHEET

REGISTERS COMMON TO BOTH FRESH START AND RESTART

MIT INSTRUMENTATION LAB CAMBRIDGE MASS	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Longillo 23 JAN 69	FRESH START AND RESTART
PRLMR J. Ryl 23 JAN 69	COLOSSUS IIaD
ANALYST	DOCUMENT NO. FC-2020
DOC MGR C. H. Beck 1-23-69	REV 3
APPR'D John A. Moore 23 JAN 69	SHEET 16 OF 50



T5LOC IS SET TO APPROPRIATE RESTART ADDRESS, DEPENDING UPON WHICH DAP (DIGITAL AUTO PILOT) IS OPERATING. NORMALLY (NO RESTART) T5LOC IS SET BY PROGRAMS USING THE DAP OR BY THE DAP ROUTINES

TIME5 WAS SET IN STARTSUB TO INITIATE EXECUTION OF T5RUPT ROUTINE IN 40 MS

T5IDLER TABLE

T5RUPT ROUTINE (DETERMINED BY BITS 15 AND 14 OF FLAGWRD6)

BITS 15	BIT 14	
0	0	2CADR T5IDLOC (ON THIS SHEET—EXECUTED WITHIN 40 MS AND EVERY 163.84 SECONDS THEREAFTER IF NO OTHER ROUTINE IS USING T5RUPT)
0	1	2CADR REDORCS (REESTABLISH RCS DAP ROUTINE)
1	0	2CADR REDOTVC (REESTABLISH TVC DAP ROUTINE)
1	1	2CADR REDOSAT (REESTABLISH SATURN CONTROL FUNCTION ROUTINE)

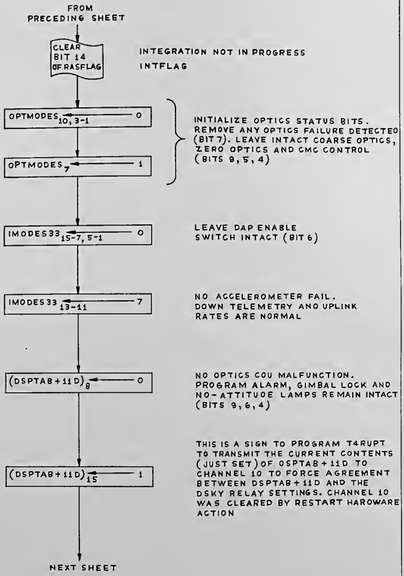
FLOW CHART TABLE

ROUTINE	FLOW CHART
REDORCS	FC-2380
REDOTVC	FC-2430
REDOSAT	FC-2540
T5IDLOC	THIS SHEET

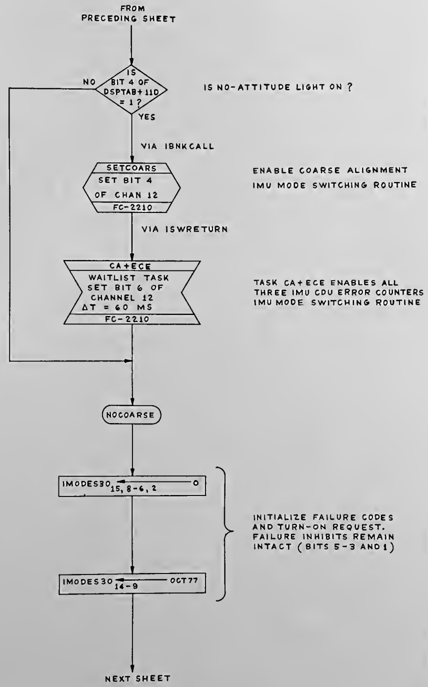
IDLING ROUTINE (DAP ROUTINES INACTIVE)

BBANK OF INTERRUPTED ROUTINE

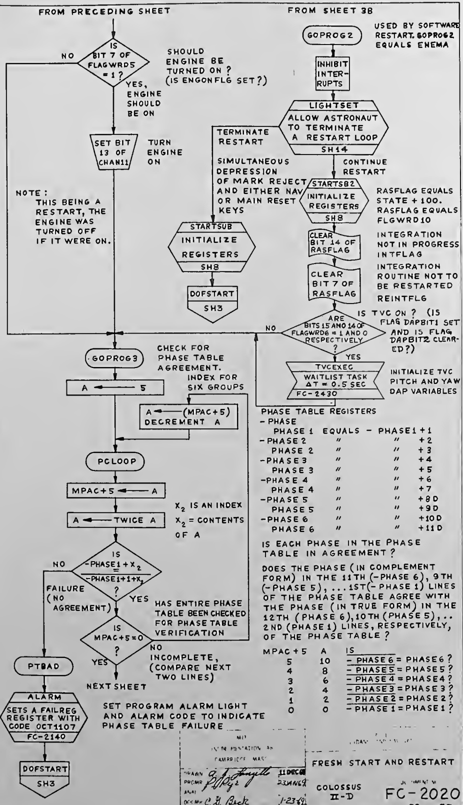
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN O. J. Longville 22MAY69	FRESH START AND RESTART
PRGMR P. Ryst 6-24-69	COLOSSUS IIBD
ANALYST	DOCUMENT NO. FC-2020
DOC MGR C. H. Beck 6-26-69	REV 3
APPR'D	SHEET 17 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN G. J. Fongello 5 DEC 68	FRESH START AND RESTART	
CHECKED 23 JAN 69	COLOSSUS II & D	DOCUMENT NO. FC-2020
SUPVR C. D. Beck 1-23-69	REV 3	SH 18 OF 50
APPD John A. Moore 23 JAN 69		



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 5 DEC 68; PRGMR 23 JAN 69; ANALYST; DOC MGR C. H. Beck 1-23-69; APPR'D John A. Moore 23 JAN 69	FRESH START AND RESTART
REV 3	COLOSSUS II-D — DOCUMENT NO. FC-2020 — SHEET 19 OF 50



PHASE TABLE REGISTERS

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

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

FRESH START AND RESTART

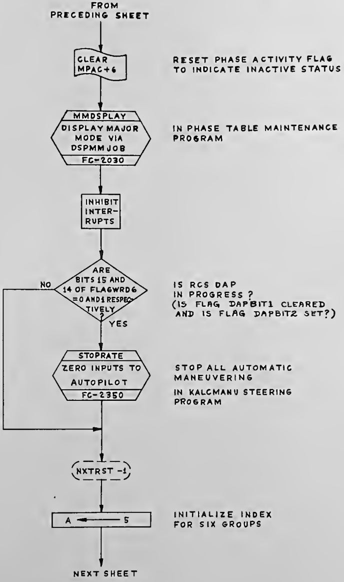
DRAWN G. J. Fanzillo 11DEC68
PROGMR 23JAN69
CHKR C. G. Beck 1-23-69
APPR John A. Moore 23JAN69

COLOSSUS II-D

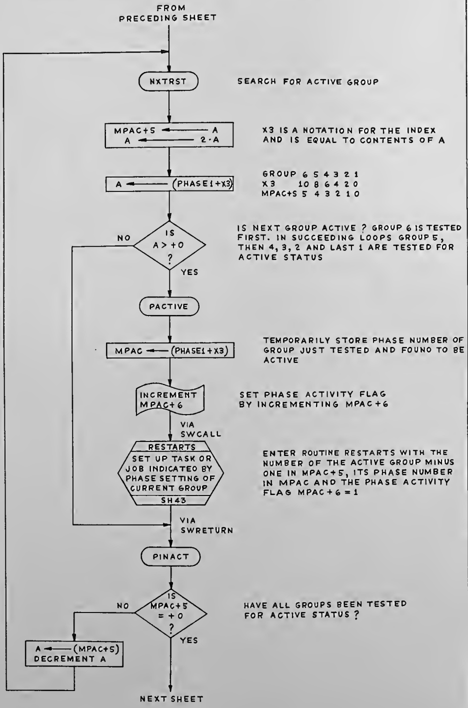
FC-2020

REV 3

20 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 12 DEC 68	FRESH START AND RESTART
PRGMR 23 JAN 69	
ANALYST	COLOSSUS II+D
DOC MGR 1-23-69	DOCUMENT NO. FC-2020
APPR'D 23 JAN 69 REV 3	SHEET 21 OF 50



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN G. J. Lanzitte 13DEC68
PRGMR P. J. Pye 2 JAN69
ANALST
CHKR C. G. Beck 1-23-69
APPR'D John A. Moss 23 JAN69

GUIDANCE AND NAVIGATION

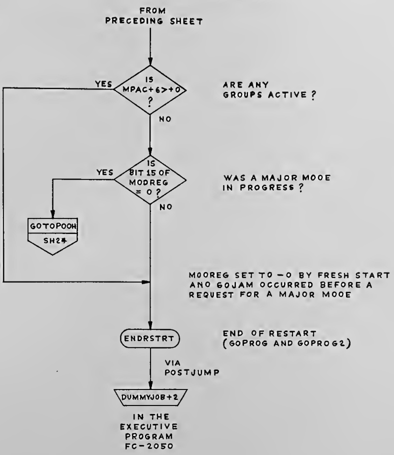
FRESH START AND RESTART

COLOSSUS II-D

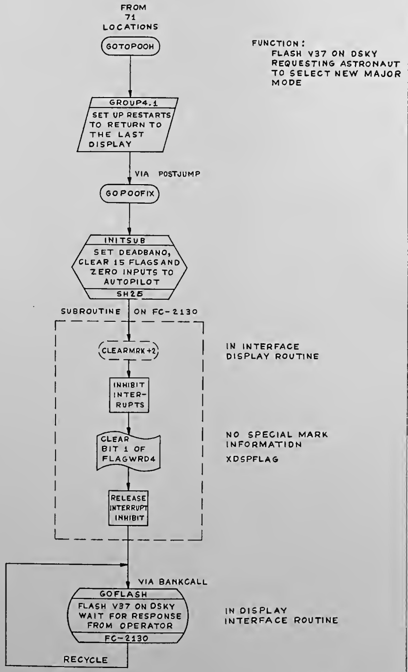
REV 3

DRAWING NO. FC-2020

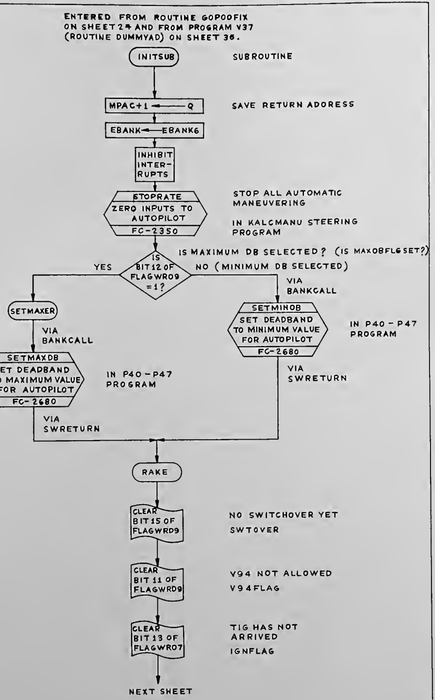
SHT 22 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 12DEC68	FRESH START AND RESTART
PRGMR 14JAN69	COLOSSUS II-D
ANALYST	DOCUMENT NO FC-2020
DOCMR 1-23-69	REV 3
APPR'D 23JAN69	SHEET 23 OF 50



MIT INSTRUMENTATION LAB, CAMBRIDGE, MASS	APOLLO GUIDANCE AND NAVIGATION
	FRESH START AND RESTART
	COLOSSUS II-D — FC-2020
REV 3	SH 24 OF 50



MIT INSTRUMENTATION LAB, CAMBRIDGE, MASS.

GUIDANCE AND NAVIGATION

FRESH START AND RESTART

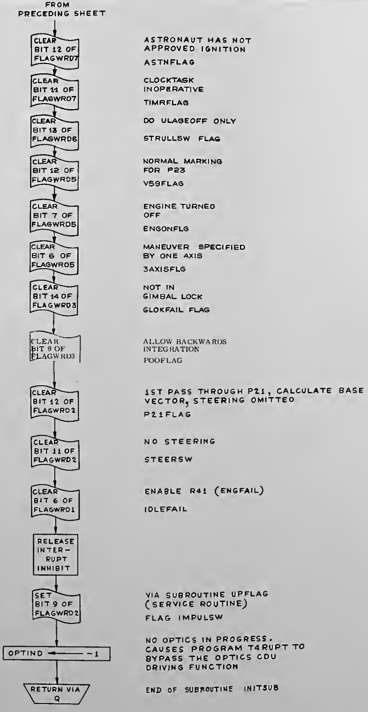
DRAWN 17DEC68
PROGMR 23JAN69
DOC MP 1-23-69
APPR'D 23JAN69

COLOSSUS II-D

REV 3

DOCUMENT NO. FC-2020

SHEET 25 OF 59



CAMBRIDGE, MA

27 MAY 69

6-26-69

6-26-69

APOLLO GUIDANCE AND NAVIGATION

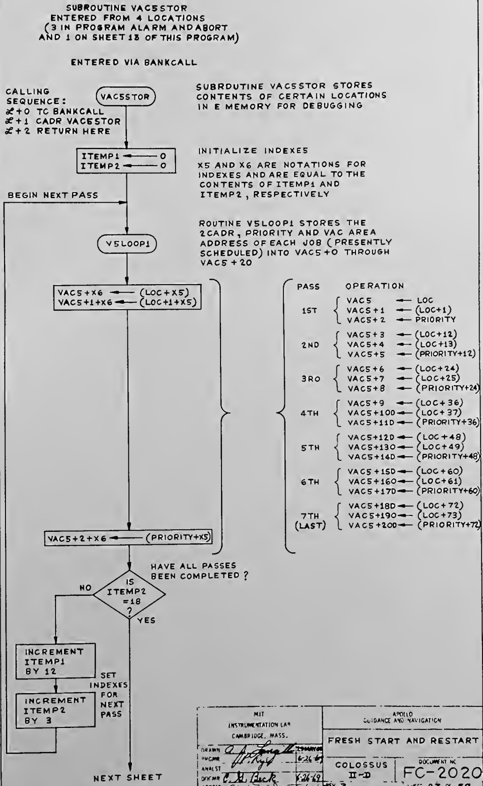
FRESH START AND RESTART

COLOSSUS II+D

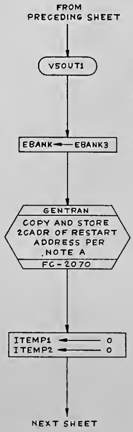
FC-2020

3

SHEET 26 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Longo 29 MAY 69	FRESH START AND RESTART
PGMR W. Ryf 6-26-69	COLOSSUS II-D
ANALST	DOCUMENT NO FC-2020
DOCMR C. L. Beck 6-26-69	REV 3
APPR'D 6/26/69	SHEET 27 OF 50



ROUTINE V5OUT1 STORES THE 2CADR OF RESTART ADDRESS OF EACH RESTART GROUP INTO VAC5+21D THROUGH VAC5+32D

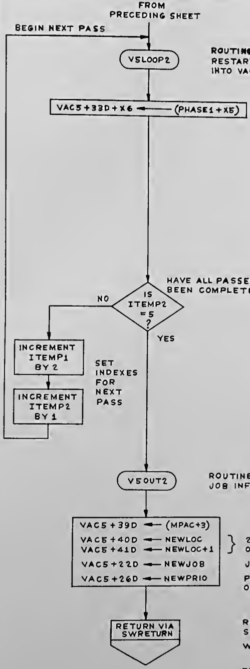
PHSNAME AND PHSBB REGISTERS ARE IN E BANK 3

NOTE A:

VAC5 + 32D ← PHSBB6
VAC5 + 31D ← PHSNAME6
VAC5 + 30D ← PHSBB5
VAC5 + 29D ← PHSNAME5
VAC5 + 28D ← PHSBB4
VAC5 + 27D ← PHSNAME4
VAC5 + 26D ← PHSBB3
VAC5 + 25D ← PHSNAME3
VAC5 + 24D ← PHSBB2
VAC5 + 23D ← PHSNAME2
VAC5 + 22D ← PHSBB1
VAC5 + 21D ← PHSNAME1

INITIALIZE INDEXES FOR ROUTINE V5LOOP2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Lenzilli 30MAY69	FRESH START AND RESTART
PRGMR W. Ryel 6-26-69	COLOSSUS II & D
ANALST	DOCUMENT NO FC-2020
DOCMR C. G. Beck 6-26-69	REV 3
APPR'D Alex M. Dorant 6/26/69	SHEET 28 OF 80



ROUTINE V5LOOP2 STORES RESTART PHASE DATA (IN PHASE REGISTERS) INTO VAC5+33D THROUGH VAC5+38D

PASS	X5	X6	OPEPATION
1ST	0	0	VAC5+33D ← PHASE1
2ND	2	1	VAC5+34D ← PHASE2
3RD	4	2	VAC5+35D ← PHASE3
4TH	6	3	VAC5+36D ← PHASE4
5TH	8	4	VAC5+37D ← PHASE5
6TH (LAST)	10	5	VAC5+38D ← PHASE6

PHASE2 = PHASE1+2
PHASE3 = PHASE1+4
PHASE4 = PHASE1+6
PHASE5 = PHASE1+8
PHASE6 = PHASE1+10

HAVE ALL PASSES BEEN COMPLETED?

ROUTINE V5OUT2 STORES JOB INFORMATION

2CADR OF JOB LAST SCHEDULED OR AWAKENED.

JOB ACTIVITY STATUS INDICATOR.

PRIORITY OF JOB LAST SCHEDULED OR AWAKENED.

RETURN TO CALLING SEQUENCE AT $\mathcal{L}+2$

WHERE $\mathcal{L}$ = TC BANKCALL AND $\mathcal{L}+1$ = CADR VAC5STOR

END OF SUBROUTINE VAC5STOR

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

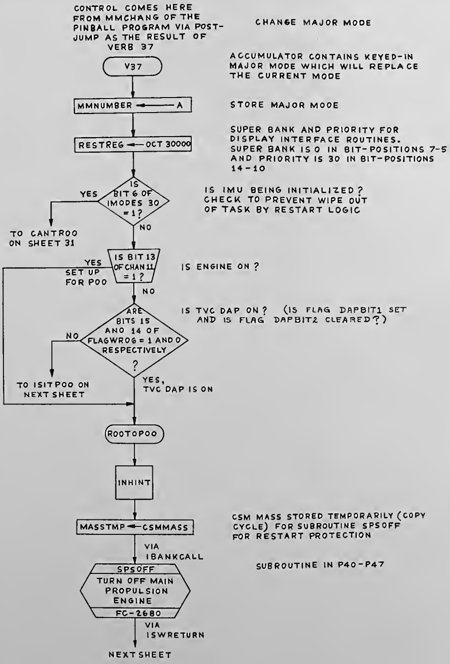
APOLLO GUIDANCE AND NAVIGATION

FRESH START AND RESTART

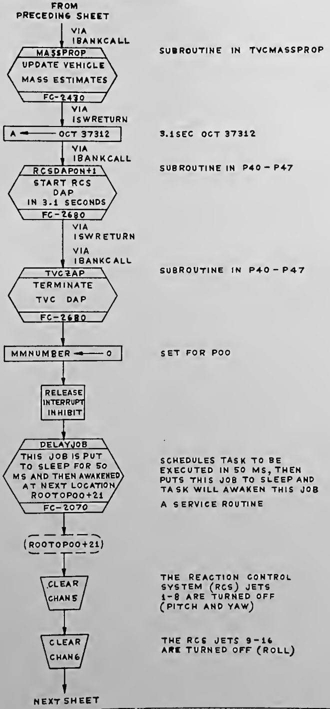
COLOSSUS II+D

DOCUMENT NO. FC-2020

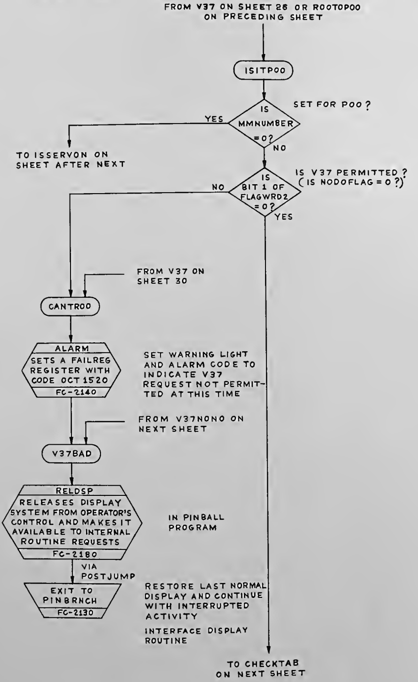
DRAWN A. J. Laxeille — PRGMR ... 6-26-69 — ANALST — DOCMR C. H. Beck 6-21-69 — APPR'D Alida M. ... — REV 3



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Langill 18 DEC 68 PROGMR. [signature] 23 JAN 69 ANALYST DOCMR C. H. Beck 1-23-69 APPR'D John A. Moore 23 JAN 69	FRESH START AND RESTART COLOSSUS II-D — DOCUMENT NO. FC-2020 REV 3 — SHEET 30 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	FRESH START AND RESTART
PRGMR	COLOSSUS IIID
ANALST	DOCUMENT NO. FC-2020
DOCMR C.H. Beck	REV 3
APPR'D	SHEET 39 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

GUIDANCE AND NAVIGATION

FRESH START AND RESTART

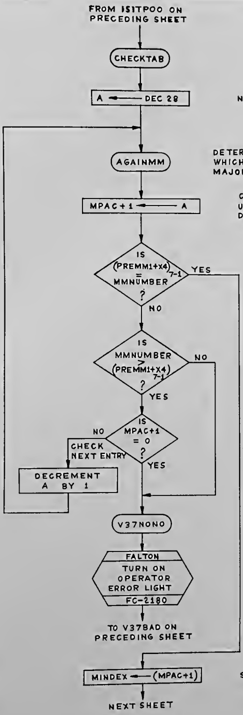
DRAWN 18 DEC 68
PRGMR 23 JAN 69
ANA ST
IN CHKR 1-23-69
APPR'D 23 JAN 69

COLOSSUS II-D

DOCUMENT NO. FC-2020

REV 3

SHEET 32 OF 50



NUMBER OF MAJOR MODES

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

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

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

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

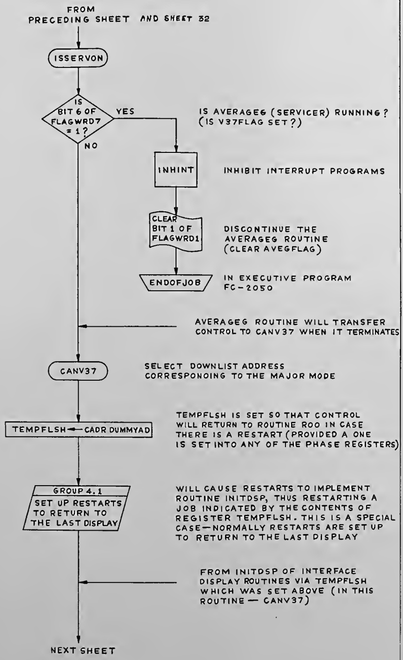
HAS THE MAJOR MODE OF EACH ENTRY OF THE PREMM1 TABLE BEEN COMPARED WITH THE KEYED-IN MAJOR MODE ?

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

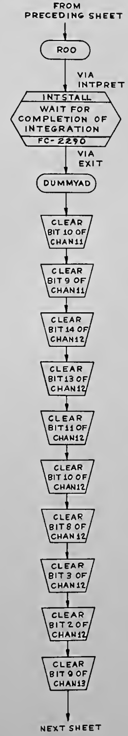
IN PINBALL PROGRAM

SAVE INDEX FOR FURTHER USE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. L. Laughlin 19 DEC 68	FRESH START AND RESTART
PRGMR F. L. Kay 2-3-69	COLOSSUS II & D
ANALYST	DOCUMENT No. FC-2020
DOCMR C. E. Bean 1-23-69	REV 3
APPR'D John A. Moore 23-1-69	SHEET 33 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Fongill 19DEC68	FRESH START AND RESTART
CHECKED F. Kupe 25JAN69	COLOSSUS II-D
DES ENGR C. J. Beck 1-23-69	DOCUMENT NO. FC-2020
APPR'D John A. Moore 23JAN69	REV 3 SHEET 34 OF 50



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

CLEARS CAUTION RESET SIGNAL

AVERAGE -G IS NOT RUNNING

TERMINATE S4B CUTOFF

TERMINATE S4B INJECTION SEQUENCE

ENGAGE OPTICS DIGITAL TO ANALOG CONVERTER (DAC)

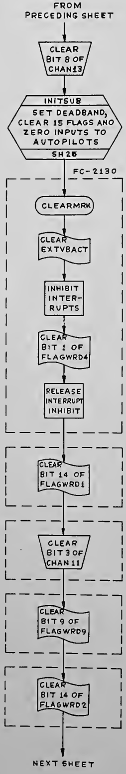
ZERO OPTICS TERMINATED

TERMINATE TVC (THRUST VECTOR CONTROL) ENABLE

TERMINATE STAR TRACKER

ENABLE OPTICS CDU ERROR COUNTERS ARE CLEARED TO ZERO

NOT ASSIGNED



TERMINATE INPUTS TO BMAG X, BMAGY AND BMAGZ

SUBROUTINE CLEARMRK IS IN INTERFACE DISPLAY ROUTINE

RELEASES EXTENDED VERB AND MARK ACTIVITY

NO SPECIAL MARK INFORMATION

XDSPFLAG

SUBROUTINE DOWNFLAG

CMC CONTROL

STIKFLAG

SUBROUTINE UPACTOFF

TURN OFF UPLINK ACTIVITY LIGHT

SUBROUTINE DOWNFLAG

STOP ACCEPTANCE OF RANGE DATA

VHFRFLAG

SUBROUTINE DOWNFLAG

OPTION TWO FOR MARKRUPT

R21MARK FLAG

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

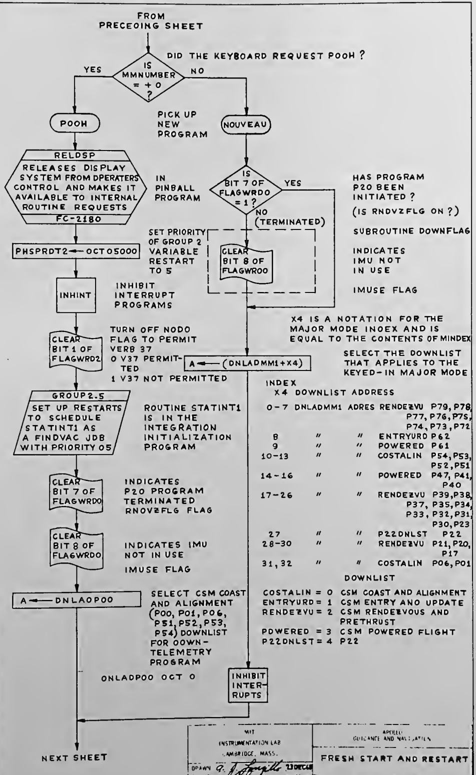
FRESH START AND RESTART

COLOSSUS IID

DOCUMENT NO. FC-2020

REV 3

SHEET 36 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

FRESH START AND RESTART

DRAWN 23 DEC 68
PROG'D 23 MAY 69
ANALYST
DOCMR 4-23-69
APPR'D 23 MAY 69

COLOSSUS II-D

REV 3

DOCUMENT NO. FC-2020

SHEET 37 OF 50

FROM PRECEDING SHEET

SEUOOPOO

DNLSTCOD ← 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 ← OCT 76657

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

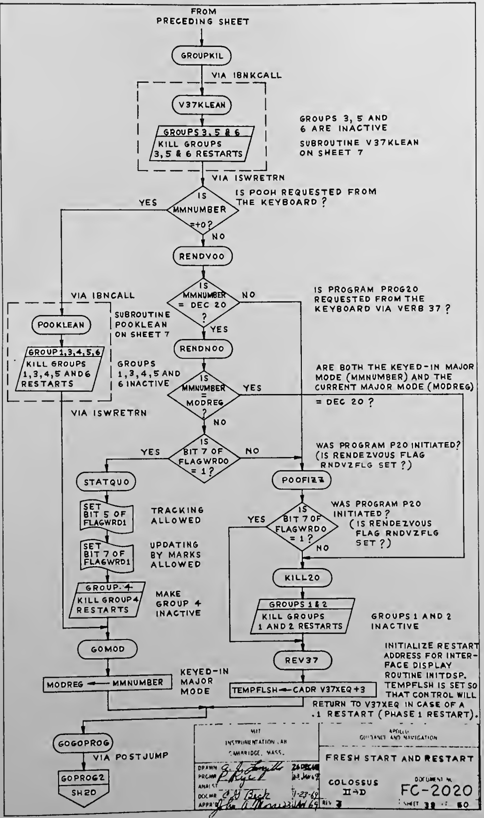
UPDATFLG

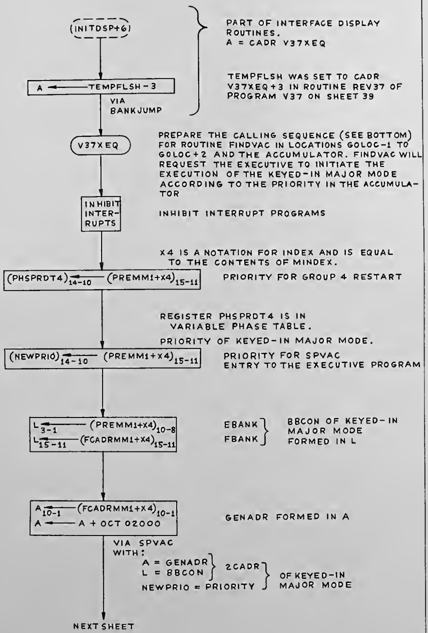
CLEAR BIT 10 OF FLAGWRD1

INDICATES NOT SIGHTING LEM

TARG1FLG

NEXT SHEET


FROM PRECEDING SHEET
GROUPKIL
VIA IBNKCALL
V37KLEAN
GROUPS 3, 5 & 6
KILL GROUPS 3, 5 & 6 RESTARTS
GROUPS 3, 5 AND 6 ARE INACTIVE
SUBROUTINE V37KLEAN ON SHEET 7
VIA ISWRETRN
IS MMNUMBER =+0?
IS POOH REQUESTED FROM THE KEYBOARD ?
YES
NO
RENDVOO
IS MMNUMBER = DEC 20 ?
NO
YES
IS PROGRAM PROG20 REQUESTED FROM THE KEYBOARD VIA VERB 37 ?
VIA IBNCALL
POOKLEAN
SUBROUTINE POOKLEAN ON SHEET 7
GROUP 1,3,4,5,6
KILL GROUPS 1,3,4,5 AND 6 RESTARTS
GROUPS 1,3,4,5 AND 6 INACTIVE
VIA ISWRETRN
RENDNOO
IS MMNUMBER = MODREG ?
YES
NO
ARE BOTH THE KEYED-IN MAJOR MODE (MMNUMBER) AND THE CURRENT MAJOR MODE (MODREG) = DEC 20 ?
IS BIT 7 OF FLAGWRD0 = 1 ?
YES
NO
WAS PROGRAM P20 INITIATED? (IS RENDEZVOUS FLAG RNDVZFLG SET ?)
STATQUO
SET BIT 5 OF FLAGWRD1
TRACKING ALLOWED
SET BIT 7 OF FLAGWRD1
UPDATING BY MARKS ALLOWED
GROUP 4
KILL GROUP 4 RESTARTS
MAKE GROUP 4 INACTIVE
POOFIZZ
IS BIT 7 OF FLAGWRD0 = 1 ?
YES
NO
WAS PROGRAM P20 INITIATED ? (IS RENDEZVOUS FLAG RNDVZFLG SET ?)
KILL20
GROUPS 1 & 2
KILL GROUPS 1 AND 2 RESTARTS
GROUPS 1 AND 2 INACTIVE
GOMOD
MODREG ◄— MMNUMBER
KEYED-IN MAJOR MODE
REV37
TEMPFLSH ◄— CADR V37XEQ +3
INITIALIZE RESTART ADDRESS FOR INTERFACE DISPLAY ROUTINE INITDSP. TEMPFLSH IS SET SO THAT CONTROL WILL RETURN TO V37XEQ IN CASE OF A .1 RESTART (PHASE 1 RESTART).
GOGOPROG
VIA POSTJUMP
GOPROG2
SH20
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.
APOLLO GUIDANCE AND NAVIGATION
FRESH START AND RESTART
DRAWN
PROGMR
ANALST
DOCMR
APPR'D
COLOSSUS II-D
DOCUMENT №
FC-2020
REV 3
SHEET 38 OF 60



FRESH START AND RESTART

COLOSSUS II-D

FC-2020

3

40 50

FROM
PRECEDING SHEET

VIA SPVAC
WITH :

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

SEE FCADRMM1 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 FCADRMM1 AND PREMM1 TABLES AS FOLLOWS :

$PREMM1_{15-11}$ = PRIORITY

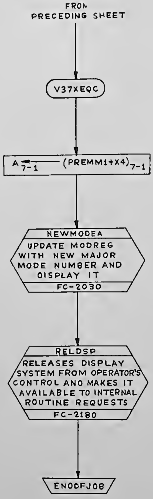
$PREMM1_{10-8}$ = E BANK NUMBER

$PREMM1_{7-1}$ = MAJOR MODE NUMBER

FCADRMM1 = FCADR OF THE MAJOR MODE

PREMM1 TABLE (OCT)	PRIORITY (OCT)	E BANK NO.	MAJOR MODE NO. (DEC)	FCADRMM1 TABLE FCADR 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
27657	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	GTSCPSS1

TO
V37XEQC
ON NEXT SHEET



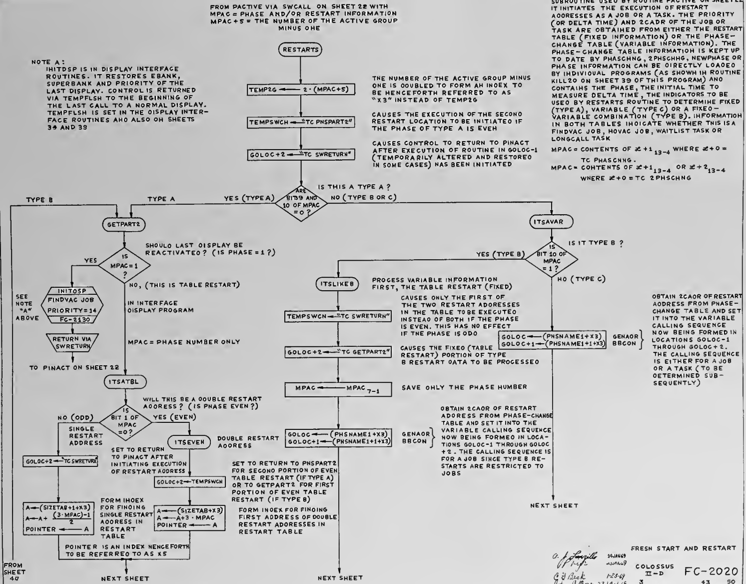
NEW (KEYED-IN) MAJOR MODE NUMBER.
$A_{15-8} = 0$

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 REQESTED 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

IN PINBALL PROGRAM

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	FRESH START AND RESTART
DRAWN A. Longill 27DEC68	
CHECKED Ryl 23JAN69	COLOSSUS II-D
APPROVED G. H. Beck 1-23-69	FC-2020
APPROVED John A. Mora 23JAN69	REV 3 SHEET 42 OF 50

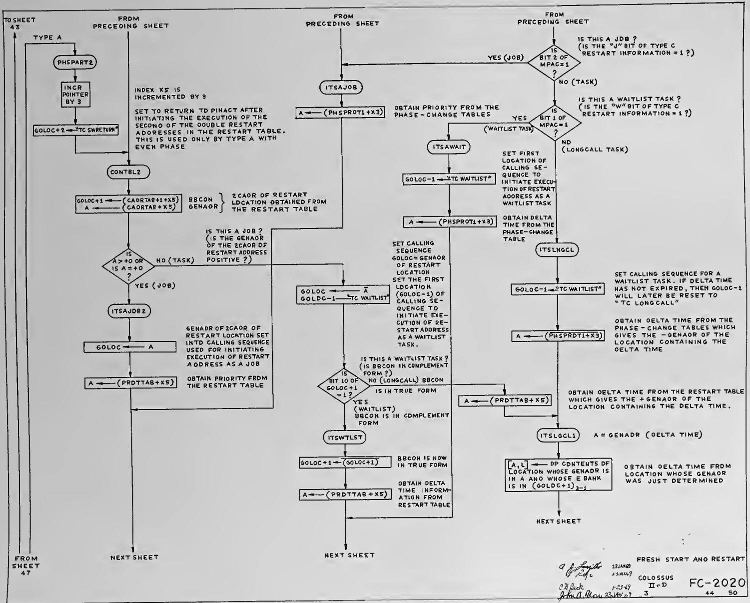


FRESH START AND RESTART

COLOSSUS II-D

FC-2020

3 43 50


TO SHEET 43
TYPE A
FROM PRECEDING SHEET
PHSPART2
INCR POINTER BY 3
GOLOC+2 ← "TC SWRETURN"
INDEX X5 IS INCREMENTED BY 3
SET TO RETURN TO PINACT AFTER INITIATING THE EXECUTION OF THE SECOND OF THE DOUBLE RESTART ADDRESSES IN THE RESTART TABLE. THIS IS USED ONLY BY TYPE A WITH EVEN PHASE
CONTBL2
GOLOC+1 ← (CADRTAB+1+X5)
A ← (CADRTAB+X5)
BBCON
GENADR
2CADR OF RESTART LOCATION OBTAINED FROM THE RESTART TABLE
IS A>+0 OR IS A=+0 ?
NO (TASK)
YES (JOB)
IS THIS A JOB ? (IS THE GENADR OF THE 2CADR OF RESTART ADDRESS POSITIVE ?)
ITSAJOB2
GOLOC ← A
GENADR OF 2CADR OF RESTART LOCATION SET INTO CALLING SEQUENCE USED FOR INITIATING EXECUTION OF RESTART ADDRESS AS A JOB
A ← (PRDTTAB+X5)
OBTAIN PRIORITY FROM THE RESTART TABLE
NEXT SHEET
FROM SHEET 47
FROM PRECEDING SHEET
ITSAJOB
A ← (PHSPRDT1+X3)
OBTAIN PRIORITY FROM THE PHASE-CHANGE TABLES
GOLOC ← Ā
GOLOC-1 ← "TC WAITLIST"
SET CALLING SEQUENCE GOLOC=GENADR OF RESTART LOCATION SET THE FIRST LOCATION (GOLOC-1) OF CALLING SEQUENCE TO INITIATE EXECUTION OF RESTART ADDRESS AS A WAITLIST TASK.
IS BIT 10 OF GOLOC+1 =1 ?
IS THIS A WAITLIST TASK ? (IS BBCON IN COMPLEMENT FORM ?)
NO (LONGCALL) BBCON IS IN TRUE FORM
YES (WAITLIST) BBCON IS IN COMPLEMENT FORM
ITSWTLST
GOLOC+1 ← (GOLOC+1)‾
BBCON IS NOW IN TRUE FORM
A ← (PRDTTAB+X5)
OBTAIN DELTA TIME INFORMATION FROM RESTART TABLE
NEXT SHEET
FROM PRECEDING SHEET
IS BIT 2 OF MPAC=1 ?
IS THIS A JOB ? (IS THE "J" BIT OF TYPE C RESTART INFORMATION = 1 ?)
YES (JOB)
NO (TASK)
IS BIT 1 OF MPAC=1 ?
IS THIS A WAITLIST TASK ? (IS THE "W" BIT OF TYPE C RESTART INFORMATION = 1 ?)
YES (WAITLIST TASK)
NO (LONGCALL TASK)
ITSAWAIT
GOLOC-1 ← "TC WAITLIST"
SET FIRST LOCATION OF CALLING SEQUENCE TO INITIATE EXECUTION OF RESTART ADDRESS AS A WAITLIST TASK
A ← (PHSPRDT1+X3)
OBTAIN DELTA TIME FROM THE PHASE-CHANGE TABLE
ITSLNGCL
GOLOC-1 ← "TC WAITLIST"
SET CALLING SEQUENCE FOR A WAITLIST TASK. IF DELTA TIME HAS NOT EXPIRED, THEN GOLOC-1 WILL LATER BE RESET TO "TC LONGCALL"
A ← (PHSPRDT1+X3)
OBTAIN DELTA TIME FROM THE PHASE-CHANGE TABLES WHICH GIVES THE -GENADR OF THE LOCATION CONTAINING THE DELTA TIME
A ← (PRDTTAB+X5)
OBTAIN DELTA TIME FROM THE RESTART TABLE WHICH GIVES THE +GENADR OF THE LOCATION CONTAINING THE DELTA TIME.
ITSLGCL1
A = GENADR (DELTA TIME)
[A,L] ← DP CONTENTS OF LOCATION WHOSE GENADR IS IN A AND WHOSE E BANK IS IN (GOLOC+1)3-1
OBTAIN DELTA TIME FROM LOCATION WHOSE GENADR WAS JUST DETERMINED
NEXT SHEET
FRESH START AND RESTART
COLOSSUS
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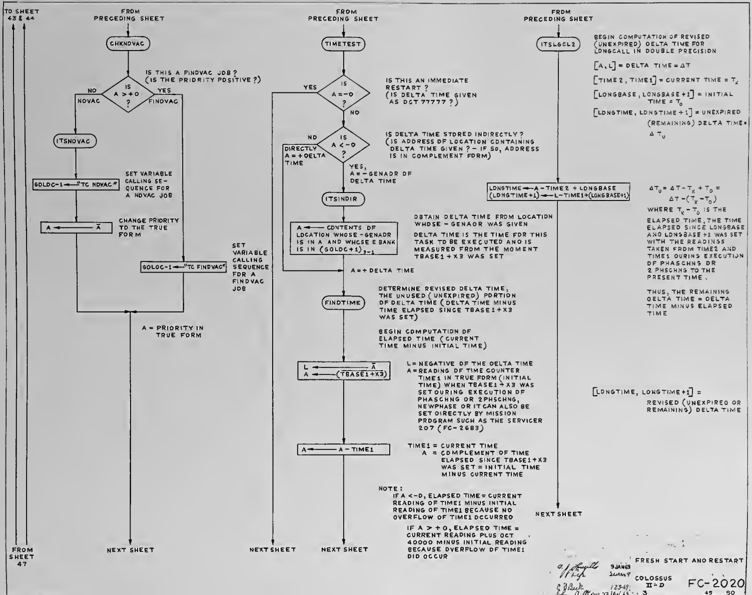
TO SHEET 43 & 44
FROM SHEET 47
FROM PRECEDING SHEET
CHKNOVAC
IS THIS A FINDVAC JOB ? (IS THE PRIORITY POSITIVE ?)
IS A >+0 ?
NO
NOVAC
YES
FINDVAC
ITSNOVAC
GOLOC-1 ←"TC NOVAC"
SET VARIABLE CALLING SE-QUENCE FOR A NOVAC JOB
A ← Ā
CHANGE PRIORITY TO THE TRUE FORM
GOLOC-1 ←"TC FINDVAC"
SET VARIABLE CALLING SEQUENCE FOR A FINDVAC JOB
A = PRIORITY IN TRUE FORM
NEXT SHEET
FROM PRECEDING SHEET
TIMETEST
IS A =-0 ?
YES
NO
IS THIS AN IMMEDIATE RESTART ? (IS DELTA TIME GIVEN AS OCT 77777 ?)
IS A <-0 ?
NO
DIRECTLY A = +DELTA TIME
YES, A = -GENADR OF DELTA TIME
IS DELTA TIME STORED INDIRECTLY ? (IS ADDRESS OF LOCATION CONTAINING DELTA TIME GIVEN ? - IF SO, ADDRESS IS IN COMPLEMENT FORM)
ITSINDIR
A ← CONTENTS OF LOCATION WHOSE -GENADR IS IN A AND WHOSE E BANK IS IN (GOLOC+1)3-1
OBTAIN DELTA TIME FROM LOCATION WHOSE -GENADR WAS GIVEN
DELTA TIME IS THE TIME FOR THIS TASK TO BE EXECUTED AND IS MEASURED FROM THE MOMENT TBASE1 + X3 WAS SET
A = + DELTA TIME
FINDTIME
DETERMINE REVISED DELTA TIME, THE UNUSED (UNEXPIRED) PORTION OF DELTA TIME (DELTA TIME MINUS TIME ELAPSED SINCE TBASE1 + X3 WAS SET)
BEGIN COMPUTATION OF ELAPSED TIME (CURRENT TIME MINUS INITIAL TIME)
L ← Ā
A ← (TBASE1 + X3)
L = NEGATIVE OF THE DELTA TIME
A = READING OF TIME COUNTER TIME1 IN TRUE FORM (INITIAL TIME) WHEN TBASE1 + X3 WAS SET DURING EXECUTION OF PHASCHNG OR 2PHSCHNG, NEWPHASE OR IT CAN ALSO BE SET DIRECTLY BY MISSION PROGRAM SUCH AS THE SERVICER 207 (FC-2683)
A ← A - TIME1
TIME1 = CURRENT TIME
A = COMPLEMENT OF TIME ELAPSED SINCE TBASE1 + X3 WAS SET = INITIAL TIME MINUS CURRENT TIME
NOTE:
IF A <-0, ELAPSED TIME = CURRENT READING OF TIME1 MINUS INITIAL READING OF TIME1 BECAUSE NO OVERFLOW OF TIME1 OCCURRED
IF A > +0, ELAPSED TIME = CURRENT READING PLUS OCT 40000 MINUS INITIAL READING BECAUSE OVERFLOW OF TIME1 DID OCCUR
NEXT SHEET
NEXT SHEET
FROM PRECEDING SHEET
ITSLGCL2
BEGIN COMPUTATION OF REVISED (UNEXPIRED) DELTA TIME FOR LONGCALL IN DOUBLE PRECISION
[A, L] = DELTA TIME = ΔT
[TIME 2, TIME1] = CURRENT TIME = Tx
[LONGBASE, LONGBASE + 1] = INITIAL TIME = T0
[LONGTIME, LONGTIME + 1] = UNEXPIRED (REMAINING) DELTA TIME = ΔTU
LONGTIME ← A - TIME2 + LONGBASE
(LONGTIME + 1) ← L - TIME1 + (LONGBASE + 1)
ΔTU = ΔT - Tx + T0 = ΔT - (Tx - T0)
WHERE Tx - T0 IS THE ELAPSED TIME, THE TIME ELAPSED SINCE LONGBASE AND LONGBASE +1 WAS SET WITH THE READINGS TAKEN FROM TIME2 AND TIME1 DURING EXECUTION OF PHASCHNG OR 2 PHSCHNG TO THE PRESENT TIME.
THUS, THE REMAINING DELTA TIME = DELTA TIME MINUS ELAPSED TIME
[LONGTIME, LONGTIME + 1] = REVISED (UNEXPIRED OR REMAINING) DELTA TIME
NEXT SHEET
FRESH START AND RESTART
COLOSSUS
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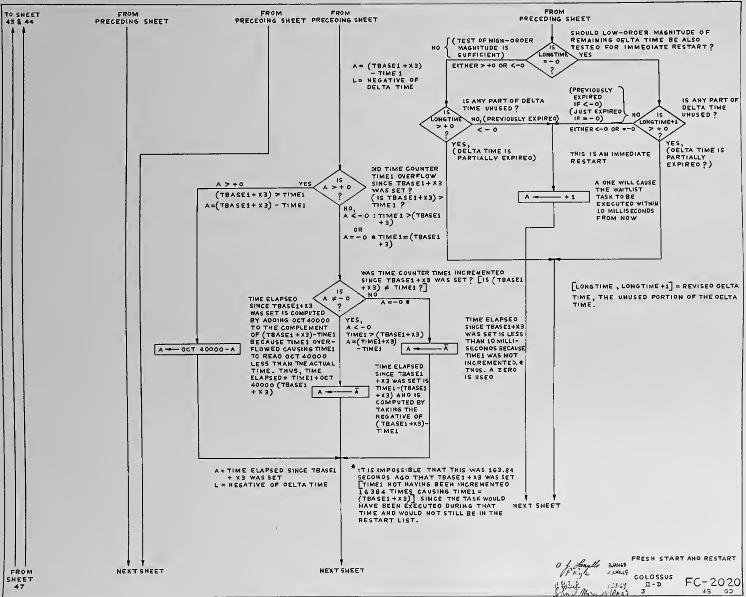
TO SHEET 43 & 44
FROM PRECEDING SHEET
FROM PRECEDING SHEET
FROM PRECEDING SHEET
FROM PRECEDING SHEET
IS LONGTIME = -0 ?
SHOULD LOW-ORDER MAGNITUDE OF REMAINING DELTA TIME BE ALSO TESTED FOR IMMEDIATE RESTART ?
YES
NO { (TEST OF HIGH-ORDER MAGNITUDE IS SUFFICIENT)
EITHER > +0 OR < -0
A = (TBASE1 + X3) - TIME 1
L = NEGATIVE OF DELTA TIME
IS LONGTIME > +0 ?
IS ANY PART OF DELTA TIME UNUSED ?
NO, (PREVIOUSLY EXPIRED)
< -0
YES, (DELTA TIME IS PARTIALLY EXPIRED)
(PREVIOUSLY EXPIRED IF < -0) (JUST EXPIRED IF = -0)
NO
IS LONGTIME+1 > +0 ?
IS ANY PART OF DELTA TIME UNUSED ?
EITHER < -0 OR = -0
YES, (DELTA TIME IS PARTIALLY EXPIRED ?)
THIS IS AN IMMEDIATE RESTART
A ← +1
A ONE WILL CAUSE THE WAITLIST TASK TO BE EXECUTED WITHIN 10 MILLISECONDS FROM NOW
IS A > +0 ?
YES
A > +0
(TBASE1 + X3) > TIME1
A = (TBASE1 + X3) - TIME1
DID TIME COUNTER TIME1 OVERFLOW SINCE TBASE1 + X3 WAS SET ? (IS TBASE1 + X3) > TIME1 ?
NO, A < -0 : TIME1 > (TBASE1 + 3)
OR
A = -0 * TIME1 = (TBASE1 + 3)
WAS TIME COUNTER TIME1 INCREMENTED SINCE TBASE1 + X3 WAS SET ? [IS (TBASE1 + X3) ≠ TIME1 ?]
IS A ≠ -0 ?
NO
A = -0 *
YES, A < -0 TIME1 > (TBASE1 + X3) A = (TIME1 + X3) - TIME1
A ← OCT 40000 - A
TIME ELAPSED SINCE TBASE1+X3 WAS SET IS COMPUTED BY ADDING OCT 40000 TO THE COMPLEMENT OF (TBASE1 + X3) - TIME1 BECAUSE TIME1 OVER-FLOWED CAUSING TIME1 TO READ OCT 40000 LESS THAN THE ACTUAL TIME. THUS, TIME ELAPSED = TIME1 + OCT 40000 (TBASE1 + X3)
A ← Ā
TIME ELAPSED SINCE TBASE1 + X3 WAS SET IS TIME1 - (TBASE1 + X3) AND IS COMPUTED BY TAKING THE NEGATIVE OF (TBASE1 + X3) - TIME1
A ← Ā
TIME ELAPSED SINCE TBASE1+X3 WAS SET IS LESS THAN 10 MILLI-SECONDS BECAUSE TIME1 WAS NOT INCREMENTED.* THUS. A ZERO IS USED
[LONGTIME , LONGTIME +1] = REVISED DELTA TIME, THE UNUSED PORTION OF THE DELTA TIME.
A = TIME ELAPSED SINCE TBASE1 + X3 WAS SET
L = NEGATIVE OF DELTA TIME
* IT IS IMPOSSIBLE THAT THIS WAS 163.84 SECONDS AGO THAT TBASE1 + X3 WAS SET [TIME1 NOT HAVING BEEN INCREMENTED 16384 TIMES CAUSING TIME1 = (TBASE1 + X3)] SINCE THE TASK WOULD HAVE BEEN EXECUTED DURING THAT TIME AND WOULD NOT STILL BE IN THE RESTART LIST.
NEXT SHEET
FROM SHEET 47
NEXT SHEET
NEXT SHEET
FRESH START AND RESTART
COLOSSUS II-D
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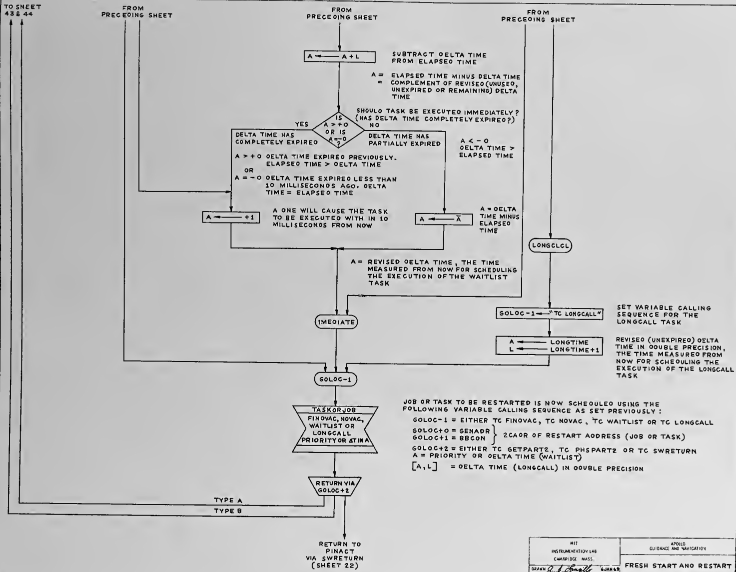

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

APOLLO GUIDANCE AND NAVIGATION

FRESH START AND RESTART

DRAWN 6 JAN 69; PRGMR 23 JAN 69; CO MR 1-29-69

COLOSSUS II-D

FC-2020

REV 3

SHEET 47 OF 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
MMDSPLAY	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 STOR 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
RCSDAPON+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 ROOTOPOO+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

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

REGISTER	SHEET	ROUTINE
ATTCADR	11	DSPOFF
CADRSTOR	10	DSPOFF
CADRTAB	44	CONTBL2
CHAN 5	3	DOFSTART
CHAN 5	31	ROOTOPOO
CHAN 6	3	DOFSTART
CHAN 6	31	ROOTOPOO
CHAN 11	14	DOFSTART
CHAN 11	8	STARTSB2
CHAN 11	30	V37
CHAN 11	20	NOCOARSE
CHAN 11	35	DUMMYAD
CHAN 11	36	DUMMYAD
CHAN 12	4	DOFSTART
CHAN 12	35	DUMMYAD
CHAN 13	4	DOFSTART
CHAN 13	8	STARTSB2
CHAN 13	35	DUMMYAD
CHAN 13	36	DUMMYAD
CHAN 14	4	DOFSTART
CHAN 15	14	LIGHTSET
CHAN 16	14	LIGHTSET
CHAN 33	13	GOPROG
CLPASS	10	DSPOFF
CSMMASS	30	ROOTOPOO
DELAYLOC	10	DSPOFF
DNLADMMI	37	NOUVEAU
DNLADPOO	37	POO
DNLSTCOD	4	DOFSTART
DNLSTCOD	38	SEUDOPOO
DNTMGOTO	8	STARTSUB
DSPCNT	10	DSPOFF
DSPCOUNT	12	DSPOFF
DSPLIST	11	DSPOFF
DSPLOCK	10	DSPOFF
DSPTAB+11D	2	SKIPSIM
DSPTAB+11D	4	DOFSTART
DSPTAB+11D	18	ELRSKIP
DSPTAB+11D	19	ELRSKIP
DSPTAB+10D through DSPTAB+0	10	DSPOFF
DSRUPTSW	3	SKIPSIM
DSRUPTSW	9	STARTSB2
DUMMYAD	34	CANV37
EBANKTEM	4	DOFSTART
EBANKTEM	38	SEUDOPOO
ERCOUNT	2	SKIPSIM
ERESTORE	3	DOFSTART
ERESTORE	15	BUTTONS
ERESTORE	16	BUTTONS

REGISTER	SHEET	ROUTINE
EXTVBACT	4	DOFSTART
EXTVBACT	12	DSPOFF
EXTVBACT	36	DUMMYAD
FAILREG	2	SKIPSIM
FLAGWRD0	6	DOFSTART
FLAGWRD0	37	POOH
FLAGWRD0	37	NOUVEAU
FLAGWRD0	39	RENDNOO
FLAGWRD0	39	POOFIZZ
FLAGWRD1	6	DOFSTART
FLAGWRD1	26	RAKE
FLAGWRD1	34	ISSERVON
FLAGWRD1	36	DUMMYAD
FLAGWRD1	38	SEUDOPOO
FLAGWRD1	39	STATQUO
FLAGWRD2	6	DOFSTART
FLAGWRD2	8	STARTSB2
FLAGWRD2	26	RAKE
FLAGWRD2	32	ISITPOO
FLAGWRD2	36	DUMMYAD
FLAGWRD2	37	POOH
FLAGWRD3	6	DOFSTART
FLAGWRD3	26	RAKE
FLAGWRD4	6	DOFSTART
FLAGWRD4	12	DSPOFF
FLAGWRD4	24	GOPOOFIX
FLAGWRD4	36	DUMMYAD
FLAGWRD5	6	DOFSTART
FLAGWRD5	20	NOCOARSE
FLAGWRD5	26	RAKE
FLAGWRD6	6	DOFSTART
FLAGWRD6	20	GOPROG2
FLAGWRD6	21	PCLOOP
FLAGWRD6	26	RAKE
FLAGWRD6	30	V37
FLAGWRD7	6	DOFSTART
FLAGWRD7	26	RAKE
FLAGWRD7	34	ISSERVON
FLAGWRD8	6	DOFSTART
FLAGWRD9	6	DOFSTART
FLAGWRD9	25	INITSUB
FLAGWRD9	25	RAKE
FLAGWRD9	36	DUMMYAD
FLGWRD10	6	DOFSTART
FLGWRD11	6	DOFSTART
FCADRMMI	40	V37XEQ
FCADRMMI	41	V37XEQ
GROUP 1-6.0	4	DOFSTART
GROUP 1, 2.0	39	KILL20
GROUP 1, 3, 4, 5, 6.0	39	GROUPKIL

REGISTER	SHEET	ROUTINE
GROUP 1, 4.0	7	POOKLEAN
GROUP 2.0	7	MR. KLEAN
GROUP 2.5	37	POOH
GROUP 3, 5, 6.0	7 39	V37KLEAN GROUPKIL
GROUP 4.0	39	STAQUO
GROUP 4.1	24	GOTOPOOH
GROUP 4.1	34	CANV37
IMODES30	5	DOFSTART
IMODES30	19	NOCOARSE
IMODES30	30	V37
IMODES33	5	DOFSTART
IMODES33	18	ELRSKIP
IMUCADR	11	DSPOFF
INLINK	10	DSPOFF
LGYRO	12	DSPOFF
LOC	27	V5LOOP1
LONGBASE	45	ITSLGCL2
LONGTIME	45	ITSLGCL2
LONGTIME	46	ITSLGCL2
LONGTIME	47	LONGCLCL
LST1	9	STARTSB2
LST2	9	STARTSB2
MARKSTAT	11	DSPOFF
MASSTMP	30	ROOTOPOO
MMNUMBER	30	V37
MMNUMBER	31	ROOTOPOO
MMNUMBER	32	ISITPOO
MMNUMBER	33	AGAINMM
MMNUMBER	37	DUMMYAD
MMNUMBER	39	GROUPKIL
MMNUMBER	39	RENDNOO
MMNUMBER	39	RENDVOO
MMNUMBER	39	GOMOD
MINDEX	33	AGAINMM
MODREG	5	DOFSTART
MODREG	23	PINACT
MODREG	39	RENDNOO
MODREG	39	GOMOD
MONSAVE	10	DSPOFF
MONSAVE1	10	DSPOFF
NEWJOB	9	STARTSB2
NEWJOB	29	V5OUT2
NEWLOC	29	V5OUT2
NEWPRIO	29	V5OUT2
NEWPRIO	40	V37XEQ
NOUNREG	11	DSPOFF
NOUT	12	DSPOFF
NVSAVE	4	DOFSTART
OPTCADR	11	DSPOFF
OPTIND	5	DOFSTART

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DRAWN	9-5-69	FRESH START & RESTART	
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DOCMR			
APPR'D	9-9-69	REV 3	SHEET 49 OF 50

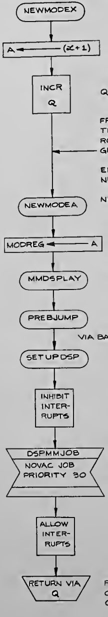
PHASE TABLE MAINTENANCE

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.

CONTROL ARRIVES HERE FROM ANY OF 12 LOCATIONS (L) WITH Q = L+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:
L+0 TO NEWMODEX
L+1 MM(THE NEW MAJOR MODE)
L+2 RETURN HERE UNCONDITIONALLY



A = THE NEW MAJOR MODE (PROGRAM REGISTER NUMBER)

Q = L+2, THE RETURN ADDRESS

FROM ROUTINE V37XEQC (FC-2020, SHEET 30) OF V37 IN THE FRESH START AND RESTART PROGRAM AND, FROM ROUTINE UPOUT (FC-2160, SHEET 7) OF UPDATE PROGRAM AND FROM ROUTINE ENDTEST1 OF IMU CALIBRATION AND ALIGNMENT PROGRAM. ENTRY MADE WITH A = THE NEW MAJOR MODE NUMBER

NEWMODEA IS SAME AS NEWMODEX+3

CALLING SEQUENCE FOR NEWMODEA
L-1 CAF L+N
L+0 TC NEWMODEA
L+1 RETURN HERE UNCONDITIONALLY
L+N NEW MAJOR MODE

MODREG = NEW MAJOR MODE

PREPARE TO DISPLAY THE NEW MAJOR MODE (IN MODREG)

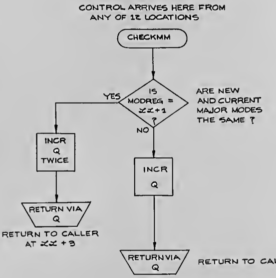
ROUTINE DSPMMJOB CAUSES THE NEW MAJOR MODE IN REGISTER MODREG TO BE DISPLAYED

RETURN TO CALLER AT L+2 OF NEWMODEX CALLING SEQUENCE OR AT L+1 OF NEWMODEA CALLING SEQUENCE

D.J. Chmelnick 4DEC68
P. Rye 23JAN69
C.G. Beck 1-23-69
John A. Moore 23JAN69

PHASE TABLE MAINTENANCE

COLOSSUS II FC-2030

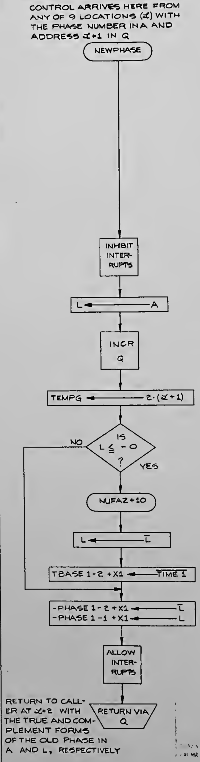


SUBROUTINE FOR COMPARING NEW MAJOR MODE WITH CURRENT MAJOR MODE

CALLING SEQUENCE:

LL+0 TC CHECKMM
LL+1 MM (THE NEW MAJOR MODE)
LL+2 RETURN HERE IF NEW MAJOR MODE AND CURRENT MAJOR MODE (IN MODREG) ARE NOT THE SAME
LL+3 RETURN HERE IF THEY ARE THE SAME -THEY MATCH

MIT INSTRUMENTATION LAB CAMBRIDGE MASS		APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature]	4DEC68	PHASE TABLE MAINTENANCE
PRGMR [signature]	13JAN69	
ANALYST		COLOSSUS II — DOCUMENT NO. FC-2030
DOCMR C.G. Beck	1-23-69	
APPR'D [signature]	23JAN69	REV 1 — SHEET 3 OF 16



SUBROUTINE NEWPHASE IS USED TO MAKE A QUICK NON-VARIABLE PHASE CHANGE. IT ALSO PERMITS THE STORING OF TIME 1 INTO TBASE IN COMPLEMENT FORM

CALLING SEQUENCE:

```
ɑ-1  CA(OR CS*) ɑ±N
ɑ+0  TO NEWPHASE
ɑ+1  OCT XXXXX (GROUP)
ɑ+2  RETURN HERE UNCONDITIONALLY
 :    :
ɑ±N  OCT YYYYY (PHASE)
  *   CA IF TBASE IS NOT TO BE SET
      CS IF TBASE IS TO BE SET
```

OCT XXXXX = BINARY 000 000 000 000 GGG
OCT YYYYY = BINARY 000 000 00P PPP PPP
WHERE G IS THE GROUP NUMBER AND P IS THE PHASE NUMBER

INHIBIT INTERRUPT PROGRAMS

L = PHASE NUMBER

Q = ɑ+2, THE RETURN ADDRESS

DOUBLE THE GROUP NUMBER IN LOCATION ɑ+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 ɑ+1 OF THE CALLING SEQUENCE

STORE THE COMPLEMENT OF THE CONTENTS OF TIME COUNTER TIME1 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 PHSPRDT1 TABLES

-PHASE 1
PHASE 1
-PHASE 2
PHASE 2
-PHASE 3
PHASE 3
-PHASE 4
PHASE 4
-PHASE 5
PHASE 5
-PHASE 6
PHASE 6
TBASE 1
PHSPRDT1
TBASE 2
PHSPRDT2
TBASE 3
PHSPRDT3
TBASE 4
PHSPRDT4
TBASE 5
PHSPRDT5
TBASE 6
PHSPRDT6

CAMBRIDGE, MASS.

D. J. Chmielinski 5DEC68
F. Kyo 23JAN69
C. H. Beck 1-23-69
John A. Moore 23 JAN 69

PHASE TABLE MAINTENANCE

COLOSSUS II FC-2030

1 4 16

CONTROL ARRIVES HERE FROM
ANY ONE OF 114 LOCATIONS WITH
$Q = \mathcal{L} + 1$
A = IRRELEVANT CONTENTS

PHASCHNG

NEXT PAGE

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:

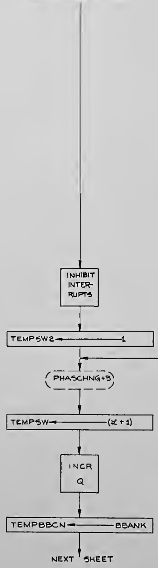
TYPE A FIXED PHASE CHANGES STORED IN PERMANENT FORM
TYPE B COMBINATION OF FIXED AND VARIABLE PHASE CHANGES
TYPE C VARIABLE PHASE CHANGE INFORMATION STORED IN ERASABLE LOCATION

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 CJW 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 PHSPRDT 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

FROM PRECEDING SHEET



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

	TYPE A	TYPE B OR C	
IF α+1 IS	TYPE A	TYPE B OR C	
AND PRIORITY (OR ΔT) IS		OLD (IN PHSPRDT1 TABLE)	NEW (IN α+2)
AND THE VARIABLE (IF ANY) RESTART ADDRESS IS	α+2	2CADR IN α+2, α+3	α+3 / 2CADR IN α+3, α+4
α+2 RETURN HERE IF (A=0, D=0) *	X	X	
α+3 RETURN HERE IF (A=0, D=1)			X
α+4 RETURN HERE IF (A=1, D=0)		X	
α+5 RETURN HERE IF (A=1, D=1)			X

*NOTE:
A IS BIT-POSITION 11 OF α+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 INTERRUPT PROGRAMS

INDICATES THAT ENTRY WAS MADE VIA PHASCHNG

ENTRY FROM ROUTINE 2 PHSCHNG

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

SET RETURN ADDRESS TO α+2

STORE BBANK OF CALLER

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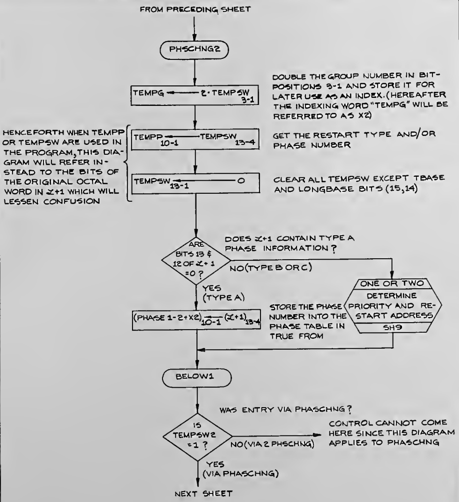
PHASE TABLE MAINTENANCE
COLOSSUS II FC-2030
1 6 16



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DRAWN [signature] 3DEC68
PRGMR [signature] 23JAN69
ANALST
DOCMR C. J. Beck 1-23-69
APPP'D John A. Moore 28JAN69

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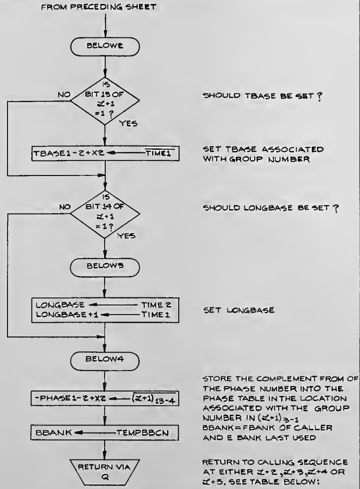
PHASE TABLE MAINTENANCE

COLOSSUS II

DOCUMENT NO. FC-2030

REV 1

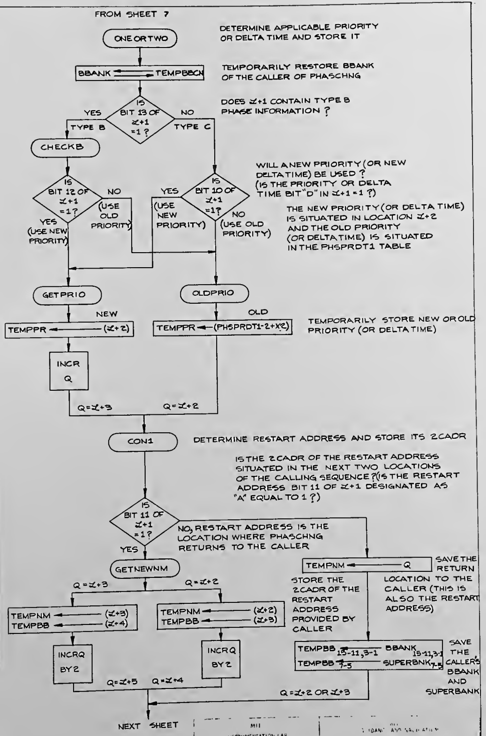


IF: TYPE A	TYPE B OR C — RESTART ADDRESS IS ONE OF LOCATIONS IN THE CALLING SEQUENCE (A=0); PRIORITY (OR DELTA TIME) TO BE USED IS: OLD (D=0)	NEW (D=1)	TYPE B OR C — RESTART ADDRESS IS 2CADR IN TWO LOCATIONS OF THE CALLING SEQUENCE (A=1); PRIORITY (OR DELTA TIME) TO BE USED IS: OLD (D=0)	NEW (D=1)	THEN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

PHASE TABLE MAINTENANCE

COLOSSUS II FC-2030

1 8 16



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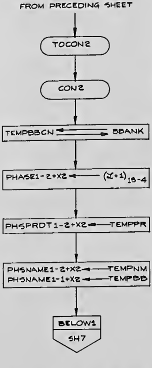
APPR John A. Morse 23 JAN 69	REV 1 SHEET 9 of 16



STORE THE PHASE NUMBER, PRIORITY (OR DELTA TIME) AND 2CADR 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 $(L+1)_{3-1}$

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

STORE THE 2CADR 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)	2CADR OF RESTART ADDRESS
-PHASE 1	TBASE 1	PHSNAME 1
PHASE 1	PHSPRDT 1	PHSBB1
-PHASE 2	TBASE 2	PHSNAME 2
PHASE 2	PHSPRDT 2	PHSBB 2
-PHASE 3	TBASE 3	PHSNAME 3
PHASE 3	PHSPRDT 3	PHSBB 3
-PHASE 4	TBASE4	PHSNAME4
PHASE 4	PHSPRDT 4	PHS BB 4
-PHASE 5	TBASE 5	PHSNAME 5
PHASE 5	PHSPRDT 5	PHSBB5
-PHASE 6	TBASE 6	PHSNAME 6
PHASE 6	PHSPRDT6	PHSBB6

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PHASE TABLE MAINTENANCE

COLOSSUS II

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1

10 16

2PHSCHNG

SUBROUTINE FOR CHANGING TWO GROUPS AT ONCE

IN FIXED-FIXED MEMORY

THE CALLING SEQUENCE IS:

L+0 TC 2PHSCHNG
L+1 OCT XXXXX (TYPE A)
L+2 OCT YYYYY (TYPE A, B OR C)

IF L+2 IS	TYPE A	TYPE B OR C	
AND PRIORITY (OR ΔT) IS	—	OLD (IN PHSPRDT1 TABLE)	NEW (IN L+3)
		2CADR IN	2CADR IN
AND THE VARIABLE (IF ANY) RESTART ADDRESS IS	— L+3	L+3, L+4	L+4
		L+4	L+5

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

*NOTE: A IS BIT-POSITION 11 OF L+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 YYYYY

INHIBIT INTERRUPTS

$TEMPP2 \leftarrow (L+1)$

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

INCR Q

Q = L+2

$TEMPG2 \leftarrow 2\cdot(TEMPP2)_{3-1}$

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 "TEMPG2" WILL BE REFERRED TO AS X3)

$TEMPP2_{10-1} \leftarrow TEMPP2_{13-4}$

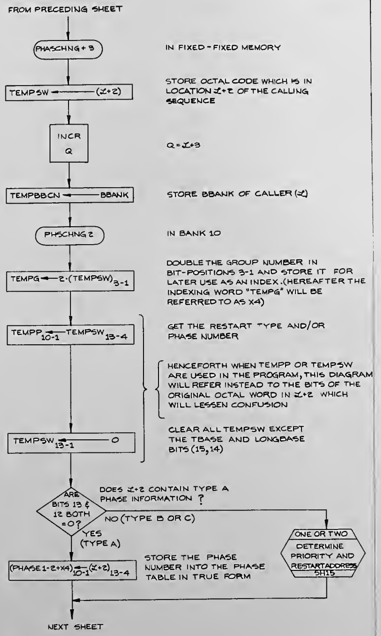
GET THE PHASE NUMBER

HENCEFORTH WHEN TEMPP2 OR TEMPSW2 ARE USED IN THE PROGRAM, THIS DIAGRAM WILL REFER INSTEAD TO THE BITS OF THE ORIGINAL OCTAL WORD IN L+1 WHICH WILL LESSEN CONFUSION. AN EXCEPTION IS TEMPSW2 USED IN ROUTINE BELOW 1 TO INDICATE THE ENTRY

$TEMPSW2_{15} \leftarrow TEMPP2_{15}$
$TEMPSW2_{14-1} \leftarrow 0$

SAVE TBASE INDICATOR (BIT15)
1 - TBASE SHOULD BE SET
0 - TBASE SHOULD NOT BE SET

NEXT SHEET



PHASE TABLE
MAINTENANCE

COLOSSUS II FC-2030

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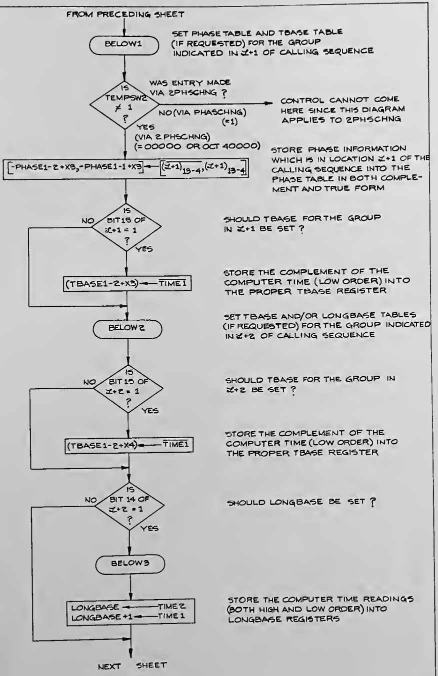

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APPR'D John A. Moran 23JAN69

PHASE TABLE MAINTENANCE

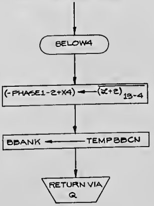
COLOSSUS II

FC-2030

REV 1

SHEET 13 OF 16

FROM PRECEDING SHEET



SET REMAINING PART OF PHASE TABLE AND RESTORE BBANK

STORE THE COMPLEMENT FORM OF PHASE INFORMATION WHICH IS IN LOCATION L+2 OF THE CALLING SEQUENCE INTO THE PHASE TABLE

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

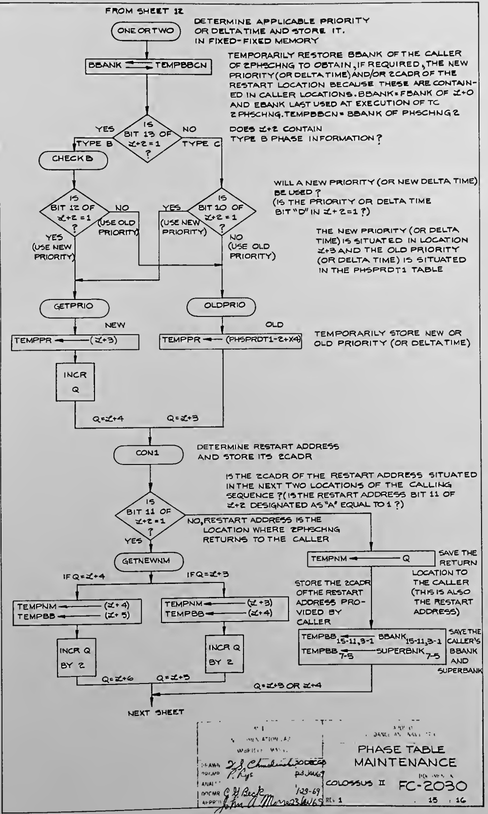
RETURN TO CALLING SEQUENCE AT EITHER L+3, L+4, L+5 OR L+6. SEE TABLE BELOW

IF					THEN THE RETURN TO THE CALLING SEQUENCE IS AT LOCATION
TYPE A	TYPE B OR C				
	RESTART ADDRESS IS ONE OF LOCATIONS IN THE CALLING SEQUENCE (A=0) AND PRIORITY (OR DELTA TIME) TO BE USE IS:		RESTART ADDRESS IS 2CADR IN TWO LOCATIONS OF THE CALLING SEQUENCE (A=1) AND PRIORITY (OR DELTA TIME) TO BE USED IS:		
	OLD (D=0)	NEW (D=1)	OLD (D=0)	NEW (D=1)	
X	X				L+3
		X			L+4
			X		L+5
				X	L+6

PHASE TABLE MAINTENANCE

COLOSSUS II FC-2030

1 14 16


FROM SHEET 12
ONE OR TWO
DETERMINE APPLICABLE PRIORITY OR DELTA TIME AND STORE IT. IN FIXED-FIXED MEMORY
BBANK ⇄ TEMPBBCN
TEMPORARILY RESTORE BBANK OF THE CALLER OF 2PHSCHNG TO OBTAIN, IF REQUIRED, THE NEW PRIORITY (OR DELTA TIME) AND/OR 2CADR OF THE RESTART LOCATION BECAUSE THESE ARE CONTAINED IN CALLER LOCATIONS. BBANK = FBANK OF L+0 AND EBANK LAST USED AT EXECUTION OF TC 2PHSCHNG. TEMPBBCN = BBANK OF PHSCHNG2
IS BIT 13 OF L+2 = 1 ?
YES
TYPE B
NO
TYPE C
DOES L+2 CONTAIN TYPE B PHASE INFORMATION?
CHECKB
IS BIT 12 OF L+2 = 1 ?
NO
(USE OLD PRIORITY)
YES
(USE NEW PRIORITY)
WILL A NEW PRIORITY (OR NEW DELTA TIME) BE USED? (IS THE PRIORITY OR DELTA TIME BIT "D" IN L+2 = 1 ?)
IS BIT 10 OF L+2 = 1 ?
YES
(USE NEW PRIORITY)
NO
(USE OLD PRIORITY)
THE NEW PRIORITY (OR DELTA TIME) IS SITUATED IN LOCATION L+3 AND THE OLD PRIORITY (OR DELTA TIME) IS SITUATED IN THE PHSPRDT1 TABLE
GETPRIO
OLDPRIO
NEW
TEMPPR ← (L+3)
OLD
TEMPPR ← (PHSPRDT1-2+X4)
TEMPORARILY STORE NEW OR OLD PRIORITY (OR DELTA TIME)
INCR Q
Q = L+4
Q = L+3
CON1
DETERMINE RESTART ADDRESS AND STORE ITS 2CADR
IS THE 2CADR OF THE RESTART ADDRESS SITUATED IN THE NEXT TWO LOCATIONS OF THE CALLING SEQUENCE? (IS THE RESTART ADDRESS BIT 11 OF L+2 DESIGNATED AS "A" EQUAL TO 1 ?)
IS BIT 11 OF L+2 = 1 ?
NO, RESTART ADDRESS IS THE LOCATION WHERE 2PHSCHNG RETURNS TO THE CALLER
YES
GETNEWNM
IF Q = L+4
IF Q = L+3
TEMPNM ← (L+4)
TEMPBB ← (L+5)
TEMPNM ← (L+3)
TEMPBB ← (L+4)
STORE THE 2CADR OF THE RESTART ADDRESS PROVIDED BY CALLER
TEMPNM ← Q
SAVE THE RETURN LOCATION TO THE CALLER (THIS IS ALSO THE RESTART ADDRESS)
TEMPBB 15-11,3-1 ← BBANK 15-11,3-1
TEMPBB 7-5 ← SUPERBNK 7-5
SAVE THE CALLER'S BBANK AND SUPERBANK
INCR Q BY 2
INCR Q BY 2
Q = L+6
Q = L+5
Q = L+3 OR L+4
NEXT SHEET
PHASE TABLE MAINTENANCE
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PROMD P. Kyz 23JAN69
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COLOSSUS II
FC-2030
REV 1
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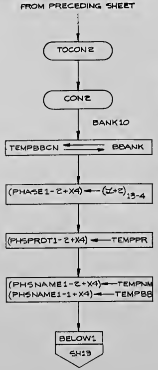

FIXED-FIXED MEMORY

STORE THE PHASE NUMBER, PRIORITY (OR DELTA TIME) AND 2CADR OF THE RESTART ADDRESS INTO TABLES FOR USE BY THE RESTART ROUTINES

SAVE CALLER'S BBANK
BBANK = BBANK OF PHSCHNG2
TEMPBBCN = B BANK OF CALLER ($\mathcal{L}$)

STORE THE TRUE FORM OF THE PHASE INFORMATION INTO THE PHASE TABLE IN THE LOCATION ASSOCIATED WITH THE GROUP NUMBER IN $(\mathcal{L}+2)_{3-1}$

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

STORE THE 2CADR OF THE RESTART ADDRESS INTO THE ADDRESS TABLE IN THE LOCATIONS ASSOCIATED WITH THE GROUP NUMBER

THE PHASE-CHANGE TABLES ARE AS FOLLOWS:

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PHASE1	PHSPRDT1	PHSBB1
-PHASE2	TBASE2	PHSNAME2
PHASE2	PHSPRDT2	PHSBB2
-PHASE3	TBASE3	PHSNAME3
PHASE3	PHSPRDT3	PHSBB3
-PHASE4	TBASE4	PHSNAME4
PHASE4	PHSPRDT4	PHSBB4
-PHASE5	TBASE5	PHSNAME5
PHASE5	PHSPRDT5	PHSBB5
-PHASE6	TBASE6	PHSNAME6
PHASE6	PHSPRDT6	PHSBB6

PHASE TABLE MAINTENANCE

THE EXECUTIVE

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

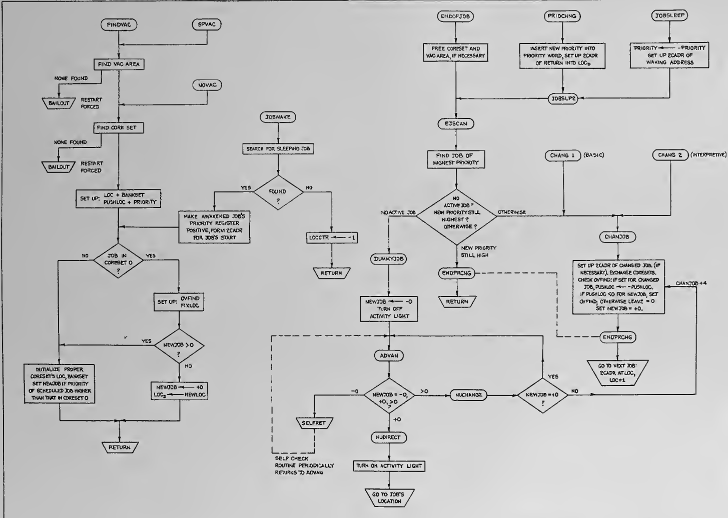
FINDVAC:	USED TO SCHEDULE A JOB NEEDING A SET OF ERASABLE LOCATIONS, CALLED THE VAC AREA.	SH. 3
SPVAC:	SAME AS FINDVAC, EXCEPT THAT NEWPRIO IS ALREADY LOADED, A, L = 2CADR OF JOB TO BE SCHEDULED, AND INTERRUPTS ALREADY INHIBITED.	SH. 3
NOVAC:	USED TO SCHEDULE A JOB NOT NEEDING A VAC AREA.	SH. 4
ENDOFJOB:	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
PRIOCHNG:	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



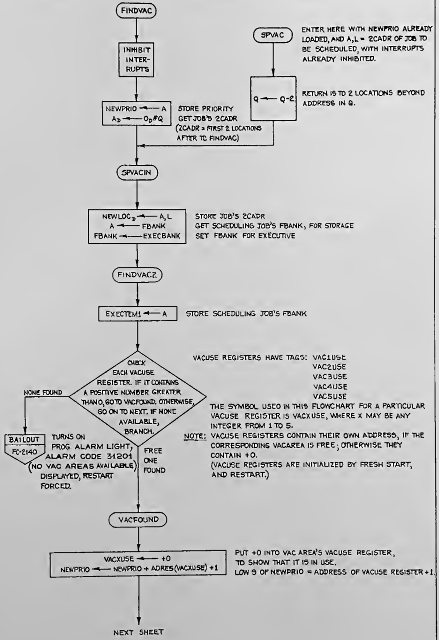
A.C. WILLIAMS 4MAR69
P. Rye 6-26-69
D. Riolo 6-27-69
Aldo M. Grant 6/27/69

THE EXECUTIVE

COLOSSUS II C

FC-2050

1 2 of 20



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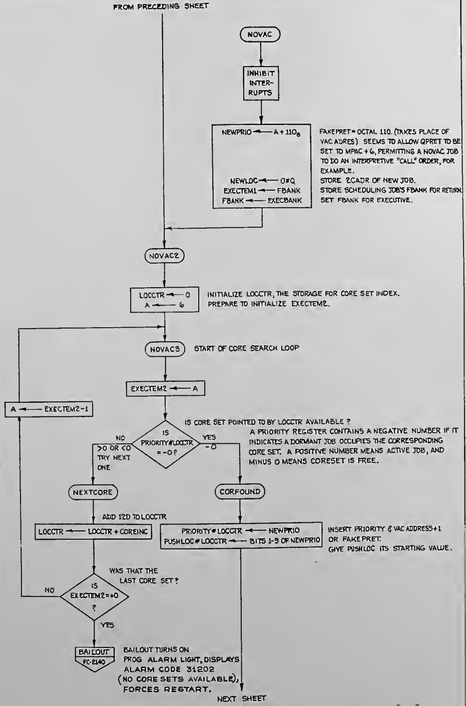
THE EXECUTIVE

COLOSSUS II C

FC-2050

REV 1

SHEET 3 OF 20



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THE EXECUTIVE

COLOSSUS IIC

FC-2050

REV 1

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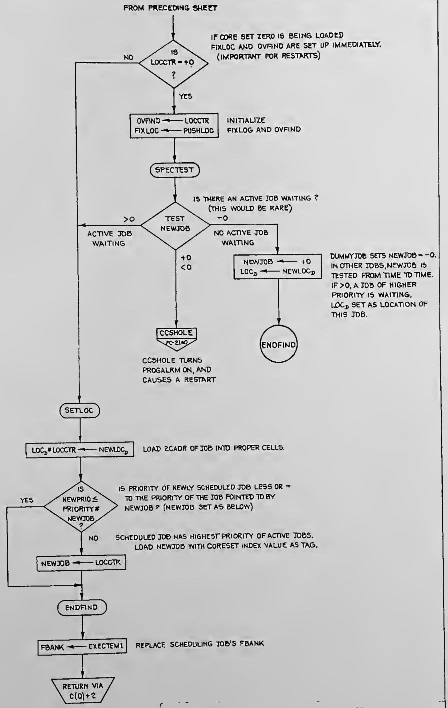

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THE EXECUTIVE

COLOSSUS II C

FC-2050

REV 1

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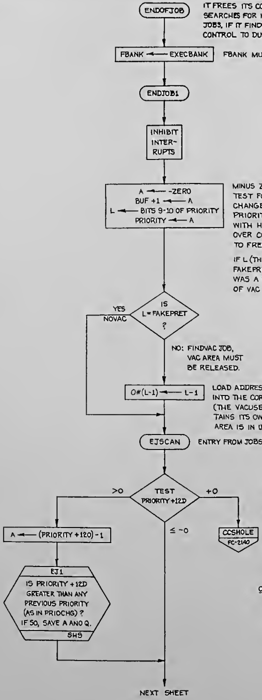

THIS ROUTINE IS CALLED TO TERMINATE A JOB. IT FREES ITS CORE SET AND VAC AREA, IF ANY, AND SEARCHES FOR HIGHEST PRIORITY AMONG THE ACTIVE JOBS. IF IT FINDS NO ACTIVE JOBS, IT TRANSFERS CONTROL TO DUMMY JOB.

FBANK MUST BE SET.

MINUS ZERO INITIALIZES BUF +1 FOR EJSCAN 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_8), THEN THE JOB TO BE ENDED WAS A NOVAC JOB. OTHERWISE, L = ADDRESS OF VAC AREA +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)

ENTRY FROM JOBSLEEP AND PRIOCHNG (VIA JOBSLP2.)

EJ1: FIRST TIME ENTERED

INPUT:
- A = (PRIORITY + 12D) - 1
- BUF + 1 = -0, IF ENTERED FROM ENDOFJOB OR JOBSLEEP
  = -NEW PRIORITY IF ENTERED VIA PRIOCHNG.
- BUF = +ZERO, IF PRIOCHNG, INDETERMINATE, OTHERWISE.

OUTPUT: IF A PRIOCHNG, 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

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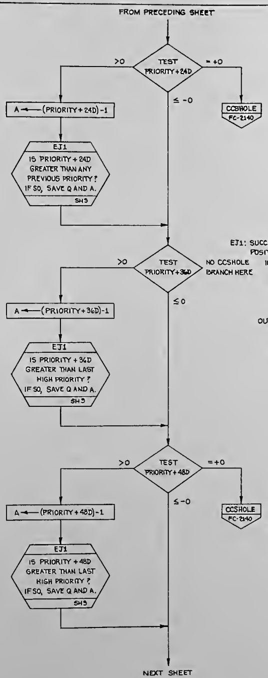
PROGMR P. Rye 6-26-69
ANALYST
DEV MGR D. L. Cook 6-27-69
APPR'D Alex M. Shaw 6/27/69

THE EXECUTIVE

COLOSSUS II C FC-2050

REV 1 6 20



EJ1: SUCCEEDING ENTRANCES (CONSIDER 12X TO BE POSITIVE, NON-ZERO MULTIPLE OF 12D)

INPUT:

A_S = (PRIORITY + 12X) − 1

BUF+1 = −HIGHEST PRIORITY YET FOUND.

BUF = +ZERO IF ENTERED VIA PRIOCHNG, & 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.

CCSHOLE TURNS PROGALRM ON, AND CAUSES A SOFTWARE RESTART (POODOO)

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PRGMR P. Rye 6-16-69
DOCMR D. S. Rinke 6-27-69
APPR'D Alex M. Sorant

THE EXECUTIVE

COLOSSUS IIC FC-2050

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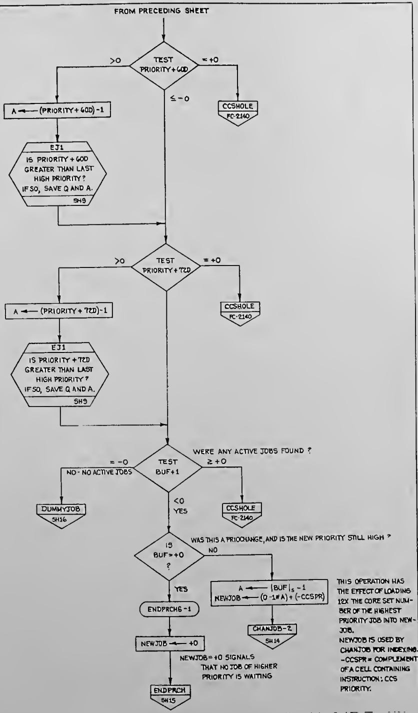

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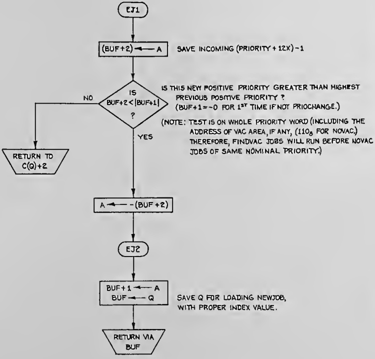

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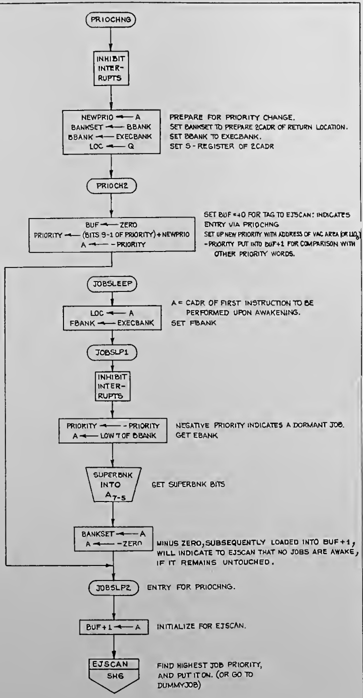

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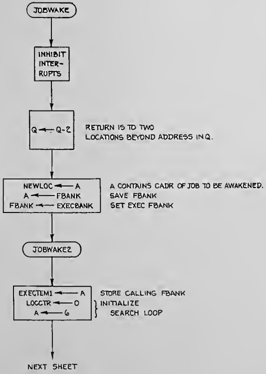

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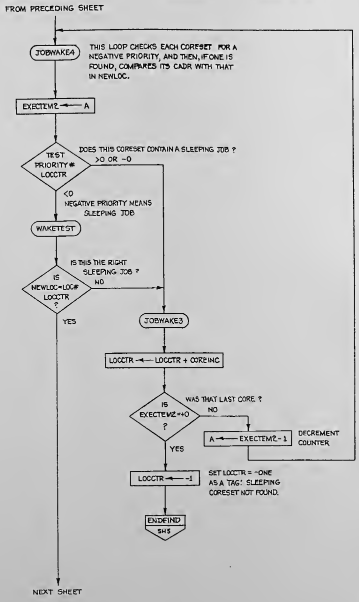

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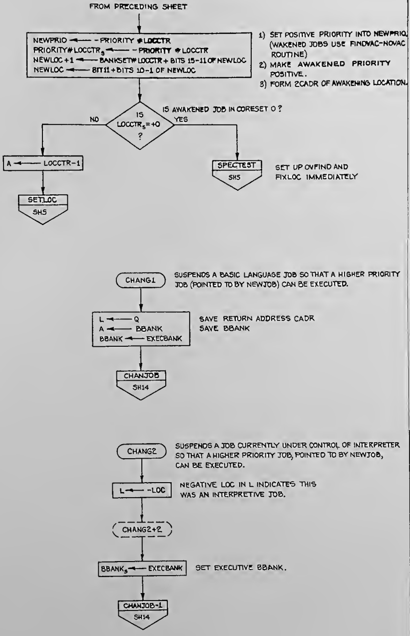

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P. Rye 6-26-62	
D. Rinker 6-27-62	COLOSSUS II C — DOCUMENT NO. FC-2050
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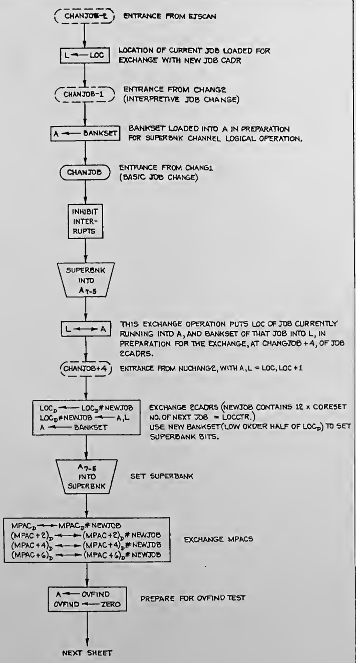

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DRAWN A.C. WILLIAMS	2APR69		
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DOCMR	6-27-69		
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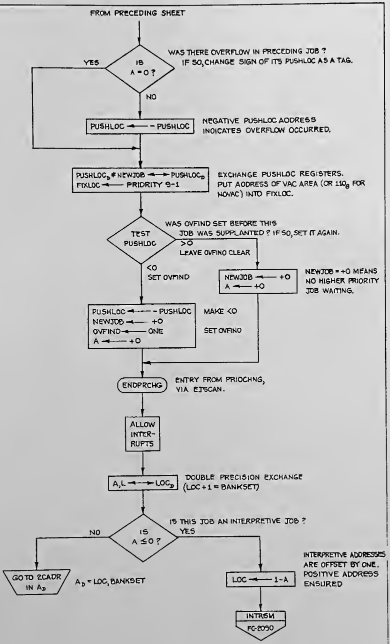

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DRAWN	A.C.WILLIAMS	5APR69
PRGMR	P. Rye	6-26-69
ANALST		
DOCMR	[signature]	6-27-69
APPR'D	[signature]	6/27/69

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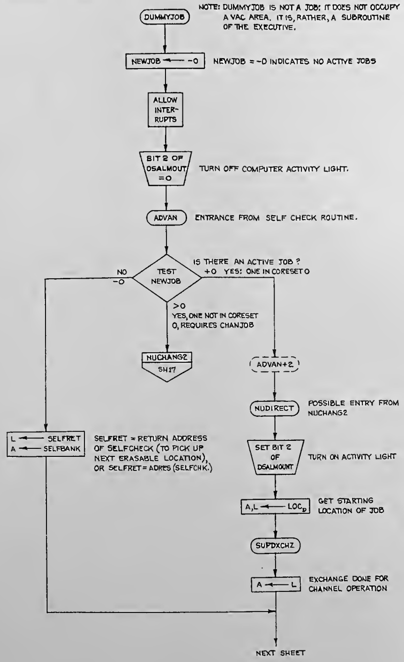

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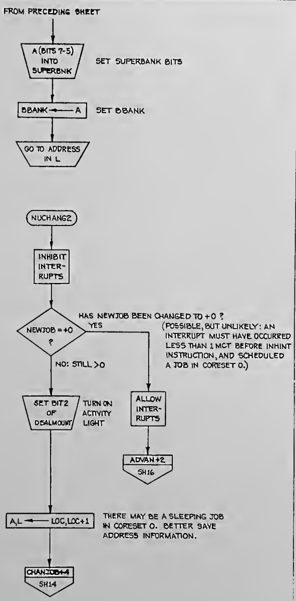

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APPR'D [signature] 6/27/69	REV 1 — SHEET 17 OF 20

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 72D LOC TIONS, FOR NON-ACTIVE JOBS, ALL IDENTICAL, AND ACCESSIBLE BY INDEXING.

ERASABLE LOCATIONS USED

AGC TAG	MEANING
NOTE:	IF A REGISTER IN CORESET 0 IS LISTED, IT SHOUL D 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
DSALMOUT	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, MPAC +2, ETC.	MULTIPURPOSE ACCUMULATOR FOR INTERPRETER, OTHERWISE STORAGE.
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 PRIOCHNG)
OVFIND	OVERFLOW REGISTER (INTERPRETER)
PRIORITY	PRIORITY OF JOB (IN HIGH ORDER BITS) AND IN LOW ORDER BITS: ADDRESS OF THE VAC AREA (OR 110_8 IF A NOVAC JOB).
PUSHLOC	ACTIVE: CURRENT ADDRESS OF NEXT CELL TO BE LOADED IN PUSHLIST, IF INTERPRETER. NOT ACTIVE: IF OVFIND +0, SET TO -PUSHLOC, SAME AS ACTIVE, OTHERWISE.
SELFRET	RETURN ADDRESS TO SELF CHECK ROUTINE
VAC1USE, VAC2USE, VAC3USE, VAC4USE, VAC5USE	CONTAIN OWN ADDRESS IF VAC AREA NOT IN USE. OTHERWISE, CONTAIN +0.

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.

WAITLIST PROGRAM SECTION

ENTRIES	SHEET	DESCRIPTION
TWIDDLE	9	SCHEDULES TASK IN SAME BANK. GENADR OF TASK IS GIVEN IN LOCATION ∠+ 1, WHERE ∠ = TC TWIDDLE. DELTA TIME IS IN A. RETURNS TO LOCATION ∠+ 2 OF CALLING SEQUENCE. SINGLE-PRECISION DELTA TIME.
WAITLIST	9	SCHEDULES TASK IN ANOTHER BANK. 2CADR OF TASK IS GIVEN IN LOCATIONS ∠+ 1 AND ∠+ 2, WHERE ∠= TC WAITLIST. DELTA TIME IS IN A. RETURNS TO LOCATION ∠+ 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 ∠+ 2 BY SCHEDULING LOCATION ∠+ 2 OF CALLING SEQUENCE AS A TASK WHERE ∠= TC FIXDELAY. DELTA TIME IS GIVEN IN ∠+ 1. CALLING SEQUENCE IS A TASK WHICH CONTINUES INTO FIXDELAY, WHERE THIS TASK IS TERMINATED WITH A TRANSFER TO TASKOVER, UNTIL RESUMED AT ∠+ 2.
VARDELAY	10	DELAYS EXECUTION OF LOCATION ∠+ 1 BY SCHEDULING LOCATION ∠+ 1 OF CALLING SEQUENCE AS A TASK WHERE ∠= 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 ∠+ 1.
T3RUPT	16	TRANSFERS CONTROL TO TASK WHOSE 2CADR IS IN LOCATION LST2+0 AND LST2+1. BEFORE EXECUTION OF TASK, TIME3 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 ∠+ 1 AND ∠+ 2, WHERE ∠= TC LONGCALL. RETURNS TO LOCATION ∠+ 3 OF CALLING SEQUENCE

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2. Sh. 7 20 23

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PRGMR		
ANALST	7-17-69	COLOSSUS IIC — DOCUMENT NO FC-2060
DOCMR		
APPR'D	7/18/69	REV 2 — 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 ΔT) 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 (α+2) AND VARDELAY (α+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, ..., T_8 AND T_9. ASSUME $T_9 > T_8 > T_7$, etc. UNTIL TASK N IS SCHEDULED, TIME3 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:

TASK	LST1 TABLE	LST2 TABLE
1	TIME3 = OCT 40000 - $(T_1 - T)$	LST2+0 = GENADR OF TASK 1 LST2+1 = BBCON OF TASK1
2	LST1+0 = $-(T_2 - T_1) + 1$	LST2+2, LST2+3 } = 2CADR OF TASK 2
3	LST1+1 = $-(T_3 - T_2) + 1$	LST2+4, LST2+5 } = 2CADR OF TASK 3
4	LST1+2 = $-(T_4 - T_3) + 1$	LST2+6, LST2+7 } = 2CADR OF TASK 4
5	LST1+3 = $-(T_5 - T_4) + 1$	LST2+8, LST2+9 } = 2CADR OF TASK 5
6	LST1+4 = $-(T_6 - T_5) + 1$	LST2+10, LST2+11 } = 2CADR OF TASK 6
7	LST1+5 = $-(T_7 - T_6) + 1$	LST2+12, LST2+13 } = 2CADR OF TASK 7
8	LST1+6 = $-(T_8 - T_7) + 1$	LST2+14, LST2+15 } = 2CADR OF TASK 8
9	LST1+7 = $-(T_9 - T_8) + 1$	LST2+16, LST2+17 } = 2CADR OF TASK 9
α	LST1 + α - 2 = $-(T_\alpha - T_{\alpha-1}) + 1$	LST2 + 2α - 2, LST2 + 2α - 1 } = 2CADR OF TASK α

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 1 ($T_1 > T_N$), THEN

(1) OCT 40000 - $(T_N - T)$ IS SET INTO TIME3.

(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 1 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 $T_6 > T_N > T_5$, THEN THE TIME INTERVAL $-(T_N - T_5) + 1$ WOULD BE COMPUTED AND PLACED INTO LST1+4. ALSO, THE TIME INTERVAL $-(T_6 - T_N) + 1$ WOULD BE COMPUTED AND PLACED INTO LST1+5 REPLACING $-(T_7 - T_8) + 1$, 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 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.

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 (ΔT = 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, THUS 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 T3RUPT ENTRY. ASSUME TASKS 1 THROUGH 9 ARE SCHEDULED AND THEIR TIME DATA AND 2CADR'S ARE IN THE TIME3 (TASK 1) COUNTER AND LST1 AND LST2 TABLES. THEN CONTROL IS TRANSFERRED TO ENTRY T3RUPT VIA THE LEAD-IN INTERRUPT ROUTINE AFTER INTERRUPTING SOME ROUTINE ELSEWHERE. WHEN $T = T_1$, THEN OCT 40000 - $(T_1 - T)$ IN TIME COUNTER TIME3 WILL EQUAL OCT 40000, THE OVERFLOW CONDITION. ACTUALLY, TIME3 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 ZRUPT (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 T3RUPT LEAD-IN ROUTINE FOR SAVING CONTENTS OF CERTAIN REGISTERS. CONTROL IS THEN TRANSFERRED TO ROUTINE T3RUPT. BEFORE TASK 1 IS EXECUTED, TIME3 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 TIME3 FOR TASK 2, THE CONTENTS $(T - T_1)$ OF TIME3, 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 TIME3. IF TASK 2 WAS SCHEDULED FOR THE SAME TIME AS TASK 1 $(T_1 = T_2)$ OR THE T3RUPT WAS DELAYED BY AN INHIBIT OR ANOTHER INTERRUPT $(T \geq T_2)$, THEN ROUTINE TASKOVER IS NOTIFIED THAT TASK 2 SHOULD BE EXECUTED IMMEDIATELY AFTER TASK 1 INSTEAD OF RESUMING THE INTERRUPTED ROUTINE. THE 2CADRS 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 $T \geq T_2$ WHEN CONTROL ARRIVED AT T3RUPT TO EXECUTE TASK 1, THEN CONTROL WILL PASS FROM ROUTINE TASKOVER TO T3RUPT2 LOCATION OF T3RUPT TO INITIATE THE EXECUTION OF TASK 2, SET TIME3 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.

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.

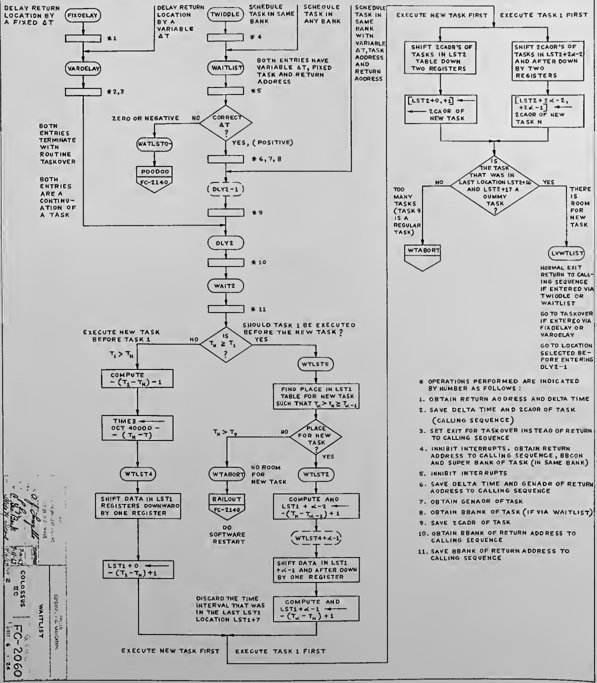
SUMMARY OF THE TWO SALIENT OPERATIONS

SCHEDULING A NEW TASK THE DELTA TIME OF THE NEW TASK IS $T_N - T = \Delta T_N$. IF $T_{\alpha-1} \leq T_N < T_\alpha$, THE TIME INTERVAL $-(T_N - T_{\alpha-1})+1$ REPLACES $-(T_\alpha - T_{\alpha-1})+1$ AND $-(T_\alpha - T_N)+1$ REPLACES $-(T_{\alpha+1} - T_\alpha)+1$, WHICH IN TURN REPLACES $-(T_{\alpha+2} - T_{\alpha+1})+1$, ETC. IN THE LSTI 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 TIME3 AND $-(T_1 - T_N)+1$ REPLACES $-(T_2 - T_1)+1$, WHICH IN TURN REPLACES $-(T_3 - T_2)+1$, ETC. IN THE LSTI TABLE. IF $T_N > T_9$, THERE IS NO ROOM IN THE LST TABLES FOR THE NEW TASK, AND A RESTART IS INITIATED.

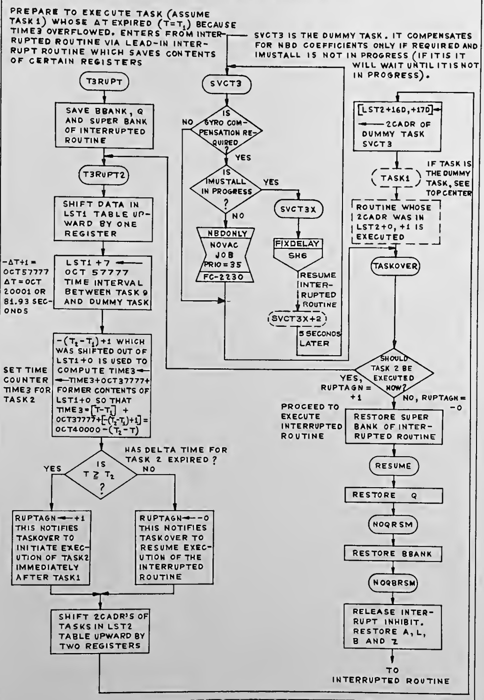
INITIATING THE EXECUTION OF A TASK(TASK1): THE $-(T_2 - T_1)+1$ IN THE TOP OF THE LST1 TABLE, THE $(T - T_1)$ IN TIME3 $(T \geq T_1)$ AND OCT 37777 ARE ADDED TOGETHER TO OBTAIN OCT 40000 - $(T_2 - T)$ TO BE SET INTO TIME3 FOR TASK 2 AND ALL OTHER TIME INTERVALS IN THE LST1 TABLE ARE MOVED UP.

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, ..., 8 AND 9) THAT HAVE BEEN SCHEDULED, BUT NOT EXECUTED YET. T1, T2, T3, ..., T8, T9 AND T_N ARE THE EXECUTION TIMES OF TASKS 1, 2, 3, ..., 8, 9 AND N, RESPECTIVELY. ASSUME $T_1 < T_2 < T_3 < ... < T_8 < T_9$. T IS CURRENT TIME.

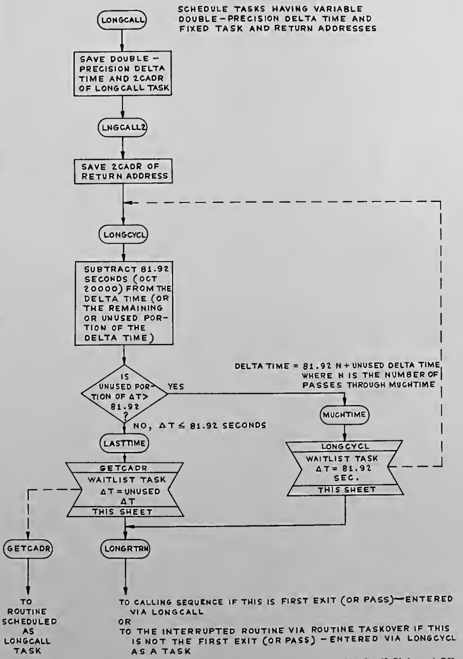


FUNCTIONAL FLOW CHART FOR EXECUTION OF TASK



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN G. J. Langille 14APR69	WAITLIST
PRGMR	
ANALYST P. Rye 16JUL67	COLOSSUS IIC — DOCUMENT NO FC-2060
DOCMR	
APPR'D Jack C. Reed	REV 2 — SHEET 7 OF 24

FUNCTIONAL FLOW CHART OF LONGCALL



MIT INSTRUMENTATION LAB, CAMBRIDGE, MASS.

A. J. Longillo 14APR69
P. Fyr 7-16-69
C. Geo. Beck 7-11-69
[illegible] 7/14/69

APOLLO GUIDANCE AND NAVIGATION

WAITLIST

COLOSSUS IIE

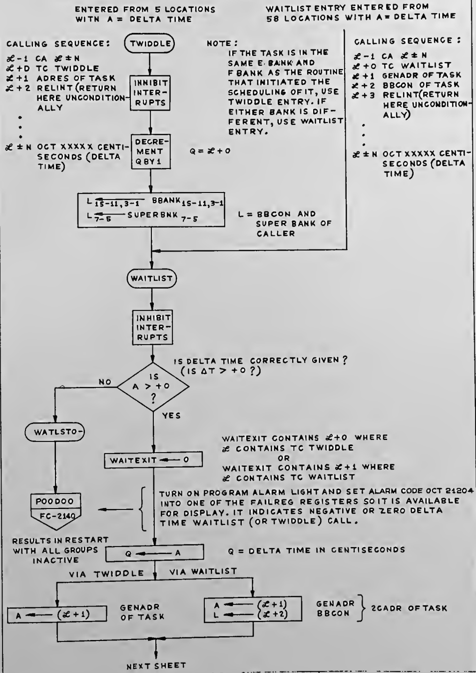
REV 2

FC-2060

SHEET 8 OF 24

MAIN (DETAILED) FLOW CHART

ENTRIES TWIDDLE AND WAITLIST ON THIS SHEET AND DLY2-1, FIXDELAY AND VARDELAY ON NEXT SHEET ARE USED FOR SCHEDULING TASKS



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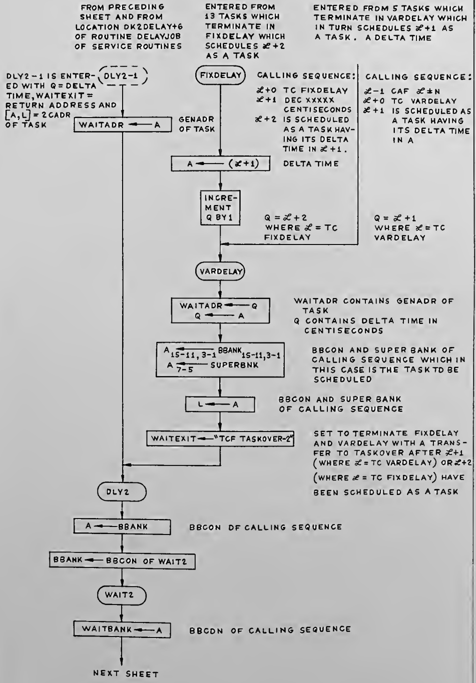
DRAWN A. J. Laspillo 15APR69	WAITLIST
CHECKED P. Ry... 7-8-69	COLOSSUS IIC
APPROVED C. Geo. Beek 7-11-69	DOCUMENT NR FC-2060
REV 2	SHEET 9 OF 24

MAIN (DETAILED) FLOW CHART

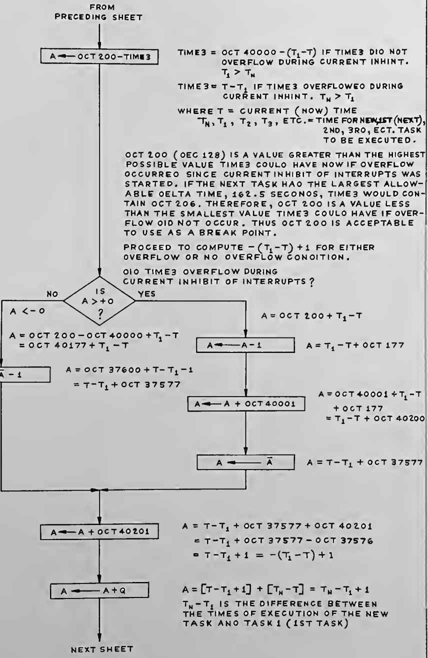


WAITLIST

COLOSSUS IIC

FC-2060

2 10 24



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

APOLLO GUIDANCE AND NAVIGATION

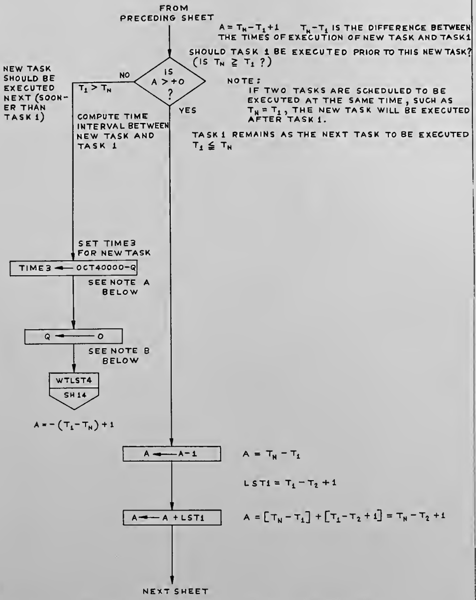
WAITLIST

COLOSSUS IIC

REV 2

DOCUMENT NO FC-2060

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

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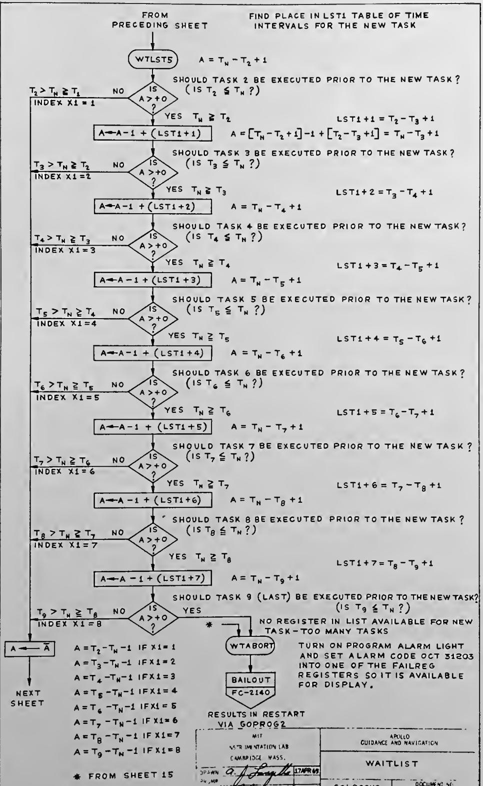
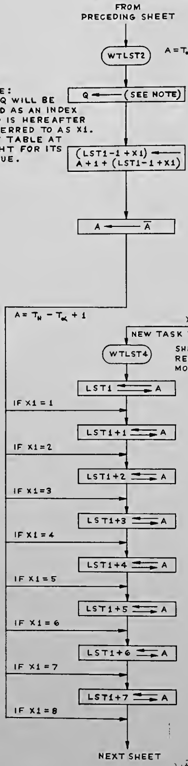
DRAWN A. J. Lanzilli 16APR69	WAITLIST
CHECKED C. Rin 7-4-69	COLOSSUS IIC
DESIGNED C. Dan Beck 7-11-69	DOCUMENT NO. FC-2060
APPROVED 7/14/69	REV 2 SHEET 12 OF 24



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. J. Laughlin 17APR69	WAITLIST	
CHECKED / ANAL'ST / PROGRAM / APPROVED: P. Ryan 7-16-69; C. Geo. Beck 7-11-69; [illegible] 7/16/69	COLOSSUS IIC	DOCUMENT NO. FC-2060
	REV 2	SHEET 13 OF 24

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



A PLACE HAVING BEEN FOUND IN THE LST1 TABLE FOR THE NEW TASK, PROCEED NOW TO COMPUTE THE TIME INTERVAL BETWEEN THE NEW TASK AND TASKS BEFORE AND AFTER IT.

$A = T_\alpha - T_N - 1$ 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):

X1	LST1-1+X1 (BEFORE)	LST1-1+X1 (NOW)	
1	$-(T_2-T_1)+1$	$-(T_N-T_1)+1$	IF $T_2>T_N \geq T_1$, LST1+0
2	$-(T_3-T_2)+1$	$-(T_N-T_2)+1$	IF $T_3>T_N \geq T_2$, LST1+1
3	$-(T_4-T_3)+1$	$-(T_N-T_3)+1$	IF $T_4>T_N \geq T_3$, LST1+2
4	$-(T_5-T_4)+1$	$-(T_N-T_4)+1$	IF $T_5>T_N \geq T_4$, LST1+3
5	$-(T_6-T_5)+1$	$-(T_N-T_5)+1$	IF $T_6>T_N \geq T_5$, LST1+4
6	$-(T_7-T_6)+1$	$-(T_N-T_6)+1$	IF $T_7>T_N \geq T_6$, LST1+5
7	$-(T_8-T_7)+1$	$-(T_N-T_7)+1$	IF $T_8>T_N \geq T_7$, LST1+6
8	$-(T_9-T_8)+1$	$-(T_N-T_8)+1$	IF $T_9>T_N \geq T_8$, LST1+7

NOW:

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

FROM WAIT2 ON SHEET 12 WITH $A = T_N - T_1 + 1$, $T_1 > T_N$

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

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

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

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DRAWN A. J. Langlotto 17APR69
CHECKED [illegible]
APPROVED P. [illegible] 7-16-69
[illegible] C. Geo. Beck 7-11-69
[illegible] [illegible] 7/16/69

APOLLO GUIDANCE AND NAVIGATION

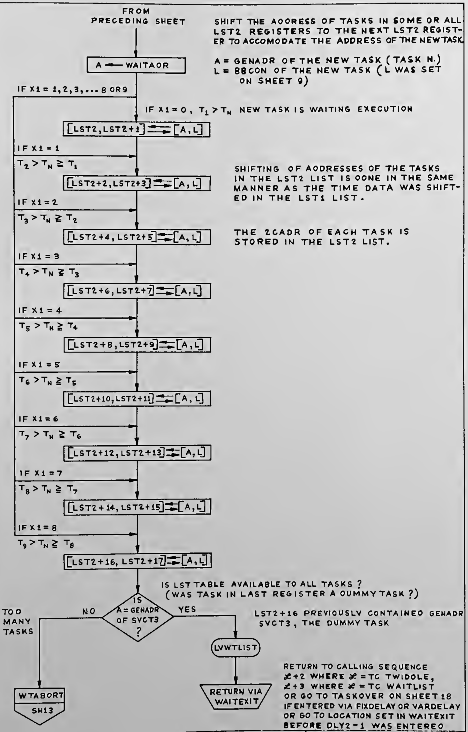
WAITLIST

COLOSSUS IIC

REV 2

DOCUMENT NO. FC-2060

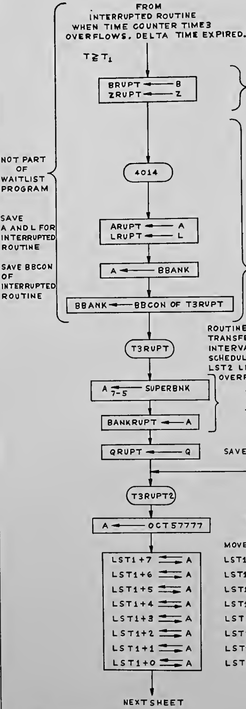
SHEET 14 OF 24



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Langill	WAITLIST
PRGMR	
ANALST P. R. 7/1/69	COLOSSUS IIC — DOCUMENT NO FC-2060
DOCMR C. Geo. Beck 7-11-69	
APPR'D 7/14/69 — REV 2	SHEET 15 OF 24

INTERRUPTED ROUTINE SEQUENCE

$\alpha+0$ α (α IS INSTRUCTION BEING EXECUTED WHEN INTERRUPT BEGAN)
$\alpha+1$ β (β IS INSTRUCTION TO BE EXECUTED FIRST UPON RESUMING INTERRUPTED ROUTINE)
$\alpha+2$



SAVE NEXT INSTRUCTION β AND ADDRESS $\alpha+2$ 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 TIME3 OVERFLOWS, INTERRUPTS ARE INHIBITED BY AN INHINT OR ANOTHER INTERRUPT IS IN PROGRESS AND/OR WAITING (T_6, T_5), TRANSFER OF PROGRAM CONTROL TO LOCATION 4014 WILL BE DELAYED UNTIL THE INHIBIT IS RELEASED (RELINT) OR INTERRUPT IN PROGRESS IS TERMINATED AND/OR T6 OR T5 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 2CADR FOR THE REMAINING SCHEDULED TASKS UPWARD ONE PLACE IN THE LST1 AND LST2 LISTS SO TASK 2 WILL BE READY NEXT TIME TIME3 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	= OCT 57777 *	DUMMY TASK SVCT3
LST1+6	$= -(T_9 - T_8) + 1$	TASK 9
LST1+5	$= -(T_8 - T_7) + 1$	TASK 8
LST1+4	$= -(T_7 - T_6) + 1$	TASK 7
LST1+3	$= -(T_6 - T_5) + 1$	TASK 6
LST1+2	$= -(T_5 - T_4) + 1$	TASK 5
LST1+1	$= -(T_4 - T_3) + 1$	TASK 4
LST1+0	$= -(T_3 - T_2) + 1$	TASK 3
A	$= -(T_2 - T_1) + 1$	TASK 2

* $-(T_D - T_9) + 1 =$ OCT 57777 OR $(T_D - T_9) = -$ OCT 57776 = OCT 20001 OR 81.93 SECONDS WHERE T_D IS EXECUTION TIME OF DUMMY TASK SVCT3 (WILL BE EXECUTED 81.93 SECONDS AFTER TASK 9)

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DRAWN A. J. Lanzetta 22APR69
CHECKED
ASST. ST. P. Rye 7-8-69
DIV. MGR. C. Geo. Beck 7-11-69
APPR'D Alex M. Sonnk 7/14/69

APOLLO GUIDANCE AND NAVIGATION

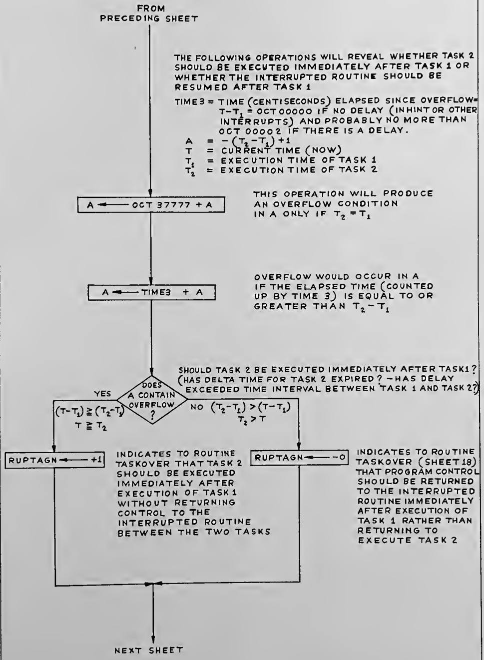
WAITLIST

COLOSSUS IIC

REV 2

DOCUMENT NO. FC-2060

SHEET 16 OF 24



MIT INSTRUMENTATION LAB, CAMBRIDGE, MA

DRAWN	A. J. Langille	3 JUL 69
CHECKED		
ANALYST	P. Rye	7-16-69
DOC MGR	E. Geo. Beck	7-11-69
APPROVED	Alex W. Kosmala	7/14/69

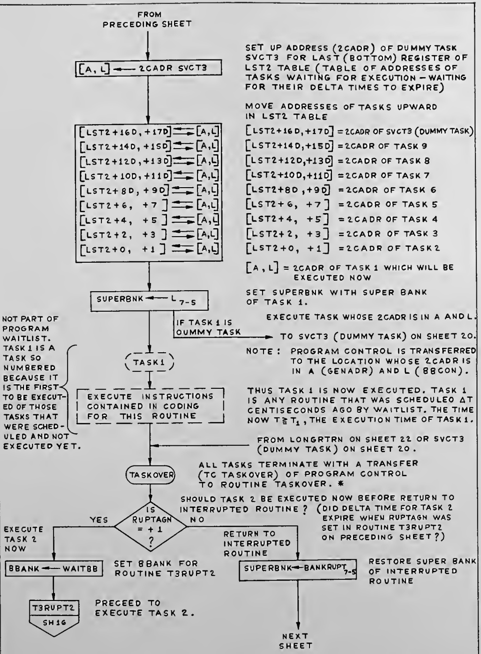
WAITLIST

COLOSSUS IIC

REV 2

DOCUMENT NO. FC-2060

SHEET 17 OF 24



* ROUTINE TASKOVER IS ENTERED FROM 73 LOCATIONS DIRECTLY.

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.

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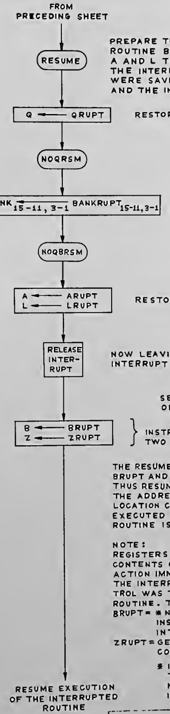
DIV MGR A. Lee Beck 7-11-69	DOCUMENT NO. FC-2060
APPROVED 7/14/69	REV 2 · SHEET 18 OF 24



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.

RESTORE Q

RESTORE BBANK

RESTORE A AND L

NOW LEAVING INTERRUPT MODE

SET UP TO EXECUTE NEXT INSTRUCTION OF INTERRUPTED ROUTINE

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 INTERRUTED 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.

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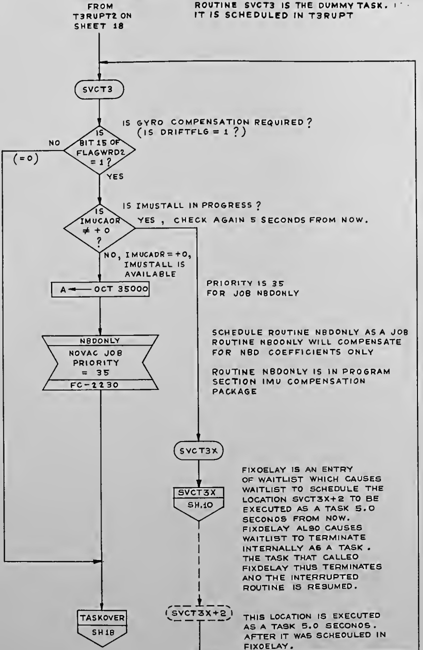
ANALST	P. Rye 7/16/69	COLOSSUS IIC	DOCUMENT NO. FC-2060
DOC MGR	C. Geo. Beck 7-11-69		
APPR'D	[illegible] 7/14/69	REV 2	SHEET 19 OF 24



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DRAWN *G. J. Lonigetto* 29APR69
ANALYST *P. Ryan* June 14 69
APPR'D *Jack E. Read*

APOLLO GUIDANCE AND NAVIGATION

WAITLIST

COLOSSUS IIC

REV 2

DOCUMENT NO FC-2060

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 OCT 00001 (0.01 SECOND) TO [OCT 37777, OCT 37777] (2,684, 354.55 SECONDS OR 745 HOURS 39 MINUTES AND 14.55 SECONDS OR APPROXIMATELY ONE MONTH).
[OCT 37777, OCT 37777] = OCT 1,777,777,777 = DEC 268,435,455

CALLING SEQUENCE:

```
L-2     EXTEND
L-1     DCA    L±N
L+0     TC     LONGCALL
L+1     GENADR OF TASK
L+2     BBCON  OF TASK
L+3     RETURN HERE UNCONDITIONALLY
  :
L±N     2DEC ΔT CENTISECONDS
L±N+1
```

(LONGCALL)

| LONGTIME ← A
LONGTIME +1 ← L | DOUBLE-PRECISION DELTA TIME |

| LONGCADR ← (L+1)
LONGCADR +1 ← (L+2) | GENADR
BBCON } 2CADR OF LONGCALL TASK |

(LNGCALL2)

| LONGEXIT +1 ← BBCON OF L | BBCON OF RETURN ADDRESS |

| LONGEXIT ← GENADR OF L+3
Q ← GENADR OF L+3 | GENADR OF RETURN ADDRESS |

← ENTERED HERE FROM ROUTINE T3RUPT LONGCYCL IS SCHEDULED AS A TASK IN ROUTINE MUCHTIME

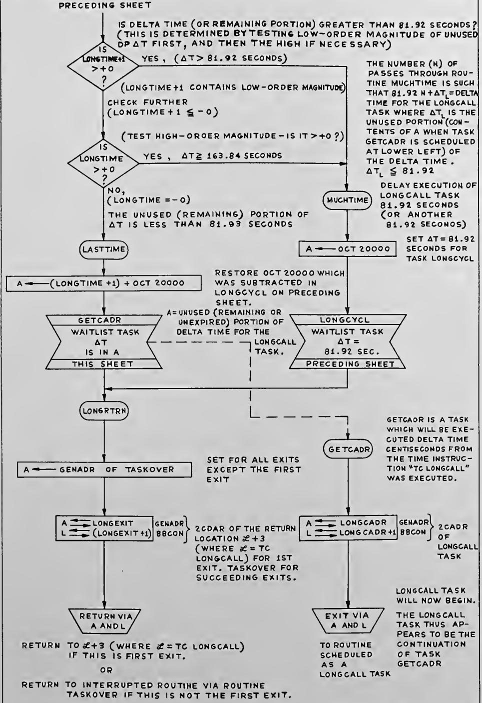
(LONGCYCL)

| [LONGTIME, LONGTIME +1] ← [LONGTIME, LONGTIME +1] - OCT 20000 | SUBTRACT 81.92 SECONDS FROM DELTA TIME (OR REMAINING DELTA TIME) |

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).

NEXT SHEET

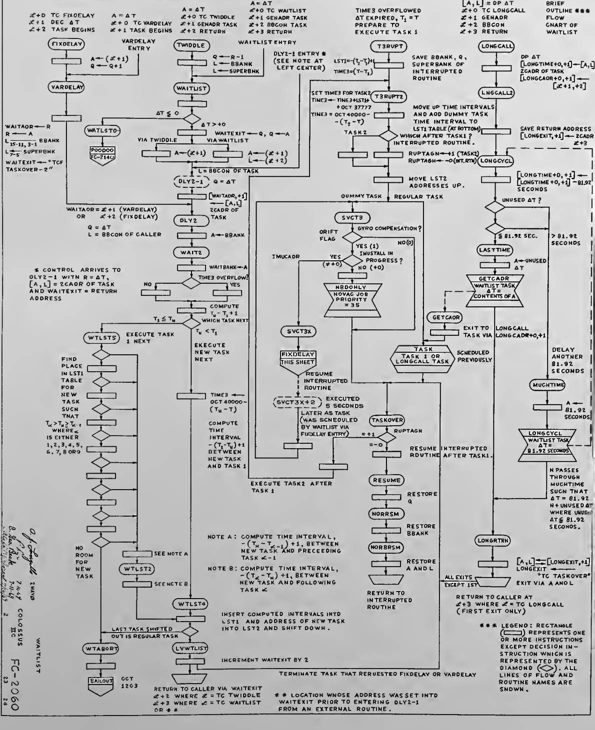
THIS DOUBLE-PRECISION SUBTRACTION OPERATION PERFORMED EACH PASS RESULTS IN THE HIGH-ORDER MAGNITUDE IN LONGTIME BEING DECREMENTED BY ONE WHEN AN OVERFLOW OCCURRED IN THE LOW-ORDER MAGNITUDE SUBTRACTION. ALSO, THE LOW-ORDER MAGNITUDE IS INCREASED BY OCT 40000 AT THE SAME TIME. THIS DOES NOT OCCUR WHEN 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: G. J. Langille 1 MAY 69	WAITLIST
CHECKED: P. Ryz 7/4/69	COLOSSUS IIC
DEV HEAD: C. Geo Beck 7-11-69	DOCUMENT NO. FC-2060
APPROVED: [signature] 7/16/69	REV 2 — SHEET 22 OF 24

OUTLINE FLOW CHART OF WAITLIST PROGRAM SECTION

USED FOR SCHEDULING (ALL ENTRIES EXCEPT T3RUPT) AND EXECUTION (T3RUPT) OF TASKS.



WAITLIST

COLOSSUS IIC

FC-2060

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
BAILOUT	FC-2140	TURNS 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 GOPROG2.	SH. 13
POODOO	FC-2140	TURNS 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 GOPROG2. 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
BANKRUPT	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
LRUPT	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

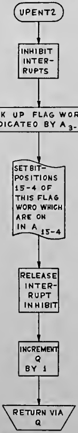
SERVICE ROUTINES

LIST OF REVISIONS

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

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 α+2 OF CALLING SEQUENCE

EXAMPLE OF CALLING SEQUENCE:

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

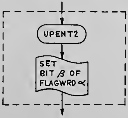
SUBROUTINE FOR SETTING SELECTED BIT POSITIONS OF A SELECTED FLAG WORD.

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 = α+2 OF CALLING SEQUENCE

CALLING SEQUENCE:

```
α + 0   TC UPENT2
α + 1   OCT ANY DATA
α + 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.

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.

RETURN TO $\mathscr{L}+2$ OF CALLING SEQUENCE

EXAMPLE OF CALLING SEQUENCE:

```
ENDRET+7   CA    GENMASK
           MSK   PINIDMSK
           TC    DOWNENT2

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

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

CALLING SEQUENCE:

$\mathscr{L}+0$ TC DOWNENT2
$\mathscr{L}+1$ OCT ANY DATA
$\mathscr{L}+2$ 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.

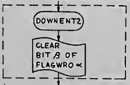
THE FLAG WORD SELECTED IS DETERMINED BY THE CONTENTS OF A_{3-1}. THE CONTENTS ARE USED AS AN INDEX TO SELECT FLAG WORDS AS SHOWN IN THE FOLLOWING TABLE:

A_{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

$Q = \mathscr{L}+2$ OF CALLING SEQUENCE WHERE $\mathscr{L}$ 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.

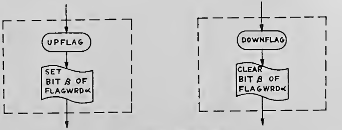
THIS SUBROUTINE WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING IT:



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, . . . , FLGWRD10 AND FLGWRD11. 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 (FLAGWRDα WHERE α IS 0, 1, 2, . . . , 10 OR 11) AND THE BIT POSITION β (WHERE β 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 α) AND THE BIT POSITION OF THAT FLAG WORD WILL BE β (β IS 15 MINUS R, THE REMAINDER). THUS, THE CODE NUMBER IS $15\alpha + R$ OR $15\alpha + 15 - \beta$. AS AN EXAMPLE, THE CODE NUMBER FOR MIDAVFLG IS DEC 148. THE QUOTIENT OF $148 \div 15$ IS 9 AND THE REMAINDER IS 13 ($\alpha = 9$, $R = 13$, $\beta = 15 - R = 2$). THUS, THE FLAG MIDAVFLG IS IN FLAG WORD FLAGWRD0+9 WHICH IS FLAGWRD9. FLAG MIDAVFLG IS BIT-POSITION2 OF FLAGWRD9.

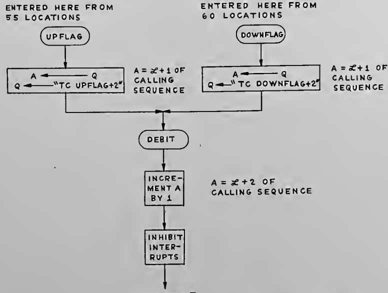
THESE SUBROUTINES WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING IT.



CALLING SEQUENCE:

$\mathcal{L}+0$ TC UPFLAG
$\mathcal{L}+1$ ADRES FLAG NAME
$\mathcal{L}+2$ RETURN HERE UNCONDITIONALLY

$\mathcal{L}+0$ TC DOWNFLAG
$\mathcal{L}+1$ ADRES FLAG NAME
$\mathcal{L}+2$ RETURN HERE UNCONDITIONALLY



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 27JAN69	SERVICE ROUTINES
PRGMR [signature] 3/21/69	COLOSSUS II-D — DOCUMENT NO. FC-2070
ANALST	
DOCMR D. B. Buck 3-12-69	
APPR'D [signature] 24 MAR 69 REV 2	SHEET 4 OF 14

FROM PRECEDING SHEET

SERVICE ROUTINES (UPFLAG AND DOWNFLAG)

ITEMP3 ← A

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

ITEMP1 ← QUOTIENT OF ($\mathscr{X}$+1) ÷ DEC 15

ITEMP1 = $\propto$ (THE QUOTIENT)
THE QUOTIENT WILL BE USED AS AN INDEX FOR SELECTING THE FLAG WORD AND WILL BE REFERRED TO AS "X1"

ITEMP2 ← REMAINDER OF ($\mathscr{X}$+1) ÷ DEC 15

ITEMP2 = $\mathscr{R}$ (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 "X2"

L ← (FLAGWRD0+X1)

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

	INDEX X1	FLAG WORD
FLAGWRD0	+ 0	FLAGWRD0
"	+ 1	FLAGWRD1
"	+ 2	FLAGWRD2
"	+ 3	FLAGWRD3
"	+ 4	FLAGWRD4
"	+ 5	FLAGWRD5
"	+ 6	FLAGWRD6
"	+ 7	FLAGWRD7
"	+ 8	FLAGWRD8
"	+ 9	FLAGWRD9
"	+10	FLGWRD10
"	+11	FLGWRD11

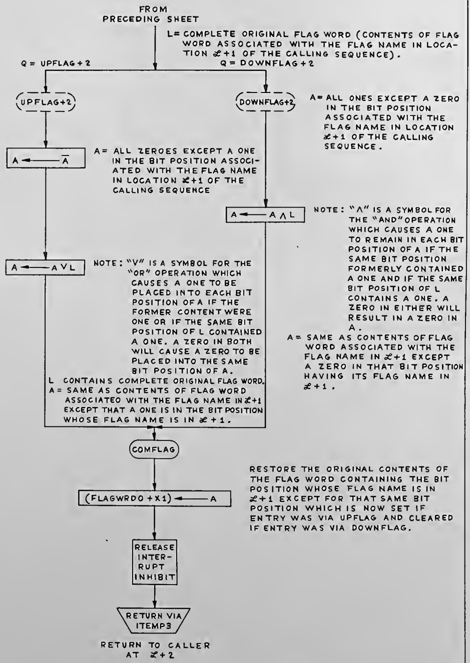
A ← $\overline{\text{(BIT15 + X2)}}$

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

	INDEX X2	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

SERVICE ROUTINES
(UPFLAG AND DOWNFLAG)



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN ... 31 JAN 69 PRGMR ... 3/3/69 ANALYST I.COMP ... 3-12-69 APP'D John A. Moore 24 MAR 69	SERVICE ROUTINES
	COLOSSUS II-D — DOCUMENT NO. FC-2070
	REV 2 — SHEET 6 OF 14

SERVICE ROUTINES
(UPFLAG AND DOWNFLAG)

CODES FOR EACH FLAG (DECIMAL)

BIT-POSITION β / FLAGWORD α	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
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
FLGWRD10	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164
FLGWRD11	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
0	CPHIFLAG	45	V50N18FL	90	DAPBIT1	135	[illegible]
1	JSWITCH	46	GLOKFAIL	91	DAPBIT2	136	-
2	MIDFLAG	47	REFSMFLG	*92	STRULLSW	137	V82EMFLG
3	MOONFLAG	48	LUNAFLAG	93	CMDAPARM	138	MAXDBFLG
4	NORFHOR	49	P22MKFLG	94	GAMDIFSW	139	V94FLAG
5	ZMEASURE	50	VFLAG	95	GONEPAST	140	[illegible]
6	NEEDLFLG	51	POOFLAG	96	RELVELSW	141	VHFRFLAG
7	IMUSE	52	PRECIFLG	*97	[illegible]	142	SOURCFLG
8	RNDVZFLG	53	CULTFLAG	98	NOSWITCH	143	R22CAFLG
9	R53FLAG	54	ORBWFLAG	99	HIND	144	[illegible]
10	[illegible]	55	STATEFLG	100	INPLSW	145	[illegible]
11	TRUNFLAG	56	INTYPFLG	101	LATSW	146	R31FLAG
12	FREEFLAG	57	VINTFLAG	102	-	147	MID1FLAG
13	[illegible]	58	D6OR9FLG	103	CM/DSTBY	148	[illegible]
14	FFLAG	59	DIMOFLAG	104	GYMDIFSW	149	[illegible]
15	NJETSFLG	60	MRKIDFLG	105	TERMIFLG	150	-
16	STIKFLAG	61	PRIODFLG	106	ITSWICH	151	[illegible]
17	ERADFLAG	62	NRMIDFLG	107	IGNFLAG	152	-
18	[illegible]	63	PDSPFLAG	108	ASTNFLAG	153	-
19	ENG2FLAG	64	MWAITFLG	109	TIMRFLAG	154	-
20	TARG1FLG	65	NWAITFLG	110	NORMSW	155	-
*21	TARG2FLG	66	MRKNVFLG	111	RVSW	156	-
22	VEHUPFLG	67	NRMNVFLG	112	GONEBY	157	-
23	UPDATFLG	68	PRONVFLG	113	-	158	REINTFLG
24	IDLEFAIL	69	PINBRFLG	114	V37FLAG	159	-
25	TRACKFLG	70	MRUPTFLG	115	-	160	-
26	TRM03FLG	71	NRUPTFLG	116	UPLOCKFL	161	-
27	SLOPESW	72	MKOVFLAG	117	VERIFLAG	162	-
28	GUESSW	73	-	118	ATTCHFLG	163	-
29	[illegible]	74	XDSPFLAG	119	TFFSW	164	-
30	DRIFTFLG	75	DSKYFLAG	120	RPQFLAG	165	[illegible]
31	P21MARK	76	RETROFLG	121	-	166	[illegible]
32	22DSPFLG	77	SLOWFLG	122	NEWIFLG	167	[illegible]
33	P21FLAG	78	V59FLAG	123	CMOONFLG	168	[illegible]
34	STEERSW	79	INCORFLG	124	LMOONFLG	169	-
35	SKIPVHF	*80	RNGSCFLG	125	ADVTRK	170	-
36	IMPULSW	81	DMENFLG	126	P39/79SW	171	-
37	XDELVFLG	82	COMPUTER	127	SURFFLAG	172	-
*38	ETPIFLAG	83	ENGONFLG	128	INFINFLG	173	-
39	FINALFLG	84	3AXISFLG	129	ORDERSW	174	-
40	AVFLAG	85	GRRBKFLG	130	APSESW	175	-
41	PFRATFLG	86	R60FLAG	131	COGAFLAG	176	-
42	-	87	SOLNSW	132	V96ONFLG	177	-
43	CALCMAN2	88	MGLVFLAG	133	-	178	-
44	NODOFLAG	89	RENDWFLG	134	360SW	179	-

*ALSO					
CODE	21	38	80	92	97
FLAG NAME	R23FLG	FIRSTFLG OPTNSW	PRFTRKAT	ENTRYDSP	KNOWNFLG R57FLAG

SERVICE ROUTINES (DELAYJOB)

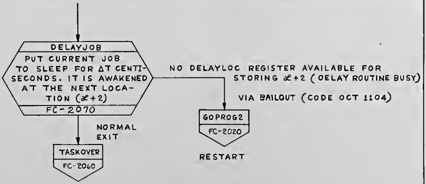
SUBROUTINE DELAYJOB IS USED TO PUT THE CURRENT JOB TO SLEEP FOR ΔT CENTISECONOS. AT THE END OF THIS TIME PERIOD THIS JOB IS AWAKENEO AT THE NEXT LOCATION (ℒ+2 OF THE CALLING SEQUENCE).

THIS IS ACCOMPLISHEO 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 SCHEDULEO TO BE EXECUTED AS A TASK ΔT CENTISECONDS FROM NOW. THE CAOR OF ℒ+2 IS FORMED ANO STOREO INTO THE AVAILABLE DELAYLOC REGISTER. THEN THIS CURRENT JOB IS PUT TO SLEEP. AFTER ΔT CENTISECONOS HAVE ELAPSED, TASK WAKER IS EXECUTED AND CAUSES THE LOCATION ℒ+2 OF THE CALLING SEQUENCE TO BE AWAKENED. TASK WAKER IS THEN TERMINATED.

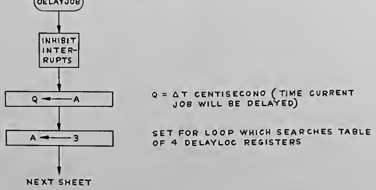
CALLING SEQUENCE:

```
ℒ-1     CAF      ℒ±N
ℒ+0     TC       BANKCALL
ℒ+1     CADR     DELAYJOB
ℒ+2     RETURN HERE AFTER A DELAY OF ΔT CENTISECONOS
 .        .
 .        .
 .        .
ℒ±N     OEC      ΔT CENTISECONDS
```

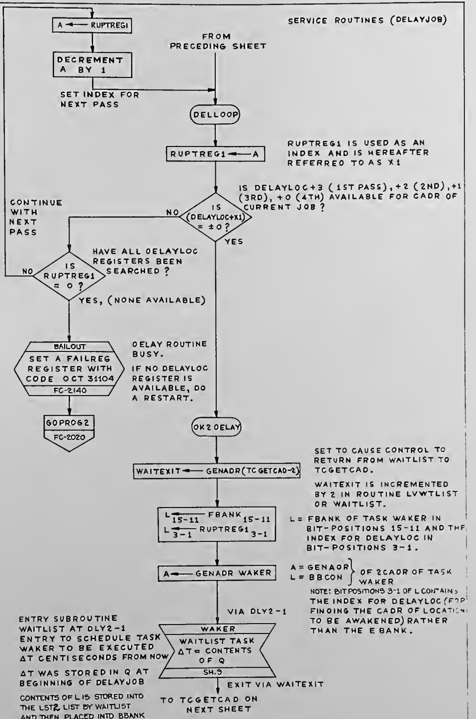
THIS SUBROUTINE WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING IT:



ENTERED FROM 13 LOCATIONS VIA BANKCALL WITH A = ΔT AND 2CADR OF LOCATION ℒ+2, THE RETURN TO THE CALLING SEQUENCE, IN BUF2 AND BUF2+1. BUF2 AND BUF2+1 WERE SET BY BANKCALL.



SERVICE ROUTINES (DELAYJOB)



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

GUIDANCE AND NAVIGATION

SERVICE ROUTINES

DRAWN G. J. Smith 3 FEB 69
CHKR Densmore 3/4/69
APPD D. H. Beck 3-12-69
APPD John A. Moore 24 MAR 69 REV 2

COLOSSUS II-D

FC-2070

9 14

SERVICE ROUTINES (DELAYJOB)

FROM PRECEDING SHEET

(TCGETCAD)

MAKECADR
CONSTRUCT THE CADR OF $\mathcal{L}+2$ FROM GENADR IN BUF AND F BANK IN BUF+1 AND LEAVE IT IN A
FC-2080

A = CADR OF $\mathcal{L}+2$ OF CALLING SEQUENCE

(DELAYLOC+X1) ← A

ADDRESS OF $\mathcal{L}+2$, THE LOCATION TO BE AWAKENED ΔT CENTISECONDS AFTER CURRENT JOB IS PUT TO SLEEP

JOBSLEEP
FC-2050

PUT CURRENT JOB (NOW BEING EXECUTED) TO SLEEP. IT WILL BE ASLEEP UNTIL IT IS AWAKENED AT LOCATION $\mathcal{L}+2$ BY TASK WAKER BELOW

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

(WAKER)

WAKER IS A TASK, IT WAS SCHEDULED TO BE EXECUTED IN ΔT CENTISECONDS. THE SCHEDULING BY WAITLIST WAS INITIATED IN ROUTINE OK2DELAY ON PRECEDING SHEET. T3RUPT PLACES CONTENTS OF L INTO BBANK.

A ← (DELAYLOC+X1)

X1 IS AN INDEX AND IS EQUAL TO THE CONTENTS OF RUPTREG1 AND OF BIT-POSITIONS 3-1 OF BBANK (FBANK MUST REMAIN 00)

OBTAIN CADR OF LOCATION $\mathcal{L}+2$ WHICH IS TO BE AWAKENED

(DELAYLOC+X1) ← +0

MAKE THIS DELAYLOC REGISTER AVAILABLE

JOBWAKE
WAKE UP JOB ($\mathcal{L}+2$) WHOSE CADR IS IN A
FC-2050

LOCATION $\mathcal{L}+2$ OF THE CALLING SEQUENCE IS AWAKENED. IT WILL BE EXECUTED WHEN ITS PRIORITY IS HIGHER THAN THE PRIORITIES OF OTHER SCHEDULED JOBS

TASKOVER
FC-2060

TERMINATE TASK WAKER AND RESUME EXECUTION OF INTERRUPTED ROUTINE

END OF DELAYJOB

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 𝒲.

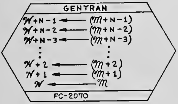
THE CALLING SEQUENCE IS:

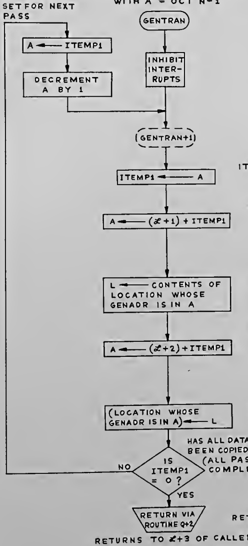
```
L-1    CAF      L±α
L+0    TC       GENTRAN
L+1    ADRES    M
L+2    ADRES    W
L+3    RETURN HERE UNCONDITIONALLY
 :              :
L±α    OCT      N-1
```

EXAMPLE OF CALLING SEQUENCE:

```
MARKIT1 CAF    SIX
        TC     GENTRAN
        ADRES  MRKBUF1
        ADRES  MRKBUF2
```

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





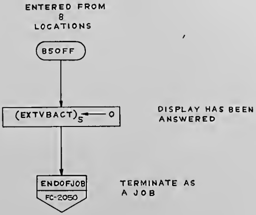
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 4FEB69	SERVICE ROUTINES
CHKD [signature] 3/21/69	COLOSSUS II-D
ANALYST	FC-2070
DOCMS C. H. Beck 3-12-69	
APPR'D John A. Moore 24 MAR 69 REV 2	16 OF 14

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:

$\mathcal{L}$+0 TC B5OFF



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. J. Lenzillo 4 FEB 69	SERVICE ROUTINES	
PRGMR D. Densmore 2/21/69	COLOSSUS II-D	DOCUMENT NO. FC-2070
ANALYST		
PGMR D. H. Beck 3-12-69		
APPR'D John A. Moore 24 MAR 69	REV 2	SHEET 12 OF 14

SERVICE ROUTINES
(TRFAILON AND TRFAILOF)

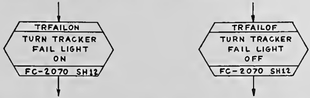
SUBROUTINES TRFAILON AND TRFAILOF ARE USED TO TURN THE TRACKER FAIL LIGHT (OPTICS CDU FAIL) ON AND OFF, RESPECTIVELY

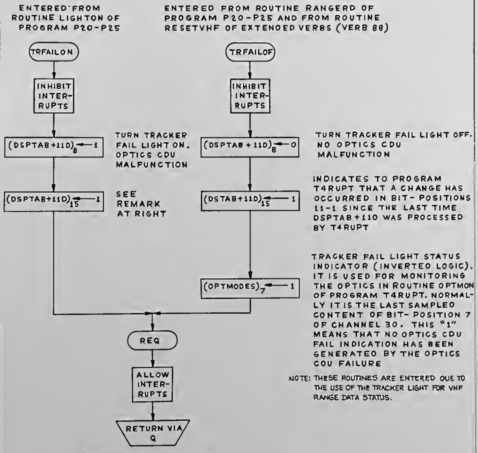
THE CALLING SEQUENCES ARE:

$\mathcal{L}$+0	TC	TRFAILON
$\mathcal{L}$+1		RETURN HERE UNCONDITIONALLY

$\mathcal{L}$+0	TC	TRFAILOF
$\mathcal{L}$+1		RETURN HERE UNCONDITIONALLY

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





RETURN TO CALLER AT $\mathcal{L}$+1

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. [signature] 4 FEB 69	SERVICE ROUTIONS
PRGMR [signature]	
ANALYST	COLOSSUS II-D
DOCMR C. J. Beck 3-12-69	DOCUMENT NO FC-2070
APP'D John A. Moore 24 MAR 69 REV 2	SHEET 13 OF 14

SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
MAKECADR	FC-2080	CONSTRUCT THE CADR OF A LOCATION WHOSE GENADR IS IN BUF AND F BANK IS IN BUF+1 AND LEAVE IT IN A	SH. 10
JOBWAKE	FC-2050	WAKE UP JOB WHOSE CADR IS IN A	SH. 10

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
EXTVBACT BIT 5	DISPLAY WAITING TO BE ANSWERED	DISPLAY HAS BEEN ANSWERED	—	SH. 12	—
DSPTAB+11D BIT 8	TURNS TRACKER FAIL LIGHT ON (OPTICS CDU MALFUNCTION)	TURNS TRACKER FAIL LIGHT OFF (NO OPTICS CDU MALFUNCTION)	SH. 13	SH. 13	—
OPTMODES BIT 7	NO OPTICS CDU FAIL INDICATION HAS BEEN GENERATED	OPTICS CDU FAIL INDICATION HAS BEEN GENERATED	SH. 13	—	—

F. J. Lauseiles 19 MAR 69
Densmore 21 MAR 69
C H Beck 3-12-69
John A. Moore 24 MAR 69

SERVICE ROUTINES

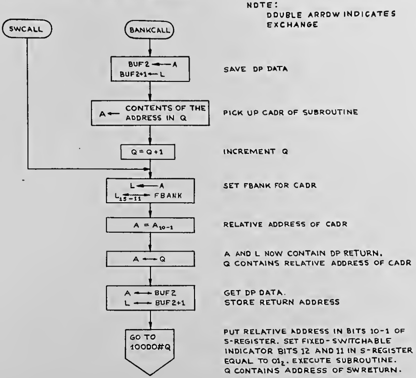
COLOSSUS II-D

FC-2070

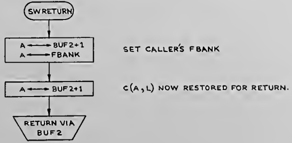
REV 2

SHEET 14 OF 14

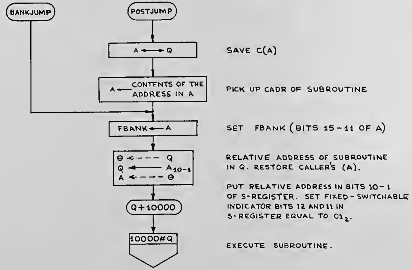
THE FOLLOWING ROUTINE CAN BE USED TO CALL A SUBROUTINE IN A BANK DIFFERENT FROM THE CALLER'S. THE BANKCALL VERSION PRESERVES THE DP CONTENTS OF THE ACCUMULATOR; THE CADR OF THE SUBROUTINE IMMEDIATELY FOLLOWS THE TC BANKCALL INSTRUCTION. IN THE SWCALL VERSION THE CADR OF THE SUBROUTINE IMMEDIATELY PRECEDES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



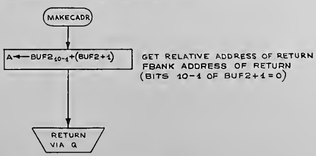
IT IS POSSIBLE TO RETURN FROM THE SUBROUTINE CALLED BY BANKCALL OR SWCALL BY TERMINATING SUBROUTINE WITH TC SWRETURN OR TC Q.



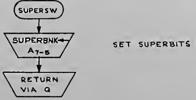
THE POSTJUMP AND BANKJUMP ROUTINES PERMIT UNIDIRECTIONAL JUMPS TO ANOTHER BANK. POSTJUMP PROTECTS C(A) WITH THE CADR IMMEDIATELY FOLLOWING THE TC POSTJUMP INSTRUCTION. BANKJUMP DOES NOT PROTECT C(A). ENTERS WITH CADR OF SUBROUTINE IN A.



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.

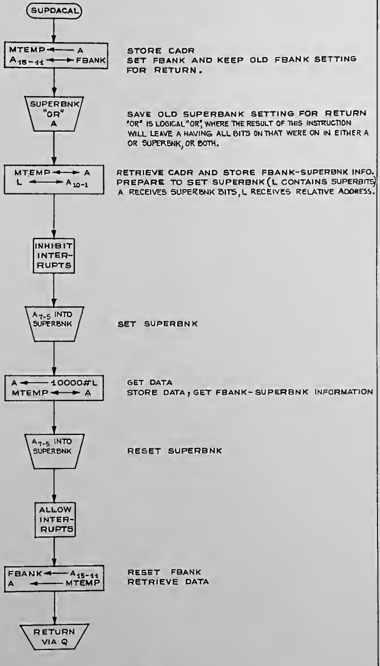


INTERBANK COMMUNICATION

COLOSSUS II FC-2080

2 5

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



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN P. M. Dietrich 22 JAN 69
PRGMR Densmore 28 FEB 69
ANALST
DOCMR D. Brink 25 Feb 69
APPR'D John A. Miller 6 MAR 69

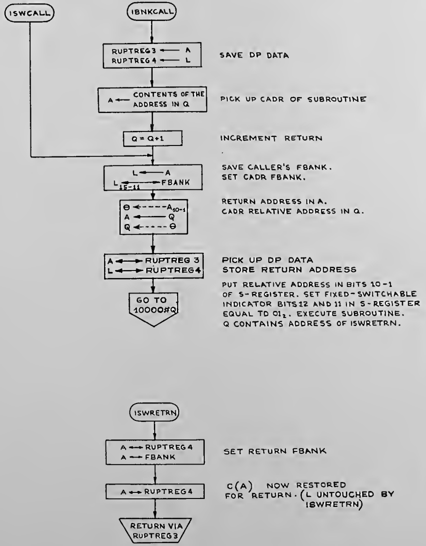
INTERBANK COMMUNICATION

COLOSSUS II

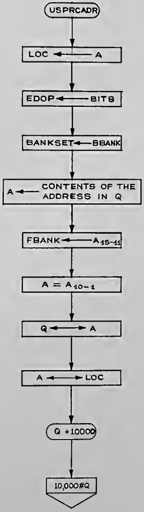
FC-2080

3 5

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



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. USPRCADR CHANGES FBANK. ENTER WITH CADR INTPRETX IMMEDIATELY FOLLOWING THE TC USPRCADR INSTRUCTION.



SAVE CALLER'S (A)

PREPARE FOR EXIT FROM INTERPRETIVE ROUTINE VIA DANZIG

SAVE CALLER'S FBANK.

PICK UP CADR OF INTERPRETIVE SUBROUTINE

SET FBANK OF SUBROUTINE

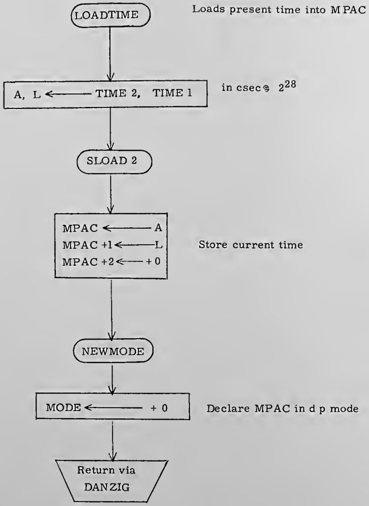
OBTAIN RELATIVE ADDRESS OF INTERPRETIVE ROUTINE.

PUT RELATIVE ADDRESS IN Q.

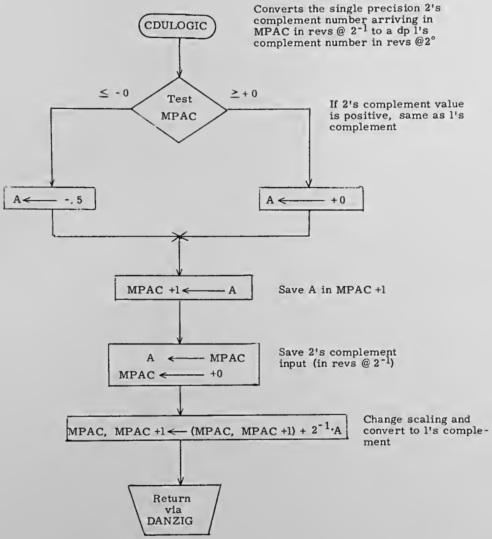
RESTORE CALLER'S (A), PUT Q IN LOC.

INSTRUMENTATION LAB CAMBRIDGE, MASS.	INTERBANK COMMUNICATION
DRAWN 22JAN63 PRGMR ANALST DOCMR 25FEB63 APPR'D 6MAR63	COLOSSUS II FC-2080
	REV 5 5

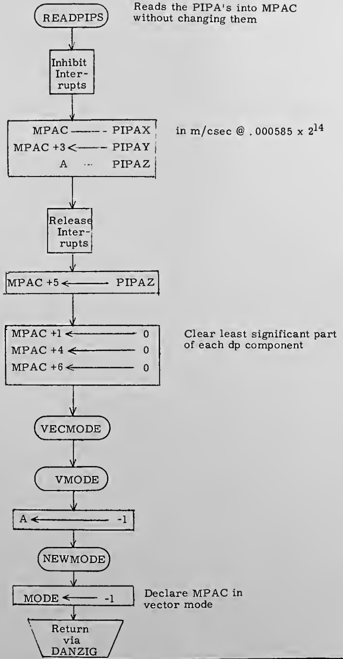
RTB OP CODES



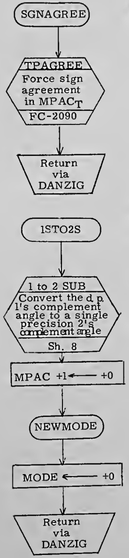
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Newer	11/22/69	RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2100
ANALST			
DOCMR R.M. Eaton	12/3/69		
APPR'D R.M. Eaton		REV	SHEET 2 OF 17



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



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reiner	11/22/69	RTB Op Codes	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2100
DOCMR R.M. Eutes	12/3/69		
APPR'D R.M. Eutes		REV	SHEET 4 OF 17



Forces sign agreement in $MPAC_T$

Converts the d. p. 1's complement angle in revs @ 2° to a single precision 2's complement angle in revs 2^{-1}

Input:
$MPAC_D$ = 1's complement angle in revs 2°

Output:
A = MPAC = 2's complement angle in revs @ 2 [1]

Declare MPAC in d. p. mode

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reiser	11/22/69	RTB Op Codes	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2100
ANALST			
DOCMR R. M. Eaton	12/3/69		
APPR'D R. M. Eaton		REV	SHEET 5 OF 17

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}

V1STO2S

↓

1TO2SUB
Convert 1st angle from d. p. 1's complement to single precision 2's complement
Sh. 8

Input:
$MPAC_D$ = 1st 1's complement angle in revs @ 2^0
Output:
A = MPAC = 2's complement angle in revs @ 2^{-1}

↓

$MPAC_D \leftarrow (MPAC\ +5)_D$

Put 3rd angle into $MPAC_D$
Save 1st angle result in $(MPAC\ +5)_D$

↓

1TO2SUB
Convert 3rd angle from d. p. 1's complement to single precision 2's complement
Sh. 8

Input:
$MPAC_D$ = 3rd 1's complement angle in revs @ 2^0
Output:
A = MPAC = 2's complement angle in revs @ 2^{-1}

↓

MPAC +2
$(MPAC\ +3)_D$

Save 3rd angle result in MPAC +2
Put 2nd angle into $MPAC_D$

↓

1TO2SUB
Convert 2nd angle from d. p. 1's complement to single precision 2's complement
Sh. 8

Input:
$MPAC_D$ = 2nd 1's complement angle in revs @ 2^0
Output:
A = MPAC = 2's complement angle in revs @ 2^{-2}

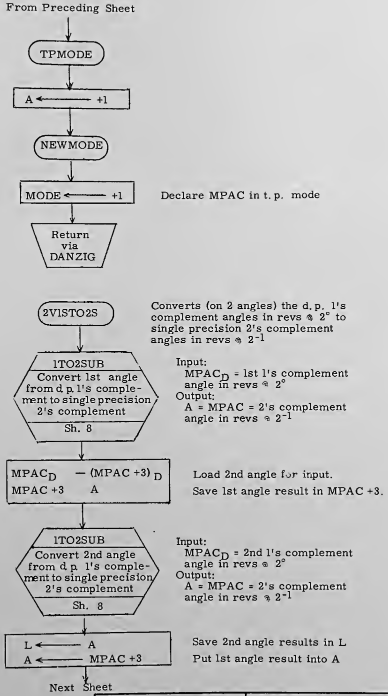
↓

MPAC +1 ←
— MPAC +5

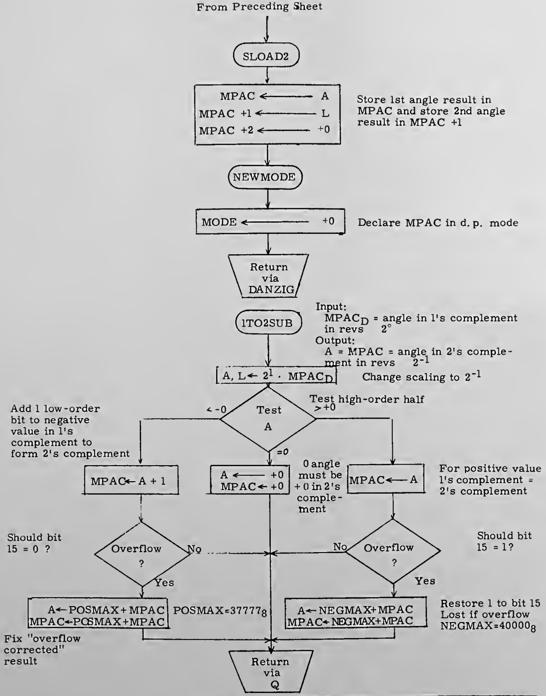
Save 2nd angle result in MPAC +1
Put 1st angle result into MPAC

↓

Next Sheet

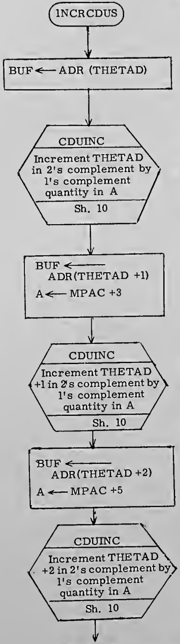


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reiser	11/22/69	RTB Op Codes	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2100
DOCMR R. M. Eaton	12/3/69		
APPR'D R. M. Eaton		REV	SHEET 7 OF 17



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reider	11/22/69	RTB Op Codes	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2100
DOCMR R. M. Entes	12/3/69		
APPR'D R. M. Entes		REV	SHEET 8 OF 17

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

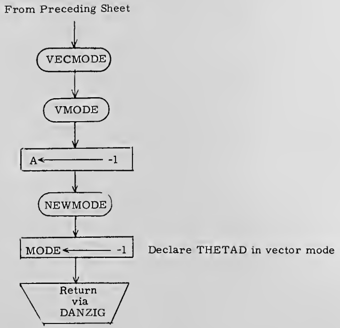


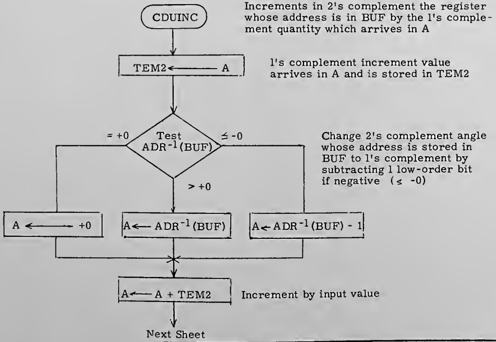
Input: A = MPAC
BUF = Address of quantity to be incremented (here = address of THETAD)
Result: ADR^{-1} (BUF) = THETAD incremented in 2's complement by 1's complement quantity in MPAC

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

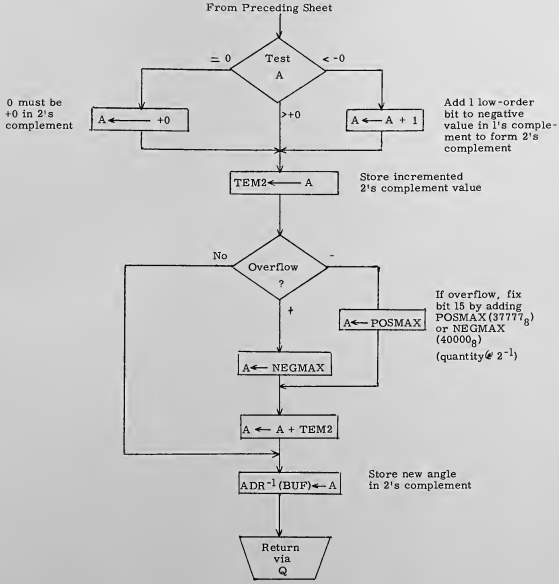
Input: A = MPAC +5
BUF = address of quantity to be incremented (here = address of THETAD +2)
Result: ADR^{-1} (BUF) = THETAD +2 incremented in 2's complement by 1's complement quantity in MPAC +5

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

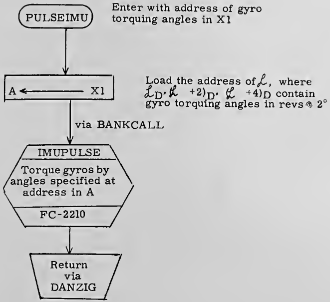


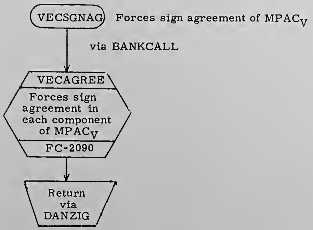


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reiser	11/22/69	RTB Op Codes	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2100
DOCMR R.M. Eaton	12/3/69		
APPR'D R.M. Eaton		REV	SHEET 10 OF 17

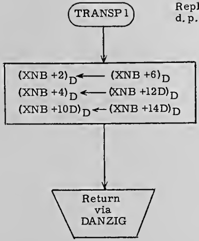


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reiser	11/22/69	RTB Op Codes	
PRGMR			DOCUMENT NO.
ANALST			
DOCMR R. M. Estes	12/3/69	COLOSSUS 2D	FC-2100
APPR'D R. M. Estes		REV	SHEET 11 OF 17

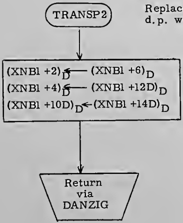




MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reiser	11/22/69	RTB Op Codes	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2100
DOCMR R. M. Enter	12/3/69		
APPR'D R. M. Enter		REV	SHEET 12 OF 17



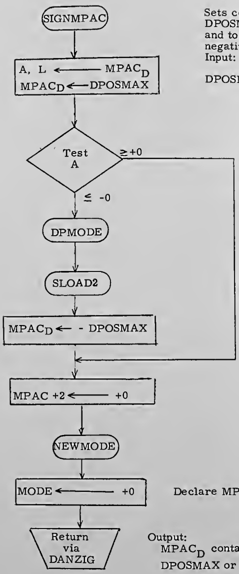
Replaces a 3 x 3 matrix in d.p. with the transpose matrix



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

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

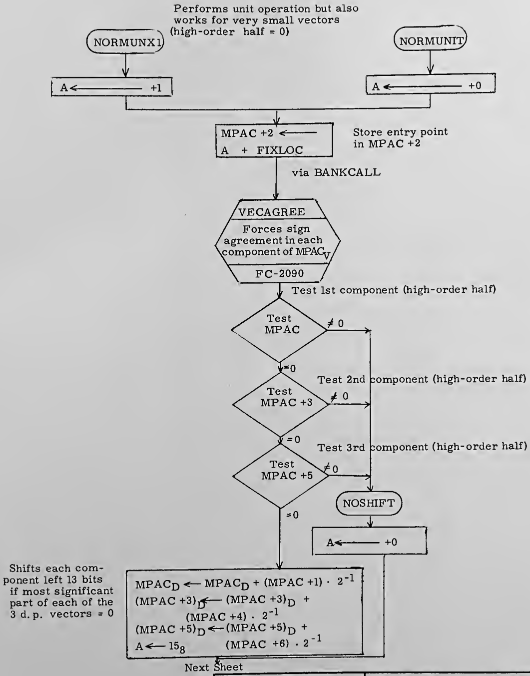


For positive MPAC, set $MPAC_D$ = DPOSMAX.
For negative MPAC, set $MPAC_D$ = - DPOSMAX = maximum d. p. Nagative magnitude.

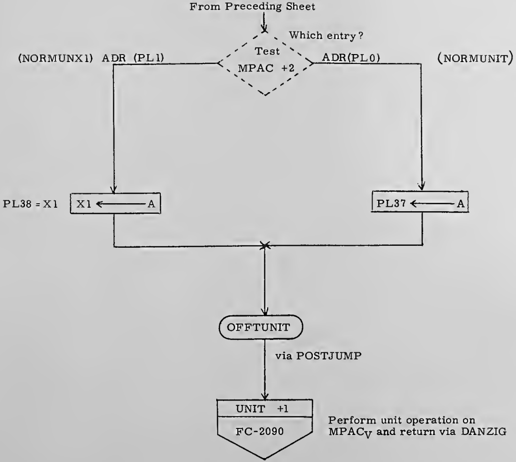
Declare MPAC in d. p. mode

Output:
$MPAC_D$ containing DPOSMAX or -DPOSMAX

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E Reisner	11/22/69	RTB Op Codes	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2100
DOCMR R M Estes	12/3/69		
APPR'D R. M. Estes		REV	SHEET 14 OF 17



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reiser	11/22/69	RTB Op Codes	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2100
DOCMR R. M. Enter	12/3/69		
APPR'D R. M. Enter	—	REV	SHEET 15 OF 17



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Reiser	11/22/69	RTB Op Codes	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2100
DOCMR R. M. Eaton	12/3/69		
APPR'D R. M. Eaton		REV	SHEET 16 OF 17

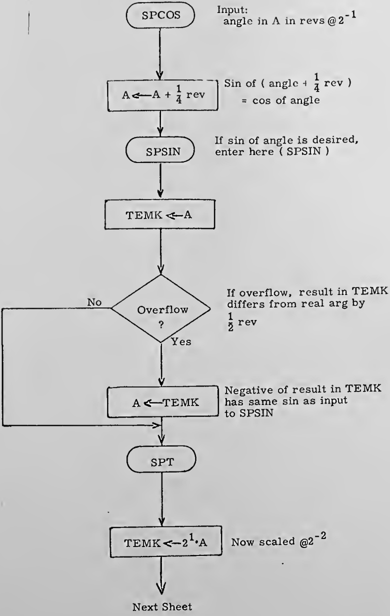
SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
IMUPULSE	FC-2210	Torques gyros	Sh. 12
TPAGREE	FC-2090	Forces sign agreement in $MPAC_T$	Sh. 5
UNIT	FC-2090	Performs unit operation	Sh. 16
VECAGREE	FC-2090	Forces sign agreement in each component of $MPAC_V$	Sh. 12, 15

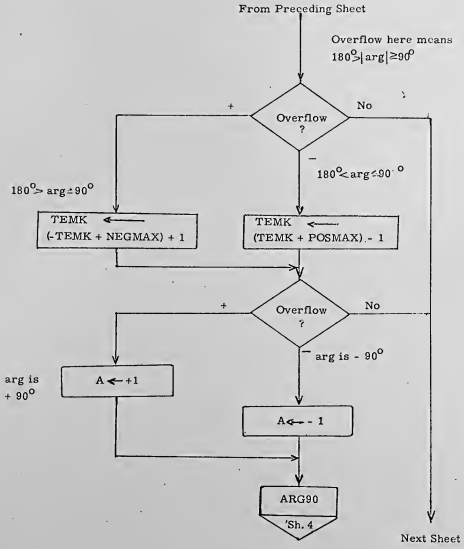
Single Precision Subroutines

SPCOS	Sh. 2
SPSIN	Sh. 2

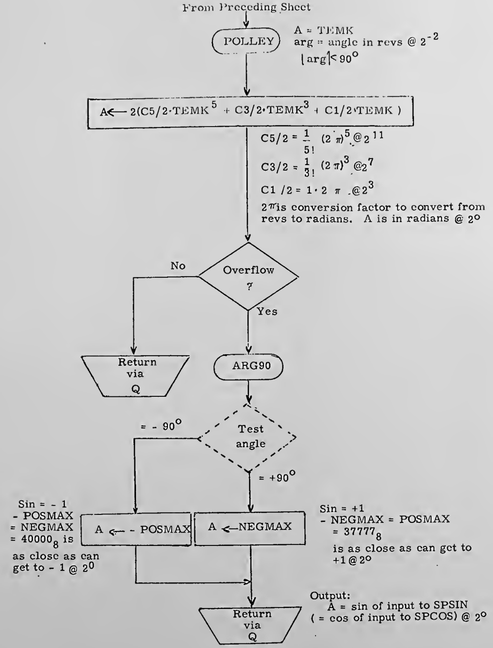
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN	Single Precision Subroutines	
PRGMR	COLOSSUS 2D	DOCUMENT NO. FC-2110
ANALST		
DOCMR		
APPR'D	REV	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		Single Precision Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2110
ANALST	10-20-67		
DOCMR	10/20/67		
APPR'D	10/20/67	REV	SHEET 2 OF 4

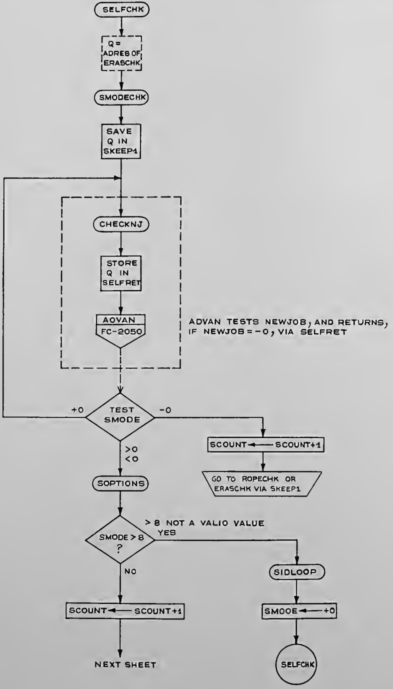


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		Single Precision Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2110
ANALST	10-20-69		
DOCMR Roberta M. Eaton	10/20/69		
APPR'D Roberta M. Eaton	10/20/69	REV	SHEET 3 OF



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		Single Precision Subroutines	
PRGMR			
ANALST	10-20-67	COLOSSUS 2D	DOCUMENT NO. FC-2110
DOCMR	10/20/69		
APPR'D	10/20/69	REV	SHEET 4 OF [illegible]

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

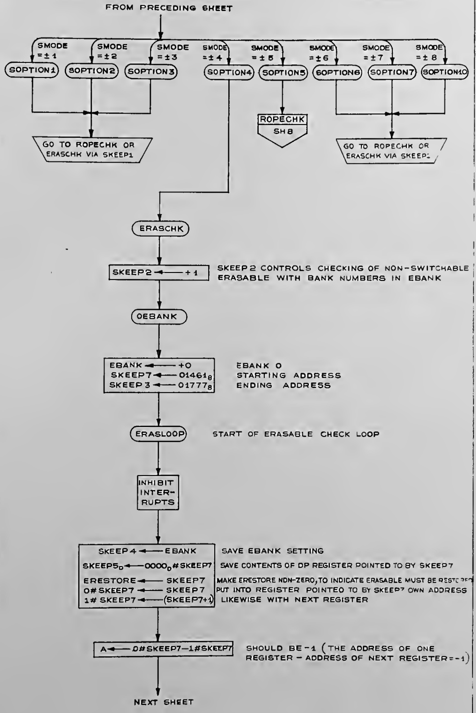


27JAN68
5-28-69

SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

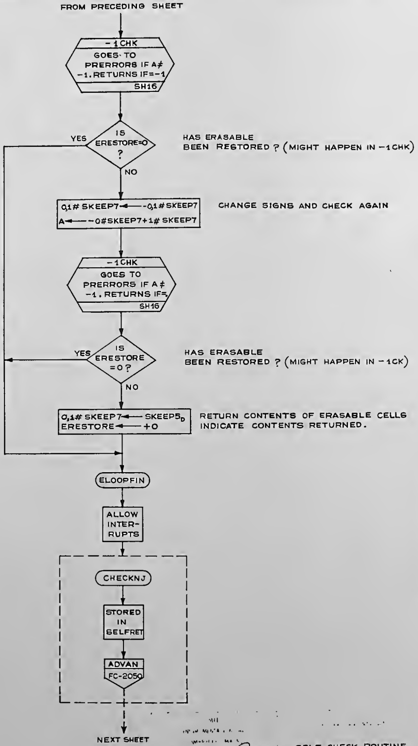
2 18



SELF CHECK ROUTINE

27JAN69

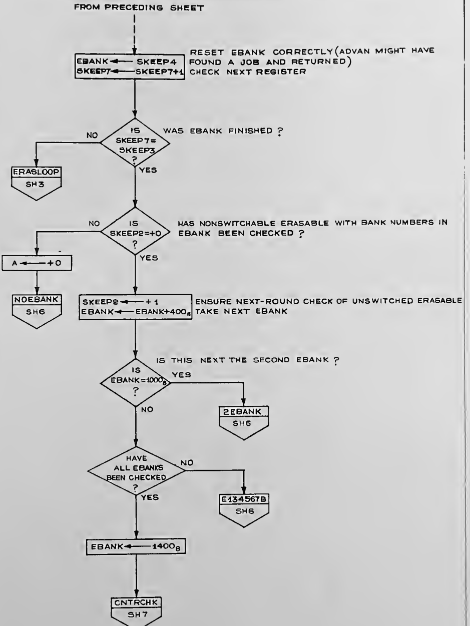
COLOSSUS IIA FC-2120



SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

4 18



SELF CHECK ROUTINE

COLOSSUS II A FC-2120

5 18

NOEBANK — CHECKS UNSWITCHED ERASABLE

SKEEP2 ← A — +0 TO SKEEP2 FOR NEXT-ROUND CHECK OF SWITCHED ERASABLE
SKEEP7 ← 0061_8 — STARTING ADDRESS
SKEEP3 ← 01373_8 — ENDING ADDRESS

ERASLOOP SH3

2EBANK — CHECKS SECOND EBANK

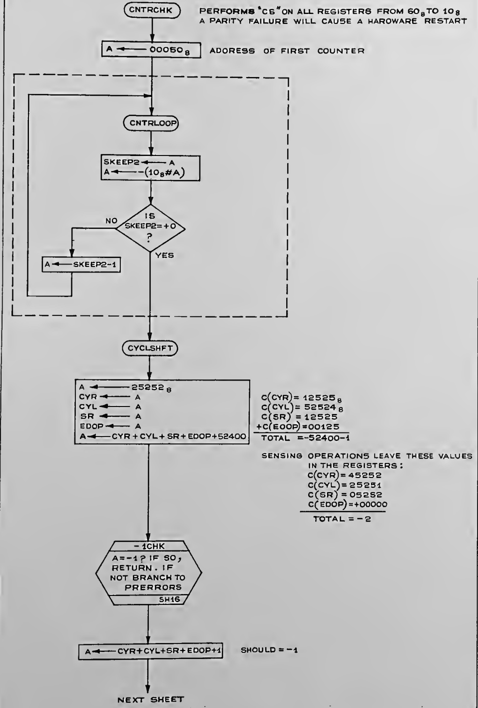
SKEEP7 ← 01400_8 — STARTING ADDRESS
SKEEP3 ← 01773_8 — ENDING ADDRESS

ERASLOOP SH3

$E134567_8$

SKEEP7 ← 01400_8 — STARTING ADDRESS
SKEEP3 ← 01777_8 — ENDING ADDRESS

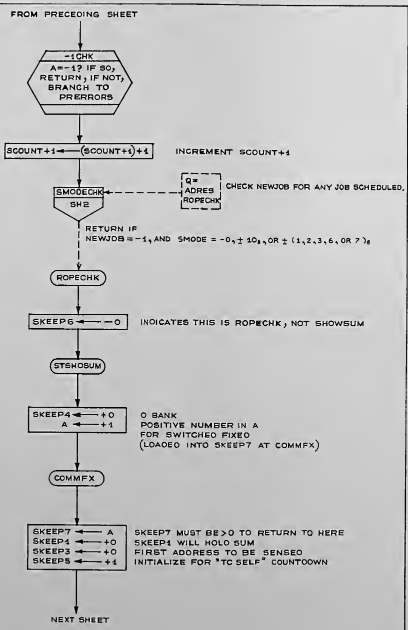
ERASLOOP SH3



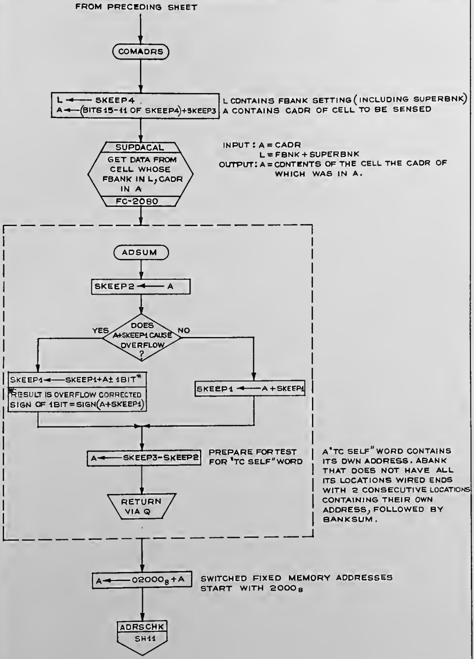
SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

7 18



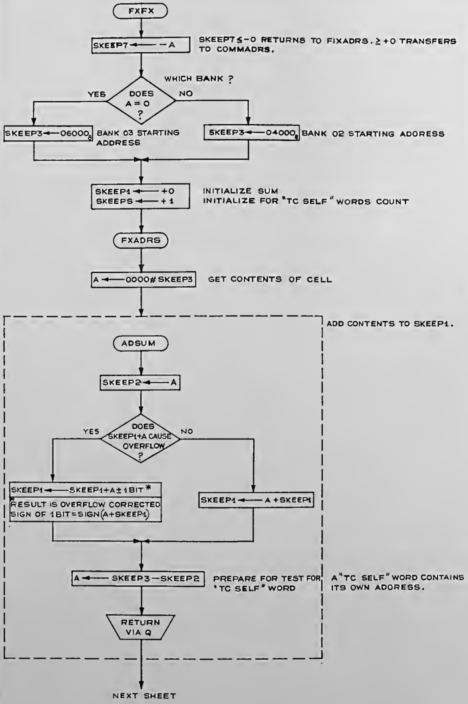
DRAWN P.M. Dietrich 29JAN69	SELF CHECK ROUTINE
PROGMR Frank E. Grant 5-28-69	
ANALS	COLOSSUS IIA FC-2120
DIV MGR D. L. Reinke 28 May 69	
APPR Alexander M. Grant 5/28/69	8 18



SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

9 18



MIT INSTRUMENTATION LAB CAMBRIDGE MA

30JAN69

5-28-69

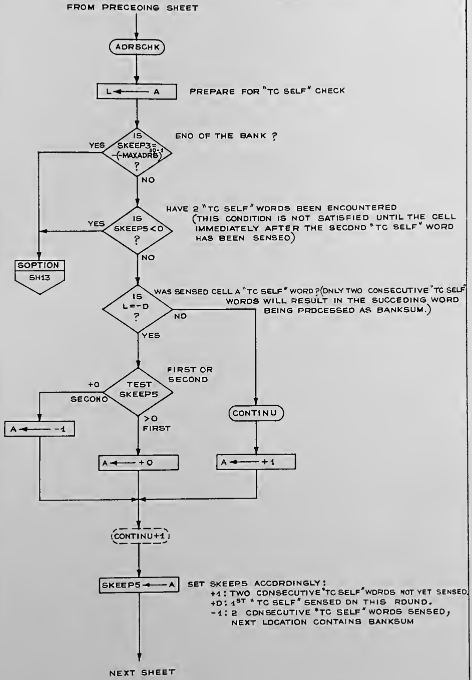
25 May 69

5/28/69

SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

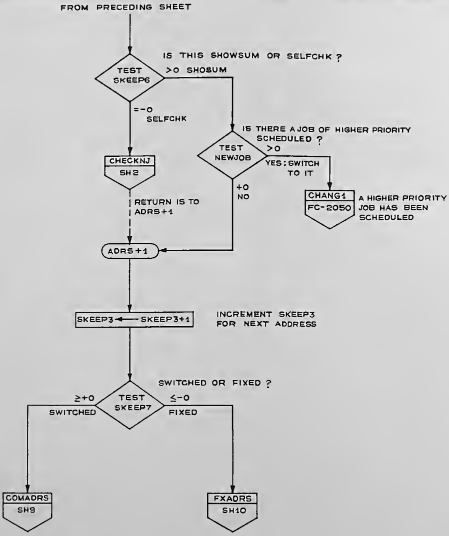
10 18



SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

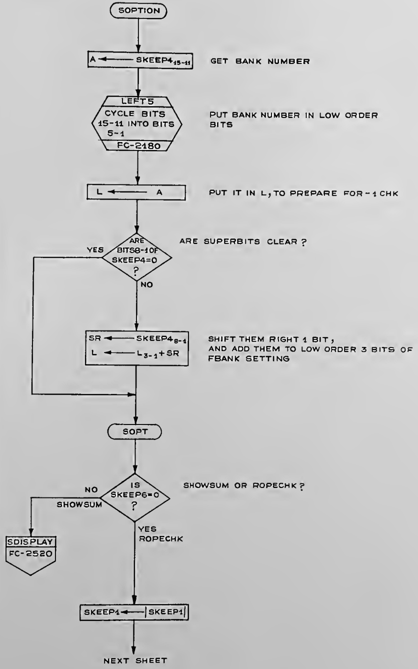
11 18



SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

12 18



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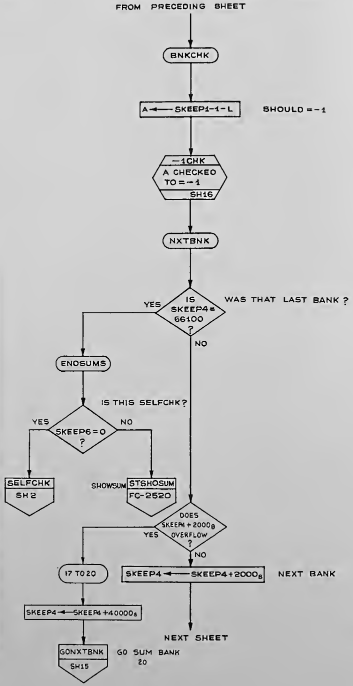
SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

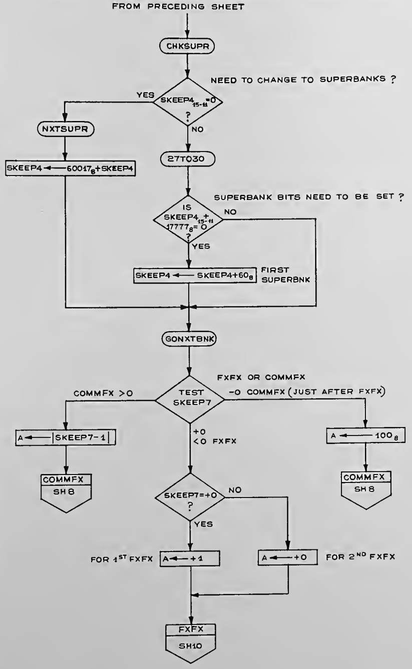
13 18



SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

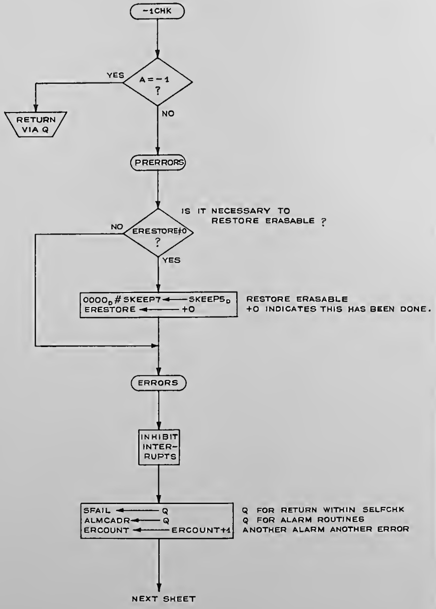
14 18



SELF CHECK ROUTINE

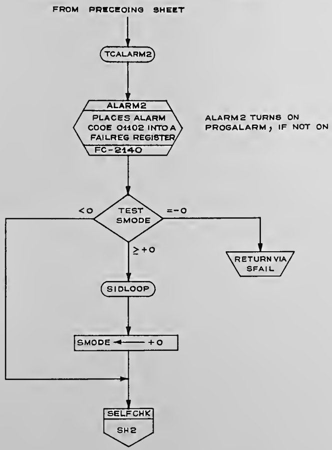
COLOSSUS IIA FC-2120

15 18



SELF CHECK ROUTINE

COLOSSUS IIA FC-2120



4FEB69
6-28-69
28 May 69
5/29/69

SELF CHECK ROUTINE

COLOSSUS IIA FC-2120

17 13

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), or sum of bank			
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 EBANK 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			

P.M. Fuchs Jr. 4FEB69
Frank E. Fauntt 5-28-69
D. J. Rembe 28 May 69
Alistair M. Soran 5/28/69

SELF CHECK ROUTINE

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 CCSHOLE.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkevich	8-12-69	Alarm and Abort	
PRGMR S. Rosenberg	11-6-69		DOCUMENT NO.
ANALST			
DOCMR C. Geo. Beck	11-6-69	COLOSSUS II-D	FC-2140
APPR'D Robert M. Eaton	11/6/69	REV 2	SHEET 1 OF 16

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.

Two Of The Five
Non-Abortive Entries with Return

Displays Alarm Code

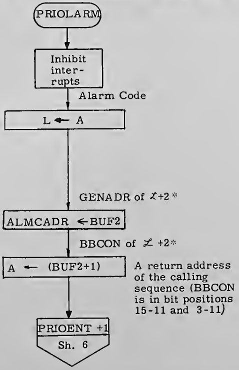
From location R52L+5 of P51-P53 via BANKCALL with A = ALARM code. [BUF2, BUF2+1] = 2CADR of $\mathcal{L}$+2

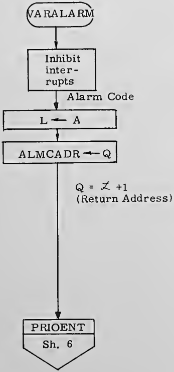
Calling sequence

$\mathcal{L}$ +0	TC	BANKCALL
$\mathcal{L}$ +1	CADR	PRIOLARM
$\mathcal{L}$ +2		TERMINATE
$\mathcal{L}$ +3		PROCEED
$\mathcal{L}$ +4		ENTER
$\mathcal{L}$ +5		IMMEDIATE RETURN

From 3 locations with A = alarm code

Calling sequence
$\mathcal{L}$ +0 TC VARALARM
$\mathcal{L}$ +1 Return

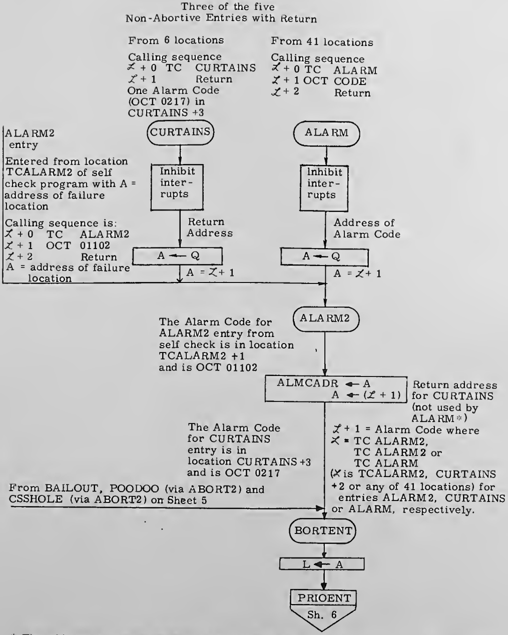




Note: Symbol " = " means "contains" in this flow chart.

* 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 CCSHOLE) 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.

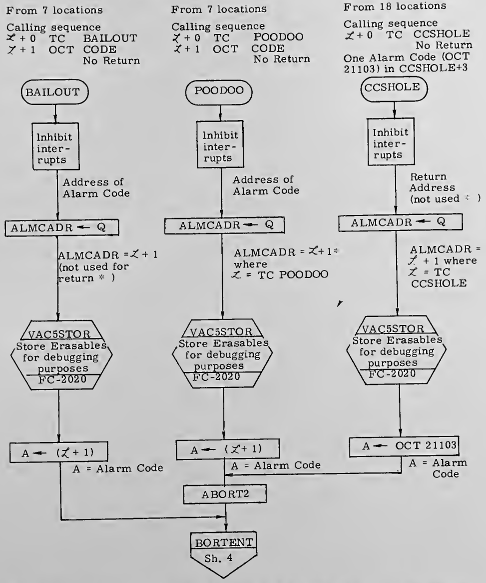
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkewich	8/12/69	Alarm and Abort	
PRGMR S. Rosenberg	11-6-69		DOCUMENT NO.
ANALST			
DOCMR C. Geo. Beck	11-6-69	COLOSSUS II-D	FC-2140
APPR'D Robert M. Estes	11/6/69	REV 2	SHEET 3 OF 16



* 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 CCSHOLE) 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.

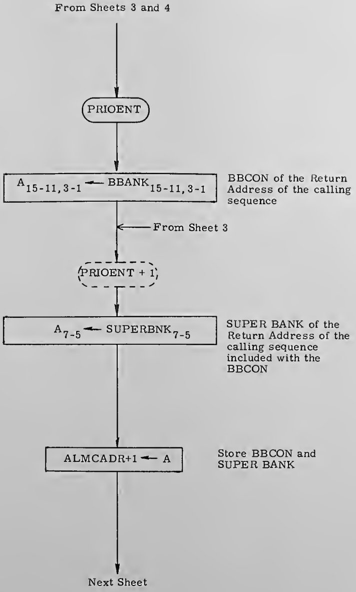
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Sutkowski	8-12-69	Alarm and Abort	
PRGMR S. Rosenberg	11-6-69		DOCUMENT NO.
ANALST			
DOCMR O. Geo. Beck	4-6-69	COLOSSUS 11-D	FC-2140
APPR'D Robert M. Easton	11/6/69	REV 2	SHEET 4 OF 16

Abortive Entries Ending in Restart

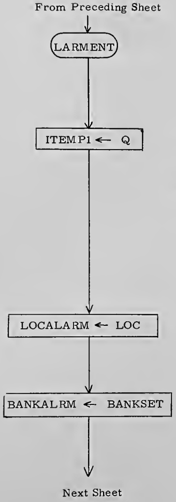


* The address stored in register ALMCADR is not used as a return address for these entries (PRIOLARM, ALARM, ALARM2 via self check, BAILOUT, POODOO and CCSHOLE) while the other two entries (VARALARM and CURTAINS) do use the address as a return address. However, the address associated with each entry 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 D. Lutkevich	8-19-69	Alarm and Abort	
PRGMR S. Rosenberg	11-6-69		DOCUMENT NO.
ANALST			
DOCMR C. Geo. Beck	11-6-69	COLOSSUS II-D	FC-2140
APPR'D Roberta M. Eaton	11/6/69	REV 2	SHEET 5 OF 16



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



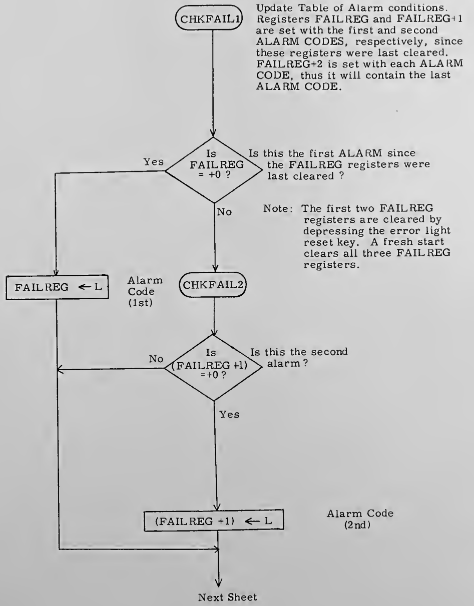
Return Address to either the entry calling sequence or the BORTENT (or PRIOENT) calling sequence. ITEMP1 contains one of the following Return Addresses depending upon which entry was used:

ITEMP1 = PRIOLARM+6
ITEMP1 = VARALARM+5
ITEMP1 = CURTAINS+3
ITEMP1 = $\mathcal{L}$+1 where $\mathcal{L}$ = TC ALARM
ITEMP1 = BAILOUT +8
ITEMP1 = ABORT2 + 1 if via POODOO or CSSHOLE
ITEMP1 = $\mathcal{L}$ +1 where $\mathcal{L}$ = TC ALARM2

Save for debugging

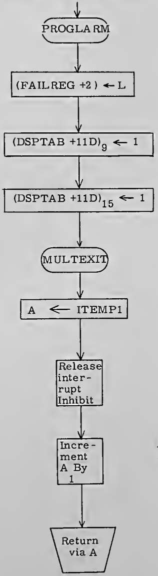
NOTE: Symbol " = " means "contains" in this flowchart

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkevich	8-12-68	Alarm and Abort	
PRGMR S. Rosenberg	11-6-69		DOCUMENT NO.
ANALST			
DOCMR E. Geo. Beck	11-6-69	COLOSSUS II-D	FC-2140
APPR'D Roberta M. Eastman	11/6/69	REV 2	SHEET 7 OF 16



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Littlewood 9-12-69	Alarm and Abort	
PRGMR I. Rosenberg 11-6-69		DOCUMENT NO.
ANALST		
DOCMR C. Geo. Beck 11-6-69	COLOSSUS II-D	FC-2140
APPR'D Robert M. Estes 11/6/69	REV 2	SHEET 8 OF 16

From Preceding Sheet



Most recent Alarm Code

Turn on Program Alarm light

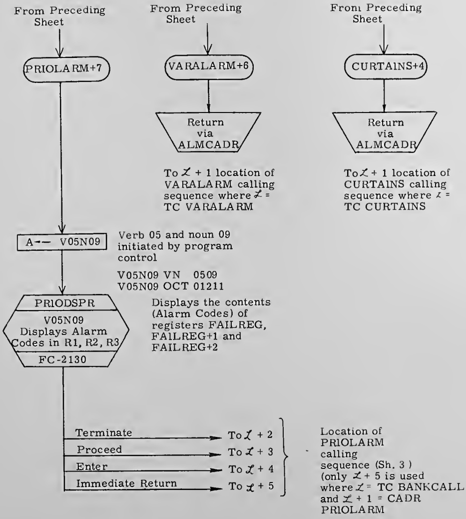
Causes T4RUPT Program to transmit contents of BIT-positions 11-1 of DSPTAB +11D to CHAN 10 during next pass through T4RUPT.

Return Address

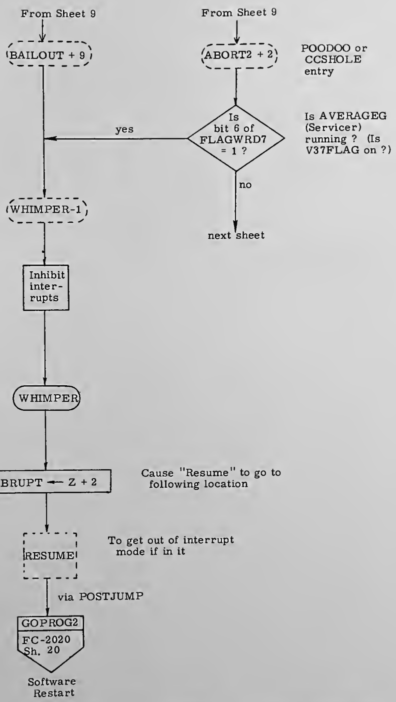
According to the entry used. A contains one of the following return addresses:

A = PRIOLARM +7
A = VARALARM +6
A = CURTAINS +4
A = ($\mathcal{L}$+2) where $\mathcal{L}$ = TC ALARM
A = BAILOUT +9
A = ABORT2 + 2 if via POODOO or CCSHOLE.

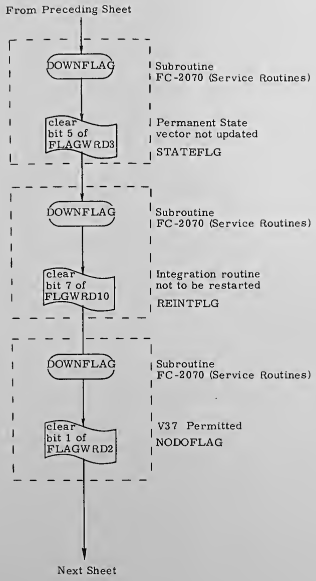
A = ($\mathcal{L}$+2) Where $\mathcal{L}$ = TC ALARM2



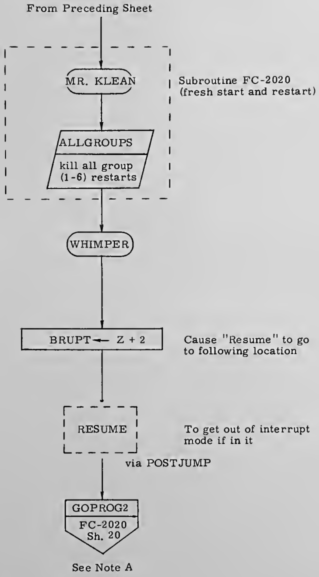
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	8-12-69	Alarm and Abort	
PRGMR [signature]	11-6-69		DOCUMENT NO.
ANALST			
DOCMR [signature]	11-6-69	COLOSSUS II-D	FC-2140
APPR'D [signature]	11/6/69	REV 2	SHEET 10 OF 16



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Litkewich	8-12-69	Alarm and Abort	
PRGMR I. Rosenberg	11-6-69		DOCUMENT NO.
ANALST			
DOCMR C. Geo. Beale	11-6-69	COLOSSUS II-D	FC-2140
APPR'D Robert M. Eastwood	11/6/69	REV 2	SHEET 11 OF 16



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkevich	8-12-69	Alarm and Abort	
PRGMR E. Rosenberg	11-6-69		DOCUMENT NO.
ANALST		COLOSSUS II-D	FC-2140
DOCMR C. Geo. Beck	11-6-69		
APPR'D Roberta M. Ester	11/6/69	REV 2	SHEET 12 OF 16



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 D. Lutkevich	8-12-69	Alarm and Abort	
PRGMR S. Rosenberg	11-6-69		DOCUMENT NO.
ANALST		COLOSSUS II-D	FC-2140
DOCMR C. Geo. Beck	11-6-69		
APPR'D Robert M. Eaton	11/6/69	REV 2	SHEET 13 OF 16

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 REFSMMAT	R02, P51	VARALARM
00401	Desired gimbal angles yield gimbal lock	INF ALIGN, IMU-2	ALARM

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 ≥ 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	INTER-PRETER	ALARM
01407	VG increasing	S40.8	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

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	
DRAWN D. Lutkevich	8-12-69	Alarm and Abort	
PRGMR S. Rosenberg	11-6-69		DOCUMENT NO.
ANALST			
DOCMR C. Geo. Beck	11-6-69	COLOSSUS II-D	FC-2140
APPR'D Roberta M Enter	11/6/69	REV 2	SHEET 16 OF 16

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 positons 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 ia 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 ia 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 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.

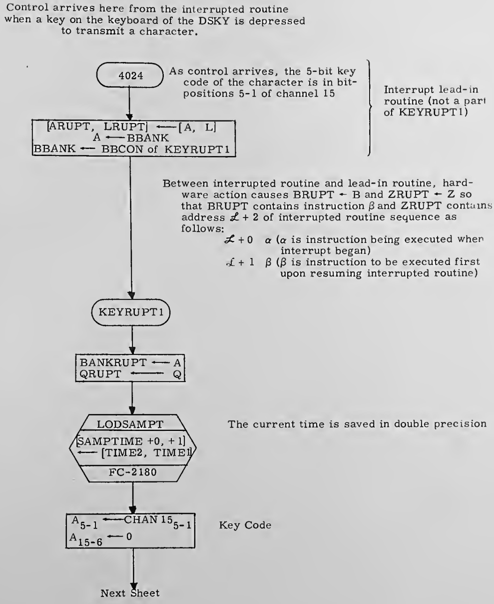
The characters are represented by the following key codes:

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		

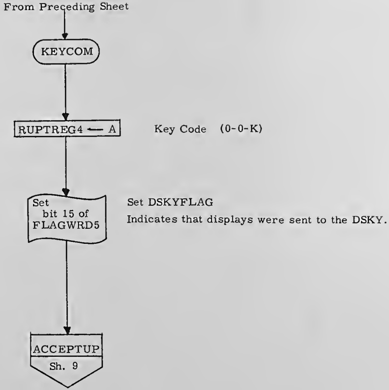
Both routines preserve the banks, Q register and the current time (double precision) and make the key code available for routine CHARIN of program Pinball.

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	8/18/69	KEYRUPT AND UPRUPT	
PRGMR	8/28/69	COLOSSUS II-C	DOCUMENT NO. FC-2150
ANALST			
DOCMR	8-28-69		
APPR'D	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

Control arrives here from the interrupted routine each time a character is transmitted from the ground.

4034

As control arrives the 5-bit key code of the character is in bit-positions 15-11 (true form), 10-6 (complement form) and 5-1 (true form) of the counter INLINK.

Interrupt lead-in routine (not part of UPRUPT)

[ARUPT, LRUPT] ← [A, L]
A ← BBANK
BBANK ← BBCON of UPRUPT

Between interrupted routine and lead-in routine, hardware action causes BRUPT ← B and ZRUPT ← Z so that BRUPT contains instruction β and ZRUPT contains address $\mathcal{L}+2$ of interrupted routine sequence as follows:

$\mathcal{L}+0$ α (α is instruction being executed when interrupt began)

$\mathcal{L}+1$ β (β is instruction to be executed first upon resuming interrupted routine)

UPRUPT

BANKRUPT ← A
QRUPT ← Q

LODSAMPT
[SAMPTIME +0, +1] ← [TIME2, TIME1]
FC-2180

The current time is saved in double precision

KEYTEMP1 ← INLINK
INLINK ← +0

$INLINK_{5-1}$ = Key code in true form
$INLINK_{10-6}$ = Key code in complement form
$INLINK_{15-11}$ = Key code in true form
INLINK is cleared to allow the next key code word to be processed

Set bit 3 of Chan 11

Turn on UPLINK activity light

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R.A. Donnelly	[illegible]	KEYRUPT AND UPRUPT	
PRGMR John Vella	9/29/69		
ANALST		COLOSSUS II- C	DOCUMENT NO. FC-2150
DOCMR C. Geo. Beck 8-28-69			
APPR'D [illegible]	[illegible]	REV	SHEET 5 OF 9

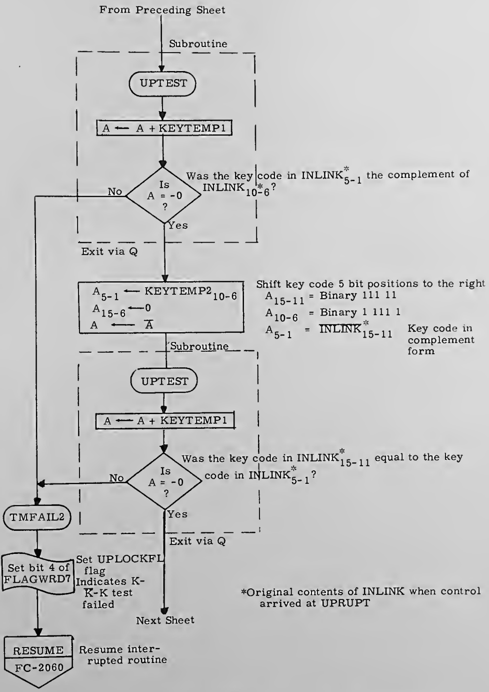
From Preceding Sheet

UPRPT1

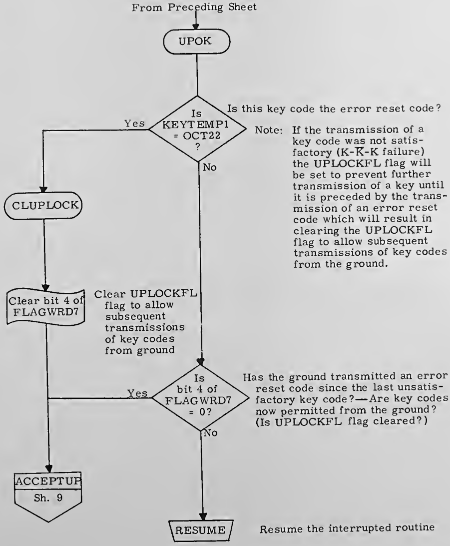
Test for triple character redundancy. If the key codes in bit-positions 5-1 and 15-11 agree and if the key code in bit-positions 10-6 is the complement of the key code in bit positions 5-1, then the key code is accepted.

Step	Comment
A ← KEYTEMP1	Key code (three in K-$\overline{K}$-K arrangement)
$KEYTEMP1_{15-6}$ ← 0	$KEYTEMP1_{5-1}$ = Key code in true form $KEYTEMP1_{15-6}$ = 0
A_{10-1} ← A_{15-6} A_{15-11} ← 0	Shift key code arrangement to the right 5 bit positions so that A contains the 0-K-$\overline{K}$ arrangement
KEYTEMP2 ← A	Key code arranged 0-K-$\overline{K}$ will be used for second part of redundancy test.
A_{15-6} ← All 1's	A_{5-1} = Key code in complement form A_{15-6} = Binary 111 111 111 1

Next Sheet



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature] 8/15/69	KEYRUPT AND UPRUPT	
PRGMR [signature] 8/28/69	COLOSSUS II-C	DOCUMENT NO. FC-2150
ANALST		
DOCMR C. Geo. Back 8-28-69		
APPR'D [signature]	REV	SHEET 7 OF 9



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature] 8/18/69	KEYRUPT AND UPRUPT	
PRGMR [signature] 8/28/69	COLOSSUS II-C	DOCUMENT NO. FC-2150
ANALST		
DOCMR C. Geo. Beck 8-28-69		
APPR'D [signature]	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

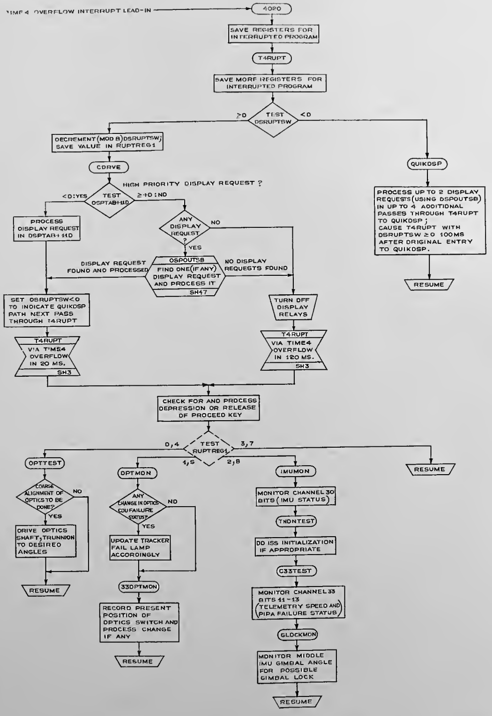
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	8/19/67	KEYRUPT AND UPRUPT	
PRGMR		COLOSSUS II-C	DOCUMENT NO. FC-2150
ANALST			
DOCMR	8-28-69		
APPR'D		REV.	SHEET 9 OF 9

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
TNONTEST	ENTERED FROM IMUMON EVERY 480 MS, DOES ISS INITIALIZATION IF APPROPRIATE	SH. 33
ENDTNON	ENDS ISS TURN-ON SEQUENCE	SH. 35
C33TEST	ENTERED FROM TNONTEST EVERY 480 MS, MONITORS CHANNEL 33 BITS 11 - 13	SH. 38
PIPFAIL	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
QUIKDSP	BRANCH OF T4RUPT ENTERED BETWEEN 120 MS PASSES, EXECUTES DISPLAY FUNCTIONS ONLY	SH. 46
DSPOUTSB	FINDS AND PROCESSES ONE DISPLAY REQUEST	SH. 47

SPECIAL CONVENTIONS:

$\ominus$	MODULAR SUBTRACTION
$\veebar$	LOGICAL "EXCLUSIVE OR"
$\bar{a}$	LOGICAL COMPLEMENT OF a

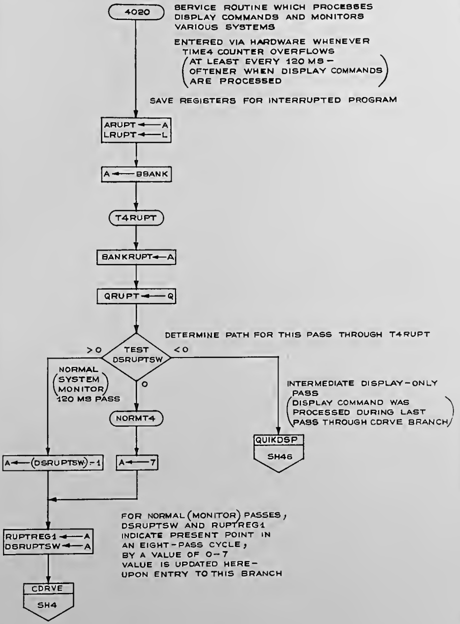
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN *[signature]* 17 MAR 69	T4RUPT
PRGMR *J. E. Crocker* 23 June 69	DOCUMENT NO.
ANALYST	COLOSSUS II-A FC-2200
DOCMR *Alala M. Grant* 23 June 69	
APPR'D *Alala M. Grant* 23 June 69	REV / SHEET 1 OF 55



T4RUPT

COLOSSUS II-A

FC-2200 2 55

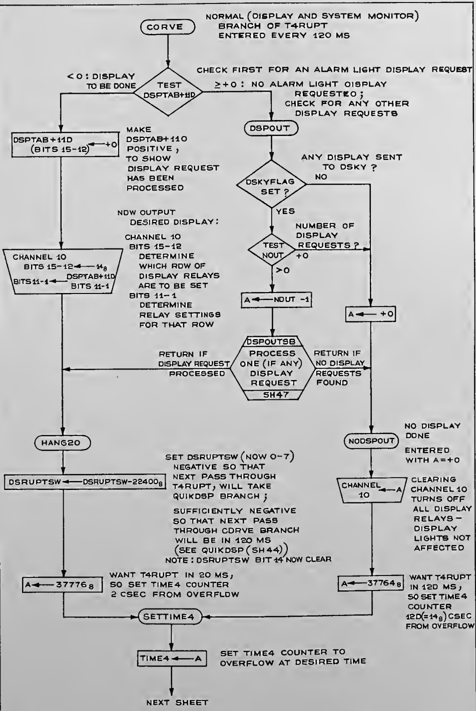


T4RUPT

COLOSSUS II-A

FC-2200

3 55

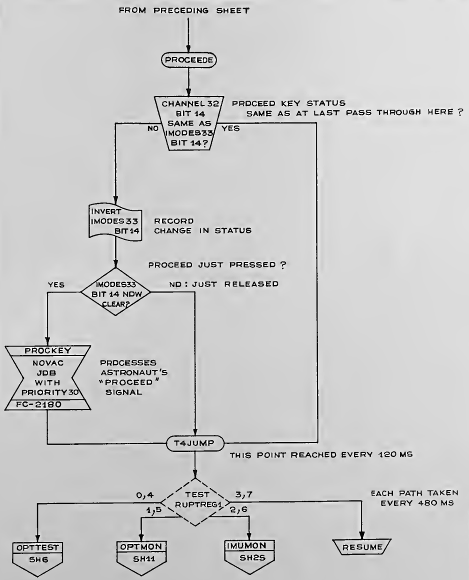


T4RUPT

COLOSSUS II-A

FC-2200

4 53

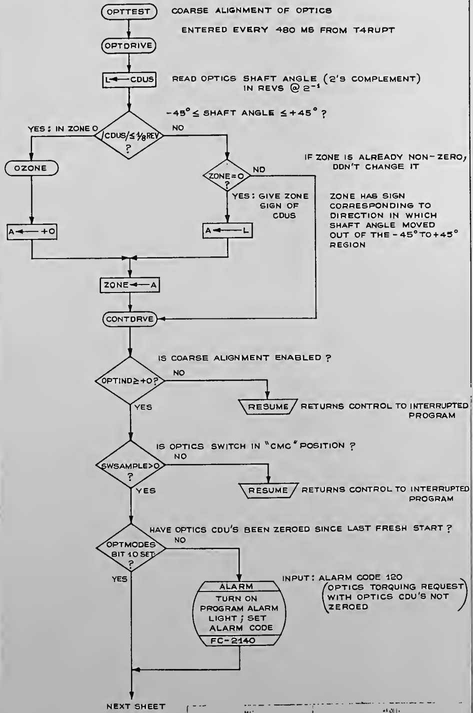


T4RUPT

COLOSSUS II-A

FC-2200

5 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

19MAR69

23 Jun 69

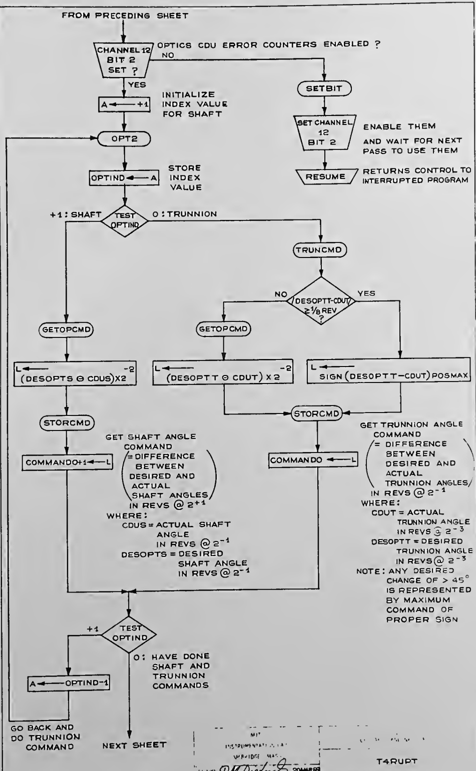
APOLLO GUIDANCE AND NAVIGATION

T4RUPT

COLOSSUS II-A

DOCUMENT NO. FC-2200

6 of 55



FROM PRECEDING SHEET
CHANNEL 12 BIT 2 SET ?
OPTICS CDU ERROR COUNTERS ENABLED ?
NO
YES
A ←— +1
INITIALIZE INDEX VALUE FOR SHAFT
SETBIT
SET CHANNEL 12 BIT 2
ENABLE THEM
AND WAIT FOR NEXT PASS TO USE THEM
RESUME
RETURNS CONTROL TO INTERRUPTED PROGRAM
OPT2
OPTIND ←— A
STORE INDEX VALUE
+1: SHAFT
TEST OPTIND
0 : TRUNNION
TRUNCMD
NO
DESOPTT-CDUT ≥ 1/8 REV ?
YES
GETOPCMD
GETOPCMD
L ←— (DESOPTS ⊖ CDUS)X2 -2
L ←— (DESOPTT ⊖ CDUT) X 2 -2
L ←— SIGN (DESOPTT−CDUT) POSMAX
STORCMD
STORCMD
COMMANDO+1 ←— L
COMMANDO ←— L
GET SHAFT ANGLE COMMAND (= DIFFERENCE BETWEEN DESIRED AND ACTUAL SHAFT ANGLES) IN REVS @ 2+1
WHERE:
CDUS = ACTUAL SHAFT ANGLE IN REVS @ 2-1
DESOPTS = DESIRED SHAFT ANGLE IN REVS @ 2-1
GET TRUNNION ANGLE COMMAND (= DIFFERENCE BETWEEN DESIRED AND ACTUAL TRUNNION ANGLES) IN REVS @ 2-1
WHERE:
CDUT = ACTUAL TRUNNION ANGLE IN REVS @ 2-3
DESOPTT = DESIRED TRUNNION ANGLE IN REVS @ 2-3
NOTE: ANY DESIRED CHANGE OF > 45° IS REPRESENTED BY MAXIMUM COMMAND OF PROPER SIGN
+1
TEST OPTIND
0: HAVE DONE SHAFT AND TRUNNION COMMANDS
A ←— OPTIND-1
GO BACK AND DO TRUNNION COMMAND
NEXT SHEET
MIT
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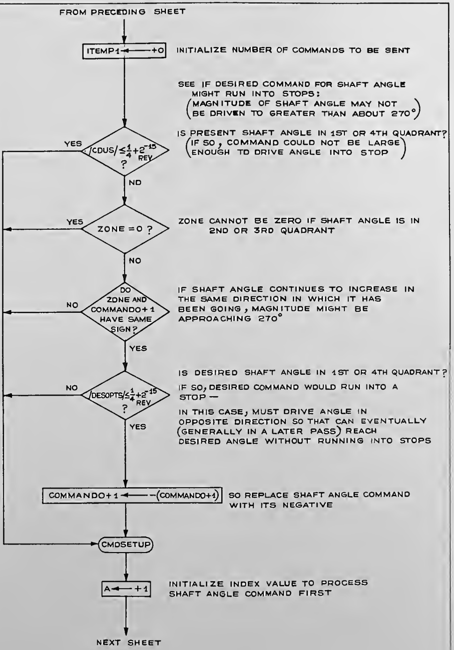

P.M. Dietrich 21MAR69
J. E. Corker 23 June 69
Alexa M. Grant 23 June 69
Alexa M. Grant 23 June 69

T4RUPT

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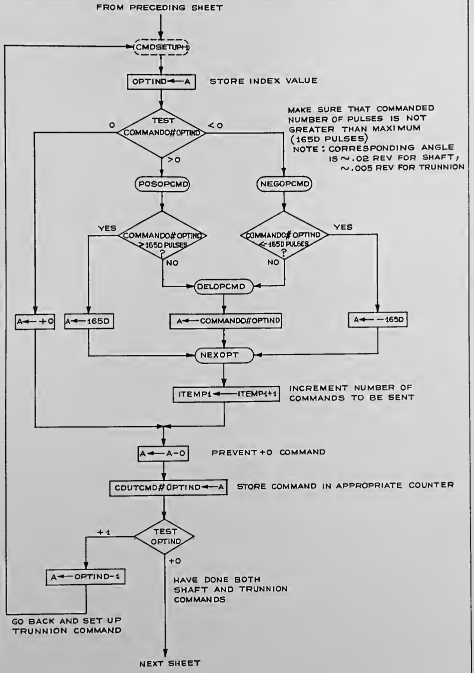
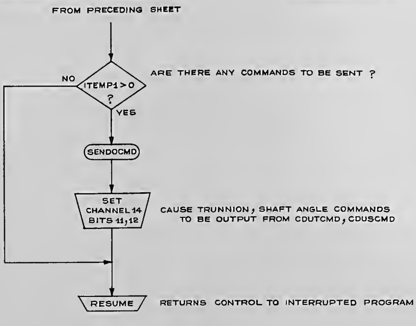


MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	GUIDANCE AND NAV...
DRAWN P.M. Dietrich 21MAR69	T4RUPT
CHECKED J. E. Corben 23June69	COLOSSUS II-A
ANALYST	FC-2200
... Aleta M. Grant 23June69	9 · 55
APPR'D Aleta M. Grant 23June69	



MIT

P. M. Dietrich 21 MAR 69
J. E. Canton 23 June 69
Alice M. Sorant 23 JUNE 69
Alice M. Sorant 23 JUNE 69

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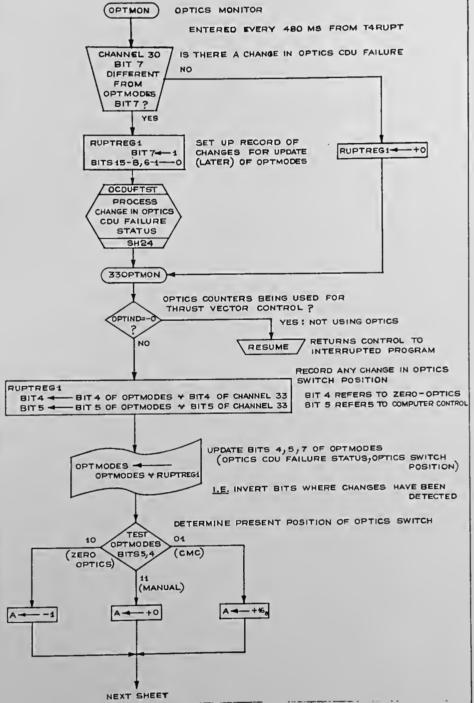

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DRAWN P. M. Dietor 24MAR68
CHECKED J E Cracker 23 June 68
APPROVED Alan M Grant 25 June 68
APPROVED Alan M Grant 25 June 68

T4RUPT

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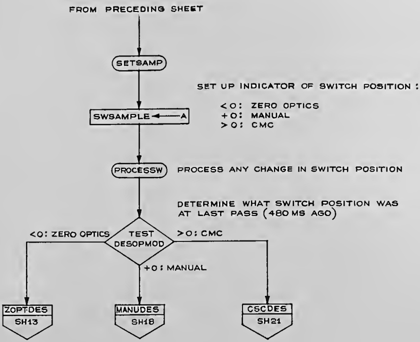
11 55

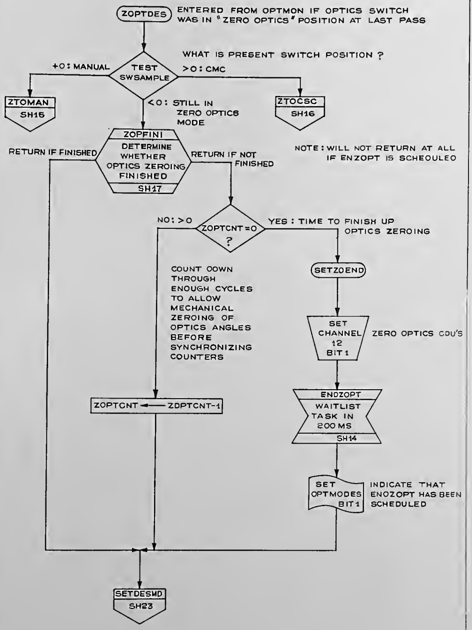


T4RUPT

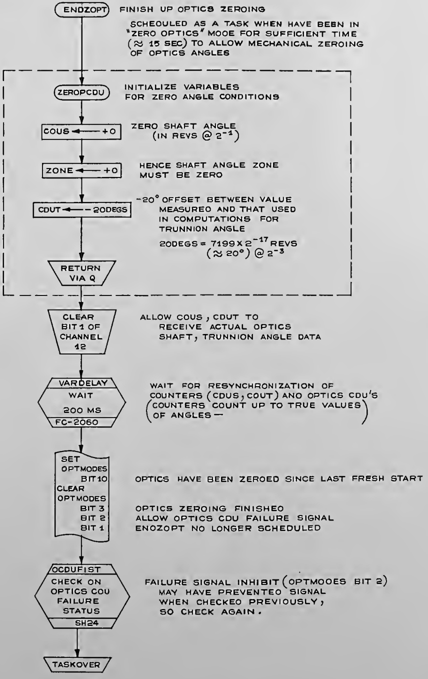
COLOSSUS II-A

FC-2200

12 55



ZOPTDES
ENTERED FROM OPTMON IF OPTICS SWITCH WAS IN "ZERO OPTICS" POSITION AT LAST PASS
WHAT IS PRESENT SWITCH POSITION ?
TEST SWSAMPLE
+0: MANUAL
>0: CMC
<0: STILL IN ZERO OPTICS MODE
ZTOMAN
SH16
ZTOCSC
SH16
ZOPFINI
DETERMINE WHETHER OPTICS ZEROING FINISHED
SH17
RETURN IF FINISHED
RETURN IF NOT FINISHED
NOTE: WILL NOT RETURN AT ALL IF ENZOPT IS SCHEOULEO
ZOPTCNT = 0 ?
NO: >0
YES: TIME TO FINISH UP OPTICS ZEROING
COUNT OOWN THROUGH ENOUGH CYCLES TO ALLOW MECHANICAL ZEROING OF OPTICS ANGLES BEFORE SYNCHRONIZING COUNTERS
SETZOEND
SET CHANNEL 12 BIT 1
ZERO OPTICS CDU'S
ZOPTCNT ← ZDPTCNT-1
ENOZOPT
WAITLIST TASK IN 200 MS
SH14
SET OPTMODES BIT 1
INDICATE THAT ENOZOPT HAS BEEN SCHEDULED
SETDESMD
SH23
T4RUPT
COLDSSUS II-A
FC-2200
13 55

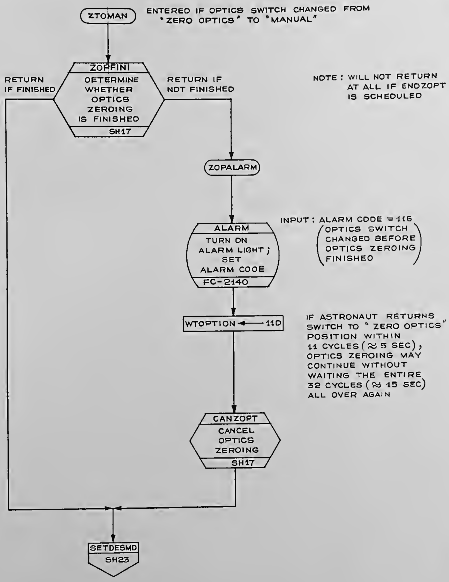


T4RUPT

COLOSSUS II-A

FC-2200

14 58

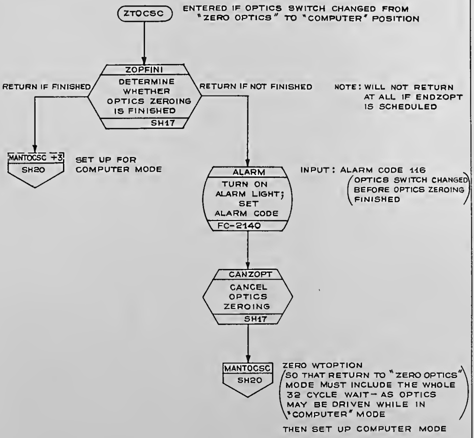


T4RUPT

COLOSSUS II-A

FC-2200

45 55



26MAR69

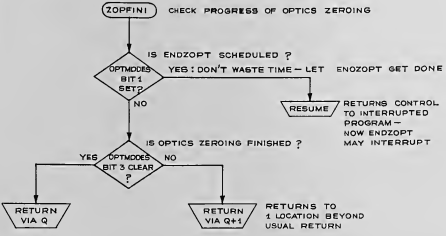
23June69

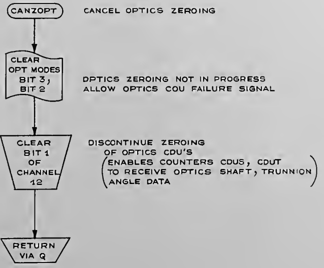
T4RUPT

COLOSSUS II-A

FC-2200

16 55





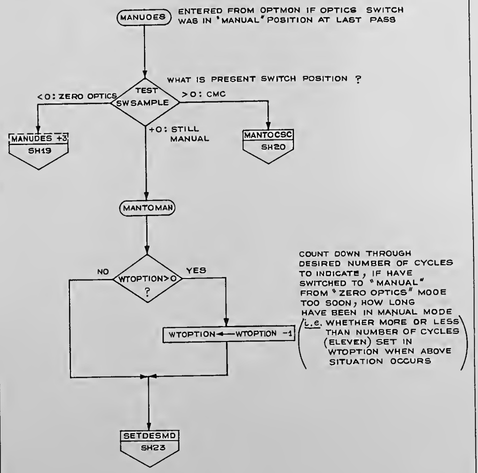
27MAR69
23June69

T4RUPT

COLOSSUS II-A

FC-2200

17 55



T4RUPT

COLOSSUS II-A FC-2200

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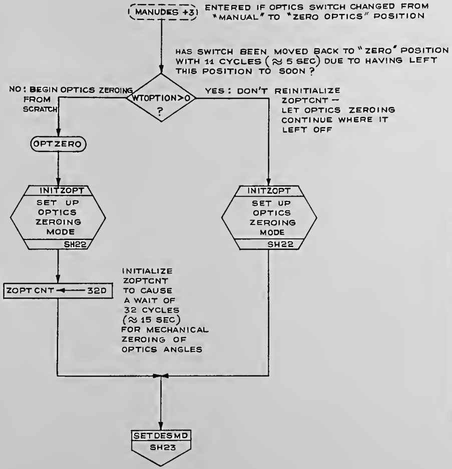
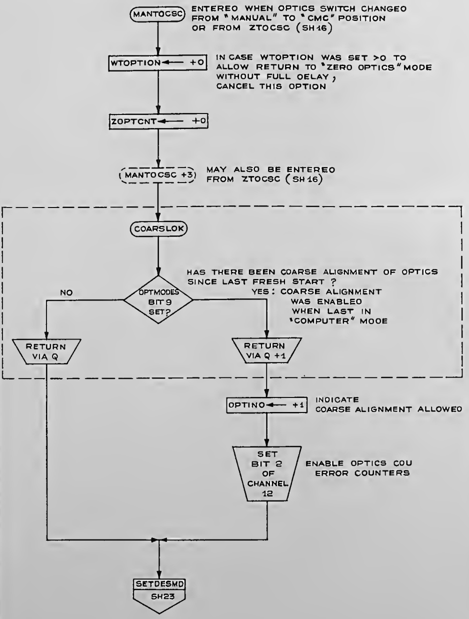


T4RUPT

COLOSSUS II-A

FC-2200

19 55



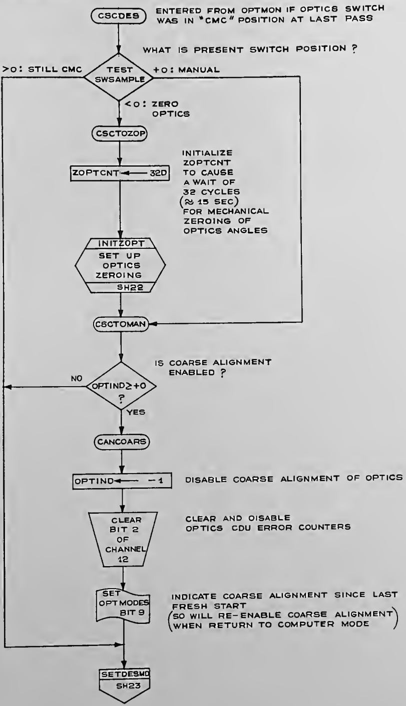
P.M. Dietrich 28
E Crocker 13 June 69
Alena M. Soranthshnes

T4RUPT

COLOSSUS II - A

FC-2200

20 - 55



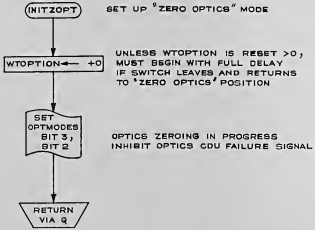
MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

T4RUPT

COLOSSUS II-A

FC-2200

21 55



T4RUPT

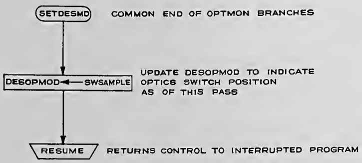
COLOSSUS II-A

FC-2200

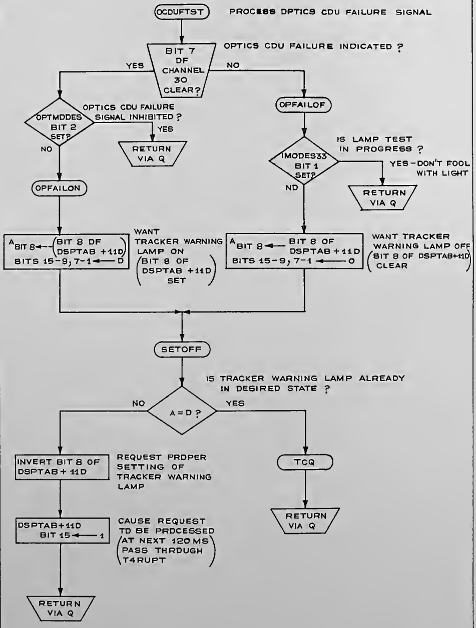
22 55

31 MAR 69

23 June 69



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	T4RUPT
DRAWN P. M. Dietrich 31MAR69	
PRGMR T. E. Crocker	
ANAL	
APPR Aleda M. Grant	COLOSSUS II-A
REV	FC-2200 23 55



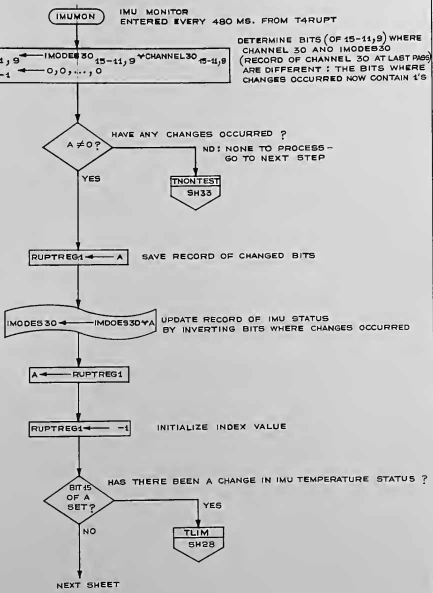
INSTRUMENTATION LAB
P.A. Dietz 1 APRIL 69
T E Crocker 23 June 69
Alesa M. Sosnat
Alesa M. Sosnat

T4RUPT

COLOSSUS II-A

FC-2200

24 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN R.M. Dietrich 1 APR 68

CHECKED T.E. Lahey

ANALYST

DOC. MGR. Alexa M. Grant

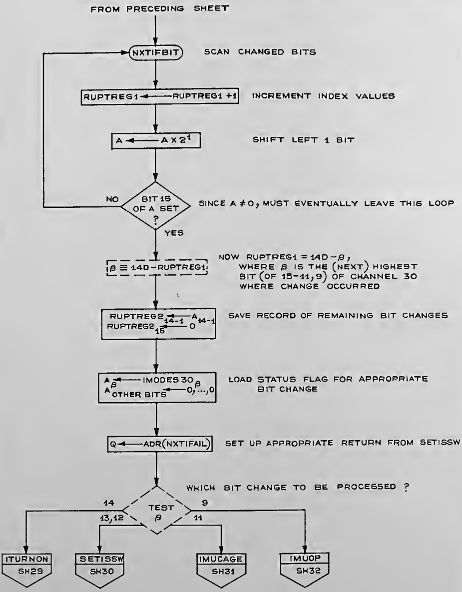
APP'D Alexa M. Grant

T4RUPT

COLOSSUS II-A

FC-2200

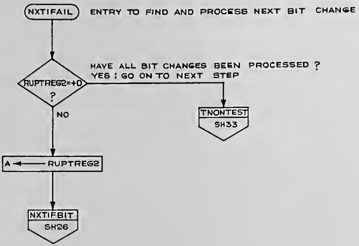
25 55



T4RUPT

COLOSSUS II-A FC-2200

26 55



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

DRAWN D.M. Diefenbach 2APRIL68
CHKR T.E. Cochran 23 June 67
ANALYST
PROG MR Alex M Kosmala 23 June 67
APPR'D Alex M Kosmala 23 June 67

APOLLO GUIDANCE AND NAVIGATION

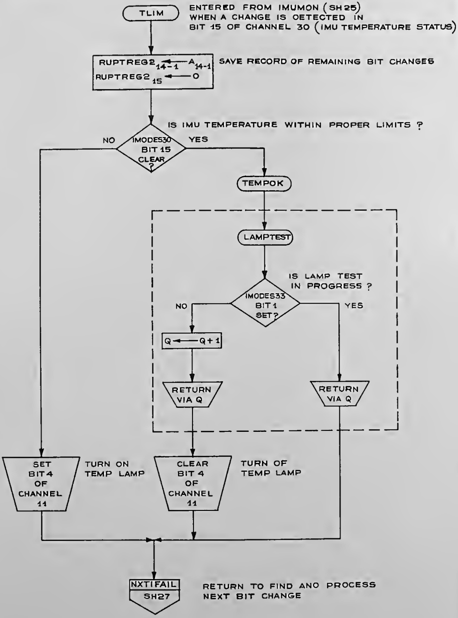
T4RUPT

COLOSSUS II-A

REV

DOCUMENT No. FC-2200

SHEET 27 OF 55



MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS

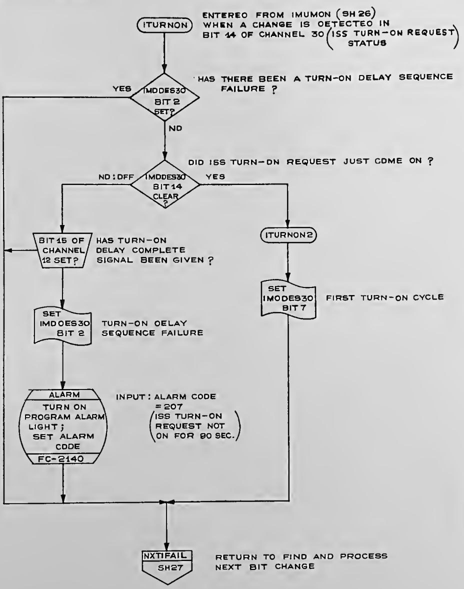
P.M. Dietrich 2 APRIL 68
F. Crocker 23 June 69
Alex M. Saint
Alex M. Saint

T4RUPT

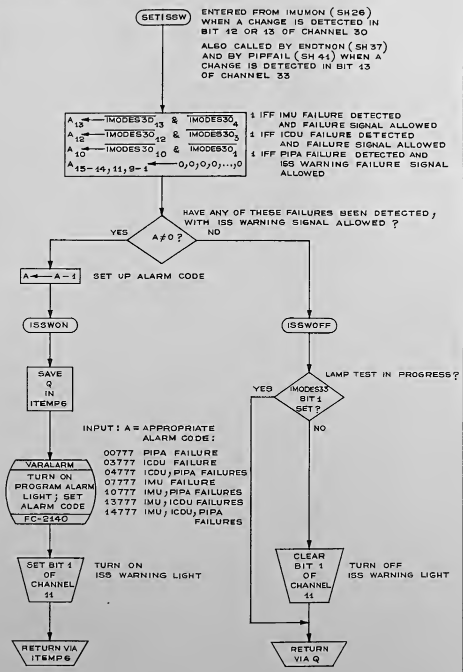
COLOSSUS II-A

FC-2200

28 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 3 APRIL	T4RUPT
PROGMR 23 June 69	COLOSSUS II-A
ANALYST	DOCUMENT NO. FC-2200
DOC MGR 25 June 69	
APPR'D 25 June 69	REV SHEET 29 OF 55



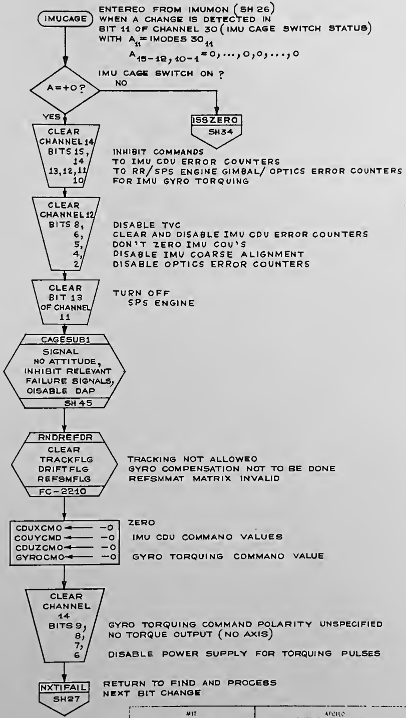
P.M. Dietrich 3 APRIL 69
T.E. Crocker 23 June 69

T4RUPT

COLOSSUS II-A

FC-2200

30 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

DRAWN P.M. Dietrich 4 APRIL 69
PR. MR J. E. Cooke 23 June 69
ANALYST
DOC MR Alvin M. Spencer
APPR'D Alvin M. Spencer

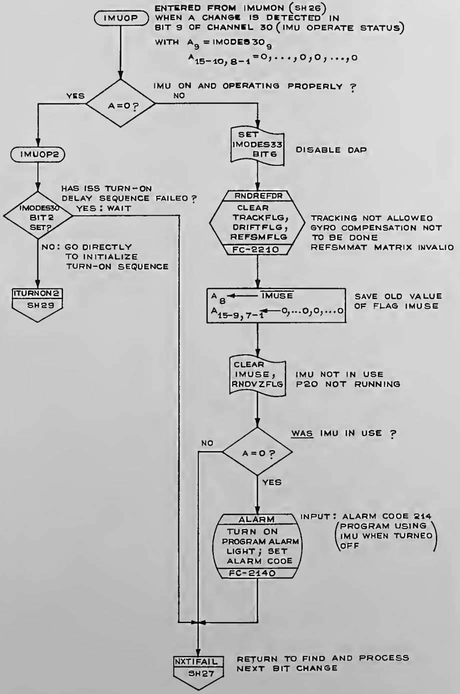
T4RUPT

COLOSSUS II-A

DOCUMENT NO. FC-2200

REV

SHEET 31 OF 55

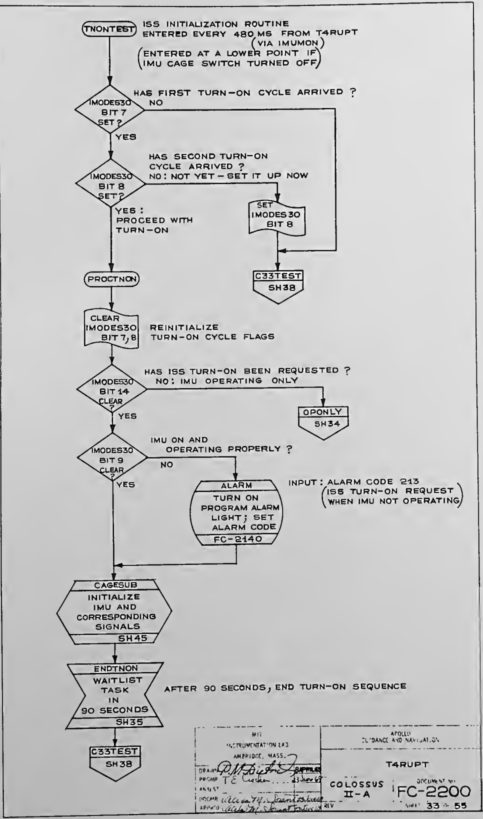


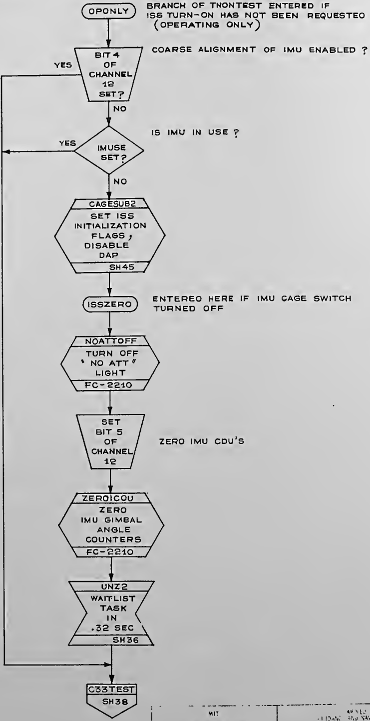
T4RUPT

COLOSSUS II-A

FC-2200

32 55


TNONTEST
ISS INITIALIZATION ROUTINE
ENTERED EVERY 480 MS FROM T4RUPT
(VIA IMUMON)
(ENTERED AT A LOWER POINT IF IMU CAGE SWITCH TURNED OFF)
HAS FIRST TURN-ON CYCLE ARRIVED ?
IMODES30 BIT 7 SET ?
NO
YES
HAS SECOND TURN-ON CYCLE ARRIVED ?
NO: NOT YET - SET IT UP NOW
IMODES30 BIT 8 SET ?
YES: PROCEED WITH TURN-ON
SET IMODES30 BIT 8
C33TEST
SH38
PROCTNON
CLEAR IMODES30 BIT 7, 8
REINITIALIZE TURN-ON CYCLE FLAGS
HAS ISS TURN-ON BEEN REQUESTED ?
NO: IMU OPERATING ONLY
IMODES30 BIT 14 CLEAR ?
YES
OPONLY
SH34
IMU ON AND OPERATING PROPERLY ?
IMODES30 BIT 9 CLEAR ?
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
SH38
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.
APOLLO GUIDANCE AND NAVIGATION
T4RUPT
COLOSSUS II-A
DOCUMENT NO FC-2200
SHEET 33 OF 55



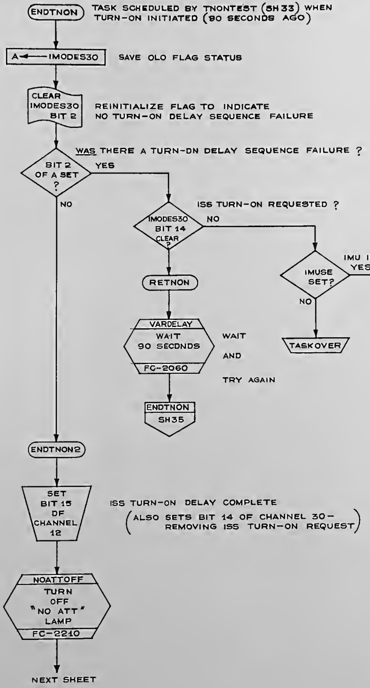
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

T4RUPT

COLOSSUS II-A

FC-2200

34 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

T4RUPT

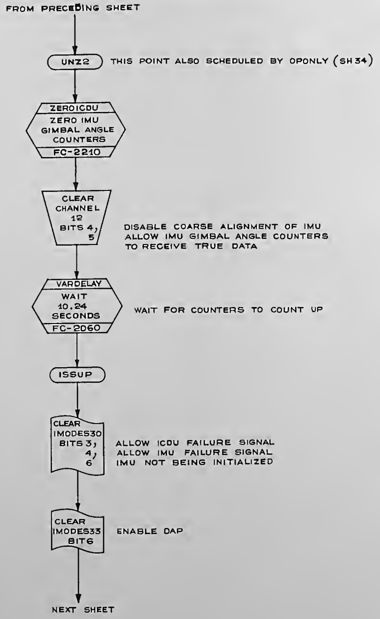
DRAWN P.M. Dickson 24 APRIL 69
CHECKED T.E. Crocker 23 June 69
ANALYST
DOCUMENT Alexa M. Sorant 23 June 69
APPROVED Alexa M. Sorant 23 June 69

COLOSSUS II-A

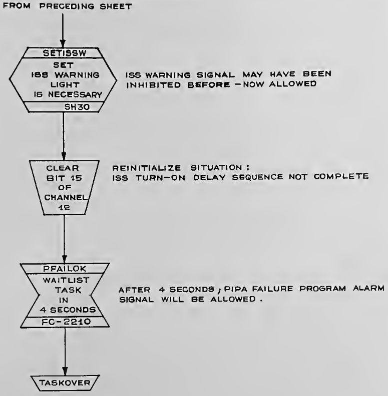
DOCUMENT NO. FC-2200

REV

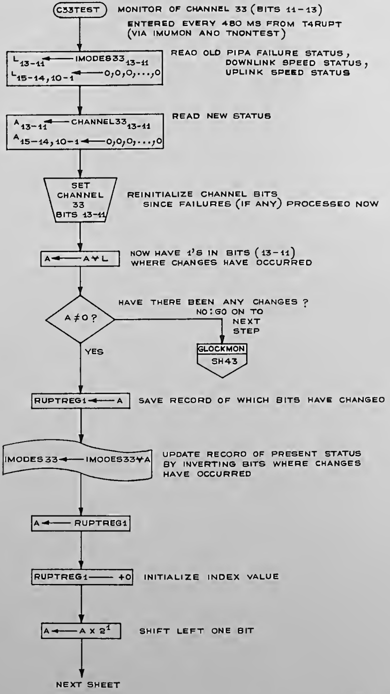
SHEET 35 OF 55



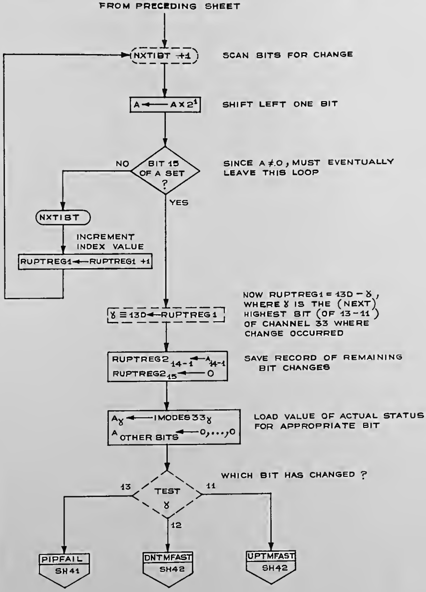
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietz 9APRIL69 PO MP T.E. Crocker 23 June 69 ANALYST DOCMR Alex M. Grant 23 June 69 APPR'D Alex M. Grant 23 June 69	T4RUPT COLOSSUS II-A DOCUMENT NO FC-2200 SHEET 36 OF 55 REV

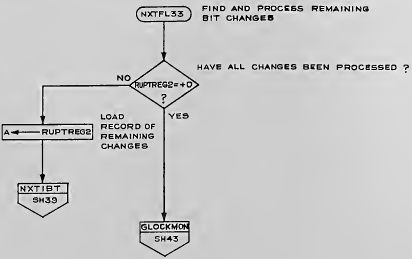


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature]	T4RUPT
PROGMR T. E. Crocker 23 June 69	COLOSSUS II-A
ANALYST	FC-2200
DIV MGR [signature] 23 June 69	
APPR'D [signature] 23 June 69 REV	SHEET 37 OF 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P. W. Dixon — 10 APR 1968	T4RUPT
PREPARED E. Cukes — 23 Jun 69	COLOSSUS II-A
ANALYST	DOCUMENT NO. FC-2200
DOLMK Alex W. Grant	SHEET 38 OF 55
APP'D Alex W. Grant	REV


FROM PRECEDING SHEET
NXTIBT +1
SCAN BITS FOR CHANGE
A ← A X 2^1
SHIFT LEFT ONE BIT
BIT 15 OF A SET ?
NO
YES
SINCE A ≠ 0, MUST EVENTUALLY LEAVE THIS LOOP
NXTIBT
INCREMENT INDEX VALUE
RUPTREG1 ← RUPTREG1 +1
γ ≡ 13D ← RUPTREG1
NOW RUPTREG1 = 13D − γ, WHERE γ IS THE (NEXT) HIGHEST BIT (OF 13-11) OF CHANNEL 33 WHERE CHANGE OCCURRED
RUPTREG2 14-1 ← A 14-1
RUPTREG2 15 ← 0
SAVE RECORD OF REMAINING BIT CHANGES
A γ ← IMODES33 γ
A OTHER BITS ← 0,...,0
LOAD VALUE OF ACTUAL STATUS FOR APPROPRIATE BIT
WHICH BIT HAS CHANGED ?
TEST γ
13
12
11
PIPFAIL
SH41
DNTMFAST
SH42
UPTMFAST
SH42



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INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN P.M. Dustons
PROG MR T E Crocker 23June69
ANA ST
DO MR Alvin Ty. Sorant 23June69
APPRO Alvin Ty. Sorant 23June69

APOLLO
GUIDANCE AND NAVIGATION

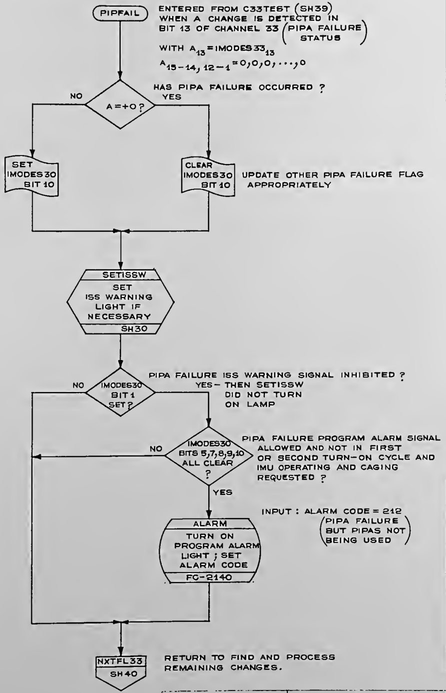
T4RUPT

COLOSSUS II-A

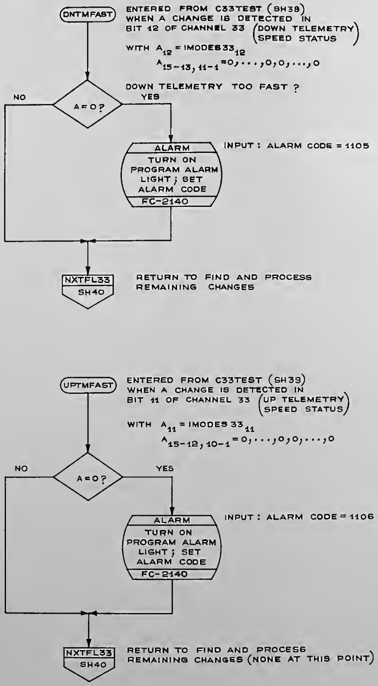
DOCUMENT No FC-2200

REV

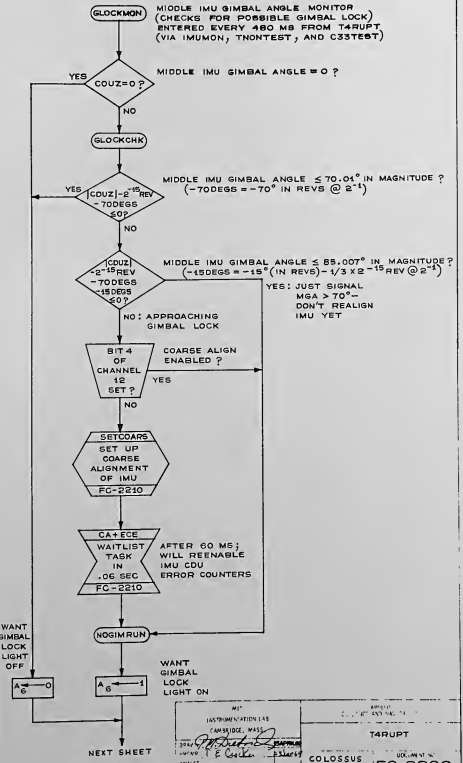
SHT 40 · 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietrich	T4RUPT
PGMR T. E. Crocker 23 June 68	COLOSSUS II-A
ANALYST	DOCUMENT NO. FC-2200
DOCMR Alicia M. Sorant 23 June 68	
APPR'D Alicia M. Sorant 23 June 68	REV SHEET 41 OF 55



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. M. Dietz 15 APRIL 68	T4RUPT	
PREPARED T. E. Crocker 23 June 68	COLOSSUS II-A	DOCUMENT NO. FC-2200
ANALYST		
ENGINEER Alexander Grant 25 June 68		
APPROVED Alexander Grant 25 June 68	REV	SHEET 42 OF 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN [signature] 25APR69
CHECKED T E Crocker 23Jun69
ANALYST
DOC'MR Alexis M. Sorant
APPR'D Alexis M. Sorant

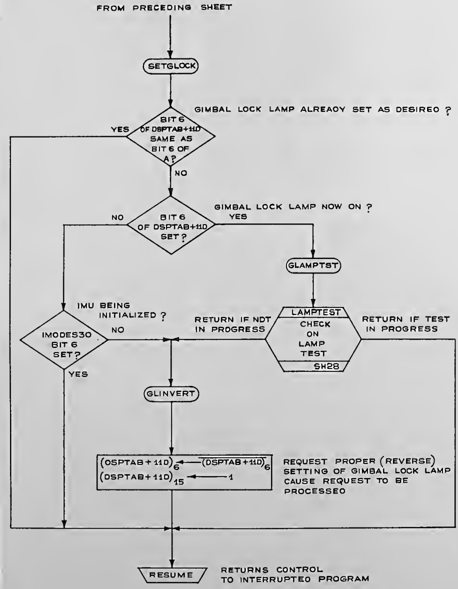
APOLLO GUIDANCE AND NAVIGATION

T4RUPT

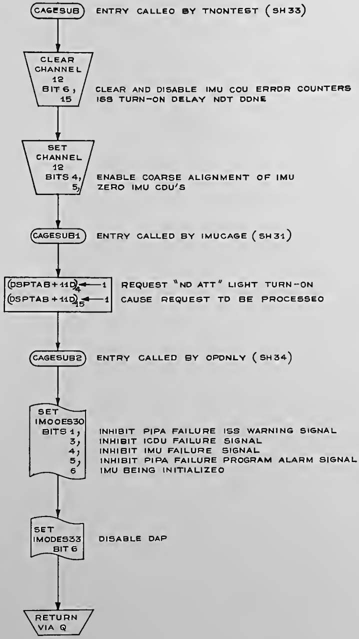
COLOSSUS II-A

DOCUMENT NO FC-2200

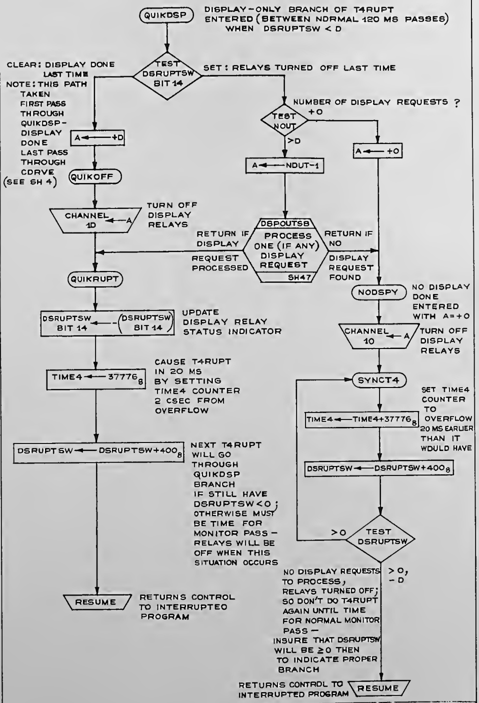
SHEET 43 of 55



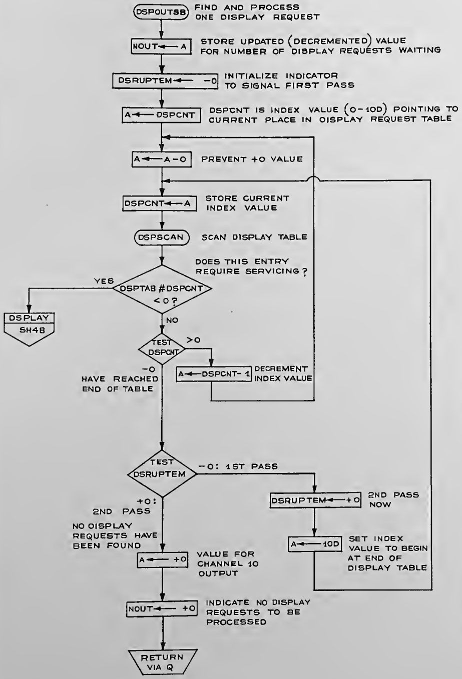
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO G. DANCE AND NAVIGATION
DRAWN D. M. Dietz 16APRIL69	T4RUPT
PROGMR T. E. Cooke 23June69	
ANALYST	COLOSSUS II-A
DIV. MGR	DOCUMENT NO. FC-2200
APPR'D	SH. 44 OF 55



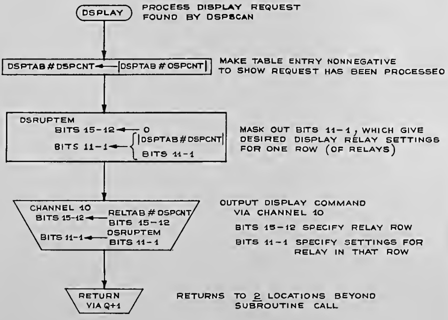
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D.M. Dietrich	T4RUPT
CHECKED J.E. Crocker	COLOSSUS II-A
ANALYST	DOCUMENT NO. FC-2200
APPROVED	SHEET 45 OF 55



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietz 17APRIL68	T4RUPT
PROGMR J. E. Crocker 23June68	COLOSSUS II-A
ANALYST	DOCUMENT NO. FC-2200
COGMR Alexa M. Grant	SH 46 OF 55
APP'D Alexa M. Grant	REV



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	T4RUPT
PR.MAN T E Crocker 23 June 68	
ANALYST	COLOSSUS II-A
DOC.MR	DOCUMENT NO. FC-2200
APPR'D	REV / SHEET 47 OF 55



DSPLAY
PROCESS DISPLAY REQUEST FOUND BY DSPSCAN
DSPTAB # DSPCNT ← |DSPTAB # DSPCNT|
MAKE TABLE ENTRY NONNEGATIVE TO SHOW REQUEST HAS BEEN PROCESSED
DSRUPTEM
BITS 15-12 ← 0
BITS 11-1 ← |DSPTAB # DSPCNT| 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
BITS 11-1 ← DSRUPTEM 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

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
PFAILOK	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	T3RUPT CALLS GYRO COMPENSATION	T3RUPT DOES NO GYRO COMPENSATION		SH. 31, 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. 46	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

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 6	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 FLAGWRD0 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.[illegible], 17	SH.[illegible]
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.20
OPTMODES BIT 10	OPTICS HAVE BEEN ZEROED SINCE LAST FRESH START	OPTICS HAVE NOT BEEN ZEROED SINCE LAST FRESH START	SH.14		

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 BBANK (BELOW) DURING INTERRUPT			
BBANK		CENTRAL REGISTER CONTAINING ADDRESS INFORMATION (USED BY CENTRAL PROCESSOR)			
CDUS		OPTICS SHAFT ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-1}
CDUSCMD (=CDUTCMD+1)		COMMANDED CHANGE IN SHAFT ANGLE (OUTPUT COUNTER)	DEGREES	REVS	2^{+1}
CDUT		OPTICS TRUNNION ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-3}
CDUTCMD		COMMANDED CHANGE IN TRUNNION ANGLE (OUTPUT COUNTER)	DEGREES	REVS	2^{-1}
CDUXCMD		COMMANDED VALUE FOR OUTER IMU GIMBAL ANGLE	DEGREES	REVS	2^{1}
CDUYCMD		COMMANDED VALUE FOR INNER IMU GIMBAL ANGLE	DEGREES	REVS	2^{1}
CDUZ		MIDDLE IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-1}

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^{1}
COMMANDO		PRELIMINARY COMMAND FOR CHANGE IN TRUNNION ANGLE	DEGREES	REVS	2^{-1}
COMMANDO+1		PRELIMINARY COMMAND FOR CHANGE IN SHAFT ANGLE	DEGREES	REVS	2^{+1}
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^{+1}
DESOPTT		DESIRED TRUNNION ANGLE	DEGREES	REVS	2^{-1}
DSPCNT		INDEX VALUE POINTING TO ENTRY IN DISPLAY REQUEST TABLE (SEE DSPTAB BELOW)			
DSPTAB, . . . , DSPTAB+11D		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.			
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^{7}
ITEMP1		USED HERE TO INDICATE NUMBER OF OPTICS COMMANDS TO BE SENT			2^{14}
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 ≥ +0 OR ≤ -0, RESPECTIVELY. IF ≥ +0, +1 INDICATES SHAFT ANGLE IS UNDER CONSIDERATION, AND +0 INDICATES TRUNNION ANGLE IS UNDER CONSIDERATION. IF ≤ -0, -0 INDICATES OPTICS NOT BEING USED AS OPTICS ERROR COUNTERS ARE BEING USED FOR THRUST VECTOR CONTROL, AND <-0 MERELY DISABLES COARSE ALIGNMENT.			

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			
$TIME2_D$ $= \begin{pmatrix} TIME2 \\ TIME1 \end{pmatrix}$		PRESENT TIME FROM LIFTOFF	SECS	CSECS	2^{28}
TIME4		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^{14}
ZONE		INDICATES WHETHER MAGNITUDE OF OPTICS SHAFT ANGLE IS $\leq 45°$ (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^{14}

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 TORQUING; BOTH CLEAR MEANS NO AXIS SPECIFIED.			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

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

T4RUPT

DRAWN H. A. Hart 1 MAY 68
PRGMR J. E. Crohn 23 ...
ANALYST
DOCMR
APPR'D

COLOSSUS II-A

DOCUMENT NO. FC-2200

REV

SHEET 54 OF 55

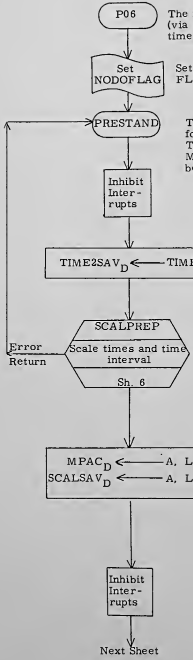
CHANNEL BITS (CONTINUED)

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 15-1 ALL CLEARED, ALL DISPLAY RELAYS TURNED OFF (THIS DOES NOT TURN OFF THE LIGHTS)				

P06 GNCS POWER DOWN

SCALPREP	Sh. 7
POSTAND	Sh. 4

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty	11/24/69	P06 GNCS Power Down	
PRGMR Densmore	12-3-69		DOCUMENT NO.
ANALST			
DOCMR G. B. Swift	12/3/69	COLOSSUS 2D	FC-2220
APPR'D Roberta M. Eitel	12/3/69	REV	SHEET 1 OF 8



The function of the P06 routine is to set up and execute (via GOPERF1) a CMC STANDBY. P06 also gives a time counter update after the STANDBY execution.

Set bit 1, FLAGWRD2 — Set for V37 permitted; done via subroutine UPFLAG.

The PRESTAND portion of this routine prepares for STANDBY by snapshotting the scaler and TIME1, TIME2 reading previous to actuating STANDBY. Makes sure (via SCALPREP) of compatability between scaler and TIME1, TIME2 reading.

Store value in time counter.

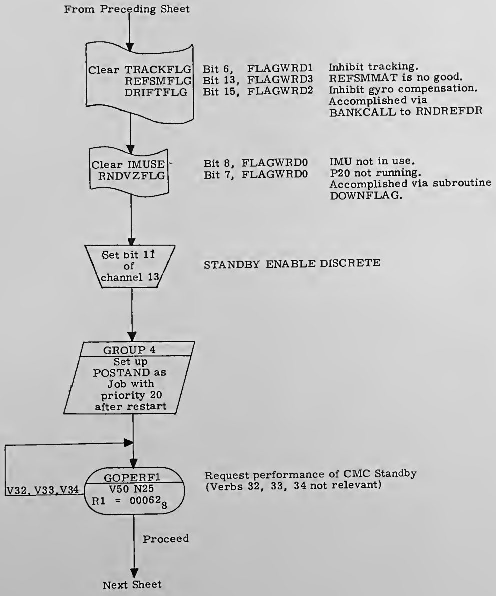
Incompatability error return to PRESTAND

Inputs: Previous reading of TIME1, TIME2 in A and L; return address.

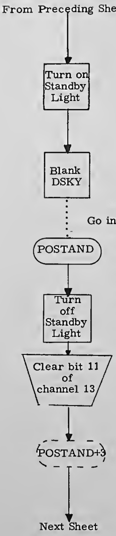
Outputs: Forced compatability in TIME1, TIME2 and scaler. Results in A, L and MPAC, MPAC +1.

Put old TIME1, TIME2 into MPAC and store scaler.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty 10/20/68	P06 GNCS Power Down	
PRGMR Densmore 12/3/69	COLOSSUS 2D	DOCUMENT NO. FC-2220
ANALST		
DOCMR O.H. Smith 12/3/69		
APPR'D Robert M. [illegible]	REV	SHEET 2 OF 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Yuchalke	11-25-69	P06 GNCS Power Down	
PRGMR Densmore	12-3-69		DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2220
DOCMR	12/ /69		
APPR'D	12/13/69	REV	SHEET 3 OF 8

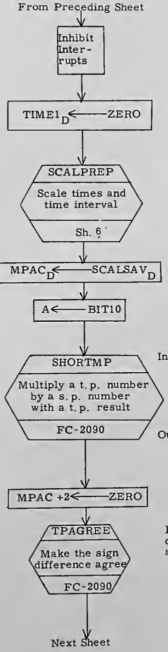


Go into standby (exit P06)

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.

Clear STANDBY ENABLE bit

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Jucholke	11-26-69	P06 GNCS Power Down	
PRGMR Densmore	12-3-69		
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2220
DOCMR G. Smith	12/3/69		
APPR'D Roberta M. Estey	12/3/69	REV	SHEET 4 OF 8



Clear TIME1, TIME2 clocks.

Inputs: See Sh. 1

Outputs: See Sh. 1

Form d. p. difference of post-STANDBY scaler.

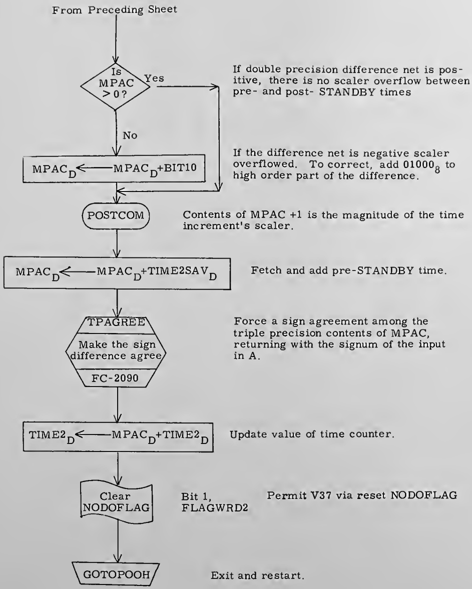
Align bits with TIME1, TIME2

Inputs: A triple precision number in MPAC, and in A, a single precision number

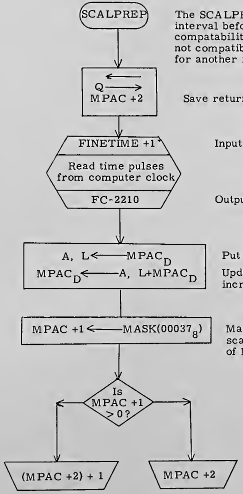
Output: The triple precision quotient in MPAC

Force a sign agreement among the triple precision contents of MPAC, returning with the signum of the input in A.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN	P06 GNCS Power Down	
PRGMR		
ANALST	COLOSSUS 2D	DOCUMENT NO. FC-2220
DOCMR		
APPR'D	REV	SHEET 5 OF 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty	10/20/69	P06 GNCS Power Down	
PRGMR Densmore	12-3-69		
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2220
DOCMR	12/3/69		
APPR'D	12/3/69	REV	SHEET 6 OF 8



The SCALPREP portion compares TIME1, TIME2 interval before and after STANDBY to assure compatability with the scaler. If the readings are not compatible, SCALPREP provides for a return for another reading.

Save return address in third cell in MPAC.

Input: Return address.

Output: Readings from computer clock in A, L.

Put times into MPAC.

Update time save area (where time is incremented 5 ms. out of phase).

Mask out low order 5 bits to zero (of scaler +5 ms.) and store in second cell of MPAC.

Checking scaler to see if it is the first interval after the T1 interval.

Exit via address in MPAC +2.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty	10/20/69	P06 GNCS Power Down	
PRGMR Densmore	12-3-69	COLOSSUS 2D	DOCUMENT NO. FC-2220
ANALST			
DOCMR O.B. Smith jr	12/3/69		
APPR'D Robert M. Eaton	12/3/69	REV	SHEET 7 OF 8

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	

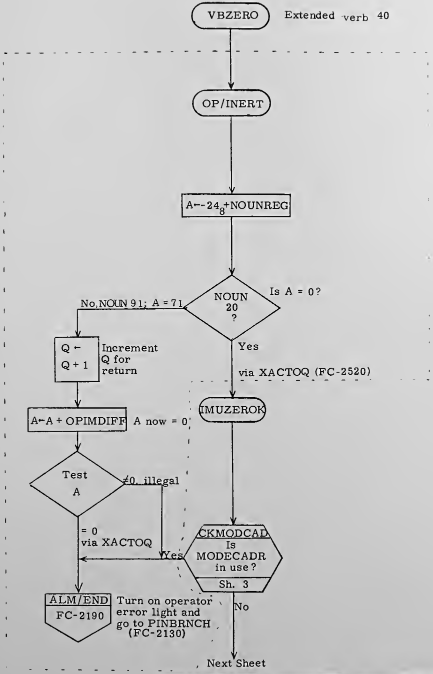
SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

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

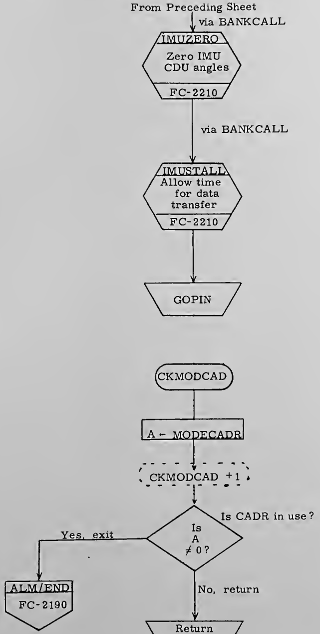
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN J. Flaherty 11/20/69	P06 GNCS Power Down
PRGMR W. Densmore 12-3-69	DOCUMENT NO. FC-2220
ANALST	COLOSSUS 2D
DOCMR J. Smith 12/3/69	
APPR'D Robert M. Estes 12/3/69	REV; SHEET 8 OF 8

IMU EXTENDED VERBS

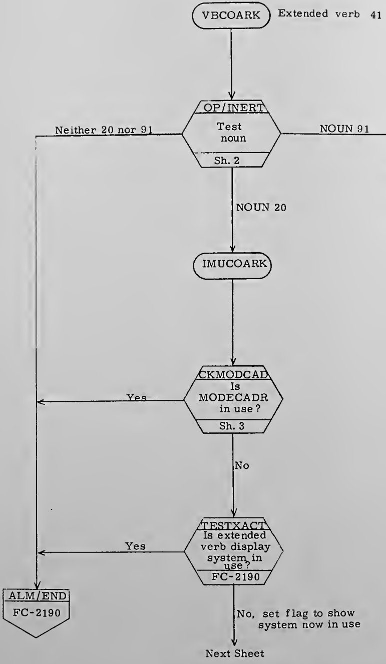
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN M. Connor	11-24-69	IMU Extended Verbs	
PRGMR E. Grace	12-4-69	COLOSSUS 2D	DOCUMENT NO. FC-2235
ANALST			
DOCMR Roberta M. Estes	12/4/69		
APPR'D Roberta M. Estes	12/4/69	REV	SHEET 1 OF 10



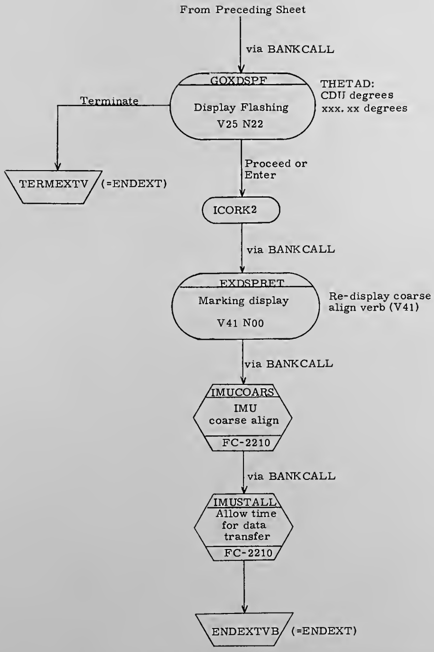
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN M. Lennick	11-24-67	IMU Extended Verbs	
PRGMR S. Gray	12-4-69		DOCUMENT NO.
ANALST			
DOCMR Roberta M. Entes	12/4/67	COLOSSUS 2D	FC - 2235
APPR'D Roberta M. Entes	12/4/67	REV	SHEET 2 OF 10



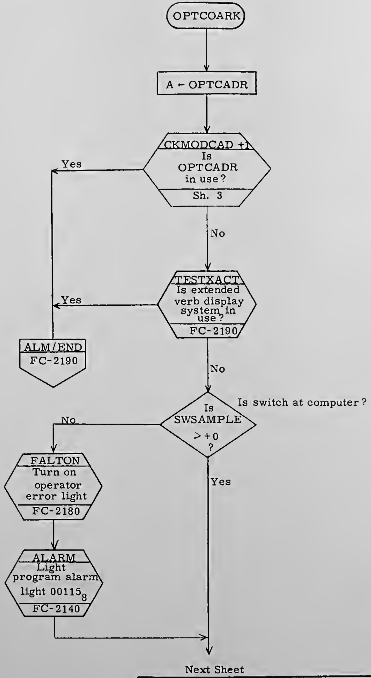
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN M. Conner	11/24/69	IMU Extended Verbs	
PRGMR E. Grace	12-4-69	COLOSSUS 2D	DOCUMENT NO. FC-2235
ANALST			
DOCMR Roberta M. Eaton	12/4/69		
APPR'D Roberta M. Eaton	12/4/69	REV	SHEET 3 OF 10



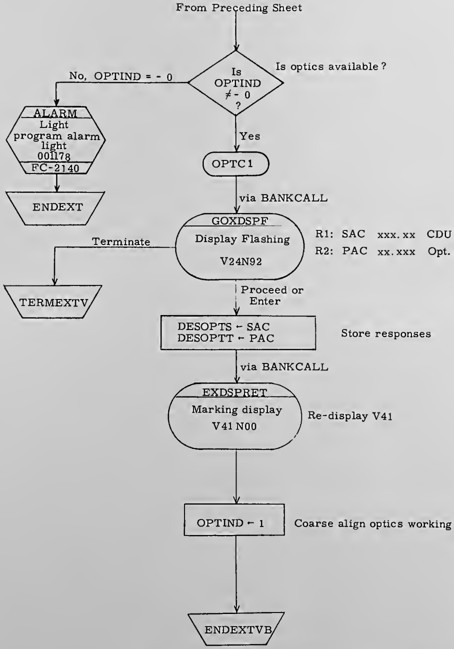
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN M. Conner	11 24 67	IMU Extended Verbs	
PRGMR E. Grace	12-4-65	COLOSSUS 2D	DOCUMENT NO. FC-2235
ANALST			
DOCMR Roberta M. Eaton	12/4/69		
APPR'D Roberta M. Eaton	12/4/69	REV	SHEET 4 OF 10



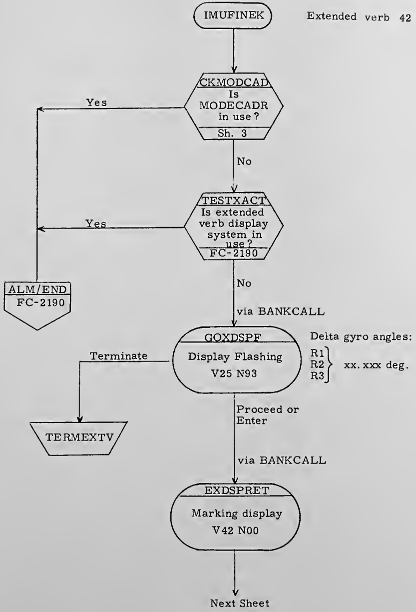
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN M. Cernik	11-24-69	IMU Extended Verbs	
PRGMR S. Grace	12-4-69		DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2235
DOCMR Roberta M. Estes	12/4/69		
APPR'D Roberta M. Estes	12/4/69	REV	SHEET 5 OF 10



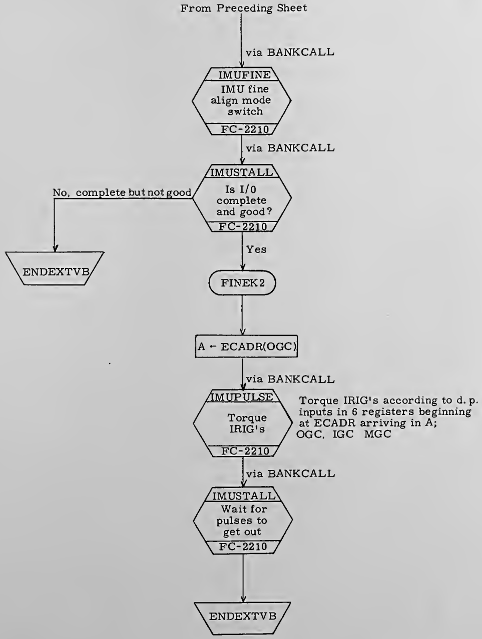
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION		
DRAWN	M. Connor	11-26-69	IMU Extended Verbs	
PRGMR	E. Grace	12-4-69		DOCUMENT NO.
ANALST			COLOSSUS 2D	FC-2235
DOCMR	[signature]	12/4/69		
APPR'D	[signature]	12/4/69	REV	SHEET 6 OF 10



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN M. Conner	11 26 69	IMU Extended Verbs	
PRGMR S. Grace	12-4-69		DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2235
DOCMR Roberta M. Cutts	12/4/69		
APPR'D Roberta M. Cutts	12/4/69	REV	SHEET 7 OF 10



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN M Conner	11/26/69	IMU Extended Verbs	
PRGMR E Grace	12-4-69	COLOSSUS 2D	DOCUMENT NO. FC-2235
ANALST			
DOCMR Roberta M. Enter	12/4/69		
APPR'D Roberta M. Enter	12/4/69	REV	SHEET 8 OF 10



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN M. Connor	11 26 69	IMU Extended Verbs	
PRGMR S. Grau	12-4-69	COLOSSUS 2D	DOCUMENT NO. FC-2235
ANALST			
DOCMR Roberta M. Cutri	12/4/69		
APPR'D Roberta M. Cutri	12/4/69	REV	SHEET 9 OF 10

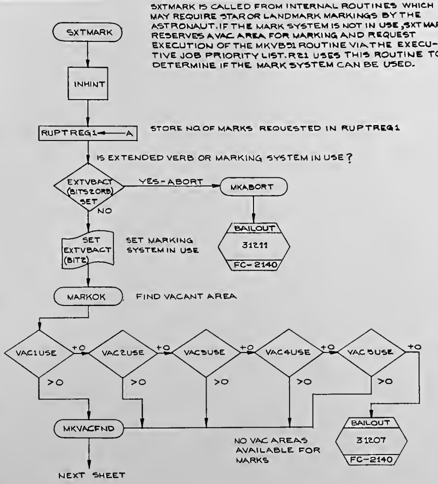
SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOWCHARTS

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/0 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

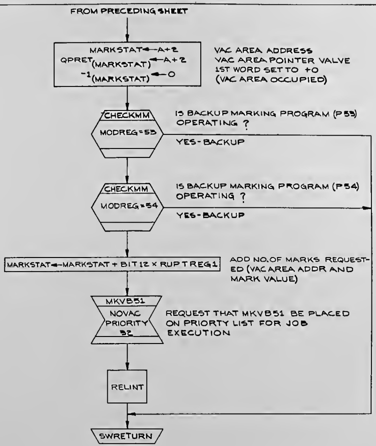
SXTMARK

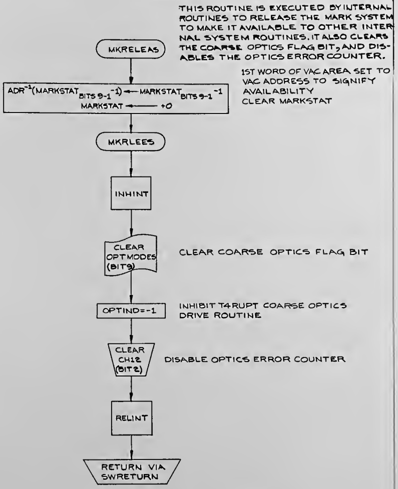
ENCLOSED IS A REPLACEMENT SHEET TO UPDATE THE COLOSSUS II FLOWCHART FC-2240, REV. 0, TO THE COLOSSUS IIC FLOWCHART FC-2240, REV. 1
EFFECTIVE SHEETS FOR THE COLLOSSUS IIC FLOWCHART FC-2240, REV. 1, ARE: SH. 1 — REV. 1 SH. 2-9 — REV. 0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN D.M. Dietrich	7AUG68	SXTMARK
PRGMR [illegible]	[illegible]	
ANALST		COLOSSUS IIC — DOCUMENT NO. FC-2240
DOCMR G.S. NALLY		
APPR'D Alex M. Grant	8/7/69	REV 1 SHEET OF

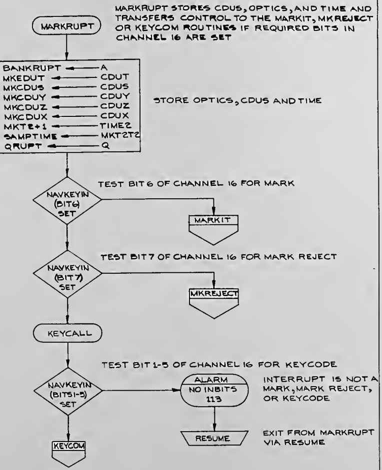


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN J.S. Chisholm 9 OCT 68	SXTMARK
PRGMR J. McCarthy 12 MAR 69	COLOSSUS IIC
ANALST	DOCUMENT NO. FC-2240
DOCMR G. S. NALLY 12 MAR 69	REV 1
APPR'D John A. Moore 12 MAR 69	SHEET 1 OF 5


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 + BIT12 × RUPTREG1
ADD NO.OF MARKS REQUESTED (VAC AREA ADDR AND MARK VALUE)
MKVB51
NOVAC
PRIORITY
32
REQUEST THAT MKVB51 BE PLACED ON PRIORTY LIST FOR JOB EXECUTION
RELINT
SWRETURN



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	AP 11 GUIDANCE AND NAVIGATION
DRAWN [signature]	SXTMARK
PRGMR [signature] 12MAR69	COLOSSUS IIC
ANALYST	DOCUMENT NO FC-2240
DOCMR G. S. NALLY 12MAR69	REV 1
APPR'D John A. Moore 12MAR69	SHEET 5 OF 9



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN
PROGMR
ANALST
DOCMR G. S. NALLY
APPR'D

GUIDANCE AND NAVIGATION

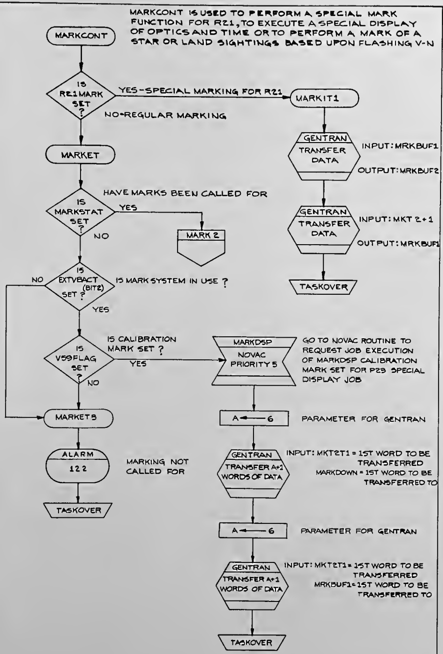
SXTMARK

COLOSSUS IIC

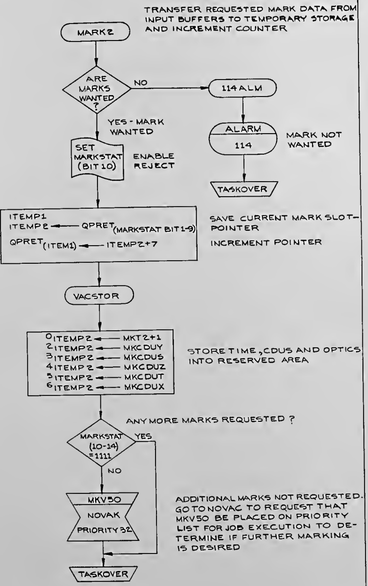
DOCUMENT NO. FC-2240

REV 1

SHEET 4 OF 9



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 31OCT68	SXT MARK
PRGMR [signature] 12MAR69	COLOSSUS IIC
ANALST	DOCUMENT NO. FC-2240
DOCMR G. S. NALLY 12MAR69	REV 1
APPR'D John A. Morse 12MAR69	SHEET 5 OF 5



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

DRAWN
PR. MR
ANALYST
GO MR C. J. NALLY
APPR'D

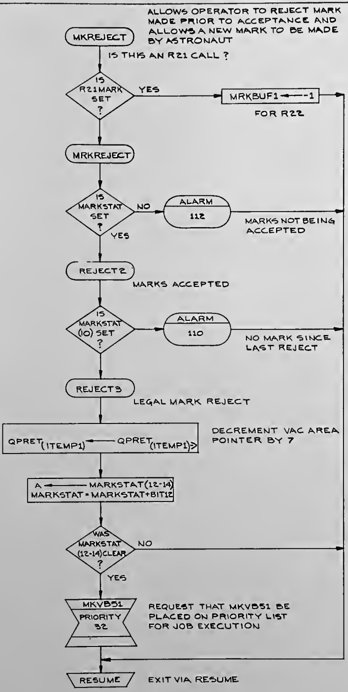
GUIDANCE AND NAVIGATION

SXTMARK

COLOSSUS IIC

DOCUMENT NO FC-2240

REV 1



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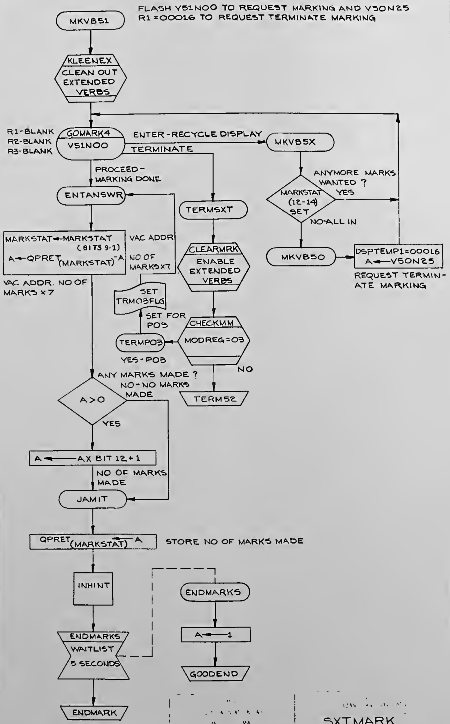
DRAWN [signature] 11 OCT 68	SXTMARK
PRGMR [signature] 12 MAR 69	COLOSSUS IIC
ANALYST	DOCUMENT NO FC-2240
DOCMR G. S. NALLY 12 MAR 69	REV 1
APPR'D [signature] 12 MAR 69	SHEET 7 OF 9



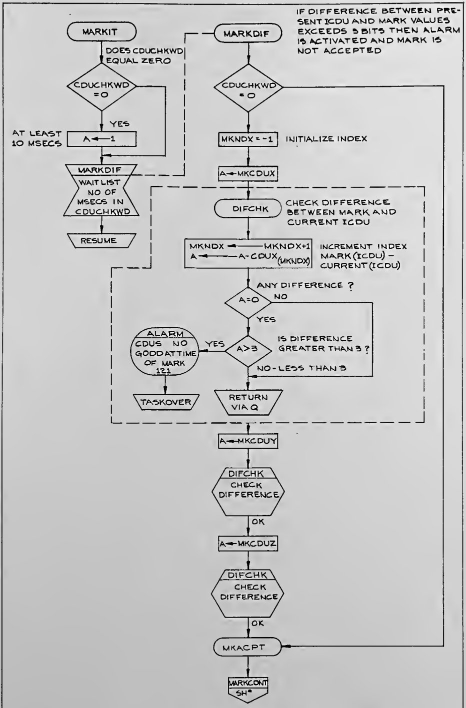
G. S. NALLY 12MAR69

SXTMARK

COLOSSUS IIC

FC-2240

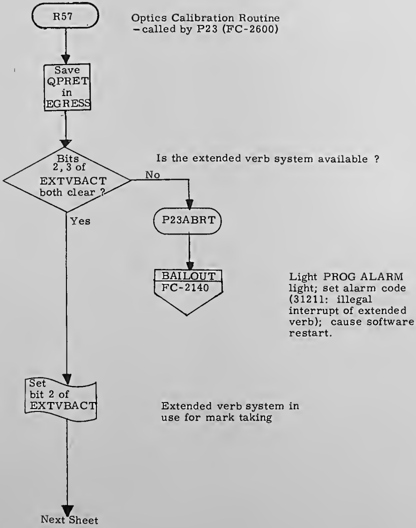
REV 1



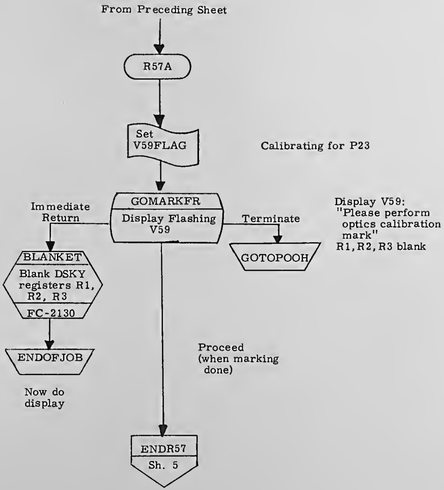
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
	SXTMARK	
DRAWN [signature] 15 OCT 68		
PRGMR [signature] 12 MAR 69	COLOSSUS IIC	DOCUMENT NO. FC-2240
ANALST		
DOCMR G. S. NALLY 12 MAR 69		
APPR'D [signature] 12 MAR 69	REV 1	SHEET 9 OF 9

R57: OPTICS CALIBRATION ROUTINE

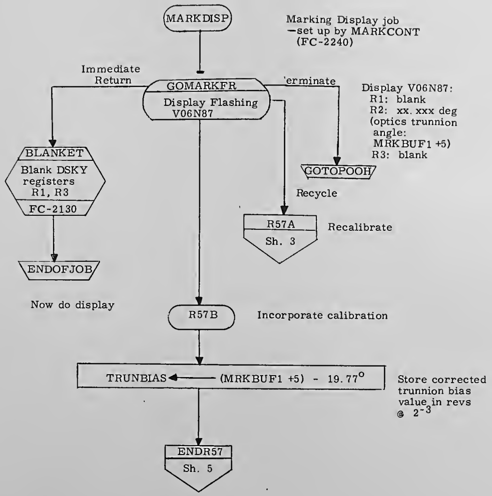
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	8-4-69	R57: Optics Calibration Routine	
PRGMR [signature]	9/8/69		
ANALST		COLOSSUS IIC	DOCUMENT NO. FC-2242
DOCMR			
APPR'D [signature]	9-8-69	REV 1	SHEET 1 OF 7



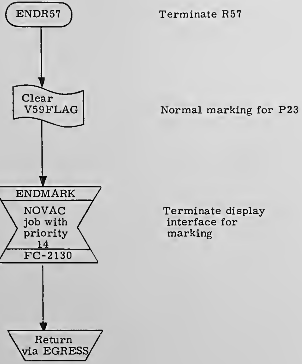
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. Lutkewich	8-06-69	R57: Optics Calibration Routine	
PRGMR R.S. Whittredge	9-4-69	COLOSSUS IIC	DOCUMENT NO. FC-2242
ANALST			
DOCMR			
APPR'D Roberta M. Eaton	9-8-69	REV 1	SHEET 2 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	8-06-?9	R57: Optics Calibration Routine	
PRGMR [illegible]	7-?-6?		DOCUMENT NO.
ANALST		COLOSSUS IIC	FC-2242
DOCMR			
APPR'D [illegible]	9-8-69	REV 1	SHEET 3 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	8 ... 69	R57: Optics Calibration Routine	
PRGMR [signature]	7-8-69		DOCUMENT NO.
ANALST		COLOSSUS IIC	FC-2242
DOCMR			
APPR'D [signature]	9-?-69	REV 1	SHEET 4 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkewich	8-01-69	R57: Optics Calibration Routine	
PRGMR R.S. Millard	[illegible]		DOCUMENT NO.
ANALST		COLOSSUS IIC	FC-2242
DOCMR			
APPR'D Robert M. Evans	8-8-69	REV 1	SHEET 5 OF 7

Subroutines Called which are on Other Flow Charts

Subroutine	Flow Chart	Description	Where Called
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

Verb-Noun	Type of Display	Description of Registers	Where Called
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 D Lutkewich	8-06-69	R57: Optics Calibration Routine	
PRGMR R.S. Whittredge	9-8-69		DOCUMENT NO.
ANALST		COLOSSUS IIC	FC-2242
DOCMR			
APPR'D Roberta M. Estes	9-8-69	REV 1	SHEET 6 OF 7

Flags

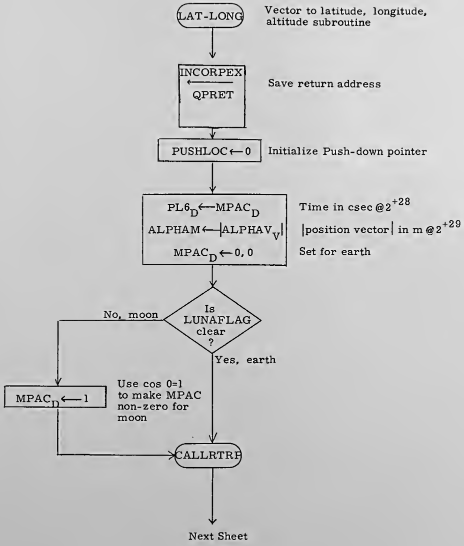
Flag	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
EXTVBACT bit 2	Extended verb system in use for marking	Extended verb system not in use for marking	Sh. 2		Sh. 2
EXTVBACT bit 3	Extended verb system in use for extended verb	Extended verb system not in use for extended verb			Sh. 2
V59FLAG (FLAGWRD5 bit 12)	Calibrating for P23	Normal marking for P23	Sh. 3	Sh. 5	

Erasable Locations Used:

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scale Factor
MRKBUF1 +5	Optics trunnion angle displayed in noun 87	degrees	revs	2^{-3}
TRUNBIAS	Trunnion bias angle	degrees	revs	2^{-3}

LATITUDE LONGITUDE SUBROUTINES

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/7/69	Latitude Longitude Subroutines	
PRGMR			
ANALST J. M. Reber	4.XII.69	COLOSSUS 2D	DOCUMENT NO. FC-2280
DOCMR Roberta M. Entes	12/4/69		
APPR'D Roberta M. Entes	12/4/69	REV	SHEET 1 OF 13



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/9/69	Latitude Longitude Subroutines	
PRGMR			
ANALST J. M. Reber	4. XII. 69	COLOSSUS 2D	DOCUMENT NO. FC-2280
DOCMR Roberta M. Eutes	12/4/69		
APPR'D Roberta M. Eutes	12/4/69	REV	SHEET 2 OF 13

From Preceding Sheet

R-TO-RP
Convert r vector to $\underline{r}_P$ vector
FC-2283

Convert vector in reference coord. system to vector in planetary coord. system

Output: $MPAC_V = \underline{r}_P$ vector
in m @ 2^{+29} for earth
in m @ 2^{+27} for moon

$ALPHAV_V \leftarrow unit(MPAC_V)$

Unit $\underline{r}_P$ @ 2^{+1}

SETGAMMA
Set earth or moon
Sh. 10

Input:
LUNAFLAG:
clear for earth
set for moon

Output:
GAMRP containing
B2/A2 (earth γ) @ 2^{+1}
or 1B1 (=1, moon γ) @ 2^{+1}

SETRE
Set earth or moon radius
Sh. 11

Output:
$ERADM_D$ = earth or moon radius in m @ 2^{+29}

$$\cos(LAT) = \gamma \sqrt{u_0^2 + u_1^2}$$

$$COSTH_D \leftarrow 2^1 \cdot GAMRP \sqrt{(ALPHAV_D)^2 + (ALPHAV + 2_D)^2}$$

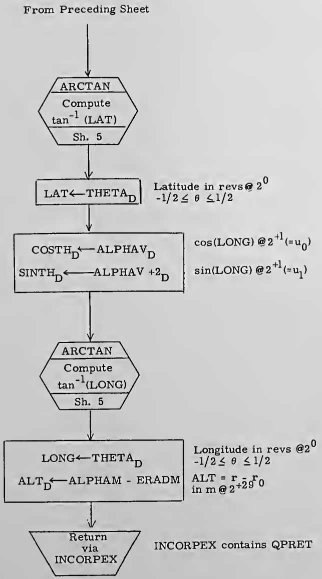
cos(LAT) @ 2^{+1}

$$SINTH_D \leftarrow ALPHAV + 4_D$$

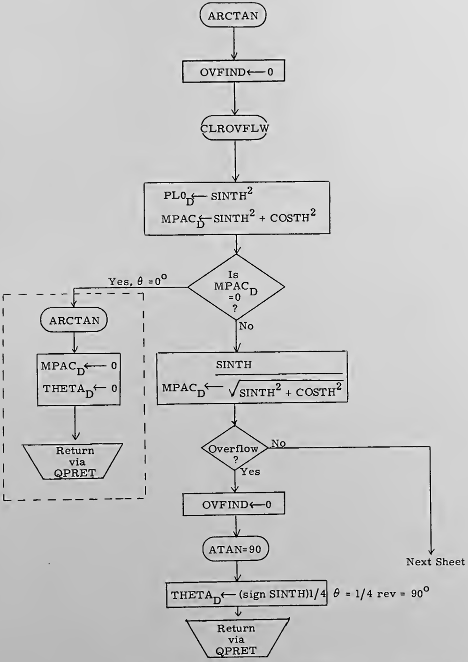
sin(LAT) @ 2^{+1} $(= u_2)$

Next Sheet

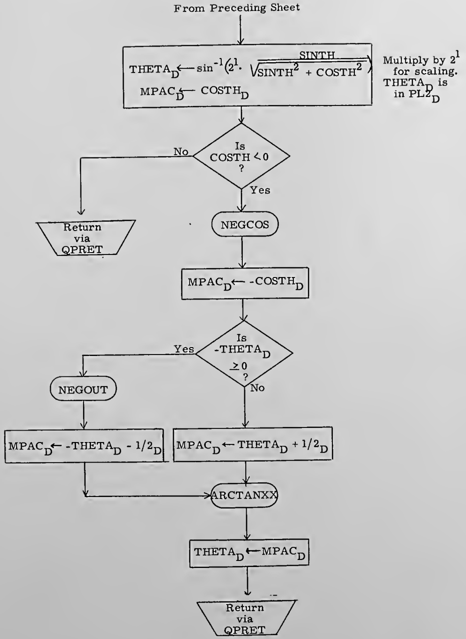
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H Bright	11/2/69	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALST J. M. Reber	4.XII.69		
DOCMR Roberta M. Eaton	12/4/69		
APPR'D Roberta M. Eaton	12/4/69	REV	SHEET 3 OF 13



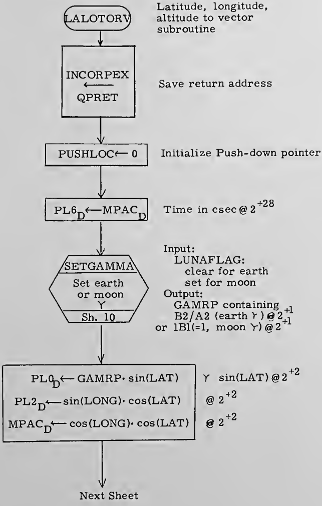
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/7/69	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALST J. M. Reber	4.XII.69		
DOCMR Robert M. Estes	12/4/69		
APPR'D Robert M. Estes	12/4/69	REV	SHEET 4 OF 13



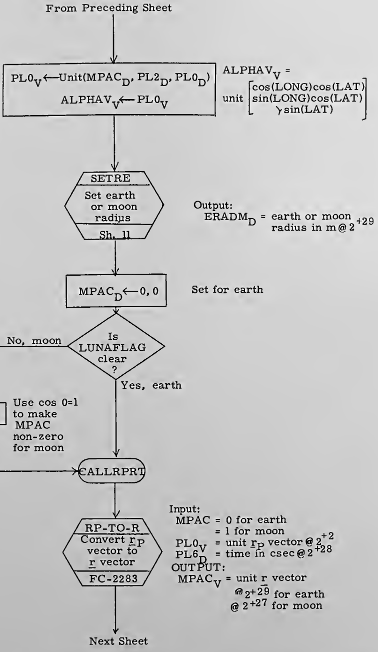
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDA.ICE AND NAVIGATION	
DRAWN H Bright	11/7/67	Latitude Longitude Subroutines	
PRGMR			
ANALST J. M. Reber	4.XII.67	COLOSSUS 2D	DOCUMENT NO. FC-2280
DOCMR Roberta M. Eutas	12/14/67		
APPR'D Roberta M. Eutas	12/14/67	REV	SHEET 5 OF 13



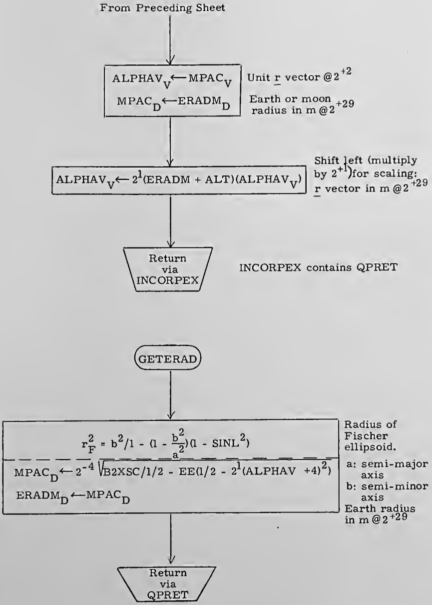
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/7/69	Latitude Longitude Subroutines	
PRGMR			
ANALST J. M. Nolen	4.XII.69	COLOSSUS 2D	DOCUMENT NO. FC-2280
DOCMR Roberta M. Estes	12/4/69		
APPR'D Roberta M. Estes	12/4/69	REV	SHEET 6 OF 13



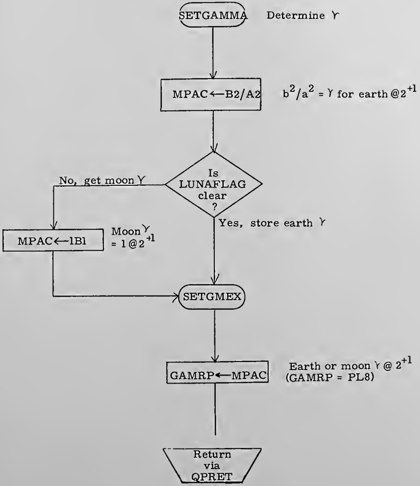
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/7/69	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALST J. M. Reber	4.XII.69		
DOCMR Roberta M. Estes	12/4/69		
APPR'D Roberta M. Estes	12/4/69	REV	SHEET 7 OF 13

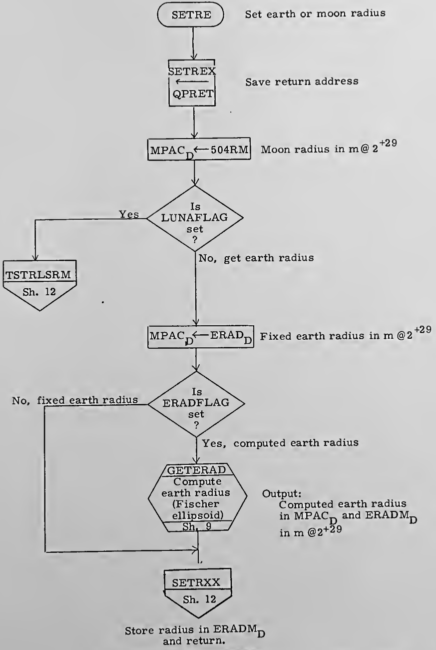


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/3/69	Latitude Longitude Subroutines	
PRGMR			
ANALST J. M. Peters	4.XII.69	COLOSSUS 2D	DOCUMENT NO. FC-2280
DOCMR Roberta M. Estes	12/4/69		
APPR'D Roberta M. Estes	12/4/69	REV	SHEET 8 OF 13

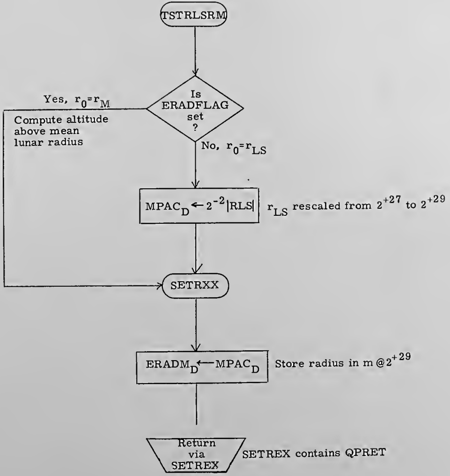


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/7/69	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALST J. M. Reber	4.XII.69		
DOCMR Roberta M. Eaton	12/4/69		
APPR'D Roberta M. Eaton	12/4/69	REV	SHEET 9 OF 13


SETGAMMA
Determine γ
MPAC←B2/A2
b²/a² = γ for earth @2⁺¹
Is LUNAFLAG clear ?
No, get moon γ
Yes, store earth γ
MPAC←1B1
Moon γ = 1@2⁺¹
SETGMEX
GAMRP←MPAC
Earth or moon γ @ 2⁺¹
(GAMRP = PL8)
Return via QPRET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/2/69	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALST J. M. Reber	4.XII.69		
DOCMR Robert M. Estes	12/14/69		
APPR'D Robert M. Estes	12/14/69	REV	SHEET 11 OF 13



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	11/7/69	Latitude Longitude Subroutines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2280
ANALST J. M. Peker	4.XII.69		
DOCMR Roberta M. Estes	12/4/69		
APPR'D Roberta M. Estes	12/4/69	REV	SHEET 12 OF 13

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

PLANTEARY INERTIAL ORIENTATION SUBROUTINE (PIOS)

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

1. GUIDANCE SYSTEM OPERATIONS PLAN USING PROGRAM COLOSSUS 2C (GSOP), R-557, SECTION 5, GUIDANCE EQUATIONS, (REV. 8), JULY 1969

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstein	[illegible]	PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2283
ANALST			
DOCMR			
APPR'D		REV	SHEET 1 OF 9

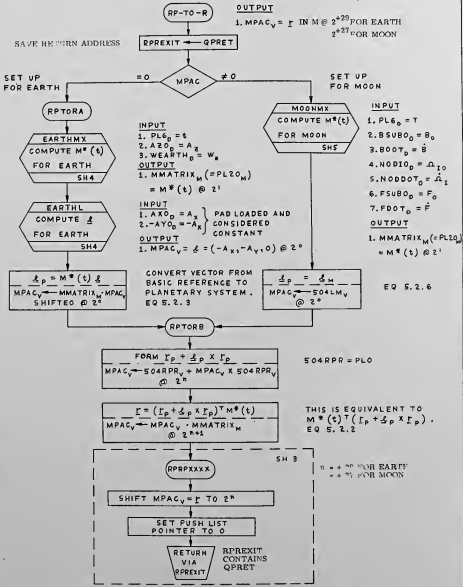
RP-TO-P CONVERTS $\underline{r}_P$, A VECTOR EXPRESSED IN THE PLANETARY (EARTH FIXED OR MOON FIXED) COORDINATE SYSTEM TO $\underline{r}$, THE SAME VECTOR EXPRESSED IN THE BASIC REFERENCE COORDINATE SYSTEM

INPUT:

1. MPAC = { = 0 FOR EARTH; ≠ 0 FOR MOON
2. $PLO_V = \underline{r}_P$ @ 2^n
3. $PL6_D$ = t, TIME OF $\underline{r}_P$, IN CSEC AT 2^{28}

OUTPUT

1. $MPAC_V = \underline{r}$ IN M @ 2^{+29} FOR EARTH, 2^{+27} FOR MOON



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]		PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2283
DOCMR			
APPR'D		REV	SHEET 2 OF 9

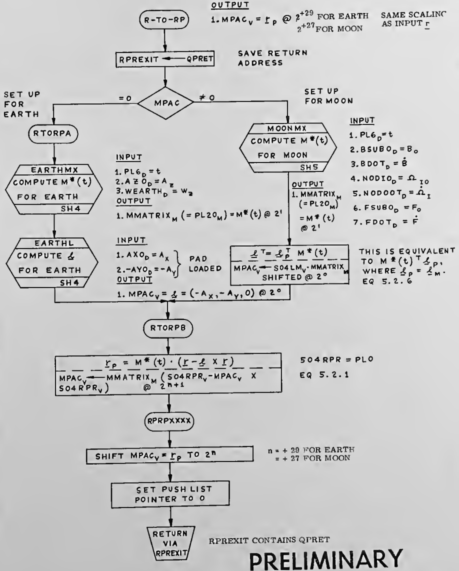
R-TO-RP CONVERTS $\underline{r}$, A VECTOR EXPRESSED IN THE BASIC REFERENCE COORDINATE SYSTEM TO $\underline{r}_p$, THE SAME VECTOR EXPRESSED IN THE PLANETARY (EARTH FIXED OR MOON FIXED) COORDINATE SYSTEM.

INPUT

1. MPAC = { = 0 FOR EARTH; ≠ 0 FOR MOON }
2. $PLO_V = \underline{r}$ @ 2^n
3. $PL6_D$ = t, TIME OF $\underline{r}$, IN CSEC, AT 2^{28}

OUTPUT

1. $MPAC_V = \underline{r}_p$ @ 2^{+29} FOR EARTH, 2^{+27} FOR MOON — SAME SCALING AS INPUT $\underline{r}$



PRELIMINARY

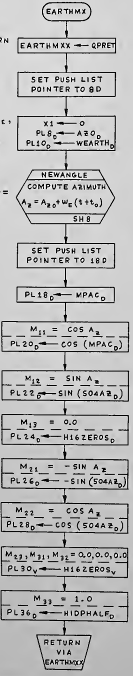
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN *J. Goldstein*	12/7/67	PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR		COLOSSUS 2D	DOCUMENT NO. Fc-2283
ANALST			
DOCMR			
APPR'D		REV	SHEET 3 OF 9

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. $PL6_D$ = t, TIME SINCE AGC CLOCK WAS ZEROED, IN CSEC AT 2^{28}.
2. $AZ0_D = A_{z0}$, ANGLE BETWEEN X-AXIS OF BASIC SYSTEM AND X-AXIS OF EARTH SYSTEM AT JULY 1.0, 1968
3. $WEARTH_D = w_E$, ANGULAR VELOCITY OF EARTH IN REVS/CSEC AT 2^{-23}
4. $TIMSUB0_T = t_0$, ELAPSED TIME FROM JULY 1.0, 1968 TO ZEROING OF AGC CLOCK, IN CSEC AT 2^{28}

OUTPUT
1. $MMATRIX_M (= PL20_M) = M^*(t)$ AT 2^1 WHERE

$$M^*(t) = \begin{bmatrix} \cos A_z & \sin A_z & 0 \\ -\sin A_z & \cos A_z & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



SAVE RETURN ADDRESS

LOAD A_{z0}, w_E, AND SHIFT VALUE FOR NEWANGLE

TIMSUB0 = TEPHEM

504AZ = PL18

EARTHMXX CONTAINS QPRET

INPUT
1. $PL8_D = A_{z0}$ IN REVS AT 2^0
2. $PL10_D = w_z$ IN REVS/CSEC AT 2^{-23}
3. X1 = 0, SHIFT VALUE
4. $PL6_D$ = t IN CSEC AT 2^{28}
5. $TIMSUB0_D = t_0$ IN CSEC A 2^{28}

OUTPUT
1. $MPAC_D = A_z$ IN REV AT 2^0 AT TIME t

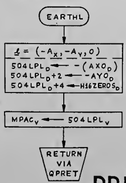
STORE A_z IN TEMPORARY STORAGE

M_{11} THROUGH M_{33} ARE THE ELEMENTS OF MATRIX M*(t)

EARTHL COMPUTES THE ROTATION VECTOR ℓ FOR EARTH IN THE BASIC REFERENCE COORDINATE SYSTEM.

INPUT
1. $AX0_D = A_x$ IN REVS AT 2^0
2. $-AY0_D = -A_Y$ IN REVS AT 2^0

OUTPUT
1. $MPAC_V = \ell = (-A_x, A_Y, 0)$ AT 2^0



EQ 5.2.3
A_x AND A_Y (AND HENCE ℓ) ARE CONSIDERED CONSTANT THROUGHOUT THE MISSION

LOAD ℓ

PRELIMINARY

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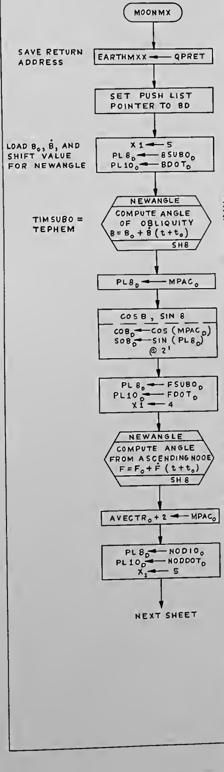
DRAWN [signature]	PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR		
ANALST	COLOSSUS 2D	DOCUMENT NO. FC-2283
DOCMR		
APPR'D	REV	SHEET 4 OF 9

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

1. $PL6_D = t$, TIME SINCE AGC CLOCK WAS ZEROED, IN CSEC AT 2^{28}
2. $TIMSUBO_T = t_0$, ELAPSED TIME FROM JULY 1.0, 1968 TO ZEROING OF AGC CLOCK, IN CSEC AT 2^{28}
3. $BSUBO_D = B_0$
4. $BDOT_D = \dot{B}$ } ANGLE AND IT'S DERIVATIVE BETWEEN EARTH'S EQUATORIAL PLANE AND THE ECLIPTIC AT JULY 1.0, 1968.
5. $NODIO_D = \Omega_{I0}$
6. $NODDOT_D = \dot{\Omega}_I$ } LONGITUDE OF NODE OF MOONS ORBIT AND DERIVATIVE, IN BASIC SYSTEM AT JULY 1.0, 1968
7. $FSUBO_D = F_0$
8. $FDOT_D = \dot{F}$ } ANGLE MEAN ASCENDING NODE OF MOON'S ORBIT AND DERIVATIVE AT JULY 1.0, 1968

OUTPUT

1. $MMATRIX_M$ ($= PL20_M$) $= M^*(t)$ AT 2^1

INPUT

1. $PL8_D = B_0$ IN REVS AT 2^0
2. $PL10_D = \dot{B}$ IN REVS/CSEC AT 2^{-28}
3. X1 = 5, SHIFT VALUE
4. $PL6_D = t$ IN CSEC AT 2^{28}
5. $TIMSUBO_D = t_0$ IN CSEC AT 2^{28}

OUTPUT

1. $MPAC_D = B$ IN REVS AT 2^0 AT TIME t

STORE B IN TEMPORARY STORAGE

LOAD F_0, $\dot{F}$, AND SHIFT VALUE FOR NEWANGLE

INPUT

1. $PL8_D = F_0$ IN REVS AT 2^0
2. $PL10_D = \dot{F}$ IN REVS/CSEC AT 2^{-27}
3. X1 = 4, SHIFT VALUE
4. $PL6_D = t$ IN CSEC AT 2^{28}
5. $TIMSUBO_0 = t_0$ IN CSEC AT 2^{28}

OUTPUT

1. $MPAC_D = F$ IN REVS AT 2^0 AT TIME t

SAVE F IN TEMPORARY STORAGE. AVECTR + 2 = PL22

LOAD Ω_{I0}, $\dot{\Omega}_I$, AND SHIFT VALUE FOR NEWANGLE

PRELIMINARY

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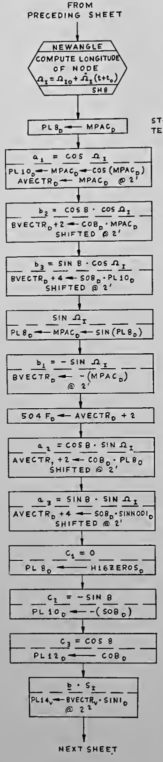
DRAWN [signature]	[date]	PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2283
DOCMR			
APPR'D		REV	SHEET 5 OF 9



INPUT

1. $PL8_D = \Omega_{I0}$ IN REVS AT 2^0
2. $PL10_D = \dot{\Omega}_I$ IN REVS/CSEC AT 2^{-28}
3. X1 = 5, SHIFT VALUE
4. $PL6_D = t$ IN CSEC AT 2^{28}
5. TIMSUBO = t_0 IN CSEC AT 2^{28}

OUTPUT

1. $MPAC_D = \Omega_I$ IN REVS AT 2^0 AT TIME t

STORE Ω_I IN TEMPORARY STORAGE

STORE F IN TEMPORARY STORAGE
504F = PL6

SINNODI = PL8

CVECTR = PL8

PRELIMINARY

$S_I = \sin I$, $C_I = \cos I$, WHERE $I = 1^\circ 32.1'$, THE CONSTANT ANGLE BETWEEN THE LUNAR EQUATORIAL PLANE AND THE PLANE OF THE ECLIPTIC

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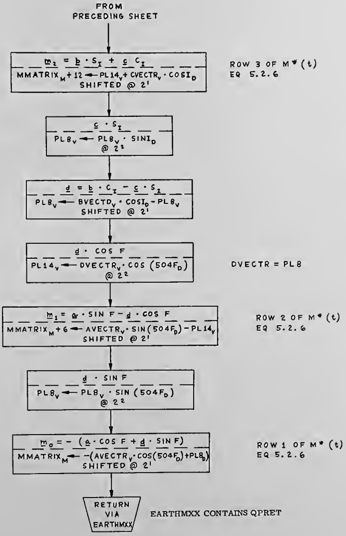
DRAWN L. Johnston	[illegible]	PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2283
ANALST			
DOCMR			
APPR'D		REV	SHEET 6 OF 0



PRELIMINARY

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DRAWN	[signature]	PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR			
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DOCMR			
APPR'D		REV	SHEET 7 OF 9

NEWANGLE IS A GENERAL PURPOSE SUBROUTINE FOR EVALUATING THE FUNCTION:

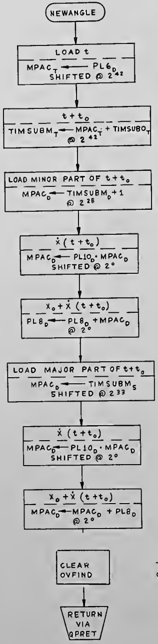
$$x = x_0 + \dot{x}\,(t + t_0)$$

INPUT

1. $PL8_D = x_0$ IN REVS AT 2^0
2. $PL10_D = \dot{x}$ IN REVS/CSEC AT $2^{-22}/2^{-28}/2^{-27}$
3. X1 = SHIFT VALUE OF 0/5/4 CORRESPONDING TO $\dot{x}$ SCALING
4. $PL6_D = t$, TIME IN CSEC AT 2^{28}
5. $TIMSUBO_T = t_0$, TIME IN CSEC AT 2^{42}

OUTPUT

1. $MPAC_D = x$ IN REVS AT 2^0



TIMSUBM = PL14

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

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DRAWN	[illegible] 12/2/69	PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2283
ANALST			
DOCMR			
APPR'D		REV	SHEET 8 OF 9

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$HI6ZEROS_V$		THE VECTOR (0, 0, 0)	(0, 0, 0)	(0, 0, 0)	2^0
$HIDPHALF_D$		THE NUMBER 1	1.0	0.5	2^1
$NODIO_D$	Ω_{IO}	LONGITUDE OF NODE OF LUNAR ORBIT IN BASIC REFERENCE SYSTEM, AT JULY 1.0, 1988	-6.03249419 RADS	-.960101269 REVS	2^0
$NODDOT_D$	$\dot{\Omega}_I$	DERIVATIVE OF LONGITUDE OF NODE	-1.07047016 E-8 RAD/SEC	-.457335143 E-2 REV/CSEC	2^{-28}
$FSUBO_D$	F_O	ANGLE FROM MEAN ASCENDING NODE OF LUNAR ORBIT TO THE MOON, AT JULY 1.0, 1968	2.61379488 RADS	.415998375 REVS	2^0
$FDOT_D$	$\dot{F}$	DERIVATIVE OF ANGLE F	2.67240019 E-6 RAD/SEC	.570862491 REV/CSEC	2^{-27}
$BSUBO_D$	B_O	OBLIQUITY, ANGLE BETWEEN MEAN EARTH EQUATORIAL PLANE AND ECLIPTIC, AT JULY 1.0, 1968	.409164173 RADS	.0651205006 REVS	2^0
$BDOT_D$	$\dot{B}$	DERIVATIVE OF OBLIQUITY B	-7.19756666 E-14 RAD/SEC	-3.07500412 E-8 REV/CSEC	2^{-28}
$WEARTH_D$	ω_E	ANGULAR VELOCITY OF THE EARTH	7.29211515 E-5 RAD/SEC	.973561855 REV/CSEC	2^{-23}
$COSI_D$	C_1	COS I } WHERE I IS ANGLE BETWEEN MEAN LUNAR EQUATORIAL PLANE AND ECLIPTIC (1°32.1′)	.99964115	SAME	2^1
SIN1	S_I	SIN 1 } (see above)	.02678760	SAME	2^I

PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
$504LM_V$	$\underline{l}_M$	VECTOR LIBRATION I_P IN MOON SYSTEM		RADS	2^0	
AXO_D	A_X	ANGLES ABOUT X- AND Y- AXES OF BASIC SYSTEM DESCRIBING PRECESSION AND NUTATION	4.652459×10^{-5} RADS	RADS	2^0	
$-AYO_D$	$-A_Y$	(see above)	$2.147535 \cdot 10^{-5}$ RADS	RADS	2^0	
AZO_D	A_Z	ANGLE BETWEEN X-AXIS OF BASIC SYSTEM AND EARTH SYSTEM, JULY 1.0, 1968	.7753206164 REVS	REVS	2^0	

PRELIMINARY

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DRAWN J. Gilbertson	4/6/65	PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2283
ANALST			
DOCMR			
APPR'D		REV	SHEET 9 OF 9

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

VESO - 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

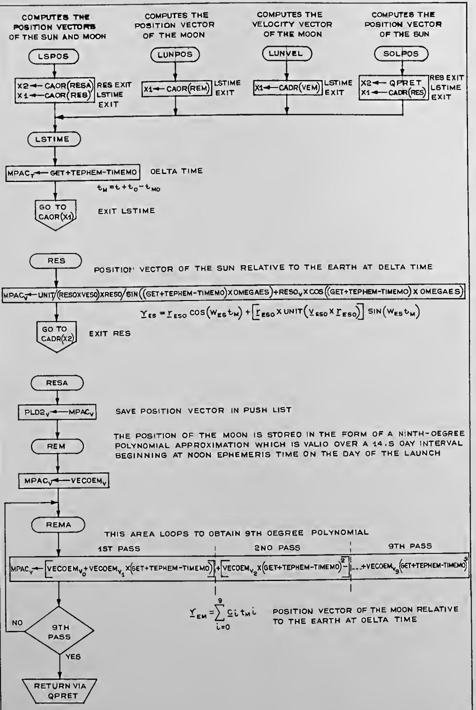
LUNVEL

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

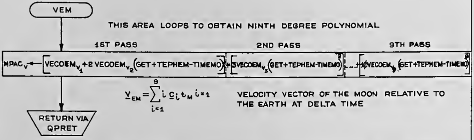
NOTE: ALL INPUT EXCEPT GET IS INCLUDED IN THE PRE-LAUNCH ERASABLE DATA LOAD.



LSPOS, LUNPOS, LUNVEL, SOLPOS LUNAR AND SOLAR EPHEMERIDES SUBROUTINES

COLOSSUS II FC-2286

2 3



$$\underline{V}_{EM} = \sum_{i=1}^{9} i\, \underline{C}_i\, t_M^{\,i-1}$$

VELOCITY VECTOR OF THE MOON RELATIVE TO THE EARTH AT DELTA TIME

THIS DIAGRAM ILLUSTRATES HOW THE POSITION OF THE SUN IS ARRIVED AT

R_{ESO_V} = POSITION VECTOR OF SUN AT T_0

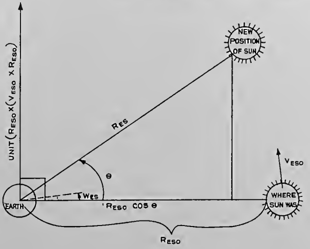
V_{ESO_V} = VELOCITY VECTOR OF SUN AT T_0

$\theta = W_{ES} \cdot \Delta t$

$RES = R_{ESO}\ \cos\theta\,[\text{UNIT RESO}] + \text{RESO}\ \sin\theta\,(K)$

WHERE $K = \text{UNIT}\left[R_{ESO} \times (V_{ESO} \times R_{ESO})\right]$

$= R_{ESO}\ \cos\theta + \left[R_{ESO} \times \text{UNIT}(V_{ESO} \times R_{ESO})\right] \sin\theta$



MIT INSTRUMENTATION LAB, CAMBRIDGE, MASS.	LSPOS, LUNPOS, LUNVEL, SOLPOS LUNAR AND SOLAR EPHEMERIDES SUBROUTINES
DRAWN P. M. Dietor 26NOV68	
PRGMR P. White 21FEB69	
ANALYST	COLOSSUS II FC-2286
DEV MGR S. J. Nolley ... 69	
APPRD John A. Mass 21FEB69	3 · 3

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS		
STATINT1	POO: PRECISION INTEGRATES BOTH STATE VECTORS TO WITHIN 10 MINUTES OF CURRENT TIME	SH. 3
STATINT	SCHEDULES STATINT1	SH. 3
ATOPCSM	UPDATE PERMANENT CSM STATE VECTOR	SH. 5
ATOPLEM	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
INTEGRVS	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, FC#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.

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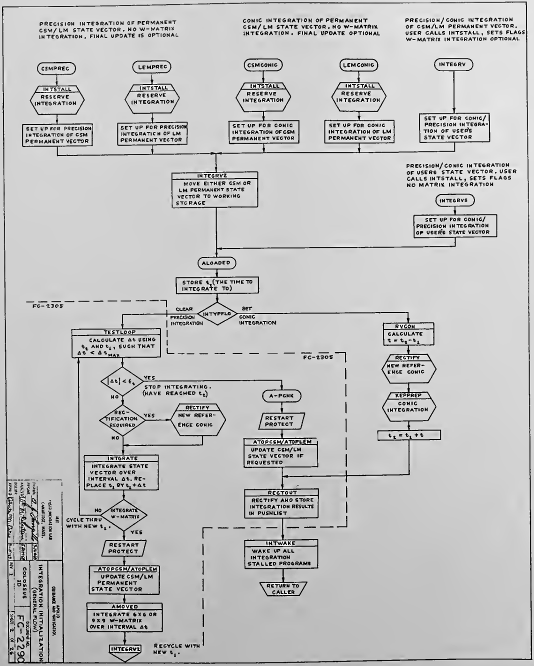
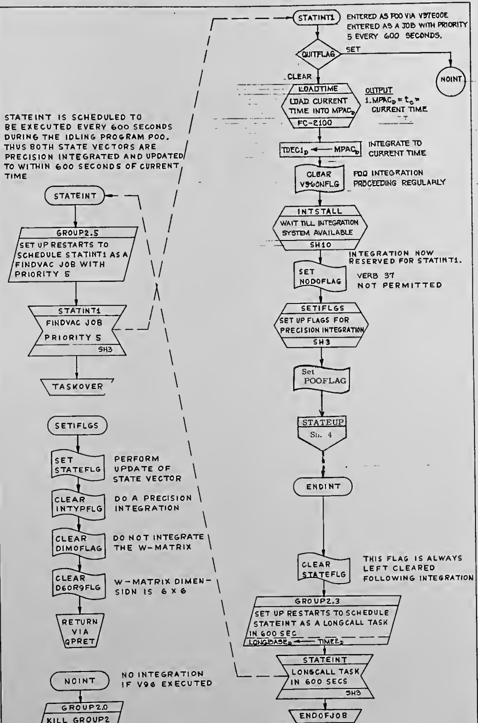
DRAWN A. Welch	12/4/69	INTEGRATION INITIALIZATION	
PRGMR			
ANALST Wm M. Robertson	12/4/69		DOCUMENT NO.
DOCMR Roberta M. Enter	12/4/69	COLOSSUS 2D	FC-2290
APPR'D Roberta M. Enter	12/4/69	REV 1	SHEET 1 OF 26


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 INTSTALL, SETS FLAGS W-MATRIX INTEGRATION OPTIONAL
CSMPREC
LEMPREC
CSMCONIC
LEMCONIC
INTEGRV
INTSTALL
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
INTEGRV2
MOVE EITHER CSM OR LM PERMANENT STATE VECTOR TO WORKING STORAGE
PRECISION/CONIC INTEGRATION OF USERS STATE VECTOR. USER CALLS INTSTALL, SETS FLAGS NO MATRIX INTEGRATION
INTEGRVS
SET UP FOR CONIC/ PRECISION INTEGRATION OF USER'S STATE VECTOR
ALOADED
STORE t2 (THE TIME TO INTEGRATE TO)
FC-2305
CLEAR PRECISION INTEGRATION
INTYPFLG
SET CONIC INTEGRATION
TESTLOOP
CALCULATE Δt USING t2 AND t1, SUCH THAT Δt < Δt MAX
RVCON
CALCULATE t = t2 - t1
RECTIFY
NEW REFERENCE CONIC
KEPPREP
CONIC INTEGRATION
t2 = t1 + t
FC-2305
|Δt| < ε1
YES
STOP INTEGRATING. (HAVE REACHED t2)
NO
A-PCHK
RECTIFICATION REQUIRED
YES
NO
RECTIFY
NEW REFERENCE CONIC
RESTART PROTECT
ATOPCSM/ATOPLEM
UPDATE CSM/LM STATE VECTOR IF REQUESTED
INTGRATE
INTEGRATE STATE VECTOR OVER INTERVAL Δt. REPLACE t1 BY t1 + Δt
RECTOUT
RECTIFY AND STORE INTEGRATION RESULTS IN PUSHLIST
NO
INTEGRATE W-MATRIX
YES
CYCLE THRU WITH NEW t1.
INTWAKE
WAKE UP ALL INTEGRATION STALLED PROGRAMS
RETURN TO CALLER
RESTART PROTECT
ATOPCSM/ATOPLEM
UPDATE CSM/LM PERMANENT STATE VECTOR
AMOVED
INTEGRATE 6X6 OR 9X9 W-MATRIX OVER INTERVAL Δt
INTEGRV2
RECYCLE WITH NEW t1.
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.
APOLLO GUIDANCE AND NAVIGATION
INTEGRATION INITIALIZATION (GENERAL FLOW)
COLOSSUS 2D
DOCUMENT NO. FC-2290
REV 1
SHEET 2 OF 26



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN	G. J. Langille	5 NOV 68
PRGMR		
ANALST	Wm. M. Robertson	5 SEPT 69
DOC MR		
APPR'D	Roberta M. Eaton	9-5-69

APOLLO
GUIDANCE AND NAVIGATION

INTEGRATION INITIALIZATION

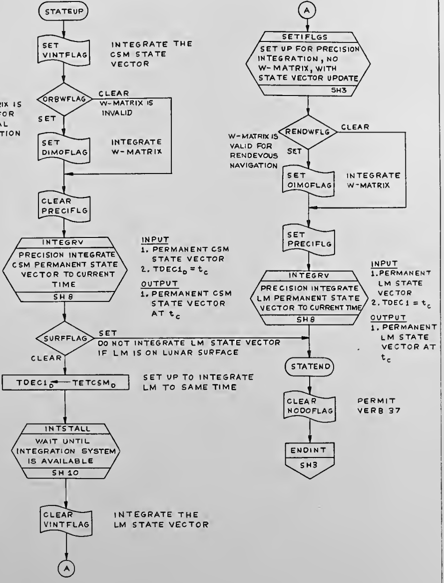
COLOSSUS 2D

REV 1

DOCUMENT No. FC-2290

SHEET 3 OF 26

STATEUP DOES THE P00 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.



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

A. J. Langillo 4JUN69

Wm. M. Robertson 5 SEPT 69

Robert M. Cutts 9-5-69

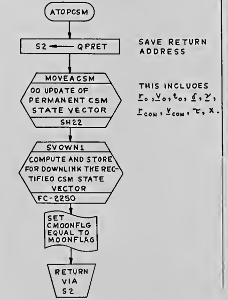
INTEGRATION INITIALIZATION

COLOSSUS 2D

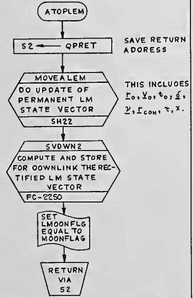
FC-2290

1 4 26

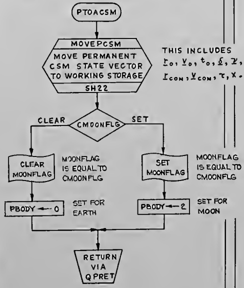
PERFORM AN UPDATE OF PERMANENT CSM STATE VECTOR AND FLAG CMOONFLG



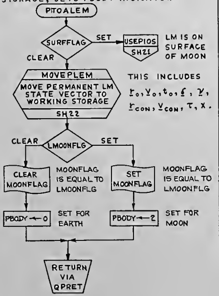
PERFORMS AN UPDATE OF PERMANENT LM STATE VECTOR AND FLAG LMOONFLG



MOVES PERMANENT CSM STATE VECTOR AND FLAG CMOONFLG TO WORKING STORAGE, SETS PBODY INDICATOR

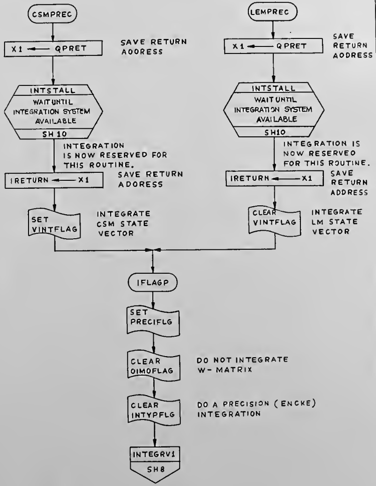


MOVES PERMANENT LM STATE VECTOR AND FLAG LMOONFLG TO WORKING STORAGE, SETS PBODY INDICATOR



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Longille	5 NOV 68	INTEGRATION INITIALIZATION
PRGMR		
ANALST Wm. M. Robertson	5 SEPT 69	COLOSSUS 2D
DOCMR		DOCUMENT NO. FC-2290
APPR'D Robert M. Covey	9-5-69	REV 1 — SHEET 5 OF 26

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 $TDEC1_D = t_2$. THE ENTRIES AUTOMATICALLY LOAD THE APPROPRIATE STATE VECTOR AND TIME OF VALIDITY FROM PERMANENT STORAGE INTO RCV_V, VCV_V AND TET_D. 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_D.



MIT INSTRUMENTATION LAB CAMBRIDGE, MA

DRAWN A. J. Langello 6NOV68

APPROVED Wm. M. Robertson 5SEPT69

APPROVED Robert M. Estes 9-5-69

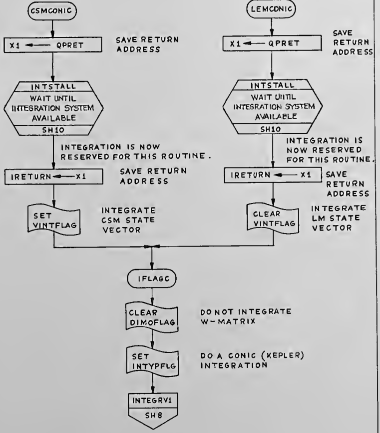
INTEGRATION INITIALIZATION

COLOSSUS 2D

FC-2290

6 - 26

CSMCONIC AND LEMCONIC ARE ENTRIES TO THE INTEGRATION ROUTINE FOR PERFORMING ORBIT 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 TDEC1 = t_2. THE ENTRIES AUTOMATICALLY LOAD THE APPROPRIATE STATE VECTOR AND TIME OF VALIDITY FORM PERMANENT STORAGE INTO RCV_V, VCV_V AND TET_D. 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_D.



MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS

DRAWN	A. J. Engelle	6NOV68
PROGMR		
ANALYST	Wm. M. Robertson	5SEP69
CHK MR		
APPR'D	Robert M. [illegible]	9-5-69

INTEGRATION INITIALIZATION

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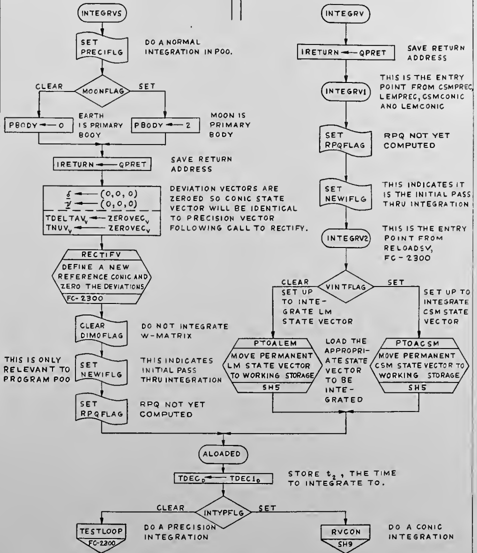
FC-2290

REV 1 7 26

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_V, VCV_V AND TET_D. THE TIME TO INTEGRATE TO MUST BE LOADED IN $TDEC1_D = t_2$.

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, D6OR9FLG AND STATEFLG. THE TIME TO INTEGRATE TO MUST BE LOADED IN $TDEC1_D = t_2$. THIS ENTRY LOADS THE APPROPRIATE STATE VECTOR AND TIME FROM PERMANENT STORAGE INTO RCV_V, VCV_V AND TET_D. THIS IS THE ONLY ENTRY THAT PERMITS W-MATRIX INTEGRATION AS AN OPTION. THIS ENTRY IS USED GENERALLY BY THE NAVIGATION PROGRAMS.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS

DRAWN A. J. Longitto 7 NOV 68

A. Wm. M. Robertson 5 SEPT 69

Roberta M. Cutts 9-5-69

INTEGRATION INITIALIZATION

COLOSSUS 2D

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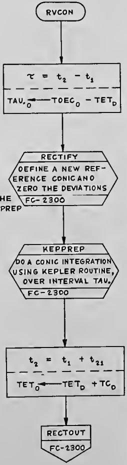
6 26

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 CSMCONIC OR LEMCONIC WAS CALLED OR IF INTEGRVS OR INTEGRV WAS CALLED WITH INTYPFLG SET.



$TAU._0$ IS INPUT TO KEPPREP
TET_D IS TIME OF VALIDITY OF PRESENT CONIC STATE VECTOR $\underline{r}_{CON}$, $\underline{v}_{CON}$
$TDEC_D$ IS TIME TO INTEGRATE TO

THE STATE VECTOR MUST BE RECTIFIED PRIOR TO THE CALL TO KEPPREP

INPUT
1. $RCV_V = \underline{r}_{CON}$
2. $VCV_V = \underline{v}_{CON}$
3. $TDELTAV_V = \underline{\delta}$
4. $TNUV_V = \underline{\nu}$
5. X2 = PBODY

OUTPUT
1. $RRECT_V = \underline{r}_0 = \underline{r}_{CON} + \underline{\delta}$
2. $VRECT_V = \underline{v}_0 = \underline{v}_{CON} + \underline{\nu}$
3. $RCV_V = \underline{r}_{CON}$ = NEW $\underline{r}_0$
4. $VCV_V = \underline{v}_{CON}$ = NEW $\underline{v}_0$
5. $TDELTAV_V = \underline{\delta} = (0,0,0)$
6. $TNUV_V = \underline{\nu} = (0,0,0)$
7. $TC_D = \tau = 0$
8. $XKEP_D = X = 0$

INPUT
1. $RCV_V = \underline{r}_{CON}$
2. $VCV_V = \underline{v}_{CON}$
3. $TAU._D = t_D \; (=t_{21})$
4. $XKEP_D = X'$
5. $TC_D = t'_{21}$
6. PBODY = 0 FOR EARTH, = 2 FOR MOON
7. MOONFLAG : CLEAR FOR EARTH, SET FOR MOON.

OUTPUT:
1. $RCV_V = \underline{r}(t_2)$
2. $VCV_V = \underline{v}(t_2)$
3. $TC_D = t_2$ = TIME TO WHICH ITERATION CONVERGED $\approx t_D$
4. $XPREV_D = X' = XKEP_D$

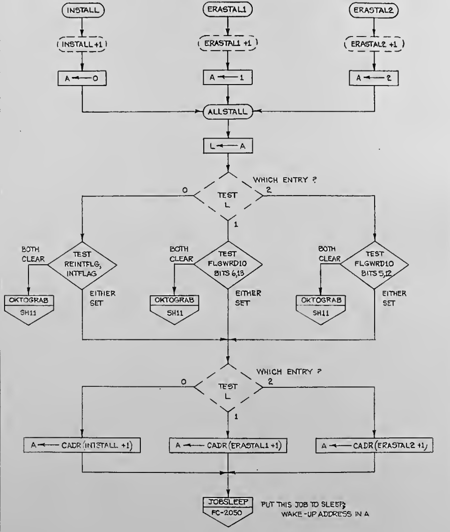
NOTE: OUTPUT IS FOR ENTIRE KEPPREP AND KEPLERN COMPUTATIONS (SEE FC-2310, CONIC SUBROUTINES).

COMPUTE THE TIME OF VALIDITY OF THE KEPLER OUTPUT $\underline{r}_{CON}$, $\underline{v}_{CON}$. $TC_D = t_{21}$ IS THE TIME INCREMENT THAT KEPLER ACTUALLY INTEGRATED OVER

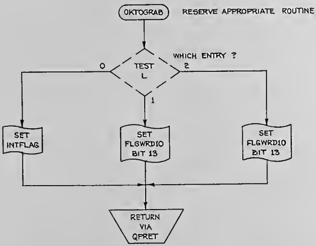
RECTOUT COMPLETES THE INTEGRATION PROCEDURE BY RECTIFYING, STORING THE STATE VECTOR INTO THE OUTPUT LOCATIONS, SETTING APPROPRIATE FLAGS, AND GOING TO INTWAKE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN G. J. Levy [signature] 7 NOV 68	INTEGRATION INITIALIZATION
PPGMR	
ANALST Wm. M. Robertson [signature] 5 SEPT 69	COLOSSUS 2D — DOCUMENT No. FC-2290
DOCMR	
APPR'D Robert M. Estes [signature] 19-5-69	REV 1 — 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.

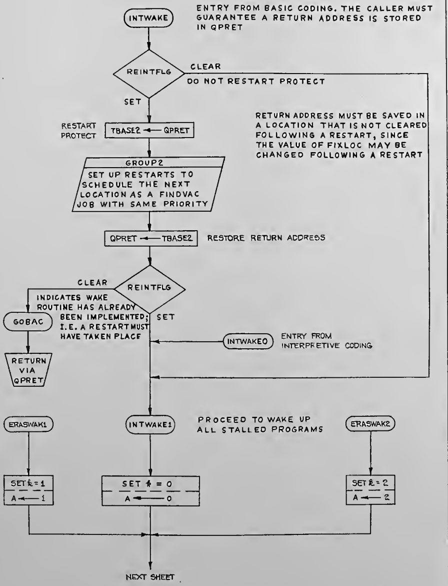


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 20JUN69	INTEGRATION INITIALIZATION
PRGMR	
ANALYST Wm M. Robertson 5 SEPT 69	COLOSSUS 2D ; DOCUMENT FC-2290
DOC MR	
APPR'D Robert M. Estes 9-5-69	REV 1 SHEET 10 OF 26



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 20JUN69	INTEGRATION INITIALIZATION
PRGMR	
ANALST Wm M. Robertson 5 SEPT 69	COLOSSUS 2D — DOCUMENT NO FC-2290
DOC MR	
APPR'D 9-5-69	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 INTSTALL.



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN: A. J. Sangillo
ANALYST: Wm. M. Robertson 5 SEPT 69
APPR: Robert M. Estes 9-6-69

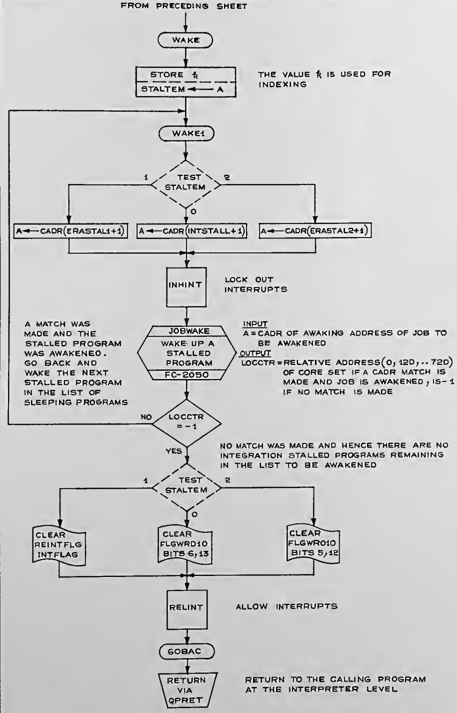
INTEGRATION INITIALIZATION

COLOSSUS 2D

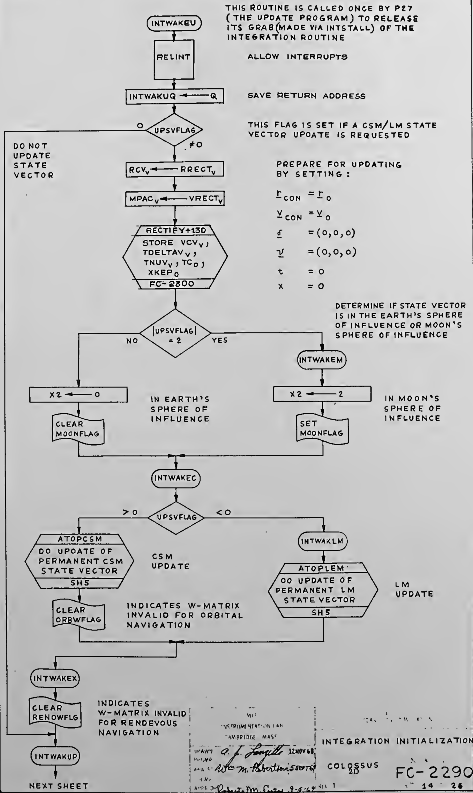
REV 1

FC-2290

SHEET 12 OF 26



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietrich 25JUNE69	INTEGRATION INITIALIZATION
ANALYST Wm. M. Robertson 5 SEPT69	COLOSSUS 2D — DOCUMENT NO FC-2290
APPR'D Roberta M. Eaton 19-5-69	REV 1 — SHEET 13 OF 26



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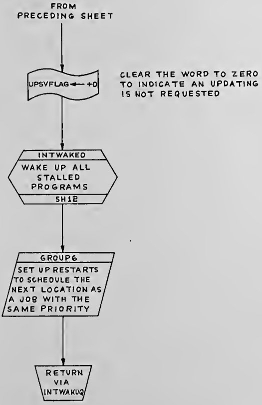
DRAWN A. J. Lanzillo 12NOV68
APPD Wm. M. Robertson 5SEP69
APPD Robert M. Cutler 9-5-69

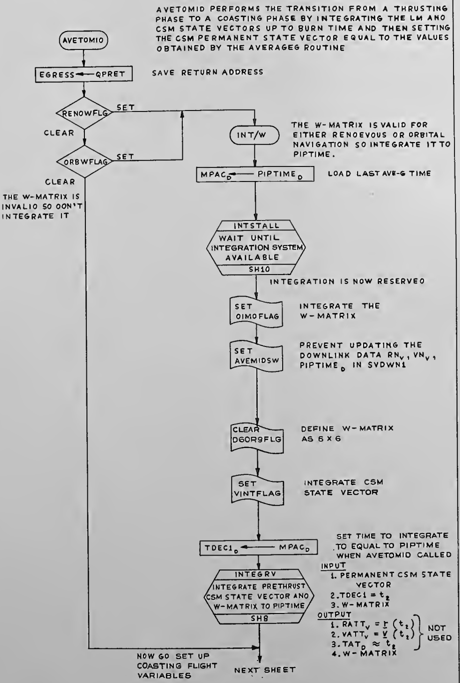
INTEGRATION INITIALIZATION

COLOSSUS 2D

FC-2290

14 26


FROM
PRECEDING SHEET
UPSVFLAG ← +0
CLEAR THE WORD TO ZERO
TO INDICATE AN UPDATING
IS NOT REQUESTED
INTWAKE0
WAKE UP ALL
STALLED
PROGRAMS
SH12
GROUP6
SET UP RESTARTS
TO SCHEDULE THE
NEXT LOCATION AS
A JOB WITH THE
SAME PRIORITY
RETURN
VIA
INTWAKUQ



INTEGRATION INITIALIZATION

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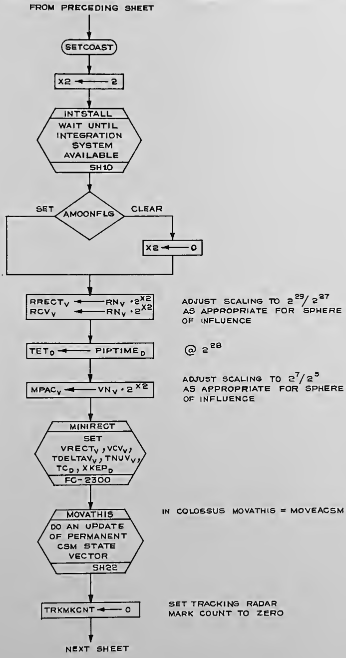
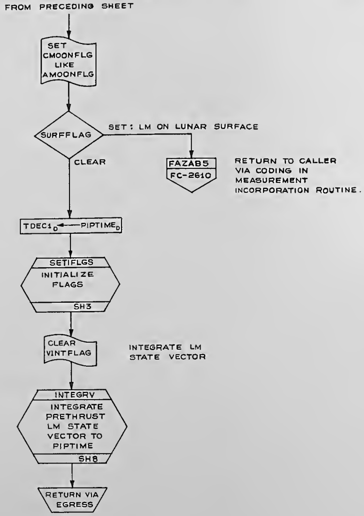
FC-2290

16 26

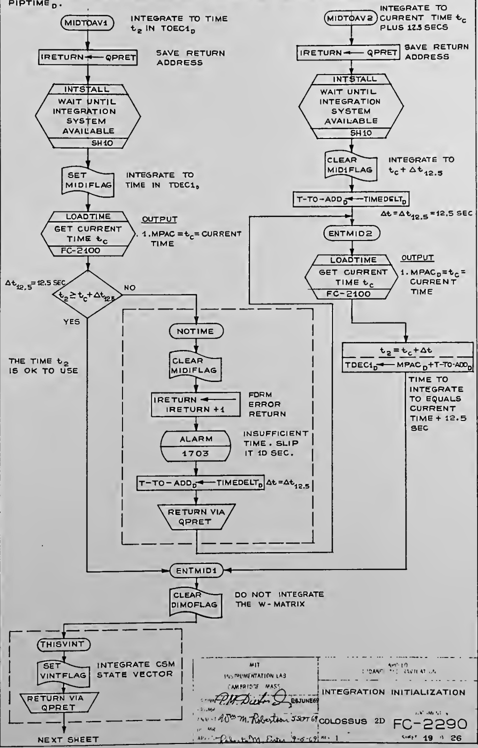


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 25JUNE69	INTEGRATION INITIALIZATION
PRGMR	
ANALYST 5 SEPT 69	COLOSSUS 2D — DOCUMENT NO. FC-2290
DCCMR	
APPR'D 9-5-69	REV 1 — SHEET 17 OF 26



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	GUIDANCE AND NAVIGATION
P. M. Dieterle 28 JUNE 68	INTEGRATION INITIALIZATION
Wm. M. Robertson 5 SEPT 69	COLOSSUS 2D FC-2290
Carrie M. Estes 9-5-69	REV. 1 SHEET 18 OF 26

MIDTOAV1 DOES PRECISION INTEGRATION OF THE CSM PERMANENT STATE VECTOR TO THE TIME t_2 SPECIFIED IN $TDEC1_D$. 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 A PRESISION 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_V, VN_V, $PIPTIME_D$.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

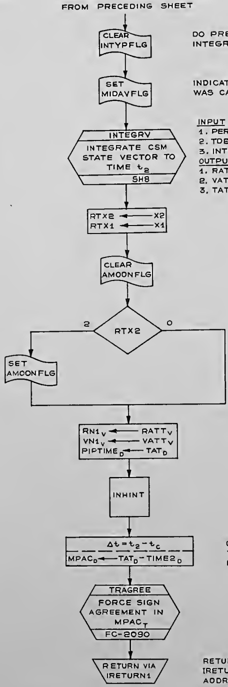
APOLLO GUIDANCE AND NAVIGATION

INTEGRATION INITIALIZATION

P.M. Dietz 26JUNE69
Wm. M. Robertson 5 SEPT 69
Robert M. Estes 9-5-69

COLOSSUS 2D FC-2290

REV. 1 SHEET 19 OF 26



DO PRECISION INTEGRATION

INDICATE TO INTEGRATION THAT IT WAS CALLED BY THE MIDTOAVE ROUTINE

INPUT
1. PERMANENT CSM STATE VECTOR
2. $TDEC1_D = t_2$
3. INTERPRETIVE FLAGS

OUTPUT
1. $RATT_V = \underline{r}(t_2)$
2. $VATT_V = \underline{v}(t_2)$
3. $TAT_D \approx t_2$

SET FLAG ACCORDING TO SPHERE OF INFLUENCE (FOR SCALING OF STATE VECTOR)

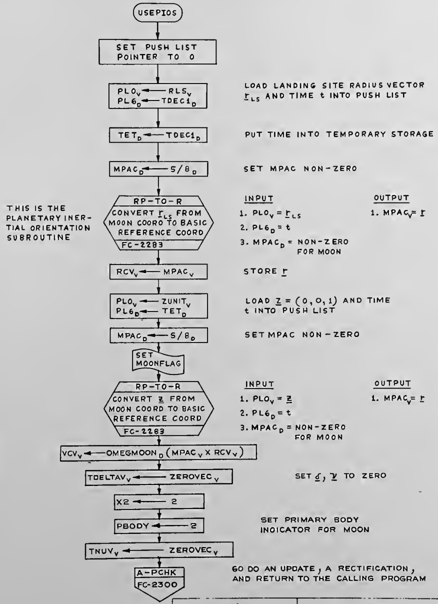
STORE THE OUTPUT OF INTEGRV

INHIBIT INTERRUPTS

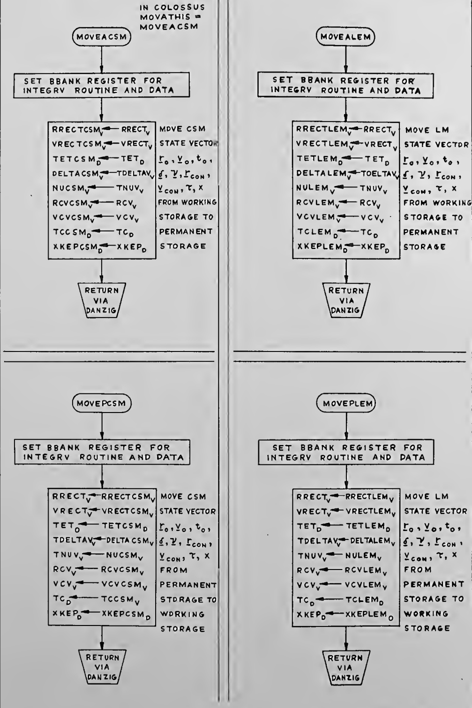
COMPUTE A DELTA TIME EQUAL TO TIME ACTUALLY INTEGRATED TO MINUS THE CURRENT TIME IN TIME2, TIME1

RETURN IS MADE VIA SUBROUTINE BANK JUMP. IRETURN1 CONTAINS EITHER NORMAL RETURN ADDRESS OR ERROR RETURN ADDRESS

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.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Longhi 10NOV68	INTEGRATION INITIALIZATION
PRGMR	
ANALYST Wm. M. Robertson 5 Sept 69	COLOSSUS 2D — DOCUMENT NO. FC-2290
DOCMR	
APPR'D Robert M. Evans 9-6-69	REV 1 — SHEET 21 OF 26



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

DRAWN A. J. Longello 6 JUN 69
ANAL Wm M. Robertson 5 SEPT 69
APPR Robert M. Estes 9-5-69

APOLLO GUIDANCE AND NAVIGATION

INTEGRATION INITIALIZATION

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REV 1

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
INTYPFLG (4, 3)	DO CONIC (KEPLER) INTEGRATION	DO PRECISION (ENCKE) INTEGRATION	SH. 7	SH. 3, 6, 20	SH. 8
VINTFLAG (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, 16	SH. 3, 6, 7, 8, 19	
D6OR9FLG (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, 9)	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
RENDWFLG (1, 5)	W-MATRIX IS VALID FOR RENDEZVOUS NAVIGATION	W-MATRIX IS INVALID FOR RENDEZVOUS NAVIGATION		SH. 14	SH. 4, 16

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 INTEGRATION LOOP	SH. 8		
RPQFLAG (15, 8)	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		
MID1FLAG (3, 9)	INTEGRATE TO TIME IN TDEC1	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. 16		
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 (9, 3)	IN 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

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$TDEC1_D$	t	TIME TO INTEGRATE TO	CSEC	CSEC	2^{28}
$TETCSM_D$	t	TIME TO INTEGRATE TO IN P00	CSEC	CSEC	2^{28}
RCV_V	$\underline{r}_{con}$	CONIC POSITION VECTOR	M	M	$2^{29}/2^{27}$
VCV_V	$\underline{v}_{con}$	CONIC VELOCITY VECTOR	M/CSEC	M/CSEC	$2^7/2^5$
TET_D	t	TIME OF VALIDITY OF STATE VECTOR	CSEC	CSEC	2^{28}
$RRECT_V$	$\underline{r}_o$	POSITION VECTOR AT RECTIFICATION	M	M	$2^{29}/2^{27}$
$VRECT_V$	$\underline{v}_o$	VELOCITY VECTOR AT RECTIFICATION	M/CSEC	M/CSEC	$2^7/2^5$
$TDELTAV_V$	$\underline{\delta}$	POSITION DEVIATION VECTOR	M	M	$2^{22}/2^{18}$
$TNUV_V$	$\underline{\nu}$	VELOCITY DEVIATION VECTOR	M/CSEC	M/CSEC	$2^3/2^{-1}$
TC_D	t_{21}	TIME SINCE RECTIFICATION	CSEC	CSEC	2^{28}
$XKEP_D$	x	UNIVERSAL VARIABLE	$M^{1/2}$	$M^{1/2}$	$2^{17}/2^{16}$
$TDEC_D$	t	TIME TO INTEGRATE TO	CSEC	CSEC	2^{28}
PBODY	P	PRIMARY BODY INDICATOR	INTEGER	INTEGER	
IRETURN		LOCATION FOR STORING RETURN ADDRESS	INTEGER	INTEGER	
$TAU._D$	τ	TIME INTERVAL FOR CONIC INTEGRATION	CSEC	CSEC	2^{28}
TBASE2		TEMPORARY STORAGE FOR RETURN ADDRESS	INTEGER	INTEGER	
STALTEM		TEMPORARY STORAGE FOR SUBSCRIPT k	INTEGER	INTEGER	
EGRESS		LOCATION FOR STORING RETURN ADDRESS	INTEGER	INTEGER	
$PIPTIME_D$	t	BURN TIME	CSEC	CSEC	2^{28}
TAT_D	t	TIME ACTUALLY INTEGRATED TO	CSEC	CSEC	2^{28}
TRKMKCNT		TRACKING RADAR MARK COUNT	INTEGER	INTEGER	
RN_V	$\underline{r}_{con}$	POSITION VECTOR OF CSM FOR DOWNLINK	M	M	$2^{29}/2^{27}$
VN_V	$\underline{v}_{con}$	VELOCITY VECTOR OF CSM FOR DOWNLINK	M/CSEC	M/CSEC	$2^7/2^5$
$R\text{-}OTHER_V$	$\underline{r}_{con}$	POSITION VECTOR OF LM FOR DOWNLINK	M	M	$2^{29}/2^{27}$
$V\text{-}OTHER_V$	$\underline{v}_{con}$	VELOCITY VECTOR OF LM FOR DOWNLINK	M/CSEC	M/CSEC	$2^7/2^5$

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$OMEGMOON_D$			$2.66169947 \times 10^{-8}$	$2.66169947 \times 10^{-8}$	2^{-23}
$ZEROVEC_V$	(0, 0, 0)	THE ZERO VECTOR	(0.0, 0.0, 0.0)	(0, 0, 0)	ANY
$UPMNSVCD_D$		INTEGER 2	2	2	2^{14}
$TIMEDELT_D$	$\Delta t_{12.5}$	USED IN TEST TO DETERMINE IF TIME TO INTEGRATE TO MUST BE SLIPPED	12.5 SEC	1250 CSEC	2^{28}
$5/8_D$		A NON-ZERO CONSTANT	5/8	5/8	2^3

PAD LOADS

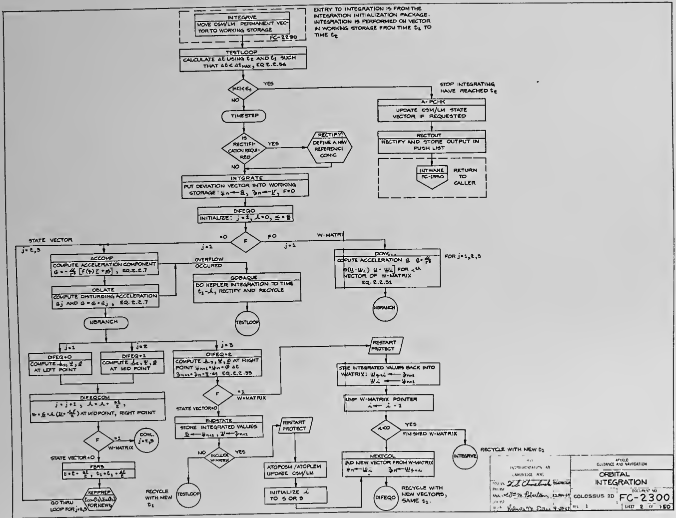
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
RLS_V	$\underline{r}_{LS}$	LUNAR LANDING SIGHT VECTOR				

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 $\underline{a}_p$ DUE TO THE ATTRACTION OF THE PRIMARY BODY	SH. 23
DIFEQ+0	EVALUATE $\underline{\psi}$ AND $\underline{\phi}$ AT THE LEFT HAND POINT	SH. 27
DIFEQ+1	EVALUATE $\underline{\psi}$ AND $\underline{\phi}$ 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 $\underline{\psi}$ AND $\underline{\phi}$ AT THE RIGHT HAND POINT AND THEN CALCULATE THE FUNCTION $\underline{y}$ AND ITS DERIVATIVE $\underline{z}$ 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 $\underline{a}_p$ AND $\underline{a}_q$	SH. 42
RECTIFY	DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS	SH. 43
MINIRECT	ENTRY POINT IN RECTIFY IF $\underline{\delta}$, $\underline{\nu}$ MUST BE INITIALLY ZERO	SH. 43
RECTIFY +13D	ENTRY POINT IN MINIRECT IF $VRECT_V$ ALREADY STORED	SH. 43
ORIGCHNG	CHANGE ORIGIN OF COORDINATE SYSTEM	SH. 44

REFERENCES FOR ORBITAL INTEGRATION

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.


ENTRY TO INTEGRATION IS FROM THE INTEGRATION INITIALIZATION PACKAGE. INTEGRATION IS PERFORMED ON VECTOR IN WORKING STORAGE FROM TIME t1 TO TIME t2
INTEGRVE
MOVE CSM/LM PERMANENT VECTOR TO WORKING STORAGE
FC-2290
TESTLOOP
CALCULATE Δt USING t2 AND t1 SUCH THAT Δt < Δt MAX, EQ 2.2.36
YES
NO
STOP INTEGRATING HAVE REACHED t2
A-PCHK
UPDATE CSM/LM STATE VECTOR IF REQUESTED
RECTOUT
RECTIFY AND STORE OUTPUT IN PUSH LIST
INTWAKE
FC-1950
RETURN TO CALLER
TIMESTEP
IS RECTIFICATION REQUIRED
RECTIFY
DEFINE A NEW REFERENCE CONIC
INTGRATE
PUT DEVIATION VECTOR INTO WORKING STORAGE
DIFEQO
INITIALIZE
F
STATE VECTOR
W-MATRIX
FOR j=1,2,3
ACCOMP
COMPUTE ACCELERATION COMPONENT
EQ.2.2.7
OVERFLOW OCCURED
GOBAQUE
DO KEPLER INTEGRATION TO TIME t1-λ, RECTIFY AND RECYCLE
OBLATE
COMPUTE DISTURBING ACCELERATION
EQ. 2.2.7
DOW..
COMPUTE ACCELERATION
VECTOR OF W-MATRIX
EQ. 2.2.51
NBRANCH
TESTLOOP
DIFEQ+0
AT LEFT POINT
DIFEQ+1
AT MID POINT
DIFEQ+2
AT RIGHT POINT
EQ.2.2.35
DIFEQCOM
AT MIDPOINT, RIGHT POINT
STATE VECTOR=0
ENDSTATE
STORE INTEGRATED VALUES
INCLUDE W-MATRIX
RESTART PROTECT
ATOPCSM /ATOPLEM
UPDATE CSM/LM
INITIALIZE i TO 5 OR 8
STORE INTEGRATED VALUES BACK INTO W-MATRIX
JUMP W-MATRIX POINTER
FINISHED W-MATRIX
NEXTCOL
LOAD NEW VECTOR FROM W-MATRIX
FBR3
KEPPREP
GO THRU LOOP FOR j=2,3
RECYCLE WITH NEW t1
DIFEQO
RECYCLE WITH NEW VECTORS, SAME t1.
INTEGRVE
RECYCLE WITH NEW t1
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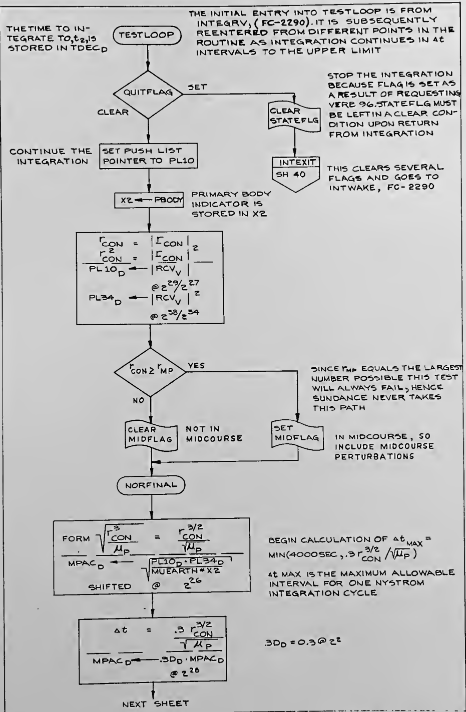

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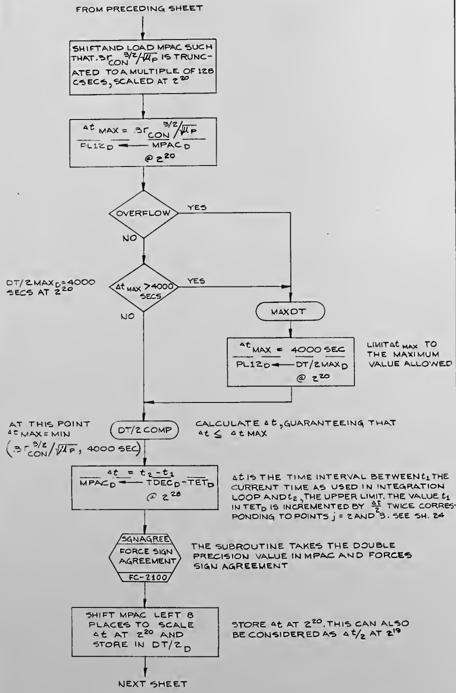

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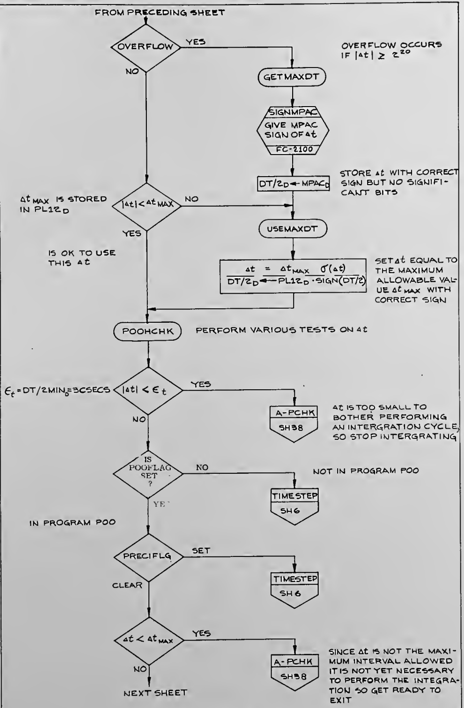

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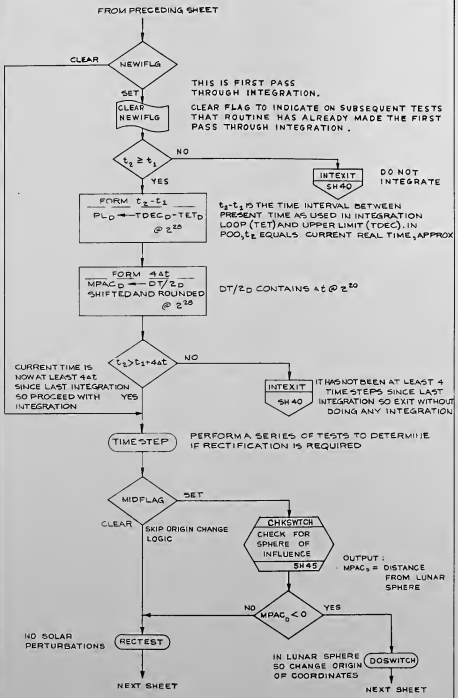

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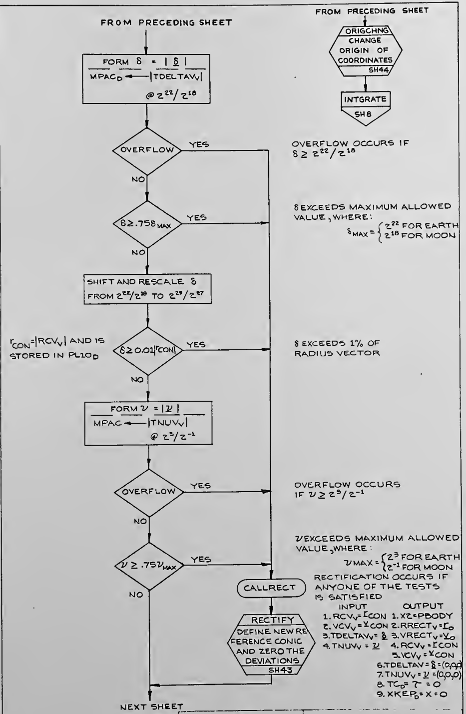

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INTGRATE

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

$ZV_V \leftarrow TNUV_V$ @ $2^{3}/2^{-1}$
$YV_V \leftarrow TDELTAV_V$ @ $2^{22}/2^{18}$

STORE ν, δ IN WORKING STORAGE PRIOR TO INTEGRATING THE STATE VECTOR

CLEAR JSWITCH

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 Δt 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 Δt. DIFEQCNT TAKES ON THE VALUES 0, -12D, -24D

$\alpha_j = \delta$
$ALPHAV_V \leftarrow YV_V$ @ $2^{22}/2^{18}$

INITIALIZE α_j
α_j IS THE ESTIMATE OF δ USED ON EACH OF THE THREE PASSES THROUGH THE INTEGRATION LOOP

$h = 0$
$H_D \leftarrow DPZERO_D$

INITIALIZE h.
h 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 Δt.

JSWITCH — CLEAR / SET

CLEAR: ACCOMP (SH9) — INTEGRATE THE STATE VECTOR

SET: DOW.. (SH41) — INTEGRATE A VECTOR FROM THE W-MATRIX

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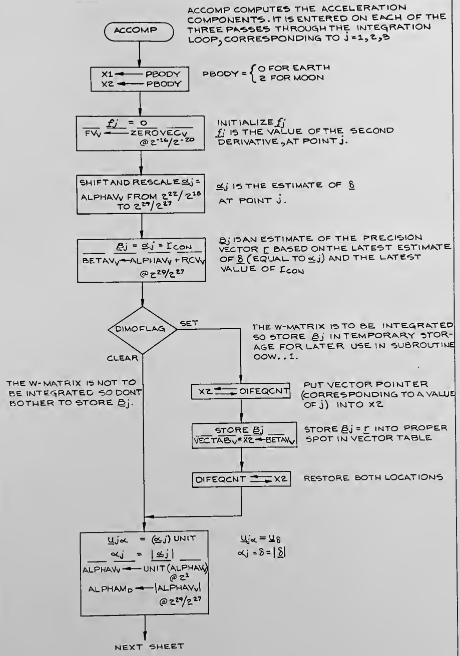

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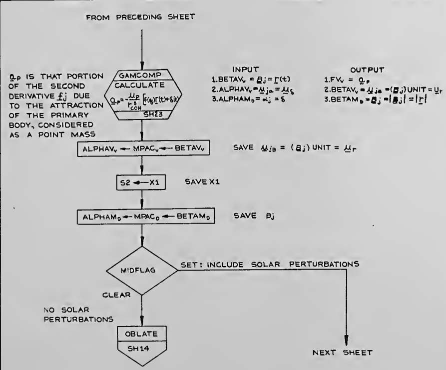

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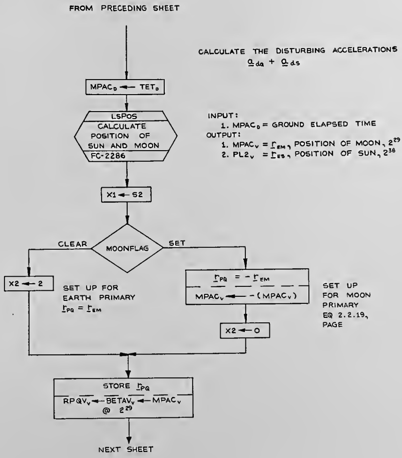

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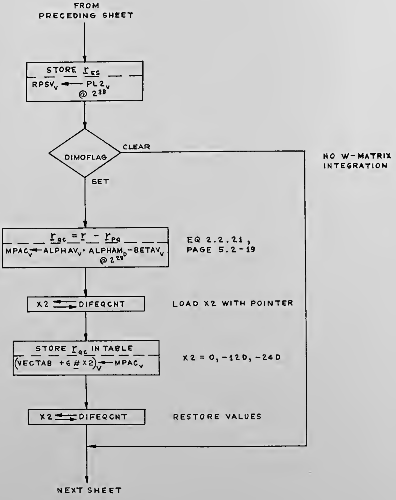

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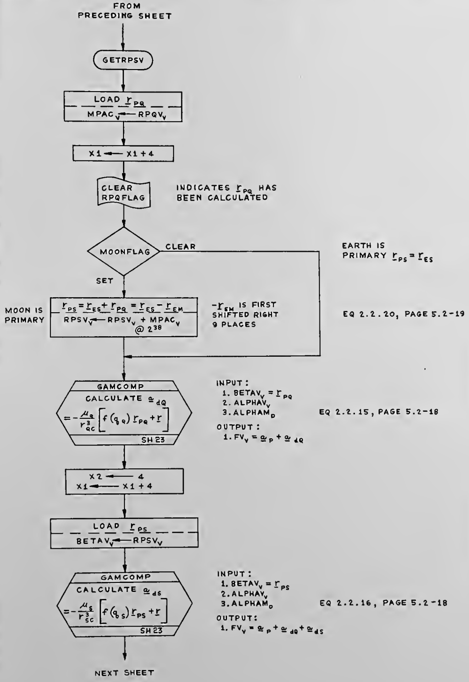

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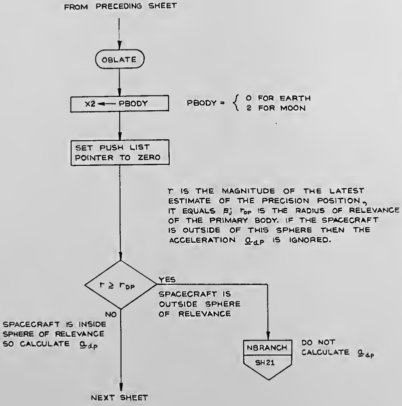

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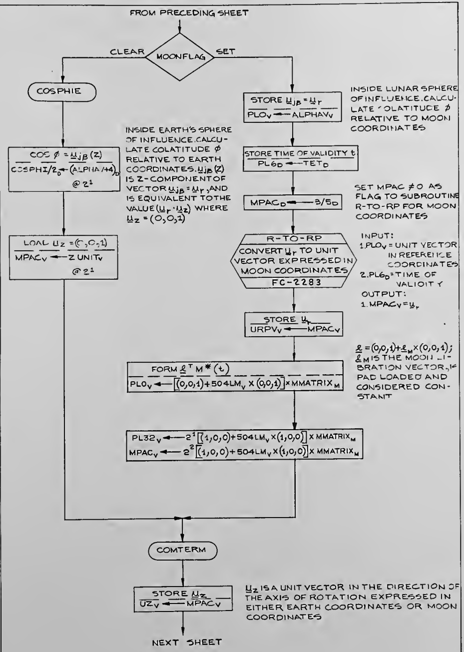

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↓

$P_2' = 3 \cos \phi$

$PLO_D \leftarrow COSPHI/2_D \cdot 3/32_D$ @ 2^6

$3/32_D = 3.0 @ 2^5$

↓

FORM $15 \cos^2 \phi$

$MPAC_D \leftarrow (COSPHI/2_D)^2 \cdot 15/16_D$ @ 2^6

$15/16_D = 15.0 @ 2^4$

↓

$P_3' = \frac{1}{2}(15 \cos^2 \phi - 3)$

$PL2_D \leftarrow MPAC_D \leftarrow (MPAC_D - 3/64_D)/2$ @ 2^5

$3/64_D = 3.0 @ 2^6$
DIVISION BY 2 IS ACCOMPLISHED BY A CHANGE IN THE SCALE FACTOR

↓

FORM $\frac{7}{3} \cos \phi \, P_3'$

$PL4_D \leftarrow 7/12_D \cdot COSPHI/2_D \cdot MPAC_D$ SHIFTED @ 2^7

$7/12_D = \frac{7}{3} @ 2^2$

↓

FORM $\frac{4}{3} P_2'$

$MPAC_D \leftarrow 2/3_D \cdot PLO_D$ @ 2^7

$2/3_D = \frac{4}{3} @ 2^1$

↓

$P_4' = \frac{7}{3} \cos \phi \, P_3' - \frac{4}{3} P_2'$

$PL4_D \leftarrow MPAC_D \leftarrow PL4_D - MPAC_D$ @ 2^7

↓

FORM $\frac{9}{4} \cos \phi \, P_4'$

$PL6_D \leftarrow 9/16_D \cdot COSPHI/2_D \, MPAC_D$ @ 2^{10}

$9/16_D = \frac{9}{4} @ 2^2$

↓

$P_5' = \frac{9}{4} \cos \phi \, P_4' - \frac{5}{4} P_3'$

$MPAC_D \leftarrow PL6_D - 5/128_D \cdot PL2_D$ @ 2^{10}

$5/128_D = \frac{5}{4} @ 2^5$

↓

FORM $\frac{J_{4P} r_P}{J_{3P}} P_5'$

$MPAC_D \leftarrow (J4REQ/J3\#X2)_D \cdot MPAC_D$ @ 2^{36}

$$\frac{J_{4P} r_P}{J_{3P}} = \begin{cases} \frac{J_{4E} r_E}{J_{3E}} = 4991607.391 @ 2^{26} \text{ FOR EARTH} \\ \frac{J_{4M} r_M}{J_3} = -176236.02 @ 2^{25} \text{ FOR MOON} \end{cases}$$

↓

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FORM $\frac{J_{4P} r_P P_5'}{J_{3P}} \Big/ r + P_4' = \frac{J_{4P}}{J_{3P}}\left(\frac{r_P}{r}\right) P_5' + P_4'$

$MPAC_D \leftarrow MPAC_D / ALPHAM_D + PL4_D$ @ 2^7

FORM $\left[\frac{J_{4P}}{J_{3P}}\left(\frac{r_P}{r}\right) P_5' + P_4'\right] \frac{J_{3P} r_P}{J_{2P}} \Big/ r = \frac{J_{4P}}{J_{2P}}\left(\frac{r_P}{r}\right)^2 P_5' + \frac{J_{3P}}{J_{2P}}\left(\frac{r_P}{r}\right) P_4'$

$MPAC_D \leftarrow MPAC_D \cdot (2J3RE/J2*X2)_D / ALPHAM_D$ @ 2^5

$$\frac{J_{3P} r_P}{J_{2P}} = \begin{cases} \frac{J_{3E} r_E}{J_{2E}} = 13554.26363 \text{ @ } 2^{27} \text{ FOR EARTH} \\ \frac{J_{3M} r_M}{J_{2M}} = .3067493316 \times 10^{18} \text{ @ } 2^{+60} \text{ FOR MOON} \end{cases}$$

FORM $K_2 \underline{u}_r = \left[\frac{J_{4P}}{J_{2P}}\left(\frac{r_P}{r}\right)^2 P_5' + \frac{J_{3P}}{J_{2P}}\left(\frac{r_P}{r}\right) P_4' + P_3'\right] \underline{u}_r$

$TVEC_V \leftarrow [MPAC_D + PL2_D]\ ALPHAV_V$ @ 2^6

FORM $\frac{J_{4P} r_P}{J_{3P}} P_4'$

$MPAC_D \leftarrow (J4REQ/J3*X2)_D \cdot PL4_D$

SHIFTED @ 2^{34}

FORM $\frac{J_{4P} r_P}{J_{3P}} P_4' \Big/ r + P_3' = \frac{J_{4P}}{J_{3P}}\left(\frac{r_P}{r}\right) P_4' + P_3'$

$MPAC_D \leftarrow MPAC_D / ALPHAM_D + PL2_D$ @ 2^5

FORM $\left[\frac{J_{4P}}{J_{3P}}\left(\frac{r_P}{r}\right) P_4' + P_3'\right] \frac{J_{3P} r_P}{J_{2P}} \Big/ r = \frac{J_{4P}}{J_{2P}}\left(\frac{r_P}{r}\right)^2 P_4' + \frac{J_{3P}}{J_{2P}}\left(\frac{r_P}{r}\right) P_3'$

$MPAC_D \leftarrow MPAC_D \cdot (2J3RE/J2*X2)_D / ALPHAM_D$

SHIFTED @ 2^6

FORM $K_2 \underline{u}_z = \left[\frac{J_{4P}}{J_{2P}}\left(\frac{r_P}{r}\right)^2 P_4' + \frac{J_{3P}}{J_{2P}}\left(\frac{r_P}{r}\right) P_3' + P_2'\right] \underline{u}_z$

$MPAC_V \leftarrow [MPAC_D + PL0_D]\ UZ_V$

SHIFTED @ 2^6

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FORM $K_1 \underline{u}_r - K_2 \underline{u}_z$

$TVEC_V \leftarrow TVEC_V - MPAC_V$ @ 2^6

NORMALIZE r

$MPAC_D \leftarrow ALPHAM_D$

NORMALIZE AT $2^{29-m}/2^{27-m}$

THE NORMALIZING VALUE $-m$ IS STORED IN X1

FORM r^4

$MPAC_D \leftarrow (MPAC_D)^4$

@ $2^{116-4m}/2^{108-4m}$

NORMALIZE AND STORE r^4

$PLO_D \leftarrow MPAC_D$

NORMALIZED AT $2^{116-4m-n}/2^{108-4mn}$

THE NORMALIZING VALUE $-n$ IS STORED IN S1

FORM $J_{2P} r_P^2 \mu_P / r^4$

$MPAC_C \leftarrow (J2REQSQ \# X2)_D / MPAC_D$

$$J_{2P} r_P^2 \mu_P = \begin{cases} J_{2E} r_E^2 \mu_E = 1.75501139 \times 10^{21} \text{ B-72 FOR EARTH} \\ J_{2M} r_M^2 \mu_M = 0.3067493316 \times 10^{16} \text{ B-60 FOR MOON} \end{cases}$$

FORM $\left[K_1 \underline{u}_r - K_2 \underline{u}_z\right] \frac{J_{2P} r_P^2 \mu_P}{r^4} = \frac{\mu_P}{r^2} \sum_{i=2}^{4} J_{iP} \left(\frac{r_P}{r}\right)^i \left[P'_{i+1} \underline{u}_r - P'_i \underline{u}_z\right]$

$MPAC_V \leftarrow TVEC_V \cdot MPAC_D$

THIS IS $\underline{a}_{dE}$ FOR THE EARTH OR THE MAJOR PART OF $\underline{a}_{dM}$ FOR THE MOON

CLEAR OVFIND IF SET

FORM $-3m-n$

$X1 \leftarrow 3 \cdot X1 + S1$

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$$\left\{K_1 \underline{u}_r - K_2 \underline{u}_z\right\} \frac{J_{2P} r_P^2 \mu_P}{r^4}$$

$$= \left\{\left[\frac{J_{4P}}{J_{2P}}\left(\frac{r_P}{r}\right)^2 P_5' + \frac{J_{3P}}{J_{2P}}\left(\frac{r_P}{r}\right) P_4' + P_3'\right] \underline{u}_r - \left[\frac{J_{4P}}{J_{2P}}\left(\frac{r_P}{r}\right)^2 P_4' + \frac{J_{3P}}{J_{2P}}\left(\frac{r_P}{r}\right) P_3' + P_2'\right] \underline{u}_z\right\} \frac{J_{2P} r_P^2 \mu_P}{r^4}$$

$$= \frac{\mu_P}{r^2}\left\{\left[J_{4P}\left(\frac{r_P}{r}\right)^4 P_5' + J_{3P}\left(\frac{r_P}{r}\right)^3 P_4' + J_{2P}\left(\frac{r_P}{r}\right)^2 P_3'\right] \underline{u}_r - \left[J_{4P}\left(\frac{r_P}{r}\right)^4 P_4' + J_{3P}\left(\frac{r_P}{r}\right)^3 P_3' + J_{2P}\left(\frac{r_P}{r}\right)^2 P_2'\right] \underline{u}_z\right\}$$

$$= \frac{\mu_P}{r^2} \sum_{i=2}^{4} J_{iP} \left(\frac{r_P}{r}\right)^i \left[P'_{i+1} \underline{u}_r - P'_i \underline{u}_z\right]$$

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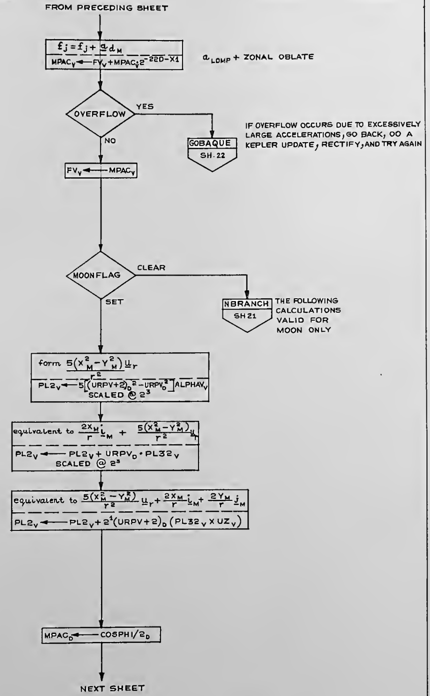

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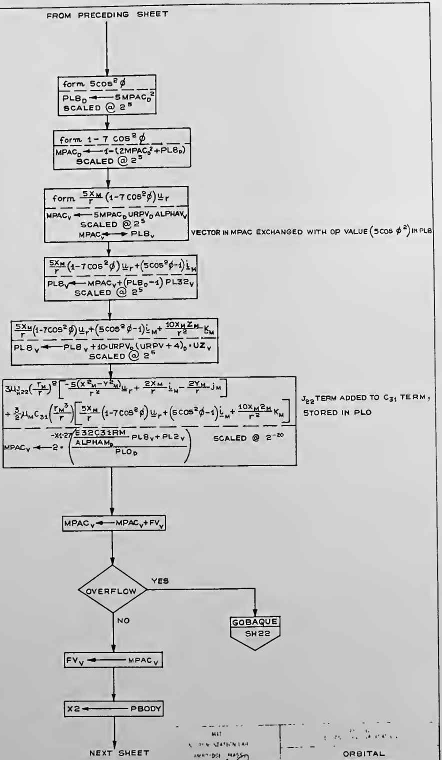

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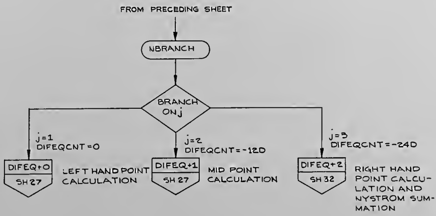

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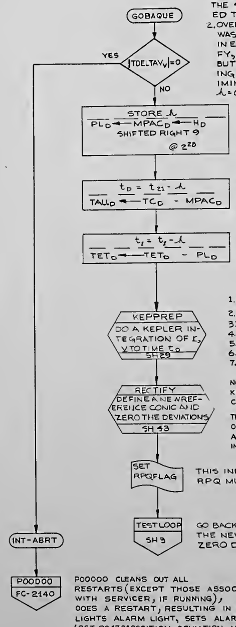
GOBAQUE IS ENTERED IF EITHER:

1. OVERFLOW OCCURED IN GAMCOMP WHEN THE SECOND DERIVATIVE INCREMENT WAS ADDED TO f_j, OR,
2. OVERFLOW OCCURED IN OBLATE WHEN a_{dp} WAS ADDED TO a_p.

IN EITHER CASE DO A KEPLER UPDATE, RECTIFY, AND GO BACK AND INTEGRATE AGAIN BUT NOW WITH A NEW REFERENCE CONIC. HAVING A NEW REFERENCE CONIC SHOULD ELIMINATE THE PROBLEM OF OVERFLOW.

$\lambda = 0, \frac{\Delta t}{2}, \Delta t$



$\lambda = 0, \frac{\Delta t}{2}, \Delta t$

t_D = DESIRED TRANSFER TIME. IT MUST BE REDUCED BY λ 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_1 IS REDUCED BY λ TO MAKE IT AGREE WITH TIME OF VALIDITY OF RCV_V, VCV_V

INPUT	OUTPUT
1. PBODY = {0 FOR EARTH / 2 FOR MOON	1. $RCV_V = \underline{r}(t_2)$
2. $RCV_V = \underline{r}'(t'_{21})$	2. $VCV_V = \underline{v}(t_2)$
3. $VCV_V = \underline{v}'(t'_{21})$	3. $TC_D = t_2$, TIME CONVERGED TO $\approx t_D$
4. $XKEP_D = X'$	4. $XPREV_D = X' = XKEP_D$
5. TAU. $= t_D$, DESIRED TIME	
6. $TC_D = t'_{21}$	
7. MOONFLAG {CLEAR FOR EARTH / SET FOR MOON	

NOTE: OUTPUT IS FOR ENTIRE KEPPREP AND KEPLERN 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

P00000 CLEANS OUT ALL RESTARTS (EXCEPT THOSE ASSOCIATED WITH SERVICER, IF RUNNING), DOES A RESTART, RESULTING IN P00. LIGHTS ALARM LIGHT, SETS ALARM CODE (OCT 20430: POSITION DEVIATION VECTOR = 0)

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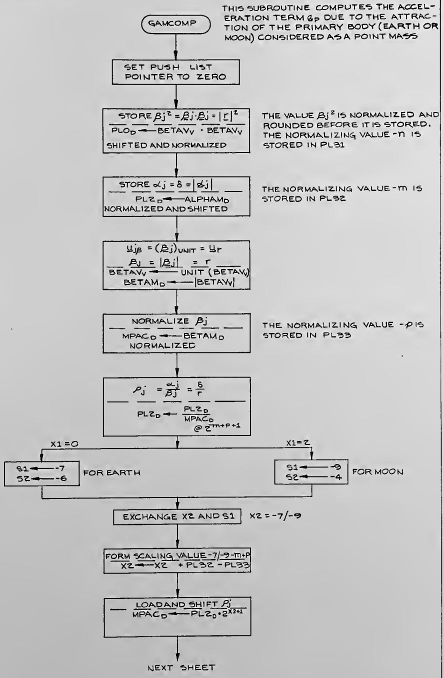

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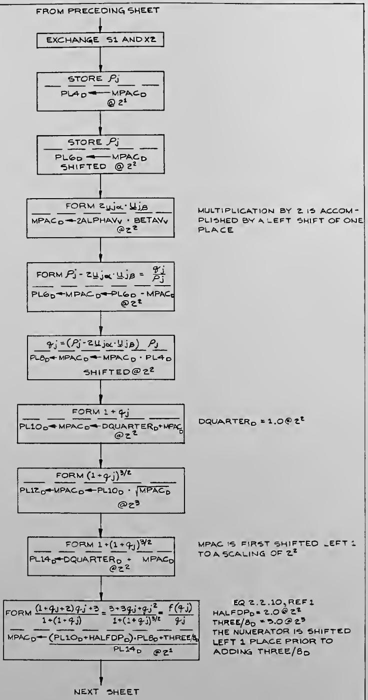

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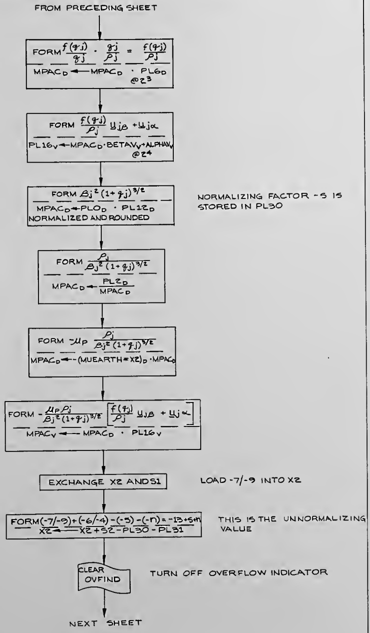

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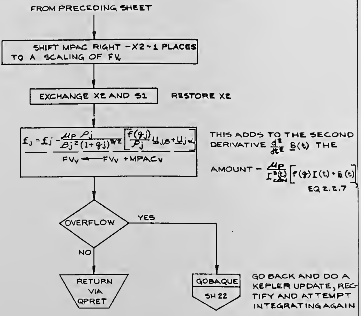

THE DIFFERENTIAL EQUATION FOR THE ENCKE VARIABLE $\underline{\delta}(t)$ CAN BE WRITTEN AS:

$$\frac{d^2}{dt^2}\,\underline{\delta}(t) = -\frac{\mu_P}{r^3_{CON}(t)}\left[f(q)\,\underline{r}(t) + \underline{\delta}(t)\right] + \underline{a}_{dP}(t) \qquad (2.2.7)$$

THE FIRST TERM ON THE RIGHT, CALLED γ, IS EVALUATED IN GAMCOMP AS PART OF THE NYSTROM INTEGRATION SCHEME IN THE SUBSCRIPTED FORM:

$$\gamma_j = -\frac{\mu_P \rho_j}{\beta_j^2(1+q_j)^{3/2}}\left[\frac{f(q_j)}{\rho_j}\,\underline{u}_{j\beta} + \underline{u}_{j\alpha}\right], \text{ FOR A GIVEN } j .$$

THE FOLLOWING SHOWS THAT γ_j IS EQUIVALENT TO THE FIRST TERM IN 2.2.7. LET $\underline{\delta}(t) = \underline{\alpha}_j = \alpha_j \underline{u}_{j\alpha}$ AND $\underline{r}(t) = \underline{\beta}_j = \beta_j \underline{u}_{j\beta}$, WHERE α_j AND β_j ARE MAGNITUDES OF THE RESPECTIVE VECTORS. DEFINE $\rho_j = \alpha_j/\beta_j$. THEN γ CAN BE WRITTEN AS

$$\gamma_j = -\frac{\mu_P}{\beta_j^3(1+q_j)^{3/2}}\left[f(q_j)\,\underline{\beta}_j + \underline{\alpha}_j\right],$$ WHERE r^3_{CON} HAS BEEN REPLACED BY $\beta_j^3\,(1+q_j)^{3/2}$. CONTINUING,

$$\gamma_j = -\frac{\mu_P}{\beta_j^3(1+q_j)^{3/2}}\left[f(q_j)\,\beta_j\,\underline{u}_{j\beta} + \alpha_j\,\underline{u}_{j\alpha}\right]$$

$$= -\frac{\mu_P}{\beta_j^2(1+q_j)^{3/2}}\left[f(q_j)\,\underline{u}_{j\beta} + \frac{\alpha_j}{\beta_j}\,\underline{u}_{j\alpha}\right]$$

$$= -\frac{\mu_P \rho_j}{\beta_j^2(1+q_j)^{3/2}}\left[\frac{f(q_j)}{\rho_j}\,\underline{u}_{j\beta} + \underline{u}_{j\alpha}\right]$$

THE VARIABLE q IS EVALUATED AS,

$$q_j = \frac{(\underline{\alpha}_j - 2\underline{\beta}_j)\cdot\underline{\alpha}_j}{\beta_j^2} = \frac{(\alpha_j\,\underline{u}_{j\alpha} - 2\beta_j\,\underline{u}_{j\beta})\cdot\alpha_j\,\underline{u}_{j\alpha}}{\beta_j^2}$$

$$= \left[\left(\frac{\alpha_j}{\beta_j}\right)\underline{u}_{j\alpha} - 2\underline{u}_{j\beta}\right]\left(\frac{\alpha_j}{\beta_j}\right)\underline{u}_{j\alpha} = \rho_j\left[\rho_j - 2\underline{u}_{j\alpha}\cdot\underline{u}_{j\beta}\right]$$

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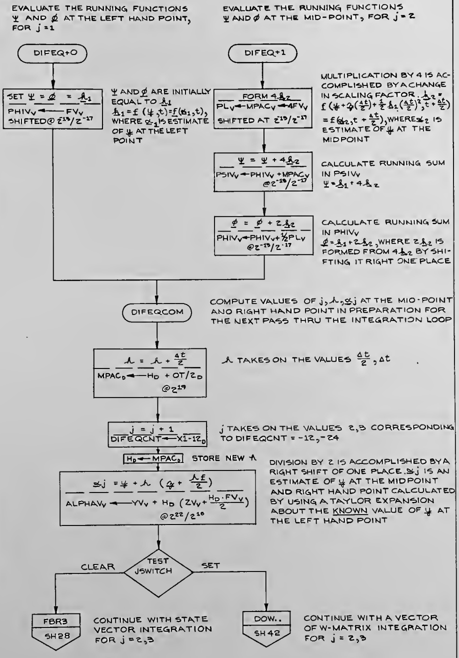

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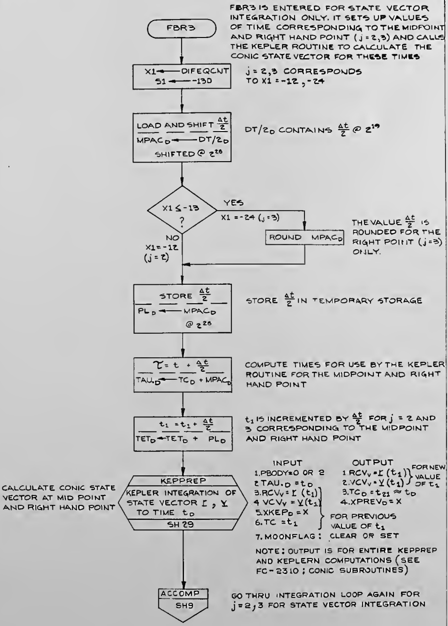

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THIS SUBROUTINE COMPUTES AN ESTIMATE OF THE VARIABLE X AT TIME t_D BASED ON THE VALUES x', $\underline{r}'(t_{z1}')$, $\underline{v}'(t_{z1}')$ AT TIME t_{z1}' FROM THE PREVIOUS COMPUTATION CYCLE. THIS INITIAL ESTIMATE OF X IS USED AS INPUT TO KEPLER TO SPEED UP CONVERGENCE.

INPUT:
1. PBODY = 0 FOR EARTH PRIMARY, 2 FOR MOON
2. $RCV_V = \underline{r}' = \underline{r}_{con}(\tau - \frac{\Delta t}{2})$ } THE STATE VECTOR CORRESPONDING TO PREVIOUS CYCLE
3. $VCV_V = \underline{v}' = \underline{v}_{con}(\tau - \frac{\Delta t}{2})$
4. $XKEP_D = x' = x(\tau - \frac{\Delta t}{2})$
5. $TAU_D = t_D$, DESIRED TRANSFER TIME
6. $TC_D = t_{z1}' = \tau - \frac{\Delta t}{2}$, PREVIOUS TRANSFER TIME
7. MOONFLAG: CLEAR FOR EARTH, SET FOR MOON

OUTPUT: (OUTPUT FOR KEPPREP ONLY)
1. $XKEPNEW = x_t$, FIRST ESTIMATE OF X CORRESPONDING TO THE TRANSFER TIME t_D
2. $X1 = \mu$-TABLE POINTER, -2 FOR EARTH, -10D FOR MOON
3. PUSH LIST POINTER AT PL4

KEPPREP

LOAD X2 WITH PRIMARY BODY INDICATOR

$X2 \leftarrow PBODY$

SET PUSH LIST POINTER TO 0

STORE $\sqrt{\mu_P}$

$PL0_D \leftarrow \sqrt{MUEARTH\#X2}$ @ $2^{19}/2^{15}$

$\underline{u}_{r'} = \underline{r}'_{UNIT}$

$r' = |\underline{r}'|$

$MPAC_V \leftarrow UNIT(RCV_V)$ @ 2^1

$PL2_D \leftarrow |RCV_V|$ NORMALIZED @ $2^{29-m}/2^{27-m}$

r' IS STORED IN NORMALIZED FORM THE VALUE -m IS STORED IN PL36

r' IS STORED IN NORMALIZED FORM AND THE NORMALIZING VALUE -m IS STORED IN X1. THE UNIT OPERATION ALSO STORES r' IN PL36 @ $2^{29}/2^{27}$

FORM $\underline{u}_{r'} \cdot \underline{v}'$

$PL4_D \leftarrow MPAC_V \cdot VCV_V$ @ $2^8/2^6$

$\frac{\Delta t}{2} = t_D - t_{z1}'$

$MPAC_D \leftarrow TAU_D - TC_D$ NORMALIZED @ 2^{28-n}

A COMPLETE INTEGRATION STEP CORRESPONDS TO TWO $\frac{\Delta t}{2}$ INCREMENTS. THE VALUE $\frac{\Delta t}{2}$ IS NORMALIZED AND THE NORMALIZING VALUE -n IS STORED IN S1.

FORM $\frac{\Delta t}{2} / r'$

$MPAC_D \leftarrow \frac{MPAC_D}{PL2_D}$ @ $2^{m-n}/2^{2+m-n}$

$PL4_D \leftarrow \frac{1}{r'}\left(\frac{\Delta t}{2}\right)$

$MPAC_D \leftarrow \underline{u}'_r \cdot \underline{v}'$

EXCHANGE MPAC AND PL4

$rs = \frac{\underline{u}'_r \cdot \underline{v}'}{2r'}\left(\frac{\Delta t}{2}\right)$

$PL6_D \leftarrow MPAC_D \leftarrow MPAC_D \cdot PL4_D$ @ 2^{7+m-n}

DIVISION BY 2 IS ACCOMPLISHED BY A CHANGE IN THE SCALING FACTOR

FORM $2(rs)^2$

$PL8_D \leftarrow (MPAC_D)^2$ @ $2^{15+2(m-n)}$

MULTIPLICATION BY 2 IS ACCOMPLISHED BY A CHANGE IN THE SCALING FACTOR

NEXT SHEET

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FROM PRECEDING SHEET

FORM $\frac{1}{(r')^2}\left(\frac{\Delta t}{2}\right)^2$

$PL10_D \leftarrow (PL4_D)^2$

$@\ 2^{2(m-n)}/2^{4+2(m-n)}$

STORE μ_P

$PL12_D \leftarrow (MUEARTH + X2)_D$

SHIFTED $@\ 2^{43}/2^{37}$

FORM $\frac{\mu_P - (v')^2 r'}{r'}$

$MPAC_D \leftarrow \frac{PL12_D - (VCV_V \cdot VCV_V)PL36_D}{PL2_D}$

$@\ 2^{14+m}/2^{10+m}$

FORM $-\frac{1}{6}\left(\frac{1}{r'} - \alpha\right)s^2 = \frac{1}{6}\left(\frac{\mu_P - (v')^2 r'}{r'}\right)\left(\frac{1}{(r')^2}\right)\left(\frac{\Delta t}{2}\right)^2$

$MPAC_D \leftarrow DP2/3_D \cdot MPAC_D \cdot PL10_D$

SHIFTED $@\ 2^{15+2(m-n)}$

$DP2/3 = \frac{1}{6}\ @\ 2^{-2}$

FORM $(-m)-(-n) = n-m$

$X1 \leftarrow X1 - S1$

FORM $2(\gamma s)^2 - \frac{1}{6}\left(\frac{1}{r'} - \alpha\right)s^2$

$MPAC_D \leftarrow PL8_D + MPAC_D$

SHIFTED $@\ 2^{7+m-n}$

FORM $-\gamma s + 2(\gamma s)^2 - \frac{1}{6}\left(\frac{1}{r'} - \alpha\right)s^2$

$MPAC_D \leftarrow -(PL6_D) + MPAC_D$

$@\ 2^{7+m-n}$

FORM $x' + s\left[-\gamma s + 2(\gamma s)^2 - \frac{1}{6}\left(\frac{1}{r'} - \alpha\right)s^2\right]$

$MPAC_D \leftarrow XKEP_D + PL0_D \cdot PL4_D \cdot MPAC_D$

SHIFTED $@\ 2^{17}/2^{16}$

$PL0_D \cdot PL4_D = \sqrt{\mu_P} \cdot \frac{1}{r'}\left(\frac{\Delta t}{2}\right) = s$

EXCHANGE $MPAC_D$ AND $PL4_D$

STORE PRECEDING CALCULATION IN $PL4_D$
LOAD $MPAC_D$ WITH $\frac{1}{r'}\left(\frac{\Delta t}{2}\right)$

NEXT SHEET

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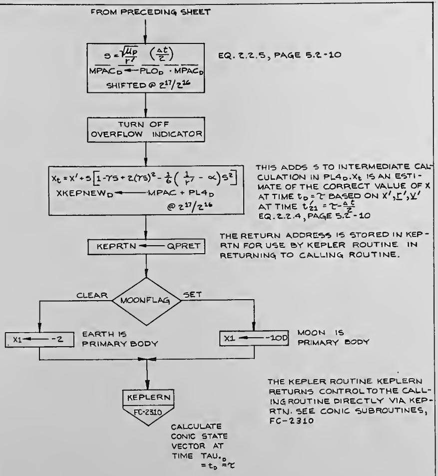

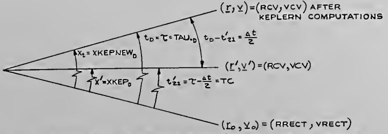

$X', \underline{r}', \underline{v}'$ CORRESPOND TO THE PREVIOUS TIME t'_{21}. A VALUE OF X FOR TIME t_D IS CALCULATED BY A TAYLOR EXPANSION TYPE METHOD FOR AN INTERVAL OF TIME $\frac{\Delta t}{2} = t_D - t'_{21}$ TO GET AN ESTIMATE X_t FOR TIME t_D.

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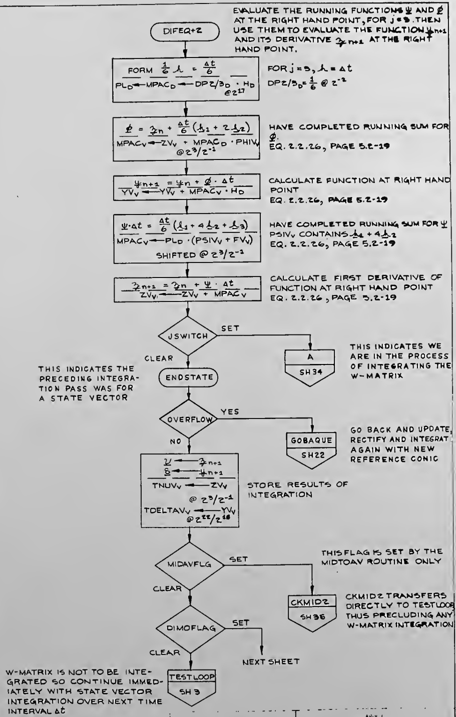

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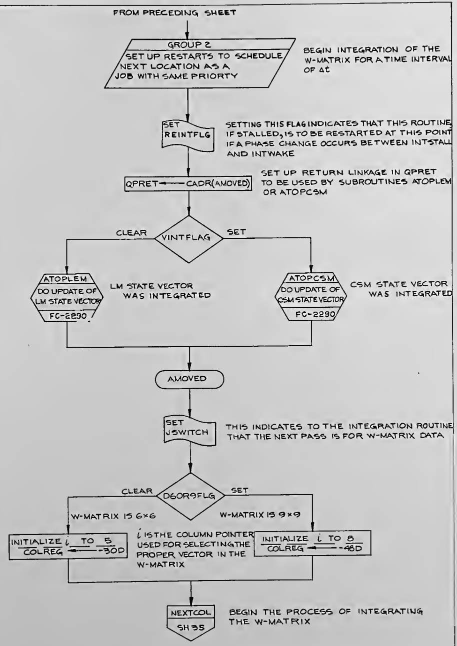

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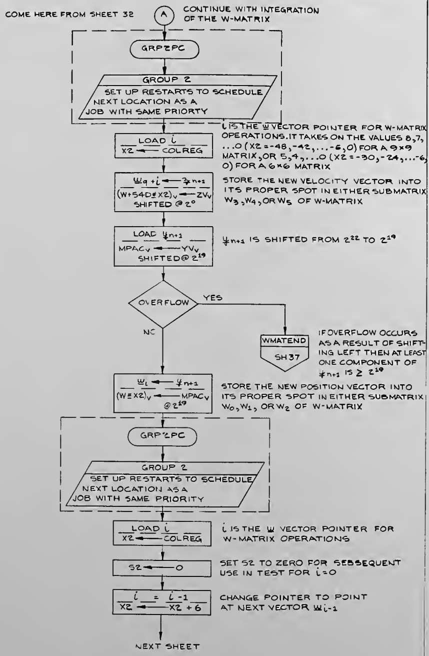

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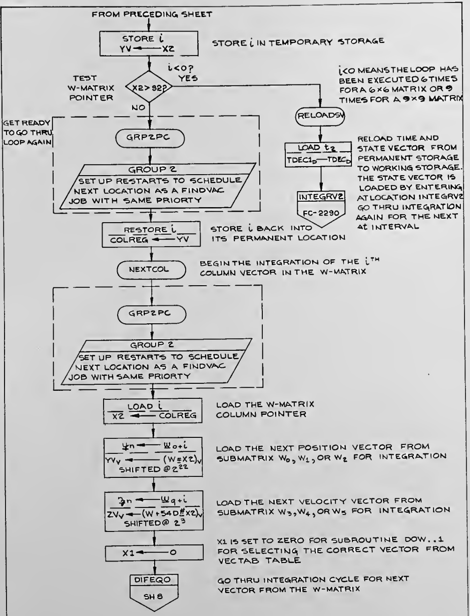

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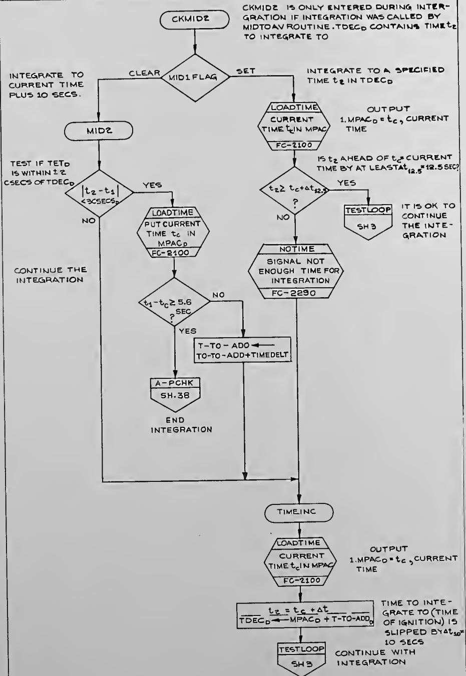

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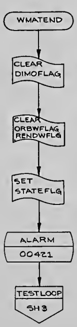


THIS ROUTINE IS ENTERED FROM DIFEQ+2 IF OVERFLOW OCCURRED DURING INTEGRATION OF THE W-MATRIX. THIS ROUTINE ENDS W-MATRIX INTEGRATION.

BECAUSE OVERFLOW OCCURRED THIS FLAG IS CLEARED SO THE INTEGRATION ROUTINE WILL NO LONGER INTEGRATE THE W-MATRIX AS IT CONTINUES INTEGRATING THE STATE VECTOR.

CLEAR BOTH FLAGS TO INDICATE TO BOTH ORBITAL NAVIGATION AND RENDEVOUS NAVIGATION THAT THE W-MATRIX IS INVALID

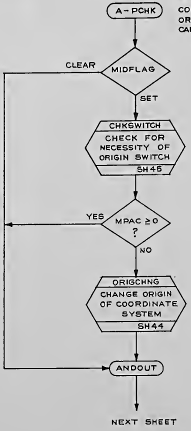
SET FLAG TO FORCE A STATE VECTOR UPDATE IN A-PCHK, SHEET 34

ALARM 00421 INDICATES A W-MATRIX OVERFLOW

CONTINUE INTEGRATING WITHOUT THE W-MATRIX

A-PCHK CHECKS TO SEE IF AN UPDATE IS DESIRED AND, IF SO, PERFORMS IT.

COME HERE FROM POOHCHK IF $|\Delta t| \leq 2$ CSEC OR IF $\Delta t < \Delta t_{MAX}$ AND INTEGRATION WAS CALLED BY P00



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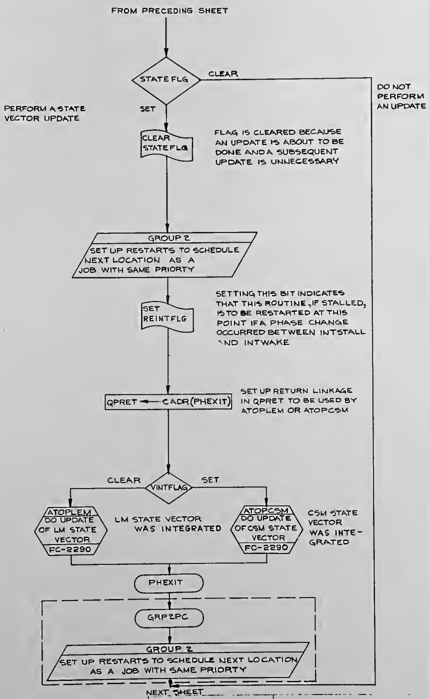

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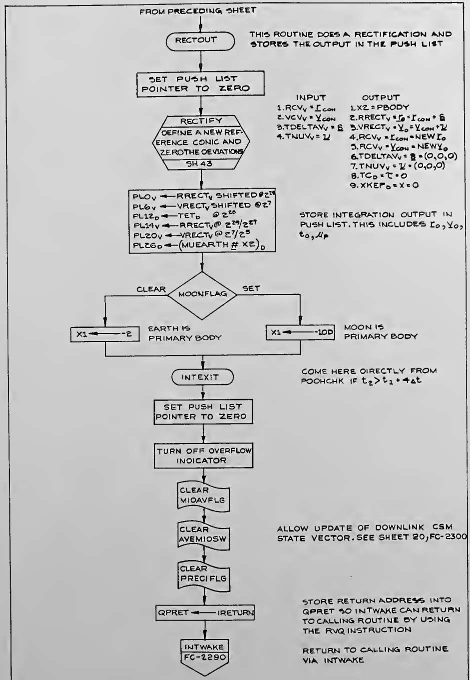

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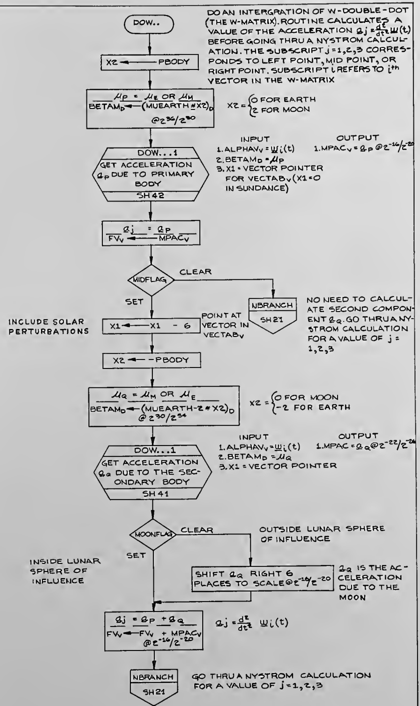
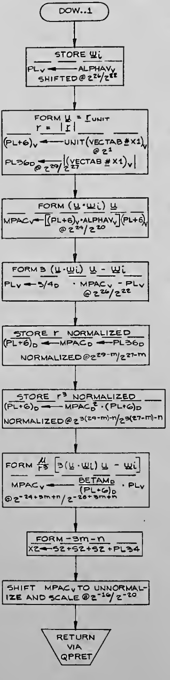
DRAWN J. S. Chmelewski 7 NOV 68	
ANALYST Wm. M. Robertson 26 SEPT 69	COLOSSUS FC-2300
APPROVED Roberta M. Eaton 9-23-69	REV 1 40 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D. S. Chmielecki 8 NOV 68	ORBITAL INTEGRATION
CHECKED	
ANAL. Wm. M. Robertson 22 SEPT 69	COLOSSUS
ENGR.	FC-2300
APPROVED Robert M. Eaton 9-23-69	REV 1	SHEET 41 OF 50



CALCULATE THE ACCELERATION COMPONENT a_p OR a_q FOR A GIVEN $\underline{w}_i$

X1 IS A POINTER USED TO SELECT EITHER $\underline{r}(t)$ OR $\underline{r}_{ac}(t)$ FROM A TABLE. IN SUNDANCE X1=0.

PROJECT $\underline{w}_i$ ONTO $\underline{r}$ WHERE $\underline{u} \cdot \underline{w}_i$ IS THE MAGNITUDE OF $\underline{w}_i$ IN THE DIRECTION OF $\underline{r}$.

$3/4 = 3.0 @ 2^2$

THE NORMALIZING COUNT −m IS STORED IN S2

THE NORMALIZING COUNT −n IS STORED IN PL34.

THIS IS THE ACCELERATION COMPONENT a_p OR a_q. EQ 2.2.31, PAGE 5.2-23

−3m−n IS THE UNNORMALIZING COUNT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

8NOV68

12SEPT69

9.23.69

ORBITAL INTEGRATION

COLOSSUS

1

FC-2300

42 / 50

THE RECTIFY SUBROUTINE IS CALLED BY THE INTEGRATION ROUTINE AND OCCASIONALLY BY THE MEASUREMENT INCORPORATION ROUTINES TO DEFINE A NEW REFERENCE CONIC.

(RECTIFY)

X2 ← PBODY — PRIMARY BODY INDICATOR = { 0 FOR EARTH, 2 FOR MOON }

$MPAC_V$ ← $TDELTAV_V$ SHIFTED FROM $2^{22}/2^{18}$ TO $2^{29}/2^{27}$ — LOAD $\underline{\delta}$

$\underline{r}_0 = \underline{r}_{CON} + \underline{\delta}$; $RRECT_V$ ← $MPAC_V$ ← $RCV_V + MPAC_V$ @ $2^{29}/2^{27}$ — COMPUTE THE RECTIFIED POSITION VECTOR

$\underline{r}_{CON} = \underline{r}_0$; RCV_V ← $MPAC_V$ @ $2^{29}/2^{27}$ — THIS DEFINES THE NEW CONIC POSITION VECTOR

$MPAC_V$ ← $TNUV_V$ SHIFTED FROM $2^3/2^{-1}$ TO $2^7/2^5$ — LOAD $\underline{\nu}$

$\underline{v}_0 = \underline{v}_{CON} + \underline{\nu}$; $MPAC_V$ ← $VCV_V + MPAC_V$ @ $2^7/2^5$ — COMPUTE THE RECTIFIED VELOCITY VECTOR

(MINIRECT) — ENTRY POINT FROM ROUTINES THAT REQUIRE $\underline{\delta}$, $\underline{\nu}$ TO BE INITIALLY ZERO

STORE $\underline{v}_0$; $VRECT_V$ ← $MPAC_V$ @ $2^7/2^5$

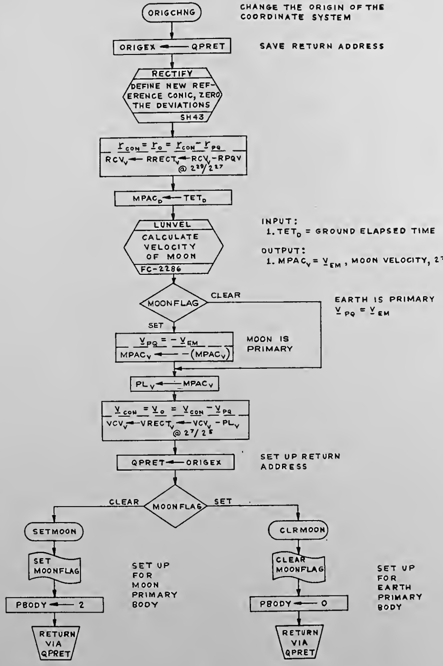
(RECTIFY +13D)

$\underline{v}_{CON} = \underline{v}_0$; VCV_V ← $MPAC_V$ @ $2^7/2^5$ — THIS DEFINES THE NEW CONIC VELOCITY VECTOR

$\underline{\delta} = (0,0,0)$
$\underline{\nu} = (0,0,0)$
$\tau = 0$
$x = 0$
$TDELTAV_V$ ← $ZEROVEC_V$
$TNUV_V$ ← $ZEROVEC_V$
TC_D ← $ZEROVEC_D$
$XKEP_D$ ← $ZEROVEC_D$
— ZERO THE DEVIATIONS, TIME SINCE RECTIFICATION τ AND UNIVERSAL VARIABLE X.

RETURN VIA QPRET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN F. S. Chmielewski 8 NOV 68	ORBITAL INTEGRATION
ANAL. Wm. M. Robertson 22 SEPT 69	COLOSSUS — DOCUMENT No. FC-2300
APPR'D Robert M. Satin 9-23-69	REV 1 — SHEET 43 OF 5?



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN A. J. Smith 4 APR 69
Wm. M. Robertson
Roberta M. Eutes 9-23-69

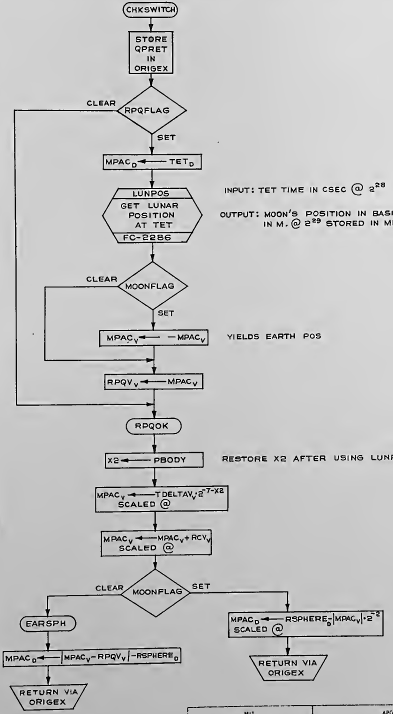
ORBITAL INTEGRATION

COLOSSUS

REV 1

DOCUMENT FC-2300

SHEET 44 OF 50



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietrich 9 JUNE 69	ORBITAL INTEGRATION
PROJMR	DOCUMENT NO.
ANALYST Wm. M. Robertson 22 SEPT 69	COLOSSUS 2D FC-2300
DOCMR	
APPR'D Roberta M. Eaton 9-23-69	REV 1 SHEET 45 OF 50

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. 5
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 t 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. 11
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
DIMOFLAG (1 3)	INTEGRATE THE W-MATRIX	DO NOT INTEGRATE THE W-MATRIX		SH. 37	SH 9 12 32
D6OR9FLG (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. 6 10 38 41
PRECIFLG (8. 3)	CSMPREC OR LEMPREC CALLED	INTEGRV 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

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
RPQFLAG (15, 8)	CALCULATE THE VECTOR RPQ	DO NOT CALCULATE THE VECTOR RPQ	SH. 22		SH. 44
MIDAVFLG (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		
MID1FLAG (3, 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
$DT/2_D$	t	TIME INTERVAL FOR ONE INTEGRATION CYCLE	CSEC	CSEC	2^{20}
$TDECI_D$	t_2	TIME TO INTEGRATE TO	CSEC	CSEC	2^{26}
RCV_V	$\underline{r}_{con}$	CONIC POSITION VECTOR	M	M	$2^{29}/2^{27}$
VCV_V	$\underline{v}_{con}$	CONIC VELOCITY VECTOR	M/CSEC	M/CSEC	$2^7/2^5$
TET_D	t	TIME OF VALIDITY OF STATE VECTOR	CSEC	CSEC	2^{28}
$RRECT_V$	$\underline{r}_o$	POSITION VECTOR AT RECTIFICATION	M	M	$2^{29}/2^{27}$

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$VRECT_V$	$\underline{v}_o$	VELOCITY VECTOR AT RECTIFICATION	M/CSEC	M/CSEC	$2^7/2^5$
$TDELTAV_V$	$\underline{\delta}$	POSITION DEVIATION VECTOR	M	M	$2^{22}/2^{18}$
$TNUV_V$	$\underline{\nu}$	VELOCITY DEVIATION VECTOR	M/CSEC	M/CSEC	$2^3/2^{-4}$
TC_D	t_{21}	TIME SINCE RECTIFICATION	CSEC	CSEC	2^{28}
$XKEP_D$	x	UNIVERSAL VARIABLE	$M^{1/2}$	$M^{1/2}$	$2^{17}/2^{16}$
YV_V	$\underline{\delta}$	INTERMEDIATE VALUE OF $\underline{\delta}$	M	M	$2^{22}/2^{18}$
ZV_V	$\underline{\nu}$	INTERMEDIATE VALUE OF $\underline{\nu}$	M/CSEC	M/CSEC	$2^3/2^{-4}$
DIFEQCNT	j	SUBSCRIPT FOR LEFT, MID, AND RIGHT POINTS	INTEGER	INTEGER	
$ALPHAV_V$	$\underline{\alpha}_j$	INTERMEDIATE VALUE OF $\underline{\delta}$	M	M	$2^{22}/2^{18}$
H_D	h	RUNNING TIME INCREMENT EQUALS 0, Δ 1/2, Δt	CSEC	CSEC	2^{19}
EV_V	$\underline{f}_j$	VALUE OF SECOND DERIVATIVE AT POINT j	$M/(CSEC)^2$	$M/(CSEC)^2$	$2^{-16}/2^{-20}$
$BETAV_V$	$\underline{\beta}_j$	INTERMEDIATE VALUE OF r_o	M	M	2^{29} 2^{27}
$VECTAB_V$	$\underline{\beta}_j$	WORKING STORAGE FOR $\underline{\beta}_j$	M	M	$2^{29}/2^{27}$
$ALPHAM_D$	α_j	$\lvert\underline{\alpha}_j\rvert$, MAGNITUDE OF $\underline{\alpha}_j$	M	M	2^{29} 2^{27}
$BETAM_D$	β_j	$\lvert\underline{\beta}_j\rvert$, MAGNITUDE OF $\underline{\beta}_j$	M	M	$2^{29}/2^{27}$
UZ_V	$\underline{u}_z$	UNIT VECTOR IN DIRECTION OF ROTATION AXIS			2^1
$COSPHI/2_D$	COS φ	COSINE OF COALTITUDE φ			2^1
$URPV_V$	$\underline{u}_r$	UNIT VECTOR OF POSITION IN MOON COORDINATES			2^1
$TVEC_V$	$\underline{a}_v$	THE DISTURBING ACCELERATION	$M/(CSEC)^2$	$M/(CSEC)^2$	
$TAU._D$	t_D	DESIRED TRANSFER TIME	CSEC	CSEC	2^{28}
$PHIV_V$	$\underline{\varphi}$	RUNNING SUM OF $\underline{k}_1+2\underline{k}_2$	$M/(CSEC)^2$	$M/(CSEC)^2$	2^{-13} 2^{-17}
$PSIV_V$	$\underline{\psi}$	RUNNING SUM OF $\underline{k}_1+\underline{k}_2+\underline{k}_3$	$M/(CSEC)^2$	$M/(CSEC)^2$	2^{-13} 2^{-17}
PBODY	P	PRIMARY BODY INDICATOR	INTEGER	INTEGER	
$XKEPNEW_D$	x	INITIAL ESTIMATE OF NEW VALUE OF x	$M^{1/2}$	$M^{1/2}$	2^{17} 2^{16}
W_M	W	W-MATRIX	M, M/CSEC	M, M/CSEC	2^{19}, 2^0

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$.3D_D$			.3	.3	2^2
$DT/2MAX_D$		LIMIT ON SIZE OF t	1000 SEC	100,000 CSEC	2^{20}
$DT/2MIN_D$	ϵ_t	MINIMUM VALUE OF t ALLOWED	3 CSEC	3 CSEC	2^{20}
$3/4_D$			0.75	3	2^2
$RECRATIO_D$			0.01	.01	2^0
$ZEROVEC_V$		(0, 0, 0)	(0.0, 0.0, 0.0)		
RDE_D	r_{DE}	RADIUS OF RELEVANCE OF EARTH	80467200 M	SAME	2^{29}
RDM_D	r_{DM}	RADIUS OF RELEVANCE OF MOON	16093440 M	SAME	2^{27}
$3/5_D$			3/5	.6	2^2
$ZUNIT_V$		(0, 0, 1)	(0.0, 0.0, 1.0)	(0.0, 0.0, 0.5)	2^I
$3/32_D$			3.0	3.0	2^5
$15/16_D$			15.0	15.0	2^4
$7/12_D$			7/3	.5833...33	2^0
$2/3_D$			4/3	.666...67	2^0
$9/16_D$			9/4	9.0	2^4
$5/128_D$			5/4	5.0	2^7
$J4REZ/J3_D$	$\frac{J_{4E} r_E}{J_{3E}}$	RATIO OF COEFFICIENTS OF FOURTH AND THIRD HARMONICS OF EARTH'S POTENTIAL FUNCTION	4991607.391	SAME	2^{26}
$2J3RE/J2_D$	$\frac{J_{3E} r_E}{J_{2E}}$	RATIO OF COEFFICIENTS OF THIRD AND SECOND HARMONICS OF EARTH'S POTENTIAL FUNCTION	13554.26363	SAME	2^{27}
$J2REQSQ_D$	$J_{2E} r_E^2 \mu_E$	SECOND HARMONIC, RADIUS AND MU OF EARTH	1.75501139 $\times 10^{21}$	SAME	2^{72}
$J2REQSQ_D$ -2	$J_{2M} r_M^2 \mu_M$	SECOND HARMONIC, RADIUS AND MU OF MOON	.3067493316 $\times 10^{18}$	SAME	2^{60}
$5/8_D$			5.0	5.0	2^3
$3J22R2MU_D$	$3. I_{22M} r_M^2 \mu_M$		9.20479048 $\times 10^{-16}$	SAME	2^{58}
$DQUARTER_D$			1.0	0.25	2^0
$HALFDP_D$			2.0	0.5	2^0
THREE/8			3.0	0.375	2^0

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	L. ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$MUEARTH_D$	μ_E	GRAVITATIONAL PARAMETER OF EARTH	3.986032×10^{10} $M^3/CSEC^2$	SAME	2^{36}
$MUEARTH_D$ -2	μ_M	GRAVITATIONAL PARAMETER OF MOON	4.902778×10^{8} $M^3/CSEC^2$	SAME	2^{30}
$MUEARTH_D$ -4	μ_S	GRAVITATIONAL PARAMETER OF SUN	$1.32715445 \times 10^{16}$ $M^3/CSEC^2$	SAME	2^{54}
DP2/3			1/6	.66...67	2^0
3CSECS			3 CSEC	3 CSEC	2^{28}
RME_D	r_{ME}	RADIUS OF INFLUENCE OF EARTH	7178165 M	SAME	2^{29}
RMM_D	r_{MN}	RADIUS OF INFLUENCE OF MOON	2538090 M	SAME	2^{27}

PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
$504LM_V$	M	MOON LIBRATION VECTOR				

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CAMBRIDGE, MASS.
DRAWN A. J. Longillo 26NOV68
ANAL Wm. M. Robertson 22NOV68
APPRD Robert M. Eiler 8-23-69

ORBITAL INTEGRATION

COLOSSUS 2D

FC-2300

TFFCONIC SUBROUTINES, AND DELRSPL

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
SIGNMPAC	2100	AFFIXES SIGN OF MPAC TO POSMAX	SH. 9
GETERAD	2280	COMPUTE RADIUS ON FISCHER ELLIPSOID, GIVEN A PARTICULAR LATITUDE	SH. 12
LALOTORV	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 $\overline{RN}$ AND VELOCITY $\overline{VN}$ TO A RADIUS LENGTH SPECIFIED BY RTERM, SUPPLIED BY THE USER IN MPAC. THE POSITION $\overline{RN}$ 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, $\overline{UNITR}$, CALCULATE A NEW $\overline{UNITR}$ THAT IS ROTATED THROUGH TRANSFER ANGLE, THETA, ALONG TRAJECTORY. THEN CALCULATE SIN(LAT) AND USE TO OBTAIN FISCHER RADIUS.	SH. 12
DELRSPL:	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

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 (E.G.) IS RELATED TO THE UNNORMALIZED CMC VARIABLE IN M BY: $TFFM = M2^{-X1}$ AND $M = NORM_{X1}(TFFM)$.

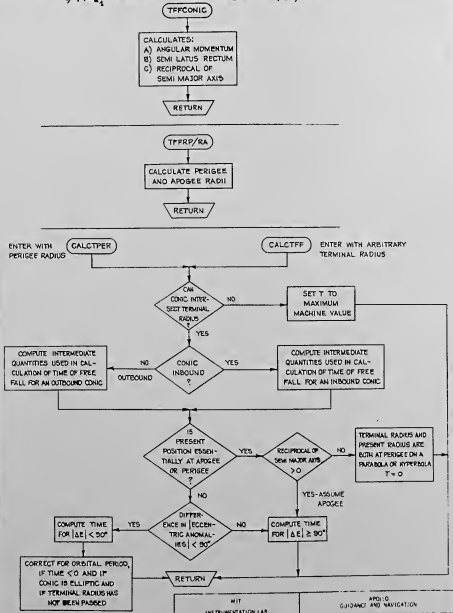
R30 APPLICATION: THE SPHERICAL VALUES OF GRAVITATIONAL CONSTANT μ ARE USED DEPENDING ON EARTH/MOON CENTERED COORDINATES:

EARTH: $1/\sqrt{\mu_E} = .50087529 \times 10^{-5}$ @ 2^{-17} $CS/(M)^{3/2}$

MOON: $1/\sqrt{\mu_M} = .45162595 \times 10^{-4}$ @ 2^{-14} $CS/(M)^{3/2}$

ENTRY APPLICATION: IN COLOSSUS P61 (FC-2760), A MODIFIED VALUE OF μ ACCOUNTING FOR NEAR EARTH PERTURBATIONS MAY BE USED:

$1/\sqrt{\mu_{E_1}} = .5005750271 \times 10^{-5}$ @ 2^{-17} $CS/(M)^{3/2}$

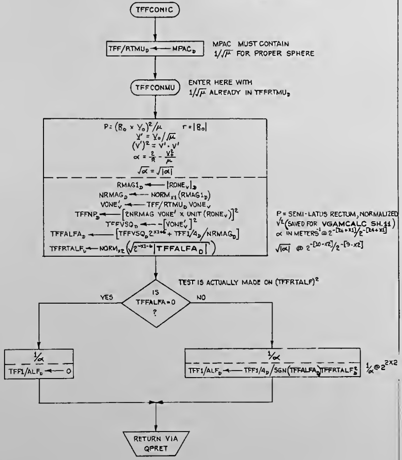


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 2 DEC 68	TIME OF FREE FALL
PROGMR [signature] 9/26/69	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2320
DOCMR [signature] 12-4-68	
APPR'D [signature] 2 APRIL 69	REV 1 — SHEET 2 OF 20

CALLED BY V82 SEQUENCE (FC-2650) OR 561.2 (FC-2760) TO COMPUTE THOSE CONIC PARAMETERS REQUIRED BY THE TFF SOUBROUTINES AND ESTABLISH THEM IN THE PUSH LIST AREA.

INPUTS: $RONE_V = R_0$ = PRESENT POSITION VECTOR IN METERS @ $2^{27}/2^{29}$
$VONE_V = V_0$ = PRESENT VELOCITY VECTOR IN M/CSEC @ $2^5/2^7$
$TFFRTMU_D = 1/\sqrt{\mu}$ FOR MOON OR EARTH

OUTPUTS: $RMAG1_D = |R_0|$
$NRMAG_D$ = (PL32) = $RMAG2^{-X1}$
$TFFNP_D$ = PL28D = P = SEMI-LATUS RECTUM
$VONE'_V = V_0/\sqrt{\mu}$
$TFFVSQ_D = V'^2$ = PL20D
TFFALFA = α = (SEMI MAJOR AXIS)$^{-1}$ = PL26D
TFFRTALF = $\sqrt{\alpha}$ = PL24D
TFF1/ALF = $1/\alpha$ = PL22D
X1 = −NORM COUNT OF $RMAG_D$
X2 = −NORM COUNT OF $\sqrt{\alpha}$



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CAMBRIDGE MASS.

DRAWN A.C. WILLIAMS 3DEC68
PROGMR R. Bairnsfather 9/26/69
ANALYST
DOCMR D. Eyles 2-4-69
APPR'D John A. Moore 2 AUG 69

APOLLO
GUIDANCE AND NAVIGATION

TIME OF FREE FALL

COLOSSUS IIC

DOCUMENT NO. FC-2320

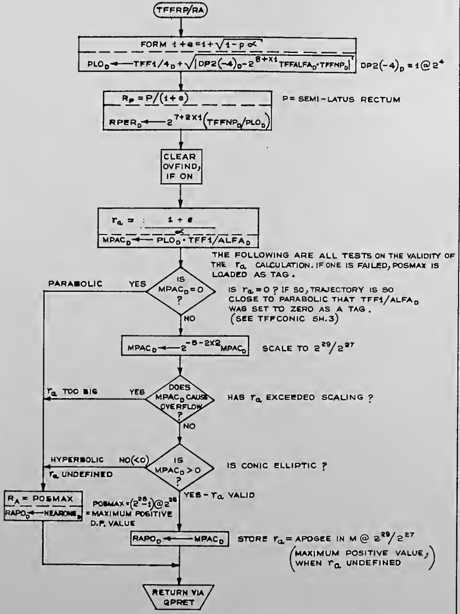
REV 1

SHEET 3 OF 20

CALLED BY V82 SEQUENCE (FC-2650).
CALCULATES APOGEE AND PERIGEE FOR A GENERAL CONIC.

INPUT: $TFFNP_D$ = SEMI-LATUS RECTUM
$TFFALFA_D$ = RECIPROCAL SEMI-MAJOR AXIS
X1, X2
} FROM TFFCONIC

OUTPUT: $RAPO_D$ = APOGEE
$RPER_D$ = PERIGEE
} IN METERS @ $2^{29}/2^{27}$

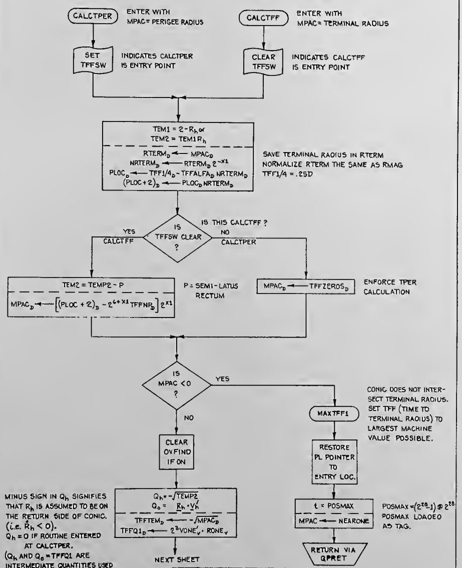


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature]	TIME OF FREE FALL
PROGR [signature] 7/26/69	
ANALYST	COLOSSUS IIC DOCUMENT NO FC-2320
DCY MGR	
APPR'D [signature: Robert M. Estes] 9-30-69	REV 1 SHEET 4 OF 20

CALLED BY V82 SEQUENCE (FC-2650) AND
S61.2 (FC-2760).
CALCULATES THE TIME OF FREE FALL FLIGHT FROM PRESENT POSITION (RN) AND VELOCITY (VN) TO A RADIUS LENGTH SPECIFIED BY R_h, SUPPLIED BY THE USER.

INPUT: MPAC = PERIGEE OR TERMINAL RADIUS (R_h)
TFFALFA, TFFNP, RMAG, NRMAG, X1, X2, TFF1/ALF, TFFRTALF — FROM TFFCONIC
$RONE_V$; $VONE_V$ = STATE VECTORS AT PRESENT

OUTPUT: MPAC = TIME OF FLIGHT TO PERIGEE OR TERMINAL RADIUS
NRTERM = NORMALIZED MAGNITUDE OF TERMINAL R.
TFFTEM = Y = PZ|Z| OR P/α SGN($Q_o + R_o/Z$)
TFFX = αZ^2 OR $1/\alpha Z^2$



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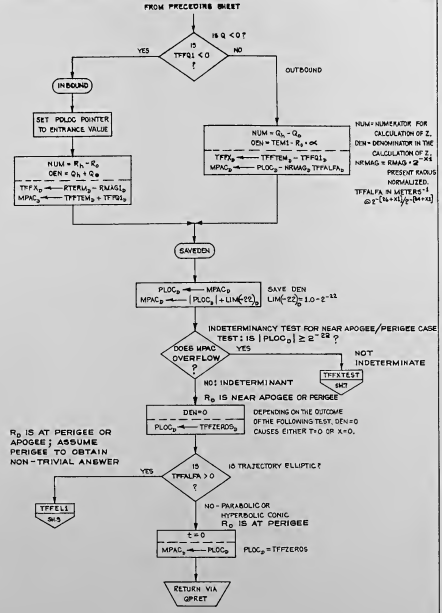
DRAWN A.C. WILLIAMS 13 DEC 68	TIME OF FREE FALL
PRGMR [signature] 2/26/69	
ANALST	
DOCMR [signature] 2-4-69	COLOSSUS IIC — DOCUMENT NO. FC-2320
APPR'D [signature]	REV 1 — SHEET 5 OF 20



MIT
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APOLLO
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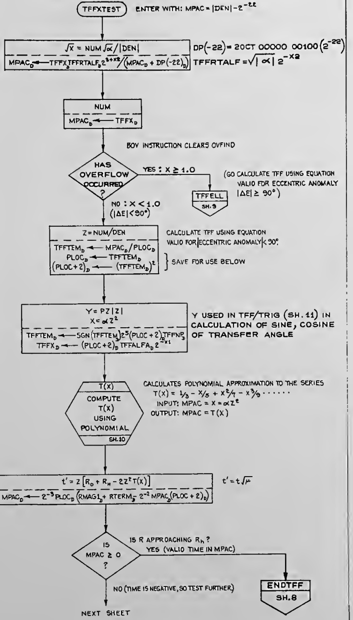
TIME OF FREE FALL

DRAWN A.C. WILLIAMS	14DEC68	
PRGMR [signature]	9/26/68	
ANALST		
DOCMR [signature]	2-4-69	
APPR'D [signature]	2 MAR 69	REV 1

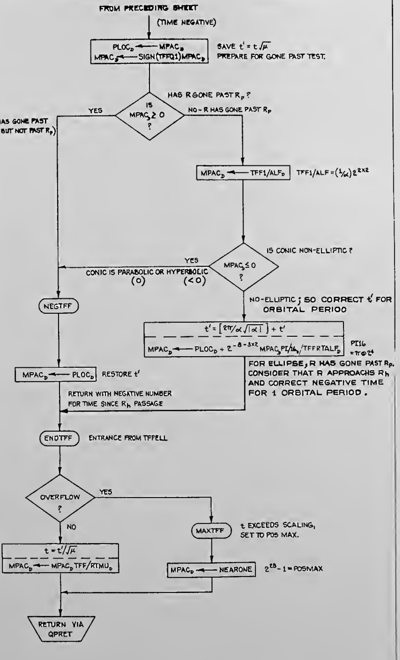
COLOSSUS IIC

DOCUMENT NO. FC-2320

SHEET 6 OF 20



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS	5DEC68	TIME OF FREE FALL
PRGMR (signature)	1/26/69	
ANALYST		COLOSSUS IIC — DOCUMENT NO. FC-2320
DOCMR (signature)	2-4-69	
APPR'D (signature)		REV 1 — SHEET 7 OF 20



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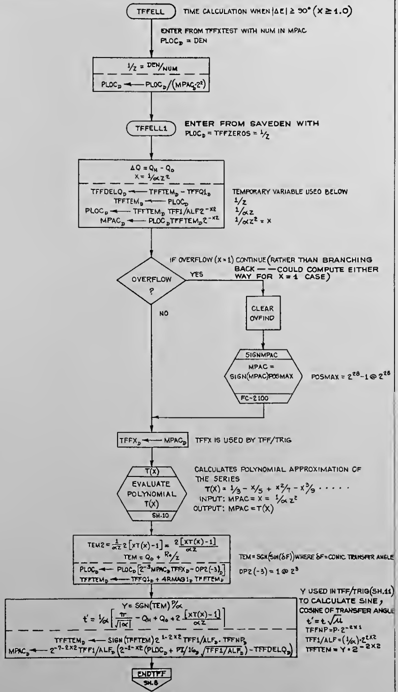
DRAWN A.C.WILLIAMS	6DEC68	TIME OF FREE FALL
PRGMR [signature]	9/26/68	COLOSSUS IIC
ANALST		DOCUMENT NO. FC-2320
DOCMR [signature]	2-4-69	
APPR'D [signature]	[illegible]	REV 1
		SHEET 8 OF 20



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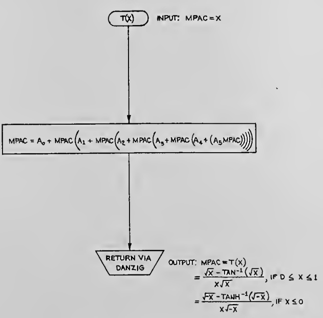
DRAWN A.C.WILLIAMS 9DEC68 PRGMR [signature] 2/26/69 ANALST DOCMR [signature] 3-4-69 APPR'D [signature] 2 APR 69	TIME OF FREE FALL COLOSSUS IIC DOCUMENT NO. FC-2320 REV 1 SHEET 5 OF 20



T(X) = POLYNOMIAL APPROXIMATION TO THE SERIES:

$1/3 - X/5 + X^2/7 - X^3/9 \cdot\cdot\cdot\cdot\cdot$

POLYNOMIAL IS OF 5[TH] ORDER, HAVING COEFFICIENTS

$A_0 = 1/3$
$A_1 = -1.999819135$ E-1
$A_2 = 1.418148467$ E-1
$A_3 = -1.01310997$ E-1
$A_4 = 5.609004986$ E-2
$A_5 = -1.536156925$ E-2

RANGE OF POLYNOMIAL FIT X = (0, +1). MAXIMUM DEVIATION OF FIT 2E-5.
RANGE OF X SATISFYING ABOVE DEVIATION IS (−.08, +1).

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ANALST		COLOSSUS IIC — DOCUMENT NO. FC-2320
DOCMR [signature]	2-4-69	
APPR'D [signature]	21APR 69	REV 1 — SHEET 10 OF 20

USED BY P61 ENTRY DISPLAY (FC-2760)

CALCULATE SIN(δf), COS(δf) FROM DATA LEFT IN PUSHLIST BY TFF SUBROUTINES. (δf = TRANSFER ANGLE)

(TFF/TRIG)

↓

$$\cos(\delta f) = 1 - 2\left|\frac{Y}{R_o R_h (1+X)}\right|$$

$$CDELF/2_D \leftarrow 1 - \left|\frac{TFFTEM_D}{NRMAG_D \cdot NRTERM_D (1 + TFFX_D)}\right|$$

INPUT:
- $NRMAG_D$ = FROM TFFCONIC
- $NRTERM_D$, $TFFX_D$, $TFFTEM_D$ } FROM CALCTFF

OUTPUT:
- $CDELF/2_D$ = COS(δf) @ 2^1
- $MPAC_D$ = SIN(δf) @ 2^1

↓

$$\sin(\delta f) = SGN(Y)\sqrt{1-\cos^2(\delta f)}$$

$$MPAC_D \leftarrow SIGN(TFFTEM_D)\sqrt{1-(CDELF/2_D)^2}$$

$TFFTEM = Y = PZ|Z|$, IF $\alpha Z^2 < 1$.

$= \left(\frac{P}{\alpha}\right) SGN\left(Q_o + \frac{R_o}{Z}\right)$, IF $\alpha Z^2 \geq 1$.

↓

RETURN VIA QPRET

USED BY P61 (FC-2760)

EARTH CENTERED VIS VIVA CALCULATIONS OF TERMINAL VELOCITY AND FLIGHT PATH ANGLE (RELATIVE TO HORIZONTAL)

(PREVGAM)

↓

NORMALIZE

$$NRTERM_D \leftarrow 2^{-X1} MPAC_D$$

($MPAC_D$ CONTAINS R_h @ $2^{29}/2^{27}$)

↓

(VGAMCALC)

INPUT:
- $NRTERM_D$, $TFFH_D$ } FROM CALCTFF
- $TFFVSQ_D$, $RMAG_D$, $NRMAG_D$ } FROM TFFCONIC

↓

$$V'_h = \sqrt{(V'_D)^2 + 2\frac{R_o - R_h}{R_o R_h}}$$

$$MPAC_D \leftarrow \sqrt{-TFFVSQ_D + \frac{NRMAG_D - NRTERM_D}{NRMAG_D \cdot NRTERM_D} 2^{-8-X1}}$$

$$PLOC_D \leftarrow MPAC_D$$

CALCULATE MAGNITUDE OF TERMINAL VELOCITY.

↓

$$V_h = \sqrt{\mu}\, V'_h$$

$$MPAC_D \leftarrow MPAC_D / TFF/RTMU_D$$

$$MPAC_D \leftrightarrow PLOC_D$$

$MPAC_D$ EXCHANGED WITH $PLOC_D$

SAVE UN-NORMALIZED VELOCITY FOR OUTPUT

↓

$$\gamma_e = \cos^{-1}\left(\frac{H'}{R_h V'_h}\right)$$

$$MPAC_D \leftarrow \cos^{-1}\left(\frac{\frac{1}{2}\sqrt{TFFNP_D}}{NRTERM_D \cdot MPAC_D}\right)$$

CALCULATE FLIGHT PATH ANGLE RELATIVE TO LOCAL HORIZONTAL.

USER MUST SUPPLY CORRECT SIGN FOR $MPAC_D$ (γ_e) ON RETURNING.

↓

RETURN VIA QPRET

OUTPUT:
- $PLOC_D$ = TERMINAL VELOCITY (V_h) IN M/CSEC @ 2^7
- $MPAC_D$ = FLIGHT PATH ANGLE AT EMS ALTITUDE (γ_e) (IN REVS @ 2^0)

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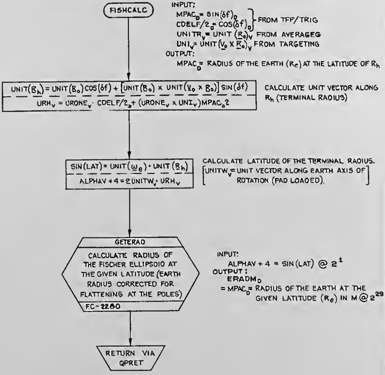
PRGMR [signature] 9/26/69	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2320
DOCMR [signature] 2-4-69	
APPR'D John A. Morse 2 APRIL 69	REV 1 — SHEET 11 OF 20

CALCULATE RADIUS OF FISCHER ELLIPSOID AT LATITUDE OF ESTIMATED TERMINAL RADIUS — USED BY P61 (FC-2760)



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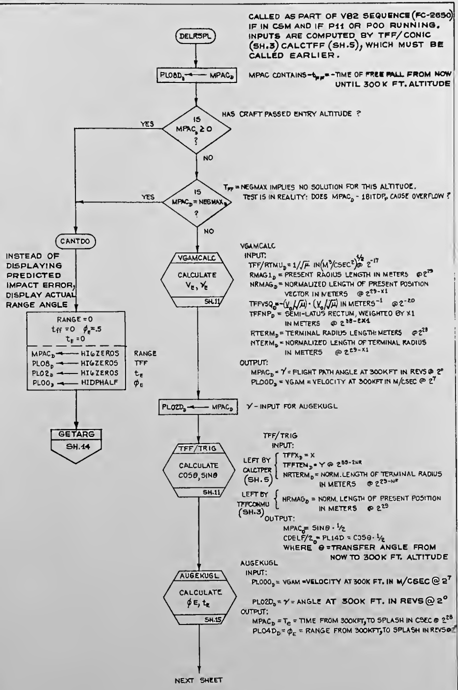
DRAWN A.C.WILLIAMS 10DEC68	TIME OF FREE FALL
PROGMR [signature] 9/26/69	
ANALYST	COLOSSUS IIC — DOCUMENT NO FC-2320
DOC MGR [signature] 2-4-69	
APPR'D [signature]	REV 1 — SHEET 12 OF 20



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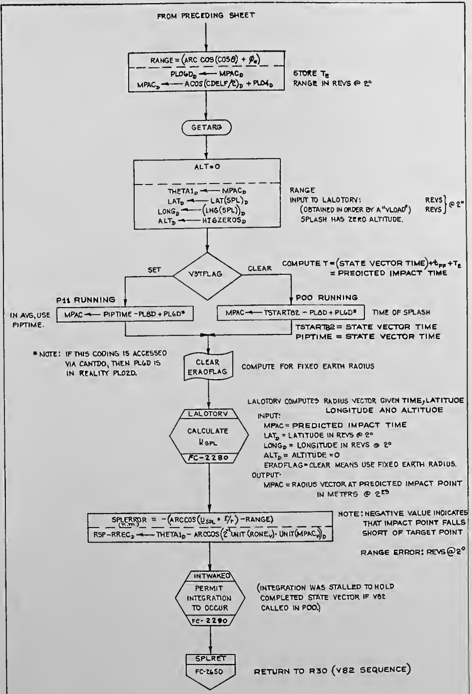
DRAWN A.C.WILLIAMS 11DEC68	TIME OF FREE FALL
PRGMR [signature] 9/26/69	
ANAL'T	COLOSSUS IIC FC-2320
DOC MR [signature] 12-4-69	
APPR'D [signature]	REV 1 SH 13 OF 20



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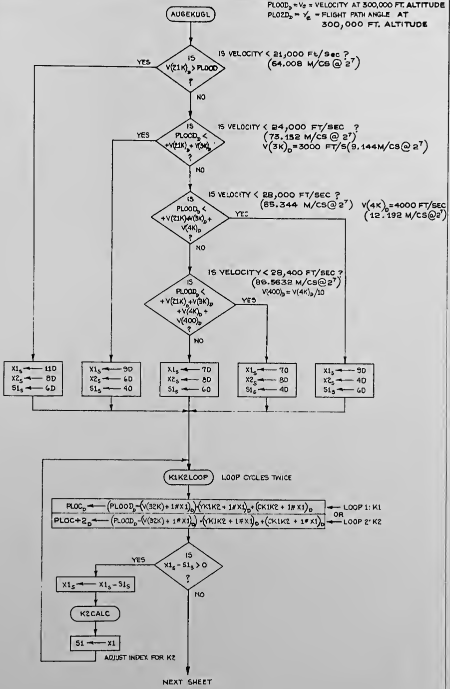
DRAWN A. C. WILLIAMS 6FEB69	TIME OF FREE FALL
PRGMR [signature] 2/26/69	
ANALYST	
DCM MGR [signature] 2-4-69	COLOSSUS IIC — DOCUMENT NO. FC-2320
APPR'D [signature] 2MAR(?)69	REV 1 — SHEET 14 OF 20



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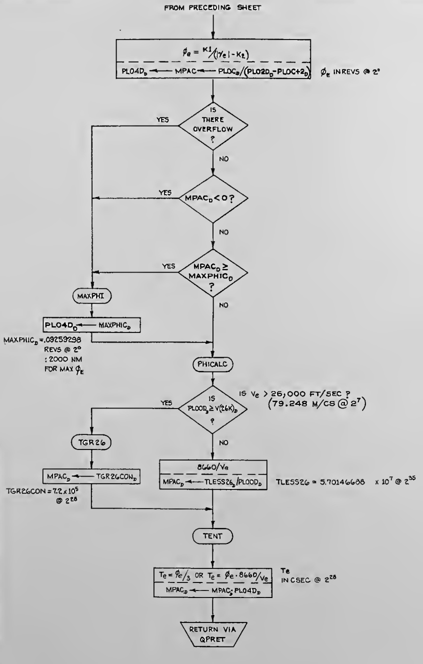
DRAWN A.C.WILLIAMS 12DEC68	
PRGMR *[signature]* 9/26/69	
ANALYST	
DOCMR *[signature]* 2-4-69	COLOSSUS IIC — FC-2320
APPR'D *John A. Moore* 2 ... 69 REV 1	SHEET 15 OF 20



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DRAWN A.C. WILLIAMS 12DEC68	TIME OF FREE FALL
PROGMR [signature] 9/26/69	DOCUMENT No. FC-2320
ANALYST	COLOSSUS IIC
DOCMR [signature] 2-7-69	
APPR'D [signature] 2 [date] 69	REV 1 SHEET 16 OF 20

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	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$ALPHAV+4_D$	SIN(LAT)	SINE OF LATITUDE OF TERMINAL RADIUS	DEGREES	REVS	2^1
ALT_D	ALT	ALTITUDE, FOR LALOTORV (EQUALS ZERO)	FEET	METERS	
$CDELF/2_D$	$COS(\delta f)$	COSINE OF TRANSFER ANGLE			2^1
LAT_D	LAT_{SPL}	INPUT FOR LALOTORV: LATITUDE	DEGREES	REVS	2^0
$LAT(SPL)_D$	LAT_{SPL}	TARGET LOCATION, LOADED INTO LAT	DEGREES	REVS	2^0
$LNG(SPL)_D$	$LONG_{SPL}$	TARGET LOCATION, LOADED INTO LONG	DEGREES	REVS	2^0
$LONG_D$	$LONG_{SPL}$	INPUT FOR LALOTORV: LONGITUDE	DEGREES	REVS	2^0
$NRMAG_D$		NORMALIZED MAGNITUDE OF $\underline{r}$	FEET	METERS	$2^{29-X1}/2^{27-X1}$
$NRTERM_D$		NORMALIZED TERMINAL RADIUS	FEET	METERS	$2^{29-X1}/2^{27-X1}$
$PIPTIME_D$	t	TIME OF STATE VECTOR COMPUTED BY AVERAGEG	SECONDS	CSEC	2^{28}
$RMAG1_D$	r	CURRENT RADIUS MAGNITUDE	FEET	METERS	$2^{29}/2^{27}$
$RONE_V$	$\underline{r}$	CURRENT RADIUS STATE VECTOR	FEET	METERS	$2^{29}/2^{27}$
$RPER_D$	r_p	MAGNITUDE OF PERIGEE	FEET	METERS	$2^{29}/2^{27}$
$RSP\text{-}RREC_D$	SPLERROR	RANGE ERROR	DEGREES	REVS	2^0

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$RTERM_D$	r_h	TERMINAL RADIUS	FEET	METERS	$2^{29}/2^{27}$
$TFFALFA_D$	α	INVERSE OF SEMI-MAJOR AXIS OF CONIC	I/FEET	1/METERS	$2^{-26+X1}/2^{-24+X1}$
$TFFDELQ_D$	$Q_h - Q_o$	TEMPORARY VARIABLE	$FEET^{1/2}$	$METERS^{1/2}$	$2^{16}/2^{15}$
$TFFNP_D$	p	SEMI-LATUS RECTUM, WEIGHTED BY X1	FEET	METERS	$2^{38+2X1}/2^{36+2X1}$
$TFFQ1_D$	Q_0	$(\underline{r}_0 \cdot \underline{v}_0)/\sqrt{\mu}$	$FEET^{1/2}$	$METERS^{1/2}$	$2^{16}/2^{15}$
$TFFRTALF_D$	$\sqrt{\alpha}$	SQUARE ROOT OF INVERSE OF SEMI-MAJOR AXIS	$1/FEET^{1/2}$	$1/METERS^{1/2}$	$2^{-10+X2}/2^{-9+X2}$
$TFFTEM_D$	$-\left(\frac{v^2}{\mu}\right)$	TEMPORARY VARIABLE LOCATION			
$TFFVSQ_D$	$-(v')^2 = -\left(\frac{v}{\mu}\right)^2$	MINUS SQUARE OF VELOCITY OVER MU	1/FEET	1/METERS	$2^{-20}/2^{-18}$
$TFFX_D$	X	$1/\alpha Z^2$ OR αZ^2			2^0
$TFF1/ALF_D$	$1/\alpha$	INVERSE OF ALPHA: SEMI-MAJOR AXIS	FEET	METERS	$2^{22-2X2}/2^{20-2X2}$
$THETA1_D$	θ	TRANSFER ANGLE	DEGREES	REVS	2^0
UNI_V	$UNIT(\underline{V}_o \times \underline{R}_o)$	UNIT NORMAL TO FLIGHT PATH PLANE			2^1
URH_V	$UNIT(\underline{R}_h)$	UNIT VECTOR OF TERMINAL			2^1
$URONE_V$	$UNIT(\underline{R}_o)$	UNIT VECTOR OF CURRENT POSITION			2^1
$VONE_V$	$\underline{V}_o$	CURRENT VELOCITY VECTOR	FEET/SEC	METERS/ CSEC	$2^7/2^5$
$VONE'_V$	$\underline{v}'$	CURRENT VELOCITY VECTOR OVER $MU^{1/2}$	$FEET^{-1/2}$	$METERS^{-1/2}$	$2^{-10}/2^{-9}$

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 DELRSPL, AND ITS SUBROUTINE AUGEKUGL. THIS IS DONE TO PRESERVE THE TEST CONSTANT TABLE, WHICH IS INDEXED.					
$DP(-22)_D$			2^{-22}	1	2^{22}
$DP2(-3)_D$	$1 @ 2^3$	ONE	$1 @ 2^3$	1	2^3
$DP2(-4)_D$	$1 @ 2^4$	ONE	$1 @ 2^4$	1	2^4
$HIDPHALF_D$	1/2		1/2	.5	2^0
$HI6ZEROS_D$	0	ZERO	00000000.0	000000.0	2^0

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$LIM(-22)_D$	$1-2^{22}$	TEST CONSTANT FOR |D|	$1-2^{22}$	$1-2^{22}$	2^0
$NEARONE_D$	$2^{28}-1$	MACHINE POSITIVE MAXIMUM	$2^{28}-1$	.999999999	2^0
$PI/16_D$	π	PI	π	π	2^4
$TFFZEROS_D$	0	ZERO	0	0	
$TFF1/4_D$	2	TWO	$2@2^3$	2	2^3

FOR DELRSPL AND AUGEKUGL

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.

$(CK1K2\ -10D)_D$		5500	$7.07304526 \times 10^{-4}$	2^0
$(CK1K2\ -8)_D$		2400	$3.08641975 \times 10^{-4}$	2^0
$(CK1K2\ -6)_D$		2400	$3.08641975 \times 10^{-4}$	2^0
$(CK1K2\ -4)_D$		-3.2	$-8.8888888 \times 10^{-3}$	2^0
$(CK1K2\ -2)_D$		1	2.7777777×10^{-3}	2^0
CK1K2		2.4	6.6666666×10^{-3}	2^0
$(CK1K2\ +2)_D$		0	0	2^0
$(CK1K2\ +4)_D$		-.443	$-1.86909989 \times 10^{-5}$	2^{-7}
$(CK1K2\ +6)_D$		0	0	2^0
$(CK1K2\ +8)_D$		.001225	$1.11639691 \times 10^{-3}$	2^{-7}
$(CK1K2\ +10D)_D$		.00105	$9.56911636 \times 10^{-4}$	2^{-7}
YK1K2		.000285	$2.59733157 \times 10^{-4}$	2^{-7}
V(400)	TEST CONSTANT	400 FT/SEC	1.2192 M/CSEC	2^7
V(28K)		28000 FT/SEC	85.344 M/CSEC	2^7
V(3K)	TEST CONSTANT	3000 FT/SEC	9.144 M/CSEC	2^7

PROGRAM CONSTANTS (CONTINUED)

DELRSPL-AUGEKUGL CONSTANTS, CONTINUED

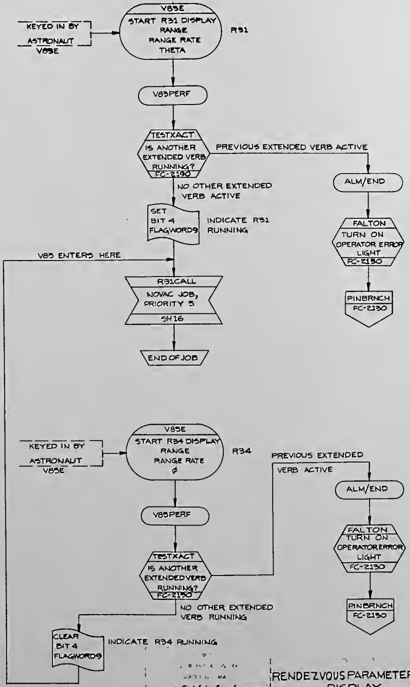
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
V(24K)			24000 FT/SEC	73.152 M/CSEC	2^7
			28000 FT/SEC	85.344 M/CSEC	2^7
V(32K)			32000 FT/SEC	97.536 M/CSEC	2^7
		END OF THE INDEXED TABLE			
V(4K)		TEST CONSTANT	4000 FT/SEC	12.192 M/CSEC	2^7
V(21K)		TEST CONSTANT	20997.3 FT/SEC	64.008 M/CSEC	2^7
TLESS26		CURVE FIT CONSTANT	8660	5.70146688×10^7	2^{35}
TGR26CON		CURVE FIT CONSTANT	PHI/3	7.2×10^5	2^{28}
V(26K)		TEST CONSTANT	26000 FT/SEC	79.248 M/CSEC	2^7
X1CON		INDEX AND STEP REGISTER INITIAL VALUES	X1 X2 S1	10D 8D 8D	2^{14}
MAXPHIC		2000 NAUTICAL MILES FOR MAXIMUM PHI ENTRY	2000 N.M.	0.09259298 REVS	2^0

RENDEZVOUS PARAMETERS DISPLAYS

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

THERE HAVE BEEN NO CHANGES FROM THE COLOSSUS II FLOWCHART FC-2325, REV. 0, TO THE COLOSSUS IIC FLOWCHART FC-2325, REV. 1

R31, R34 RENDEZVOUS PARAMETER DISPLAY

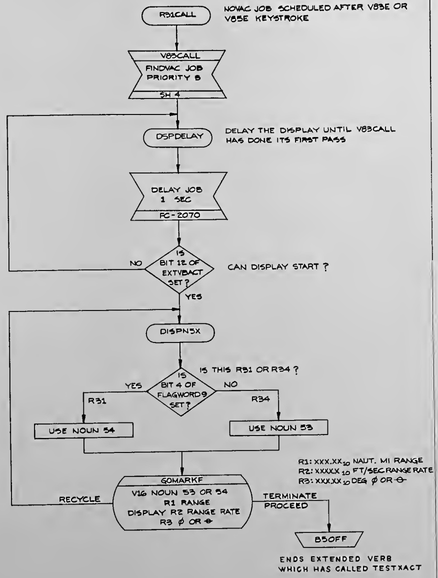


Z.S. Chmielinski 17Dec68
L.E. Crocker 25Feb69
D. Rink 25Feb69
John A. Moore 4Mar69

RENDEZVOUS PARAMETERS DISPLAY

COLOSSUS IIC FC-2325

REV 1 SHT 2 OF 14



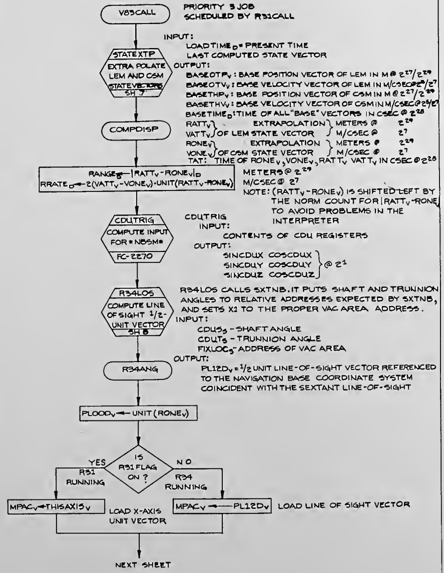
M I T
INSTRUMENTATION LAB
CAMBRIDGE MASS

DRAWN	F. S. Chmelinski	
CHCKR	T.E. Linken	28 Feb 69
ANALYST		
DOC MR	J. Reinke	28 Feb 69
APPR	John A. Moore	6 MAR 69

RENDEZVOUS PARAMETERS DISPLAY

COLOSSUS IIC FC-2325

REV 1   3   14



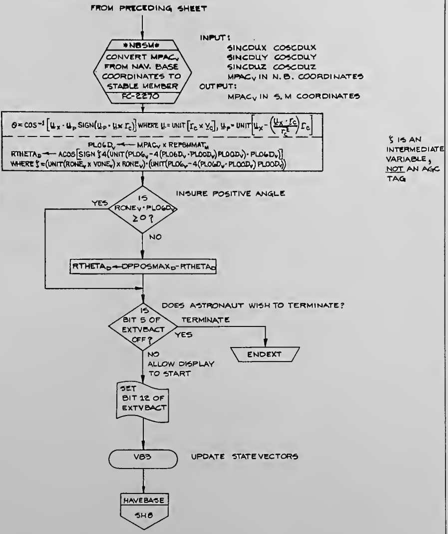
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN Z. Chmielinski 26 DEC 68
PRGMR T. E. Crocker 25 Feb 69
ANALYST
DGCMR F. Rooke 27 Feb 69
APPR'D John A. Moran 6 MAR 69

RENDEZVOUS PARAMETERS DISPLAY

COLOSSUS IIC FC-2325

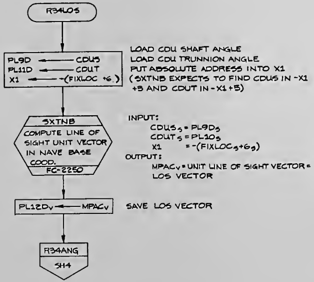
REV 1 4 14



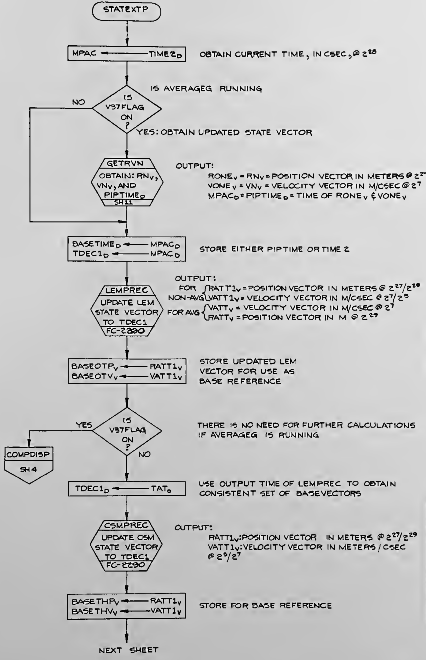
RENDEZVOUS PARAMETERS DISPLAY

COLOSSUS IIC FC-2325

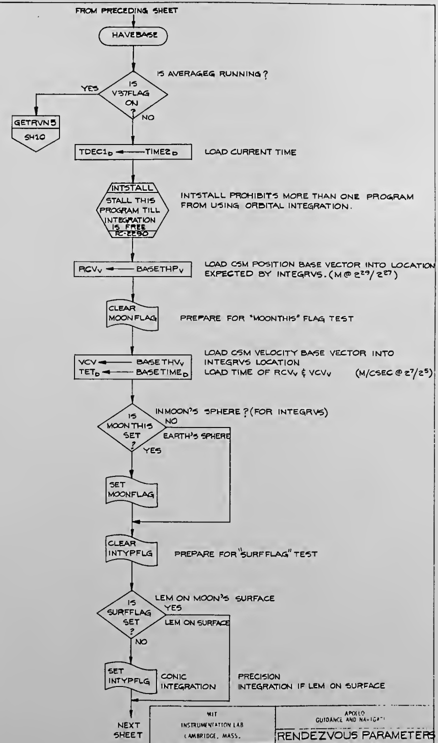
REV 1 5 14



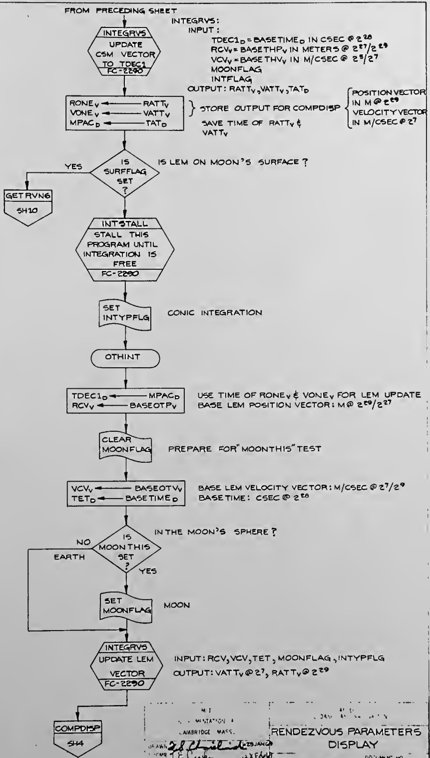
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN T.S. Chmielewski 19DEC68	RENDEZVOUS PARAMETERS DISPLAY
PRGMR I.E. Cudan 28Feb69	
ANALYST	DOCUMENT No.
DOCMR D. Reich 28Feb69	COLOSSUS IIC FC-2325
APPR'D John A. Moore 16MAR69	REV 1 SHEET 6 OF 14



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN / PRGMR / ANALYST / DOC MR / APPR'D	RENDEZVOUS PARAMETERS DISPLAY
COLOSSUS IIC	DOCUMENT NO. FC-2325
REV 1	SHEET 7 OF 14



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN J.S. Chmielewski 8 JAN 69	RENDEZVOUS PARAMETERS DISPLAY
PROGMR T.E. Crisken 25 Feb 69	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2325
DOCMR D. Reinke 27 Feb 69	
APPR'D John A. Moore 6 MAR 69	REV 1 — SHEET 8 OF 14



M.I.T.
... MENTATION ...
CAMBRIDGE, MASS.

DRAWN [signature] 23 JAN 69
CHKR I.E. Cuskan 28 Feb 69
ANALYST
DOC MGR [signature] 28 Feb 69
APPROVED John A. Moran 6 Mar 69

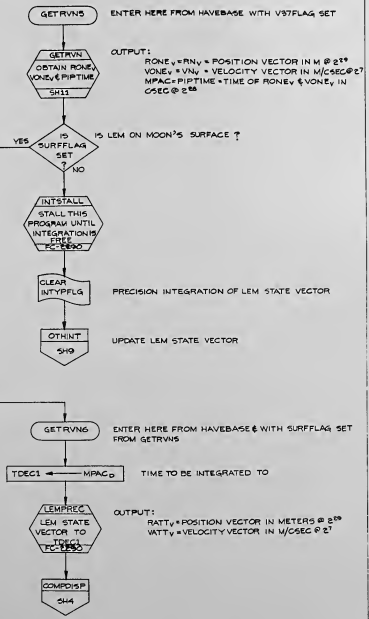
RENDEZVOUS PARAMETERS DISPLAY

COLOSSUS IIC

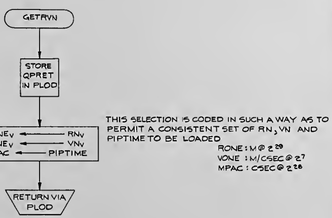
DOCUMENT NO. FC-2325

REV 1

SHEET 9 OF 14



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	A.G.C. GUIDANCE AND NAVIGATION
DRAWN / PRGMR / ANALST / DOCMR / APPR'D	RENDEZVOUS PARAMETERS DISPLAY
	COLOSSUS IIC — DOCUMENT NO. FC-2325
	REV 1 — SHEET 10 OF 14



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	GUIDANCE AND NAVIGATION
DRAWN F. E. Chingbuck / PROGMR J. E. Curran 28Feb69 / ANALYST / CHECKED D. Reinke 28Feb69 / APPROVED John A. Moore 6MAR69	RENDEZVOUS PARAMETERS DISPLAY
	COLOSSUS IIC — DOCUMENT NO. FC-2325
	REV 1 — SHEET 11 OF 14

DISPLAYS			
VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
	FALTON	TURN ON OPERATOR ERROR LIGHT: PREVIOUS EXTENDED VERB ACTIVE.	SH. 2
16-53 OR 54	GOMARKF	R1 RANGE XXX.XX D NAUT MILES R2 RANGE RATE: XXXX.X D FEET/SEC R3 θ OR φ XXX.XX D DEGREES	SH. 3

FLAGS					
NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
BIT 4 OF FLAGWORD 9	R31 RUNNING	R34 RUNNING	SH. 2	SH. 2	SH. 3
BIT 5 OF EXTVBACT	DO NOT TERMINATE EXTENDED VERB	TERMINATE EXTENDED VERB			SH. 5
BIT 12 OF EXTVBACT	START DISPN5X DISPLAY	DO NOT START DISPN5X DISPLAY	SH. 5		SH. 3
INTYPFLG	CONIC INTEGRATION	PRECISION INTEGRATION	SH. 8,9	SH. 8,9	
MOONFLAG	IN MOON'S SPHERE	IN EARTH'S SPHERE	SH. 8,9	SH. 8,9	
MOONTHIS	IN MOON'S SPHERE	IN EARTH'S SPHERE			SH. 8,9
R31FLAG	R31 RUNNING	R34 RUNNING			SH. 4
SURFFLAG	LEM ON SURFACE	LEM NOT ON SURFACE			SH. 8,9, 10
V37FLAG	AVERAGEG RUNNING	AVERAGEG NOT RUNNING			SH. 8

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS			
SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
NBSM	2270	CONVERTS NAVBASE TO STABLE MEMBER COORDINATES	SH. 5
CDUTRIG	2270	CONVERT CONTENTS OF CDU REGISTERS TO SINES AND COSINES	SH. 4
CSMPREC	2300	UPDATE CSM STATE VECTOR TO A PARTICULAR TIME	SH. 7
DELAYJOB	2070	DELAYS A JOB FOR A PARTICULAR TIME PERIOD	SH. 3
FALTON	2130	TURNS ON OPERATOR ERROR LIGHT	SH. 2
INTEGRVS	2300	ORBITAL INTEGRATION ROUTINE	SH. 9
INTSTALL	2300	STALLS CALLING PROGRAM UNTIL INTEGRATION IS NOT BEING USED, THEN STALLS ANY OTHER PROGRAMS WISHING TO USE INTEGRATION UNTIL INTWAKE IS CALLED	SH. 8,9,10
LEMPREC	2300	UPDATE LEM VECTOR TO A PARTICULAR TIME	SH. 7,10
SXTNB	2250	CHANGE SEXTANT LINE OF SIGHT TO NAVBASE COORDINATES	SH. 6
TESTXACT	2190	TEST FOR EXTENDED VERB ACTIVITY	SH. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN 28 Christ... 28 JAN 69
CHKR J E Cohen 12 Feb 69
CODMR D. Bemke 27 Feb 69
APPROVED John A. Moore 6 MAR 69

RENDEZVOUS PARAMETERS DISPLAY

COLOSSUS IIC FC-2325

REV 1

SH 12 OF 14

ERASABLE LOCATIONS USED					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$BASETOP_V$	$\underline{r}_L$	POSITION VECTOR OF LEM AT BASETIME	FEET	METERS	$2^{27}/2^{29}$
$BASEOTV_V$	$\underline{v}_L$	VELOCITY VECTOR OF LEM AT BASETIME	FEET/SEC	M/CSEC	$2^5/2^7$
$BASETHP_V$	$\underline{r}_C$	POSITION VECTOR OF CSM AT BASETIME	FEET	METERS	$2^{27}/2^{29}$
$BASETHV_V$	$\underline{v}_C$	VELOCITY VECTOR OF CSM AT BASETIME	FEET/SEC	M/CSEC	$2^5/2^7$
$BASETIME_D$		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 COSCDUY COSCDUZ	}	OUTPUT OF CDUTRIG ROUTINE			2^1
FIXLOC		ADDRESS OF VAC AREA			
$PIPTIME_D$		TIME CORRESPONDING TO CURRENT STATE VECTOR (WHEN AVERAGEG IS RUNNING)	SECONDS	CSEC	2^{28}
$RANGE_D$	RANGE	DISTANCE BETWEEN THE TWO VEHICLES	FEET	METERS	2^{29}
$RATT_V$		RADIUS VECTOR OUTPUT OF INTEGRATION	FEET	METERS	2^{29}
$RATTI_V$		SAME AS RATT, BUT VARIABLE SCALING	FEET	METERS	$2^{27}/2^{29}$
RCV_V		POSITION VECTOR FROM WHICH TO START INTEGRATION	FEET	METERS	$2^{29}/2^{27}$
$REFSMMAT_M$		TRANSFORMATION MATRIX FOR REFERENCE TO STABLE MEMBER CONVERSION			2^1
RN_V	$\underline{r}$	RADIUS VECTOR AS GIVEN BY AVERAGEG	FEET	METERS	2^{29}
$RONE_V$	$\underline{r}$	RADIUS VECTOR INPUT TO INTEGRATION	FEET	METERS	$2^{29}/2^{27}$
$RRATE_D$	RANGE RATE	RANGE RATE	FEET/SEC	M/CSEC	2^7
$RTHETA_D$	θ	THETA	DEGREES	REVS	2^0
SINCDUX SINCDUY SINCDUZ	}	OUTPUT OF CDUTRIG			2^1
TAT_D		TIME OF THE OUTPUT OF ORBITAL INTEGRATION	SECONDS	CSEC	2^{28}
$TDEC1_D$		TIME TO BE INTEGRATED TO	SECONDS	CSEC	2^{28}
TET_D		TIME TO BE INTEGRATED FROM	SECONDS	CSEC	2^{28}

ERASABLE LOCATIONS USED (CONTINUED)					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$THISAXIS_V$		UNIT X VECTOR			
$TIME2_D$		TIMING REGISTERS	SECONDS	CSEC	2^{28}
$VATT_V$		VELOCITY OUTPUT OF INTEGRATION ROUTINES	FEET/SEC	METERS/ CSEC	2^7
$VATT1_V$		VELOCITY OUTPUT OF INTEGRATION, WITH VARIABLE SCALING	FEET/SEC	M/CSEC	$2^7/2^5$
VCV_V		VELOCITY INPUT TO INTEGRATION	FEET/SEC	M/CSEC	$2^5/2^7$
VN_V		VELOCITY VECTOR, OUTPUT OF AVERAGEG	FEET/SEC	M/CSEC	2^7
$VONE_V$		VELOCITY VECTOR	FEET/SEC	M/CSEC	2^7

PROGRAM CONSTANTS					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$DPPOSMAX_D$		LARGEST POSITIVE VALUE AVAILABLE TO COMPUTER DP	$1-2^{28}$	$1-2^{28}$	2^0

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

DRAWN Z.J. Chmielewski 28 JAN 69
PROG. MGR J.E. Cutler 28 Feb 69
UNCMR D. Reinke 28 Feb 69
APPROVED John A. ... 6 MAR 69

RENDEZVOUS PARAMETERS DISPLAY

COLOSSUS IIC FC-2325

REV 1 14 14

R62 CREW DEFINED MANEUVER

MAJOR SUBROUTINE ON THIS CHART

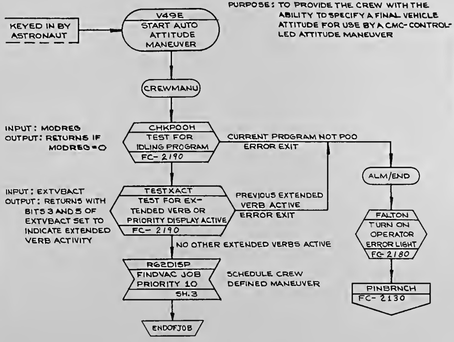
EXTENDED VERB 49 :	CREWMANU	START AUTO ATTITUDE MANEUVER	SH2
	R62DISP	CREW DEFINED MANEUVER	SH3

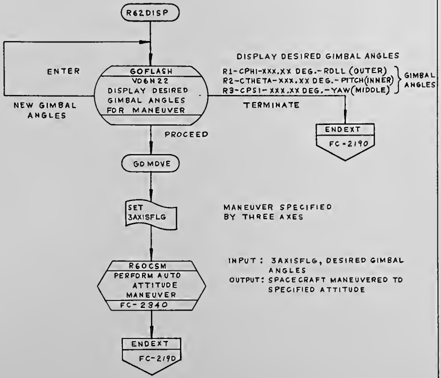
THE ENCLOSED REPLACEMENT SHEETS WILL UPDATE THE COLOSSUS I (REV 237) FLOW CHART FC-2330, REV 0, TO COLOSSUS II FC-2330, REV 1.

THE EFFECTIVE SHEETS FOR COLOSSUS II ARE

1	REV 1
2	REV 1
3	REV 0
4	REV 0

EXTENDED VERB 49: CREW DEFINED MANEUVER





6SEP68
19DEC68
20SEP68
30DEC68 REV 1

R62 CREW DEFINED MANEUVER

COLOSSUS II

FC-2330

3 4

1

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	. FLOW CHART	DESCRIPTION	WHERE CALLED
CHKPOOH	FC-2190	TEST FOR IDLING PROGRAM	SH 2
FALTON	FC-2180	TURN ON OPERATOR ERROR LIGHT	SH 2
R60CSM	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

VERBNOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N22	FLASHING	R1 – CPHI – XXX.XX DEG. – ROLL (OUTER) DESIRED GIMBAL ANGLES R2 – CTHETA – XXX.XX DEG. – PITCH (INNER) DESIRED GIMBAL ANGLES R3 – CPSI – XXX.XX DEG. – YAW (MIDDLE) DESIRED GIMBAL ANGLES	SH 3

P M Dietrich, 12SEP68
D.W. Keene 19DEC68
M C Dagostino 20SEP68
John A Morse 30 DEC 68 REV 1

R62
DEFINED MANEUVER

COLOSSUS II FC- 2330

4 4

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

10SEP68 19DEC68 25SEP68 31DEC68

R60 ATTITUDE MANEUVER

COLOSSUS II FC-2340

1 1 9

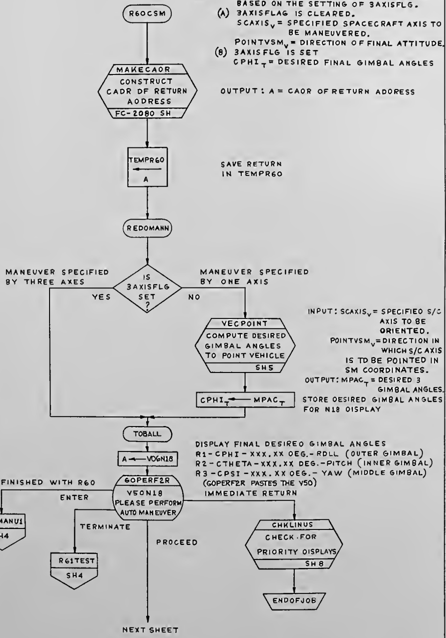
ATTITUDE MANEUVER

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) 3AXISFLAG IS CLEARED.
$SCAXIS_V$ = SPECIFIED SPACECRAFT AXIS TO BE MANEUVERED.
$POINTVSM_V$ = DIRECTION OF FINAL ATTITUDE.

(B) 3AXISFLG IS SET
$CPHI_T$ = DESIRED FINAL GIMBAL ANGLES



INSTRUMENTATION LAB
CAMBRIDGE, MA

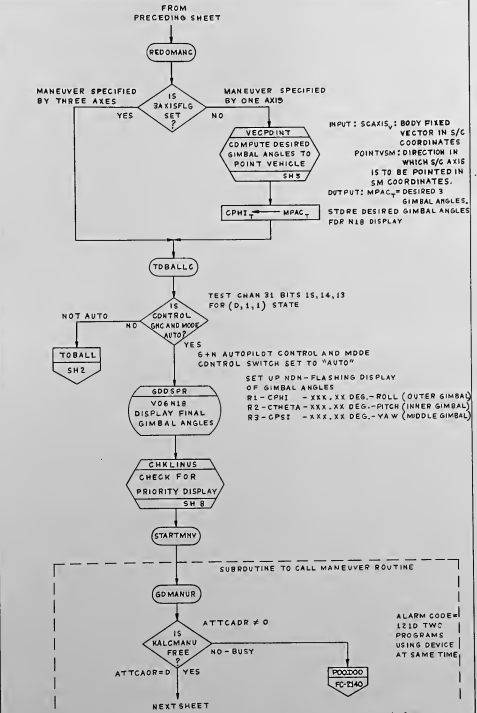
DRAWN	A. J. Lanzill	10 SEP 68
PROGRAM	D. W. Kline	19 DEC 68
ANAL		
DEV MP	W. C. Dughert	25 SEP 68
APPR	John E. Miller	31 DEC 68

R60
ATTITUDE MANEUVER

COLOSSUS II

FC-2340

1 2 9



MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

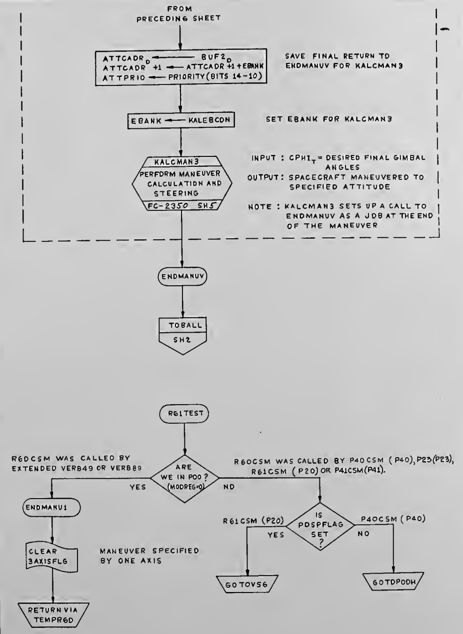
DRAWN		11SEP68
PRGMR		19 DEC 68
ANALYST		
DOCMR		25SEP68
APPR		31 DEC 68

R60
ATTITUDE MANEUVER

COLOSSUS II

FC-2340

3 9

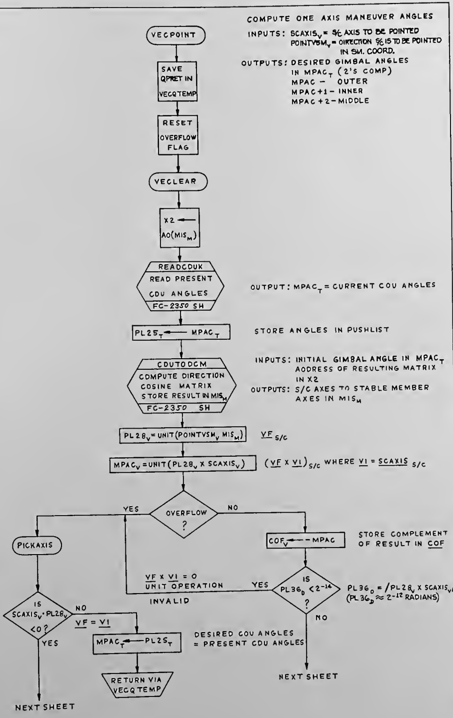


R60
ATTITUDE MANEUVER

COLOSSUS II

FC-2340

4 9



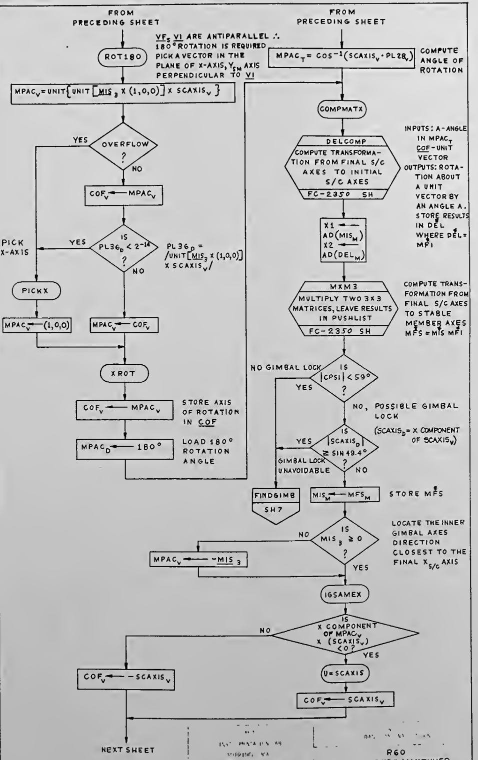
DRAWN O. J. Lungill 11SEP68
D. W. Keene 19DEC68
ANALYST
DGCMP M.C. Dotti 25SEP68
APPR'D John A. Moss 31DEC68

R60
ATTITUDE MANEUVER

COLOSSUS II

FC-2340

SH. 1 5 9



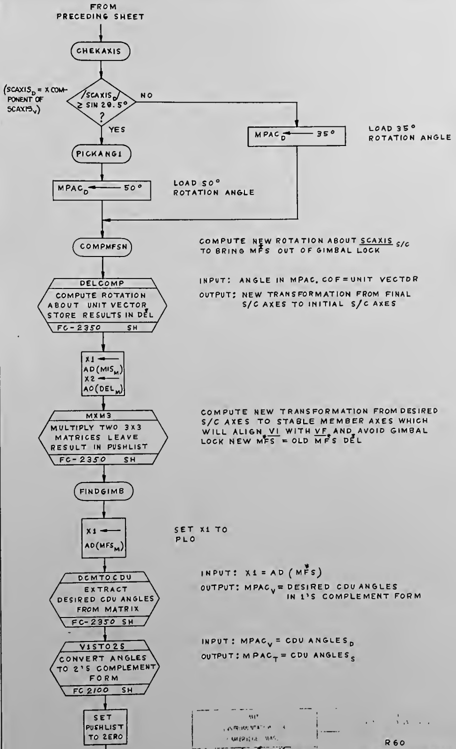
R60
ATTITUDE MANEUVER

COLOSSUS II

DRAWN	A. J. Laydtt	12 SEP 68
PRGMR	D. W. Kane	19 DEC 68
ANAL		
DCCMP	W. C. Dyrbert	25 SEP 68
APPR'D	John A. Moran	31 DEC 68

REV. 1

FC-2340
SH 6 OF 9



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

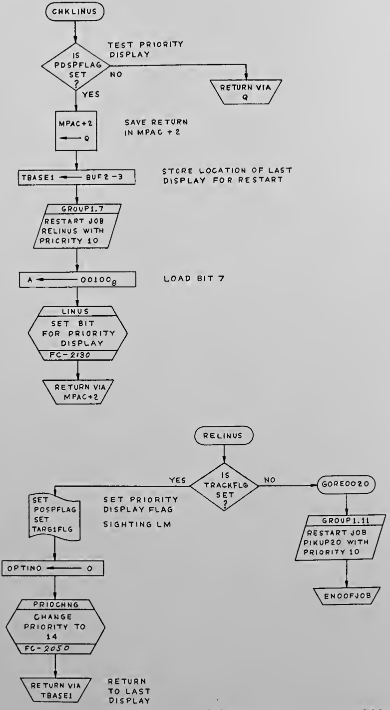
DRAWN		12 SEP 68
PROGMR		19 DEC 68
ANALYST		
DOCMR		25 SEP 68
APPR'D		31 DEC 68

R60
ATTITUDE MANEUVER

COLOSSUS II 1

FC-2340

7 OF 9



R60
ATTITUDE MANEUVER

13 SEP68
19 DEC68
25SEP68
31 DEC 68

COLOSSUS II 1

FC-2340

8 9

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	SH6,7
KALCMAN3	FC-2350	MANEUVER CALCULATIONS AND STEERING	SH4
LINUS	FC-2130	SET BIT FOR PRIORITY DISPLAY	SH8
MAKECADR	FC-2080	LOAD RETURN CADR SAVED BY BANKCALL	SH2
MXM3	FC-2350	MULTIPLY TWO 3X3 MATRICES	SH6,7
PRIOCHNG	FC-2050	CHANGE PRIORITY OF JOB IN EXECUTION	SH8
READCDUK	FC-2350	READ PRESENT CDU ANGLES	SH5
V1STO2S	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
PDSPFLAG	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
V50N18	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
V06N18	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	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$CPHI_T$		DESIRED FINAL GIMBAL ANGLES		REV	2^{-1}
$SCAXIS_V$		SPECIFIED SPACECRAFT AXIS TO BE MANEUVERED *		UNIT-VECTOR	2^{1}
$POINTVSM_V$		DIRECTION OF FINAL ATTITUDE IN STABLE MEMBER COORDINATES		UNIT-VECTOR	2^{1}

* SEE DESCRIPTION ON SHEET 3

A. J. Langelle 13SEP68
D. W. Kane 11DEC68
MC Dogtrot 23SEP68
John R. Morse 31DEC68

R60
ATTITUDE MANEUVER

COLOSSUS II

FC-2340

9 9

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 1 (REV. 237) FLOW CHART FC-2350, REV. 0, TO COLOSSUS II FC-2350, REV. 2

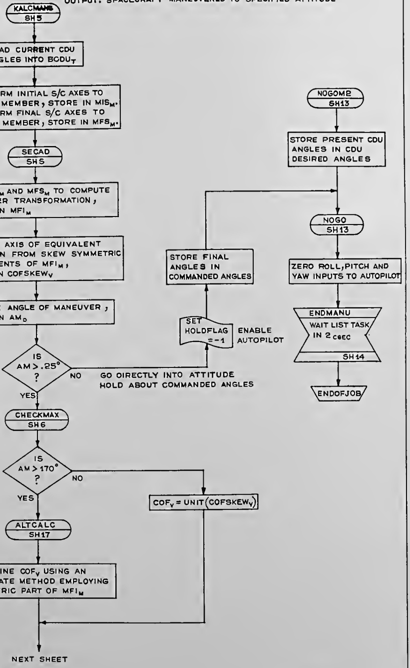
THE EFFECTIVE SHEETS FOR COLOSSUS II ARE:

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

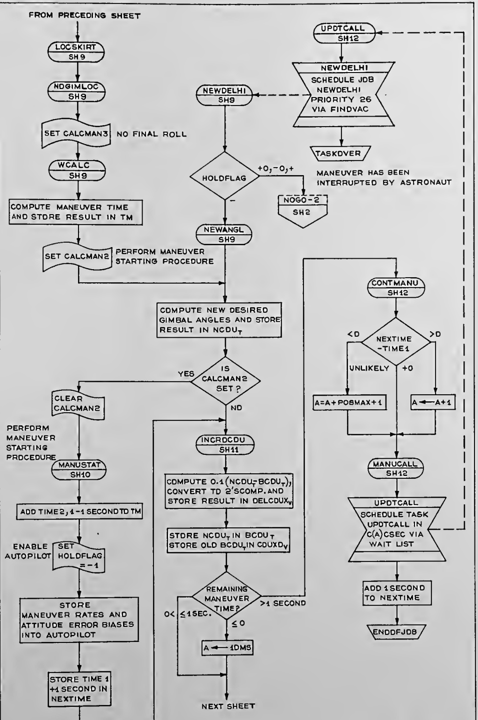
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	10APR	MANEUVER CALCULATIONS AND STEERING	
PRGMR	19 Dec 68		
ANALST		COLOSSUS II	DOCUMENT NO. FC-2350
DOCMR	15 Nov 68		
APPR'D	23 Dec 68	REV 2	SHEET 1 OF 27

SIMPLIFIED FLOW: MANEUVER CALCULATIONS AND STEERING

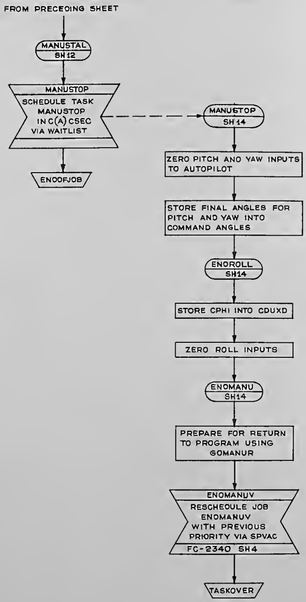
INPUT: $CPHI_T$ = DESIRED FINAL GIMBAL ANGLES
OUTPUT: SPACECRAFT MANEUVERED TO SPECIFIED ATTITUDE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 24 OCT 68	SIMPLIFIED FLOW OF MANEUVER CALCULATIONS AND STEERING
PRGMR D. W. Keene 19 DEC 68	
ANALYST	DOCUMENT NO.
DOCMR 15 NOV 68	COLOSSUS II FC-2350
APPR'D 30 DEC 68	REV 2 SHEET 2 OF 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN G.M. Dietrich 16 OCT 68	SIMPLIFIED FLOW OF MANEUVER CALCULATIONS AND STEERING
PRGMR D.W. Keene 19 DEC 68	
ANALST	COLOSSUS II — DOCUMENT NO. FC-2350
DOCMR 15 MAY 68	
APPR'D John A. Norse 30 DEC 68	REV 2 — SH 3 OF 27



SIMPLIFIED FLOW OF MANEUVER CALCULATIONS AND STEERING

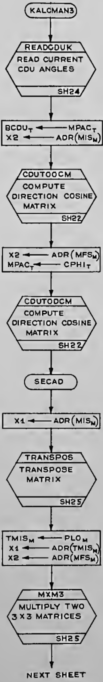
COLOSSUS II FC-2350

SHEET 4 OF 27

REV 2

MANEUVER CALCULATIONS AND STEERING

INPUT: $CPHI_T$ = DESIRED FINAL GIMBAL ANGLES
OUTPUT: SPACECRAFT MANEUVERED TO SPECIFIED ATTITUDE



OUTPUT: $MPAC_T$ = CDUX, CDUY, CDUZ

STORE INITIAL SPACECRAFT ANGLES

COMPUTE THE TRANSFORMATION FROM INITIAL S/C AXES TO STABLE MEMBER AXES.

INPUT: $MPAC_T$ = CDU ANGLES
X2 = ADR(RESULTING MATRIX)

OUTPUT: MIS_M = TRANSFORMATION MATRIX

LOAD DESIRED FINAL GIMBAL ANGLES

COMPUTE THE TRANSFORMATION FROM FINAL S/C AXES TO STABLE MEMBER AXES.

INPUT: $MPAC_T$ = FINAL GIMBAL ANGLES
X2 = ADR(RESULTING MATRIX)

OUTPUT: MFS_M = TRANSFORMATION MATRIX

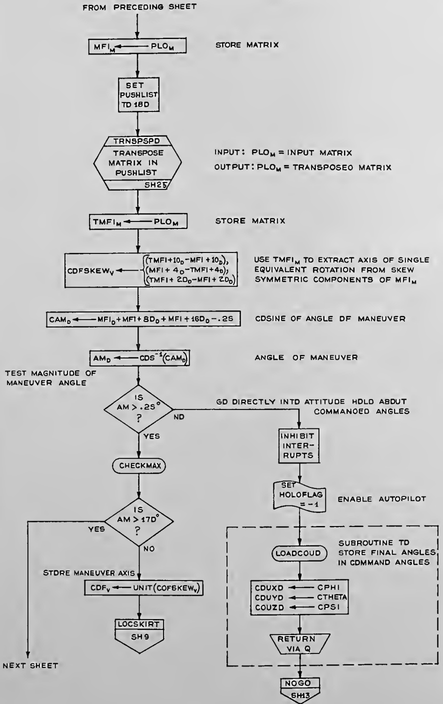
INPUT: X1 = ADR(MATRIX)

OUTPUT: PLO_M = TRANSPOSED MATRIX

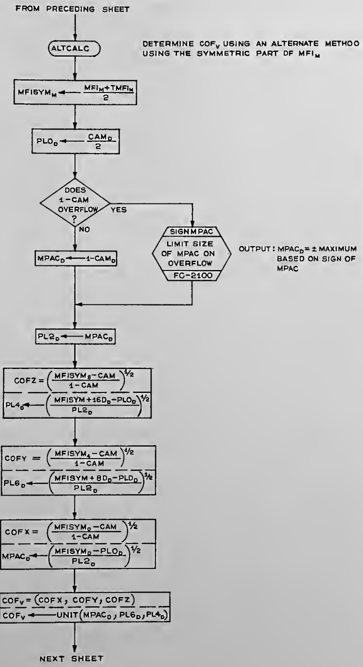
STORE MATRIX

INPUT: X1 = ADR ($TMIS_M$)
X2 = ADR (MFS_M)

OUTPUT: PLO_M = $TMIS_M$ MFS_M



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.H. Dietrich 22 OCT 68	MANEUVER CALCULATIONS AND STEERING
PRGMR D.W. Keene 19 DEC 68	
ANALYST	COLOSSUS II — DOCUMENT NO. FC-2350
DOCMR W.C. Dolphin 15 NOV 68	
APPR'D John A. Morse 30 DEC 68	REV 2 — SHEET 6 OF 27



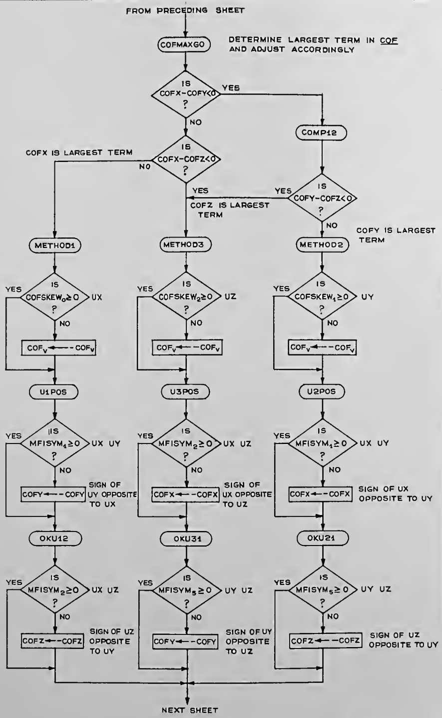
MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN D.M. Dietrich 22 OCT 68
PRGMR D.W. Keene 19 DEC 68
ANALST
DOCMR M.C. Dietrich 15 NOV 68
APPR'D John A. Moore 30 DEC 68

MANEUVER CALCULATIONS AND STEERING

COLOSSUS II FC-2350

REV 2 7 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

MANEUVER CALCULATIONS AND STEERING

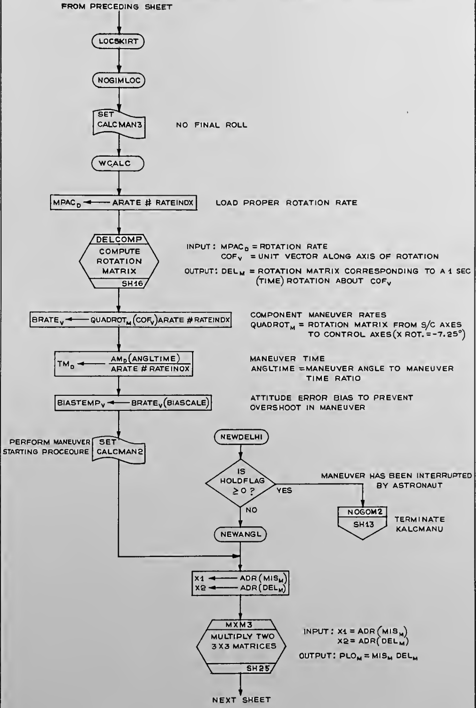
DRAWN	D.M. Dietrich	23 OCT 68
PROG'MR	D.W. Keene	19 DEC 68
ANALYST		
DOCMR	W.C. Doyle	15 NOV 68
APPR'D	John A. Moss	30 DEC 68

COLOSSUS II

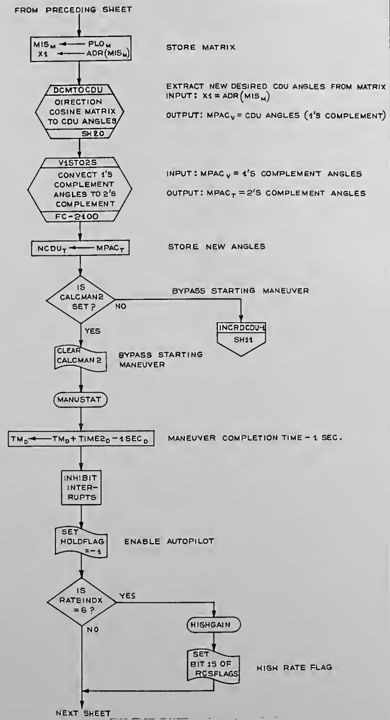
DOCUMENT NO FC-2350

REV 2

SHEET 8 OF 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN J M Dietrich 24 OCT 68	MANEUVER CALCULATIONS AND STEERING
PRGMR D W Keene 19 DEC 68	
ANALYST	
DOCMR W C Forsyth 15 NOV 68	COLOSSUS II — DOCUMENT NO. FC-2350
APPR'D John A Morse 20 DEC 68	REV 8 — SHEET 9 OF 27



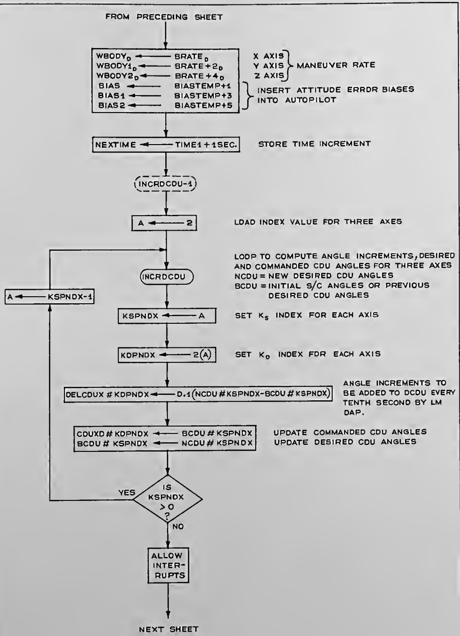
MIT INSTRUMENTATION LAB
CAMBRIDGE MASS.

DRAWN — 25 OCT 68
PRGMR — 19 DEC 68
ANALYST
DOCMR — 15 NOV 68
APPR'D — 30 DEC 68

MANEUVER CALCULATIONS AND STEERING

COLOSSUS II — FC-2350

REV. 2 — SHEET 10 OF 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN D.H.Dietrich 28 OCT 68
PRGMR D.W. Keene 19 DEC 68
ANALYST
DOCMR W.C. Daybrook 15 NOV 68
APPR'D John G. Moore 30 DEC 68

APOLLO GUIDANCE AND NAVIGATION

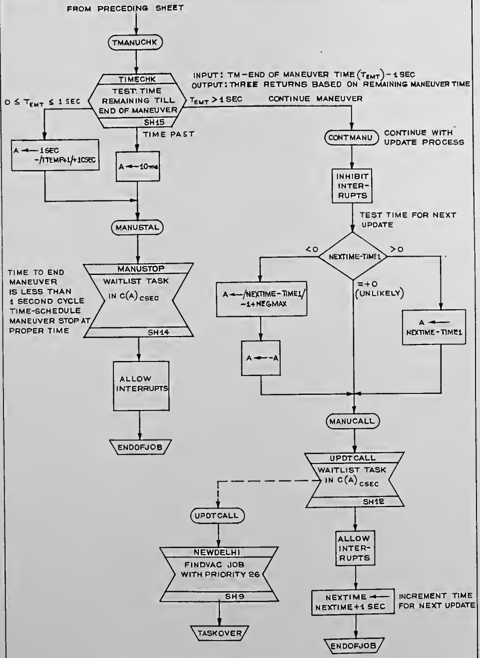
MANEUVER CALCULATIONS AND STEERING

COLOSSUS II

FC-2350

REV 8

11 OF 27



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

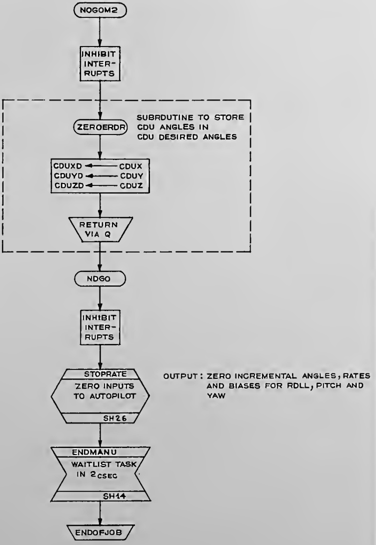
DRAWN	D. M. Dietrich	29 OCT 68
PROGMR	D. W. Keene	19 DEC 68
ANALYST		
DOCMR	W. C. Daykitt	15 NOV 68
APPR'D	John A. Moore	30 DEC 68

MANEUVER CALCULATIONS AND STEERING

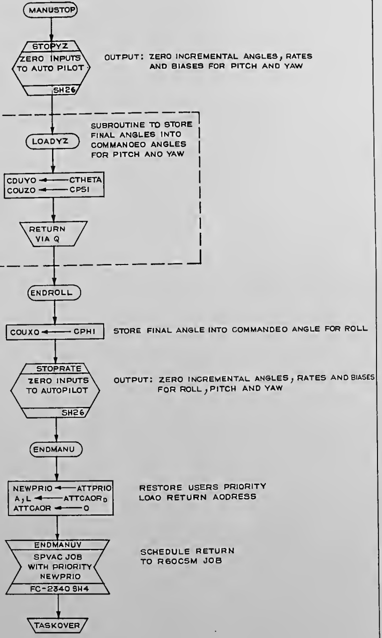
COLOSBUS II

FC-2350

REV 2 12 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	
DRAWN 29 OCT 68	MANEUVER CALCULATION AND STEERING
PROGMR 19 DEC 68	
ANALST	COLOSSUS II FC-2350
PROGMR 15 NOV 68	
APPR'D	REV 2 13 27



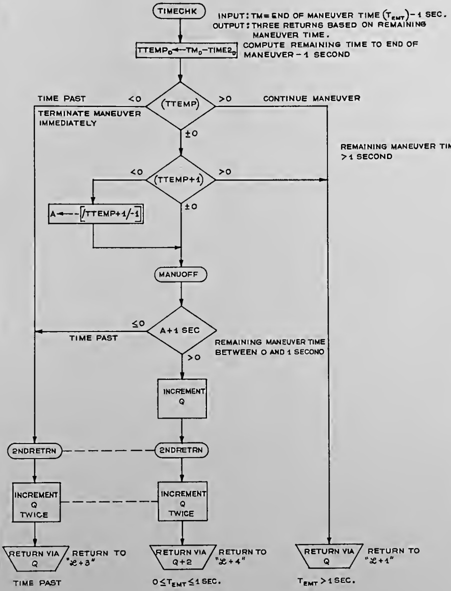
MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN D. M. Dietrich 29 OCT 68
PROGMR D. W. Keene 19 DEC 68
ANALYST
DOCMR 15 NOV 68
APPR'D 30 DEC 68

MANEUVER CALCULATIONS AND STEERING

COLOSSUS II FC-2350

REV 2 14 27



MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN		30 OCT 68
PRGMR		19 DEC 68
ANALST		
DOC MR		15 NOV 68
APPR'D		30 DEC 68

APOLLO GUIDANCE AND NAVIGATION

MANEUVER CALCULATIONS AND STEERING

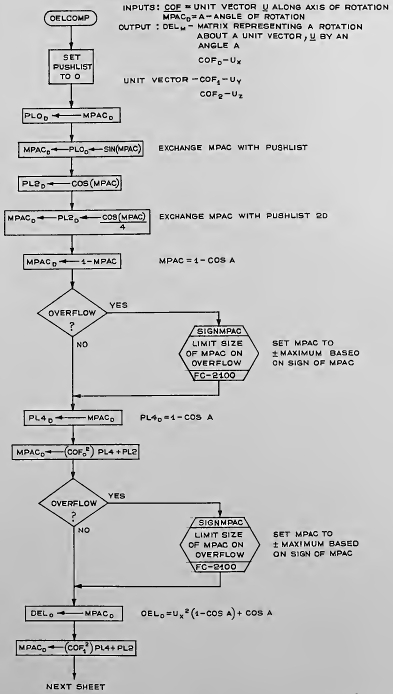
COLOSSUS II

FC-2350

REV 2

SHEET 15 OF 27

CALCULATION OF MATRIX OEL_M



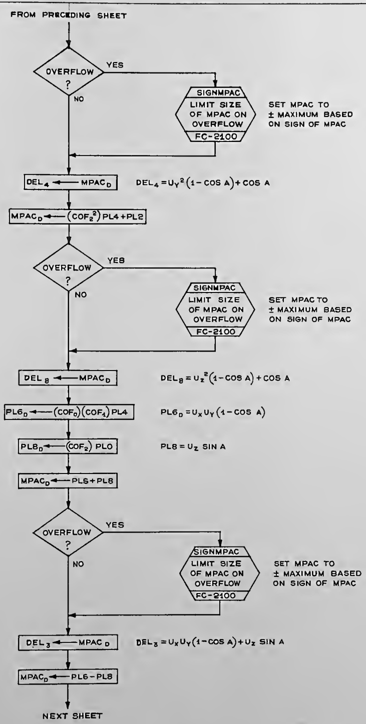
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

DRAWN J.M. Dahlen 30 OCT 68
PRGMR D.W. Keene 19 DEC 68
ANALYST
PROG MGR W.C. Dugg 15 NOV 68
APPR'D John G. Morse 30 DEC 68

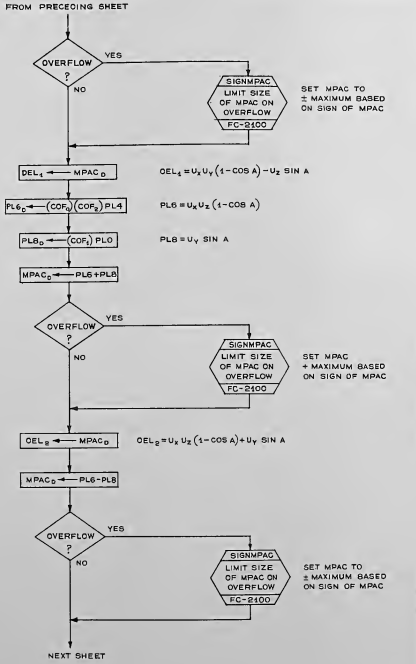
MANEUVER CALCULATIONS AND STEERING

COLOSSUS II FC-2350

REV 2 16 27



M.I.T. INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D.M. Dietrich 31 OCT 68	MANEUVER CALCULATIONS AND STEERING
PRGMR D.W. Keene 19 DEC 68	
ANALYST	
DOC M. 15 NOV 68	COLOSSUS II FC-2350
APPR'D John A. Moore 30 DEC 68	REV 2 17 of 27



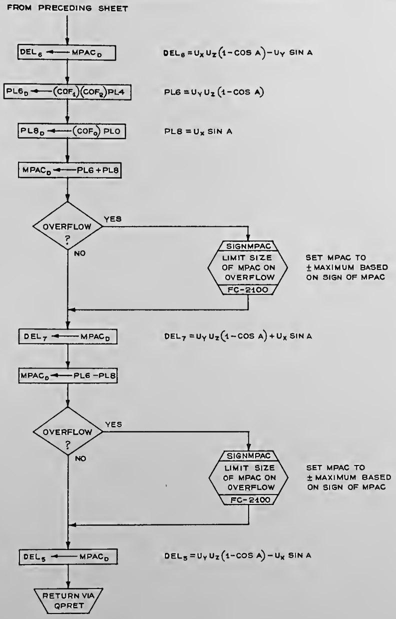
DRAWN 4 NOV 68
19 DEC 68
15 NOV 68
APP'D 30 DEC 68

MANEUVER CALCULATIONS AND STEERING

COLOSSUS II

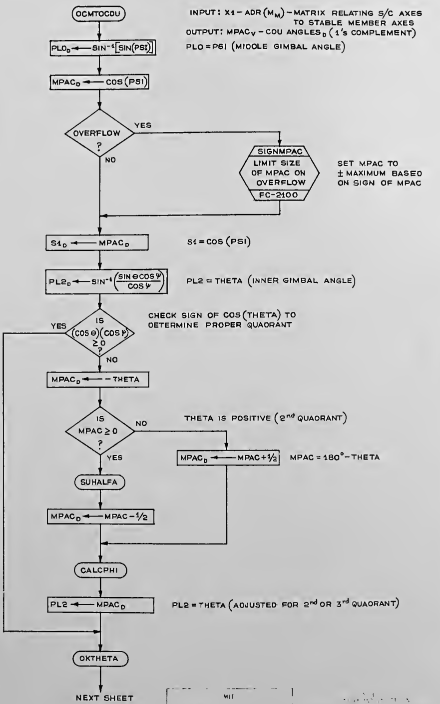
FC-2350

18 27

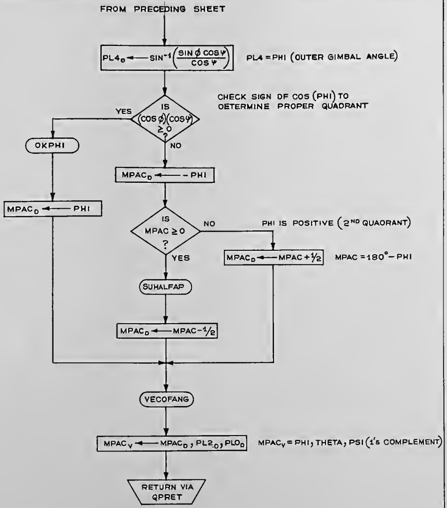


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D. M. Dighton 14 NOV 68	MANEUVER CALCULATIONS AND STEERING
PRGMR D. W. Keene 19 DEC 68	
ANALST	
DOCMR W. C. Goggin 15 NOV 68	COLOSSUS II FC-2350
APPR'D John A. Morse 30 DEC 68	REV 2 SH 19 OF 27

COMPUTE CDU ANGLES FROM DIRECTION COSINE MATRIX

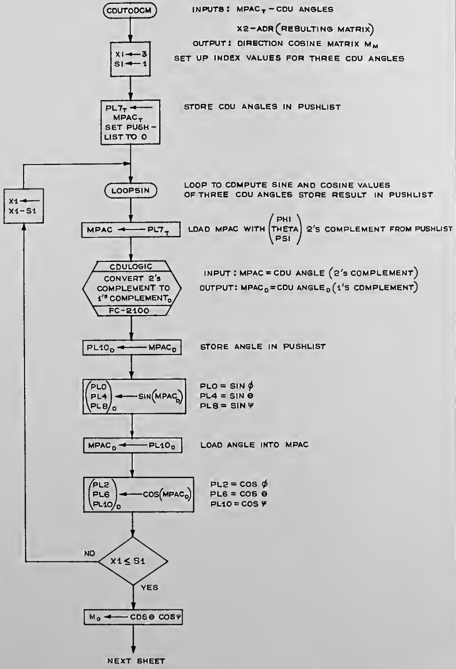


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	MANEUVER CALCULATIONS AND STEERING
DRAWN 14 NOV 68	
PROGMR 19 DEC 68	
ANALYST	
DOCMR 15 NOV 68	COLOSSUS II FC-2350
APPR'D 30 DEC 68	REV 2 20 27

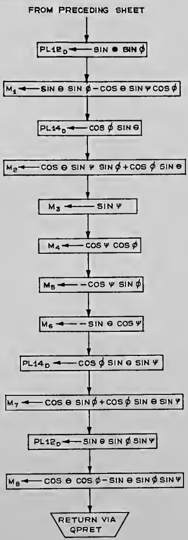


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Duford 5 NOV 68	MANEUVER CALCULATIONS AND STEERING
PRGMR D.W. Keene 19 NOV 68	DOCUMENT NO
ANALST	
DOCMR M.C. Deffott 15 NOV 68	COLOSSUS II FC-2350
APPR'D John A. Morse 20 DEC 68 REV 2	SHEET 21 OF 27

COMPUTE DIRECTION COSINE MATRIX
RELATING S/C AXES TO STABLE
MEMBER AXES



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN G.M. Dietrich 5 NOV 68	MANEUVER CALCULATIONS AND STEERING
PRGMR S.N. Kerns 19 DEC 68	
ANALST	
DOCMR W. Ostanek 15 NOV 68	COLOSSUS II FC-2350
APPR'D John A. Morse 30 DEC 68	REV 2 22 27



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

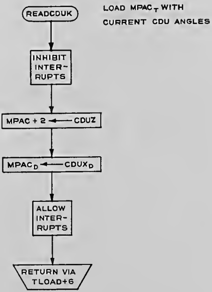
DRAWN 6 NOV 68
PRGMR 11 DEC 68
ANALYST
DOCMR 15 NOV 68
APPR'D 30 DEC 68

APOLLO GUIDANCE AND NAVIGATION

MANEUVER CALCULATIONS AND STEERING

COLOSSUS II — DOCUMENT NO. FC-2350

REV 8 — SHEET 23 OF 27



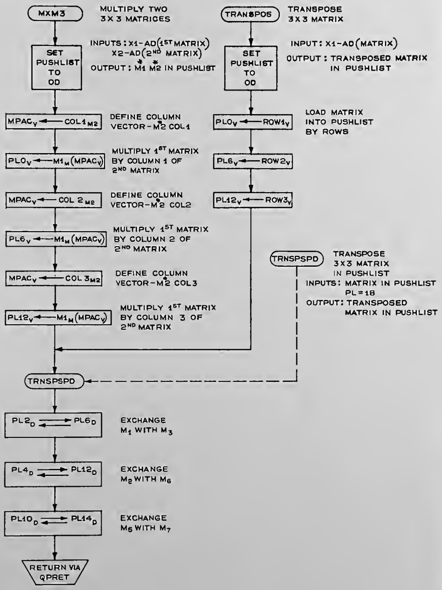
MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN P.M. Dietz 6NOV68
PREPARED D.W. Keene 19DEC68
ANALYST
PREPARED W.C. Dastitt 25NOV68
APPROVED John A. Moore 30DEC68

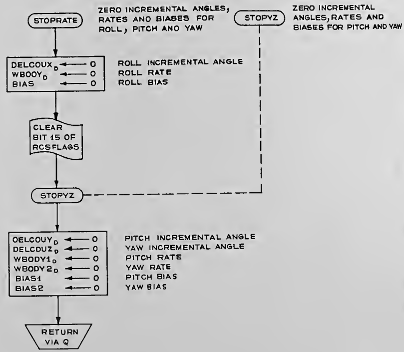
MANEUVER CALCULATIONS
AND STEERING

COLOSSUS II FC-2350

REV 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature]	7 NOV 68	MANEUVER CALCULATIONS AND STEERING
PRGMR D. W. Keene	19 DEC 68	DOCUMENT NO
ANALST		COLOSSUS II FC-2350
DOCMR [signature]	15 NOV 68	REV 2
APP'D John A. Moore	30 DEC 68	SHEET 25 OF 27



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

DRAWN	P.M. Dietrich	7 NOV 68
PRGMR	D.N. Keene	19 DEC 68
ANALYST		
GDCMF	McDaguitt	15 NOV 68
APPR'D	John A. Moss	20 DEC 68

MANEUVER CALCULATIONS AND STEERING

COLOSSUS II FC-2350

REV 2

26 27

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
V1STO2S	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
$BCDU_T$		INITIAL S/C CDU ANGLES		REV	2^{-1}
CDUXD CDUYD CDUZD		CDU COMMANDED ANGLES		REV	2^{-1}
TM_D		MANEUVER COMPLETION TIME		CSEC	2^{28}
$DELCDUX_D$ $DELCDUY_D$ $DELCDUZ_D$		ROLL, PITCH, YAW ANGLE INCREMENTS		REV	2^{-1}
$WBODY_D$ $WBODY1_D$ $WBODY2_D$		ROLL, PITCH, YAW ANGLE RATES		REV DECI-SEC	2^{-3}
BIAS BIAS1 BIAS2		ROLL, PITCH, YAW ANGLE BIASES		REV	2^{-1}

R05 S-BAND ANTENNA

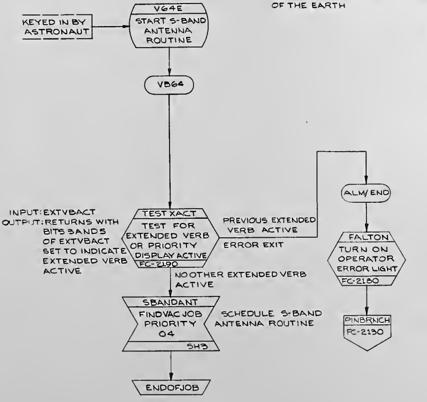
MAJOR SUBROUTINE ON THIS FLOWCHART

EXTENDED VERB 64	START S-BAND ANTENNA ROUTINE	SH 2
SBANDANT	COMPUTE AND DISPLAY S-BAND ANTENNA GIMBAL ANGLES	SH3

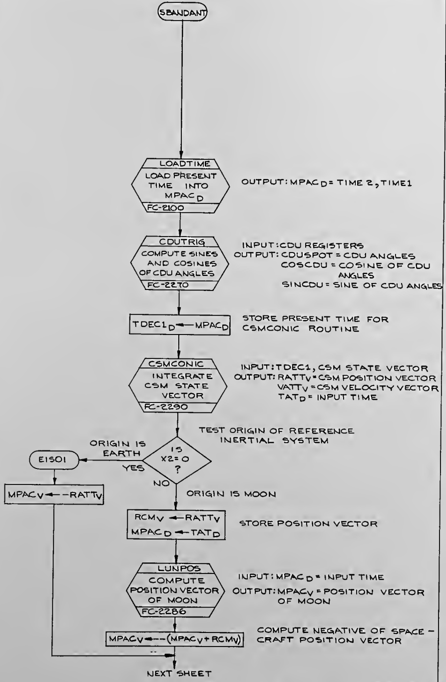
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN B. Chmielinski 8OCT68	R05 S-BAND ANTENNA
PRGMR [illegible] 16 Oct 68	COLOSSUS IIC
ANALYST	DOCUMENT NO. FC-2360
DOCMR McKnight 15OCT68	
APPR'D John A. Morse 18OCT68	REV 3 SHEET 1 OF 3

EXTENDED VERB 64: S-BAND ANTENNA

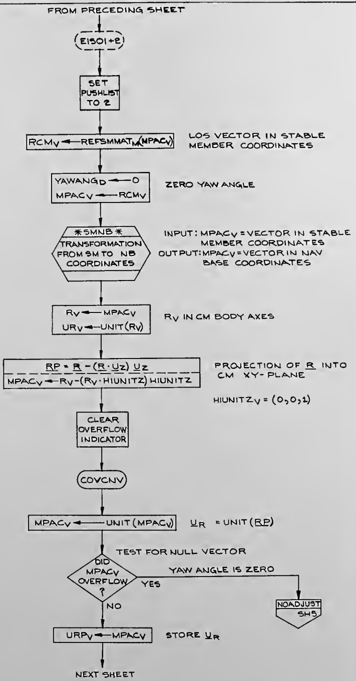
PURPOSE: TO COMPUTE AND DISPLAY THE TWO STEERABLE S-BAND ANTENNA GIMBAL ANGLES WHICH WILL POINT THE ANTENNA TOWARD THE CENTER OF THE EARTH



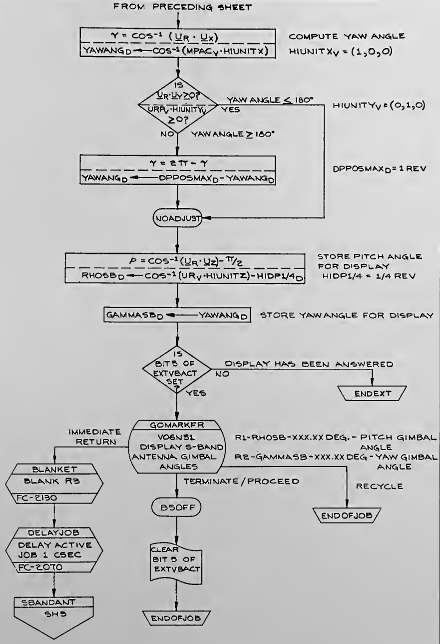
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	RO5 S-BAND ANTENNA
DRAWN D. S. Chmielinski 8 OCT 68	COLOSSUS IIC
PRGMR [illegible] 16 X 7[illegible]	FC-2360
ANALST	
DOCMR McFarl[illegible] 15 OCT 68	
APPR'D John A. Morse 15 OCT 69	REV 3



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN	9OCT68	R05 S-BAND ANTENNA
PRGMR	16OCT68	
ANALST		COLOSSUS IIC — DOCUMENT NO FC-2360
DOCMR	15OCT68	
APPR'D	18OCT68	REV 3 — SHEET 3 OF 6



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN Z. J. Chmielinski 30OCT68	R05 S-BAND ANTENNA
PRGMR J. E. Caner 16OCT68	
ANALST	COLOSSUS IIC — FC-2360
DOCMR M. [illegible] 15OCT68	
APPR'D John A. Moore 18OCT68	REV 3 — SHEET 4 OF 6



MIT INSTRUMENTATION LAB CAMBRIDGE MASS	APOLLO GUIDANCE AND NAVIGATION
DRAWN J.S. Chmelinski 9OCT68	R05 S-BAND ANTENNA
PRGMR J. E. Lesky 16OCT68	COLOSSUS IIC
ANALYST	DOCUMENT NO. FC-2360
GP MGR McFaddin 15OCT68	
APPR'D John A. Mou... 18OCT68	REV 3 SHEET 5 OF 6

SUBROUTINES CALLEO WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	OESCRIPTION	WHERE CALLEO
BLANKET	FC-2130	BLANK DSKY REGISTERS	SH5
CHKPOOH	FC-2190	TEST FOR IOLING PROGRAM	SH2
CSMCONIC	FC-2290	INTEGRATE CSM STATE VECTOR	SH3
OELAYJOB	FC-2078	OELAY ACTIVE JOB GIVEN TIME PERIOO	SH5
FALTON	FC-2180	TURN ON OPERATOR ERROR LIGHT	SH2
LOADTIME	FC-2100	LOAO PRESENT TIME INTO $MPAC_O$	SH3
LUNPOS	FC-2286	COMPUTE POSITION VECTOR OF MOON	SH3
R02BOTH	FC-2210	IMU STATUS CHECK	SH3
TESTXACT	FC-2190	TEST FOR EXTENDEO VERB OR PRIORITY DISPLAY ACTIVE	SH2
SMNB	FC-2270	TRANSFORMATION FROM SM TO NB COORDINATES	SH4

OISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTEO
V06N51	FLASHING	R1-RHOSB - XXX.XX OEG. - PITCH GIMBAL ANGLE R2-GAMMASB - XXX.XX OEG. - YAW GIMBAL ANGLE	SH5

ERASABLE LOCATIONS USEO

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$RHOSB_O$	ρ	PITCH GIMBAL ANGLE FOR S-BAND ANTENNA		REV	2^0
$GAMMASB_D$	γ	YAW GIMBAL ANGLE FOR S-BANO ANTENNA		REV	2^0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Lanzillo	3OCT68	R05 S-BAND ANTENNA
PRGMR J. R. Cronin	16OCT68	
ANALST		COLOSSUS IIC
DOCMR W. Fairbrother	15OCT68	DOCUMENT NO FC-2360
APPR'D John A. Rowe	18OCT68	REV 3 SHEET 6 OF 6

R63 - RENDEZVOUS FINAL ATTITUDE

MAJOR SUBROUTINES ON THIS CHART

EXTENDED VERB 89	V89PERF:	REQUEST RENDEZVOUS FINAL ATTITUDE	SH 2
	V89CALL:	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.

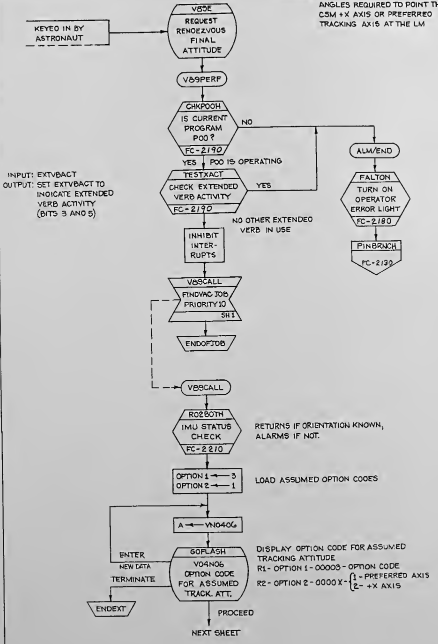
THE EFFECTIVE SHEETS FOR COLOSSUS II, FC-2361, REV. 1, ARE:

1-4	REV. 0
5-6	REV. 1
7	REV. 0

NOTE: FC-2361 WAS PREVIOUSLY CALLED FC-2190.

A.C. WILLIAMS	9SEP68	R63-RENDEZVOUS FINAL ATTITUDE	
D.W. Kane	17DEC68		
W.C. Dughtz	26SEP68	COLOSSUS II	FC-2361
John A. Moore	30DEC68	1	1 7

PURPOSE: TO CALCULATE THE FINAL GIMBAL ANGLES REQUIRED TO POINT THE CSM +X AXIS OR PREFERRED TRACKING AXIS AT THE LM



CAMBRIDGE, MASS.

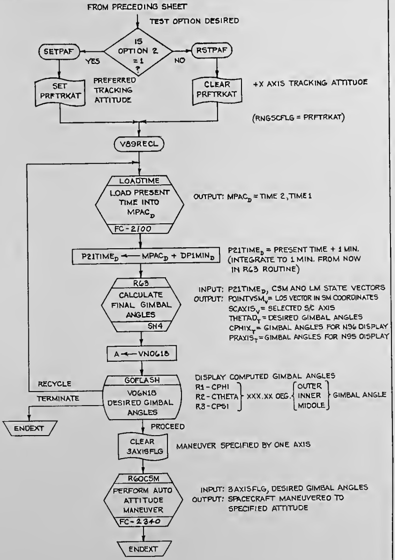
DRAWN A.C.WILLIAMS 9SEP68
D.W. Keene 19DEC68
M.C. [illegible] 25SEP68
John [illegible] 30DEC68

R63 - RENDEZVOUS FINAL ATTITUDE

COLOSSUS II

FC-2361

1 2 7



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 10SEP68	R63 - RENDEZVOUS FINAL ATTITUDE
PRGMR D.W. Keene 19DEC68	COLOSSUS II
ANALYST	DOCUMENT NO. FC-2361
DOCMN W.C. Dight 25SEP68	
APPR'D John R. More	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: $P21TIME_D$ = PRESENT TIME + 1 MIN.
CSM AND LM STATE VECTORS
$REFSMMAT_M$ = TRANSFORMATION MATRIX: BASIC REF. COORD. SYSTEM TO IMU STABLE MEMBER COORD. SYSTEM
PRFTRKAT = SWITCH INDICATING ASTRONAUT SELECTED S/C AXIS

OUTPUT: $POINTVSM_V$ = LOS VECTOR IN SM COORDINATES
$SCAXIS_V$ = SELECTED S/C AXIS
$THETAD_T$ = DESIRED GIMBAL ANGLES
$CPHIX_T$ = GIM. ANGLES FOR N96 DISPLAY
$PRAXIS_T$ = GIM. ANGLES FOR N95 DISPLAY

(R63)

SAVE RETURN IN Q6111: Q6111 ← QPRET

STORE TIME FOR CSMCONIC ROUTINE: $TDEC1_D$ ← $P21TIME_D$

CSMCONIC — EXTRAPOLATE CSM STATE VECTOR — FC-2290

INPUT: $TDEC1_D$, CSM STATE VECTOR
OUTPUT: $RATT_V$ = POSITION VECTOR, $VATT_V$ = VELOCITY VECTOR } EXTRAPOLATED TO PRESENT TIME +1 MIN.

(HOLDATT)

$SAVEPOS_V$ ← $RATT_V$
$SAVEVEL_V$ ← $VATT_V$

STORE EXTRAPOLATED POSITION AND VELOCITY

(CALCLEM)

$TDEC1_D$ ← $P21TIME_D$

STORE TIME FOR LEMCONIC ROUTINE

LEMCONIC — EXTRAPOLATE LM STATE VECTOR — FC-2290

INPUT: $TDEC1_D$, LM STATE VECTOR
OUTPUT: $RATT_V$ = POSITION VECTOR, $VATT_V$ = VELOCITY VECTOR } EXTRAPOLATED TO PRESENT TIME +1 MIN.

$DCDU_V$ ← $VATT_V$
$SAVEPOS_V$ ← UNIT($RATT_V$ − $SAVEPOS_V$)
$P21TIME_D$ ← $PL36_D$

TEMPORARY STORAGE FOR LM VEL. VECTOR
$R_L - R_C$ = LINE OF SIGHT VECTOR TO LM
ABSOLUTE VALUE OF LOS VECTOR

$POINTVSM_V$ ← $REFSMMAT_M$ ($SAVEPOS_V$)
$SCAXIS_V$ ← $UNITX_V$

$POINTVSM_V$ = LOS VECTOR IN STABLE MEMBER COORDINATES
$SCAXIS_V$ = SELECTED AXIS UNIT VECTOR
$UNITX_V$ = (0.5, 0, 0) @ 2^1 (+X AXIS)

NEXT SHEET

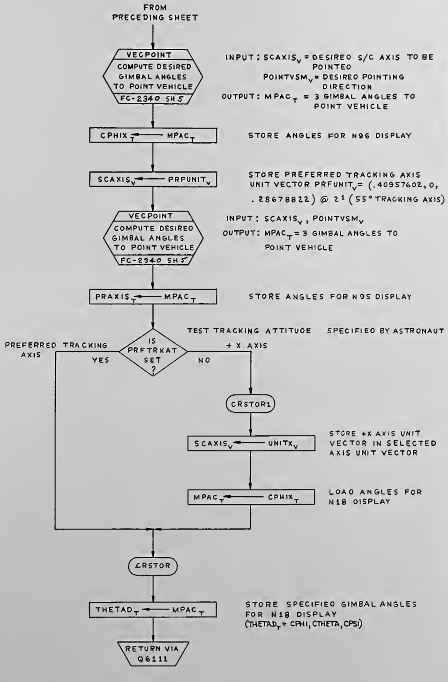
A.C.WILLIAMS 10SEP68
D.W. Kane 19DEC68
25SEP68

R63 - RENDEZVOUS FINAL ATTITUDE

COLOSSUS II

FC- 2361

4 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN: 10SEP68
PROG: 19DEC68
CON MP: 25SEP68
APPR'D: 30 ... 68

R63 – RENDEZVOUS FINAL ATTITUDE

COLOSSUS II

FC- 2361

REV 1 — 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 $MPAC_D$	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
VECPOINT	FC-2340	COMPUTE DESIRED GIMBAL ANGLES TO POINT VEHICLE	SH5

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
PRFTRKAT (RNGSCFLG) 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 } DISPLAY ASSUMED TRACKING ATTITUDE	SH2
V06N18	FLASHING	R1 - CPHI, R2 - CTHETA, R3 - CPSI } xxx.xx DEG { OUTER, INNER, MIDDLE } DESIRED GIMBAL ANGLES	SH3

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$P21TIME_D$		PRESENT TIME + 1 MIN.		CSEC	2^{28}
$POINTVSM_V$		LOS VECTOR IN SM COORDINATES		UNIT VECTOR	2^{1}
$SCAXIS_V$		SELECTED SPACECRAFT AXIS		UNIT VECTOR	2^{1}
$THETAD_T$		DESIRED GIMBAL ANGLES		REV	2^{-1}
$CPHIX_T$		GIMBAL ANGLES FOR N96 DISPLAY		REV	2^{-1}
$PRAXIS_T$		GIMBAL ANGLES FOR N95 DISPLAY		REV	2^{-1}
$TDEC1_D$		INPUT TIME FOR INTEGRATION ROUTINES		CSEC	2^{28}
$RATT_V$	$\underline{R}_L, \underline{R}_c$	OUTPUT POSITION VECTOR FROM INTEGRATION		METERS	2^{29}
$VATT_V$	$\underline{V}_L, \underline{V}_c$	OUTPUT VELOCITY VECTOR FROM INTEGRATION		M/CSEC	2^{7}

MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN P.M. Diebold 13SEP68
PRGMR D.W. Keene 19DEC68
ANALST
DOCMR MC Dougherty 25DEC68
APPR'D John A. Moore 30DEC68

APOLLO
GUIDANCE AND NAVIGATION

R63
RENDEZVOUS FINAL ATTITUDE

COLOSSUS II — DOCUMENT NO. FC-2361 — REV 1 — SHEET 6 OF 7

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$UNITX_V$		+ x AXIS UNIT VECTOR		(.5, 0, 0) UNIT VECTOR	2^1
$PRFUNIT_V$		55° TRACKING AXIS UNIT VECTOR		(.40957602, 0, .28678822) UNIT VECTOR	2^1

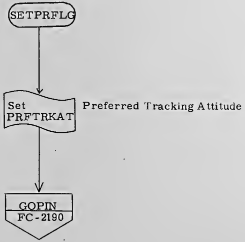
V76, V77 SET/CLEAR PREFERRED ATTITUDE FLAG

SETPRFLG Sh. 2

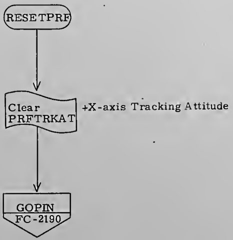
RESETPRF Sh. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	10/20/69	Set/Clear Preferred Attitude Flag	
PRGMR M. Brodeur	10/30/69	COLOSSUS 2D	DOCUMENT NO. FC-2363
ANALST			
DOCMR W. Daybook	10/29/69		
APPR'D Roberta M. Entes	10/30/69	REV	SHEET 1 OF 3

EXTENDED VERB 76



EXTENDED VERB 77



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Bright	10/28/69	Set/Clear Preferred Attitude Flag	
PRGMR N. Brodeur	10/30/69	COLOSSUS 2D	DOCUMENT NO. FC-2363
ANALST			
DOCMR W. Danforth	10/29/69		
APPR'D Roberto M. Estes	10/30/69	REV	SHEET 2 OF 3

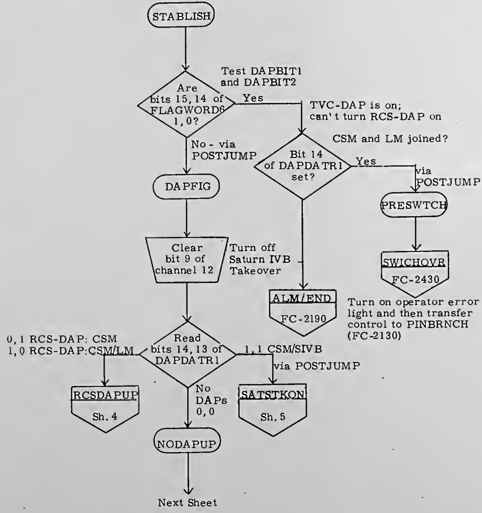
Name	Meaning When Set	Meaning When Cleared	Where Set	Where Cleared	Where Tested
PRFTRKAT Flag 5 Bit 10	Preferred tracking attitude	+X-axis tracking attitude	Sh. 2	Sh. 2	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN H. Bright	10/28/69	Set/Clear Preferred Attitude Flag	
PRGMR N. Brodeur	10/30/69		
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2363
DCGMR W. Daybroth	10/29/69		
APPR'D Roberta M. Eaton	10/30/69	REV	SHEET 3 OF 3

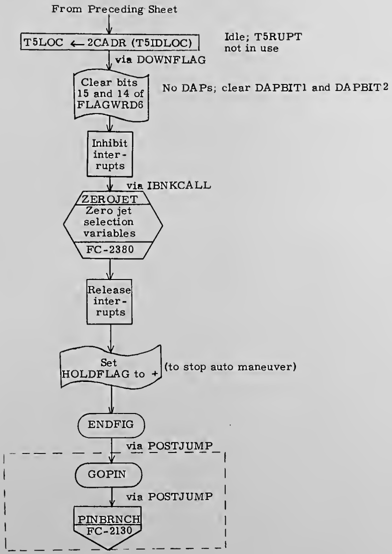
DAP INTERFACE AND SERVICE ROUTINES

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Hunter	10/28/69	DAP Interface and Service Routines	
PRGMR J.F. Burnbull	11-26-69		DOCUMENT NO.
ANALYST		COLOSSUS 2D	FC-2370
DOCMR Roberta M Entes	11/26/69		
APPR'D Roberta M. Entes	11/26/69	REV 2	SHEET 1 OF 34

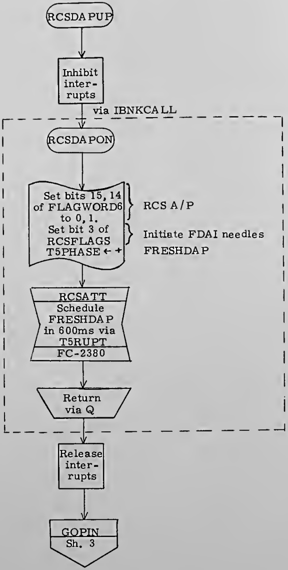
Extended Verb 46: RCS DAP Turn-on



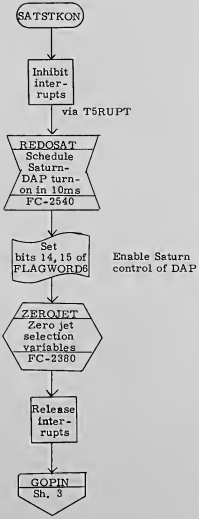
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Hunter	1/28/69	DAP Interface and Service Routines	
CHECKED J.F. Dunbar		COLOSSUS 2D	DOCUMENT NO. FC-2370
APPR'D Roberta M. Estes	11/26/69	REV 2	SHEET 2 OF 34



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		DAP Interface and Service Routines	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR Roberta M. Eutes	11/26/69		
APPR'D Roberta M. Eutes	11/26/69	REV 2	SHEET 3 OF 34

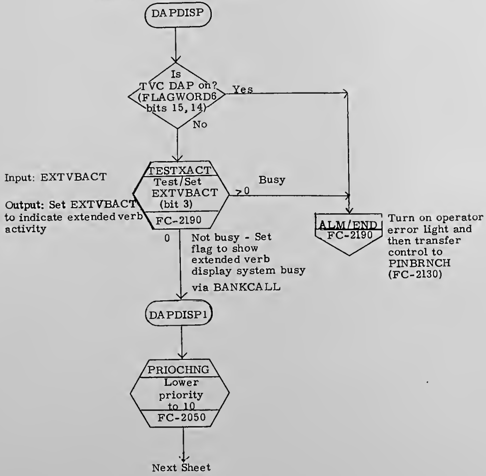


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	10/28/69	DAP Interface and Service Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR Roberta M. Eutis	11/26/69		
APPR'D Roberta M. Eutis	11/26/69	REV 2	SHEET 4 OF 34

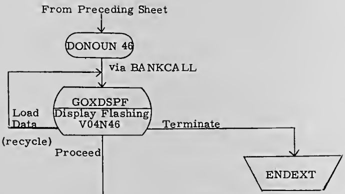


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	10/28/69	DAP Interface and Service Routines	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR Roberta M. Estes	11/26/69		
APPR'D Roberta M. Estes	11/26/69	REV 2	SHEET 5 OF 34

Verb 48: Load Autopilot Data



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	10/28/69	DAP Interface and Service Routines	
PRGMR [signature]			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR Roberta M. Estes	11/26/69		
APPR'D Roberta M. Estes	11/26/69	REV 2	SHEET 6 OF 34



Flashing V04 N46-Request Response
Autopilot Configuration (Octal Code)

R1-DAPDATR1

bits 15-13 -Vehicle Configuration
- 0-no DAP
- 1-CSM
- 2-CSM/LM
- 3-CSM/SIVB
- 6-CSM/LM (Ascent)

bits 12-10 -X Trans Code Quad AC
- 0-Fail Quad AC X-Translation
- 1-Use Quad AC

bits 9-7 -X Trans Code Quad BD
- 0-Fail Quad BD X-Translation
- 1-Use Quad BD

bits 6-4 -Deadband
- 0-±0.5 deg
- 1-±5 deg

bits 3-1 -Maneuver Rate
- 0-0.05 deg/sec
- 1-0.2 deg/sec
- 2-0.5 deg/sec
- 3-2 deg/sec

R2-DAPDATR2

bits 15-13 -Quad AC Roll
- 0-Fail Quad AC(i.e. use BD)
- 1-Use Quad AC

bits 12-10 -Quad A
- 0-Fail Quad A
- 1-Use Quad A

bits 9-7 -Quad B
- 0-Fail Quad B
- 1-Use Quad B

bits 6-4 -Quad C
- 0-Fail Quad C
- 1-Use Quad C

bits 3-1 -Quad D
- 0-Fail Quad D
- 1-Use Quad D

Next Sheet

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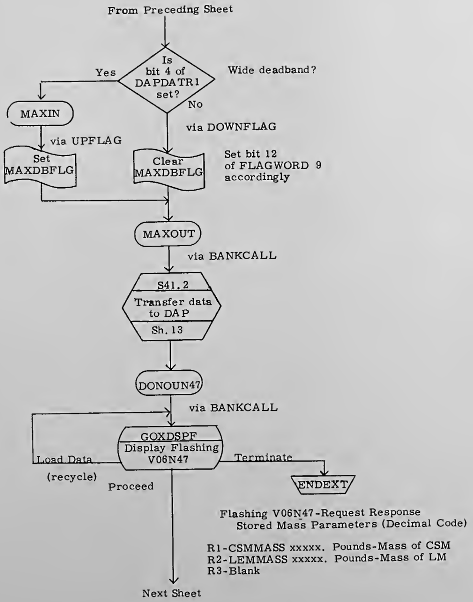
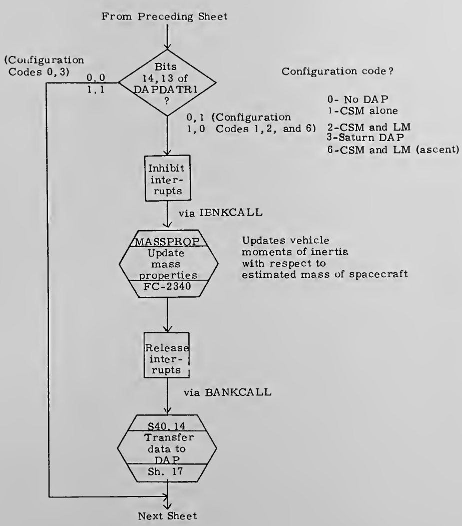
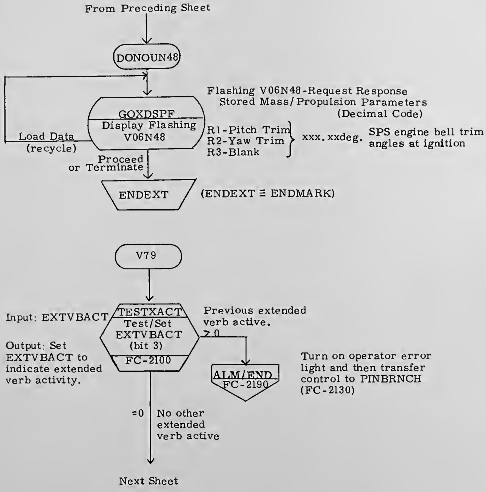
DRAWN R. Hunter	10/28/69	DAP Interface and Service Routines	
PRGMR J.F. Rusnbald		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR Roberta M. Estes	11/26/69		
APPR'D Roberta M. Estes	11/26/69	REV 2	SHEET 7 OF 34



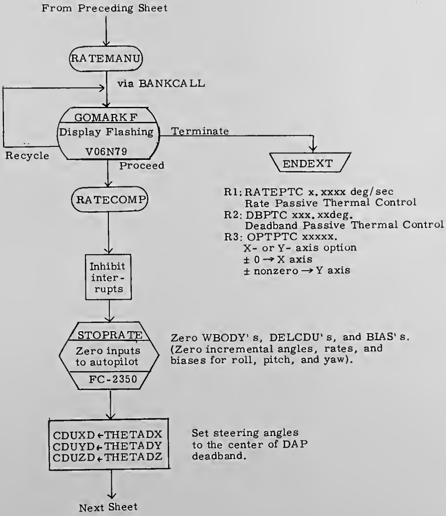
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. Hunter	10/20/69	DAP Interface and Service Routines	
PRGMR J. F. Dunnell		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR Roberta M. Enter	11/26/69		
APPR'D Roberta M. Enter	11/26/69	REV 2	SHEET 8 OF 34

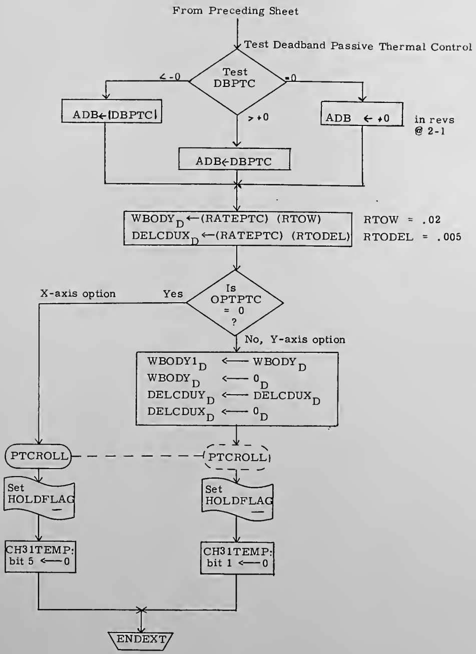


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	11/18/69	DAP Interface and Service Routines	
PRGMR [illegible]		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR [illegible]	11/26/69		
APPR'D [illegible]	11/26/69	REV 2	SHEET 9 OF 34



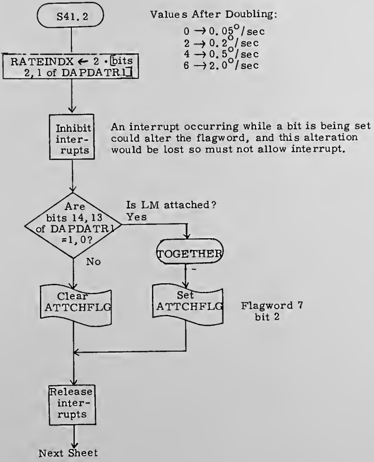
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN (signature)	10/28/69	DAP Interface and Service Routines	
PRGMR (signature)			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR Roberta M. Estes	11/26/69		
APPR'D Roberta M. Estes	11/26/69	REV 2	SHEET 10 OF 34

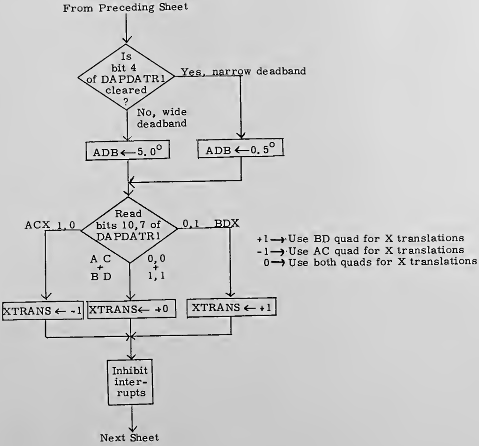

From Preceding Sheet
RATEMANU
via BANKCALL
GOMARKF
Display Flashing
V06N79
Recycle
Terminate
Proceed
ENDEXT
R1: RATEPTC x.xxxx deg/sec
Rate Passive Thermal Control
R2: DBPTC xxx.xxdeg.
Deadband Passive Thermal Control
R3: OPTPTC xxxxx.
X- or Y- axis option
± 0 → X axis
± nonzero → Y axis
RATECOMP
Inhibit interrupts
STOPRATE
Zero inputs to autopilot
FC-2350
Zero WBODY's, DELCDU's, and BIAS's.
(Zero incremental angles, rates, and biases for roll, pitch, and yaw).
CDUXD ← THETADX
CDUYD ← THETADY
CDUZD ← THETADZ
Set steering angles to the center of DAP deadband.
Next Sheet



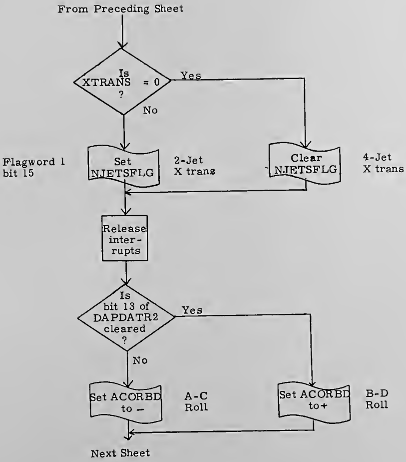
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Hunter (signature)	10/21/69	DAP Interface and Service Routines	
PRGMR J. F. Kimball (signature)			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR Roberta M. Estes (signature)	11/26/69		
APPR'D Roberta M. Estes (signature)	11/26/69	REV 2	SHEET 12 OF 34

S41.2, S40.14 and S40.15 Decode DAP Data Nouns

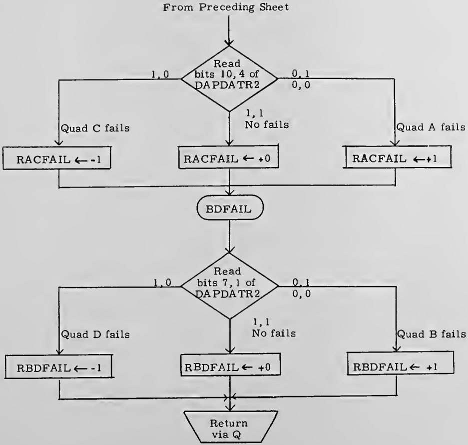




MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		DAP Interface and Service Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR Roberta M. Estes	11/26/67		
APPR'D Roberta M. Estes	11/26/67	REV 2	SHEET 14 OF 34



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	10/28/69	DAP Interface and Service Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR	11/26/69		
APPR'D	11/26/69	REV 2	SHEET 15 OF 34


From Preceding Sheet
Read bits 10, 4 of DAPDATR2
1, 0
0, 1
0, 0
1, 1
No fails
Quad C fails
Quad A fails
RACFAIL ← -1
RACFAIL ← +0
RACFAIL ← +1
BDFAIL
Read bits 7, 1 of DAPDATR2
1, 0
0, 1
0, 0
1, 1
No fails
Quad D fails
Quad B fails
RBDFAIL ← -1
RBDFAIL ← +0
RBDFAIL ← +1
Return via Q

S40.14

J/M ⟵ IXX (.662034)	S/C inertia to torque ratio-x axis
J/M1 ⟵ IAVG (.662034)	S/C inertia to torque ratio-y axis
J/M2 ⟵ IAVG (.662034)	S/C inertia to torque ratio-z axis
KMJ ⟵ .00118/IXX	S/C torque to inertia ratio -x axis
KMJ1 ⟵ .00118/IAVG	S/C torque to inertia ratio -y axis
KMJ2 ⟵ .00118/IAVG	S/C torque to inertia ratio - z axis

(J/M, J/M1, J/M2) in rev/dsec·csec $@2^{+23}$

(KMJ, KMJ1, KMJ2) in rev/dsec·csec $@2^{-13}$

Return via Q

S40.15

1/CONACC ⟵ 8·IXX·2PI/M — Desired roll gain in $(rev/sec^2)^{-1}$ $@2^{+9}$

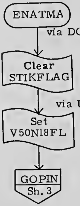
S40.15 +7

VARK ⟵ 4·KTLX/I·IAVG/TLX — Variable gain (for pitch and yaw) in rev/rev $@2^{+2}$x1.07975 for CSM/LM in rev/rev $@2^{+4}$x1.07975 for CSM

Return via Q

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Hunter	10/23/67	DAP Interface and Service Routines	
PRGMR [signature]		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR Roberta M. Eaton	11/26/68		
APPR'D Roberta M. Eaton	11/26/68	REV 2	SHEET 17 OF 34

Extended Verb 58-Enable Automatic Maneuvers

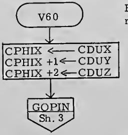


Extended Verb 58-Reset STIKFLAG (Enable automatic manuevers)

Reset flag so that R61 may perform automatic tracking maneuvers after interrupt by RHC activity (STIKFLAG - Flagwrd 1 bit 14)

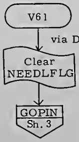
Flagword 3 bit 15

Extended Verbs 60-63 DAP Error Display Configuration



Extended Verb 60-Set N17 reference angles to current CDU readings

in revs @2^{-1}



Extended Verb 61-Clear NEEDLFLG for display of A/P following error (Display Mode 1)

Flagword 0 bit 9

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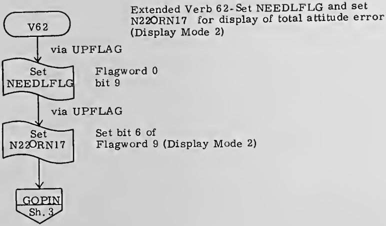
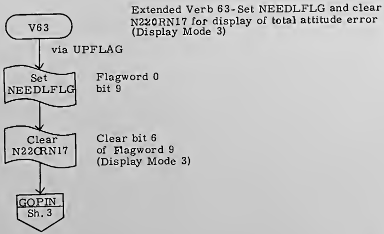
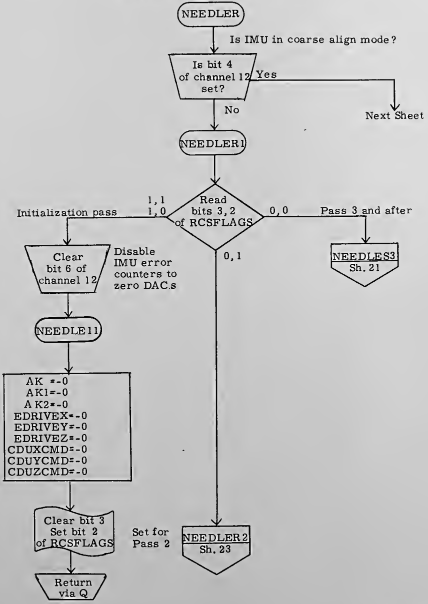
DRAWN R. Hunter	11/23/67	DAP Interface and Service Routines	
PRGMR (signature)		COLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST			
DOCMR Roberta M. Ente	11/24/67		
APPR'D Roberta M. Ente	11/24/67	REV 2	SHEET 18 OF 34


Extended Verb 62-Set NEEDLFLG and set N22ORN17 for display of total attitude error (Display Mode 2)
V62
via UPFLAG
Set NEEDLFLG
Flagword 0 bit 9
via UPFLAG
Set N22ORN17
Set bit 6 of Flagword 9 (Display Mode 2)
GOPIN
Sh. 3


Extended Verb 63-Set NEEDLFLG and clear N22ORN17 for display of total attitude error (Display Mode 3)
V63
via UPFLAG
Set NEEDLFLG
Flagword 0 bit 9
Clear N22ORN17
Clear bit 6 of Flagword 9 (Display Mode 3)
GOPIN
Sh. 3

FDAI NEEDLE DRIVE ROUTINE



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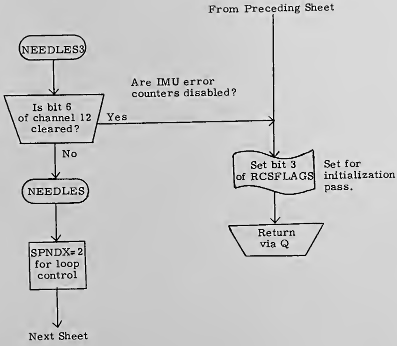
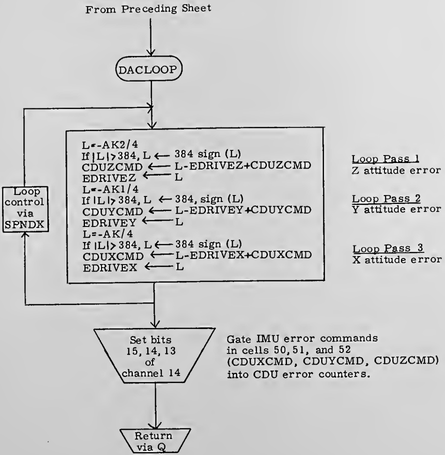
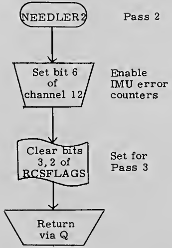
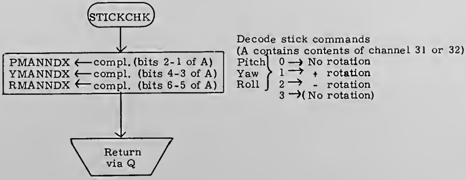
PROGMR J. F. [signature]		COLLOSSUS 2D	DOCUMENT NO. FC-2370
ANALST /			
DOCMR Roberta M. Estes	11/21/67		
APPR'D Roberta M. Estes	11/21/67	REV 2	SHEET 20 OF 34

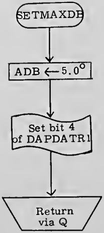

From Preceding Sheet
NEEDLES3
Are IMU error counters disabled?
Is bit 6 of channel 12 cleared?
Yes
No
Set bit 3 of RCSFLAGS
Set for initialization pass.
NEEDLES
Return via Q
SPNDX= 2 for loop control
Next Sheet


From Preceding Sheet
DACLOOP
L←-AK2/4
If |L|>384, L ← 384 sign (L)
CDUZCMD ← L-EDRIVEZ+CDUZCMD
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 control via SPNDX
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, CDUZCMD) into CDU error counters.
Return via Q

RCS-DAP Subroutines

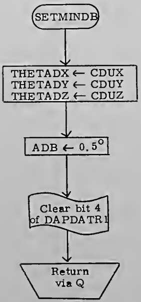






Set maximum deadband

Wide deadband (in revs @2^{-1})



Set minimum deadband

Zero attitude errors to save propellant on switchover to narrow deadband } in revs @2^{-1}

Narrow deadband (in revs @2^{-1})

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ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR Roberta M. Estes	11/26/69		
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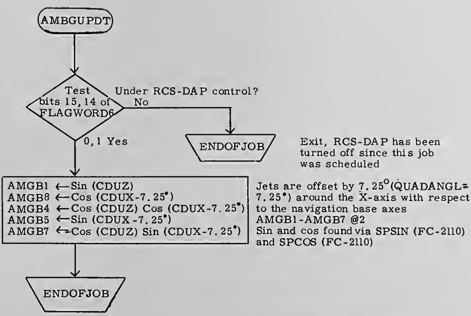
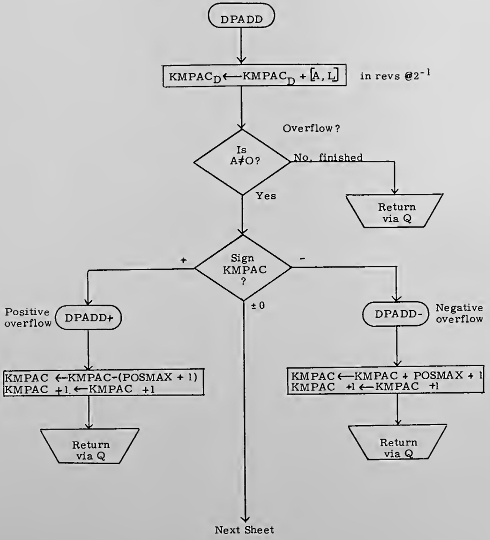
Matrix Update Subroutine



Transformation matrix: gimbal angle differences to body angle differences

$$\begin{pmatrix} 1 & \text{Sin (CDUZ)} & 0 \\ 0 & \text{Cos (CDUZ) Cos (CDUX-7.25)} & \text{Sin (CDUX-7.25)} \\ 0 & -\text{Cos (CDUZ) Sin (CDUX-7.25)} & \text{Cos (CDUX-7.25)} \end{pmatrix}$$

$$\begin{pmatrix} 1 & \text{Sin}\,\psi & 0 \\ 0 & \text{Cos}\,\psi\ \text{Cos}\,\phi & \text{Sin}\,\phi \\ 0 & \text{Cos}\,\psi\ \text{Sin}\,\phi & \text{Cos}\,\phi \end{pmatrix}$$



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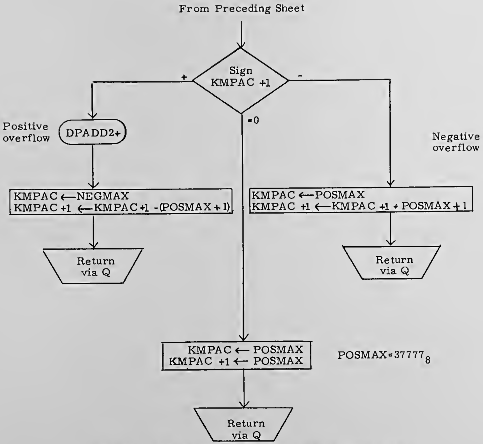
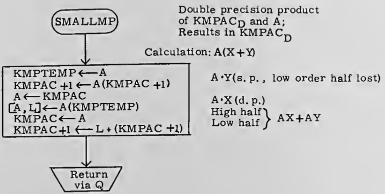
PRGMR J. F. Turnbull		
ANALST	COLOSSUS 2D	DOCUMENT NO. FC-2370
DOCMR Roberta M. Estes 11/26/69		
APPR'D Roberta M. Estes 11/26/69	REV 2	SHEET 26 OF 34



The real value of the angle stored in KMPAC lies always between ±360°. The storage capacity of KMPAC, however, is between ±180°. If positive overflow,. the real value lies between +180° and +360°, while the stored value is 180° smaller. However, by subtracting 180° (POSMAX + 1) from this stored value, it becomes equivalent to the real value (as $\Theta - 360° = \Theta$). This derived value lies between 0° and -180°, and hence is storable. A similar logic applies to negative overflow. In the case where both KMPAC and KMPAC +1 = ±0, then the real angle is 180°(=-180°), and the closest approximation is double precision POSMAX.



SMALLMP
Double precision product of KMPAC_D and A; Results in KMPAC_D
Calculation: A(X+Y)
KMPTEMP ← A
KMPAC +1 ← A(KMPAC +1)
A ← KMPAC
[A, L] ← A(KMPTEMP)
KMPAC ← A
KMPAC +1 ← L + (KMPAC +1)
A·Y(s. p., low order half lost)
A·X (d. p.)
High half
Low half
AX+AY
Return via Q

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

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	
N22ORN17 (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:	enable Saturn control of DAP	5	3, 4	2, 6, 25
DAPBIT 2 (Flagword 6 bit 14)	0, 1: 0, 0:	RCS A/P no DAP's	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

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. xxxxdeg/sec rate passive thermal control R2: xxx. xxdeg. deadband passive thermal control R3: xxxxx. x- or y- axis option	Sh. 11

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^{+14}
ADB	Attitude error deadband	deg	rev	2^{-1}
AK AK1 AK2	Attitude errors	deg	rev	2^{-1}
AMGB1 AMGB4 AMGB5 AMGB7 AMGB8	Matrix elements which are used by RCS DAP to transform information from gimbal to control axes.			2^{0}
CDUXCMD CDUYCMD CDUZCMD	Value to be transmitted to CDU IMU error counters and/or to FDAI needles.	deg	rev	2^{+1}
CDUXD CDUYD CDUZD	Values of desired DAP CDU angles for automatic maneuver.	deg	rev	2^{-1}
CPHI CTHETA CPSI	Noun 22: New ICDU angles and Noun 18: Ball angles auto maneuvers.	deg	rev	2^{-1}
DAPDATR1 DAPDATR2	see end of Erasable Locations			
$DELCDUX_D$	CDUX change; calculated every decisecond.	deg	rev	2^{-1}
EDRIVEX EDRIVEY EDRIVEZ	Buffer register used in communicating DAP attitude errors to needles.	deg	rev	2^{+1}
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^{+14}
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 x axis	$kg \cdot m^2$	$kg \cdot m^2$	2^{+20}

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/deci-sec-csec)$^{-1}$	(rev/deci-sec-csec)$^{-1}$	2^{+23}
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/deci-sec	rev/deci-sec	2^{-13}
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^{+2} x 1.07975 CSM: 2^{+4} 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^{+14}
RACFAIL	A-C Quad Failures (see DAPDATR2 bits 10, 4)			2^{+14}
RBDFAIL	B-D Quad Failures (see DAPDATR2 bits 7, 1)			2^{+14}
RMANNDX	Roll decode stick command (see PMANNDX above)			2^{+14}
THETADX THETADY THETADZ	CDU angles in DAP used for attitude errors.	deg	rev	2^{-1}
VARK	Variable gain (for pitch and yaw)	deg/deg	rev/rev	CSM/LM: 2^{+2} x 1.07975 CSM: 2^{+4} x 1.07975
$WBODY_D$	Desired angular rates	deg/deci-sec	rev/deci-sec	2^{-3}
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^{+14}
YMANNDX	Yaw decode stick command (see PMANNDX above)			2^{+14}
1/CONACC	Reciprocal of roll axis acceleration	(deg/sec^2)$^{-1}$	(rev/sec^2)$^{-1}$	2^{+9}

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scaling
DAPDATR1	Specifies vehicle configuration and desire DAP			
bit 15-13	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			

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

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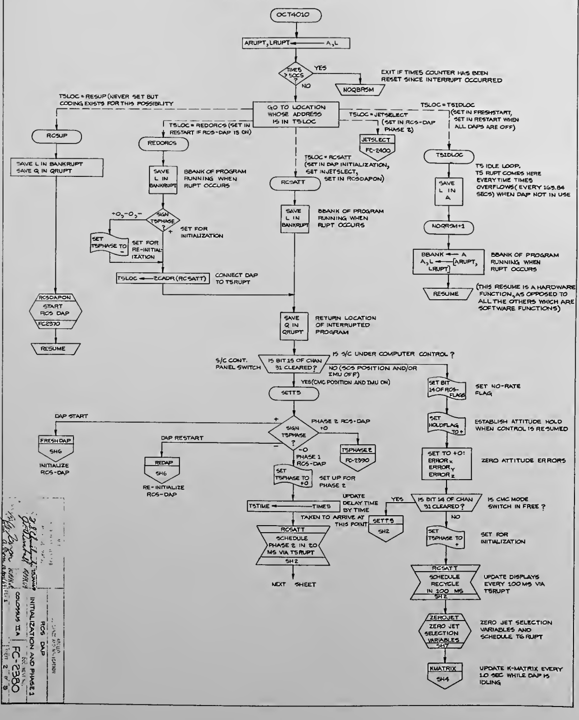
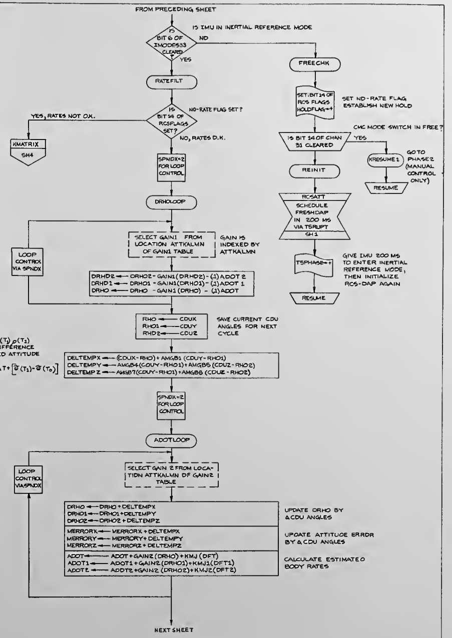
PRGMR	[signature]		
ANALST		COLOSSUS II-A	DOCUMENT NO. FC-2380
DOCMR	[signature]		
APPR'D	[signature]	REV 1	SHEET 1 OF 8

RCS DIGITAL AUTOPILOT





RATE ESTIMATION EQUATIONS

ESTIMATED RATE AT TIME T_1:

$$\hat{W}(T_1) = \hat{W}(T_0) + \int_{T_0}^{T_1} \mu(\tau)\,d\tau + W_2(T_1)\,\rho(T_1)$$

WHERE $\rho(T_1) = \hat{\theta}(T_1) - \theta(T_1)$ THE DIFFERENCE BETWEEN MEASURED AND ESTIMATED ATTITUDE ANGLES AT TIME T_1.

$$\rho(T_1) = \rho(T_0) - W_1(T_0)\,\rho(T_0) - \hat{W}(T_0)\,\Delta T + \left[\hat{\theta}(T_1) - \hat{\theta}(T_0)\right]$$

WHERE $\int_{T_0}^{T_1} \mu(\tau)\,d\tau = C\Delta T$

$\hat{W}$ = ADOT

ρ = DRHO

W_1 = GAIN1

W_2 = GAIN2

$\hat{\theta}(T_1)$ = CDU

$\hat{\theta}(T_0)$ = RHO

C = KMJ

ΔT^1 = DFT

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DRAWN / PRGMR / ANALST / DOCMR / APPR'D (signatures)

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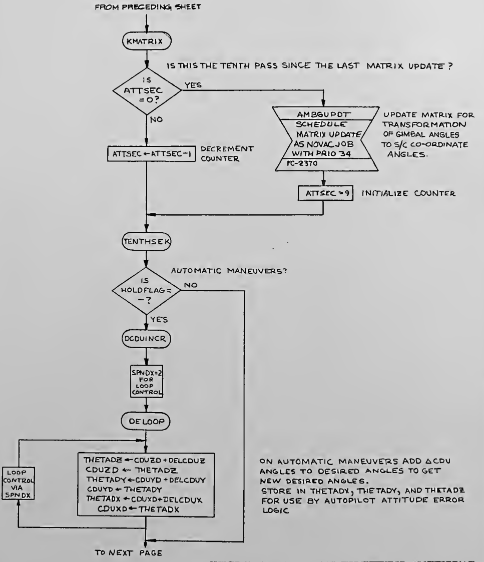
RCS DAP INITIALIZATION AND PHASE 1

COLOSSUS II A

DOCUMENT NO. FC-2380

REV 1

SHEET 3 OF 8



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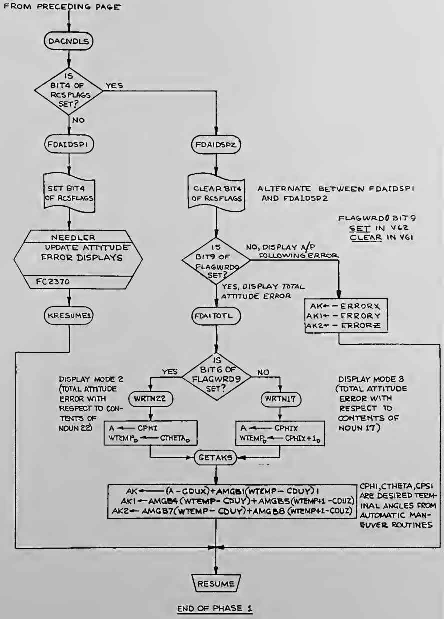
RCS DAP INITIALIZATION AND PHASE 1

COLOSSUS IIA

DOCUMENT NO. FC-2380

REV 1

SHEET 4 OF 8



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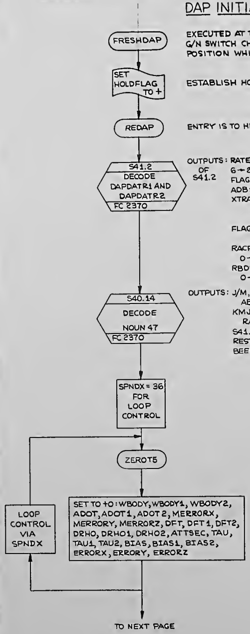
DRAWN	8-29-67	RCS DAP INITIALIZATION AND PHASE 1
	10-16-67	
DOCMR	10-16-67	COLOSSUS IIA — DOCUMENT NO. FC2380
APP'D	10-18-67	REV 1 — SHEET 5 OF 8
USED ON		

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 OF S41.2: RATE INDX: 0 → .05°/sec, 2 → .2°/sec, 4 → .5°/sec, 6 → 2.0°/sec
FLAGWRD7 BIT2: 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 BIT 15: 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

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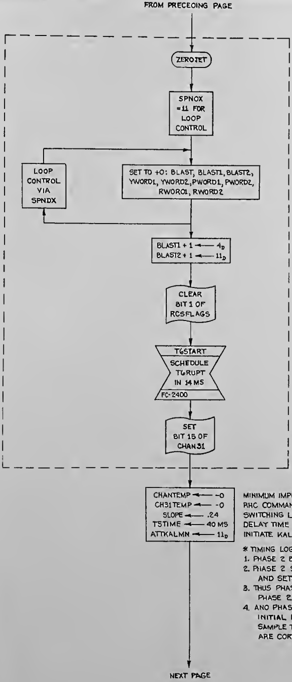
CAMBRIDGE, MASS.

DRAWN R. | 5 JAN 69
DOC MR J.E. Turnbull | 10 APR 69
ANALYST
DOC MGR G. Zimmer | 10 APR 69
APPR'D John A. Moore | 10 April 69

RCS DAP INITIALIZATION AND PHASE 1

COLOSSUS IIA | FC-2380
REV 1 | 6 · 8



ZEROJET SELECTION VARIABLES

BRANCH INDICES FOR JET SELECTION LOGIC

START TIME6 COUNTER

END OF SUBROUTINE

MINIMUM IMPULSE COMMANDS
RHC COMMANDS
SWITCHING LOGIC SLOPE
DELAY TIME *
INITIATE KALMANN FILTER GAINS

* TIMING LOGIC

1. PHASE 2 BEGINS IN 60 MS (SEE NEXT SHEET)
2. PHASE 2 SUBTRACTS TSTIME FROM 80 MS AND SETS PHASE 1 TO BEGIN AT THAT TIME.
3. THUS PHASE 1 BEGINS (80-40) = 40 MS AFTER PHASE 2.
4. AND PHASE 1 BEGINS (40+60) = 100 MS AFTER INITIAL PHASE SO THAT THE 0.1 SEC FILTER SAMPLE TIME AND 1.0 SEC MATRIX UPDATING ARE CORRECTLY TIMED.

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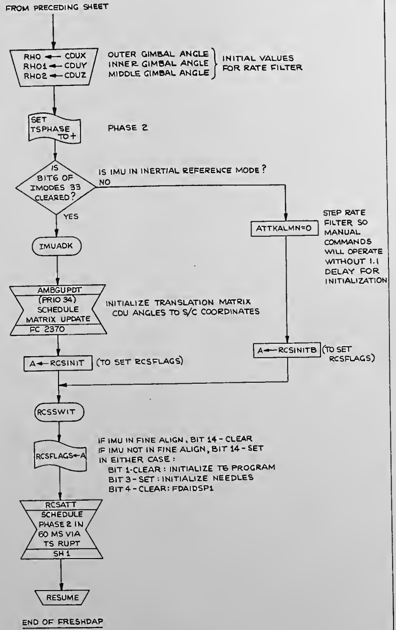
DRAWN A.C. WILLIAMS 16JAN69	RCS DAP INITIALIZATION AND PHASE 1
PROGMR J.F. Turnbull 10APR69	
ANALYST	COLOSSUS IIA — DOCUMENT NO. FC-2380
DOC MGR G. A. Tesson 10APR69	
APPR'D John A. Morse 10 April 69	REV 1 — SHEET 7 OF 8



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN 15JAN69
PRGMR 14APR69
ANALYST
DCMS 16APR69
APPR'D 10April69

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FC-2380

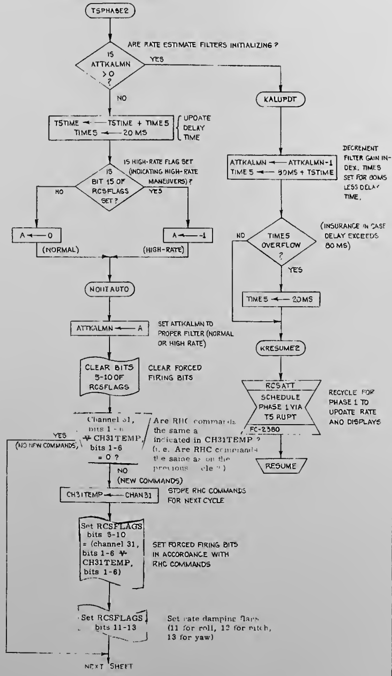
REV 1

8 8

Special Convention: $\veebar$ indicates "exclusive or" operation.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	[illegible]	RCS DAP Phase 2	
PRGMR [illegible]	11-28-69		
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2390
DOCMR Roberta M. Eaton	11/28/69		
APPR'D Roberta M. Eaton	11/28/69	REV 1	SHEET 1 OF 12

RCS-DAP PHASE 2



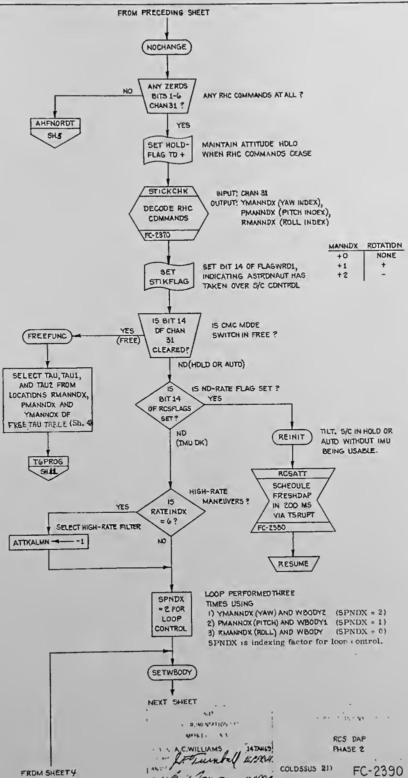
A C WILLIAMS 14JAN69

RCS DAP PHASE 2

COLOSSUS 2D

FC-2390

1 2 12



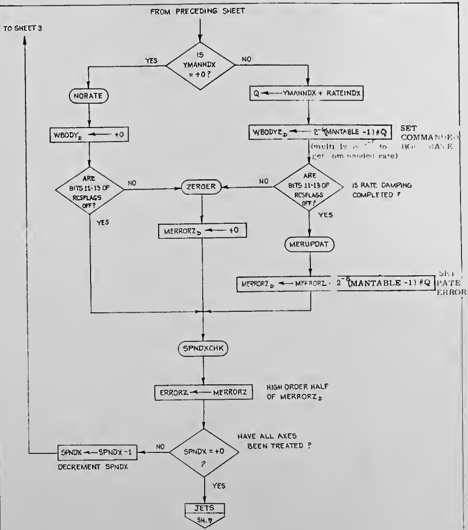
A.C.WILLIAMS 14JAN69

RCS DAP
PHASE 2

COLDSSUS 2D

FC-2390

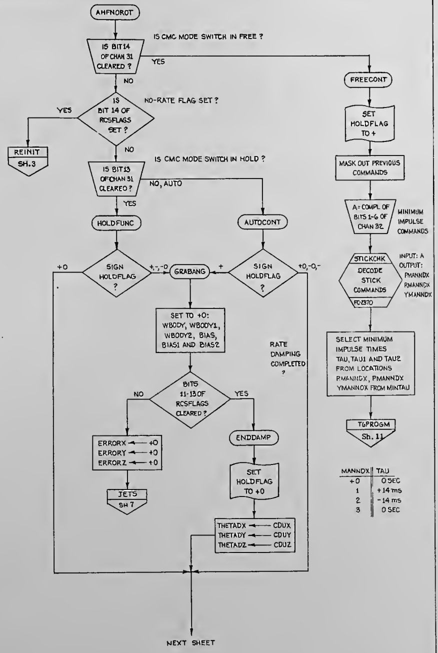
1 3 12



FREEFLAG TABLE

RMANNDX	FREEFLAG +0	0 sec.	A
PMANNDX	+1	+0.10 sec.	AU1
YMANNDX	+2	-0.10 sec.	AU2
	(+3)	0 sec.	

A C WILLIAMS 15JAN69
J. Turnbull 10APR69
[illegible] 10APR69
John A. Moore 10 Apr 69
COLOSSUS 2D
RCS DAP
PHASE 2
FC-2390
1 4 12



MANNDX	TAU
+0	0 SEC
1	+14 ms
2	-14 ms
3	0 SEC

MIT INSTRUMENTATION LAB CAMBRIDGE MASS

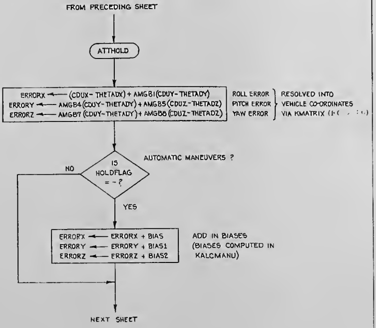
DRAWN A.C.WILLIAMS 15JAN65

RCS DAP PHASE 2

COLOSSUS 2D

FC-2390

5 12



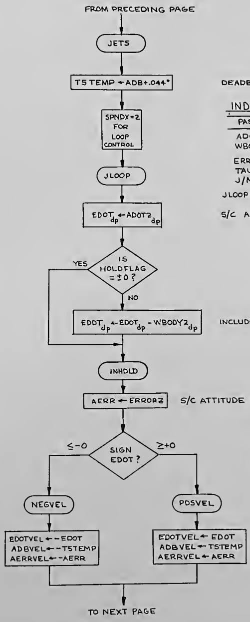
A.C.WILLIAMS

RCS DAP
PHASE 2

COLOSSUS 21

FC-2390

6 12



DEADBAND + FLAT REGION

INDEXED VARIABLES IN JLOOP

PASS 1	PASS 2	PASS 3
ADOT 2$_{dp}$	ADOT1$_{dp}$	ADOT$_{dp}$
WBODY2$_{dp}$	WBODY1$_{dp}$	WBODY$_{dp}$
ERROR Z	ERRORY	ERRORX
TAU 2	TAU 1	TAU
J/M2	J/M1	J/M

JLOOP IS EXECUTED ONCE FOR EACH AXIS

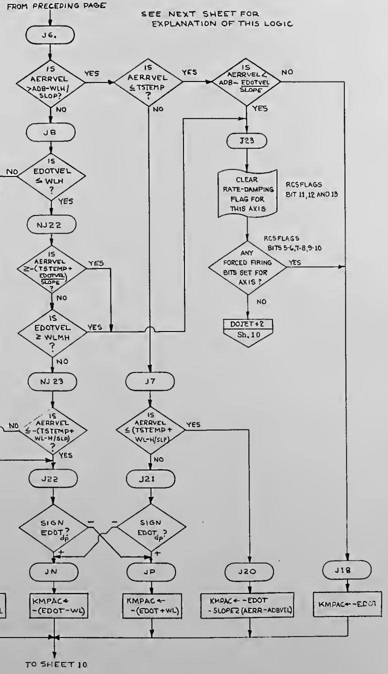
S/C ANGULAR RATE (ESTIMATE)

INCLUDE AUTOMATIC MANEUVER RATES

S/C ATTITUDE ERROR

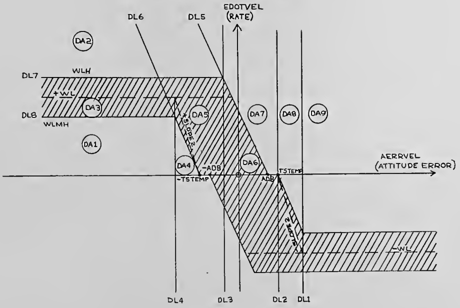
SINCE THE PHASE PLANE IS SYMMETRIC ABOUT THE ORIGIN, THE RATE IS TAKEN AS POSITIVE AND THE SIGNS OF EDOT, T5TEMP AND AERR ADJUSTED ACCORDINGLY. THE SUFFIX "VEL" IN THE MNEMONIC DESIGNATES THE ADJUSTED VALUES.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN F. Pearson Jr.	8-25-67	RCS DAP PHASE 2
PROG'MR [illegible]	[illegible]	COLOSSUS 2D — DOCUMENT NO. FC 2390
DOCMR [illegible]	10-16-67	
USED ON — APPR'D [illegible]	10-18-67	REV 1 — SHEET 7 OF 12



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
		RCS DAP PHASE 2	
	DRAWN *F. Pearson Jr.* 8-25-67	COLOSSUS 21)	DOCUMENT NO. FC 2390
	PRGMR *E. W. ...*		
	DOC MR *J. G. ...*		
USED ON	APPR'D. *J. Heinze* 10-18-67	REV 1	SHEET 8 OF 12

PHASE PLANE LOGIC



DECISION LOGIC

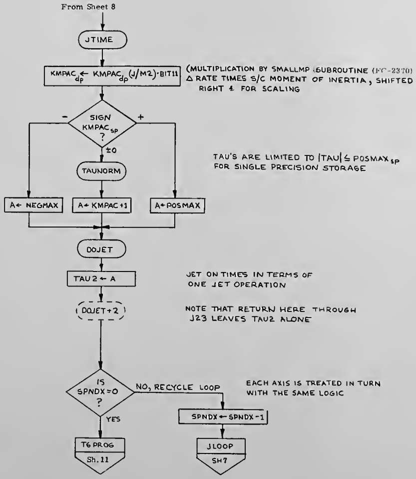
DECISION LINE (DL) ON GRAPH	1	2	3	4	5	6	7	8
DECISION POINT IN LOGIC	J7	J6+1	J6	NJ23	J6+2	NJ22	J8	NJ22+1
OUTCOME { LOGICAL "YES"	LEFT	LEFT	RIGHT	LEFT	LEFT	RIGHT	BELOW	ABOVE
OUTCOME { LOGICAL "NO"	RIGHT	RIGHT	LEFT	RIGHT	RIGHT	LEFT	ABOVE	BELOW

LOGICAL PATHS

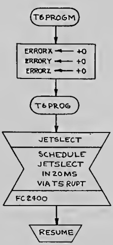
DECISION AREA (DA)	LOGICAL PATHS	RESPONSE
DA 1	J6. – J8 – NJ22 – NJ22 + 1 – NJ23 – J22 →	DRIVE RATE TO +WL
DA 2	J6. – J8 – J22 →	DRIVE RATE TO +WL
DA 3	J6. – J8 – NJ22 – NJ22 + 1 – J23 →	NO ACTION*
DA 4	J6. – J8 – NJ22 – NJ22 + 1 – NJ23 – J24 →	DRIVE RATE TO + SLOPE 2
DA 5	J6. – J8 – NJ22 – J23 →	NO ACTION*
DA 6	J6. – J6+1 – J6+2 – J23 →	NO ACTION*
DA 7	J6. – J6+1 – J6+2 – J18 →	DRIVE RATE TO ZERO
DA 8	J6. – J6+1 – J7 – J20 →	DRIVE RATE TO – SLOPE 2
DA 9	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
	DRAWN F. Pearson 8-28-67	RCS DAP PHASE 2
	PRGMR D. W. Keene 10-16-67	
	DOCMR J. A. Morse 10-6-67	COLOSSUS 2D — DOCUMENT NO. FC 2390
USED ON	APPR'D J. Hanley 10-18-67	REV 1 — SHEET 9 OF 12



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	DRAWN [signature] 8-28-67	RCS DAP PHASE 2
	PROGR [signature] 10-16-67	COLOSSUS 2D — DOCUMENT NO. FC2390
	DOCMR [signature] 10-16-67	
USED ON	APPR'D [signature] 10-18-67	REV 1 — SHEET 10 OF 12



ZERO ATTITUDE ERROR IF IN FREE MODE, OR IF MANUAL COMMANDS ARE BEING RECOGNIZED

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
	DRAWN	8-29-67	RCS DAP PHASE-2
	PROGMR	10-16-67	COLOSSUS 2D · DOCUMENT NO. FC2390
	DOCMA	10-16-67	
USED ON	APPR'D	10-18-67	REV 1 · SHEET 11 OF 12

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

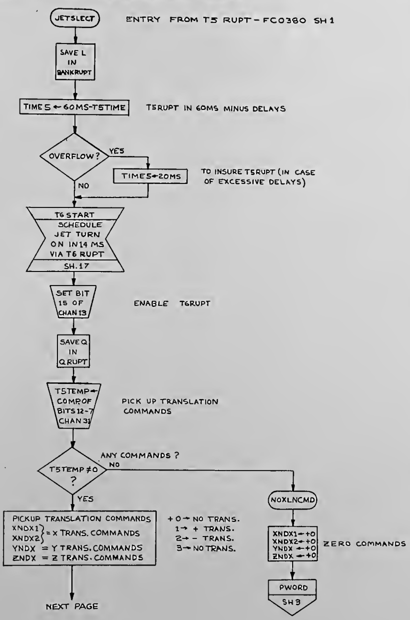
Subroutine Name	Where Flowed	Description	Where Called
JETSLECT	FC-2400	Entry to RCS DAP jet selection logic	Sh. 11
KMATRIX	FC-2380	Resolve roll, pitch, & yaw errors into vehicle co-ordinates	Sh. 6
RCSATT	FC-2380	Entry to Phase 1	Sh. 2, 3
SMALLMP	FC-2370	One and one-half precision multiplication	Sh. 10
STICKCHK	FC-2370	Decode RHC commands	Sh. 3, 5

FLAG

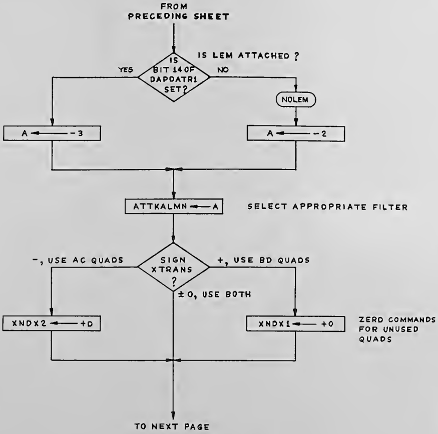
Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
STIKFLAG flagword 1 bit 14	RHC control	CMC control	Sh. 3		

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN	RCS DAP - Phase 2	
PRGMR		DOCUMENT NO
ANALST	COLOSSUS 2D	FC-2390
DOCMR	REV 1	SHEET 12 OF 12
APPR'D		

RCS-DAP JET SELECTION LOGIC



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN 8-29	RCS DAP JET SELECTION LOGIC	
CHECKED 10-16		
DOCMR 10-16	COLOSSUS II	DOCUMENT NO. FC 2400
USED ON / APP'D 10-16	REV	SHEET 1 OF 19



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN 15JAN68
PRGMR
ANALST
DOCMR
APPR'D

APOLLO
GUIDANCE AND NAVIGATION

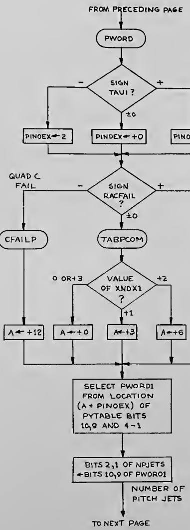
RCS DAP
JET SELECTION LOGIC

COLOSSUS
II

DOCUMENT No.
FC-2400

REV

SHEET 2 OF 19



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

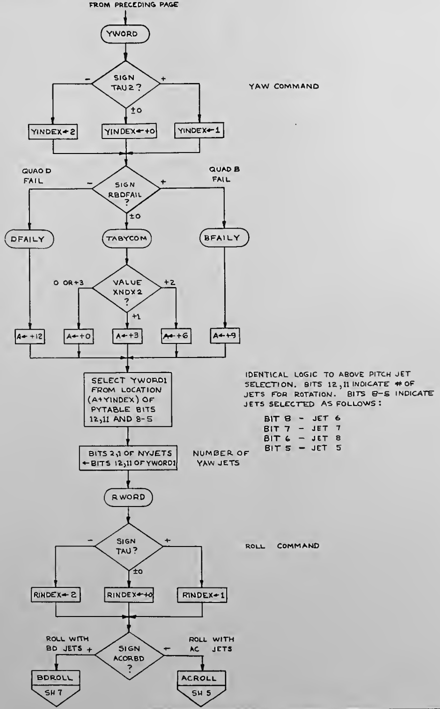
PYTABLE − PITCH COMMANDS

A	PINDEX	BITS 10,9 # JETS FOR ROT.	BIT4 JET2	BIT3 JET3	BIT2 JET4	BIT1 JET1	ROT.	TRANS.
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	
9	1	1	0	0	0	1	+	* (+)
9	2	1	0	0	1	0	−	* (−)
12	0	0	0	0	0	0	0	
12	1	1	0	1	0	0	+	* (−)
12	2	1	1	0	0	0	−	* (+)

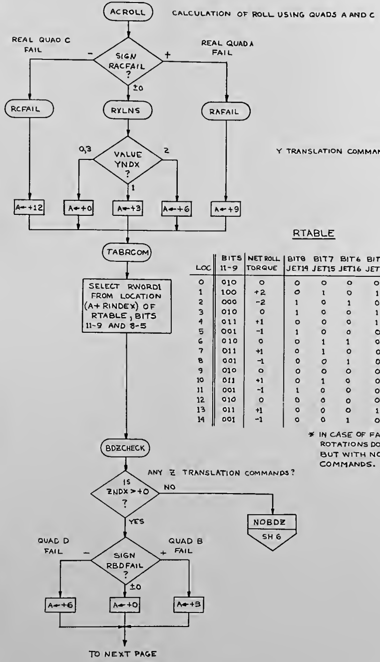
* IN THE CASE OF A OR C FAILS, THESE 1-JET ROTATIONS WILL CAUSE TRANSLATIONS WHICH MAY OR MAY NOT CO-INCIDE WITH THE ACTUAL TRANSLATION COMMANDS, WHICH ARE IGNORED.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN J. Rasmussen 6-29-67	RCS DAP JET SELECTION LOGIC
PROMOTED E. W. Keene 11-10-67	COLOSSUS II — DOCUMENT NO. FC2400
DOCMR J. A. Morse 10-16-67 / APPR'D J. Hanize 10-18-67	REV — SHEET 3 OF 19

USED ON



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN F. Pearson Jr. 8-29-67	RCS DAP JET SELECTION LOGIC	
FRGMR D. W. Keene 10-16-67	COLOSSUS II	DOCUMENT NO. FC2400
DOCMR J. A. Morse 10-16-67		
USED ON / APP'D J. Hanige 10-18-67	REV	SHEET 4 OF 19

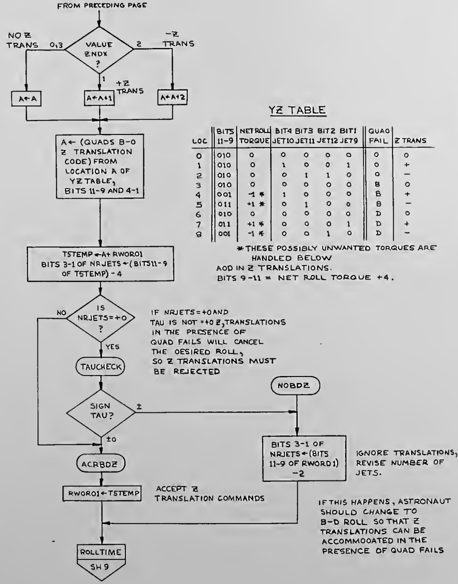


RTABLE

LOC	BITS 11-9	NET ROLL TORQUE	BIT8 JET14	BIT7 JET15	BIT6 JET16	BIT5 JET13	ROLL	Y TRANSL
0	010	0	0	0	0	0	0	0
1	100	+2	0	1	0	1	+	0
2	000	-2	1	0	1	0	-	0
3	010	0	1	0	0	1	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.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Pearson Jr. 8-29-67	RCS DAP JET SELECTION LOGIC	
PROGR D. W. Keene 10-16-67	COLOSSUS II	DOCUMENT NO. FC2400
DOCMR J. A. Moore 10-16-67		
USED ON / APPR'D J. Honig 10-18-67	REV	SHEET 5 OF 19



YZ TABLE

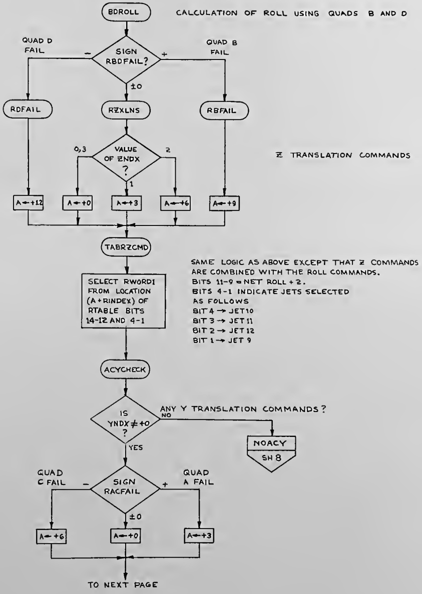
LOC	BITS 11-9	NET ROLL TORQUE	BIT4 JET10	BIT3 JET11	BIT2 JET12	BIT1 JET9	QUAD FAIL	Z TRANS
0	010	0	0	0	0	0	0	0
1	010	0	1	0	0	1	0	+
2	010	0	0	1	1	0	0	−
3	010	0	0	0	0	0	B	0
4	001	-1 *	1	0	0	0	B	+
5	011	+1 *	0	1	0	0	B	−
6	010	0	0	0	0	0	D	0
7	011	+1 *	0	0	0	1	D	+
8	001	-1 *	0	0	1	0	D	−

* THESE POSSIBLY UNWANTED TORQUES ARE HANDLED BELOW

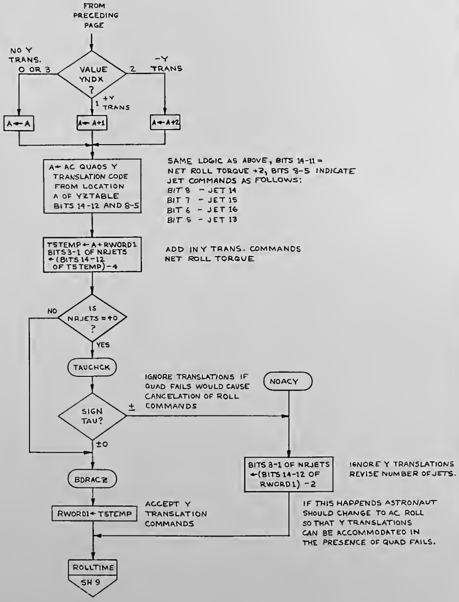
ADD IN Z TRANSLATIONS.

BITS 9-11 = NET ROLL TORQUE +4.

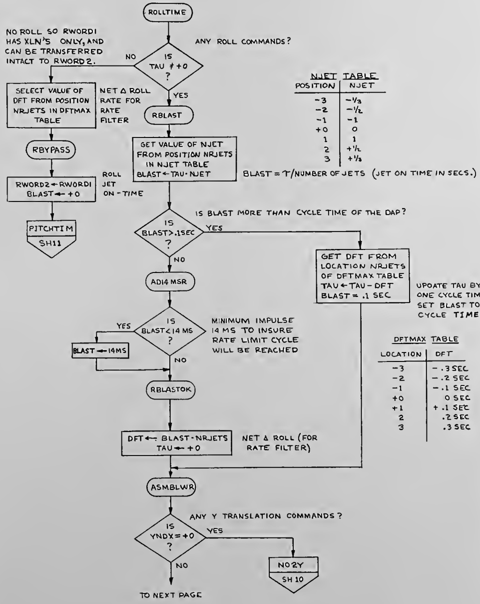
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN F. Raamon Jr.	10-29-67	RCS DAP JET SELECTION LOGIC
PROGR D. W. Keene	10-16-67	
DOC'MR J. A. Moore	10-16-67	COLOSSUS II — DOCUMENT NO. FC2400
APPR'D J. Hamje	10-18-67	REV — SHEET 6 OF 19
USED ON		



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP JET SELECTION LOGIC
	DRAWN 8-31-67	
	PROGR 10-16-67	COLOSSUS II — DOCUMENT NO. FC2400
	DOCMR 10-16-67	
USED ON	APPR'D 10-18-67	REV — SHEET 7 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	RCS DAP JET SELECTION LOGIC
FROM	COLOSSUS II
DOC CHK	DOCUMENT NO. FC2400
USED ON / APPR'D	REV / SHEET 8 OF 19



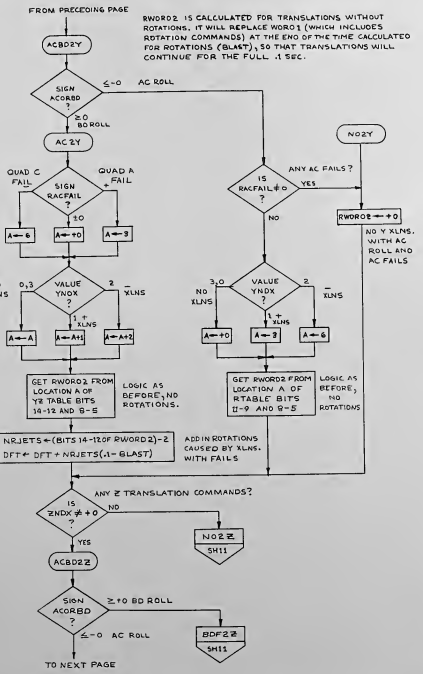
NJET TABLE

POSITION	NJET
−3	−1/3
−2	−1/2
−1	−1
+0	0
1	1
2	+1/2
3	+1/3

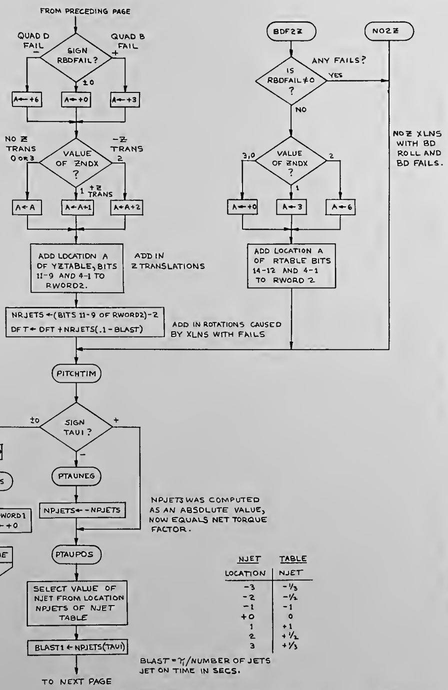
DFTMAX TABLE

LOCATION	DFT
−3	−.3 SEC
−2	−.2 SEC
−1	−.1 SEC
+0	0 SEC
+1	+.1 SEC
2	.2 SEC
3	.3 SEC

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN F. Benson Jr. 8-31-67	RCS DAP JET SELECTION LOGIC
PROGR D. W. Keene 10-16-67	COLOSSUS II — DOCUMENT NO. FC2400
DOCMR J. A. Morse 10-16-67	
APPR'D J. Hanige 10-18-67	REV — SHEET 9 OF 19
USED ON	

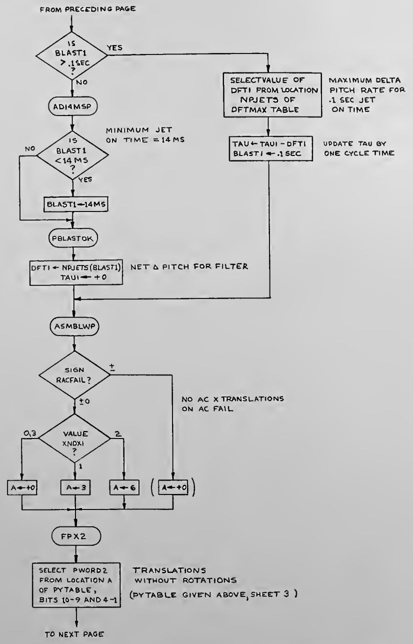


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN F. Reasoner 9-1-67	RCS DAP JET SELECTION LOGIC	
PROMR D. W. Keene 10-16-67	COLOSSUS II	DOCUMENT NO. FC2400
DOCMR J. A. Thim 10-16-67		
USED ON / APPR'D J. Hoag 10-18-67	REV	SHEET 10 OF 19

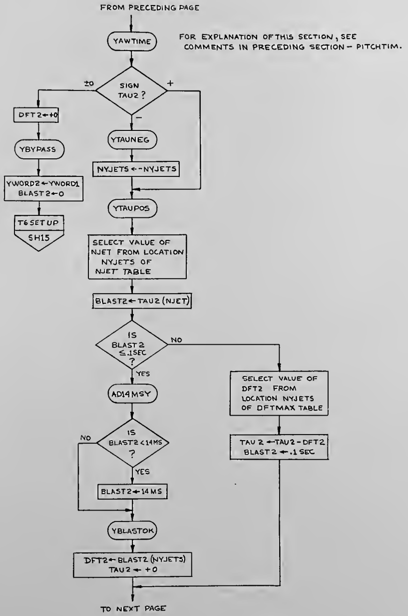


NJET LOCATION	TABLE NJET
-3	-1/3
-2	-1/2
-1	-1
+0	0
1	+1
2	+1/2
3	+1/3

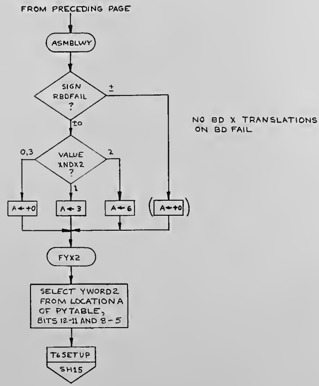
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN F. Deaner Jr.	7-1-67	RCS DAP JET SELECTION LOGIC
PROGR D. W. Keene	10-18-67	
DOCMA J. A. Moore	10-16-67	COLOSSUS II — DOCUMENT NO. FC2400
APPR'D J. Hoag	10-18-67	REV — SHEET 11 OF 19
USED ON		



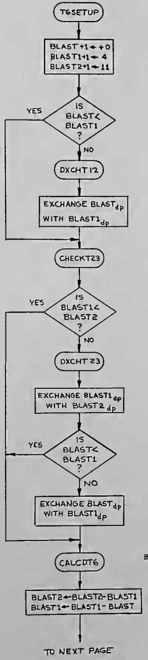
	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	DRAWN F. Reagan 9-1-67	RCS DAP JET SELECTION LOGIC
	PROGR. L. W. Kern 10-16-67	COLOSSUS II — DOCUMENT NO. FC2400
	J. A. Moore 10-16-67	
USED ON	APPR'D J. Hoag 10-18-67	REV — SHEET 12 OF 19



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP JET SELECTION LOGIC
	DRAWN F. Pearson 9-7-67	
	FROM B. W. Kane 10-16-67	COLOSSUS II — DOCUMENT NO. FC2400
	DOCMR J. A. Moore 10-16-67	
USED ON	APPR'D J. Hanley 10-18-67	REV — SHEET 13 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature] 9-5-67	RCS DAP JET SELECTION LOGIC	
PROGR [signature] 10-16-67	COLOSSUS II	DOCUMENT NO. FC2400
DOCMR [signature] 10-16-67		
USED ON / APPR'D [signature] 10-18-67	REV	SHEET 14 OF 19



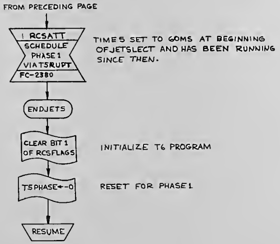
BRANCH INDEX FOR ROLL
BRANCH INDEX FOR PITCH } SEE T6START SH17
BRANCH INDEX FOR YAW

EXCHANGE IS DP SO THAT BRANCH INDEX REMAINS WITH APPROPRIATE TIME VALUE AND SERVES AS AN IDENTIFYING LABEL.

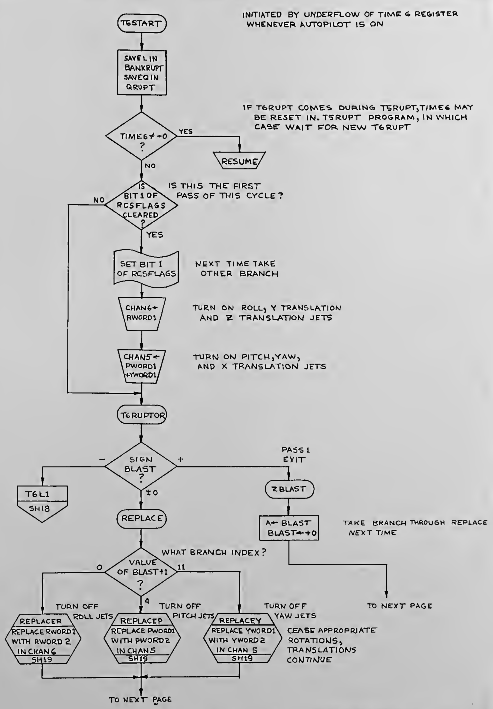
BLASTS ARE NOW IN ORDER OF INCREASING MAGNITUDE: BLAST, BLAST1, BLAST2.

Δ TIMES

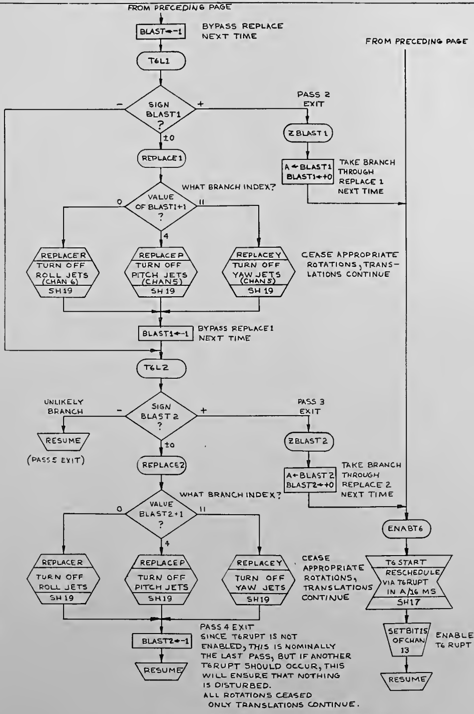
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN Z. Rearson J.	9-5-67	RCS DAP JET SELECTION LOGIC
PROG'M E. W. Kerr	10-10-67	COLOSSUS II — DOCUMENT NO. FC2400
DOC'MR J. C. Morse	10-16-67	
USED ON — APPR'D J. Hanigs	10-11-67	REV — SHEET 15 OF 19



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	DRAWN 9-5-67	RCS DAP JET SELECTION LOGIC
	PROGR 10-16-67	COLOSSUS II — DOCUMENT NO. FC2400
	DOC MGR 10-16-67	
USED ON	APPR'D 10-19-67	REV — SHEET 16 OF 19



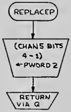
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN F. Pearson Jr.	9-5-67	RCS DAP JET SELECTION LOGIC
PROG'M L. W. Kune	10-16-67	
CHECKED J. A. Moran	10-16-67	COLOSSUS II · DOCUMENT NO. FC2400
USED ON · APPR'D J. Hanley	10-18-67	REV · SHEET 17 OF 19



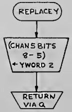
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 9-5-67	RSC DAP JET SELECTION LOGIC
PROGR D. W. Keene 10-16-67	COLOSSUS II — DOCUMENT NO. FC 2400
DOC MR J. A. Moore 10-16-67	
USED ON — APPR'D [signature] 10-11-67	REV — SHEET 18 OF 19

SUBROUTINES FOR T6START

REPLACE RWORD1 WITH RWORD2, WHICH IN EFFECT STOPS THE ROLL JETS, WHILE Y AND Z TRANSLATIONS CONTINUE.



REPLACE PWORD1 WITH PWORD2 (STOP PITCH JETS, X TRANSLATIONS CONTINUE)

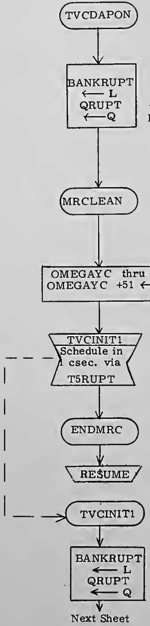


REPLACE YWORD1 WITH YWORD2 (STOP YAW JETS, X TRANSLATIONS CONTINUE)

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
	DRAWN F. Pearson	9-6-67	RCS DAP JET SELECTION LOGIC
	PROGMR D. W. Keene	10-16-67	
	DOCMR J. A. Thorne	10-16-67	COLOSSUS II — DOCUMENT NO. FC2400
USED ON	APPR'D J. Hanjes	10-18-67	REV — SHEET 19 OF 19

TVC START-UP AND EXECUTIVE ROUTINES

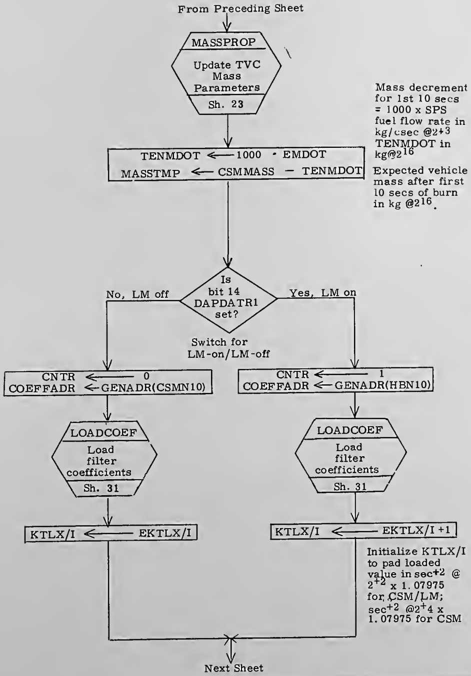
Called by T5RUPT from SPSON Allows at least .42 sec for SPS thrust buildup.
Inputs set by SPSON
TVCPHASE=1
TVCEXPHS=0
Flagword 6 bits 15, 14 =10



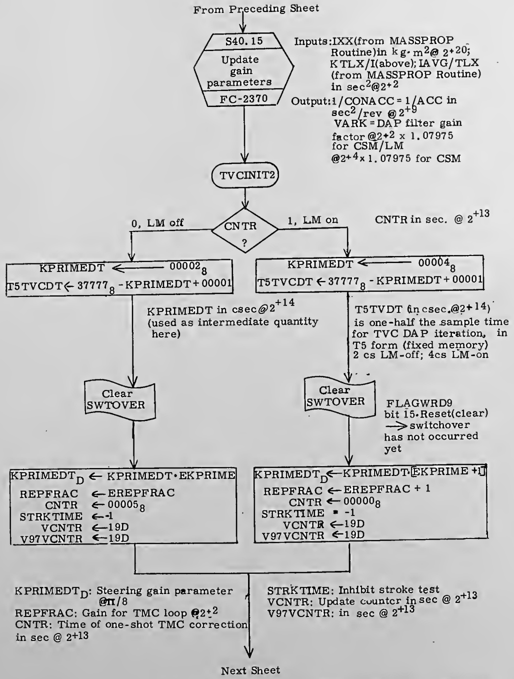
Save return values for RESUME

Reset 52 temporary DAP variables:
$OMEGAYC_D$-$OMEGAZC_D$
$OMEGAXB_D$-$OMEGAZB_D$
PTMP1-PTMP6
YTMP1-YTMP6
ROLLFIRE-ROLLWORD
TEMREG-STROKER
PERRB-YERRB
DELPBAR-DELYBAR
PDELOFF-YDELOFF

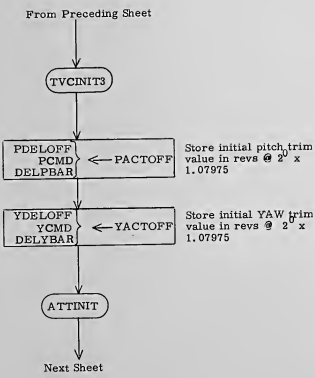
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN Ken Sullivan		TVC Start-Up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 2 OF 36

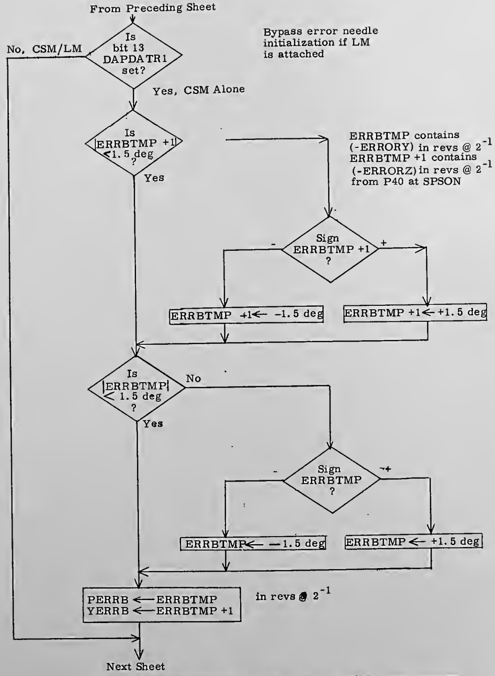


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	10-15-[illegible]	TVC Start Up and Executive Routines	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 3E	FC-2430
DOCMR			
APPR'D		REV 1	SHEET 3 OF 36

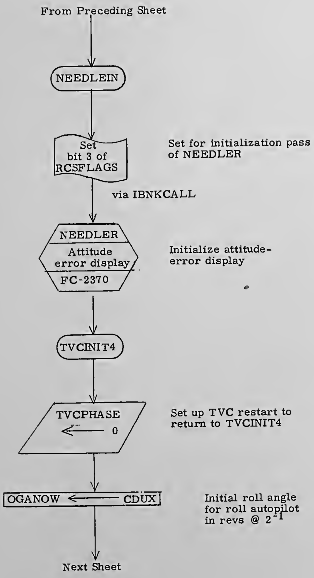


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		TVC Start-Up and Executive Routines	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2430
DOCMR			
APPR'D		REV 1	SHEET 4 OF 36

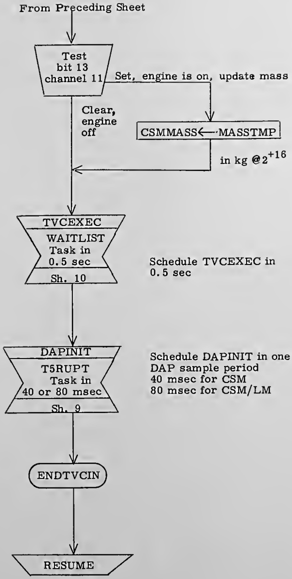

From Preceding Sheet
TVCINIT3
PDELOFF
PCMD
DELPBAR
PACTOFF
Store initial pitch trim value in revs @ 2^0 x 1.07975
YDELOFF
YCMD
DELYBAR
YACTOFF
Store initial YAW trim value in revs @ 2^0 x 1.07975
ATTINIT
Next Sheet



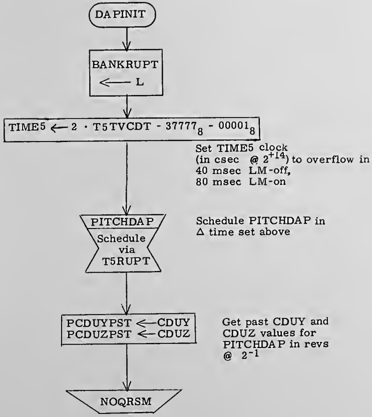
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	10-15-6[illegible]	TVC Start-Up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 6 OF 36



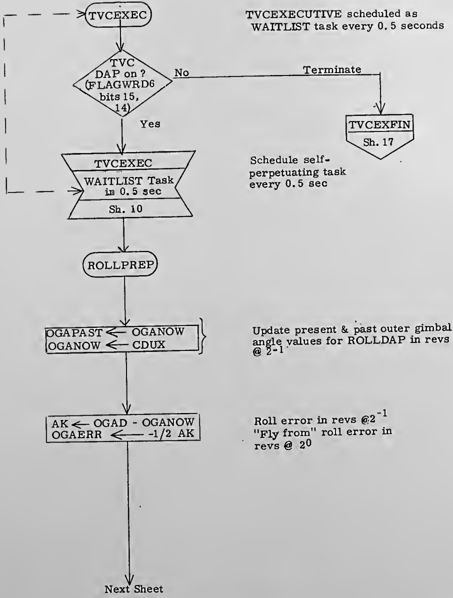
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 10-18-[illegible]	TVC Start-Up and Executive Routines
PRGMR [signature]	DOCUMENT NO.
ANALST	COLOSSUS 2D — FC-2430
DOCMR	
APPR'D	REV 1 — SHEET 7 OF 36



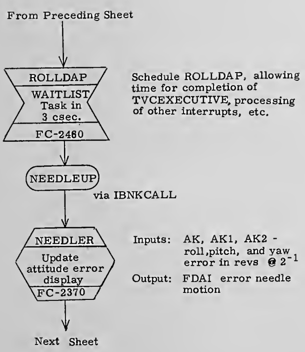
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN Jon Sullivan 10-11-68	TVC Start-up and Executive Routines	
PRGMR		
ANALST	COLOSSUS 2D	DOCUMENT NO. FC-2430
DOCMR		
APPR'D	REV 1	SHEET 8 OF 36



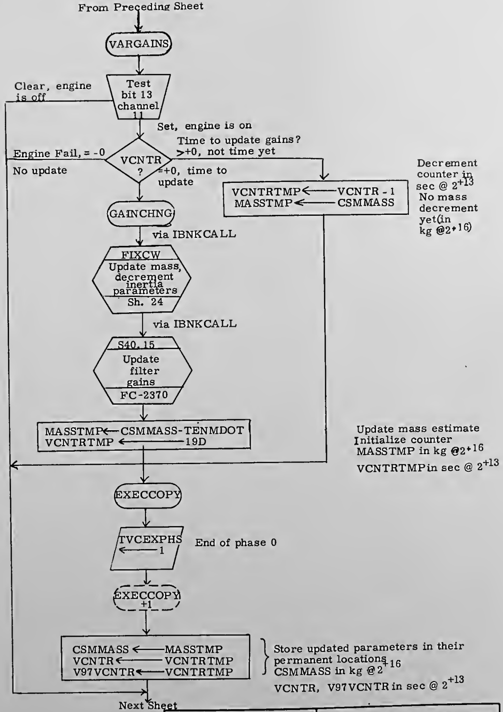
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN (signature)		TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 9 OF 36



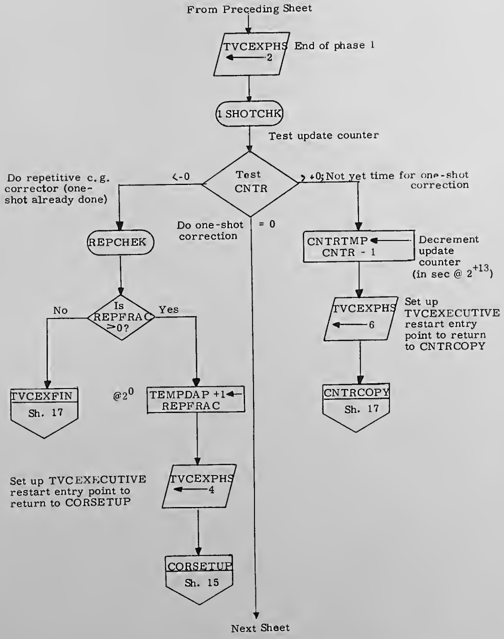
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		TVC Start-Up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 10 OF 36



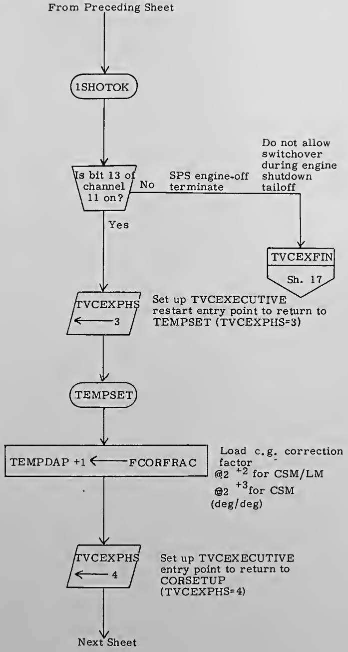
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN V. Burke	10/24/68	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV I	SHEET 11 OF 36



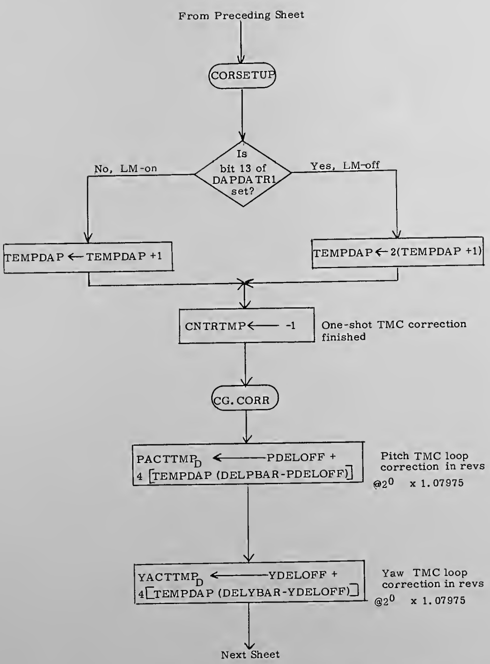
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	10/24/69	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 12 OF 36



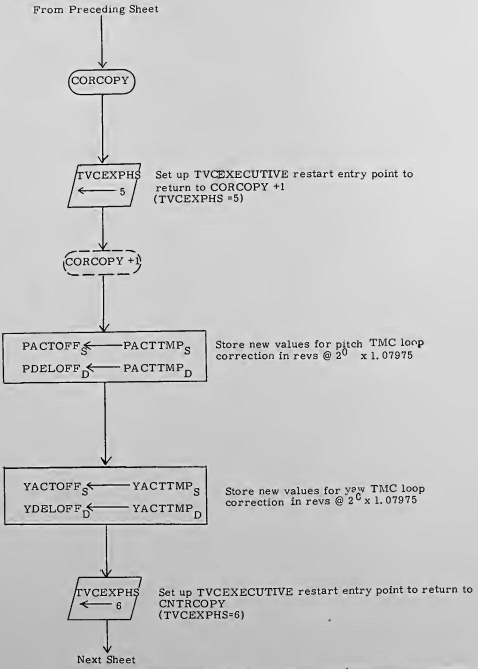
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature]	10/06/69	TVC Start-up and Executive Routines
PRGMR		COLOSSUS 2D — DOCUMENT NO. FC-2430
ANALST		
DOCMR		
APPR'D		REV 1 — SHEET 13 OF 36



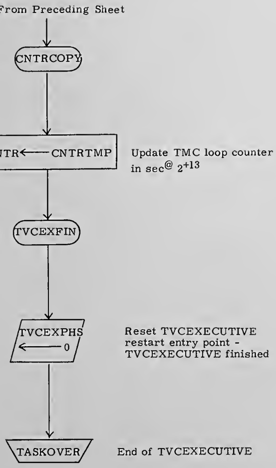
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	1/20/69	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 14 OF 36



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 15 OF 36

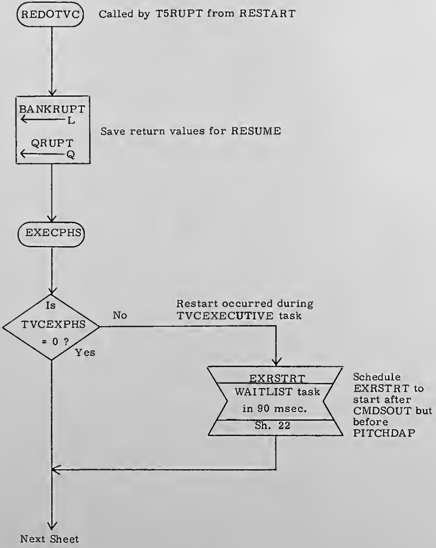


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	10/20/69	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 16 OF 36

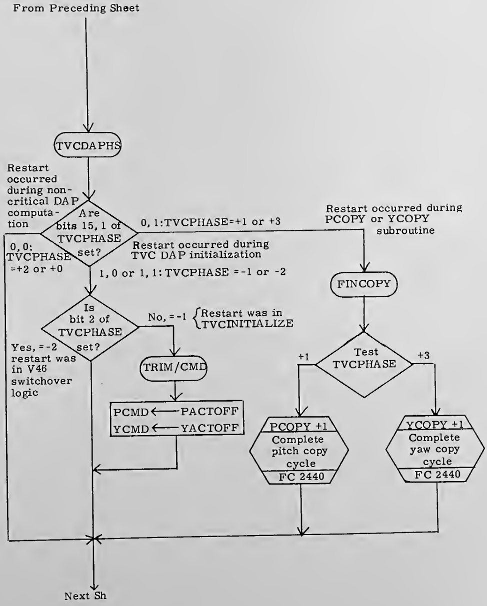


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	TVC Start-up and Executive Routines
PRGMR	COLOSSUS 2D — DOCUMENT NO. FC-2430
ANALST	
DOCMR	
APPR'D	REV 1 — SHEET 17 OF 36

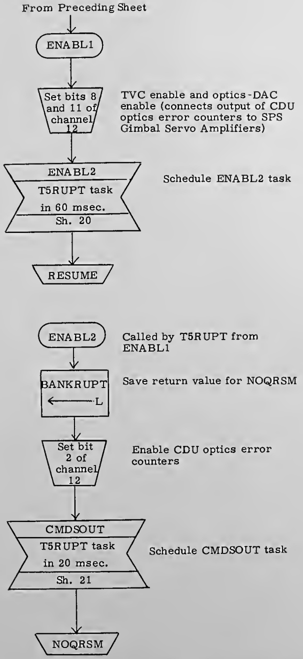
TVC Restart Package



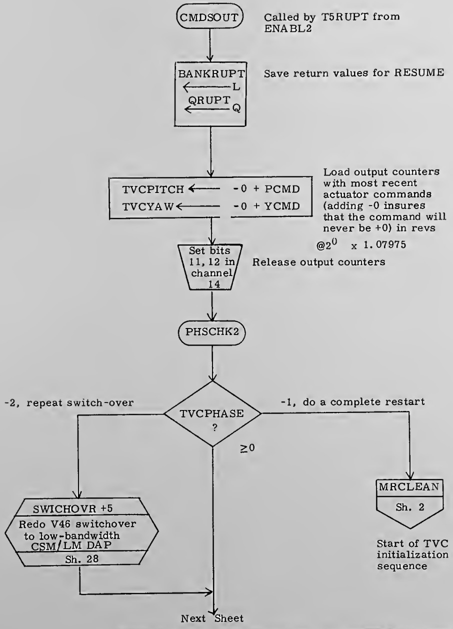
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		TVC Start-up and Executive Routines	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2430
DOCMR			
APPR'D		REV 1	SHEET 18 OF 36



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	[date]	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 19 OF 36



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Burke	9/20/69	TVC Start-up and Executive Routines	
PRGMR		COLUSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 20 OF 36



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Burke	12/2/67	TVC Start-up and Executive Routines	
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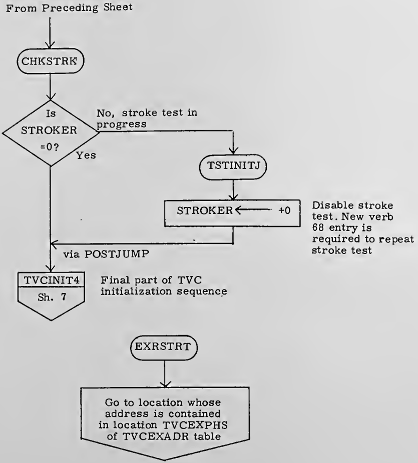
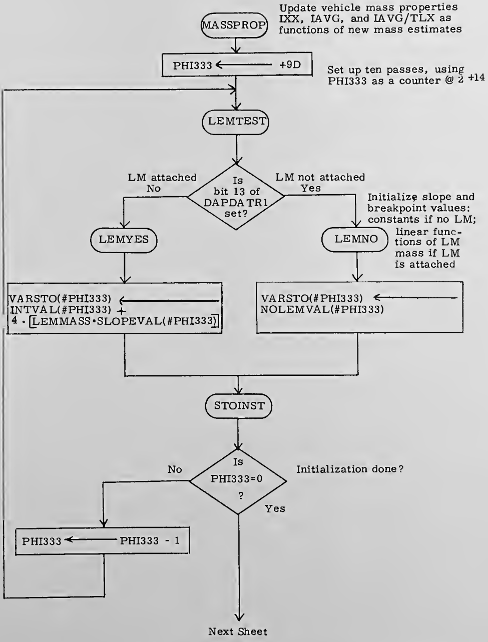
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 21 OF 36



TVCEXPHS Value	Entry Point	Sheet No.
1	EXECCOPY +1	12
2	1SHOTCHK	13
3	TEMPSET	14
4	CORSETUP	15
5	CORCOPY +1	16
6	CNTRCOPY	17



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Burke	10/21/67	TVC Start-up and Executive Routines	
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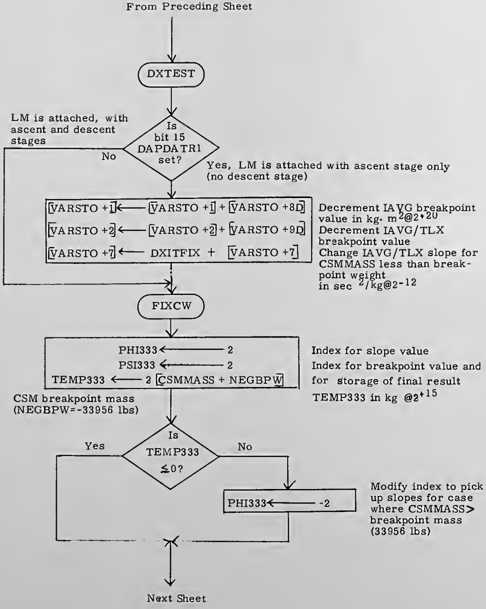
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 23 OF 36



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	10/20/69	TVC Start-up and Executive Routines	
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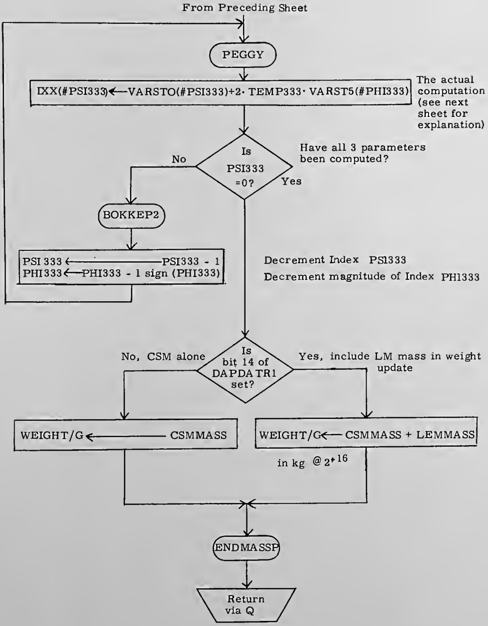
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 24 OF 36



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	10/20/69	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 25 OF 36

MASSPROP COMPUTATION:

Step 1: Compute coefficients on basis of LM mass (m_{LM}) (LEMTEST)

NO LM	LM ON
$v_0 = 25445\ (kg \cdot m^2)$	$v_0 = 26850(kg \cdot m^2) + 1.96307(m^2) \cdot m_{LM}(kg)$
$v_1 = 87450\ (kg \cdot m^2)$	$v_1 = 127518(kg \cdot m^2) + 27.5774(m^2) \cdot m_{LM}(kg)$
$v_2 = .30715\ (sec^2)$	$v_2 = .54059(sec^2) + 2.3548 \cdot 10^{-5}(sec^2 kg) \cdot m_{LM}(kg)$
$v_3 = 1.22877\ 10^{-5}(sec^2/kg)$	$v_3 = .153964 \cdot 10^{-4}(sec^2/kg) + 2.1777 \cdot 10^{-9}(sec^2/kg^2) \cdot m_{LM}(kg)$
$v_4 = 1.6096\ (m^2)$	$v_4 = -.742923(m^2) + 1.044 \cdot 10^{-3}(m^2/kg) m_{LM}(kg)$
$v_5 = 1.54\ (m^2)$	$v_5 = 1.5398(m^2) + 0$
$v_6 = 7.77177\ (m^2)$	$v_6 = 9.68(m^2) + 2.21068 \cdot 10^{-3}(m^2/kg) \cdot m_{LM}(kg)$
$v_7 = 3.46458\ 10^{-5}\ (sec^2/kg)$	$v_7 = .647625 \cdot 10^{-4}(sec^2/kg) + 1.5166\ 10^{-9}(sec^2/kg^2) \cdot m_{LM}(kg)$
v_8, v_9 } computed, but not meaningful and not used	$v_8 = -27228(kg \cdot m^2) - 1.284(m^2) m_{LM}(kg)$
	$v_9 = -.206476(sec^2) + 2 \cdot 10^{-5}(sec^2/kg) \cdot m_{LM}(kg)$

Step 2: If LM ascent stage only attached, modify v_1, v_2, and v_7: (DXTEST)

$$v_1 = v_1(kg \cdot m^2) + v_8(kg \cdot m^2)$$
$$v_2 = v_2(sec^2) + v_9(sec^2)$$
$$v_7 = v_7(sec^2/kg) - 1.88275 \cdot 10^{-5}(sec^2/kg)$$

Step 3: Compute IXX ($kg \cdot m^2$), IAVG($kg \cdot m^2$), and IAVG/TLX(sec^2):

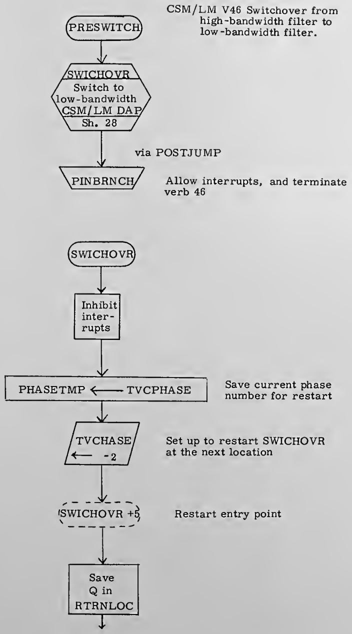
PEGGY

CSM weight ≤ 33956 lbs (15402.17kg)	CSM weight > 33956 lbs (15402.17kg)
$IXX = v_0(kg \cdot m^2) + v_5(m^2)(m_{CSM} - 15402.17)(kg)$	$IXX = v_0(kg \cdot m^2) + v_5(m^2)(m_{CSM} - 15402.17)(kg)$
$IAVG = v_1(kg \cdot m^2) + v_6(m^2)(m_{CSM} - 15402.17)(kg)$	$IAVG = v_1(kg \cdot m^2) + v_4(m^2)(m_{CSM} - 15402.17(kg)$
$IAVG/TLX = v_2(sec^2) + v_7(sec^2/kg)(m_{CSM} - 15402.17)(kg)$	$IAVG/TLX = v_2(sec^2) + v_3(sec^2/kg)(m_{CSM} - 15402.17)(kg)$

In the above equations:

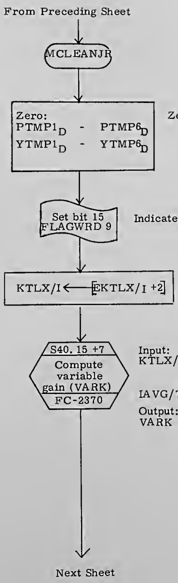
IXX=Moment of inertia about vehicle X-axis	in $kg \cdot m^2$ @ 2^{20}
IAVG=Average moment of inertia about Y and Z axes	in $kg \cdot m^2$ @ 2^{20}
IAVG/TLX=IAVG/(vehicle gain)	in sec^2 @ 2^2
m_{CSM}=CSM mass	in kg @ 2^{16}
m_{LM}=LM mass	in kg @ 2^{16}

Note: vehicle mass is keyed in in pounds, but internally, mass is stored in kg.



Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	6/2/69	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 28 OF 36



Zero temporaries for pitch and yaw filters.

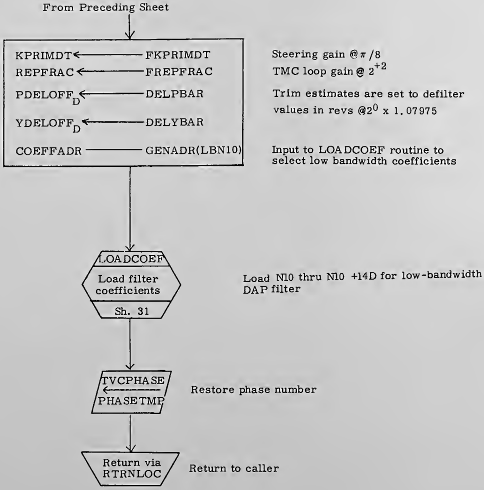
Indicate switchover has occurred

Set gain to low-bandwidth pad loaded value in sec^{-2} @ 2^{+2} x1.07975 for CSM/LM

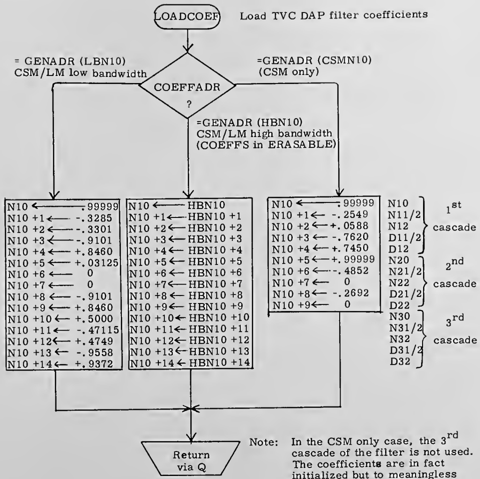
Input:
KTLX/I in sec^{-2} @ 2^{+2} x 1.07975 for CSM/LM

IAVG/TLX in sec^{2} @ 2^{+2}

Output:
VARK @ 2^{+2} x1.07975 for CSM/LM



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	[illegible signature]	TVC Start-up and Executive Routines	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2430
DOCMR			
APPR'D		REV 1	SHEET 30 OF 36



Note: In the CSM only case, the 3rd cascade of the filter is not used. The coefficients are in fact initialized but to meaningless values which are not used. As of the released version of COLOSSUS 2, these values are as follows:

N10 +10 ← +.99999
N10 +11 ← -.3285
N10 +12 ← -.3301
N10 +13 ← -.9101
N10 +14 ← +.8460

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=1, DAPBIT2=0: TVC DAP controls vehicle attitude	DAPBIT1=0, DAPBIT2=1: TVC DAP controls vehicle attitude. Both clear: no DAP control of vehicle attitude			Sh. 10
DAPBIT2 Flagword 6 bit 14					Sh. 10

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN V Burke	10/24/65	TVC Start-up and Executive Routines	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2430
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 32 OF 36

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 x 1.07975
DELYBAR		∫rate error used for offset (yaw)	deg	rev	2^0 x 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}
$ERRBTMP_D$	θ_e	Updated version of $PERRB_D$ and $YERRB_D$ (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} x 1.07975 for CSM/LM 2^{+4} x 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

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}
$PACTTMP_D$		Pitch trim-correction (temporary storage)	deg	rev	2^0 x 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 x 1.07975
$PDELOFF_D$	PDELOFF	Trim correction (pitch)	deg	rev	2^0 x 1.07975
$PERRB_D$		Body attitude error (pitch)	deg	rev	2^{-1}
REPFRAC	K_{cg}	Updated version of EREPFRAC (see pad-loads)	dimension-less	dimension-less	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}
TVCPITCH		Actuator command (pitch)	deg	rev	2^0 x 1.07975
TVCYAW		Actuator command (yaw)	deg	rev	2^0 x 1.07975
VARK	VARK or K_z	Gain for pitch and yaw channels	deg/deg	rev/rev	For CSM 2^{+4} x 1.07975 For CSM/LM 2^{+2} x 1.07975
VARSTO +1		IAVG breakpoint value	$kg \cdot m^2$	$kg \cdot m^2$	2^{+20}

AGC TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
VARSTO +2		IAVG/TLX breakpoint value	sec^2	sec^2	2^{+2}
VARSTO +7		IAVG/TLX slope for CSMMASS less than breakpoint value	sec^2/kg	sec^2/kg	2^{-12}
VCNTR		Updated version of VCNTRTMP	sec	sec	2^{+13}
VCNTRTMP		Counter	sec	sec	2^{+13}
V97VCNTR		Updated version of VCNTRTMP	sec	sec	2^{+13}
WEIGHT/G		Updated version of CSMMASS and LMMASS	kg	kg	2^{+16}
$YACTTMP_D$		Yaw trim-oorrection (temporary storage)	deg	rev	$2^0 \times 1.07975$
YCMD		Incremental yaw actuator command	deg	rev	$2^0 \times 1.07975$
$YDELOFF_D$	YDELOFF	Trim correction (yaw)	deg	rev	$2^0 \times 1.07975$
$YERRB_D$		Body attitude error (yaw)	deg	rev	2^{-1}

FIXED LOCATION USED

AGC TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
FCORFRAC		c.g. correction factor	dimension-less	dimension-less	CSM/LM 2^{+2} CSM 2^{+3}

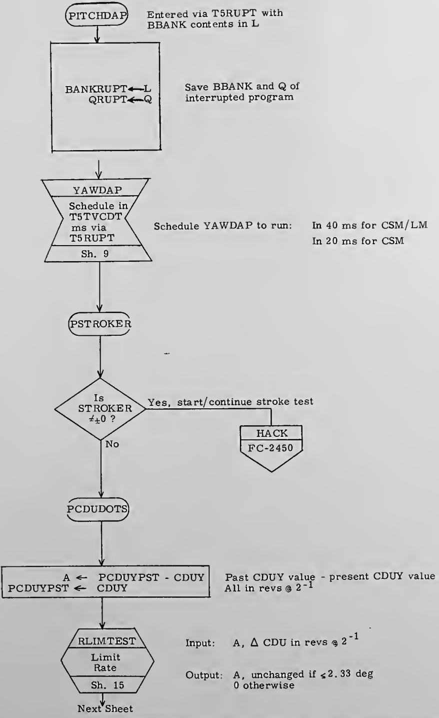
AGC TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
EKPRIME		"Steer law gain" for LM-off	deg/sec/deg	revs/csec/rad	$\pi/8$
$EKTLX/I_D$		K: DAP gain factor T: thrust LX: distance from engine gimbal point to c. g. of vehicle I: average of moments of inertia about pitch and yaw axes	sec^{-2}	sec^{-2}	CSM/LM: 2^{+2} x 1.07975 CSM: 2^{+4} x 1.07975
EREPFRAC		Gain for TMC loop (LM-off)			2^{+2}
EREPFRAC +1		Gain for TMC loop (LM-on)			2^{+2}
PACTOFF		Actuator trim value (pitch)	deg	rev	2^{0} x 1.07975
YACTOFF		Actuator trim value (yaw)	deg	rev	2^{0} x 1.07975

TVC DAP

Special convention:

TVCDT = 80 msec for CSM/LM
40 msec for CSM

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D Lutkevich	9-15-69	TVC DAP	
PRGMR R Ahlundt	10/20/69		DOCUMENT NO.
ANALST			
DOCMR Roberta M. Eaton	10/28/69	COLOSSUS 2D	FC-2440
APPR'D Roberta M. Eaton	10/28/69	REV 1	SHEET 1 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. Lutkevich	9-15-69	TVC DAP	
PRGMR R. Schlundt	10/28/69		DOCUMENT NO.
ANALST			
DOCMR Roberta M. Eaton	10/24/69	COLOSSUS 2D	FC-2440
APPR'D Roberta M. Eaton	10/28/69	REV 1	SHEET 2 OF 19

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

$\dot{\omega}_y = +\cos\phi \cdot \cos\psi \cdot \dot{\theta} + \sin\phi \cdot \dot{\psi}$

$OMEGAYB_D$ ← −4(COSCDUX· COSCDUZ· MCDUYDOT) − 2 (SINCDUX· MCDUZDOT)

Measured rate in revs/sec @ $2^{-1} \times \frac{1}{TVCDT}$

COSCDUX, COSCDUZ, SINCDUX @ 2^{+1}

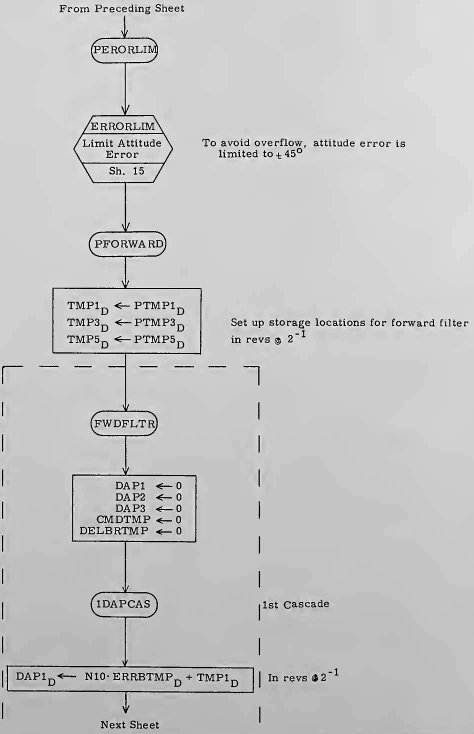
$\theta_e = \theta_e z^{-1} + \omega_{yc} - \omega_y$

$ERRBTMP_D$ ← PERRB + OMEGAYC − OMEGAYB

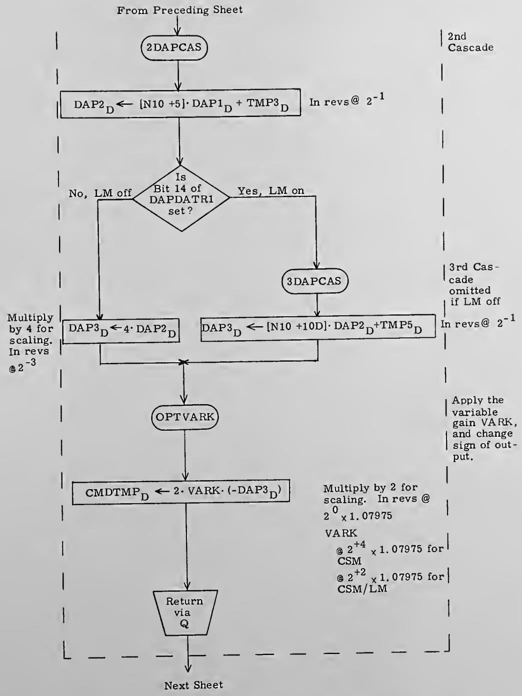
Attitude error = ∫ rate error (ω_{yc} = command rate) in revs @ 2^{-1}

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN O. Lutkevich	9-15-69	TVC DAP	
PRGMR R. Schlundt	10/28/69		DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2440
DOCMR Roberta M. Ester	10/28/69		
APPR'D Roberta M. Ester	10/28/69	REV 1	SHEET 3 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	9-15-69	TVC DAP	
PRGMR	10/28/69		DOCUMENT NO.
ANALST			
DOCMR	10/28/69	COLOSSUS 2D	FC-2440
APPR'D	10/28/69	REV 1	SHEET 4 OF 19



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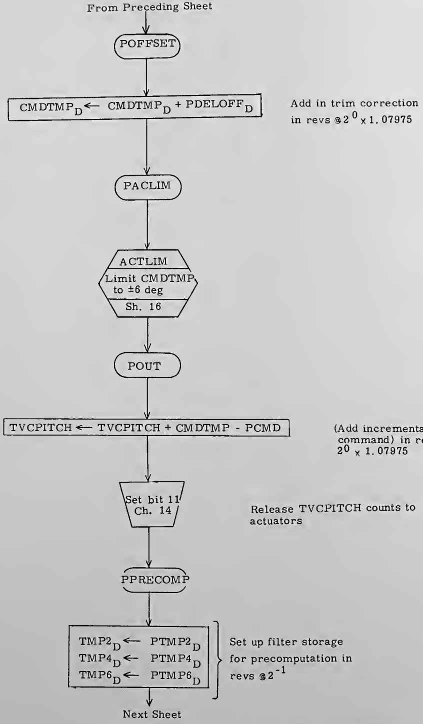
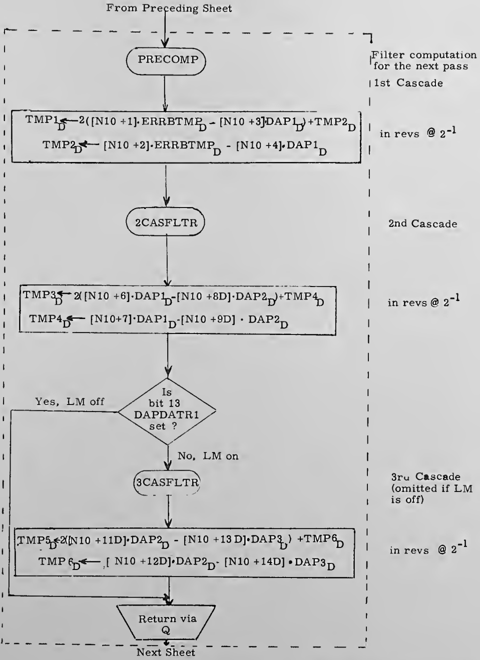
PRGMR [illegible]	10/20/69		DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2440
DOCMR [illegible]	[illegible]		
APPR'D [illegible]	[illegible]	REV	SHEET 5 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkevich	9/15/69	TVC DAP	
PRGMR R. Schlundt	10/20/69		DOCUMENT NO.
ANALST			
DOCMR Roberta M. Eastes	10/22/69	COLOSSUS 2D	FC-2440
APPR'D Roberta M. Eastes	10/22/69	REV 1	SHEET 6 OF 19



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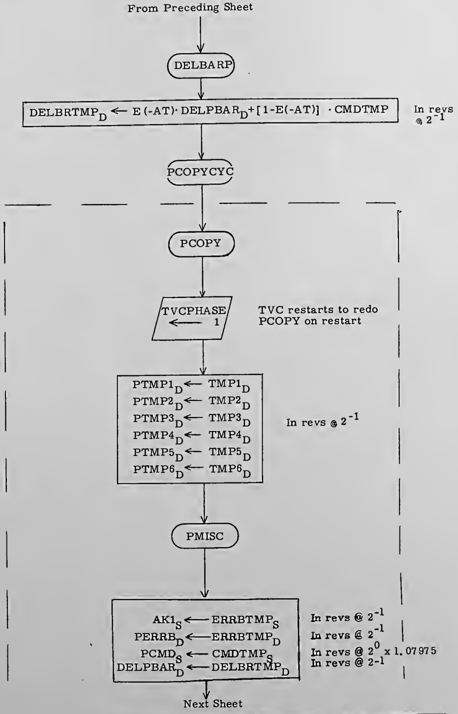
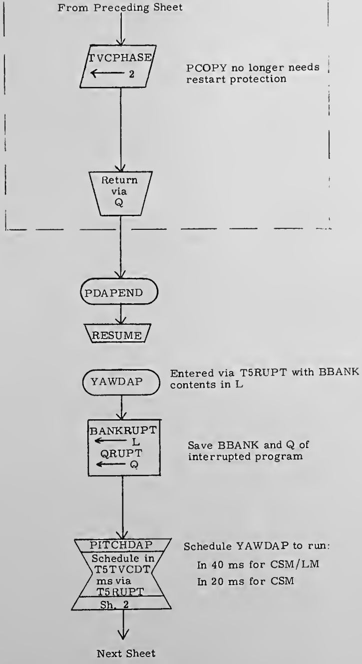
DRAWN L. Albertone 9/17/68	TVC DAP	
PRGMR R. Schlundt 9/20/68	COLOSSUS 2D	DOCUMENT NO. FC-2440
ANALST		
DOCMR Roberta M. Entz 10/28/68		
APPR'D Roberta M. Entz 10/28/68	REV 1	SHEET 7 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkevich	9-15-69	TVC DAP	
PRGMR R. Gellerst	10/20/69		DOCUMENT NO.
ANALST			
DOCMR Robert M. Eaton	10/20/69	COLOSSUS 2D	FC-2440
APPR'D Robert M. Eaton	10/20/69	REV 1	SHEET 8 OF 19



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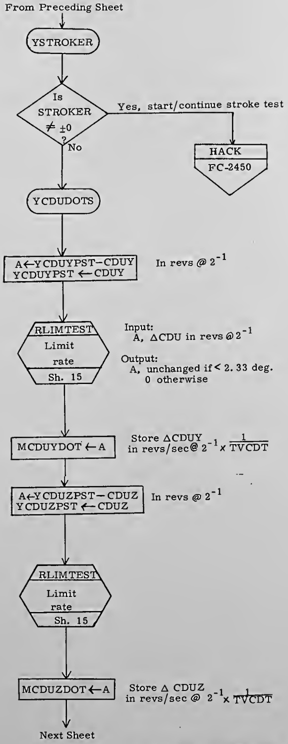
PRGMR [signature]	10/28/69		DOCUMENT NO.
ANALST			
DOCMR [signature]	10/28/69	COLOSSUS 2D	FC-2440
APPR'D [signature]	10/28/69	REV 1	SHEET 9 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature] 10/9/69	TVC DAP	
PRGMR [signature]	COLOSSUS 2D	DOCUMENT NO. FC-2440
ANALST		
DOCMR [signature] 10/20/69		
APPR'D [signature]	REV 1	SHEET 10 OF 19

From Preceding Sheet

YINTEGRL

$\omega_Z = -\cos\psi \cdot \sin\phi \cdot \dot{\theta} + \cos\phi \cdot \dot{\psi}$

OMEGAZB$_D$ ← 4(COSCDUZ • SINCDUX • MCDUYDOT) - 2(COSCDUX • MCDUZDOT)

Measured rate in revs/sec @ 2^{-1} $\frac{1}{\text{TVCDT}}$

$\theta_e = \theta_e z^{-1} + \omega_{ZC} - \omega_Z$

ERRBTMP$_D$ ← YERRB + OMEGAZC - OMEGAZB

Attitude error = ∫rate error; (ω_{ZC} = command rate) in revs @ 2^{-1}

YERORLIM

ERRORLIM
Limit attitude error
Sh. 15

To avoid overflow, attitude error is limited to ±45°

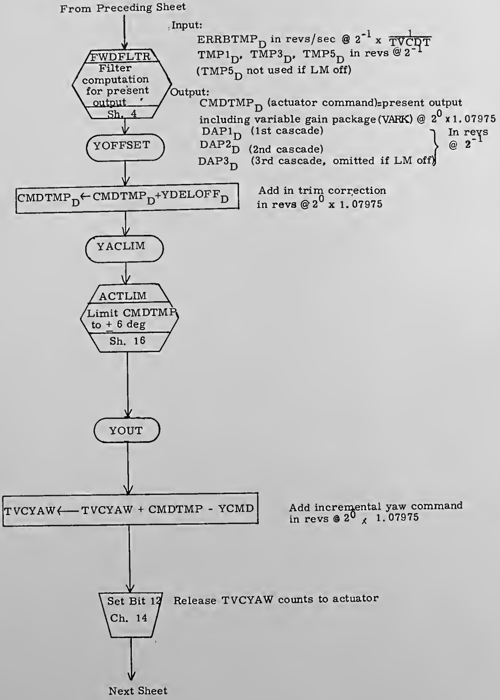
YFORWARD

TMP1$_D$ ← YTMP1$_D$
TMP3$_D$ ← YTMP3$_D$
TMP5$_D$ ← YTMP5$_D$

Set up storage locations for forward filter in revs @ 2^{-1}

Next Sheet

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	[signature]	TVC DAP	
PRGMR	[signature] 6/2/69		
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2440
DOCMR	[signature]		
APPR'D	[signature]	REV 1	SHEET 11 OF 19



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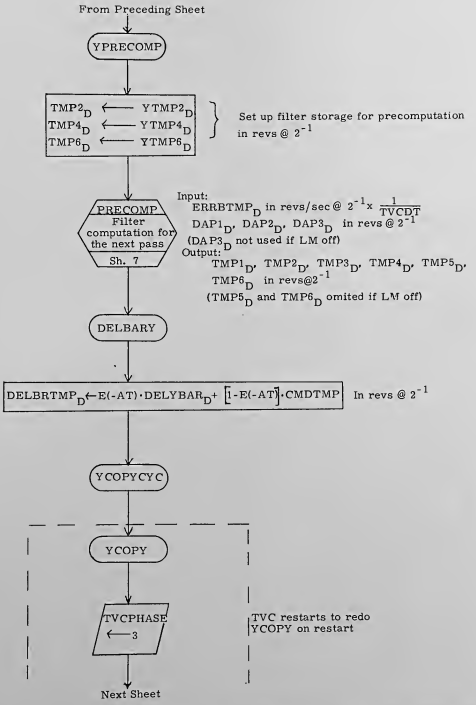
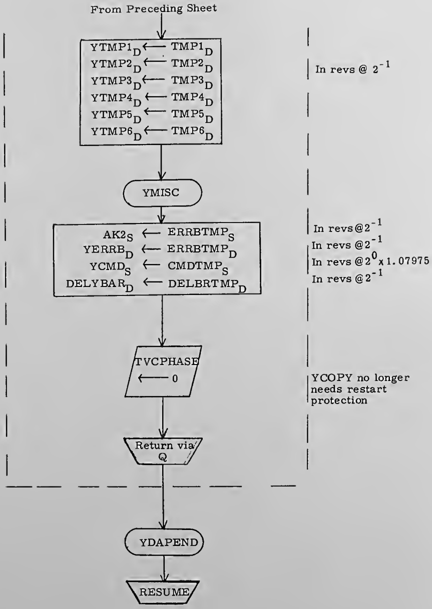
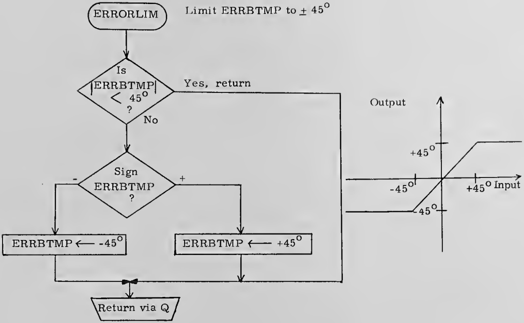
DRAWN [illegible]	10/3/69	TVC DAP	
PRGMR [illegible]	6/30/69		DOCUMENT NO.
ANALST			
DOCMR [illegible]	10/24/69	COLOSSUS 2D	FC-2440
APPR'D [illegible]	10/24/69	REV 1	SHEET 12 OF 19

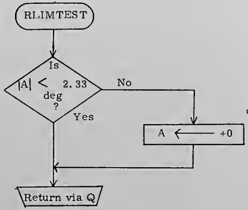


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN 11/9/69	TVC DAP	
PRGMR 6/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2440
ANALST		
DOCMR 10/28/69		
APPR'D 10/28/69	REV 1	SHEET 13 OF 19



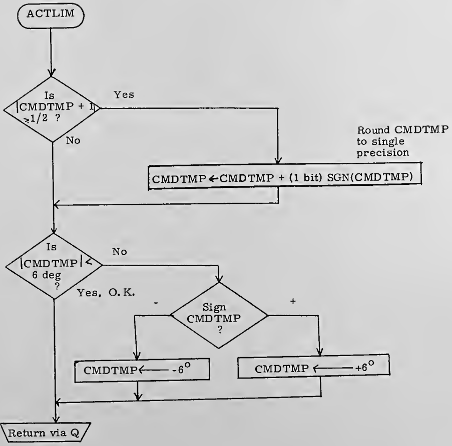
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. Lutkevich 9-15-69	TVC DAP	
PRGMR K. Jehlundt 10/20/69		DOCUMENT NO.
ANALST		
DOCMR Roberta M. Fontana 10/28/69	COLOSSUS 2D	FC-2440
APPR'D Roberta M. Fontana 10/28/69	REV 1	SHEET 14 OF 19





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 R. J. Welch	12/9/69	TVC DAP	
PRGMR R. Gilbert	6/?/69	COLOSSUS 2D	DOCUMENT NO. FC-2440
ANALST			
DOCMR Roberta M. Eutes	12/24/69		
APPR'D Roberta M. Eutes	12/24/69	REV 1	SHEET 15 OF 19



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkevich	9-15-69	TVC DAP	
PRGMR K. Ohlund	10/2/69		DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2440
DOCMR Roberta M. Eaton	10/10/69		
APPR'D Roberta M. Eaton	10/10/69	REV 1	SHEET 16 OF 19

SUBROUTINE CALLED WHICH IS
FLOWED ON OTHER FLOW CHART

Subroutine Name	Flow Chart	Description	Where Called
HACK	FC-2450	Stroke test	Sh. 2, 10

ERASABLE LOCATIONS USED

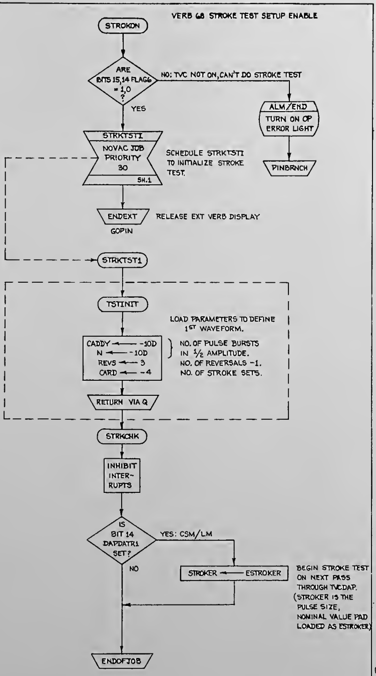
AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
$AK1_S$		Attitude error for pitch needles	deg	rev	2^{-1}
$AK2_S$		Attitude error for yaw needles	deg	rev	2^{-1}
$CMDTMP_D$		Actuator command; updated version of $PCMD_S$ and of $YCMD_S$	deg	rev	$2^0 \times 1.07975$
$DELBRTMP_D$		Updated version of $DELPBAR_D$ and of $DELYBAR_D$ (below)	deg	rev	2^{-1}
$DELPBAR_D$		Output of pitch DELFILTER (filtered engine command signal)	deg	rev	2^{-1}
$DELYBAR_D$		Output of yaw DELFILTER (filtered engine command signal)	deg	rev	2^{-1}

ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
$ERRBTMP_D$	θe	Updated version of $AK1_S$ and $AK2_S$ (above) and of $PERRB_D$ and $YERRB_D$ (below)	deg	rev	2^{-1}
MCDUYDOT		Past CDUY value - present CDUY value	deg/sec	rev/sec	$2^{-1} \times \frac{1}{TVCDT}$
MCDUZDOT		Past CDUZ value - present CDUZ value	deg/sec	rev/sec	$2^{-1} \times \frac{1}{TVCDT}$
$OMEGAYB_D$	ω_y	Measured body - axis pitch rate	rad/sec	rev/sec	$2^{-1} \times \frac{1}{TVCDT}$
OMEGAYC	ω_{yc}	Pitch body rate command	rad/sec	rev/sec	$2^{-1} \times \frac{1}{TVCDT}$
$OMEGAZB_D$	ω_z	Measured body - axis yaw rate	rad/sec	rev/sec	$2^{-1} \times \frac{1}{TVCDT}$
OMEGAZC	ω_{zc}	Yaw body rate command	rad/sec	rev/sec	$2^{-1} \times \frac{1}{TVCDT}$
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	$2^{0} \times 1.07975$
$PDELOFF_D$	PDELOFF	Engine trim correction (pitch)	deg	rev	$2^{0} \times 1.07975$
$PERRB_D$		Body attitude error (pitch)	deg	rev	2^{-1}
TVCPITCH		Pitch engine command error counter	deg	rev	$2^{0} \times 1.07975$

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	$2^0 \times 1.07975$
VARK	VARK	Gain for pitch and yaw channels	deg/deg	rev/rev	For CSM $2^{+4} \times 1.07975$ For CSM/LM $2^{+2} \times 1.07975$
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	$2^0 \times 1.07975$
$YDELOFF_D$	YDELOFF	Engine trim correction (yaw)	deg	rev	$2^0 \times 1.07975$
$YERRB_D$		Body attitude error (yaw)	deg	rev	2^{-1}



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

APOLLO GUIDANCE AND NAVIGATION

STROKE TEST PACKAGE

DRAWN A.C.WILLIAMS 28FEB69

PRGMR

ANALYST 4/9/69

DOCMR

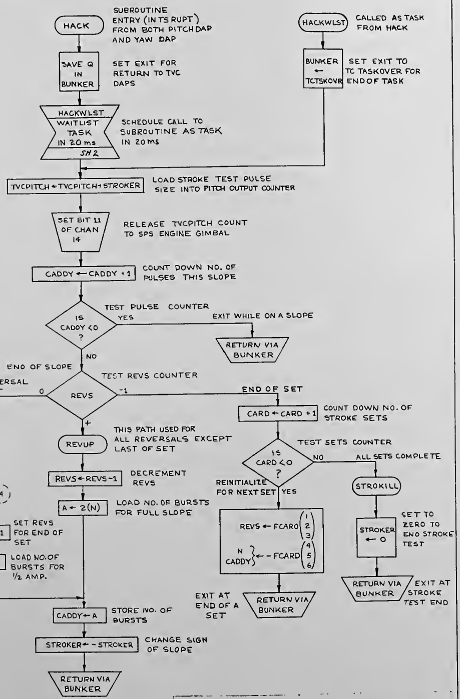
APPR'D 9 April 69

COLOSSUS II

REV

FC-2450

SHEET 1 of 2



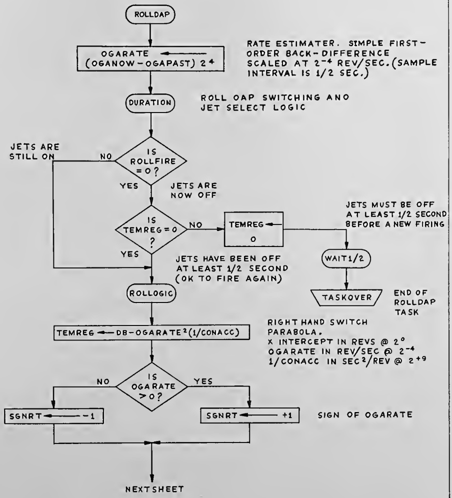
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

DRAWN D. S. Chmielinski 19 NOV 68
PROGR
APPD R. J. Schlundt 4/9/69
DOCMR
APPR'D John A. Moore 7 April 69

STROKE TEST PACKAGE

COLOSSUS II FC-2450

SHEET 2 OF 2



MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN 18NOV68
PRGMR
ANALST
DOCMR
APPR'D

APOLLO GUIDANCE AND NAVIGATION

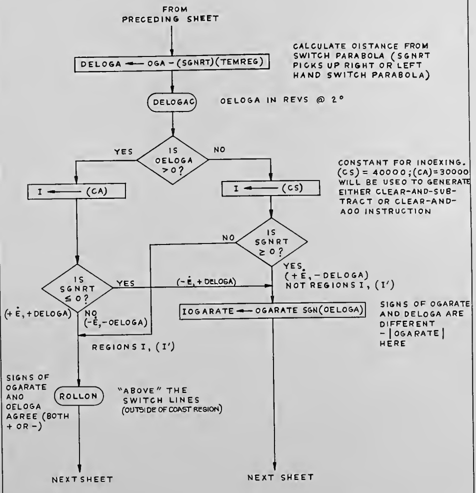
ROLL AUTOPILOT

COLOSSUS IIC

DOCUMENT NO. FC-2460

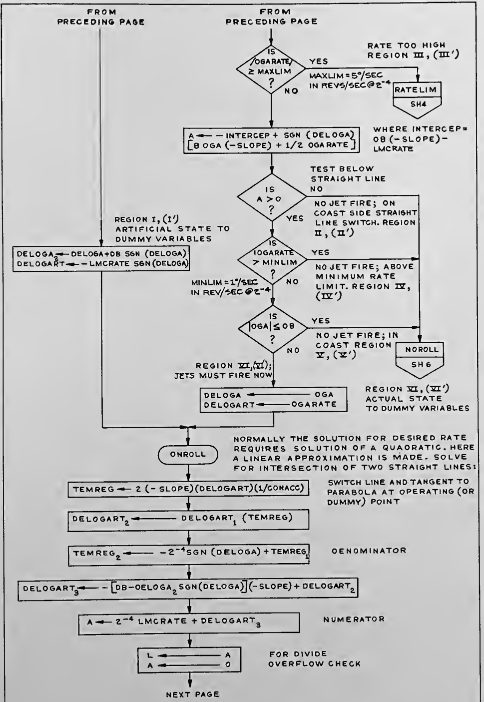
REV 1

SHEET 1 OF 7



NOTE:
1. PHASE PLANE REGIONS REFER TO FIGURE 3.3.14 OF FORTHCOMING COLOSSUS GSOP SECTION 3 R-577 (REV 4 OR 5)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 18NOV68	ROLL AUTOPILOT
PRGMR	
ANALYST 4/9/69	COLOSSUS IIC FC-2460
DOCMR	
APPR'D 9 April 69	REV 1 SHEET 2 OF 7



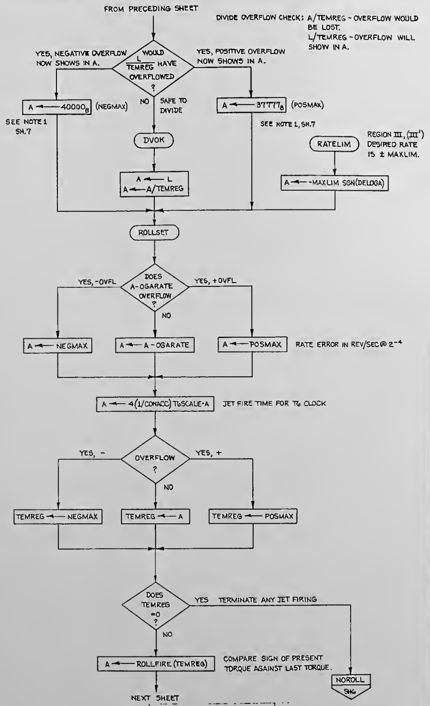
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

ROLL AUTOPILOT

DRAWN T.S. Chiahiachi 20NOV68
ANAL R.F. Schlundt 4/9/69 COLOSSUS II C
APPR'D John A. Moore 9 April 69 REV 1

FC-2460

3 of 7



MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS.

DRAWN A.C.WILLIAMS 25FEB69

ANALYST R.H. [signature] 4/2/69

APPR'D John A. Moore [signature] 1 April 69

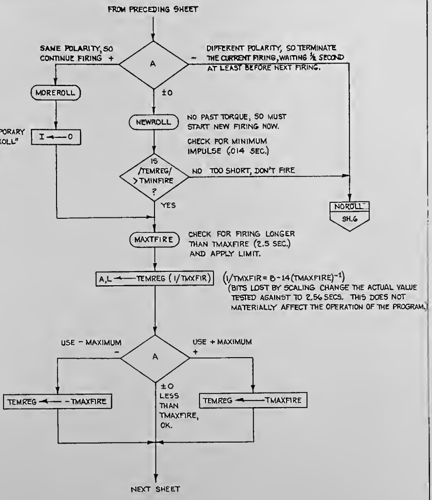
ROLL AUTOPILOT

COLOSSUS IIC

FC-2460

REV 1

4 7



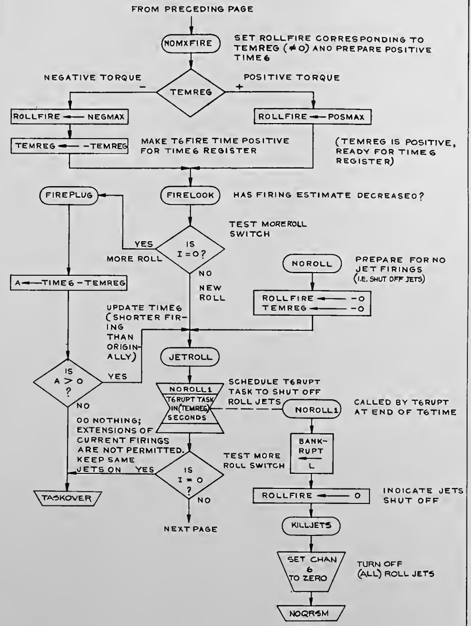
MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS.

DRAWN A.C. WILLIAMS 3MAR69
ANALST 4/9/69
APPR'D John A. Morse 9 April 69

ROLL AUTOPILOT

COLOSSUS IIC FC-2460

REV 1 SHEET 5 OF 7



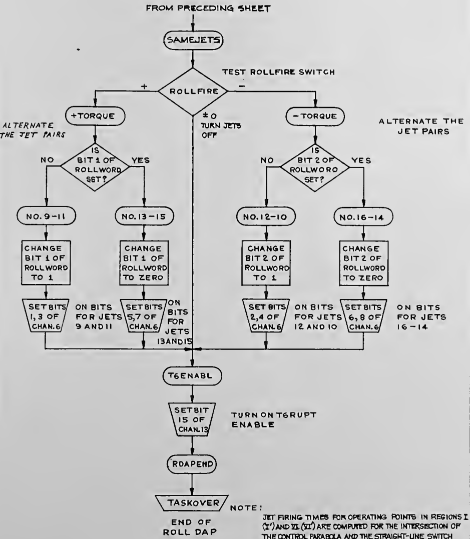
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN Z.S. Chmielewski 20NOV68
CHECKED R.L. Schlundt 4/4/69
APPR'D John A. Moore 9 April 69

ROLL AUTOPILOT

COLOSSUS IIC FC-2460

REV 1 6 7



NOTE:

JET FIRING TIMES FOR OPERATING POINTS IN REGIONS I (I') AND II (II') ARE COMPUTED FOR THE INTERSECTION OF THE CONTROL PARABOLA AND THE STRAIGHT-LINE SWITCH BOUNDARY, REGARDLESS OF WHETHER OR NOT THE ± MINIMUM BOUNDARY IS INTERSECTED. THIS MAY CAUSE UP TO 1/2 SECOND OF FIRING INTO THE COAST REGION. FUEL EXPENDITURE IS SMALL, AND PERFORMANCE IS STILL STABLE AND CONVERGENT (NO EXTRA PASSES ACROSS THE DEADBAND ARE REQUIRED), SO THE SIMPLIFICATION IS REASONABLE

ROLL AUTOPILOT

COLOSSUS IIC FC-2460

7 7

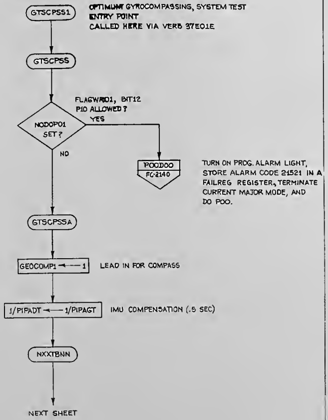
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

ENCLOSED ARE REPLACEMENT SHEETS TO UPDATE THE COLOSSUS IIA FLOWCHART 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
	P01, P02, P03, P07 PRELAUNCH INITIALIZATION & GYRO COMPASSING
DRAWN [signature]	
PRGMR E. J. [signature]	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2530
DOCMR M. LEMAN	
APPR'D [signature]	REV 2 — SHEET 1 OF 47

P01-P02
PRELAUNCH SERVICE INITIALIZATION PROGRAM

IMU PERFORMANCE TESTS



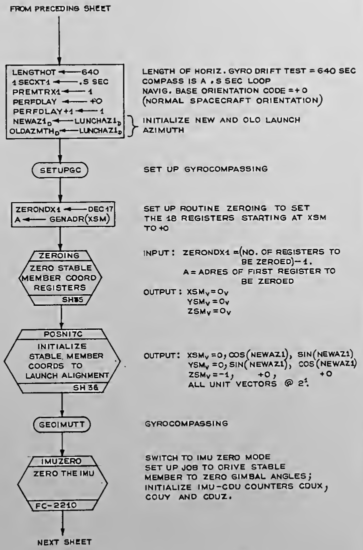
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN A.C.WILLIAMS 13MAR69
PRGMR E. J. Green
ANALYST M. A. Cowan 4-7-69
APPR John A. Noe 8 April 69

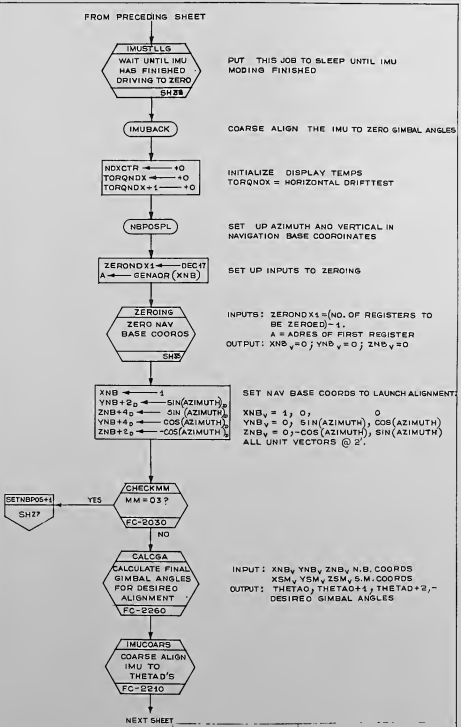
P01, P02, P03, P07 PRELAUNCH INITIALIZATION & GYRO COMPASSING

COLOSSUS IIC FC-2530

REV 2 2 47



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN R.M. Dietor 12 NOV 68	P01, P02, P03, P07 PRELAUNCH INITIALIZATION & GYROCOMPASSING
PRGMR E.J. Ryan 4/7/69	DOCUMENT NO
ANALST	COLOSSUS IIC FC-2530
DOCMR M.A. Foran 4-7-69	
APPR'D John A. Moran 8 April 69	REV 2 SHEET 3 OF 47



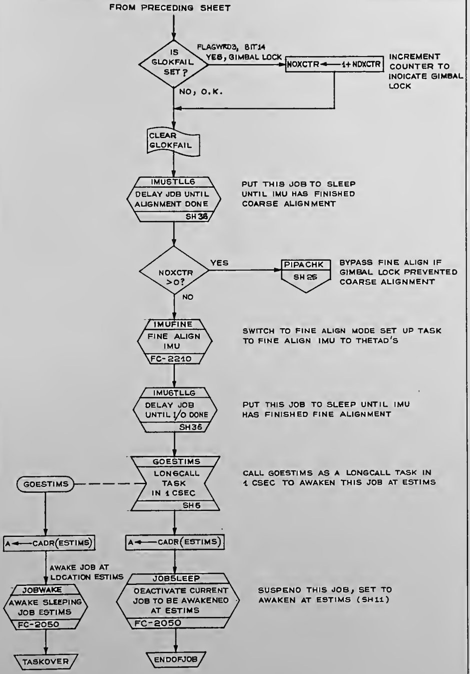
MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN P.M. Dixon 13NOV68
PRGMR E.S. Green 4/7/69
ANALYST
DSGNR [illegible] 4-7-69
APPR'D [illegible] 8 April 69

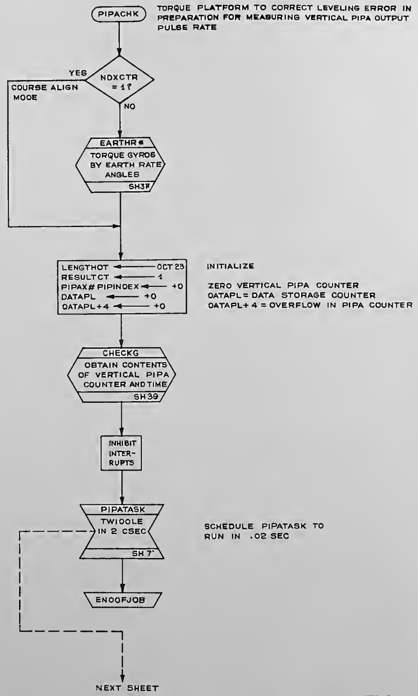
P01, P02, P03, P07,
PRELAUNCH INITIALIZATION & GYRO COMPASSING

COLOSSUS IIC FC-2530

REV 2



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN G.H. Dietrich 13 NOV 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYROCOMPASSING
PRGMR E.L. Green 4/1/69	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2530
DOC MR M.G. Farnan 4-7-69	REV 2 SH 5 OF 47
APPR'D John A. Moore 8 April 69	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

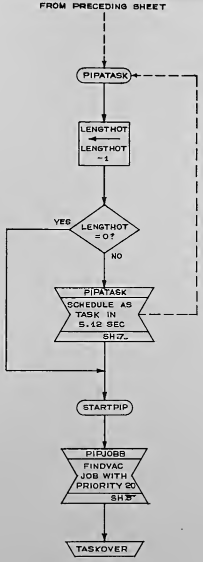
DRAWN P.M. Dietrich 16DEC68
PRGMR
ANALST
DOCMR
APPR'D

APOLLO GUIDANCE AND NAVIGATION

P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING

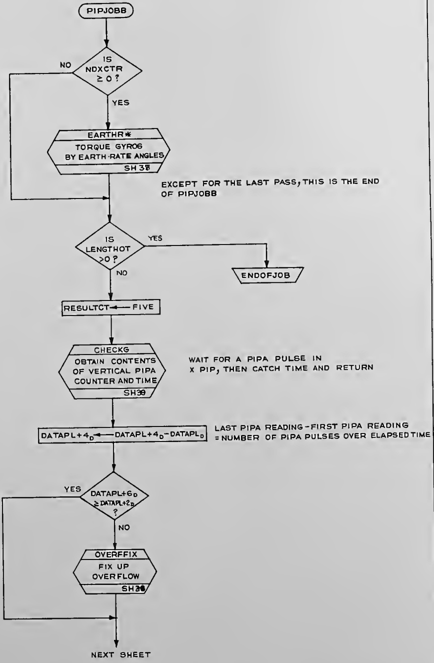
COLOSSUS IIC DOCUMENT NO FC-2530

REV 2 SHEET 6 OF 47

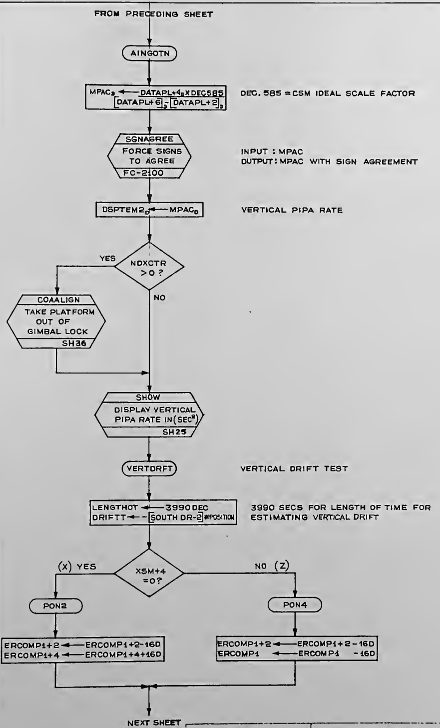


PIPATASK RUNS 18 TIMES AT 5.12 SEC INTERVALS, SO THAT PIPJOBB RUNS FOR ABOUT 1½ MINUTES.

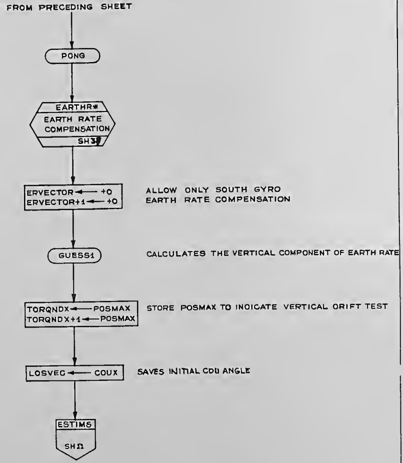
RESCHEDULE PIPATASK IN 5.12 SEC.



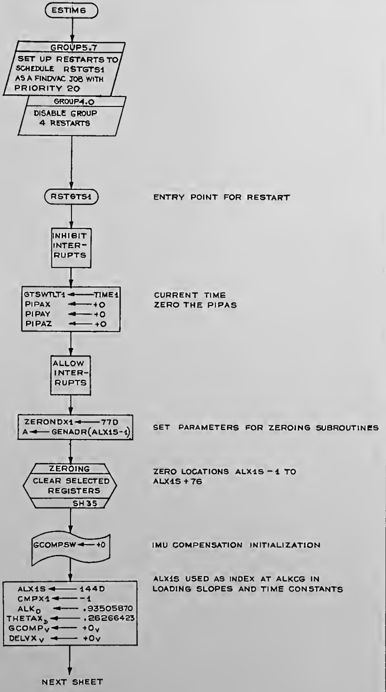
MIT INSTRUMENTATION LAB CAMBRIDGE MASS	GUIDANCE AND NAVIGATION
DRAWN P.M. Dickey 5 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR 4/2/69	COLOSSUS IIC DOCUMENT NO. FC-2530
ANALYST	
DOCMR 8-7	
APPR'D John A. Moore 8 April 69	REV 2 SHEET 8 OF 47



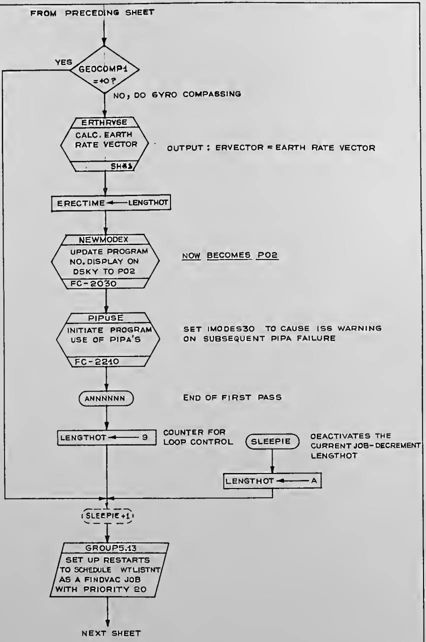
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.H. Dietrich 6DEC68 PRGMR E.J. Gunn 4/7/69 ANALST DOCMR M.G. Kiwan 4-7-69 APPR'D John A. Moore 8 April 69	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING COLOSSUS IIC DOCUMENT NO FC-2530 REV 2 SHEET 9 OF 47



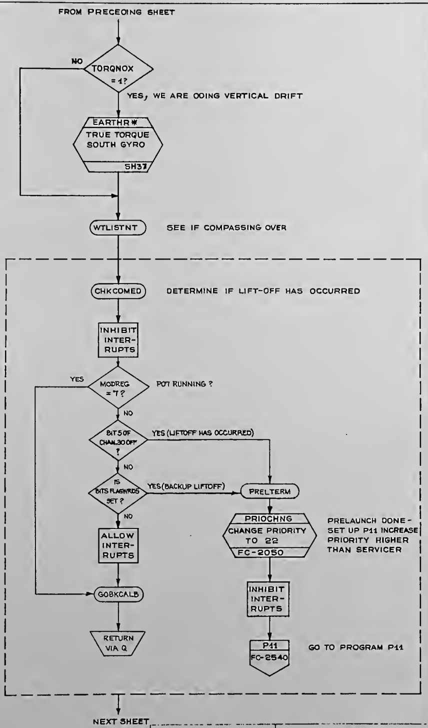
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPROVED GUIDANCE AND NAVIGATION
DRAWN 9 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PROGMR 4/7/69	DOCUMENT NO.
ANALYST	COLOSSUS IIC FC-2530
DOCMR 4-7-69	REV 2
APPR'D 8 April 69	SHEET 10 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D.M. Dietrich 14 NOV 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
CHECKED E.J. Green 4/7/69	DOCUMENT NO.
ANALYST	COLOSSUS IIC FC-2530
DOCMR M.L. Zernan 1-7-69	
APPR'D John A. Moore 8 April 69	REV 2 SHEET 11 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
DRAWN D.M. Dietrich 15NOV68 PRGMR E.S. Eyre 1/7/69 ANALYST DOCMR 1/7/69 APPR'D John A. Kern 8 April 69	COLOSSUS IIC FC-2530 REV 2 12 47



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

APOLLO GUIDANCE AND NAVIGATION

P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING

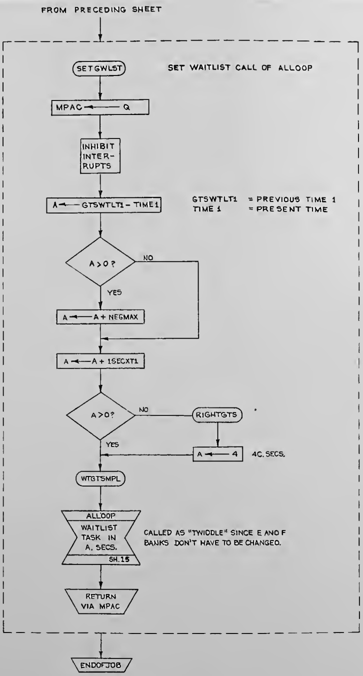
DRAWN 18 NOV 68 | PROGMR 4/7/69 | ANALYST | DOCMR | APPR'D 8 April 69

COLOSSUS IIC

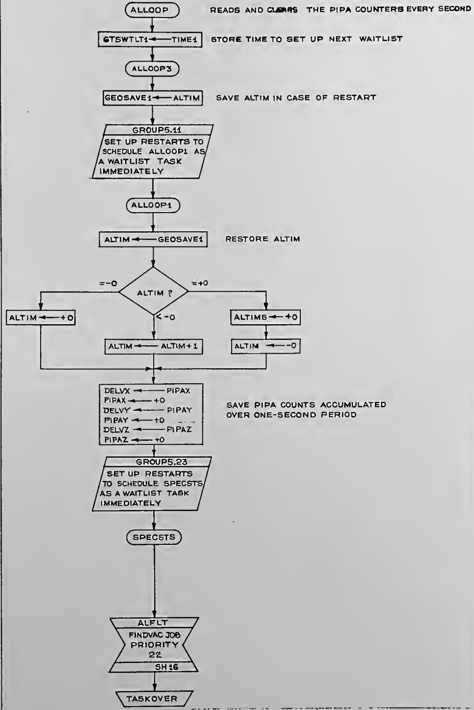
DOCUMENT NO. FC-2530

REV 2

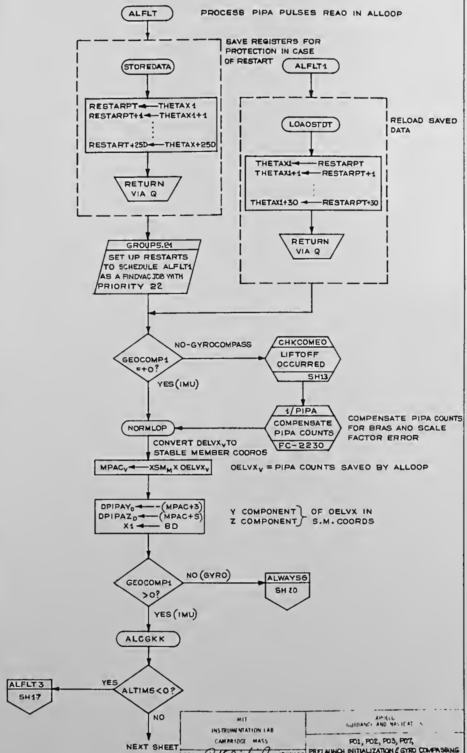
SHEET 13 OF 47



A.C.WILLIAMS 17MAR69
E.J. Grace 4/7/69
P01, P02, P03, P07,
PRELAUNCH INITIALIZATION & GYRO COMPASSING
COLOSSUS II C FC-2530
2 14 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dilton 4 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRCMR [signature]	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2530
DOCMR [signature]	
APPR'D [signature]	REV 2 SHEET 15 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

DRAWN 18NOV68
PRGMR 4/2/69
ANALST
DOCMR
APPR'D 8 April 69

APOLLO GUIDANCE AND NAVIGATION

P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING

DOCUMENT NO.

COLOSSUS IIC FC-2530

REV 2

SHT 16 OF 47

FROM PRECEDING SHEET

ALKCG

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

DELMLP

$INTY_D$ ← INTY−(DPIPAY)$(PIPASC)_D$	SOUTH PIPA INTEGRAL FROM GRAVITY AND MISSILE AWAY
$INTZ_D$ ← INTZ−(DPIPAZ)$(PIPASC)_D$	
$DELM_D$ ← 4(VELSC)(VLAUN)−$INTY_D$	MEASUREMENT DIFFERENCE
$DELM+2_D$ ← 4(VELSC)(VLAUN)−$INTY_D$	EAST PIPA INTEGRAL FROM GRAVITY AND MISSILE AWAY
$DELM+4_D$ ← 4(VELSC)(VLAUN+4)−$INTZ_D$	
$DELM+6_D$ ← 4(VELSC)(VLAUN+4)−$INTZ_D$	MEASUREMENT DIFFERENCE

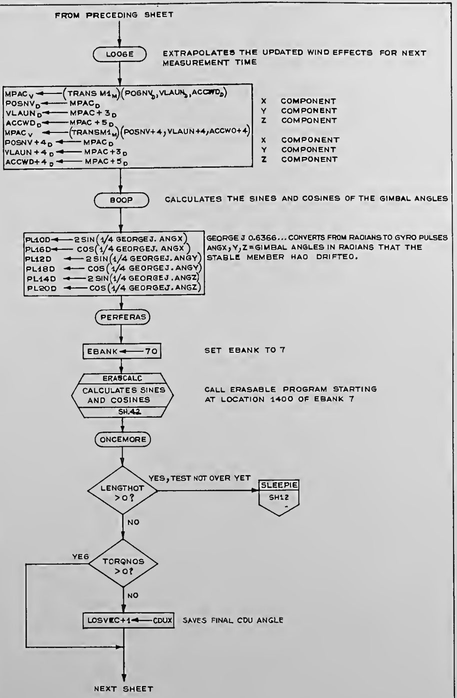
ALILP — UPDATE GAINS FOR CURRENT MEASUREMENT

ALK_D ← $(ALK_D)(ALDK_D)$
$ALK+2_D$ ← $(ALK+2_D)(ALDK+2_D)$

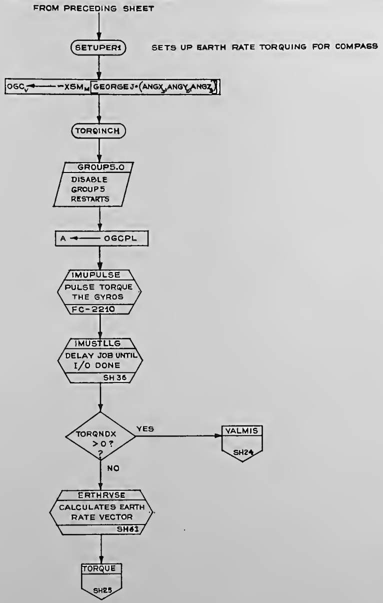
ALKLP — INCORPORATE CURRENT PIPA MEASUREMENTS INTO STATE VECTOR

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 + 2ALSK . 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
DRIFTI ← DRIFTI+(DELM+4)(ALK+8)	SOUTH GYRO DRIFT
VLAUN+4 ← (VLAUN+4)+ 2ALSK(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
DRIFTI+2 ← DRIFTI+2+(DELM+6)(ALK+10D)	EAST GYRO DRIFT
ACCWD+4 ← (ACCWD+4)+2(ALSK+2)(DELM+6)	LAUNCH VEHICLE HORIZ. ACCELERATION ALONG EAST−WEST

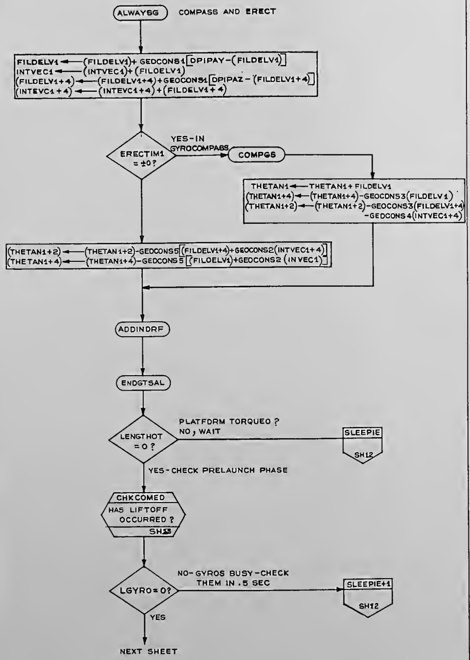
NEXT SHEET



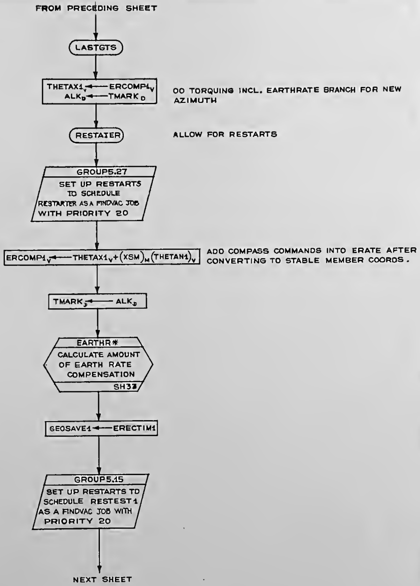
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO
DRAWN P. M. Dietrich 28 NOV 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR [signature] 4/7/69	DOCUMENT NO
ANALYST	COLOSSUS IIC FC-2530
DOCMR [signature] 4-7-69	
APPR'D John A. Moore 8 April 69	REV 2 SHEET 18 OF 47



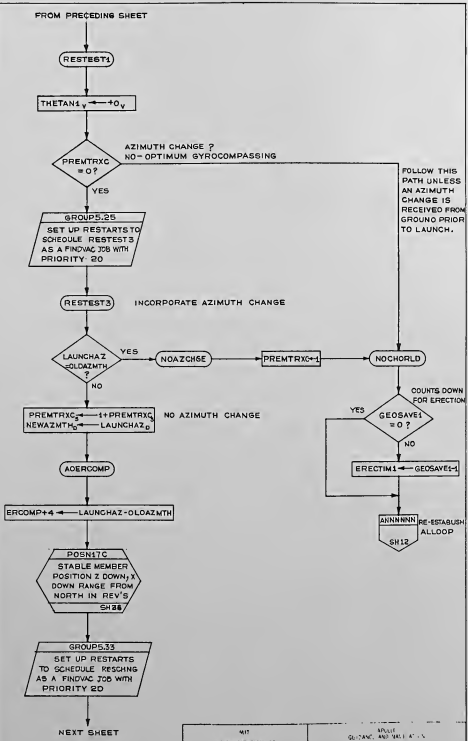
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P. M. Dietrich 2 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR E. L. Grace 4/7/69	DOCUMENT NO.
ANALST	COLOSSUS IIC — FC-2530
DOCMR M. J. Brown 4-24	
APPR'D John A. Moore 8 April 69	REV 2 — SHEET 19 OF 47



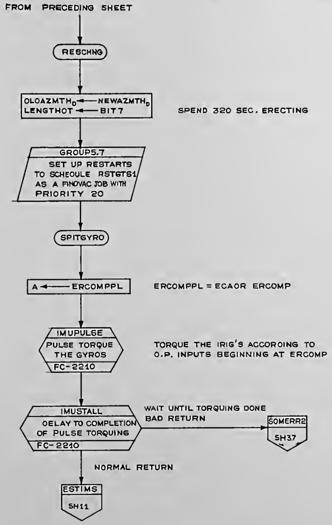
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietrich 2DEC68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR E.J. [illegible] 4/1/69	DOCUMENT No.
ANALST	COLOSSUS IIC FC-2530
DOCMR M. A. [illegible] 4-7-69	
APPR'D John A. Moore 8 April 69	REV 2 SHEET 20 OF 47



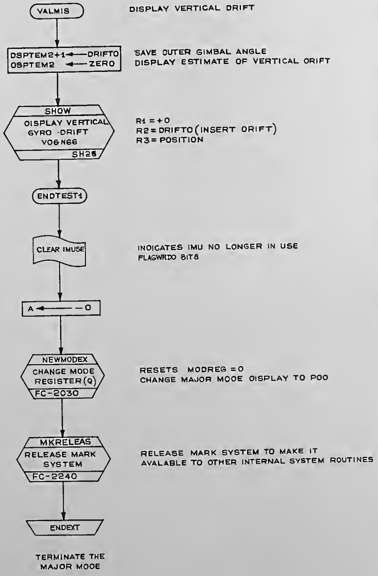
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietrich 3 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION AND GYRO COMPASSING
PRGMR 4/7/69	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2530
DOCMR 4-7-69	
APPR'D 8 April 69	REV 2 — SHEET 21 OF 47



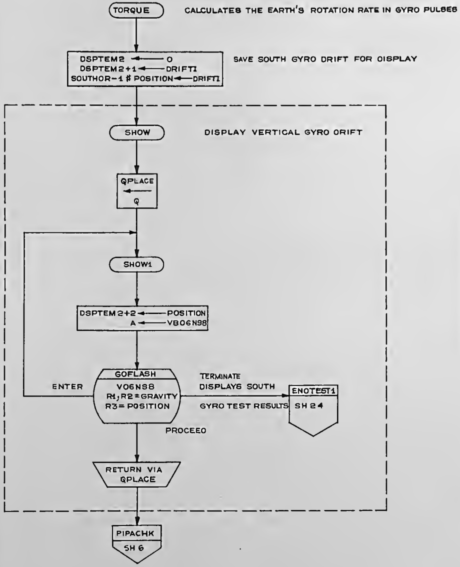
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietrich 3DEC68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR 4/7/69	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2530
DOCMR 4-7-69	
APPR'D John A. Mann 8 April 69	REV 2 — SHEET 22 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dieb Jr. 4 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR S. L. Gowan 9/1/69	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2530
DOCMR M. A. Foran 1-24	
APPR'D John A. Moran 8 Apr 69	REV 2 — SHEET 23 OF 47.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 5 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR [illegible]	DOCUMENT NO
ANALST	COLOSSUS IIC FC-2530
DOCMR [illegible] APPR'D [illegible]	REV 2 PAGE 24 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING

DRAWN D. M. Dickson Jr. 5DEC68
PRGMR E. J. Gauss 4/2/69
ANALST
DOCMR M. J. Johnson 4-7-69
APPR'D John A. Moss 8 Apr 69

COLOSSUS IIC

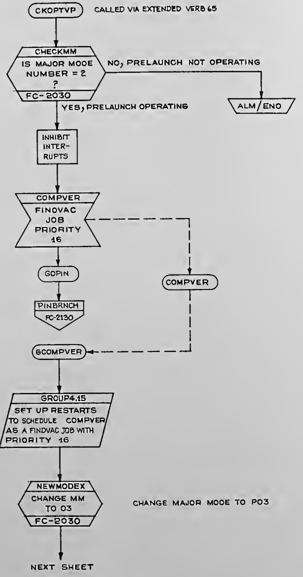
DOCUMENT NO. FC-2530

REV 2

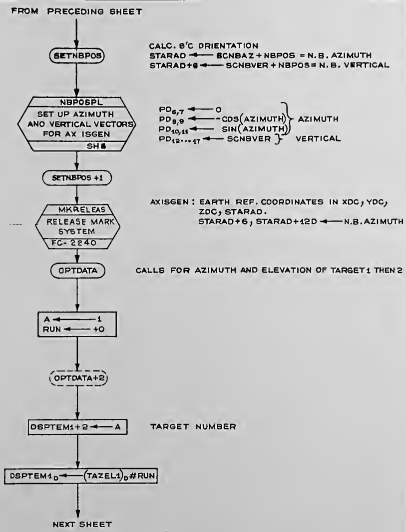
SHEET 25 OF 47

P03

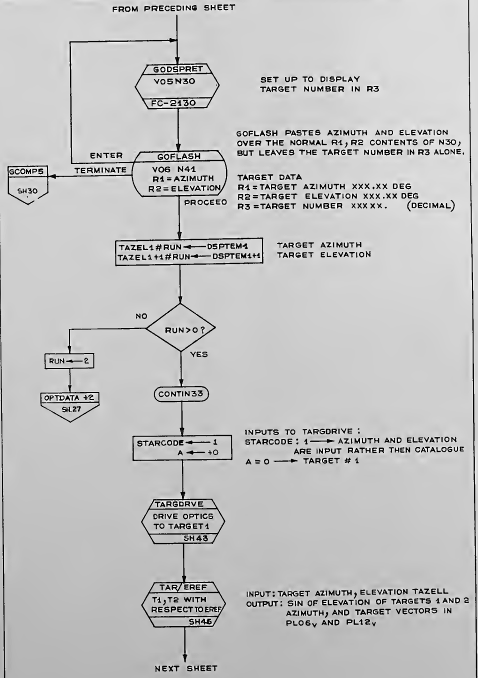
OPTICAL VERIFICATION OF GYROCOMPASSING



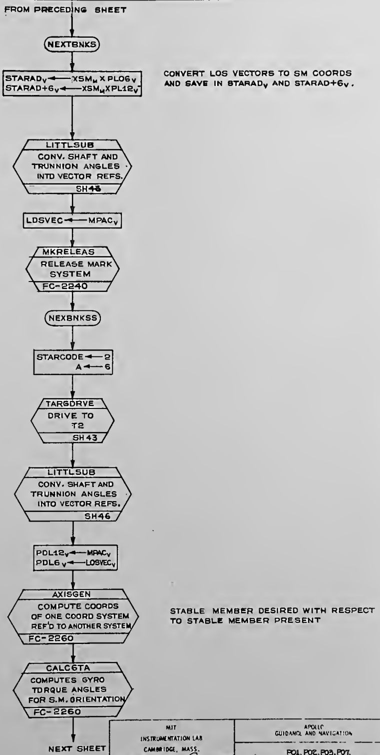
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN P. N. Dietz	31 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PROG'R E. J. [illegible]	4/7/69	
ANALYST		COLOSSUS IIC DOCUMENT NO. FC-2530
DOCMR [illegible]	4-7-69	
APPR'D John A. Moore	8 April 69	REV 2 SHEET 26 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.H. Dietrich 31 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR E.J. Green 4/7/69	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2530
DOCMB G.A. Jansen 4-7-69	
APPR'D John A. Moran 8 April 69	REV 2 SHEET 27 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
DRAWN P.M. Dideriksen 12 DEC 68 PRGMR E.J. Green 4/1/69 ANALST DOCMR R.A. Tomas 4-7-69 APPR'D John A. Moore 8 April 69	DOCUMENT NO. COLOSSUS IIC FC-2530
	REV 2 SHT 28 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

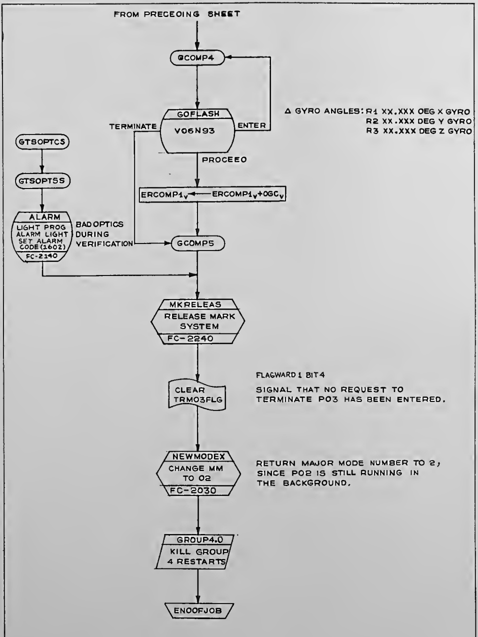
P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING

DRAWN	P.M. Dick	12DEC68
PRGMR	E. J.	4/7/69
ANALST		
DOCMR		
APPR'D	John A. Moan	8 April 69

COLOSSUS IIC — REV 2

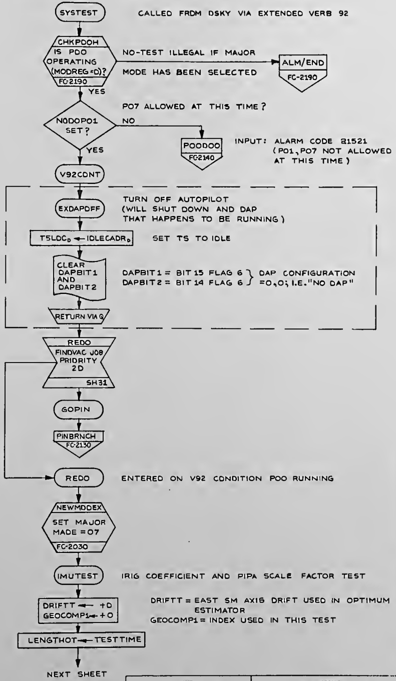
DOCUMENT NO FC-2530

SHEET 29 OF 47

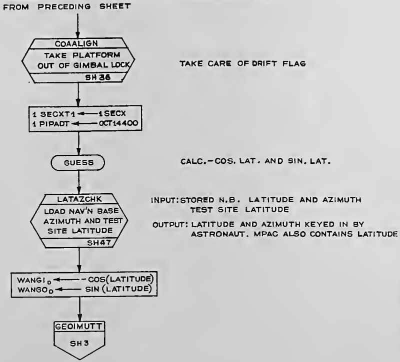


MIT INSTRUMENTATION LAB CAMBRIDGE MASS	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
DRAWN D. M. Dietrich 12DEC68	DOCUMENT NO
PPGMR 4/1/69	COLOSSUS IIC FC-2530
ANALYST	
DOCMR 4-7-69	REV 2
APPR'D John A. Moore 8 April 69	SHEET 30 47

PO7
PRELAUNCH SERVICE GYRO COMPASSING PROGRAM

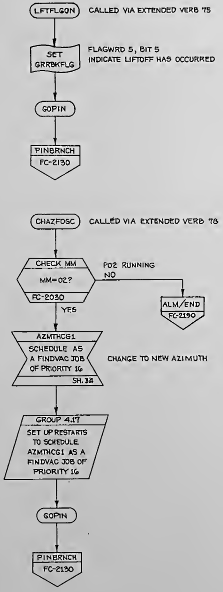


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 22MAY69	PO1, PO2, PO3, PO7 PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR E. I. Gray	COLOSSUS IIC — DOCUMENT NO. FC-2530
ANALST	
DOCMR M. LEMAN	
APPR'D [signature]	REV 2 — SHEET 31 OF 47

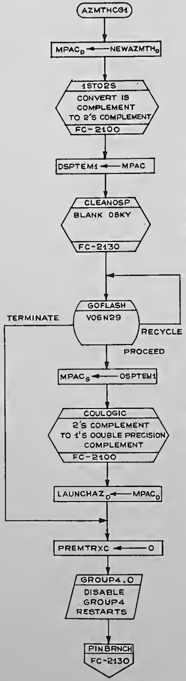


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D.M. Dietrich 24 NOV 68	P01, P02, P03, P07 PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR E.J. Grace 4/7/69	DOCUMENT №
ANALST	COLOSSUS IIC FC-2530
DOCMR W.A. Finn 4-7-69	REV 2
APPR'D John A. Moore 8 April 69	SHEET 32 OF 47

EXTENDED VERBS 75 AND 78



INSTRUMENTATION LAB	APOLLO GUIDANCE AND NAVIGATION
A.C. WILLIAMS 21MAR69	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
Ed Gross 4/7/69	COLOSSUS II C FC-2530
M. G. Toman 4-7-69	2
John A. Moore 8 April 69	33 47



CONVERT NEWAZMTH FROM DOUBLE PRECISION 1'S COMPLEMENT TO SINGLE PRECISION 2'S COMPLEMENT IN $MPAC_S$.

INPUT : $MPAC_D$

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.

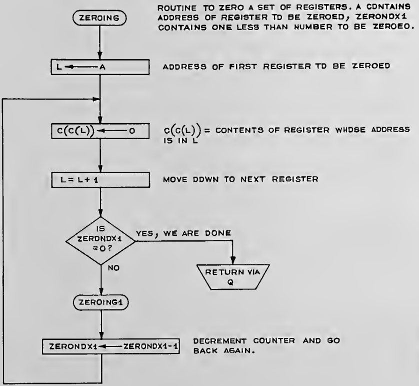
R1 = XSM LAUNCH AZIMUTH
R2, R3 = BLANK.

CONVERT DSPTEM1 FROM SINGLE PRECISIONS 2'S COMPLEMENT TO DOUBLE PRECISION 1'S COMPLEMENT.

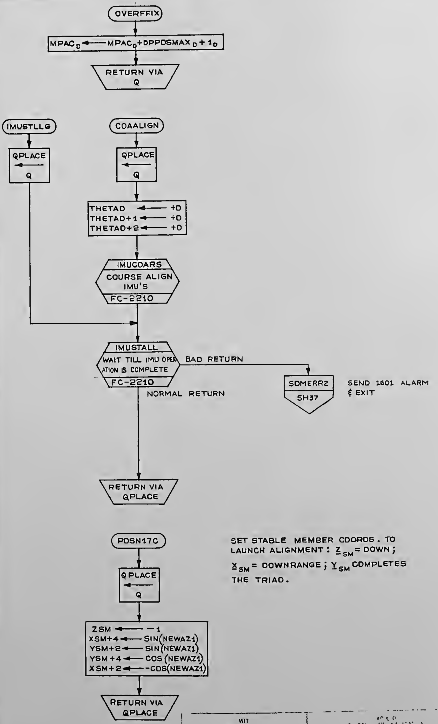
INPUT : $MPAC_S$

OUTPUT : $MPAC_D$

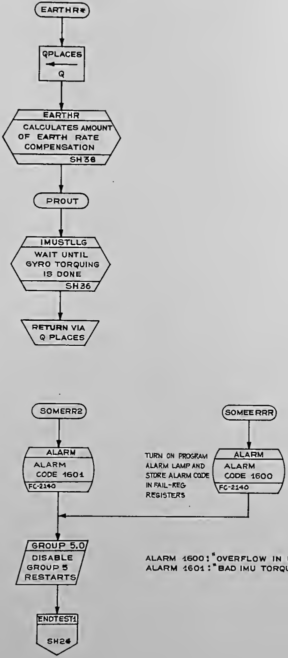
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	P01, P02, P03, P07, PRELAUNCH INITIALIZED & GYRO COMPASSING
DRAWN [signature] 18NOV68	
PRGMR E. L. [signature] 4/7/69	DOCUMENT NO
ANALST	COLOSSUS IIC FC-2530
DOCMR [signature] 1-7-69	
APPR'D [signature] 8 April 69	REV 2 34 47



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 14 NOV 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR E. J. 4/2/69	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2530
DOCMR 4-7-69	
APPR'D 8 April 69	REV 2 SHEET 35 of 47

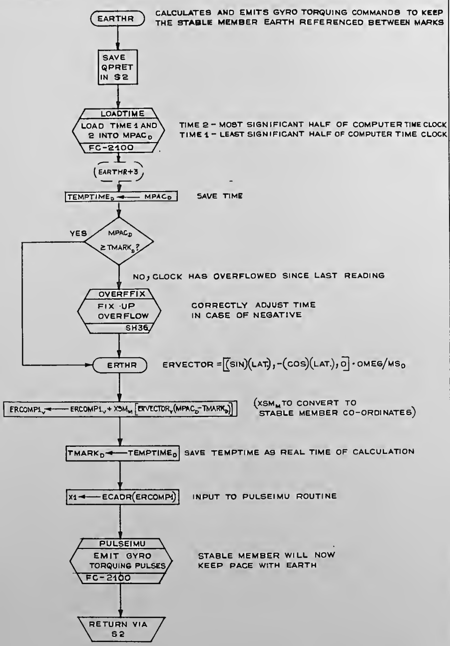


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 4 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION GYRO COMPASSING
PRGMR 4/7/69	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2530
DOCMR 4-7-69	
APPR'D 8 April 69	REV 2 SHEET 36 OF 47



ALARM 1600: "OVERFLOW IN DRIFT TEST"
ALARM 1601: "BAD IMU TORQUE, ABORT"

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN / PRGMR / ANALST / DOCMR / APPR'D	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
	COLOSSUS IIC — DOCUMENT NO. FC-2530
	REV 2 — SHEET 37 OF 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

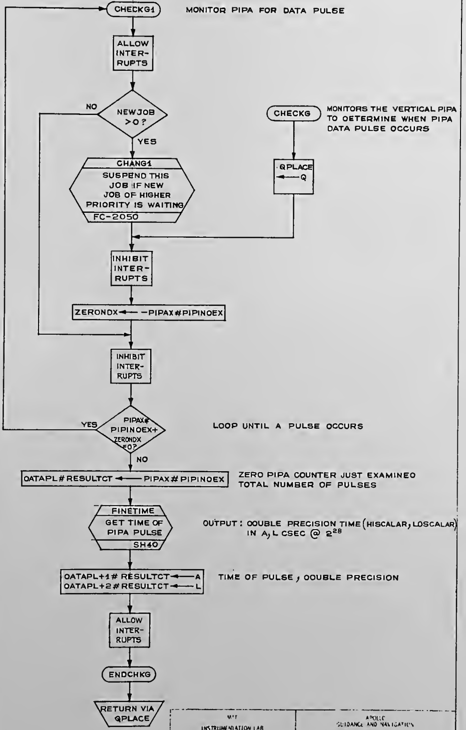
DRAWN D.H. Dietrich 10DEC68
PROGMR Ed Green 4/7/69
ANALYST
DOCMN'T A. Toman 4-7-69
APPR'D John A. Thurman 8 April 69

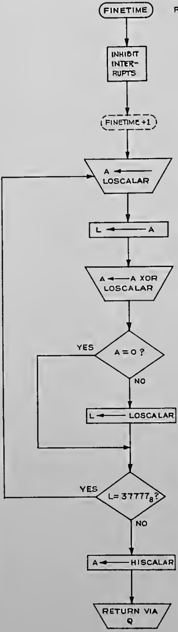
GUIDANCE AND NAVIGATION

P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING

COLOSSUS IIC FC-2530

REV 2


CHECKG1
MONITOR PIPA FOR DATA PULSE
ALLOW INTER- RUPTS
NO
NEWJOB >0?
YES
CHECKG
MONITORS THE VERTICAL PIPA TO DETERMINE WHEN PIPA DATA PULSE OCCURS
CHANG1
SUSPEND THIS JOB IF NEW JOB OF HIGHER PRIORITY IS WAITING
FC-2050
QPLACE ← Q
INHIBIT INTER- RUPTS
ZERONDX ← -PIPAX#PIPINDEX
INHIBIT INTER- RUPTS
YES
PIPAX# PIPINDEX+ ZERONDX ≠0?
LOOP UNTIL A PULSE OCCURS
NO
DATAPL#RESULTCT ← PIPAX#PIPINDEX
ZERO PIPA COUNTER JUST EXAMINED TOTAL NUMBER OF PULSES
FINETIME
GET TIME OF PIPA PULSE
SH40
OUTPUT: DOUBLE PRECISION TIME (HISCALAR, LOSCALAR) IN A, L CSEC @ 2^28
DATAPL+1#RESULTCT ← A
DATAPL+2#RESULTCT ← L
TIME OF PULSE, DOUBLE PRECISION
ALLOW INTER- RUPTS
ENDCHKG
RETURN VIA QPLACE



READS THE CLOCK AND SCALERS (CHANNELS 3,4 INTO A,L)

LOSCALAR IN CHANNEL 4 AND CONTAINS THE LOWER HALF OF THE CLOCK READING

SAVE

READ LOSCALAR AGAIN, "EXCLUSIVE OR" IT WITH PREVIOUS READING

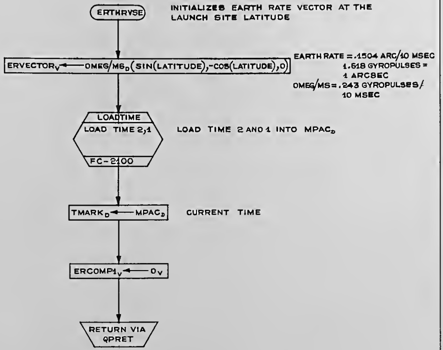
WILL BE 0 IF BOTH READINGS AGREE

IF CLOCK INCREMENTED BETWEEN READINGS, READ IT AGAIN

IF LOWER HALF OF CLOCK CONTAINS SOMETHING LESS THAN POSMAX THE HIGHER HALF OF THE CLOCK CAN BE READ SAFELY
OTHERWISE, LOOP BACK AND READ AGAIN (I.E. WAIT, UNTIL LOSCALAR OVERFLOWS BEFORE READING)

HISCALAR IS CHANNEL 3 AND CONTAINS HIGHER HALF OF THE CLOCK READING

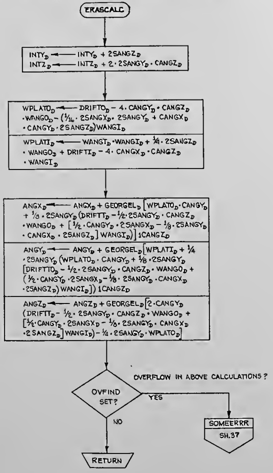
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	GUIDANCE AND NAVIGATION
DRAWN P.M. Dietrich 3 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR E. J. Green 1/7/69	DOCUMENT NO
ANALYST	COLOSSUS IIC FC-2530
DOCMR 1-7-69	
APPR'D 8 Jan 69	REV 2 SHEET 40 OF 47

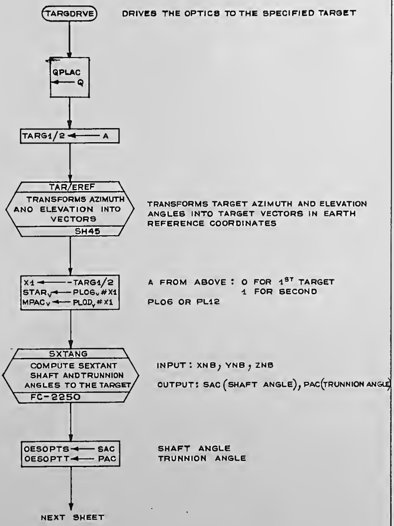

ERTHRVSE
INITIALIZES EARTH RATE VECTOR AT THE LAUNCH SITE LATITUDE
ERVECTOR_V ← OMEG/MS_D (SIN(LATITUDE), -COS(LATITUDE), 0)
EARTH RATE = .1504 ARC/10 MSEC
1.618 GYROPULSES = 1 ARCSEC
OMEG/MS = .243 GYROPULSES/10 MSEC
LOADTIME
LOAD TIME 2,1
FC-2100
LOAD TIME 2 AND 1 INTO MPAC_D
TMARK_D ← MPAC_D
CURRENT TIME
ERCOMP1_V ← 0_V
RETURN VIA QPRET

NOTE: THIS SUBROUTINE USES AS INPUT THE CONTENTS OF PUSH LIST LOCATIONS PL10-PL21.
THESE LOCATIONS ARE LOADED IMMEDIATELY BEFORE THE SUBROUTINE IS CALLED.

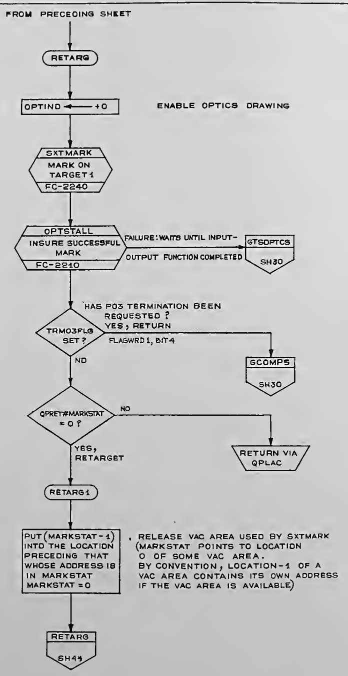
PUSH LIST LOCATION	CONTENTS OF LOCATION	DOCUMENT SYMBOL
$PL10_D$	2 SIN(1/4 GEORGEJ · ANGX)	$2\ SANGX_D$
$PL12_D$	2 SIN(1/4 GEORGEJ · ANGY)	$2\ SANGY_D$
$PL14_D$	2 SIN(1/4 GEORGEJ · ANGZ)	$2\ SANGZ_D$
$PL16_D$	COS(1/4 GEORGEJ · ANGX)	$CANGX_D$
$PL18_D$	COS(1/4 GEORGEJ · ANGY)	$CANGY_D$
$PL20_D$	COS(1/4 GEORGEJ · ANGZ)	$CANGZ_D$

THE DOCUMENT SYMBOLS ARE ONLY USED FOR CONVENIENCE IN REPRESENTING THIS SUBROUTINE.
THEY ARE NEITHER GSOP SYMBOLS NOR AGC TAGS AND ARE ONLY ON THIS PAGE.

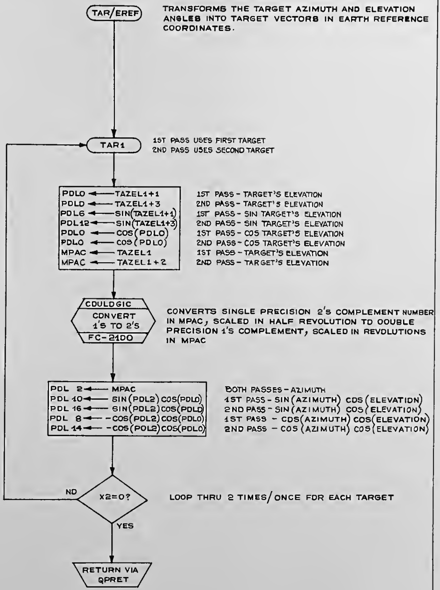




MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	16 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING	
PRGMR		COLOSSUS II C	DOCUMENT NO FC-2530
ANALYST			
DOCMR		REV 2	SHEET 43 OF 47
APPR'D			

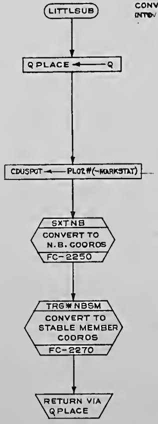


MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
DRAWN 17DEC68	
PRGMR	
ANALYST	COLOSSUS IIC FC-2530
DOCMS	
APPR'D	REV 2 44 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN R. M. Dietrich 17 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR S. J. Green 4/1/69	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2530
DOCMR M. G. Foran 1-2-69	
APPR'D John A. Miller 2 April 69	REV 2 — SHEET 46 OF 47

CONVERTS SHAFT AND TRUNNION ANGLES AND INTO A UNIT VECTOR IN SM COORDINATES



INPUT: CDUSPOT

OUTPUT: $MPAC_V$

MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS.

DRAWN P.M. Dietrich 17DEC68
PRGMR 4/7/69
ANALST
DOCMR 1-7-69
APPR'D 8 Apr 69

GUIDANCE AND NAVIGATION

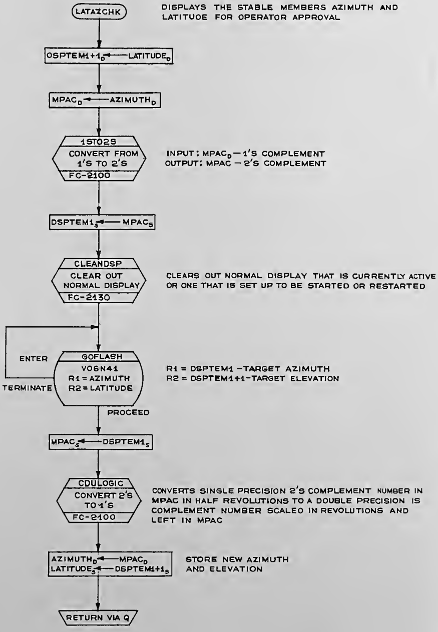
P01, P02, P03, P07,
PRELAUNCH INITIALIZATION & GYRO COMPASSING

COLOSSUS IIC

DOCUMENT NO
FC-2530

REV 2

46 · 47



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 10 DEC 68	P01, P02, P03, P07, PRELAUNCH INITIALIZATION & GYRO COMPASSING
PRGMR 4/7/69	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2530
DOCMR	
APPR'D	REV 2 SHEET 47 OF 47

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
VHHDOT:	COMPUTES AND DISPLAYS NOUN 62: VELOCITY, ALTITUDE ALTITUDE CHANGE RATE.	SH. 18
S11.1:	COMPUTES VALUES FOR NOUN 62 DISPLAY	SH. 18
SATSTKON:	ORIGINAL ENTRY TO SATURN STICK ROUTINE; SCHEDULES REDOSAT.	SH. 19
REDOSAT:	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.

DRAWN R. D. [illegible] 14APR69
PRGMR O. N. Ehrmann 18APR69
ANALST O. N. Ehrmann "
DOCMR Angela M. Saint 18APR69
APPR'D John A. Moore 22 April 69

APOLLO GUIDANCE AND NAVIGATION

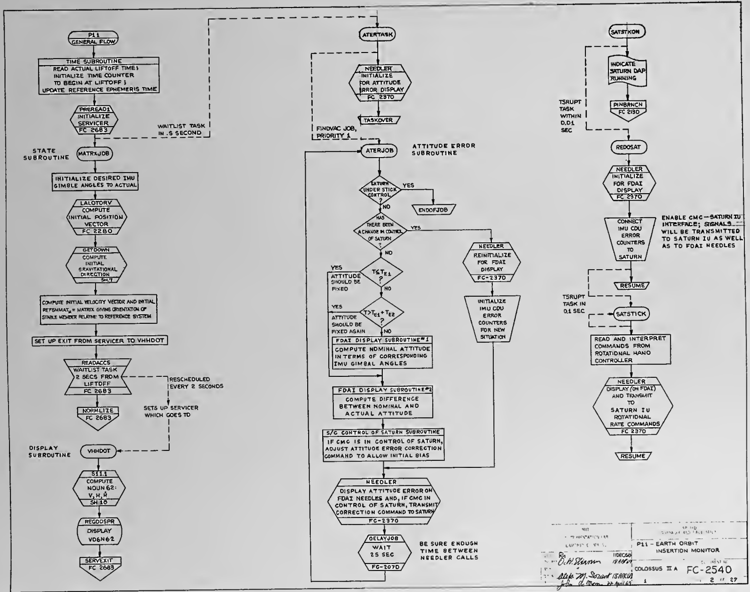
P11- EARTH ORBIT INSERTION MONITOR

COLOSSUS II A

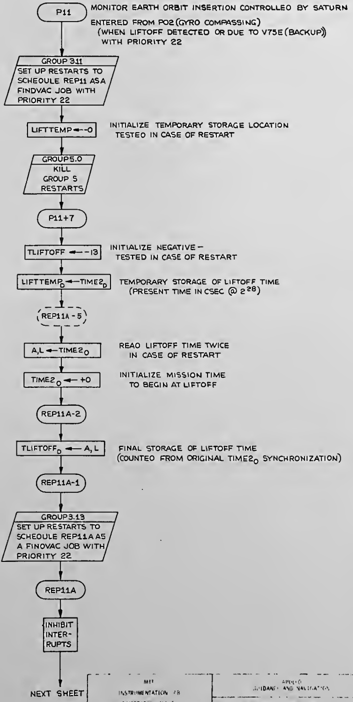
DOCUMENT NO FC-2540

REV 1

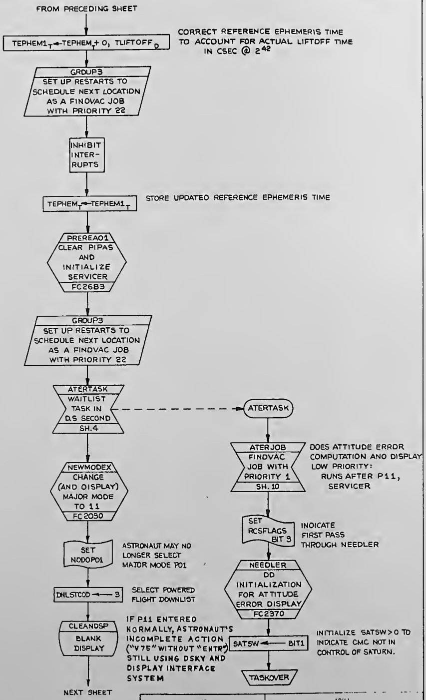
SHEET 1 OF 27



P11 GENERAL FLOW
TIME SUBROUTINE
READ ACTUAL LIFTOFF TIME; INITIALIZE TIME COUNTER TO BEGIN AT LIFTOFF; UPDATE REFERENCE EPHEMERIS TIME
PREREAD1 INITIALIZE SERVICER FC 2683
WAITLIST TASK IN .5 SECOND
STATE SUBROUTINE
MATRXJOB
INITIALIZE DESIRED IMU GIMBLE ANGLES TO ACTUAL
LALOTORV COMPUTE INITIAL POSITION VECTOR FC 2280
GETDOWN COMPUTE INITIAL GRAVITATIONAL DIRECTION SH.7
COMPUTE INITIAL VELOCITY VECTOR AND INITIAL REFSMMAT$_M$ = MATRIX GIVING ORIENTATION OF STABLE MEMBER RELATIVE TO REFERENCE SYSTEM
SET UP EXIT FROM SERVICER TO VHHDOT
READACCS WAITLIST TASK 2 SECS FROM LIFTOFF FC 2683
RESCHEDULED EVERY 2 SECONDS
SETS UP SERVICER WHICH GOES TO
NORMLIZE FC 2683
DISPLAY SUBROUTINE
VHHDOT
S11.1 COMPUTE NOUN 62: V, H, Ḣ SH 10
REGODSPR DISPLAY VD6N62
SERVEXIT FC 2683
ATERTASK
NEEDLER INITIALIZE FOR ATTITUDE ERROR DISPLAY FC 2370
TASKOVER
FINDVAC JOB, PRIORITY 1
ATERJOB
ATTITUDE ERROR SUBROUTINE
SATURN UNDER STICK CONTROL ?
YES
NO
ENDOFJOB
HAS THERE BEEN A CHANGE IN CONTROL OF SATURN ?
YES
NO
NEEDLER REINITIALIZE FOR FDAI DISPLAY FC-2370
INITIALIZE IMU CDU ERROR COUNTERS FOR NEW SITUATION
$T \le T_{E1}$?
YES
ATTITUDE SHOULD BE FIXED
NO
$T > T_{E1} + T_{E2}$?
YES
ATTITUDE SHOULD BE FIXED AGAIN
NO
FDAI DISPLAY SUBROUTINE #1
COMPUTE NOMINAL ATTITUDE IN TERMS OF CORRESPONDING IMU GIMBAL ANGLES
FDAI DISPLAY SUBROUTINE #2
COMPUTE DIFFERENCE BETWEEN NOMINAL AND ACTUAL ATTITUDE
S/C CONTROL OF SATURN SUBROUTINE
IF CMC IS IN CONTROL OF SATURN, ADJUST ATTITUDE ERROR CORRECTION COMMAND TO ALLOW INITIAL BIAS
NEEDLER
DISPLAY ATTITUDE ERROR ON FDAI NEEDLES AND, IF CMC IN CONTROL OF SATURN, TRANSMIT CORRECTION COMMAND TO SATURN
FC-2370
DELAYJOB WAIT 25 SEC FC-2070
BE SURE ENOUGH TIME BETWEEN NEEDLER CALLS
SATSTKON
INDICATE SATURN DAP RUNNING
PINBRNCH FC 2190
T5RUPT TASK WITHIN 0.01 SEC
REDOSAT
NEEDLER INITIALIZE FOR FDAI DISPLAY FC 2370
CONNECT IMU CDU ERROR COUNTERS TO SATURN
ENABLE CMC—SATURN IU INTERFACE; SIGNALS WILL BE TRANSMITTED TO SATURN IU AS WELL AS TO FDAI NEEDLES
RESUME
T5RUPT TASK IN 0.1 SEC
SATSTICK
READ AND INTERPRET COMMANDS FROM ROTATIONAL HAND CONTROLLER
NEEDLER DISPLAY (ON FDAI) AND TRANSMIT TO SATURN IU ROTATIONAL RATE COMMANDS FC 2370
RESUME
MIT
P11 - EARTH ORBIT INSERTION MONITOR
11DEC68
COLOSSUS II A
FC-2540
2 of 27



MIT INSTRUMENTATION LAB CAMBRIDGE MASS	APOLLO GUIDANCE AND NAVIGATION
DRAWN R. / PRGMR O. N. Wasson 18NOV68 / ANALST " / DOCMR Allen M. Grant 18APR69 / APPR'D John A. Moore 22 April 69	P11 - EARTH ORBIT INSERTION MONITOR
COLOSSUS II A — REV 1	DOCUMENT NO. FC-2540 — SHEET 3 OF 27



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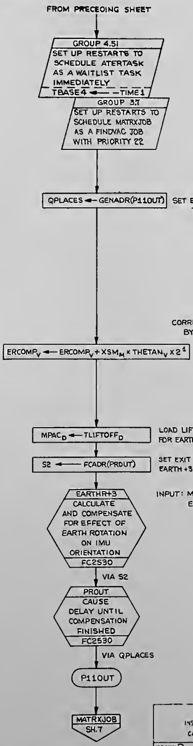
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

P11- EARTH ORBIT INSERTION MONITOR

DRAWN | 19NOV68
PRGMR
ANALST
DOCMR
APPR'D

COLOSSUS II A
DOCUMENT NO. FC-2540
REV 1
SHEET 4 OF 27



SET EXIT FROM PROUT TO P11OUT

CORRECT EARTH ROTATION RATE TO BE COMPENSATED FOR BY ADDING DRIFT NOT CORRECTED DURING PRELAUNCH IN REVS/CSEC @ 2^{21} IN STABLE MEMBER COORDINATES

WHERE: ORIGINAL ERCOMP$_V$ = EFFECT OF EARTH ROTATION RATE ON IMU, IN REVS/CSEC @ 2^{21}, IN S.M. COORDINATES.

THETAN$_V$ = DRIFT NOT CORRECTED DURING PRELAUNCH IN REVS/CSEC @ 2^{21} IN EARTH-FIXED COORDINATES.

XSM$_M$ = MATRIX FOR CONVERSION BETWEEN EARTH-FIXED AND STABLE MEMBER COORDINATE SYSTEMS @ 2^1.

2^1 FACTOR IS FOR SCALING.

LOAD LIFTOFF TIME FOR EARTHR+3

SET EXIT FROM EARTH+3 TO PROUT

INPUT: MPAC$_D$ = TIME OF LIFTOFF IN CSEC @ 2^{28}

ERCOMP$_V$ = RATE OF ROTATION TO BE COMPENSATED FOR

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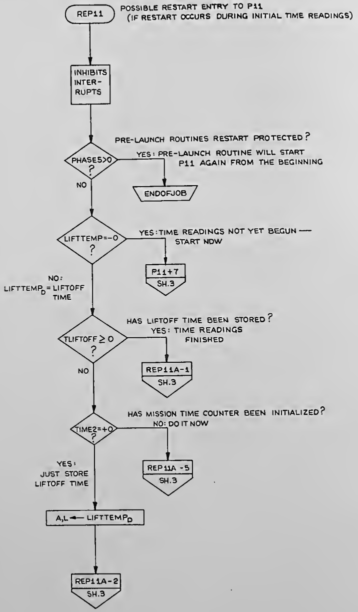
DRAWN R. 25NOV68; PRGMR D. M. Thomas 18 MAR 69; ANALST "; DOCMR Alleyn M. Sinnett 18 MAR 69; APPR'D John A. Moore 22 April 69	P11 - EARTH ORBIT INSERTION MONITOR
COLOSSUS II A	DOCUMENT NO. FC-2540
REV 1	SHEET 5 OF 27



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PRGMR O. N. Olsen 26NOV68
ANALYST 19APR69
DOCMR Alexa M. Sorari 22APR69
APPR'D John A. Moore 22 Apr/69

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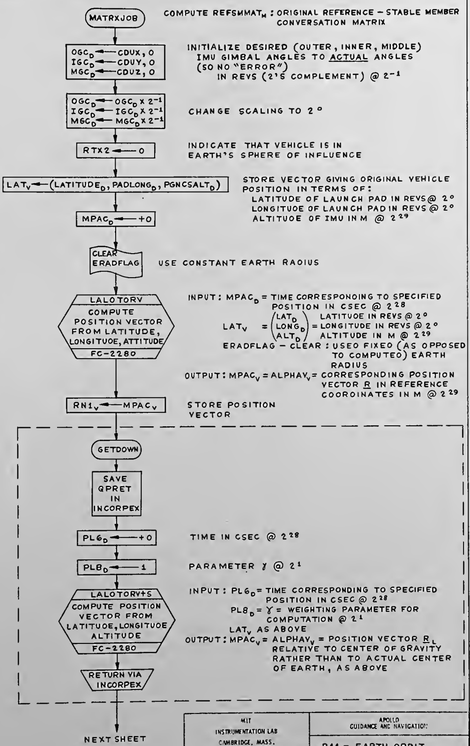
REV 1 SHEET 6 OF 27



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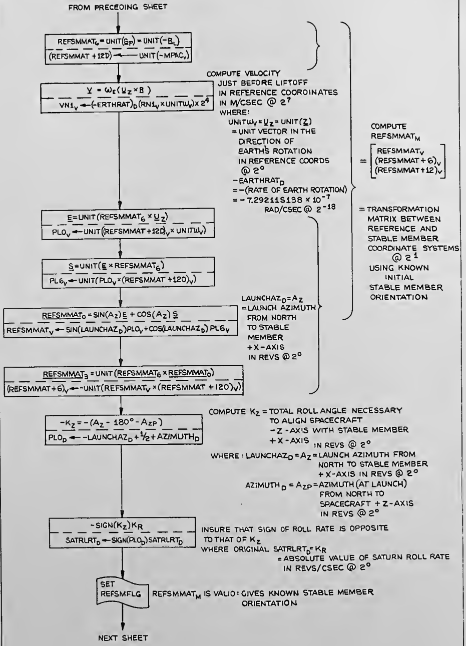
DRAWN [signature] 28MAY69; PRGMR [signature] 6-9-69; ANALST; DOCMR Aleta M. Smeal 6-9-69; APPR'D Aleta M. Smeal 6-9-69	P11 – EARTH ORBIT INSERTION MONITOR
COLOSSUS II A	DOCUMENT NO. FC-2540
REV 1	SHEET 7 OF 27



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DRAWN 2JAN69
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ANALST "
DOCMR Aleja M. Grant 18APR69
APPR'D John A. Moo... 22 Apr 69

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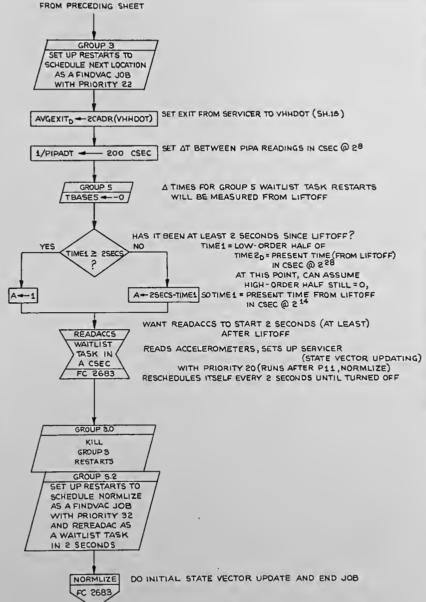

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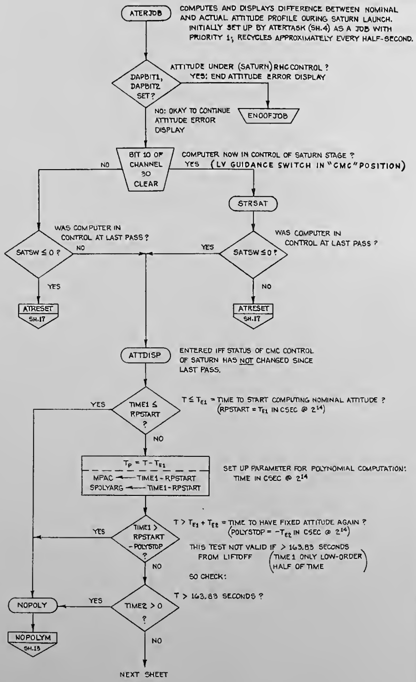
DRAWN R1 6JAN68	P11 - EARTH ORBIT INSERTION MONITOR
PRGMR O. W. Ellerson 18 APR 68	
ANALST " "	COLOSSUS II A — DOCUMENT NO. FC-2540
DOCMR Alida M. Sorant 22 APR 68	
APPR'D John A. Moon 22 April 68	REV 1 — SHEET 9 OF 27



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DRAWN A.C.WILLIAMS 13FEB69
PROG MGR D.W. Ehrman 18 APR 69
DOC MGR Alexa M. Sorant 18 APR 69
APPR'D John A. Moran 22 April 69

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P11 – EARTH ORBIT INSERTION MONITOR

COLOSSUS II A FC-2540

REV 1 10 27

FROM PRECEDING SHEET

L ← POLYNUM
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_N

(COEFFICIENTS MUST BE STORED DOUBLE PRECISION, IN THE ORDER:
A_0
A_1
⋮
A_N)

MPAC = ARGUMENT X

OUTPUT: $MPAC_D$ = VALUE OF POLYNOMIAL
$= A_0 + A_1 X + \cdots + A_N X^N$

IN THIS CASE, RESULT IS:
θ_P = NOMINAL PITCH ANGLE IN REVS @ 2^5

$MPAC_D \leftarrow MPAC_D \times 2^5$

CHANGE SCALING OF θ_P TO 2^0

$PLO_D \leftarrow MPAC_D$

$-C_P = -\cos(\theta_P)$
$PL14_D \leftarrow -\cos(MPAC_D)$

$S_P = \sin(\theta_P)$
$PL10_D \leftarrow \sin(PLO_D)$

$PL12_D \leftarrow +0$

TRIGONOMETRIC FUNCTIONS @ 2^1

COMPUTE REMAINING ROLL ANGLE IN REVS @ 2^0

$\theta_R = K_Z - \text{SIGN}(K_Z) K_R T_P$
$MPAC_D \leftarrow (LAUNCHAZ_D - 1/2 - AZIMUTH_D) + SATRLRT_D \times SPOLYARG \times 2^{14}$

WHERE: $LAUNCHAZ_D = A_Z$
= LAUNCH AZIMUTH FROM NORTH TO STABLE MEMBER + X-AXIS IN REVS @ 2^0

$AZIMUTH_D = A_{ZP}$
= AZIMUTH (AT LAUNCH) FROM NORTH TO SPACECRAFT + Z - AXIS IN REVS @ 2^0

[$K_Z = A_Z - 180° - A_{ZP}$
= TOTAL ROLL ANGLE AT LAUNCH TIME]

$SATRLRT_D = -\text{SIGN}(K_Z) K_R$
= ROLL RATE WITH SIGN OPPOSITE TO K_Z IN REVS/CSEC @ 2^0

SPOLYARG = T_P
= TIME SINCE NOMINAL START OF ROLL IN CSEC @ 2^{14}

2^{14} FACTOR IS FOR SCALING

NEXT SHEET

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DRAWN RM 10JAN69	P11 - EARTH ORBIT INSERTION MONITOR
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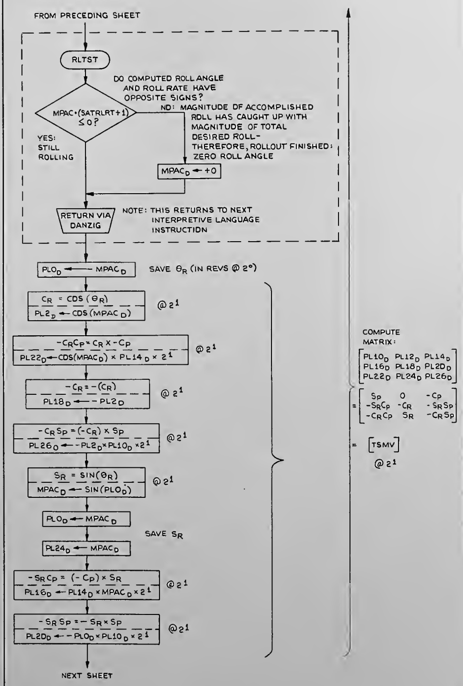
ANALST " "	COLOSSUS II A — DOCUMENT NO. FC-2540
DOCMR Alex N. Sorant 15 APR 69	
APPR'D John A. Moore 22 Apr 69	REV 1 — SHEET 11 OF 27



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DRAWN 8JAN69

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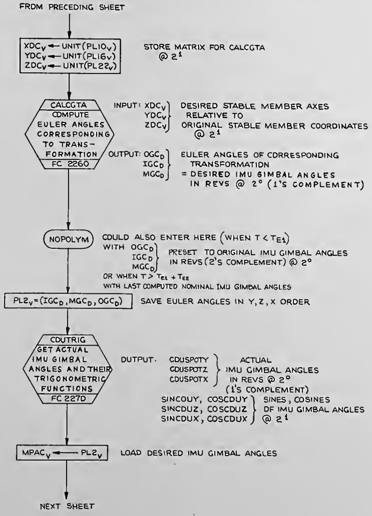

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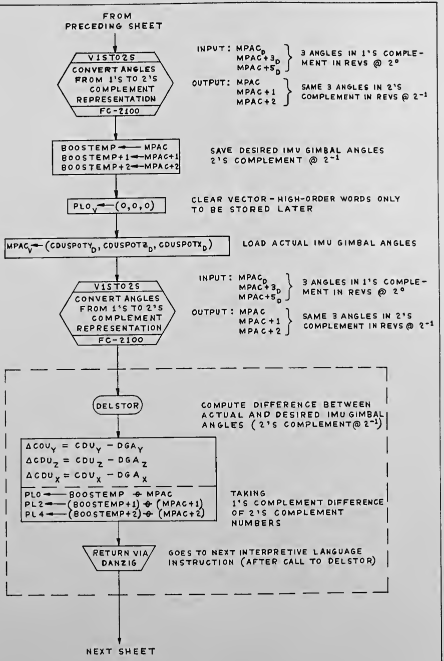
DRAWN / PRGMR C. W. Eliasson 13JAN69	P11 - EARTH ORBIT INSERTION MONITOR
ANALYST	COLOSSUS II A — DOCUMENT NO FC-2540
DOCMR Alice M. Sloan	
APPR'D John A. Moore	REV 1 — SHEET 13 OF 27



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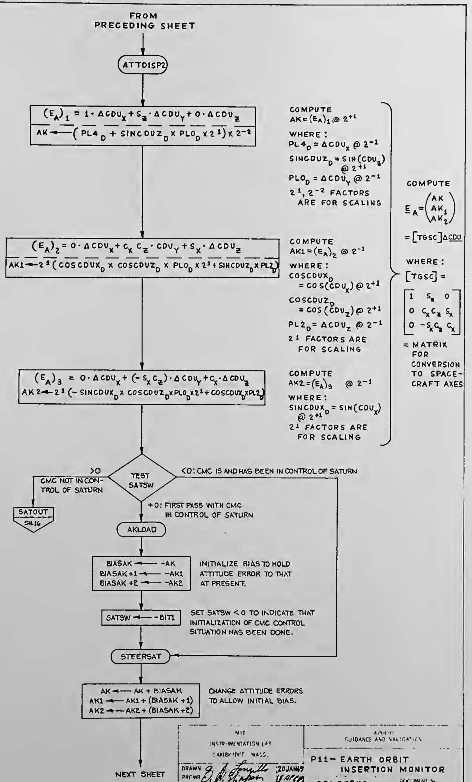
DRAWN 17JAN68	P11- EARTH ORBIT INSERTION MONITOR
PRGMR	COLOSSUS II A
ANALST	DOCUMENT NO. FC-2540
DOCMR	
APPR'D 22 April 69	REV 1 SHEET 14 OF 27



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PRGMR E. W. Tinton 18APR69
ANALST
DOCMR Alecta M. Grant 18APR69
APPR'D John A. Moran 23 April 69

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COLOSSUS IIA

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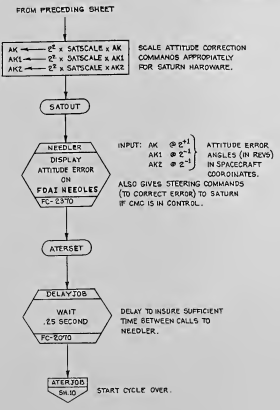

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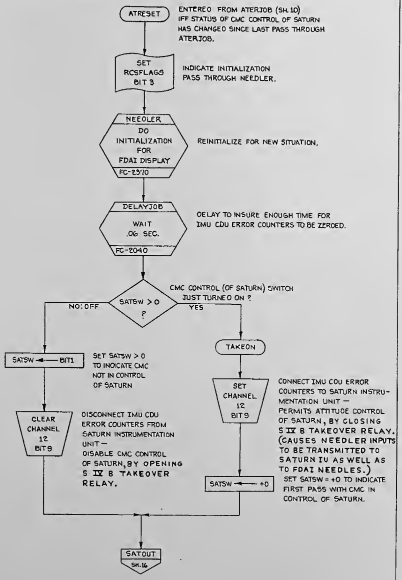
DRAWN A.C. WILLIAMS 20FEB69	P11 - EARTH ORBIT INSERTION MONITOR
CHECKED	COLOSSUS II A
ANALYST	DOCUMENT NO. FC-2540
DOCMR	REV 1
APPR'D	SHEET 16 OF 27



A.C.WILLIAMS 14FEB69
O. N. Ellason 18APR69
Alufa M Scant 18APR69
John L. Mon 22Apr/69

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COLOSSUS II A

FC-2540

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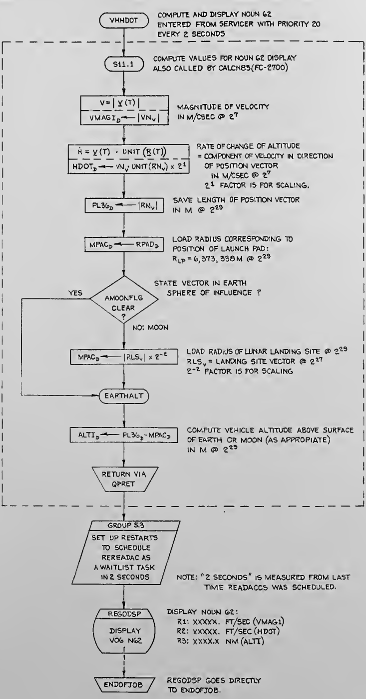

A.C.WILLIAMS 20FEB69

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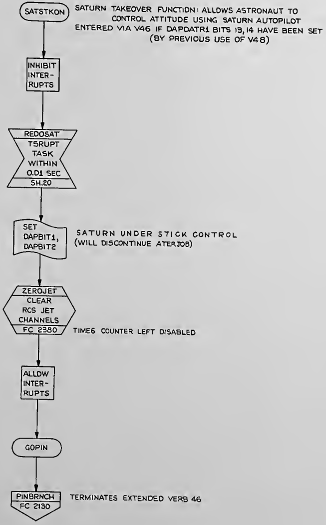

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DRAWN RA 2DEC68
PRGMR O. W. Eliasson 18 APR 69
ANAL "
DOCMR Aleta M. Dorant 18 APR 69
APPR'D John A. Moore 22 April 69

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COLOSSUS II A

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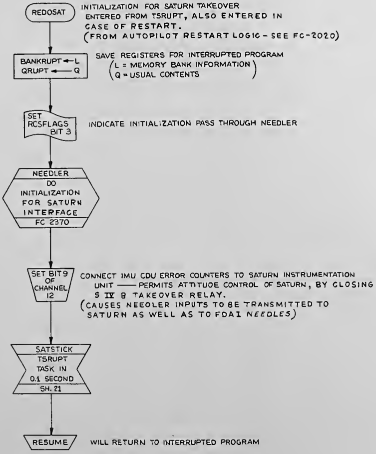

R1 4DEC68
O. W. Eliasson 11 APR 69
Alicia M. Sorant 22 APR 69
John A. Moore 28 April 69

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COLOSSUS II A

FC-2540

REV. 1

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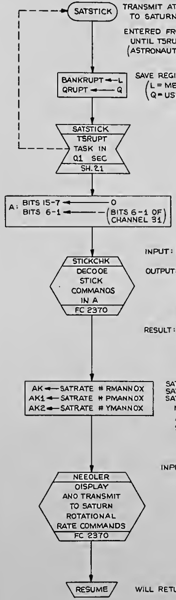

TRANSMIT ATTITUDE COMMANDS FROM ASTRONAUT TO SATURN

ENTERED FROM T5RUPT EVERY 100MS UNTIL T5RUPT CONTROL IS TAKEN OVER BY ANOTHER USER (ASTRONAUT WILL CAUSE SUCH TERMINATION)

SAVE REGISTERS FOR INTERRUPTED PROGRAM
(L = MEMORY BANK INFORMATION
Q = USUAL CONTENTS)

SET UP INPUT TO STICKCHK
SIGNALS FROM ASTRONAUT
VIA ROTATIONAL HAND CONTROLLER

INPUT: BITS 6-1 OF A = COMPLEMENT OF SOME CHANNEL INPUTS

OUTPUT:
PMANNOX: BITS 15-3 = 0, BITS 2-1 = BITS 2-1 OF A
YMANNOX: BITS 15-3 = 0, BITS 2-1 = BITS 4-3 OF A
RMANNOX: BITS 15-3 = 0, BITS 2-1 = BITS 6-5 OF A

RESULT: PMANNOX, YMANNOX, RMANNOX:
0 — INDICATES NO ROTATION
OR 1 — INDICATES POSITIVE ROTATION
OR 2 — INDICATES NEGATIVE ROTATION

IN PITCH, YAW, ROLL DIRECTIONS, RESPECTIVELY

SATRATE + 0 = ZERO ROTATION
SATRATE + 1 = POSITIVE ROTATION
SATRATE + 2 = NEGATIVE ROTATION

MAGNITUDE OF POSITIVE OR NEGATIVE ROTATION IS EXPRESSED AS FRACTION OF MAXIMUM ROTATION RATE EFFECTED BY S IV B RCS CONTROL, WHICH IS:
.5 DEG/SEC FOR ROLL
.3 DEG/SEC FOR PITCH, YAW.

INPUT: AK = ROLL RATE COMMAND
AK1 = PITCH RATE COMMAND
AK2 = YAW RATE COMMAND

WILL RETURN TO INTERRUPTED PROGRAM

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COLOSSUS II A — DOCUMENT No. 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
EARTHR+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	2280	COMPUTES POSITION VECTOR GIVEN LATITUDE, LONGITUDE, ALTITUDE, AND GAMMA (WEIGHTING PARAMETER)	SH. 7
NEEDLER	2370	DISPLAYS (ON FDAI 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	2090	EVALUATES POLYNOMIAL	SH. 11
PREREAD1	2683	CLEARS PIPAS AND INITIALIZES SERVICER	SH. 4
PROUT	2530	CAUSES DELAY UNTIL GYRO TORQUING FINISHED	SH. 5
READACCS	2683	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
V1STO2S	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
AMOONFLG 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 STICK CONTROL; DAPBIT1=1 DAPBIT2=0: TVC DAP IN CONTROL	DAPBIT1=0 DAPBIT2=1: RCS DAP IN CONTROL; BOTH CLEAR: NO DAP IN CONTROL	SH. 19		SH. 10
DAPBIT2 FLAGWRD6 BIT 14			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		
RCSFLAGS BIT 3	FIRST PASS THROUGH NEEDLER	LATER THAN FIRST PASS THROUGH NEEDLER	SH. 4, 17, 20		
REFSMFLG FLAGWRD3 BIT 13	$REFSMMAT_M$ IS VALID GIVES KNOWN ORIENTATION OF STABLE MEMBER	STABLE MEMBER ORIENTATION UNKNOWN	SH. 8		

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PRGMR [illegible]
ANALST
DOCMR [illegible]
APPR'D [illegible]

COLOSSUS IIA FC-2540

REV 1

22 27

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N62	NORMAL SNAPSHOT	R1 XXXXX. FT/SEC VMAGI = (MAGNITUDE OF VELOCITY) R2 XXXXX. FT/SEC HDOT = (RATE OF CHANGE OF ALTITUDE) R3 XXXX.X NM ALT I = (ALTITUDE ABOVE EARTH OR MOON SURFACE, AS APPROPRIATE)	SH. 18

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
AK	$(E_A)_1$	ROLL ATTITUDE ERROR (OR ROLL RATE COMMAND)	DEGREES	REVS	2^{+1}
AK1	$(E_A)_2$	PITCH ATTITUDE ERROR (OR PITCH RATE COMMAND)	DEGREES	REVS	2^{-1}
AK2	$(E_A)_3$	YAW ATTITUDE ERROR (OR YAW RATE COMMAND)	DEGREES	REVS	2^{-1}
$ALTI_D$	H	ALTITUDE OF VEHICLE ABOVE EARTH OR MOON SURFACE, AS APPROPRIATE	M	M	2^{29}
$AVEGEXIT_D$		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^{+1}
BIASAK+1		PITCH ATTITUDE ERROR AT TIME CMC IS PUT IN CONTROL OF SATURN	DEGREES	REVS	2^{-1}
BIASAK+2		YAW ATTITUDE ERROR AT TIME CMC IS PUT IN CONTROL OF SATURN	DEGREES	REVS	2^{-1}
CDUSPOTX		IMU OUTER GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)	DEGREES	REVS	2^0
CDUSPOTY		IMU INNER GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)	DEGREES	REVS	2^0
CDUSPOTZ		IMU MIDDLE GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)	DEGREES	REVS	2^0
CDUX		IMU OUTER GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-1}
CDUY		IMU INNER GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-1}
CDUZ		IMU MIDDLE GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-1}
COSCDUX		COSINE OF IMU OUTER GIMBAL ANGLE			2^1
COSCDUY		COSINE OF IMU INNER GIMBAL ANGLE			2^1

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
COSCDUZ		COSINE OF IMU MIDDLE GIMBAL ANGLE			2^1
DNLSTCOD		INDICATES WHICH LIST OF INFORMATION IS TO BE TRANSMITTED BY DOWNLINK			
$ERCOMP_V$		ROTATION RATE AFFECTING IMU IN STABLE MEMBER COORDINATES	DEG/SEC	REVS/CSEC	2^{21}
$HDOT_D$	$\dot{H}$	RATE OF CHANGE OF ALTITUDE	M/SEC	M/CSEC	2^7
IGC_D		INNER IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE	DEGREES	REVS	2^0
$LAT_V = \begin{pmatrix} LAT_D \\ LONG_D \\ ALT_D \end{pmatrix}$		POSITION SPECIFIED IN TERMS OF LATITUDE, LONGITUDE, ALTITUDE	DEGREES DEGREES M	REVS REVS M	2^0 2^0 2^{29}
$LIFTTEMP_D$		TEMPORARY STORAGE FOR LIFTOFF TIME	SEC	CSEC	2^{28}
MGC_D		MIDDLE IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE	DEGREES	REVS	2^0
OGC_D		OUTER IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE	DEGREES	REVS	2^0
PMANNDX		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			
$REFSMMAT_M$	[REFSMMAT]	TRANSFORMATION MATRIX RELATING STABLE MEMBER AND REFERENCE COORDINATE SYSTEMS			2^1
RLS_V		LUNAR LANDING SITE VECTOR IN REFERENCE COORDINATES	M	M	2^{27}
RMANNDX		INDICATES ZERO, POSITIVE OR NEGATIVE ROLL COMMAND, BY VALUE OF 0, 1 OR 2, RESPECTIVELY			
RN_V	$\underline{R}(T)$	POSITION VECTOR IN REFERENCE COORDINATES	M	M	2^{29}
$RN1_V$	$\underline{R}(T+\Delta T)$	TEMPORARY UPDATED VERSION OF RN_V (ABOVE)	M	M	2^{29}
RTX2		INDICATES WHETHER IN EARTH OR MOON SPHERE OF INFLUENCE, BY VALUE OF 0 OR 2, RESPECTIVELY			

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
SATRLRT	$-SIGN(K_2)K_R$	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}
TBASE5		-LOW-ORDER HALF OF TIME FROM WHICH Δ TIMES FOR GROUP 5 WAITLIST TASK RESTARTS ARE TO BE COUNTED	SEC	CSEC	2^{28}
$TEPHEM_T$	T_{OK}	REFERENCE EPHEMERIS TIME	SEC	CSEC	2^{42}
$TEPHEM1_T$		TEMPORARY UPDATED VERSION OF $TEPHEM_T$ (ABOVE)	SEC	CSEC	2^{42}
$THETAN_V$		STABLE MEMBER DRIFT, ETC. NOT CORRECTED DURING PRELAUNCH IN EARTH-FIXED COORDINATES	DEG/SEC	REVS/CSEC	2^{21}
$TIME2_D = \begin{pmatrix} TIME2 \\ TIME1 \end{pmatrix}$		PRESENT TIME [AFTER LIFTOFF: PRESENT Δ TIME FROM LIFTOFF]	SEC	CSEC	2^{28}
$TLIFTOFF_D$	T'	TIME OF LIFTOFF	SEC	CSEC	2^{28}
$VMAGI_D$	V	MAGNITUDE OF VELOCITY	M/SEC	M/CSEC	2^7
VN_V	$\underline{V}(T)$	VELOCITY VECTOR, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
VNI_V	$\underline{V}(T+\Delta T)$	TEMPORARY UPDATED VERSION OF VN_V (ABOVE)	M/SEC	M/CSEC	2^7
XDC_V		DESIRED STABLE MEMBER X-AXIS IN TERMS OF ORIGINAL STABLE MEMBER ORIENTATION			2^1
XSM_M		MATRIX FOR CONVERSION FROM EARTH-FIXED TO STABLE MEMBER COORDINATE SYSTEM			2^1
YDC_V		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_V		DESIRED STABLE MEMBER Z-AXIS IN TERMS OF ORIGINAL STABLE MEMBER ORIENTATION			2^1
1/PIPADT		Δ TIME BETWEEN PIPA READINGS	SEC	CSEC	2^8

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$-ERTHRAT_D$	$-\omega_E$	-RATE OF EARTH ROTATION	-7.292115138 x 10^{-5} RAD/SEC	-7.292115138 x 10^{-7} RAD/CSEC	2^{-18}
$RPAD_D$	R_{LP}	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
$AZIMUTH_D$	A_{ZP}	AZIMUTH (AT LAUNCH) FROM NORTH TO SPACECRAFT +Z-AXIS	DEGREES	REVS	2^0	
$LATITUDE_D$	LAT_P	LATITUDE OF LAUNCH PAD	DEGREES	REVS	2^0	
$LAUNCHAZ_D$	A_Z	AZIMUTH (AT LAUNCH) FROM NORTH TO STABLE MEMBER +X-AXIS	DEGREES	REVS	2^0	
$PADLONG_D$	LON_P	LONGITUDE OF LAUNCH PAD	DEGREES	REVS	2^0	
$PGNCSALT_D$	ALT_I	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	$-T_{E2}$	-(LENGTH OF TIME DURING WHICH ATTITUDE ERROR IS TO BE COMPUTED)	SEC	CSEC	2^{14}	
RPSTART	T_{E1}	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				

PAD LOADS (CONTINUED)

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
$SATRLRT_D$	K_R	ABSOLUTE VALUE OF NOMINAL SATURN ROLL RATE (SIGN ATTACHED DURING THIS PROGRAM)(SEE ERASABLE SECTION)	1 DEG/SEC	1/36000 REVS/ CSEC	2^0	00000 16441
SATSCALE		SCALING FACTOR FOR ATTITUDE CORRECTION COMMANDS TO SATURN HARDWARE				
$UNITW_V$	$\underline{U}_Z$	UNIT VECTOR IN DIRECTION OF EARTH ROTATION VECTOR (Z) IN REFERENCE COORDINATES	$\begin{pmatrix} -3.32402568949 \times 10^{-6} \\ 4.18407084553 \times 10^{-5} \\ 9.99999998 \times 10^{-1} \end{pmatrix}$	SAME	2^0	(77777 76203, 00000 25740, 37777 37777)

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.

6

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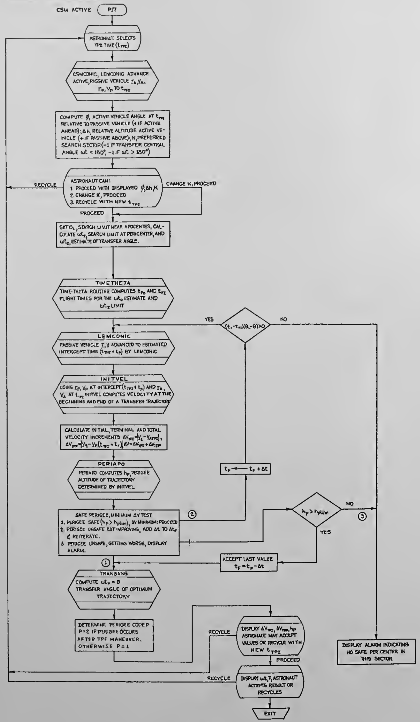
DRAWN	4NOV68	TPI SEARCH PROGRAMS P17 & P77	
PRGMR	15 July 69		
ANALST	14 July 69	COLOSSUS IIC	FC-2545
DOC MR	15 July 69		
APPR'D	15 July 69	REV 1	SHEET 1 OF 18



A.C. WILLIAMS

COLOSSUS IIC

TPI SEARCH PROGRAMS P17 & P77

FC-2545

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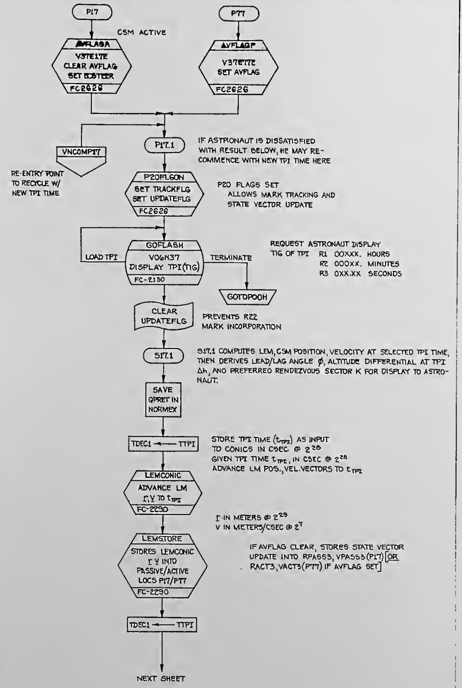

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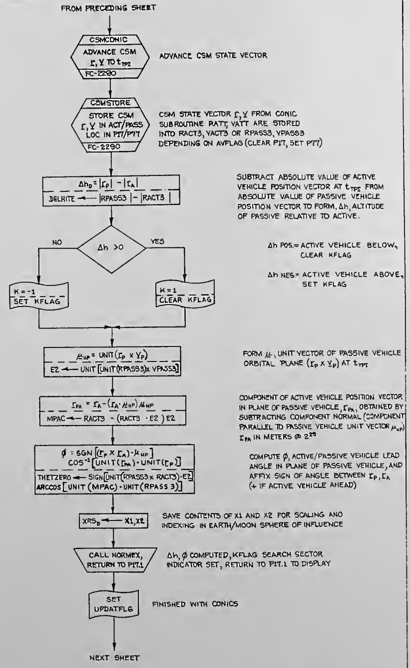

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ANALYST W. Tempelman 14 July 69	COLOSSUS IIC FC-2545
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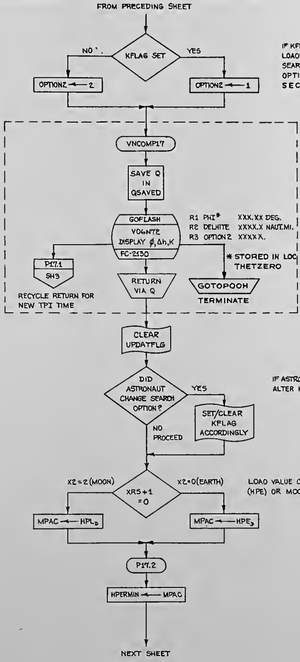
APPR'D [signature] 15 July 69	REV 1 Sheet 4 of 18



IF KFLAG IS SET (K = -1) OPTION2 IS LOADED WITH 1, INDICATING PREFERRED SEARCH SECTOR < 180°. OTHERWISE OPTION 2 = 2, SEARCH SECTOR > 180°

ASTRONAUT HAS THE FOLLOWING OPTIONS:

1. PROCEED, IF SATISFIED WITH ϕ, Δh, K DISPLAYED V33E.
2. TERMINATE, TO END MAJOR MODE, BY V34E.
3. RECYCLE V32E WHICH WILL CAUSE PROGRAM TO RETURN TO P17.1 ABOVE AND REQUEST NEW TPI TIME.

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.

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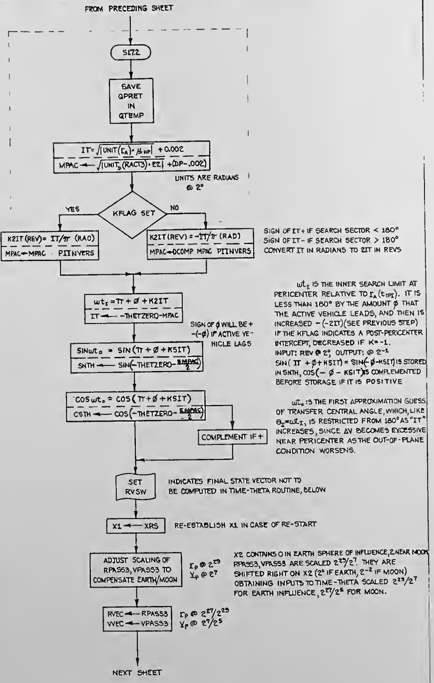
DOC MR [signature]	[illegible]		
APPR'D [signature]	[illegible]	REV 1	SHEET 6 OF 18



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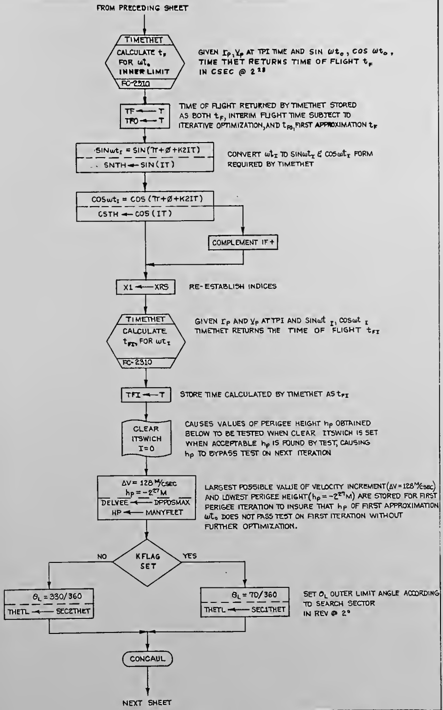

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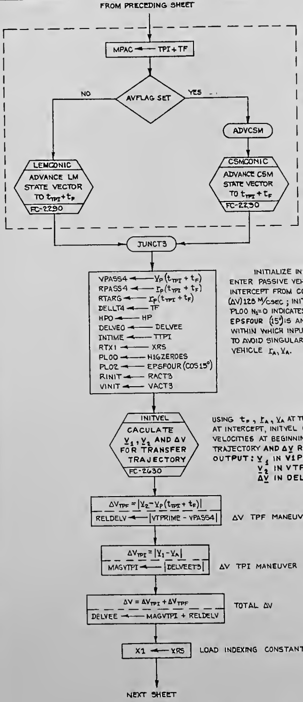

ADD t_F TO t_{TPI} ($t_F = t_{F0}$ ON FIRST PASS)

BRANCH ON AVFLAG TO SELECT PASSIVE VEHICLE

ADVANCE PASSIVE VEHICLE $\underline{r}_P, \underline{V}_P$ TO INITIAL INTERCEPT AIM POINT

INITIALIZE INITVEL

ENTER PASSIVE VEHICLE POSITION AND VELOCITY AT INTERCEPT FROM CONIC ROUTINE, t_F, h_P (-2^{27}M), DELVEE (ΔV) 128 M/CSEC ; INITIALIZE X1 (-2 EARTH, -10 LUNAR); PL00 N_1=0 INDICATES CONIC TRAJECTORY ONLY, NO OFFSETS; EPSFOUR (15°) IS ANGLE OF CONE AROUND 180° TRANSFER WITHIN WHICH INPUT TARGET VECTORS MUST BE ROTATED TO AVOID SINGULARITIES; RACT3, VACT3 ARE PASSIVE VEHICLE $\underline{r}_A, \underline{V}_A$.

USING t_F, $\underline{r}_A$, $\underline{V}_A$ AT TPI AND PASSIVE $\underline{r}_P$, AT INTERCEPT, INITVEL CALCULATES ACTIVE VEHICLE VELOCITIES AT BEGINNING $\underline{V}_1$ AND END $\underline{V}_2$ OF THE TRANSFER TRAJECTORY AND $\Delta \underline{V}$ REQUIRED FOR MANEUVER

OUTPUT: $\underline{V}_1$ IN V1PRIME
$\underline{V}_2$ IN VTPRIME
$\Delta\underline{V}$ IN DELVEET3

ΔV TPF MANEUVER

ΔV TPI MANEUVER

TOTAL ΔV

LOAD INDEXING CONSTANTS

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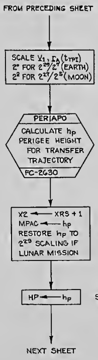
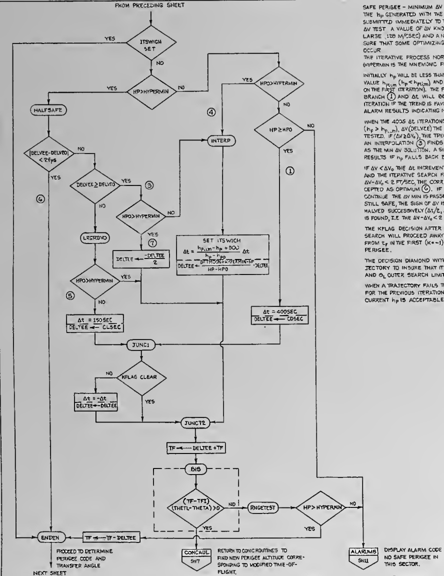


ADJUST SCALING OF TRANSFER TRAJECTORY INITIAL POS., VEL. ON X2 INDEX REGISTER TO OBTAIN CORRECT $2^{29}/2^7$ OR $2^{27}/2^5$ EARTH-MOON SCALING USING X2.

COMPUTES THE PERIGEE HEIGHT h_p BASED ON $\underline{r}_A$, $\underline{V}_1$ FOR THE TRAJECTORY RETURNED BY INITVEL.

h_p MUST BE SCALED 2^{29} IN BOTH EARTH AND MOON SPHERES OF INFLUENCE SO ITS SCALING WILL MATCH THE 2^{29} VALUE OF THE THRESHOLD VALUE hplim IN THE TESTS THAT FOLLOW.

STORE SCALED h_p @ 2^{29} FOR LIMIT TEST.



SAFE PERIGEE - MINIMUM ΔV TEST

THE h_p GENERATED WITH THE INITIAL ωt_o ESTIMATE IS NOT SUBMITTED IMMEDIATELY TO THE SAFE PERIGEE-MINIMUM ΔV TEST A VALUE OF ΔV KNOWN TO BE UNACCEPTABLY LARGE (128 M/CSEC) AND A NEGATIVE h_p ARE USED TO INSURE THAT SOME OPTIMIZING ITERATIVE TESTING WILL OCCUR

THE ITERATIVE PROCESS NORMALLY PROCEEDS AS FOLLOWS: (HYPERMIN IS THE MNEMONIC FOR h_{plim})

INITIALLY h_p WILL BE LESS THAN THE SAFE PERIGEE THRESHOLD VALUE h_{plim} ($h_p < h_{plim}$) AND h_{po} WILL BE ALSO ($h_{po} = h_p = -2^{27}M$ ON THE FIRST ITERATION). THE FLOW WILL THEREFORE FOLLOW BRANCH (1) AND Δt WILL BE INCREMENTED BY 400 SEC EACH ITERATION IF THE TREND IS FAVORABLE ($h_p > h_{po}$), OTHERWISE AN ALARM RESULTS INDICATING NO SAFE PERICENTERS.

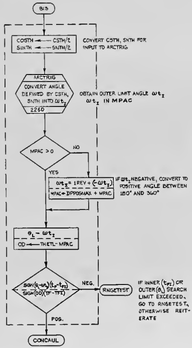
WHEN THE 400S Δt ITERATIONS PRODUCE A SAFE PERIGEE ($h_p > h_{plim}$), ΔV(DELVEE) THE VELOCITY INCREMENT IS TESTED. IF ($\Delta V \geq \Delta V_o$), THE TREND OF ΔV IS UNFAVORABLE AND AN INTERPOLATION (3) FINDS THE SAFE h_p THRESHOLD (+500 FT.) AS THE MIN ΔV SOLUTION. A SIMILAR INTERPOLATIVE SOLUTION RESULTS IF h_p FALLS BACK BELOW THE SAFE VALUE OF h_{po} (4).

IF $\Delta V < \Delta V_o$ THE Δt INCREMENT IS REDUCED TO 150 SEC (5) AND THE ITERATIVE SEARCH FOR MIN ΔV CONTINUED. IF $\Delta V - \Delta V_o < 2$ FT/SEC, THE CORRESPONDING h_p AND t_f ARE ACCEPTED AS OPTIMUM (6). IF AS THE 150 SEC INCREMENTS CONTINUE THE ΔV MIN IS PASSED ($\Delta V > \Delta V_o$), BUT h_p AND h_{po} ARE STILL SAFE, THE SIGN OF ΔV IS CHANGED (7) AND ITS VALUE HALVED SUCCESSIVELY (Δt/2, Δt/4 - - ETC.) UNTIL THE MINIMUM IS FOUND, I.E THE $\Delta V - \Delta V_o < 2$ FT/SEC TEST IS PASSED.

THE KFLAG DECISION AFTER JUNCT2 DETERMINES THAT THE SEARCH WILL PROCEED AWAY FROM PERIGEE: Δt SUBTRACTED FROM t_f IN THE FIRST (K=-1) SEARCH SECTOR, ADDED POST-PERIGEE.

THE DECISION DIAMOND WITH THE TAG BIS TESTS EACH TRAJECTORY TO INSURE THAT IT FALLS BETWEEN THE t_{fI} INNER AND θ_L OUTER SEARCH LIMITS.

WHEN A TRAJECTORY FAILS THE t_{fI}/θ_L LIMIT TEST, THE VALUE FOR THE PREVIOUS ITERATION IS ACCEPTED ($t_f - \Delta t$) IF THE CURRENT h_p IS ACCEPTABLE



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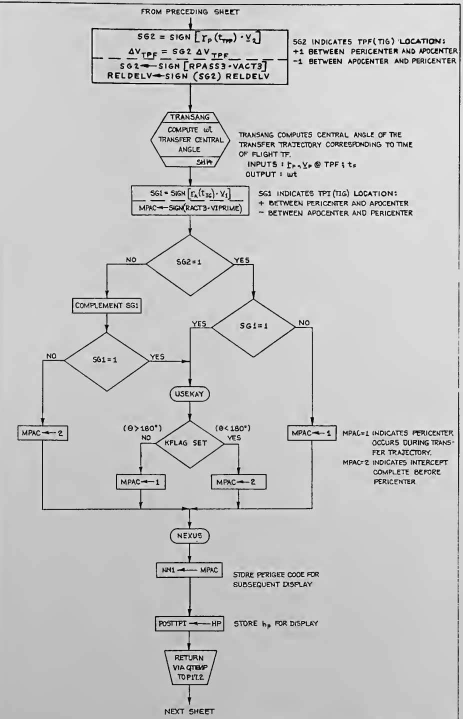

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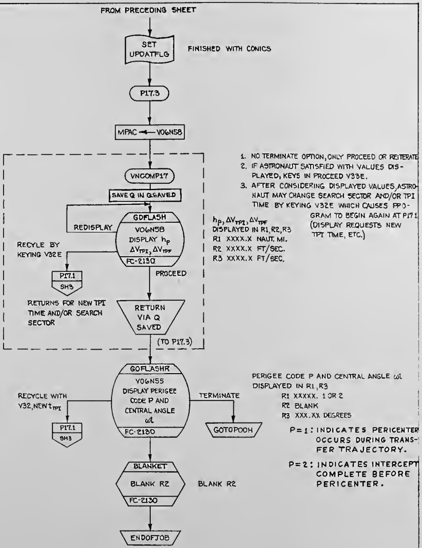

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DRAWN A.C.WILLIAMS	1MAY69	TPI SEARCH PROGRAMS P17 & P77
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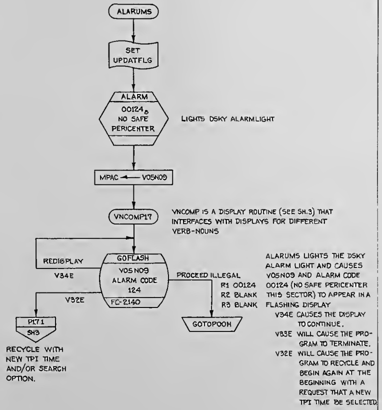
DOCMR [signature]	[illegible]	
APPR'D [signature]	[illegible]	REV 1 — SHEET 12 OF 18



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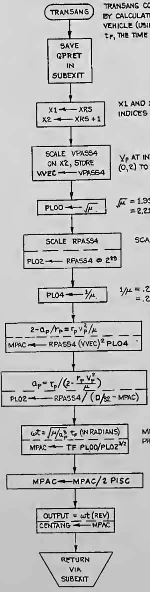
DOCMR	15 July 69	
APPR'D	15 July 69	REV 1 — SHEET 15 OF 18



TRANSANG COMPUTES THE CENTRAL ANGLE OF TRANSFER BY CALCULATING ω, THE ANGULAR VELOCITY OF THE PASSIVE VEHICLE (USING $\underline{r}_P$ AND $\underline{V}_P$ AT INTERCEPT) AND MULTIPLYING BY t_F, THE TIME OF FLIGHT.

X1 AND X2 LOADED WITH ADDRESSING AND SCALING INDICES FOR EARTH OR MOON

	X1	X2
EARTH	-2	0
MOON	-10	2

$\underline{V}_P$ AT INTERCEPT SCALED ON X2 (0,2) TO OBTAIN $2^5/2^7$ SCALING

$\sqrt{\mu} = 1.99650495 \times 10^5$ @ 2^{18} IF EARTH,
$= 2.21422176 \times 10^4$ @ 2^{15} IF MOON

SCALE $\underline{r}_P$ TO 2^{27} BY SHIFTING ON X2

$1/\mu = .25087606 \times 10^{-10}$ @ 2^{34} IF EARTH
$= .203966 \times 10^{-8}$ @ 2^{28} IF MOON

a_P IS THE SEMI-MAJOR AXIS OF THE ELLIPSE

MEAN ANGULAR VELOCITY IS INVERSELY PROPORTIONAL TO $a_P^{3/2}$

CONVERT TO REVOLUTIONS BY DIVIDING BY 2PISC
2PISC = 6.28318530 @ 2^{-6}

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SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
AVFLAGA	2630	CLEARS AVFLAG, SETS ECSTEER BIT 13	SH. 3
AVFLAGP		SETS AVFLAG	SH. 3
P20FLGON	2550	SETS TRACKFLAG, UPDATEFLAG	SH. 3
LEMCONIC	2290	ADVANCES LM $\underline{r}$, $\underline{v}$ 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 $\underline{r}$, $\underline{v}$ TO SPECIFIED TIME, t_{TPI}	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 $\underline{r}_A$, $\underline{v}_A$ AND TERMINAL $\underline{r}_P$, $\underline{v}_P$ OF TRANSFER TRAJECTORY	SH. 7(2)
INITVEL	2630	USING $\underline{r}_A$, $\underline{v}_A$ AT t_{TPI} AND $\underline{r}_P$, $\underline{v}_P$ AT $t_{TPI}+t_P$ INITVEL COMPUTES $\underline{v}_1$, $\underline{v}_2$, 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°	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

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V08N37	GOFLASH	TPI TIME IN R1 OOXXX. HOURS R2 OOOXX. MINUTES R3 OXX.XX SECONDS	SH.3
V06N72	GOFLASH	R1 PHI XXX.XX DEG ACTIVE VEHICLE LEAD ANGLE R2 BELHITE XXXX.X NM PASSIVE VEHICLE ALT. RELATIVE ACTIVE (+ ABOVE) R3 OPTION2 XXXXX. SEARCH SECTOR 1=<180°, 2=>180°	SH.5
V06N58	GOFLASH	R1 hp XXXX.X NM PERIGEE HEIGHT R2 ΔV_{TPI} XXXX.X FT/SEC VELOCITY INCREMENT IMPARTED AT t_{TPI} R3 ΔV_{TPF} XXXX.X FT/SEC VELOCITY DIFFERENTIAL AT INTERCEPT	SH 12
V06N55	GOFLASHR	R1 XXXXX. P (PERICENTER CODE) P = 1 TRANSFER COMPLETED BEFORE PERICENTER R2 BLANK R3 XXX.XX DEGREES P = 2 TRANSFER TRAJECTORY SPANS PERICENTER	SH. 12
V05N09	ALARM	R1 00124 DISPLAYS 124 ALARM CODE IN R1 INDICATING NO SAFE PERICENTER THIS SECTOR R2 BLANK R3 BLANK	SH 13

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TTPI	t_{TPI}	STORAGE LOC FOR TPI TIME	SEC	CSEC	2^{28}
TDEC1		STORAGE LOC FOR TIME INPUT TO CONICS	SEC	CSEC	2^{28}
RPASS3	$\underline{r}_P(t_{TPI})$	PASSIVE VEHICLE POSITION AT TPI (TIG)	NM	M	$2^{29}/2^{27}$
VPASS3	$\underline{v}_P(t_{TPI})$	PASSIVE VEHICLE VELOCITY AT TPI (TIG)	NM	M/CSEC	$2^{7}/2^{5}$
RACT3	$\underline{r}_A(t_{TPI})$	ACTIVE VEHICLE POSITION AT TPI (TIG)	NM	M	$2^{29}/2^{27}$
VACT3	$\underline{v}_A(t_{TPI})$	ACTIVE VEHICLE VELOCITY AT TPI (TIG)	NM	M/CSEC	$2^{7}/2^{5}$
DELHITE	Δh	ACTIVE-TO-PASSIVE VEHICLE ALTITUDE	NM	M	$2^{29}/2^{27}$
E2	μ_{HP}	UNIT VECTOR OF PASSIVE VEHICLE ORBITAL PLANE	UNITLESS FRACTION		2^{1}
THETZERO	ϕ	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	
HPERMIN	hplim	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 Θ_I & Θ_o COMPUTATION	RAD		2^{0}

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
SNTH CSTH		STORAGE LOCS IN SIN, COS FORM REQUIRED FOR $\Theta_o[wt_o]$ AND $\Theta_I[wt_I]$ INPUT TO TIMETHET			2^{+1} 2^1
TF	t_F	FLIGHT TIME FOR INTERCEPT TRAJECTORY	CSEC	2^{28}	2^{28}
TF0	t_{F0}	FLIGHT TIME FOR FIRST APPROXIMATION t_F	CSEC	2^{28}	2^{28}
TFI	t_{FI}	FLIGHT TIME FOR INNER LIMIT (wt_I) t_F	CSEC	2^{28}	2^{28}
DELVEE	ΔV	VELOCITY INCREMENT REQUIRED FOR TRANSFER	M/SEC	M/CSEC	2^7
HP	h_p	PERICENTER HEIGHT	NM	M	2^{29}
VPASS4	$\underline{v}_p(t_{TPI}+t_F)$	PASSIVE VEHICLE VELOCITY VECTOR AT INTERCEPT	M/SEC	M/CSEC	2^7
RPASS4	$\underline{r}_p(t_{TPI}+t_F)$	PASSIVE VEHICLE POSITION VECTOR AT INTERCEPT	NM	M	2^{29}
RTARG	$\underline{r}_T$	PASSIVE VEHICLE POSITION VECTOR AT INTERCEPT		M	2^{29}
HPO	h_{po}	MINIMUM SAFE h_p (HPERMIN, SEE ABOVE)	FT(MOON)/ NM(EARTH)	M	$2^{24}/2^{27}$
DELVEO	ΔV_o	VELOCITY INCREMENT TO ACHIEVE wt_o TRAJECTORY	M/SEC	M/CSEC	2^7
INTIME	t_{TPI}	TEMP LOC FOR t_{TPI} INPUT TO INITVEL	SEC	CSEC	2^{28}
XRS		TEMP LOC FOR INDEX REG STORAGE	—	—	—
RINIT	$\underline{r}_A(t_{TPI}+t_F)$	STORAGE FOR ACTIVE VEHICLE POSITION (INITVEL)	M	M	2^{29}
VINIT	$\underline{v}_A(t_{TPI}+t_F)$	STORAGE FOR ACTIVE VEHICLE VELOCITY (INITVEL)	M/SEC	M/CSEC	2^7
RELDELV	ΔV_{TPF}	ACTIVE-PASSIVE VELOCITY DIFFERENTIAL AT INTERCEPT	FT/SEC	M/CSEC	2^7
MAGVTPI	ΔV_{TPI}	ACTIVE-PASSIVE VELOCITY DIFFERENTIAL AT t_{TPI}	FT/SEC	M/CSEC	2^7
NNI		STORAGE LOC FOR PERIGEECODE	—	—	—
POSTTPI		LOC FOR OUTPUT h_p (TO BE DISPLAYED)	FT		2^{29}
RVEC	$\underline{r}_P(t_{TPI}+t_F)$	STORAGE LOC FOR PASSIVE VEHICLE POSITION VECTOR @ INTERCEPT	–	M	$2^{29}/2^{27}$
VVEV	$\underline{v}_P(t_{TPI}+t_F)$	STORAGE LOC FOR PASSIVE @ INTERCEPT VEHICLE VELOCITY	–	M/CSEC	$2^7/2^5$

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
HPE	h_{po}	EARTH } MINIMUM PERICENTER ALTITUDE	85 NM	157420.0M	2^{29}
HPL		MOON } MINIMUM PERICENTER ALTITUDE	35,000 FT	10668.0 M	2^{29}
CDSEC	Δt	t INCREMENTS FOR SAFE h_p TEST	400 SEC	40000 CSEC	2^{28}
CLSEC		t INCREMENTS FOR MIN ΔV TEST		15000 CSEC	2^{28}
PIINVERS		$1/\pi$ (USED FOR SCALING)	—	.3183098862	—
SEC1THET	θ_L	OUTER SEARCH LIMIT 70^o IF K=-1	—	1944444444	2^0
SEC2THET		OUTER SEARCH LIMIT 330^o IF K=+1	—	9166666667	2^0
MANYFEET		LARGE VALUE OF h_p CHOSEN FOR h_p TEST	—	-2^{27}M	2^2
LIMVEL		THRESHOLD FOR ΔV- ΔVo MINIMUM TEST	2 FPS	M	$10^{-2} \times 10^7$
DFTMOON		MARGIN TO ALLOW FOR UNCERTAINTY IN MOON POSITION	500 FT	192 M	2^{29}
2PISC	2π	CONSTANT FOR RADIANS-TO-DEGREES SCALING	6.28318530	6.28318530	2^{-6}
MUTABLE+2,1	$\sqrt{\mu}$	SQUARE ROOT OF UNIVERSAL GRAVITY CONSTANT		EARTH. 1.99650495×10^5 MOON. 2.21422176×10^4	2^{18} 2^{15}
MUTABLE,1	$1/\mu$	RECIPROCAL OF UNIVERSAL GRAVITY CONSTANT		EARTH: $.25087606 \times 10^{-10}$ MOON: $.203966 \times 10^{-8}$	2^{34} 2^{28}

MIT INSTRUMENTATION LAB CAMBRIDGE MASS

DRAWN 4NOV68
PROG'D 15July69
ENG. 14July69
DOC.MR 15July69
APPR'D

TPI SEARCH PROGRAM P17 & P77

COLOSSUS IIC FC-2545

REV 1 18 18

RENDEZVOUS NAVIGATION PACKAGE

THE FOLLOWING PROGRAMS AND THEIR RELATED SUBROUTINES WILL BE FOUND IN THIS FLOW CHART.

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 SCALINGS OR A TEMPORARY REGISTER WITH MANY DIFFERENT SCALINGS.

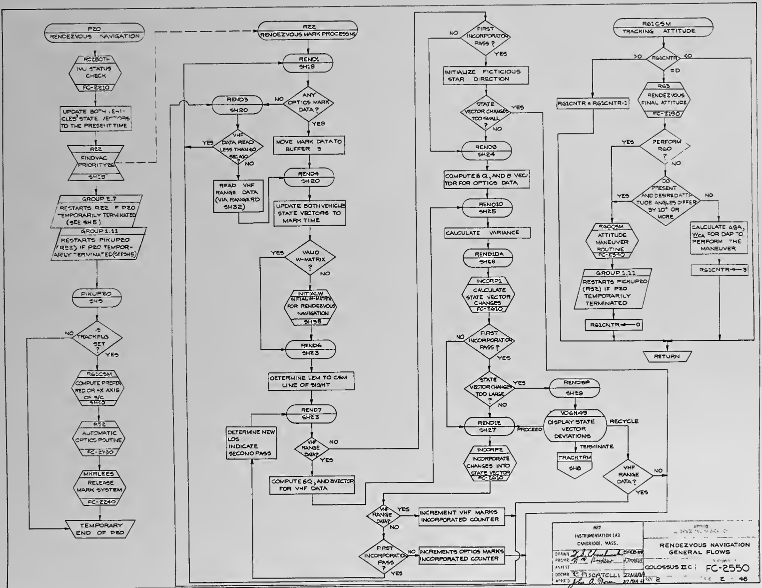
3) THE SYMBOL '#' INDICATES INDIRECT ADDRESSING
I.E., ABLE # X1 MEANS ABLE IS INDIRECTLY ADDRESSED BY X1

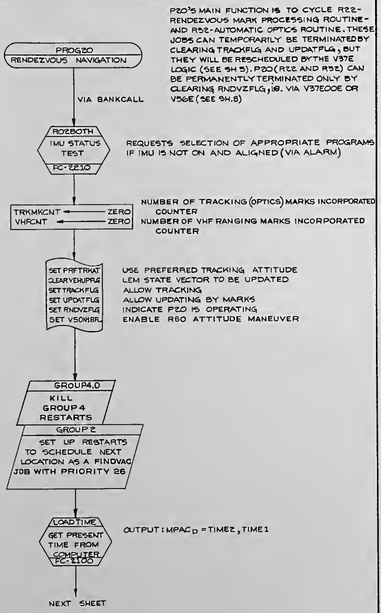
NOTE IF THE QUANTITY TO THE RIGHT OF THE '#' SIGN IS X1 OR X2, THEN THESE ARE SUBTRACTED FROM THE QUANTITY ON THE LEFT OF THE '#' SIGN TO FORM THE ADDRESS.

IF THE QUANTITY TO THE RIGHT OF THE '#' SIGN IS NOT XI 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.

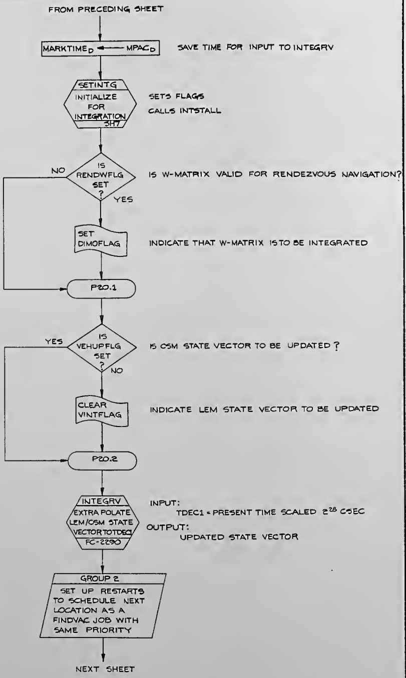
ENCLOSED ARE REPLACEMENT SHEETS TO CORRECT THE COLOSSUS IIA FLOW CHART FC-2550, REV. 1, TO THE COLOSSUS IIC FLOW CHART FC-2550, REV. 2. THE FOLLOWING SHEETS HAVE BEEN CHANGED: 3, 10, 16, 41, 45.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN Z. S. Chmielewski 27JAN69	RENDEZVOUS NAVIGATION
PRGMR N. W. Brooks 27MAR69	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2550
DOCMR R. FISCATELLI 27MAR69	
APPR'D John A. Moss 27MAR69	REV 2 — SHEET 1 OF 46


P20
RENDEZVOUS NAVIGATION
R22BOTH
IMU STATUS CHECK
FC-2210
UPDATE BOTH VEHICLES' STATE VECTORS TO THE PRESENT TIME
R22
FINDVAC PRIORITY26
SH19
GROUP 2.7
RESTARTS R22 IF P20 TEMPORARILY TERMINATED (SEE SH5)
GROUP 1.11
RESTARTS PIKUP20 (R52) IF P20 TEMPORARILY TERMINATED(SEESH5)
PIKUP20
SH5
IS TRACKFLG SET ?
NO
YES
R61CSM
COMPUTE PREFERRED OR +X AXIS OF S/C
SH10
R52
AUTOMATIC OPTICS ROUTINE
FC-2730
MKRLEES
RELEASE MARK SYSTEM
FC-2240
TEMPORARY END OF P20
R22
RENDEZVOUS MARK PROCESSING
REND1
SH19
ANY OPTICS MARK DATA ?
REND3
SH20
VHF DATA READ LESS THAN 60 SEC AGO ?
READ VHF RANGE DATA (VIA RANGERD SH32)
MOVE MARK DATA TO BUFFER B
REND4
SH20
UPDATE BOTH VEHICLES STATE VECTORS TO MARK TIME
VALID W-MATRIX ?
INITIALW
INITIAL W-MATRIX FOR RENDEZVOUS NAVIGATION
SH38
REND6
SH23
DETERMINE LEM TO CSM LINE OF SIGHT
REND7
SH23
DETERMINE NEW LOS INDICATE SECOND PASS
VHF RANGE DATA?
COMPUTE δQ, AND B VECTOR FOR VHF DATA
VHF RANGE DATA?
INCREMENT VHF MARKS INCORPORATED COUNTER
FIRST INCORPORATION PASS ?
INCREMENTS OPTICS MARKS INCORPORATED COUNTER
FIRST INCORPORATION PASS ?
INITIALIZE FICTICIOUS STAR DIRECTION
STATE VECTOR CHANGES TOO SMALL ?
REND9
SH24
COMPUTE δQ, AND B VECTOR FOR OPTICS DATA
REND10
SH25
CALCULATE VARIANCE
REND10A
SH26
INCORP1
CALCULATE STATE VECTOR CHANGES
FC-2610
FIRST INCORPORATION PASS ?
STATE VECTOR CHANGES TOO LARGE ?
RENDISP
SH29
V06N49
DISPLAY STATE VECTOR DEVIATIONS
RECYCLE
PROCEED
TERMINATE
TRACKTRM
SH8
REND12
SH27
INCORP2
INCORPORATE CHANGES INTO STATE VECTOR
FC-2610
VHF RANGE DATA ?
R61CSM
TRACKING ATTITUDE
R61CNTR
>0
=0
<0
R61CNTR = R61CNTR-1
R63
RENDEZVOUS FINAL ATTITUDE
FC-2190
PERFORM R60 ?
DO PRESENT AND DESIRED ATTITUDE ANGLES DIFFER BY 10° OR MORE
R60CSM
ATTITUDE MANEUVER ROUTINE
FC-2340
GROUP 1.11
RESTARTS PICKUP20 (R52) IF P20 TEMPORARILY TERMINATED
R61CNTR ← 0
CALCULATE ΔGA, Wca FOR DAP TO PERFORM THE MANEUVER
R61CNTR ← 3
RETURN
YES
NO
MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.
DRAWN
PRGMR
ANLST
DOCMR R. PISCATELLI 27MAR69
APPRD
RENDEZVOUS NAVIGATION GENERAL FLOWS
COLOSSUS II C
FC-2550
REV 2
2 · 46



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D. S. Chmielewski CHANGED	RENDEZVOUS NAVIGATION P20
PROGMR N. W. Brodeur 27MAR69	
ANALYST	
DOC MGR R. PISCATELLI 27MAR69	COLOSSUS IIC — DOCUMENT NO. FC-2550
APPROVED John A. Moss 27MAR69	REV 2 — SHEET 3 OF 46



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

APOLLO GUIDANCE AND NAVIGATION

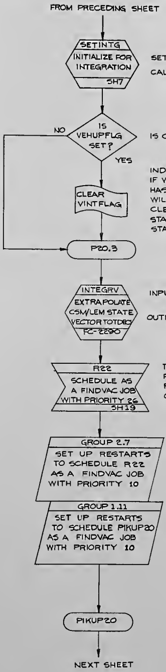
RENDEZVOUS NAVIGATION P20

COLOSSUS IIC

FC-2550

REV 2

SHEET 4 OF 46



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

INPUT:

TDEC1 = PRESENT TIME SCALED 2^{28} CSEC

OUTPUT:

UPDATED STATE VECTOR

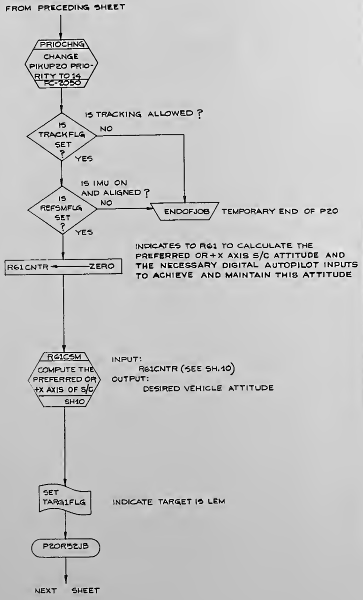
THIS IS THE RENDEZVOUS MARK PROCESSING ROUTINE. IT CHECKS FOR OPTICS MARKS OR VHF RANGE DATA EVERY 4 SEC. IT WILL TERMINATE ONLY IF TRACKFLG AND UPDATFLG ARE CLEARED.

NOTE:

THESE TWO RESTARTS WILL CAUSE R22 AND R52 (VIA PIKUP20) TO START RUNNING (IF THEY HAVE BEEN TEMPORARILY TERMINATED) WHEN A V37E XXE 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 GSOP 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 1/2 SEC DELAY, IE. DURING THE TIME THESE TWO OVERLAP THE MAJOR MODE CAN OPERATE.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN T. J. Chmielinski 20JAN69	RENDEZVOUS NAVIGATION P20
PRGMR N. M. Brodeur 27MAR69	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2550
DOCMR R. PISCATELLI 27MAR69	
APPR'D John A. Moore 27 MAR 69	REV 2 — SHEET 5 OF 46



MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

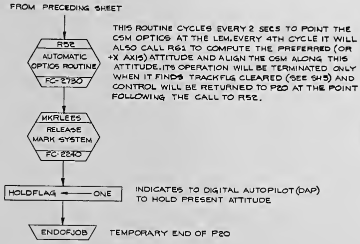
DRAWN T. S. Chmielewski 29 JAN 69
PROGMR R. W. Brodhue 27 MAR 69
ANALYST
DOCMR R. PISCATELLI 27 MAR 69
APPR'D John A. Moore 29 MAR 69

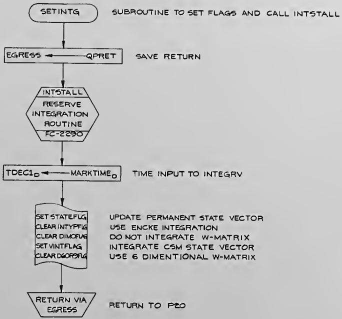
RENDEZVOUS NAVIGATION P20

COLOSSUS IIC FC-2550

REV 2

SHEET 6 of 46





MIT INSTRUMENTATION LAB, CAMBRIDGE, MASS.

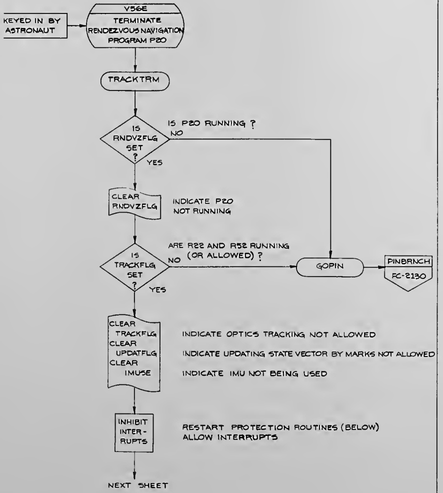
APOLLO GUIDANCE AND NAVIGATION

DRAWN	D. B. Chmielinski	29JAN69
CHECKED	R. W. Brodeur	27MAR69
ANALYST		
DOCMR	R. PISCATELLI	27MAR69
APPR'D	John A. Moore	27MAR69

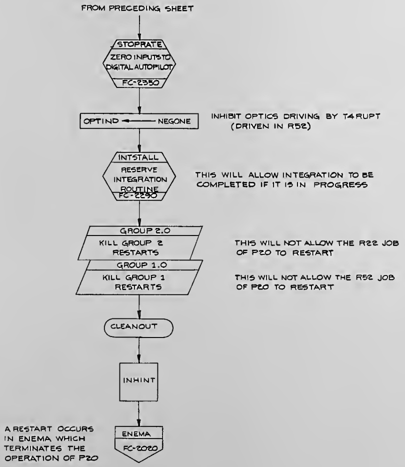
RENDEZVOUS NAVIGATION P20

COLOSSUS IIC — REV 2

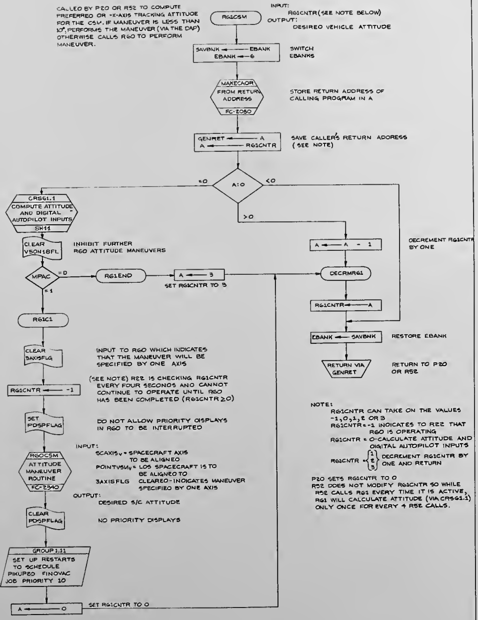
DOCUMENT NO. FC-2550



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	GUIDANCE AND NAVIGATION
DRAWN Z.S. Chmiglinski 5FEB69	RENDEZVOUS NAVIGATION V56E
PROGMR N.W. Brooker 27Mar69	
ANAL	
DOCMR R. PISCATELLI 27MAR69	COLOSSUS IIC — DOCUMENT NO. FC-2550
APPR'D John A. Moore 28 MAR 69	REV R — 8 OF 48



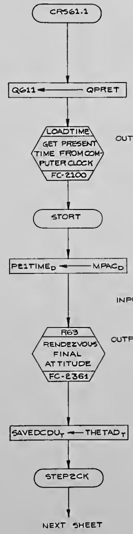
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	RENDEZVOUS NAVIGATION V56E
PROGMR 27 Mar 69	COLOSSUS IIC — DOCUMENT NO. FC-2550
ANALYST	
DOCMR B. PISCATELLI 27MAR69	REV 2
APPR'D John A. Moore 27MAR69	SHEET 9 OF 46



RENDEZVOUS NAVIGATION R61

COLOSSUS IIC FC-2550

2 10 46



INPUT:
CDUX, CDUY, CDUZ = IMU GIMBAL ANGLES SCALED 2^1 REVS PRFTRKAT, STIKFLAG, R60FLAG

OUTPUT:
MPAC = CALL R60 INDICATOR: 1 = YES, 0 = NO
CDUXD, CDUXD, CDUZD = DESIRED IMU GIMBAL ANGLES SCALED 2^1 REVS
$WBODY_V$ = DESIRED LOS ATTITUDE RATE SCALED 5/4 REVS/SEC
$DELCDUX_V$ = INCREMENTAL IMU GIMBAL CHANGES SCALED 2^1 REVS
HOLDFLAG = DIGITAL AUTOPILOT (DAP) MANEUVER INDICATOR

SAVE RETURN

OUTPUT:
$MPAC_D$ = TIME2, TIME1 SCALED 2^{28} CSEC

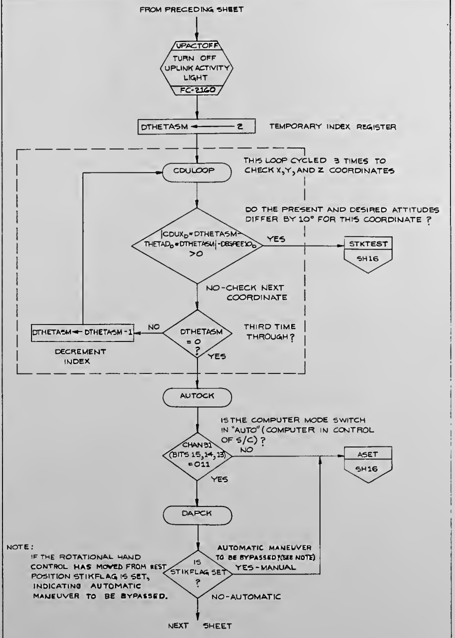
STORE TIME FOR INPUT TO R63

INPUT:
P21TIME = TIME SCALED 2^{28} CSEC
PRFTRKAT = S/C AXIS FLAG
0 = +X-AXIS 1 = PREFERRED AXIS

OUTPUT:
$THETAD_T$ = DESIRED GIMBAL ANGLES TO POINT S/C AXIS AT LEM (IGA, MGA, OGA) SCALED 2^1 REVS
$SCAXIS_V$ = DESIRED S/C AXIS UNIT VECTOR SCALED 2^1
$SAVEPOS_V$ = LOS VECTOR TO LEM (UNIT($R_L - R_C$)) SCALED 2^1
$P21TIME_D$ = |LOS| ($|R_L - R_C|$) SCALED 2^{29} METERS
$SAVEVEL_V$ = CSM VELOCITY (V_C) SCALED 2^7 METERS/CSEC
$DCDU_V$ = LEM VELOCITY (V_L) SCALED 2^7 METERS/CSEC

SAVE IMU GIMBAL ANGLES IGA, MGA, AND OGA

MIT INSTRUMENTATION LAB CAMBRIDGE MASS	APOLLO GUIDANCE AND NAVIGATION
DRAWN T. J. Chmielinski 27FEB69	RENDEZVOUS NAVIGATION R61
PRGMR R. N. Brodeur 27Mar69	COLOSSUS II C
ANALYST	DOCUMENT NO. FC-2550
SUPVR R. PISCATELLI 27MAR69	REV 2
APPR'D John A. Moore 27MAR 69	SHEET 11 OF 48



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

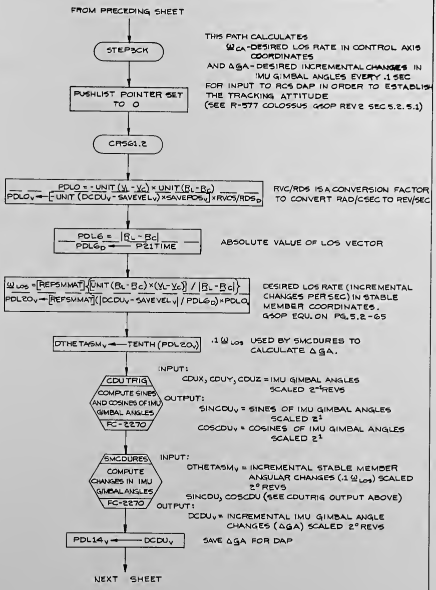
DRAWN: [signature] 7FEB69
PREPARED: M. W. Bradlow 27 Mar 69
CHECKED: R. MISCATELLI 27MAR69
APPROVED: John A. Moore 28MAR69

RENDEZVOUS NAVIGATION R61

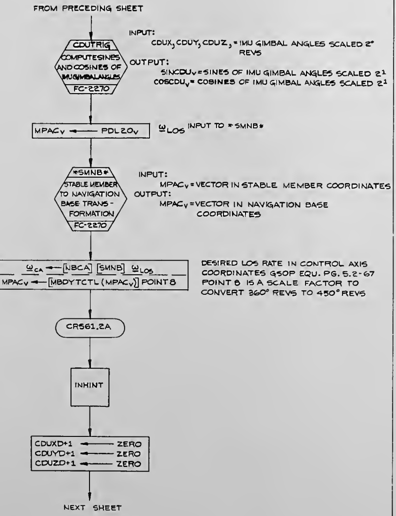
COLOSSUS IIC — FC-2550

REV 2

12 46



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D.S. Chmielewski 7 FEB 69	RENDEZVOUS NAVIGATION R61
PROGR N.M. Brothers 27 Mar 69	COLOSSUS II C
ANAL	DOCUMENT NO. FC-2550
PROGR R. PISCATELLI 27 MAR 69	REV 2
APPRO John A. Moore 29 MAR 69	SHEET 13 OF 46



MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN 21 FEB 69
PRGMR 27 Mar 69
ANALST
DOCMP R. PISCATELLI 27 MARCH
APPR'D 27 Mar 69
REV 2

RENDEZVOUS NAVIGATION R61

COLOSSUS IIC

FC-2550

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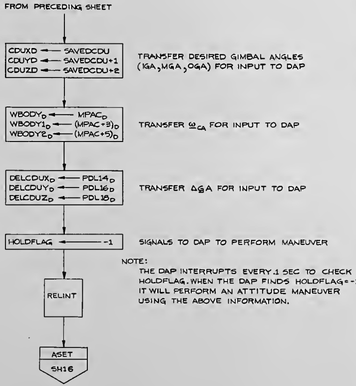
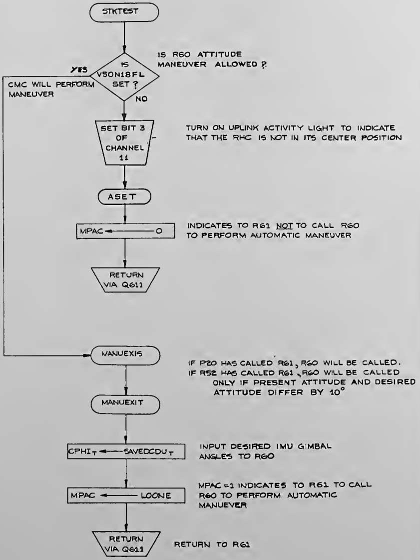
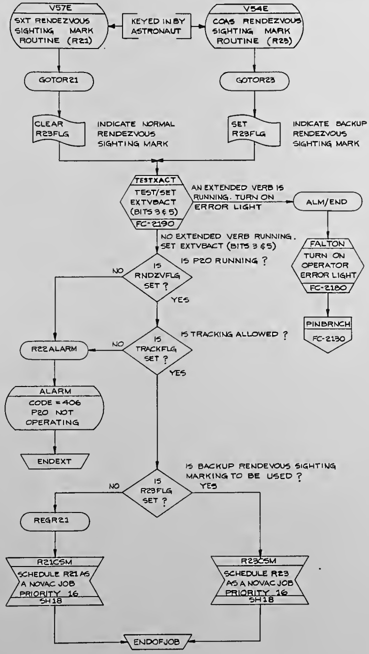


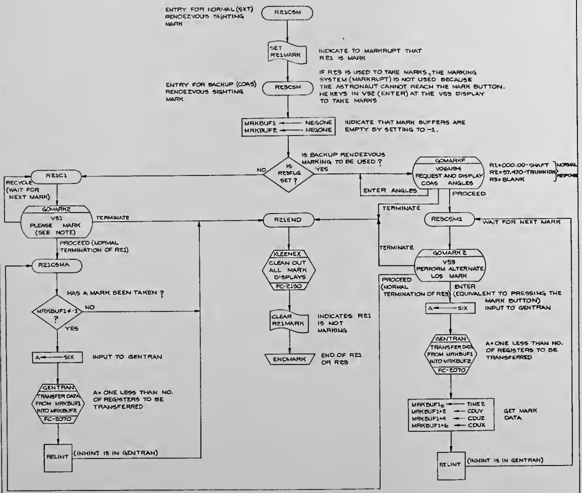
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 11FEB69	RENDEZVOUS NAVIGATION R61
PRGMR 27MAR69	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2550
DOCMR E. FISCATELLI 27MAR69	
APPR'D John A. Mone 27MAR69	REV 2 — SHEET 15 OF 46



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	RENDEZVOUS NAVIGATION R61
DRAWN Z. S. Chmielinski 12FEB69	
PRGMR N. W. Brodeur 27MAR69	
ANALST	COLOSSUS IIC FC-2550
DSGNR R. PISCATELLI 27MAR69	
APPR'D John A. Moore 27MAR69	REV 2 SHT 16 OF 48



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN Z. J. Chaplinski 12FEB69	RENDEZVOUS NAVIGATION R21, R23
PRGMR M. W. Brooks 27MAR69	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2550
DOCMR R. PISCATELLI 27MAR69	
APPR'D John A. Moore 27MAR69	REV 2 — SHEET 17 OF 46



NOTE:
WHEN MARK BUTTON IS PRESSED, R21 IS INTERRUPTED AND MARKRUPT ENTERED TO MOVE (7 REGISTERS) MRKBUF1 INTO MRKBUF2 AND THEN MKT2 +1 INTO MRKBUF1.
THIS RESULTS IN:

MRKBUF1 ← TIME2
MRKBUF1+1 ← TIME1
MRKBUF1+2 ← CDUY
MRKBUF1+3 ← CDUS
MRKBUF1+4 ← CDUZ
MRKBUF1+5 ← CDUT
MRKBUF1+6 ← CDUX

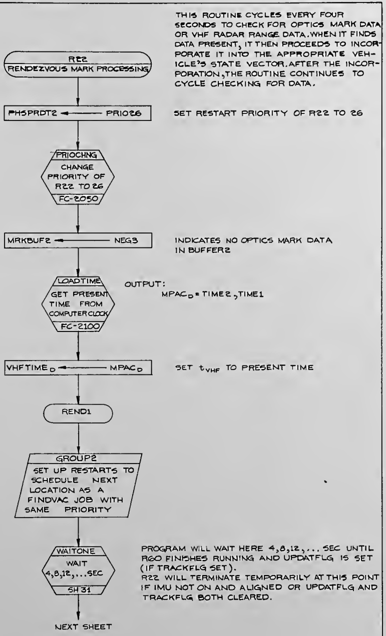
RENDEZVOUS NAVIGATION R21, R23

COLOSSUS II C

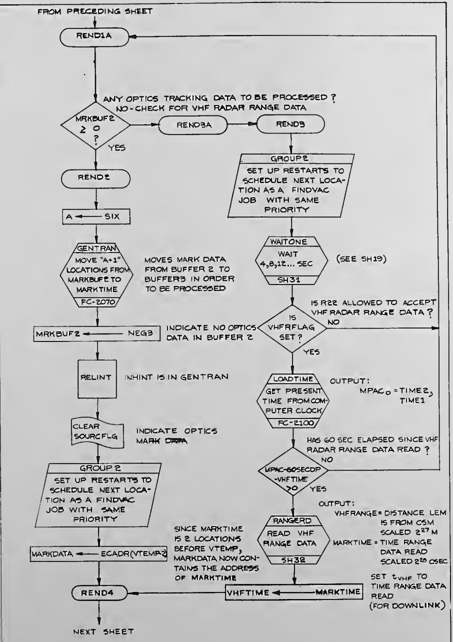
FC-2550

2

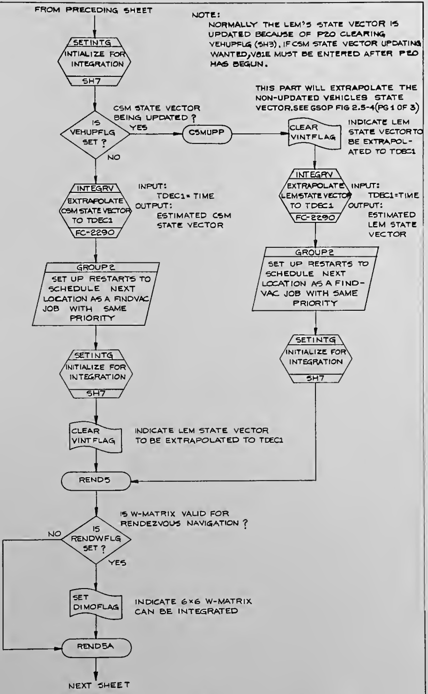
18 of 48



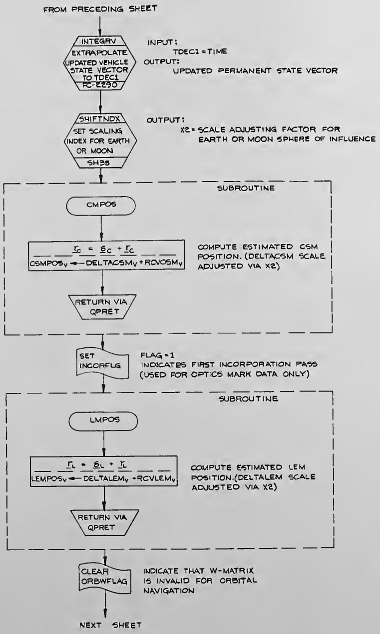
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 26 FEB 69	RENDEZVOUS NAVIGATION R22
PRI MR [signature] 27 MAR 69	
ANALST	COLOSSUS II C — DOCUMENT NO. FC-2550
DOC MR R. PISCATELLI 27 MAR 69	
APPR'D [signature] 27 MAR 69	REV 2 — SHEET 19 OF 46



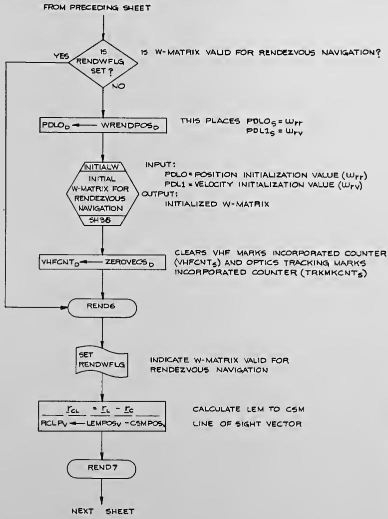
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 24 FEB 69	RENDEZVOUS NAVIGATION R22
PROMR 27 Feb 69	
ANALST	COLOSSUS IIC — DOCUMENT NO FC-2550
DOCMR R. PISCATELLI 27 MAR 69	
APPR'D John A. Moss 27 MAR 69	REV 2 — SHEET 20 OF 46



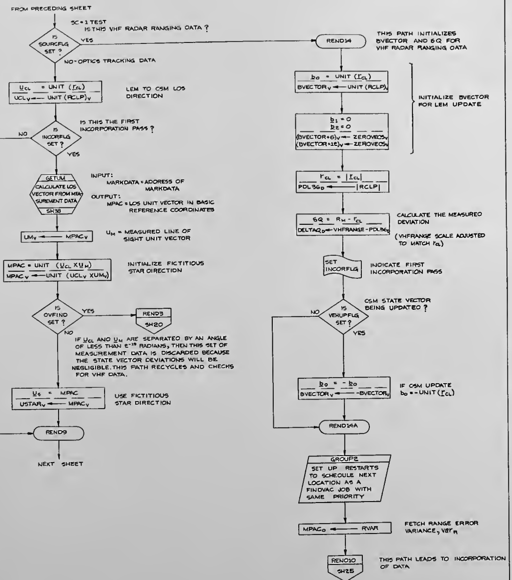
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN 2. J. Chuglinski 24 FEB 69	RENDEZVOUS NAVIGATION R22	
PRGMR M. W. Brooks 27 MAR 69		
ANALYST	COLOSSUS II C	DOCUMENT NO. FC-2550
DOCMR R. PICCATELLI 27 MAR 69		
APPR'D John A. Moore 27 MAR 69	REV 2	SHEET 21 OF 46



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 28 FEB 69	RENDEZVOUS NAVIGATION R22
CHECKED [signature] 27 MAR 69	
ANALYST	COLOSSUS IIC — FC-2550
DOCMR R. PISCATELLI 27MAR69	
APPR'D [signature] 27 MAR 69	REV 2 — SHEET 22 OF 46



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN: T. S. Chmielinski, 20 FEB 69	RENDEZVOUS NAVIGATION R22
PRGMR: N. Brodeur, 27 MAR 69	
ANALYST	COLOSSUS II C
DOCMR: R. PISCATELLI, 27 MAR 69	DOCUMENT NO. FC-2550
APPR'D: John A. Moss, 28 MAR 69	REV 2 — SHEET 23 OF 46

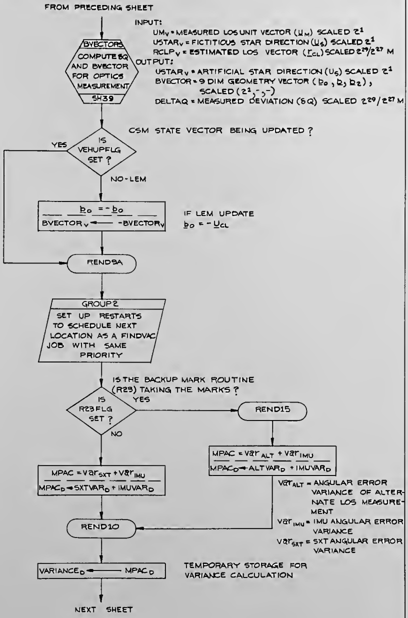


RENDEZVOUS NAVIGATION R22

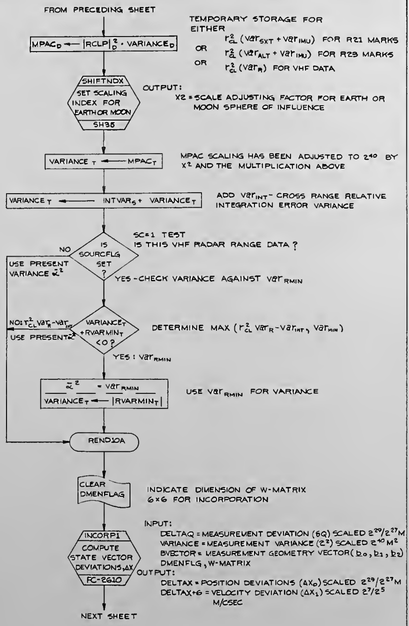
COLOSSUS IIC

FC-2550

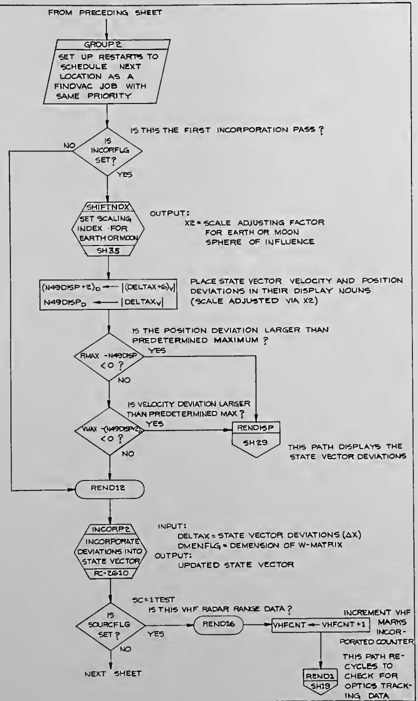
2 24 46



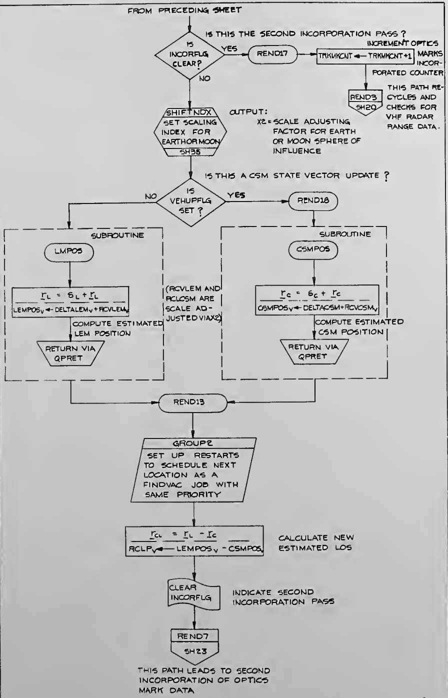
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN / PRGMR / ANALYST / DOCMR / APPR'D	RENDEZVOUS NAVIGATION R22
	COLOSSUS IIC — DOCUMENT NO. FC-2550
	REV 2 — SH 25 OF 46



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN Y. S. Chanlachi 23 FEB 67	RENDEZVOUS NAVIGATION R22
PROGMR N. V. Brookes 27 Mar 67	
ANALYST	COLOSSUS II C. FC-2550
DIV CMR E. PISCATELLI 27 MAR 67	
APPVD John A. Morse 27 MAR 67	REV 2 26 of 46



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN D. J. Chiesluski 27 FEB 69	RENDEZVOUS
PRGMR N. W. Brooker 27 Feb 69	NAVIGATION R22
ANALYST	COLOSSUS II C — DOCUMENT NO. FC-2550
DOC MGR F. PISCATELLI 27 MAR 69	
APPR'D John A. Moore 27 MAR 69	REV 2 — SHEET 27 OF 46



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

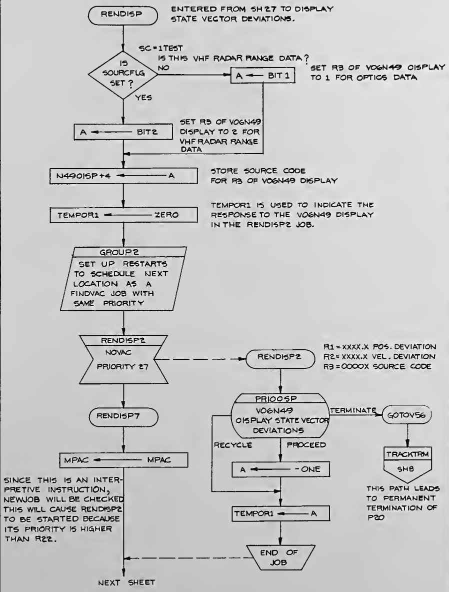
DRAWN	T. J. Chmielewski	10 FEB 69
CHKD	R. W. Brooks	27 MAR 69
COMP	PISCATELLI	27 MAR 69
APPR'D	John A. Moore	27 MAR 69

RENDEZVOUS NAVIGATION R22

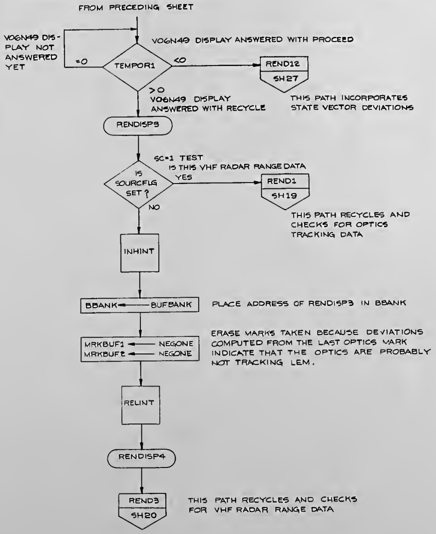
COLOSSUS IIC REV 2

FC-2550

28 46



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN J. L. Chmelinski 20FEB69	RENDEZVOUS NAVIGATION R22
PRGMR N. W. Brodeur 27MAR69	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2550
DOCMP R. PISCATELLI 27MAR69	
APPR'D John A. Moore 27MAR69	REV 2 — SHEET 29 OF 46



MIT INSTRUMENTATION LAB
CAMBRIDGE MASS.

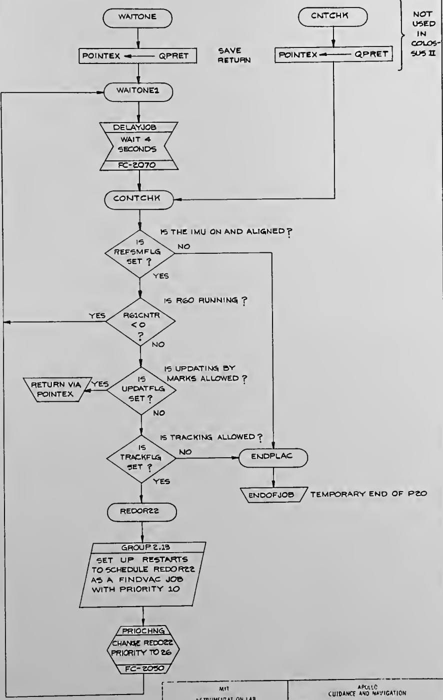
20FEB69
27MAR69
27MAR69
27MAR69

RENDEZVOUS NAVIGATION R22

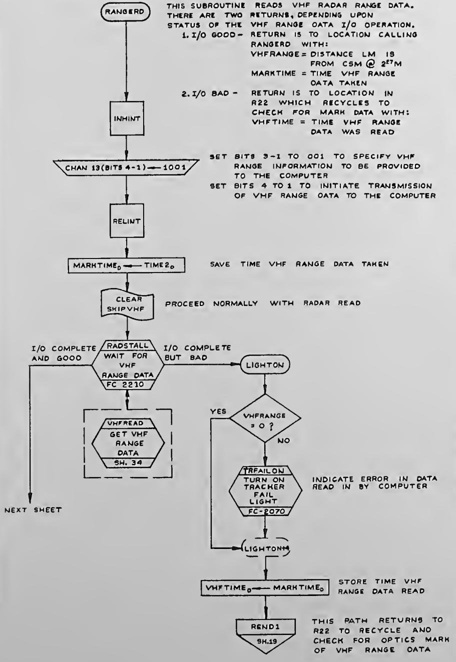
COLOSSUS IIC FC-2550

2

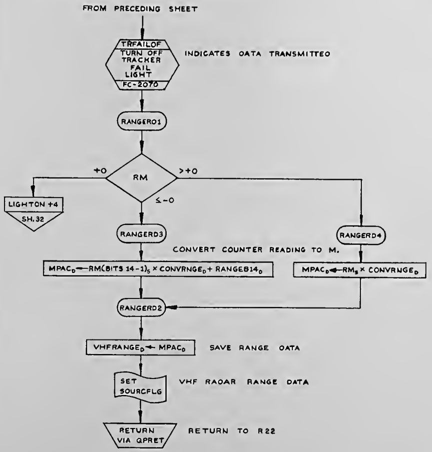
30 46



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN: T. L. Chmielewski 20 FEB 69	RENDEZVOUS NAVIGATION R22
PROGMR: R. V. Brooks 27 MAR 69	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2550
DOCMR: R. PISCATELLI 27 MAR 69	
APPR'D: John A. Morse 27 MAR 69	REV 2 — SHEET 31 OF 46

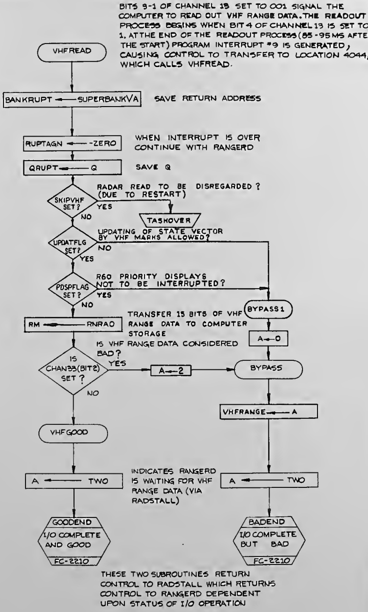


MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION RENDEZVOUS NAVIGATION R22
DRAWN F.O. LAVERRIERE 17MAR69	COLOSSUS IIC
PRGMR N. V. Brodeur 27MAR69	DOCUMENT NO FC-2550
ANALYST	
DCCMR R. PISCATELLI 27MAR69	
APPR'D John A. Moore 27MAR69	REV 2 SHEET 32 OF 46



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.	APOLLO GUIDANCE AND NAVIGATION
DRAWN F.D. LAVERRIERE 17MAR69	RENDEZVOUS NAVIGATION R22
PLGMR N.N. Brokins 27MAR69	COLOSSUS IIC
ANALYST	DOCUMENT NO. FC-2550
DOCMR R. PISCATELLI 27MAR69	REV 2
APPR'D John A. Moran 27MAR69	SHEET 33 OF 46



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

APOLLO GUIDANCE AND NAVIGATION

RENDEZVOUS NAVIGATION R22

DRAWN 26 FEB 69

PRGMR 27 MAR 69

ANALST

PRGMR R. PISCATELLI 27 MAR 69

APPR'D John A. Moore 27 MAR 69

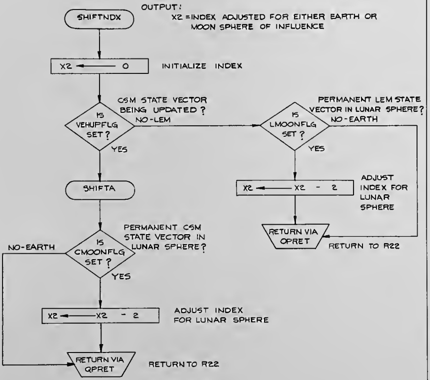
COLOSSUS II C

FC-2550

REV 2

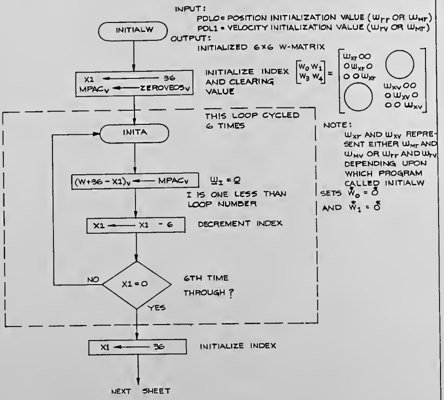
SH 34 OF 46

THIS SUBROUTINE ADJUSTS AN INDEX REGISTER FOR THE PROPER SPHERE OF INFLUENCE FOR EITHER CSM OR LEM COMPUTATIONS.

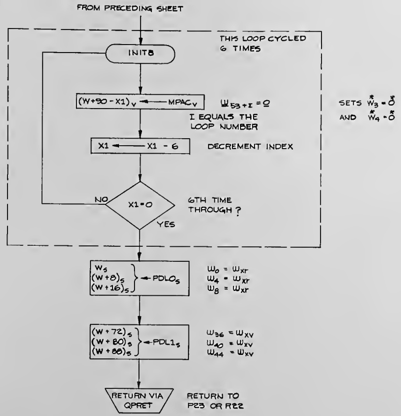


M.I.T. INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN J. J. Chmielynski 27FEB69	RENDEZVOUS NAVIGATION R22
PRGMR K. W. Brooks 27MAR69	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2550
DOCMR R. PISCATELLI 27MAR69	
APPRVD John A. Miller 27MAR69	REV 2 — SHEET 35 OF 46

THIS SUBROUTINE INITIALIZES THE W-MATRIX FOR EITHER P23-CISLUNAR MIDCOURSE NAVIGATION OR R22-RENDEZVOUS MARK PROCESSING



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN	27FEB69	RENDEZVOUS NAVIGATION R22
PRGMR	27MAR69	
ANALST		COLOSSUS IIC — DOCUMENT NO. FC-2550
DOCMR R. PISCATELLI	27MAR69	
APPR'D	27MAR69	REV 2 — SHEET 36 OF 46



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

APOLLO GUIDANCE AND NAVIGATION

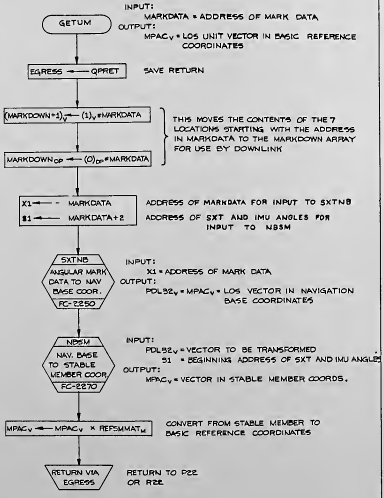
RENDEZVOUS NAVIGATION R22

R. PISCATELLI 27MAR69

COLOSSUS IIC FC-2550

2 37 46

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
DRAWN [signature]	RENDEZVOUS NAVIGATION R22
PRGMR [signature] 27 MAR 69	COLOSSUS II C — DOCUMENT NO. FC-2550
ANALST	
DOCMR R. PISCATELLI 27 MAR 69	
APPR'D [signature] 27 MAR 69	REV 2 — SHEET [illegible] OF [illegible]

CALLED BY P22 AND R22 TO COMPUTE DELTAQ (δQ) AND BVECTOR

INPUT:
- UM_V = MEASURED LOS UNIT VECTOR ($\underline{u}_M$)
- $USTAR_V$ = FICTITOUS STAR DIRECTION ($\underline{u}_S$)
- $RCLP_V$ = COMPUTED LOS UNIT VECTOR ($\underline{r}_{CL}$)

OUTPUT:
- $USTAR_V$ = ARTIFICAL STAR DIRECTION ($\underline{u}_S$)
- BVECTOR = 9 DIM GEOMETRY VECTOR ($\underline{b}_0$, $\underline{b}_1$, $\underline{b}_2$)
- DELTAQ = MEASURED DEVIATION (ΔQ)

(BVECTORS)

EGRESS ← QPRET — SAVE RETURN

$\underline{u}_{CL}$ = UNIT($\underline{r}_{CL}$)
$PDL26_D$ ← UNIT ($RCLP_V$)
— COMPUTE CSM TO LEM LINE-OF-SIGHT UNIT VECTOR GSOP EQU. 2.5.2

$TEMPOR1_D$ ← $PDL36_D$ — SAVE $|R_{CL}|$

$\underline{b}_0$ = UNIT ($\underline{u}_S \times \underline{u}_{CL}$)
$BVECTOR_V$ ← UNIT ($USTAR_V \times PDL26_V$)
— COMPUTE ARTIFICAL STAR DIRECTION GSOP EQU. 2.5.3

GROUP 2
SET UP RESTARTS TO SCHEDULE THE NEXT LOCATION AS A FINDVAC JOB WITH SAME PRIORITY

$\underline{u}_S$ = $\underline{b}_0$
$USTAR_V$ ← $BVECTOR_V$
— SAVE $\underline{u}_S$ GSOP EQU. 2.5.8

$\delta Q = r_{CL} \left[\cos^{-1}(\underline{u}_S \cdot \underline{u}_M) - \pi/2\right]$
$DELTAQ_D$ ← TEMPOR1 [($\cos^{-1}$($USTAR_V \cdot UM_V$) - DP1/4TH)PI/4.0]
— DETERMINE MEASURED DEVIATION GSOP EQU. 2.5.8 PI/4.0 IS A SCALE FACTOR TO CONVERT FROM 1/8 REVS TO RADIANS (DELTAQ IS THEN MULT. BY 8 TO ADJUST SCALING)

$(BVECTOR+6)_V$ ← $ZEROVECS_V$
$(BVECTOR+12)_V$ ← $ZEROVECS_V$
— SET $\underline{b}_1$ AND $\underline{b}_2$ TO 0

RETURN VIA EGRESS — RETURN TO R22 OR P22

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.
APOLLO GUIDANCE AND NAVIGATION

DRAWN	T. S. Chmielewski	28FEB69
PROGMR	N. W. Brooks	27MAR69
ANALYST		
DIV MGR	R. PISCATELLI	27MAR69
APPROVED	John A. Moore	27MAR69

RENDEZVOUS NAVIGATION R22

COLOSSUS IIC — REV 2

DOCUMENT NO. FC-2550

SHEET 39 OF 46

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/LEM STATE VECTOR TO TDEC1	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	2290	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
R63	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
TRFAILOF	2070	TURN OFF TRACKER FAIL LIGHT	SH. 33
TRFAILON	2070	TURN ON TRACKER FAIL LIGHT	SH. 32
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

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, 35
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
RENDWFLG FLAGWRD5 BIT 1	W-MATRIX VALID FOR RENDEZVOUS NAVIGATION	W-MATRIX NOT VALID FOR RENDEZVOUS NAVIGATION	SH. 23		SH. 4, 21, 23
DIMOFLAG 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 9 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
V50N18FL 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

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 9 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 R2 = BLANK R3 = BLANK REQUEST FOR ASTRONAUT TO MARK	SH. 18
V53	FLASHING	R1 = BLANK R2 = BLANK R3 = BLANK REQUEST FOR ASTRONAUT TO PERFORM ALTERNATE LOS SIGHTING	SH. 18
V06N94	FLASHING	R1 = 000.00 - SHAFT R2 = 57.470 - TRUNNION R3 = BLANK DISPLAY OF COAS ANGLES	SH. 18
V06N49	FLASHING PRIORITY	R1 = XXXX.X - POSITION DEVIATION R2 = XXXX.X - VELOCITY DEVIATION R3 = 00000X - SOURCE CODE DISPLAY OF EXCESSIVE UPDATE PARAMETERS	SH. 29

ERASABLE LOCATIONS USED					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TRKMKCNT		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 CALLER'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	$\cdot 1\underline{\omega}_{LOS}$	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 $\Delta\underline{GA}$	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}
REFSMMAT		BASIC REFERENCE TO STABLE MEMBER COORDINATES TRANSFORMATION MATRIX			2^{1}

ERASABLE LOCATIONS USED (CONTINUED)					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
WBODY	$\underline{\omega}_{CA}$	DESIRED LOS RATE FOR DAP (1 REV = 450°)	DEG/SEC	REVS/SEC	4/5
DELCDUX	$\underline{\Delta G A}$	DESIRED INCREMENTAL CHANGES IN IMU ANGLES	DEGREES	REVS	2^{-1}
MRKBUF1		7-LOCATION MARK DATA BUFFER 1			(VARIABLE)
MRKBUF2		7-LOCATION MARK DATA BUFFER 2			(VARIABLE)
PHSPRDT2		RESTART PRIORITY REGISTER		(INTEGER)	2^{14}
VHFTIME		TIME VHF RADAR RANGE DATA READ	SEC	CSEC	2^{28}
MARKSTAT		ADDRESS FOR MARK DATA VAC AREA IN CASE OF RESTART		(INTEGER)	2^{14}
MKBUFAD		ADDRESS OF MARK DATA VAC AREA		(INTEGER)	2^{14}
MARKDATA		ADDRESS OF TIME MARK TAKEN		(INTEGER)	2^{14}
VTEMP		ADDRESS OF MARK ANGLES		(INTEGER)	2^{14}
CSMPOS	$\underline{r}_C$	CSM PRECISION POSITION VECTOR	NAUT. MI.	METERS	$2^{29}/2^{27}$
DELTACSM	$\underline{\delta}_C$	CSM POSITION DEVIATION	NAUT. MI.	METERS	$2^{22}/2^{18}$
RCVCSM	$\underline{r}_C$	CSM CONIC POSITION VECTOR	NAUT. MI.	METERS	$2^{29}/2^{27}$
LEMPOS	$\underline{r}_L$	LEM PRECISION POSITION VECTOR	NAUT. MI.	METERS	$2^{29}/2^{27}$
DELTALEM	$\underline{\delta}_L$	LEM POSITION DEVIATION	NAUT. MI.	METERS	$2^{22}/2^{18}$
RCVLEM	$\underline{r}_L$	LEM CONIC POSITION VECTOR	NAUT. MI.	METERS	$2^{29}/2^{27}$
RCLP	$\underline{r}_{CL}$	LEM TO CSM LOS VECTOR	NAUT. MI.	METERS	$2^{29}/2^{27}$
UCL	$\underline{u}_{CL}$	ESTIMATED LEM TO CSM LOS DIRECTION			2^1
UM	$\underline{u}_M$	MEASURED LEM TO CSM LOS DIRECTION			2^1
USTAR	$\underline{u}_S$	FICTITIOUS STAR DIRECTION ALSO USED BY BVECTOR SUBROUTINE FOR ARTIFICIAL STAR DIRECTION			2^1
BVECTOR	$(\underline{b}_0, \underline{b}_1, \underline{b}_2)$	GEOMETRY OF MEASUREMENT VECTOR			$(2^1, \_, \_)$
DELTAQ	δQ	MEASUREMENT DEVIATION	NAUT. MI.	METERS	$2^{29}/2^{27}$
VHFRANGE	R_M	VHF RANGE READING	NAUT. MI.	METERS	2^{27}
VARIANCE	$\bar{\alpha}^2$	MEASUREMENT ERROR VARIANCE ALSO USED AS A TEMPORARY LOCATION DURING VARIANCE CALCULATION		$METERS^2$	2^{40}
DELTAX	Δx_0	STATE VECTOR POSITION DEVIATION	NAUT. MI.	METERS	$2^{29}/2^{27}$
DELTAX+6	Δx_1	STATE VECTOR VELOCITY DEVIATION	FT/SEC	METERS/ CSEC	$2^7/2^5$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN D. S. Chmelynski 21MAR69
PRGMR N. N. Brodeur 27MAR69
ANALST
DOCMR R. PISCATELLI 27MAR69
APPR'D [illegible] 27 MAR 69

APOLLO GUIDANCE AND NAVIGATION

RENDEZVOUS NAVIGATION

COLOSSUS IIC FC-2550

REV 2

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ERASABLE LOCATIONS USED (CONTINUED)					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
N49DISP		POSITION DEVIATION DISPLAY NOUN	NAUT. MI.	METERS	2^{29}
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}
BUFBANK		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_8 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°	.11112 REVS	2^{-1}
RVCS/RDS		CONVERSION FACTOR RAD/ CSEC TO REV/SEC	$100/2\pi \frac{\text{REV-CSEC}}{\text{RAD-SEC}}$	15.915494 (SAME UNITS)	2
TENTH	.1	DECIMAL .1	.1	.1	2^{3}
MBDYTCTL_M	[NBCA]	NAVIGATION BASE TO CONTROL AXES TRANSFORMATION MATRIX	$\begin{bmatrix} .5, & 0, & 0 \\ 0, & \cos 7.5, & \sin 7.5 \\ 0, & \sin 7.5, & \cos 7.5 \end{bmatrix}$	.5 0 0 0 .99200495 -.12619897 0 .12619897 .99200495	2^{1}
POINT8		SCALE FACTOR 1 REV = 360° TO 1 REV = 450°	.8	.8	2^{0}
SIX		DECIMAL 6	6	6	2^{14}
PRIO26		OCTAL 26000		26000_8	2^{14}
NEG3		DECIMAL -3	-3	-3	2^{14}

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_{SXT}	SXT ERROR VARIANCE	$.04 \times 10^{-6}$ RAD^2	.04 (MR)^2	2^{18}
IMUVAR	var_{IMU}	IMU ERROR VARIANCE	$.04 \times 10^{-6}$ RAD^2	.04 (MR)^2	2^{16}
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 I/8 REVS TO RADIANS	$\frac{\pi}{4}$ $\frac{RAD}{REV}$	.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	ω_{rr}	INITIAL W-MATRIX POSITION VALUES				00012
WRENDVEL	ω_{rv}	INITIAL W-MATRIX VELOCITY VALUES				00062
RVAR	var_R	VHF MEASUREMENT ERROR VARIANCE				
RVARMIN	$-var_{RMIN}$	-MINIMUM VHF ERROR VARIANCE	-16,384	-16,384	2^{40}	77777 77776
ALTVAR	var_{ALT}	ALTERNATE LOS ERROR VARIANCE				66142
INTVAR	var_{INT}	INTEGRATION ERROR VARIANCE				
RMAX	δr_{MAX}	MAXIMUM POSITION CHANGE WITHOUT APPROVAL				
VMAX	δv_{MAX}	MAXIMUM VELOCITY CHANGE WITHOUT APPROVAL				

GROUND TRACK DETERMINATION - P21

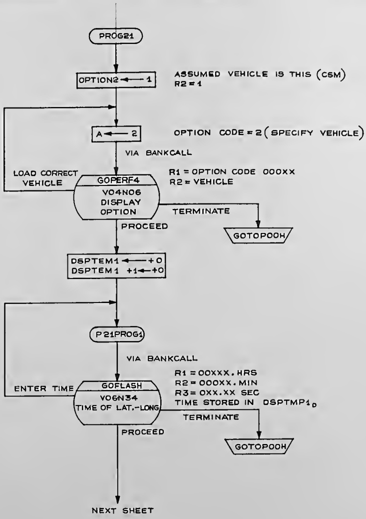
MAJOR SUBROUTINES ON THIS CHART

PROG 21 GROUND TRACK DETERMINATION SH 2

GROUND TRACK DETERMINATION P21

COLOSSUS IIC. FC-2580

2 1 7



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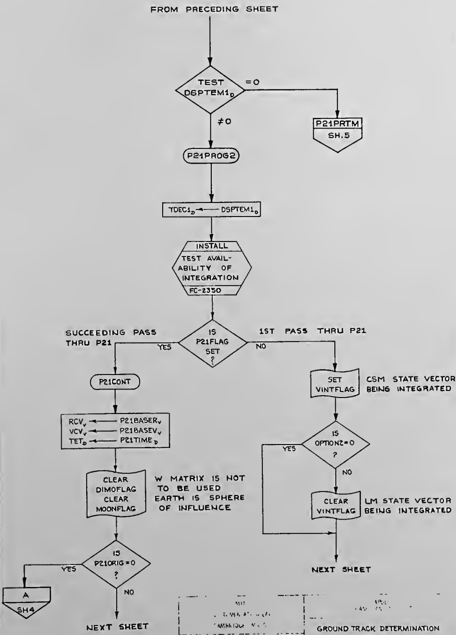
DRAWN [signature] 14 AUG 69	GROUND TRACK DETERMINATION P21
PROGMR	
ANALYST	COLOSSUS IIC — DOCUMENT NO. FC-2580
DOCMR	
APPR'D	REV 2 — SHEET 2 OF 7

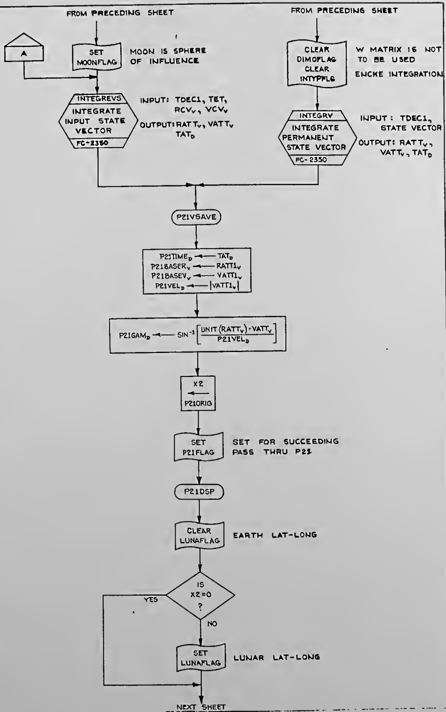


DRAWN A.C.WILLIAMS 7FEB69
PRGMR J. E. Cuda 22APR69
ANALST
DOCMR M. C. Dughall 4/18/69
APPR'D John L. Moore 28 April 69

GROUND TRACK DETERMINATION
P21

COLOSSUS IIC FC-2580

2 3 7



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APOLLO GUIDANCE AND NAVIGATION

GROUND TRACK DETERMINATION

DRAWN A.C.WILLIAMS

PRGMR

ANALST

DOCMR

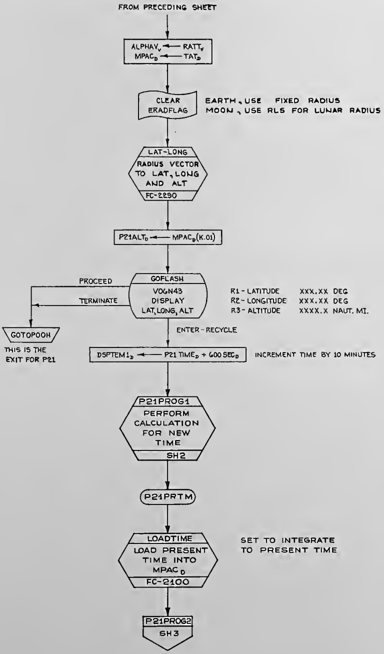
APPR'D

COLOSSUS IIC

FC-2580

REV 2

SHEET 4 OF 7



DRAWN A.C.WILLIAMS 7 FEB 69

GROUND TRACK DETERMINATION

COLOSSUS IIC

FC-2580

REV 2 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-2360	INTEGRATE INPUT STATE VECTOR	SH 4
INTEGRV	FC-2360	INTEGRATE PERMANENT STATE VECTOR	SH 4
LAT-LONG	FC-2290	RADIUS VECTOR TO LAT., LONG. AND ALT.	SH 5
LOADTIME	FC-2100	LOAD PRESENT TIME INTO $MPAC_D$	SH 5

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DIMOFLAG FLAG3 BIT1	W MATRIX IS TO BE USED	W MATRIX IS NOT TO BE USED		SH 3, 4	
ERADFLAG FLAG1 BIT13	EARTH; COMPLETE EARTH RADIUS MOON; USE FIXED RADIUS	EARTH; USE FIXED RADIUS MOON; USE RLS FOR LUNAR RADIUS		SH 5	
INTYPFLG FLAG3 BIT4	CONIC INTEGRATION	ENCKE INTEGRATION		SH 4	
LUNAFLAG FLAG3 BIT12	LUNAR LAT-LONG	EARTH LAT-LONG	SH 4	SH 4	
MOONFLAG FLAG0 BIT12	MOON IS SPHERE OF INFLUENCE	EARTH IS SPHERE OF INFLUENCE	SH 4	SH 3	
P21FLAG FLAG2 BIT12	SUCCEEDING PASS THRU P21	FIRST PASS THRU P21	SH 4		SH 3
VINTFLAG FLAG3 BIT3	CSM 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 = OOXXX. HR R2 = OOOXX. MIN R3 = OXX.XX SEC	SH 2
V06N43	FLASHING	R1 = XXX.XX DEG R2 = XXX.XX DEG R3 = XXXX.X NAUT. MI	SH 5

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
OPTION 2		VEHICLE CODE		(INTEGER)	2^{14}
DSPTEM1		DISPLAY NOUN FOR TIME		CSEC	2^{28}
P21TIME		TIME FOR LAT-LONG		CSEC	2^{28}
TDEC1	t	TIME FOR INTEGRATION		CSEC	2^{28}
RATT	r_{CON}	CONIC POSITION VECTOR		METERS	2^{29}
TAT	t	TIME OF POSITION		CSEC	2^{28}
ALPHAV		POSITION VECTOR		METERS	2^{29}
LAT		LATITUDE	DEG	REVS	2^{0}
LONG		LONGITUDE	DEG	REVS	2^{0}
ALT		ALTITUDE	NAUT. MI	METERS	2^{29}

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DRAWN [signature] 16APR69
PRGMR [signature] 22APR69
ANALST
DOCMR [signature] 4/10/69
APPR'D [signature] 22 Apr 69

APOLLO GUIDANCE AND NAVIGATION

GROUND TRACK DETERMINATION P21

COLOSSUS IIC

REV 2

DOCUMENT NO. FC-2580

SHEET 6 OF 7

PROGRAM CONSTANTS

AGC -TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
P21ONENN		VEHICLE TEST VALUE		00001	2^{14}
600SEC		10 MINUTES	10 MINUTES	60000CSEC	2^{28}

MAJOR SUBROUTINES:

S22.1 - PROCESSES MARK DATA TO UPDATE CSM STATE VECTOR.
@DWT06DW - CONVERTS W-MATRIX FROM 9 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 SCALING OR AS A TEMPORARY LOCATION HAVING MANY DIFFERENT SCALINGS.

3) $2^X/2^Y$ IN THE SCALING FIELD OF THE SUMMARY SHEETS IS USED FOR EARTH/MOON SPHERE OF INFLUENCE.
   i.e. 2^X IS THE SCALING IN EARTH SPHERE.
   2^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:

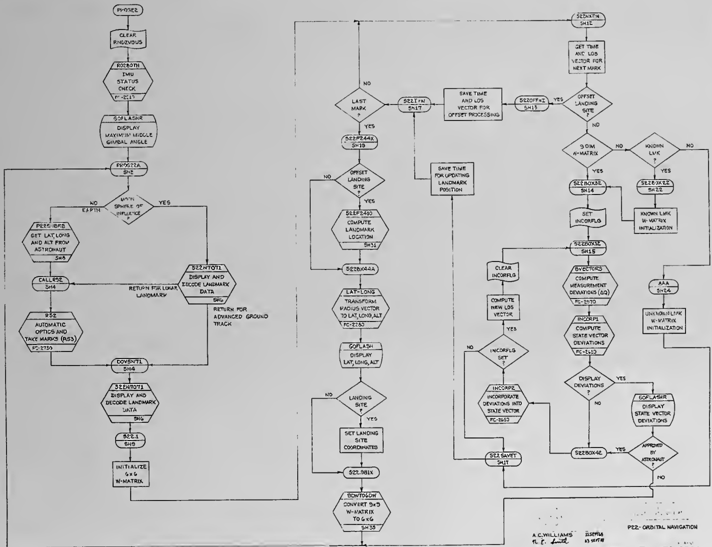
1	REV 0
2	REV 1
3	REV 0
4-8	REV 1
9	REV 0
10	REV 1
11	REV 0
12-14	REV 1
15-16	REV 0
17-19	REV 1
20	REV 0
21	REV 1
22	REV 0
23	REV 1
24	REV 0
25	REV 1
26-27	REV 0
28-31	REV 1
32-40	REV 0
41-42	REV 1
43-44	REV 0

INSTRUMENTATION LAB

DRAWN A.C.WILLIAMS 11SEPT68
PRGMR N. E. Smith 13 SEPT 69
CHECKED R. Puscatelli 21 OCT 68
APPROVED John A. Nore 21 OCT 68

P22 - ORBITAL NAVIGATION

COLOSSUS II FC-2590



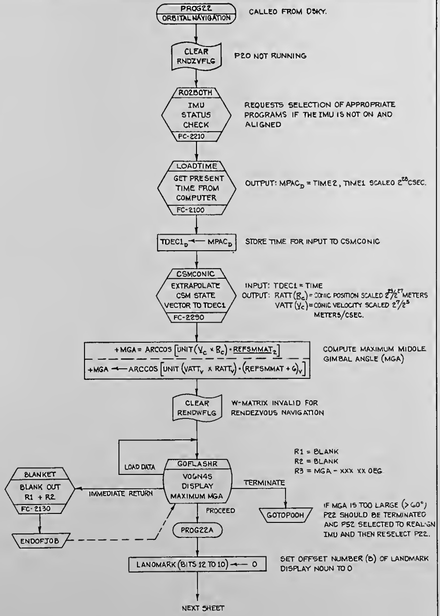
A.C. WILLIAMS 11 SEPT 68
R. E. Smith 23 SEPT 68
R. Pascatelli 24 OCT 68
John A. Moore 29 Oct 68

P22- ORBITAL NAVIGATION

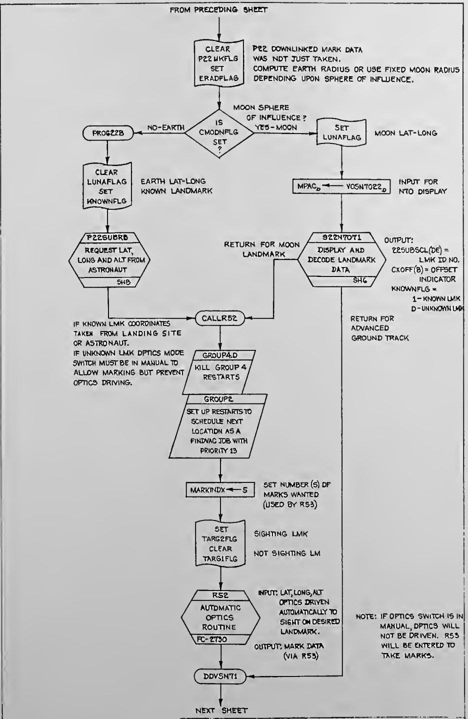
COLOSSUS II 1

FC-2590

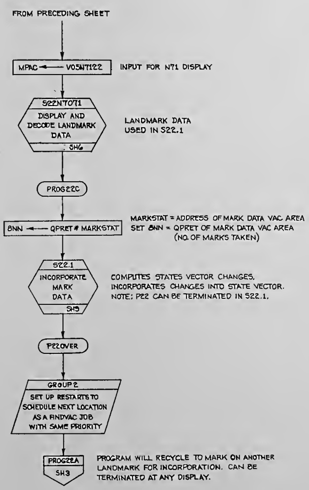
2 44



DRAWN A.C. WILLIAMS	11SEPT68	P22-ORBITAL NAVIGATION
PROGRAM N. E. Smith	13 SEPT 68	
CHECKED R. Pucatelli	24 OCT 68	COLOSSUS II
APP'D John A. Rose	29 Oct 68	FC-2590
		3 of 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. C. WILLIAMS 16APR69	P22 - ORBITAL NAVIGATION	
PROG MGR R. S. Whitney	COLOSSUS II	DOCUMENT NO. FC-2590
ANALYST		
DOCMR W. C. Dayhoff	REV 1	SHEET 4 OF 44
APPR'D		



A.C.WILLIAMS 16 SEPT 68

N.E. Smith 23 SEPT 68

R. Pucatelli 27 OCT 68

John A. Mose 29 Oct 68

P22-ORBITAL NAVIGATION

COLOSSUS II

FC-2590

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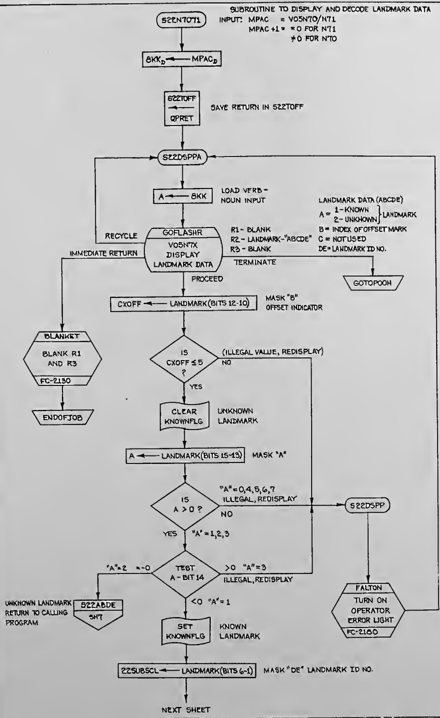
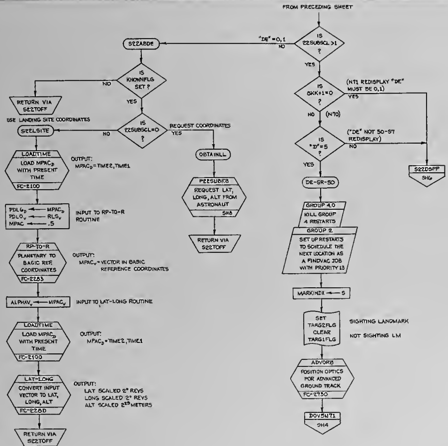


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	15APR69	P22 - ORBITAL NAVIGATION
PRGMR [signature]	12 Aug 69	
ANALST		COLOSSUS II — DOCUMENT NO. FC-2590
DOCMR [signature]	29 AUG 69	
APPR'D		REV — SHEET 6 OF 44



A.C. WILLIAMS 16APR69

R. S. Whittredge 12May69

[signature] 29Mar69

P22 - ORBITAL NAVIGATION

COLOSSUS II

FC-2590

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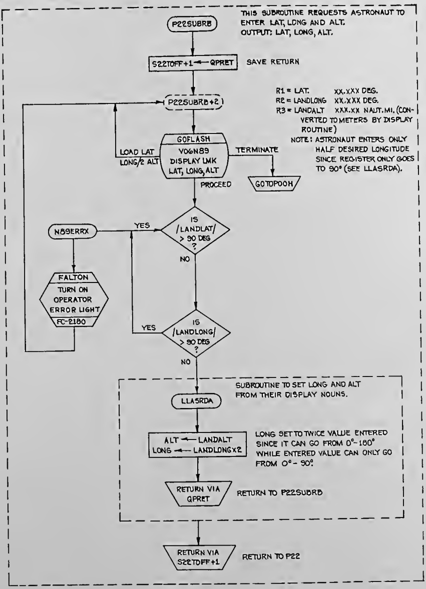

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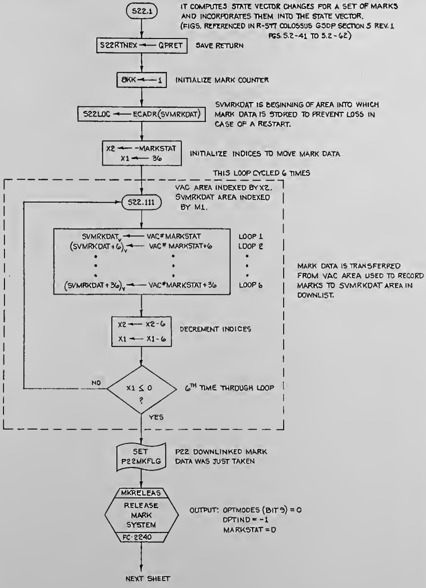
DRAWN A.C. WILLIAMS 16APR69	P22 - ORBITAL NAVIGATION
PRGMR R.L. Whitridge 12May69	
ANALST	COLOSSUS II — DOCUMENT NO. FC-2590
DOCMR McDaybirt 29APR69	
APPR'D	REV 1 — SHEET 8 OF 44

THIS SUBROUTINE PERFORMS MAJOR CALCULATIONS OF P22.
IT COMPUTES STATE VECTOR CHANGES FOR A SET OF MARKS
AND INCORPORATES THEM INTO THE STATE VECTOR.
(FIGS. REFERENCED IN R-577 COLOSSUS GSOP SECTION 5 REV. 1
PGS. 5.2-41 TO 5.2-62)



A.C. WILLIAMS 17SEP69
N.E. Smith 27 OCT 69
R. Piccatelli 24 OCT 69
John A. Moss 29 Oct 69

P22 - ORBITAL NAVIGATION

COLOSSUS II

FC-2590

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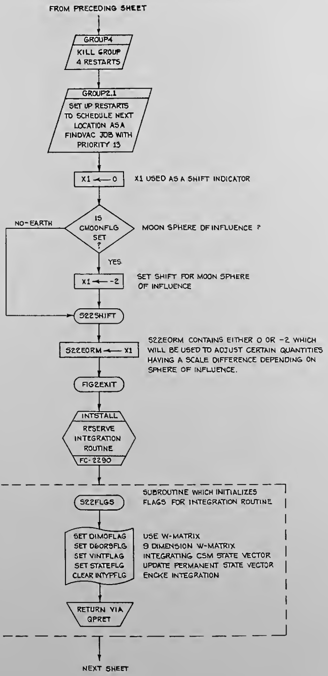

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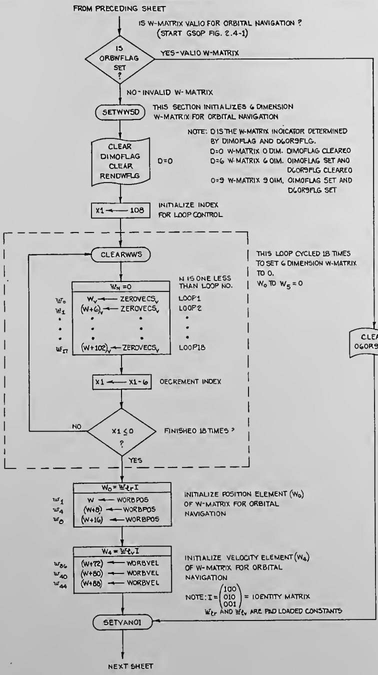
DRAWN A.C.WILLIAMS	
PRIM MR M. F. Smith 23 OCT 68	
ANALYS	COLOSSUS II FC-2590
DOC MGR R. Pricatelli 24 OCT 68	
APPR'D John A. Moo...	1 10 44

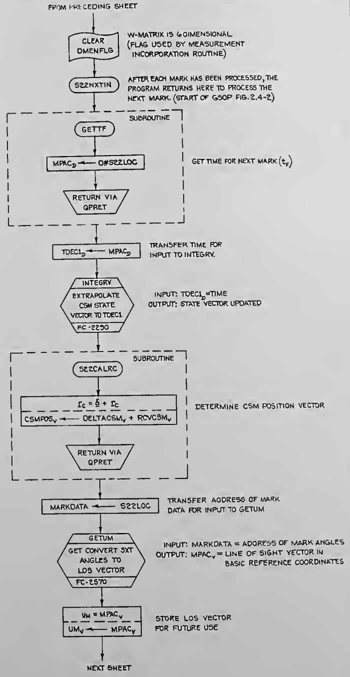


P22-ORBITAL NAVIGATION

DRAWN A.C WILLIAMS 18SEP68
CHECKED M. E. Smith 21 OCT 68
A. Puccatelli 21 OCT 68
APPROVED John A. Moore 21 OCT 68

COLOSSUS II

FC-2590



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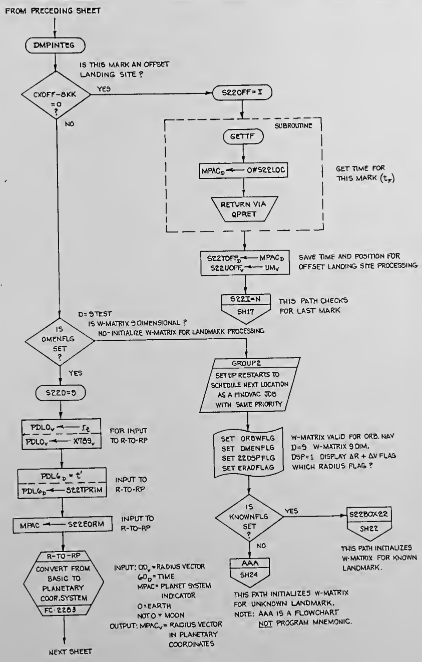
DRAWN A.C.WILLIAMS

P22-ORBITAL NAVIGATION

COLOSSUS II

FC-2590

12 44

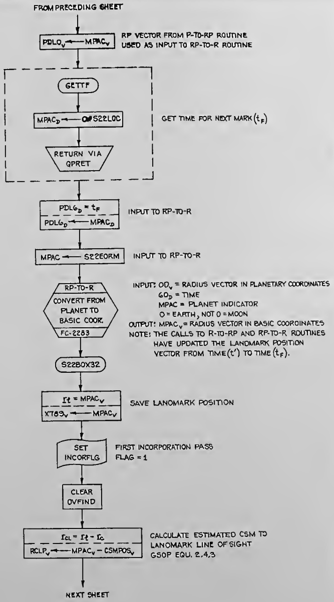


DRAWN A.C.WILLIAMS 25 SEPT 68
CHECKED M. E. Smith 31 OCT 68
R. Pucatelli 24 OCT 68
John A. Moore 31 Oct 68

P22-ORBITAL NAVIGATION

COLOSSUS II — FC-2590

1 — 13 — 44



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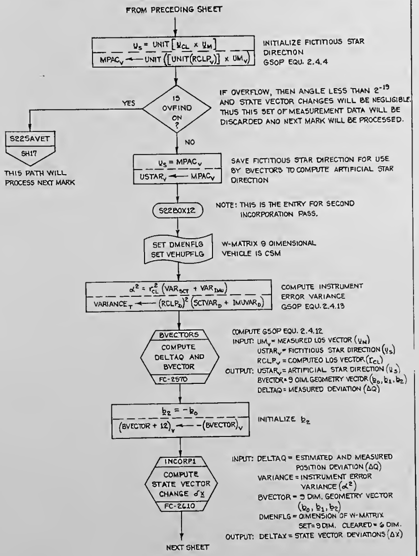
DRAWN A.C. WILLIAMS
PRGMR N. E. Smith 23 OCT 68
ANALST
DOCMR R. Ciccatelli 21 OCT 68
APPR'D

P22-ORBITAL NAVIGATION

COLOSSUS II

FC-2590

REV 1



MIT INSTRUMENTATION LAB CAMBRIDGE MASS

DRAWN A.C.WILLIAMS	03SEP68
PRGMR M.E. Smith	23OCT68
ANALYST	
DOCMN R. Puccatelli	21OCT68
APPR'D John A. Mo...	21OCT68

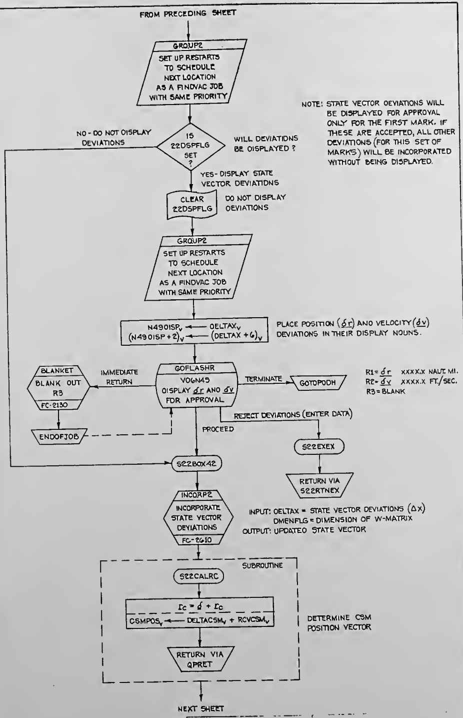
APOLLO GUIDANCE AND NAVIGATION

P22-ORBITAL NAVIGATION

COLOSSUS II

FC-2590

REV 1

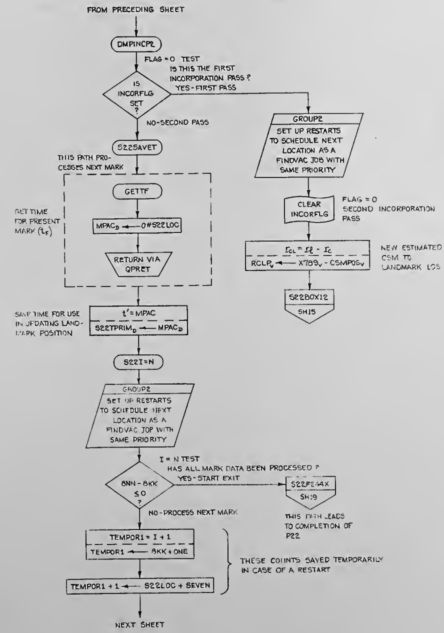


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

A-C GUIDANCE AND NAVIGATION

P22-ORBITAL NAVIGATION

DRAWN A.C.WILLIAMS	23OCT68	
PRGMR R.L. Smith	27OCT68	
ANALYST		COLOSSUS II
DOCMR R.R. [illegible]	31OCT68	FC-2590
APPR'D John A. [illegible]	31Oct68	REV 1 — SHEET 16 OF 44

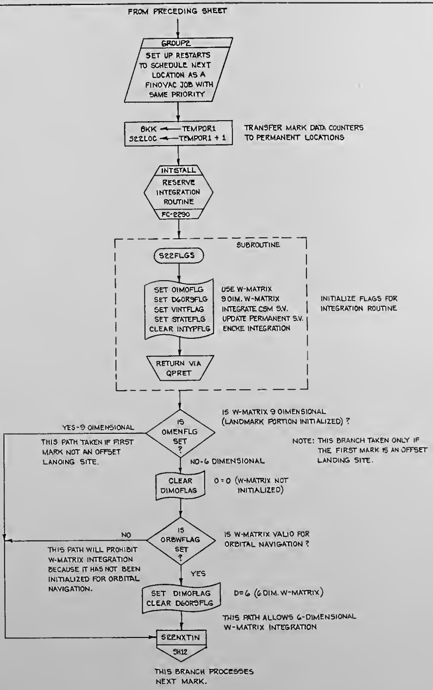


A.C.WILLIAMS 23SEPT68
N. E. Smith 23 OCT 68
R. Cricatelli 24 OCT 68
John A. Moore 29 Oct 68

P22-ORBITAL NAVIGATION

COLOSSUS II

FC-2590



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

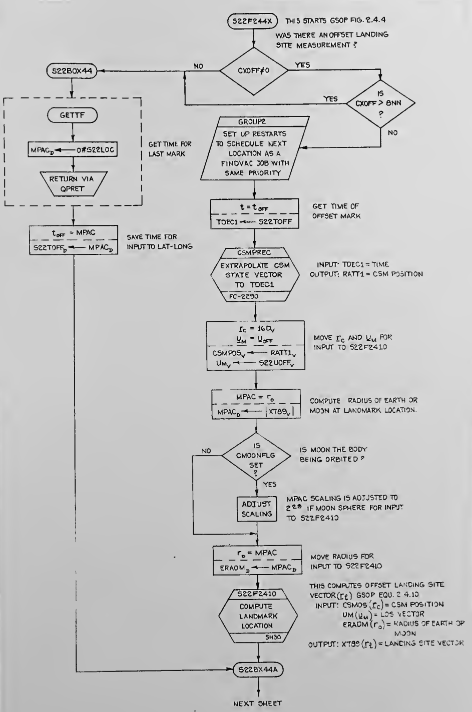
DRAWN A.C.WILLIAMS 25SEPT68
PR. MP N. E. Smith 23OCT68
ANALYST
G. N. MP R. Puccatelli 24OCT68
APPR'D John A. Moore 23OCT68

P22-ORBITAL NAVIGATION

COLOSSUS II

FC-2590

18 44



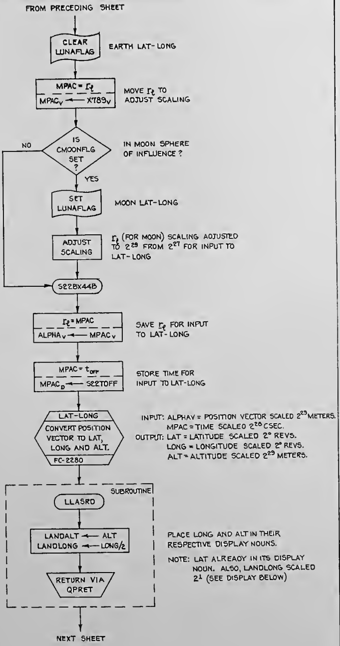
P22-ORBITAL NAVIGATION

A.C.WILLIAMS 23SEPT68
N. E. Smith 23 OCT 68
R. Cucatelli 24OCT68
John A. More 29 OCT 68

COLOSSUS II

FC-2590

1 19 44



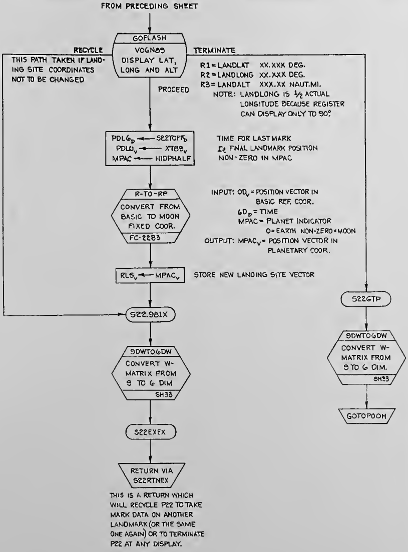
MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN A.C.WILLIAMS 23SEPT68
PPCMR R.E. Smith 23OCT68
ANALYST
DOCMR R. Ricciardelli 24OCT68
APPR'D John A. Moore 23OCT68

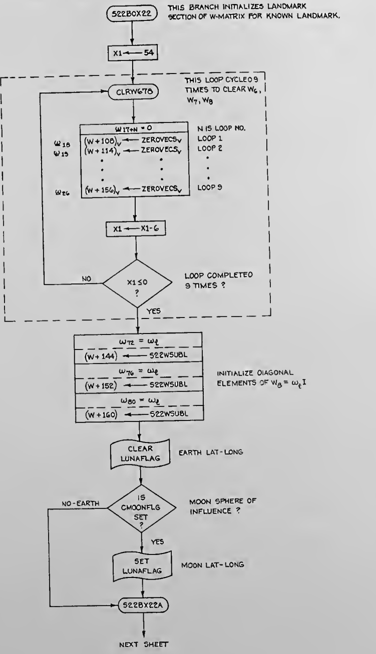
P22-ORBITAL NAVIGATION

COLOSSUS II FC-2590

1 20 44



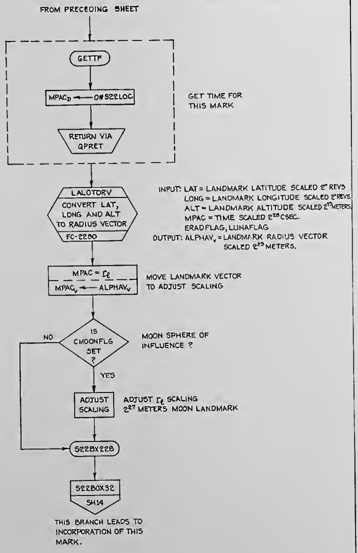
FROM PRECEDING SHEET
GOFLASH
VOGN89
DISPLAY LAT, LONG AND ALT
RECYCLE
THIS PATH TAKEN IF LANDING SITE COORDINATES NOT TO BE CHANGED
TERMINATE
R1 = LANDLAT XX.XXX DEG.
R2 = LANDLONG XX.XXX DEG.
R3 = LANDALT XXX.XX NAUT.MI.
NOTE: LANDLONG IS 1/2 ACTUAL LONGITUDE BECAUSE REGISTER CAN DISPLAY ONLY TO 90°
PROCEED
PDL6D ← S22TOFFD
PDL0V ← XT89V
MPAC ← HIDPHALF
TIME FOR LAST MARK
rt FINAL LANDMARK POSITION
NON-ZERO IN MPAC
R-TO-RP
CONVERT FROM BASIC TO MOON FIXED COOR.
FC-2283
INPUT: 0DV = POSITION VECTOR IN BASIC REF. COOR.
6DD = TIME
MPAC = PLANET INDICATOR
0 = EARTH NON-ZERO = MOON
OUTPUT: MPACV = POSITION VECTOR IN PLANETARY COOR.
RLSV ← MPACV
STORE NEW LANDING SITE VECTOR
S22GTP
9DWTO6DW
CONVERT W-MATRIX FROM 9 TO 6 DIM.
SH33
GOTOPOOH
S22.981X
9DWTO6DW
CONVERT W-MATRIX FROM 9 TO 6 DIM
SH33
S22EXEX
RETURN VIA S22RTNEX
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.



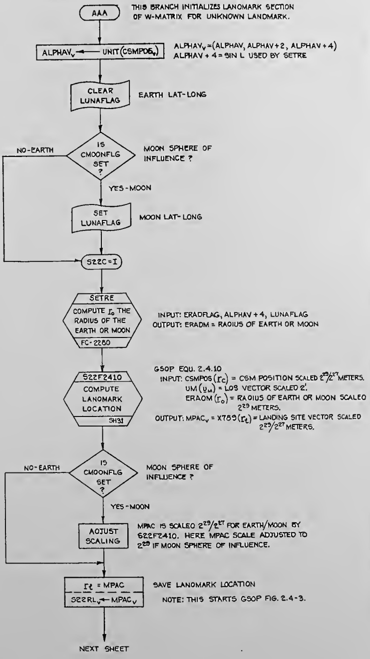
DRAWN A.C.WILLIAMS 26SEPT68
PROGR M.E. Smith 23OCT68
ANALYST
DISCMP R. Piccatelli 24OCT68
APPR John A. Miller 31OCT68

P22 - ORBITAL NAVIGATION

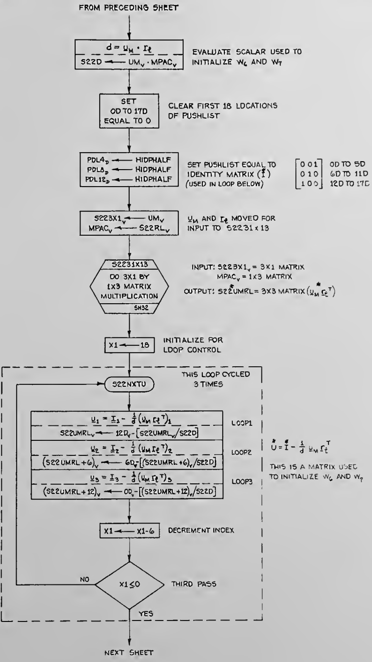
COLOSSUS II FC-2590



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 26SEPT68 PRGMR R. E. Smith 23OCT68 ANALST DOCMP R. Pescatelli 29OCT68 APPR'D John A. Moore 29Oct68	P22-ORBITAL NAVIGATION COLOSSUS II — FC-2590 REV 1 — SHEET 23 OF 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 27 SEPT 68	P22-ORBITAL NAVIGATION
CHKR N. E. Smith 27 Oct 68	COLOSSUS II
ANALYST	DOCUMENT NO. FC-2590
DOCMR R. Rucatelli 29 Oct 68	REV 1
APPR'D John A. Moore 29 Oct 68	SHEET 24 OF 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN A.C.WILLIAMS 27SEPT68
PROGR N.E. Smith 23OCT68
ANAL
APP R. Pucatelli 24OCT68
APPR John A. Moore 24Oct68

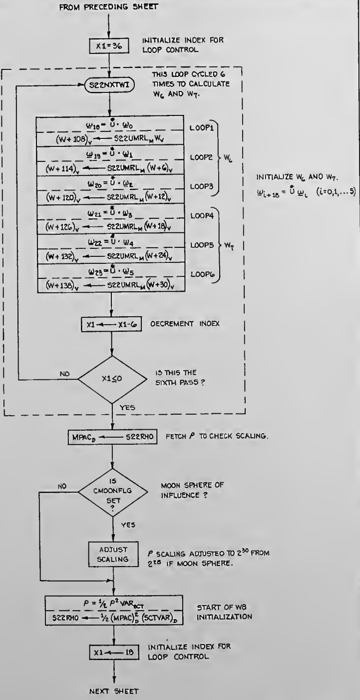
P22 - ORBITAL NAVIGATION

COLOSSUS II

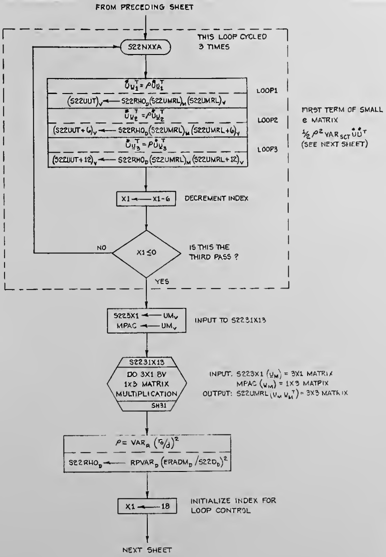
FC-2590

REV 1

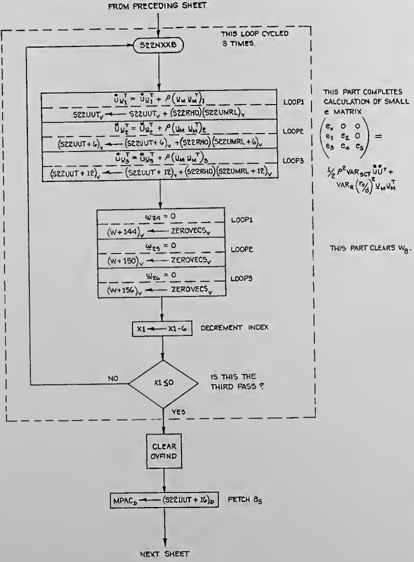
25 44



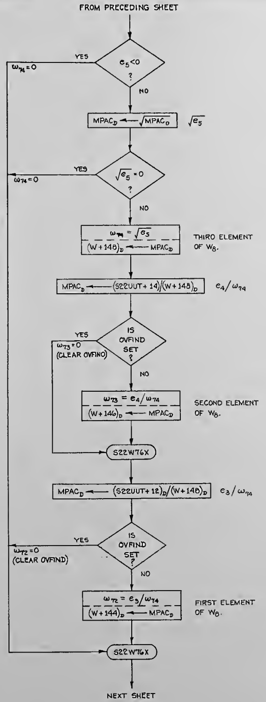
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 27SEPT68	P22-ORBITAL NAVIGATION
PREMP R. E. Smith 23 OCT 68	COLOSSUS II
ANALYST	DOCUMENT NO. FC-2590
SUP MP R. Guaratelli 24 OCT 68	
APPR'D John A. Moore 27 Oct 68 REV 1	SHEET 26 OF 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A C.WILLIAMS 30SEPT68	P22-ORBITAL NAVIGATION
PROGMR M.E Smith 23 OCT68	
ANALYST	
CHECKED R. Pucatelli 24OCT68	COLOSSUS II FC-2590
APPROVED John A Moore 29 Oct68	REV 1 27 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	30SEPT68	P22 - ORBITAL NAVIGATION
PRGMR M.E. Smith	23OCT68	
ANALYST		COLOSSUS II
DOCMR R. Ricatelli	31OCT68	DOCUMENT NO. FC-2590
APPR'D [illegible]	28OCT68	REV 1 · SHEET 28 OF 44



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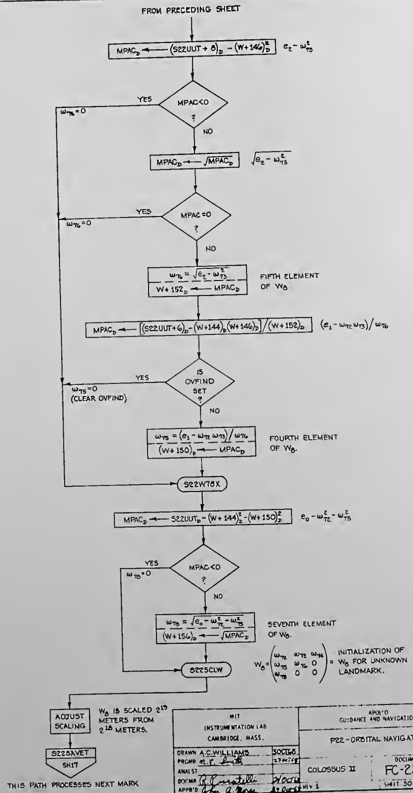
INSTRUMENTATION LAB
CAMBRIDGE MASS.

DRAWN A.C. WILLIAMS 30SEPT68
PRGMR R.E. Smith 23OCT68
ANALST
DOCMR R. Pucatelli 31OCT68
APPR'D John A. Moore 31OCT68

P22-ORBITAL NAVIGATION

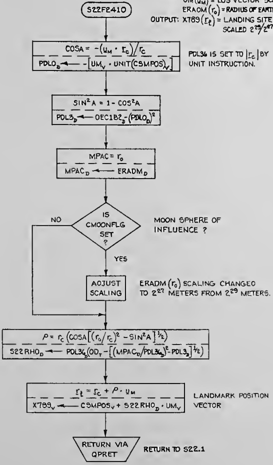
COLOSSUS II FC-2590

REV 1 29 44

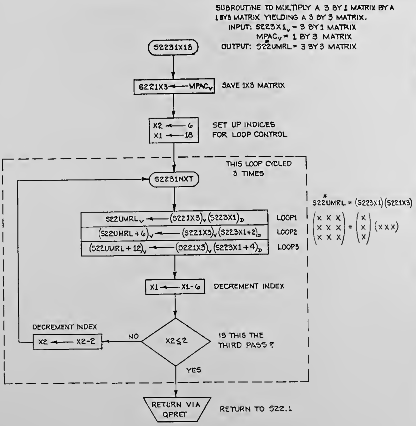


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	30OCT68	P22 - ORBITAL NAVIGATION
PRGMR N.F. Smith	27 Oct 68	
ANALYST		COLOSSUS II
DOCMR R. Curatelli	4 Oct 68	DOCUMENT NO. FC-2590
APPR'D John A. Rose	31 Oct 68	REV 1 · SHEET 30 OF 44

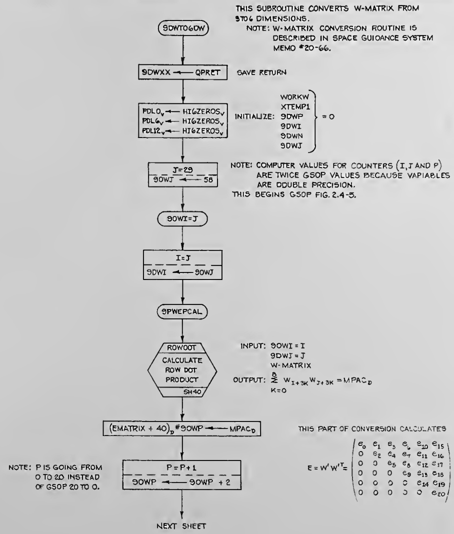
THIS SUBROUTINE CALCULATES GSOP EQU. 2.4-10.
INPUT: CSMPOS ($\underline{r}_C$) = CSM POSITION SCALED $2^{29}/2^{27}$ METERS.
UM ($\underline{u}_M$) = LOS VECTOR SCALED 2^1.
ERADM (r_0) = RADIUS OF EARTH OR MOON SCALED 2^{29} METERS.
OUTPUT: X789 ($\underline{r}_\ell$) = LANDING SITE POSITION VECTOR SCALED $2^{29}/2^{27}$ METERS.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 30OCT68	P22 - ORBITAL NAVIGATION
PRGMR N. E. Smith 31OCT68	
ANALYST	COLOSSUS II — FC-2590
R. Pescatelli 24OCT68	
John W. Moss 27Oct68	1 — 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 4OCT68	P22-ORBITAL NAVIGATION
PRGMR N.F. Smith 31OCT68	DOCUMENT NO.
ANALST	COLOSSUS II — FC-2590
DOCMR R. Pucatelli 24OCT68	
APPR'D John A. Mann 31OCT68	REV 1 — SHEET 32 OF 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN A.C WILLIAMS 7OCT68
PROGMR M.F. Smith 23OCT68
ANALYST
DOC MGR R. P. Iuscatelli 24OCT68
APPR John A. Norse 25OCT68

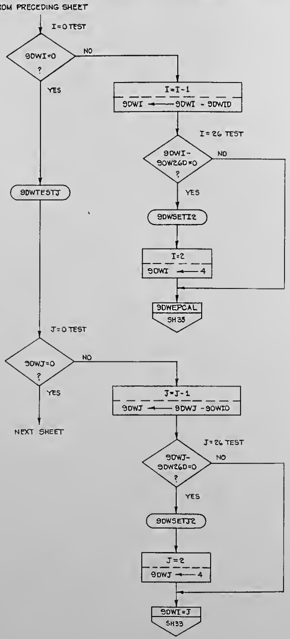
APOLLO GUIDANCE AND NAVIGATION

P22 - ORBITAL NAVIGATION

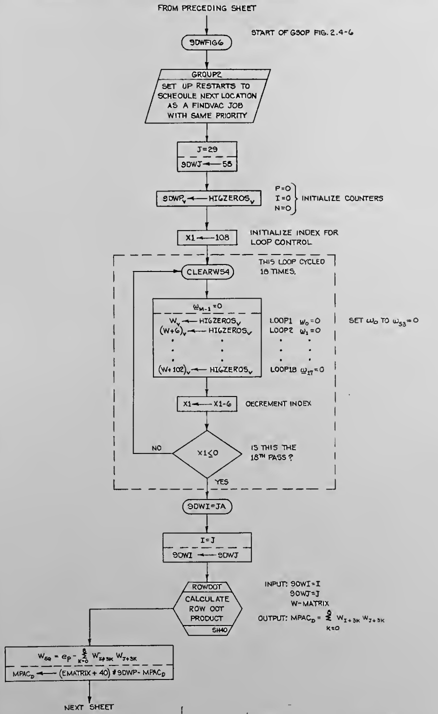
COLOSSUS II

FC-2590

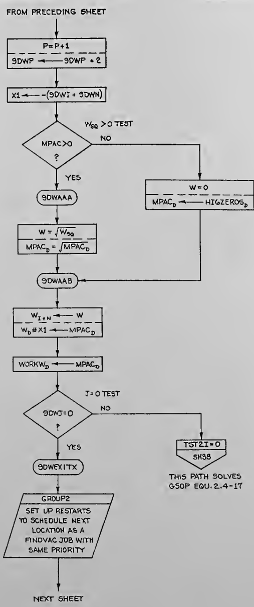
REV. 1



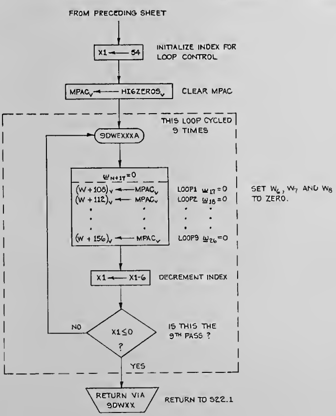
MIT INSTRUMENTATION LAB CAMBRIDGE MASS		P22-ORBITAL NAVIGATION
DRAWN A.C. WILLIAMS	7OCT68	
PRGMR R.E. Smith	23OCT68	
ANALST		COLOSSUS II — FC-2590
DOCMR R. Puscatelli	24OCT68	
APPR'D John A. Moore	29Oct68	REV 1 — 34 · 44



INSTRUMENTATION LAB, CAMBRIDGE, MA		P22-ORBITAL NAVIGATION
DRAWN A.C.WILLIAMS	7OCT68	
PR MR N.E. Smith	23OCT68	
ANAL		COLOSSUS II
DOC MR R. Pucatelli	24 OCT 68	FC-2590
APP John A. Moss	29 OCT 68	35 44



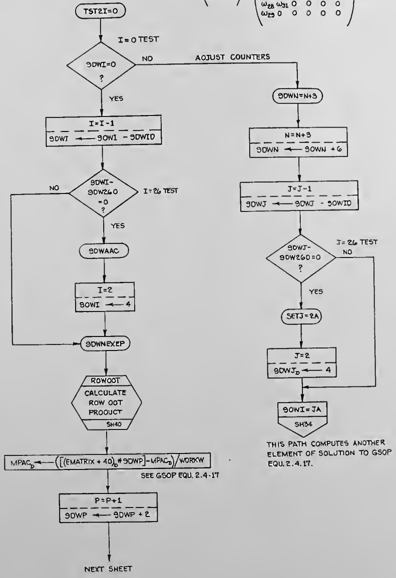
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 30OCT68	PRE-ORBITAL NAVIGATION
PRGMR R.E. Smith 23Oct68	
ANALYST	
DOCMR R. Puccatelli 24Oct68	COLOSSUS II — DOCUMENT NO. FC-2590
APPR'D John A. Moore 29Oct68	REV 1 — SHEET 36 OF 44



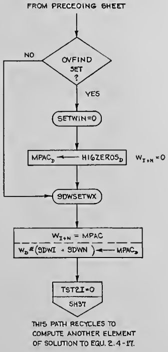
FROM PRECEDING SHEET
X1 ← 54
INITIALIZE INDEX FOR LOOP CONTROL
MPAC_V ← HI6ZEROS_V
CLEAR MPAC
THIS LOOP CYCLED 9 TIMES
9DWEXXXA
ω_{N+17}=0
(W+108)_V ← MPAC_V
(W+112)_V ← MPAC_V
(W+156)_V ← MPAC_V
LOOP1 ω_17=0
LOOP2 ω_18=0
LOOP9 ω_26=0
SET W_6, W_7 AND W_8 TO ZERO.
X1 ← X1-6
DECREMENT INDEX
NO
X1≤0 ?
IS THIS THE 9TH PASS ?
YES
RETURN VIA 9DWXX
RETURN TO S22.1

THIS PART CALCULATES THE SOLUTION (EQU. 2.4-16) TO GSOP EQU. 2.4-17.

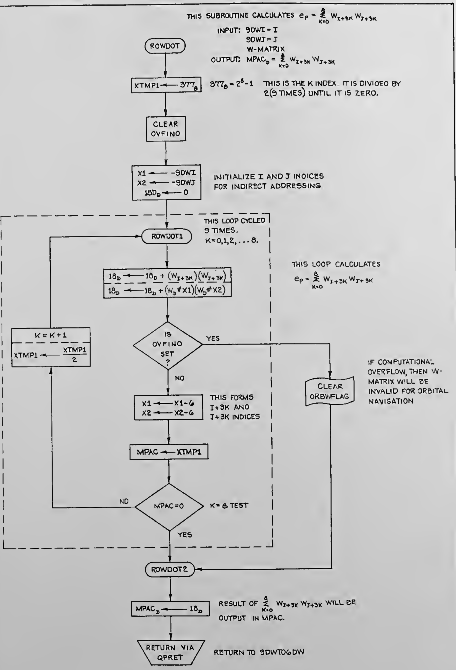
$$\begin{pmatrix} W_0^T & W_1^T \\ W_3^T & W_4^T \end{pmatrix} = \begin{pmatrix} \omega_0 & \omega_3 & \omega_6 & \omega_9 & \omega_{12} & \omega_{15} \\ \omega_1 & \omega_4 & \omega_7 & \omega_{10} & \omega_{13} & 0 \\ \omega_2 & \omega_5 & \omega_8 & \omega_{11} & 0 & 0 \\ \omega_{27} & \omega_{30} & \omega_{33} & 0 & 0 & 0 \\ \omega_{28} & \omega_{31} & 0 & 0 & 0 & 0 \\ \omega_{29} & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \quad \text{EQU. 2.14-16}$$



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 30OCT68	P22-ORBITAL NAVIGATION
PRGMR N. E. Smith 23OCT68	
ANALST	COLOSSUS II — DOCUMENT NO FC-2590
DOCMR R. Pissatelli 24OCT68	
APPR'D John A. Moore 29OCT68	REV 1 — SHEET 38 OF 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	P22-ORBITAL NAVIGATION
DRAWN A.C.WILLIAMS 18OCT68	
PRGMR N.E. Smith 23 OCT 68	
ANALST	COLOSSUS II
DOCMR R.P. [illegible] 29OCT68	FC-2590
APPR'D John A. Moore 31OCT68	REV 1 SH 39 OF 44



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	30CT68	P22-ORBITAL NAVIGATION
PRGMR M. E. Smith	23 OCT 68	
ANALST		COLOSSUS II — DOCUMENT NO. FC-2590
DOCMR R. Pusateri	24 OCT 68	
APPR'D John A. Nom	27 Oct 68	REV 1 — SHEET 40 OF 44

SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
RO2BOTH	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	2283	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	2290	RESERVE INTEGRATION ROUTINE	SH10, 18
INTEGRV	2290	EXTRAPOLATE CSM STATE VECTOR TO TIME TDEC1	SH12
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 $\delta \underline{X}$	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
LUNAFLAG 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.

APOLLO
GUIDANCE AND NAVIGATION

P22-ORBITAL NAVIGATION

DRAWN P.W. Dietrich 16SEP68
PRGMR R. E. Smith 23 OCT 68
ANALST
DOCMR R. Pucatelli 24 OCT 68
APPR'D John A. Moore 29 OCT 68

COLOSSUS II

FC-2590

REV 1

FLAGS (CONT'D)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DIMOFLAG FLAGWORD 3 BIT 1	W-MATRIX IS TO BE USED	W-MATRIX IS NOT TO BE USED	SH10, 18	SH11, 18	
D6OR9FLG FLAGWORD 3 BIT 2	W-MATRIX IS 9 DIMENSIONAL FOR INTEGRATION	W-MATRIX IS 6 DIMENSIONAL FOR INTEGRATION	SH10, 18	SH11, 18	
VINTFLAG FLAGWORD 3 BIT 3	INTEGRATE CSM STATE VECTOR	INTEGRATE LEM STATE VECTOR	SH10, 18		
STATEFLG FLAGWORD 3 BIT 5	PERMANENT STATE VECTOR TO BE UPDATED	PERMANENT STATE VECTOR NOT TO BE UPDATED	SH10, 18		
INTYPFLG FLAGWORD 3 BIT 4	CONIC INTEGRATION	ECKNE INTEGRATION		SH10, 18	
ORBWFLAG FLAGWORD 3	W-MATRIX IS VALID FOR ORBITAL NAVIGATION	W-MATRIX IS INVALID FOR ORBITAL NAVIGATION		SH39	SH11, 18
DMENFLG FLAGWORD 5 BIT 9	W-MATRIX IS 9 DIMENSIONAL FOR INCORPORATION	W-MATRIX IS 6 DIMENSIONAL FOR INCORPORATION	SH15	SH12	SH13, 18
INCORFLG FLAGWORD 5 BIT 11	FIRST INCORPORATION PASS	SECOND INCORPORATION PASS	SH14	SH17	SH17
VEHUPFLG FLAGWORD 1 BIT 8	CSM STATE VECTOR IS BEING UPDATED	LEM STATE VECTOR IS BEING UPDATED	SH15		
22DSPFLG FLAGWORD 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	STATE VECTOR R1 = xxxx.x NAUT. MI. - POSITION CHANGE R2 = xxxx.x FT/SEC - VELOCITY CHANGE R3 = BLANK	SH16

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TDEC1	t	TIME FOR INTEGRATION	SEC	CSEC	2^{28}
VATT	V_C	CONIC VELOCITY VECTOR	METERS/SEC	METERS/CSEC	$2^7/2^5$
RATT	R_C	CONIC POSITION VECTOR		METERS	$2^{29}/2^{27}$
REFSMMAT		BASIC REFERENCE TO STABLE MEMBER COORDINATE SYSTEM TRANSFORMATION MATRIX			2^1
+ MGA		MIDDLE GIMBAL ANGLE	DEG	REV	2^1
LANDMARK		LANDMARK DATA DISPLAY NOUN		(INTEGER)	2^{14}
MARKINDX		REGISTER CONTAINING NUMBER OF MARKS TO BE TAKEN BY R53		(INTEGER)	2^{14}
MARKSTAT		ADDRESS OF MARK DATA VAC AREA		(INTEGER)	2^{14}
8NN	N	NUMBER OF MARKS TAKEN		(INTEGER)	2^{14}
S22TOFF		RETURN LOCATION FROM P22SUBRA		(INTEGER)	2^{14}
22SUBSCL	DE	LANDMARK COORDINATE INDICATOR		(INTEGER)	2^{14}
LAT		LANDMARK LATITUDE	DEG	REV	2^0
LONG		LANDMARK LONGITUDE	DEG	REV	2^0
ALT		LANDMARK ALTITUDE	NAUT. MI.	METERS	2^{29}
RLS		LANDING SITE COORDINATE VECTOR	NAUT. MI.	METERS	2^{27}
ALPHAV		TEMPORARY STORAGE VECTOR			VARIABLE
CXOFF	B	OFFSET MARK INDICATOR		(INTEGER)	2^{14}
LANDALT		LANDMARK ALTITUDE DISPLAY NOUN	NAUT. MI.	METERS	$2^{29}/2^{27}$
LANDLONG		LANDMARK LONGITUDE DISPLAY NOUN	DEG	REV	2^1
S22RTNEX		RETURN LOCATION FROM S22.1		(INTEGER)	2^{14}
8KK	M	NUMBER OF MARK BEING PROCESSED		(INTEGER)	2^{14}
S22LOC		ADDRESS OF DATA FOR Mth MARK		(INTEGER)	2^{14}
SVMRKDAT		BEGINNING ADDRESS OF MARK DATA SAVE AREA		(INTEGER)	2^{14}
S22EORM		EARTH/MOON SCALE ADJUSTING REGISTER		(INTEGER)	2^{14}
CSMPOS	r_c	CONIC POSITION VECTOR		METERS	$2^{29}/2^{27}$
DELTACSM	δ	CONIC POSITION DEVIATION		METERS	$2^{29}/2^{27}$
RCVCSM	r_c	CONIC REFERENCE POSITION		METERS	$2^{29}/2^{27}$
MARKDATA		ADDRESS OF MARK ANGLES		(INTEGER)	2^{14}
UM	U_M	LINE OF SIGHT VECTOR			VARIABLE
S22TOFF		OFFSET LANDING SITE TIME	SEC	CSEC	2^{28}
S22UOFF		OFFSET LANDING SITE LOS UNIT VECTOR			2^1
X789	r_ℓ	LANDMARK POSITION VECTOR		METERS	$2^{29}/2^{27}$
S22TPRIM	t'	TIME FOR LANDMARK POSITION	SEC	CSEC	2^{28}
RCLP	r_{CL}	CSM TO LANDMARK LOS		METERS	$2^{29}/2^{27}$
USTAR	U_S	FICTITIOUS STAR DIRECTION UNIT VECTOR			2^1
VARIANCE	σ^2	INSTRUMENT ERROR VARIANCE			$2^{29}/2^{27}$
BVECTOR	(b_1, b_2, b_3)	GEOMETRY OF MEASUREMENT UNIT VECTOR			$(2^1, 2^1, 2^1)$
DELTAX	δr	STATE VECTOR POSITION DEVIATION		METERS	$2^{29}/2^{27}$
DELTAX +6	δv	STATE VECTOR VELOCITY DEVIATION	METERS/SEC	METERS/CSEC	$2^7/2^5$
ERADM	r_o	RADIUS OF EARTH/MOON		METERS	$2^{29}/2^{27}$
W		W-MATRIX			VARIABLE
S22RL	r_ℓ	TEMPORARY STORAGE OF LANDMARK POSITION		METERS	$2^{29}/2^{27}$
S22D	d	INTERMEDIATE SCALAR			$2^{30}/2^{28}$

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APOLLO GUIDANCE AND NAVIGATION

P22-ORBITAL NAVIGATION

DRAWN D. M. Dietrich 18SEP68
PRGMR R. E. Smith 23 OCT 68
ANALST
DOCMR R. Ruscitelli 24 OCT 68
APPR'D John A. Moore 31 OCT 68

COLOSSUS II

REV 1

DRAWING NO. FC-2590

ERASABLE LOCATIONS USED (CONT'D)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
S22UMRL	U	WORK MATRIX			VARIABLE
S22RHO	ρ	VARIABLE USED IN INITIALIZING W_8			$2^{30}/2^{28}$
S22UUT	$\underline{\ast}\underline{\ast}^T$ UU	VARIABLE USED IN INITIALIZING W_8			VARIABLE
9DWXX		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}
DEC1B2		DECIMAL 1	1		2^2
9DW26D		DECIMAL 52	52	(INTEGER)	2^{14}
IMUVAR	VAR_{IMU}	IMU ERROR VARIANCE	$.1313 \times 10^{-3}$ DEG^2	$.04 \times 10^{-6}$ RAD^2	2^{-18}
SCTVAR	VAR_{SCT}	SCT ERROR VARIANCE	$.328 \times 10^{-2}$ DEG^2	1.0×10^{-6} RAD^2	2^{-18}

PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
WORBPOS	$\omega_{\ell r}$	ORBITAL NAVIGATION W-MATRIX POSITION INITIALIZATION VALUE	TO BE DETERMINED	METERS	2^{19}	
WORBVEL	$\omega_{\ell v}$	ORBITAL NAVIGATION W-MATRIX VELOCITY INITIALIZATION VALUE	TO BE DETERMINED	METERS/CSEC	2^0	
S22WSUBL	ω_ℓ	ORBITAL NAVIGATION W-MATRIX LANDMARK INITIALIZATION VALUE	TO BE DETERMINED	METERS	2^{19}	
RPVAR	VAR_{RP}	VARIANCE OF PRIMARY BODY RADIUS ERROR		METERS^2	2^{28}	

P23 - CISLUNAR MIDCOURSE NAVIGATION
CALLED FROM DSKY

POINTAXS - COMPUTES THE CSM TO LANDMARK/HORIZON POINTING VECTOR Sh. 13
HORIZ - COMPUTES HORIZON LOCATION VECTOR 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.

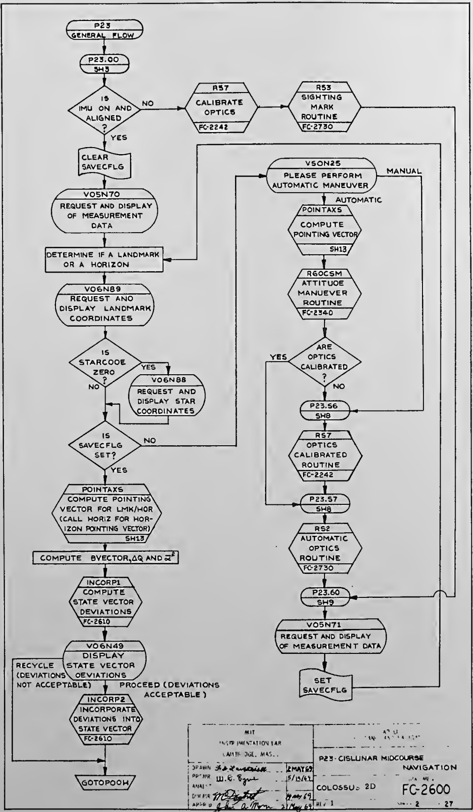
2) "VARIABLE" IN THE SCALING FIELD OF THE SUMMARY SHEETS INDICATES THAT THE ERASABLE LOCATION IS EITHER A MATRIX WHOSE COMPONENTS HAVE DIFFERENT SCALING OR A TEMPORARY REGISTER WITH MANY DIFFERENT SCALINGS.

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. N70, 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 "N70".


P23
GENERAL FLOW
P23.00
SH3
IS IMU ON AND ALIGNED ?
NO
YES
R57
CALIBRATE OPTICS
FC-2242
R53
SIGHTING MARK ROUTINE
FC-2730
CLEAR SAVECFLG
V05N70
REQUEST AND DISPLAY OF MEASUREMENT DATA
DETERMINE IF A LANDMARK OR A HORIZON
V06N89
REQUEST AND DISPLAY LANDMARK COORDINATES
IS STARCODE ZERO ?
YES
NO
V06N88
REQUEST AND DISPLAY STAR COORDINATES
IS SAVECFLG SET?
NO
YES
POINTAXS
COMPUTE POINTING VECTOR FOR LMK/HOR (CALL HORIZ FOR HORIZON POINTING VECTOR)
SH13
COMPUTE BVECTOR, ΔQ AND $\bar{\alpha}^2$
INCORP1
COMPUTE STATE VECTOR DEVIATIONS
FC-2610
V06N49
DISPLAY STATE VECTOR DEVIATIONS
RECYCLE (DEVIATIONS NOT ACCEPTABLE)
PROCEED (DEVIATIONS ACCEPTABLE)
INCORP2
INCORPORATE DEVIATIONS INTO STATE VECTOR
FC-2610
GOTOPOOH
V50N25
PLEASE PERFORM AUTOMATIC MANEUVER
MANUAL
AUTOMATIC
POINTAXS
COMPUTE POINTING VECTOR
SH13
R60CSM
ATTITUDE MANUEVER ROUTINE
FC-2340
ARE OPTICS CALIBRATED ?
YES
NO
P23.56
SH8
R57
OPTICS CALIBRATED ROUTINE
FC-2242
P23.57
SH8
R52
AUTOMATIC OPTICS ROUTINE
FC-2730
P23.60
SH9
V05N71
REQUEST AND DISPLAY OF MEASUREMENT DATA
SET SAVECFLG
MIT
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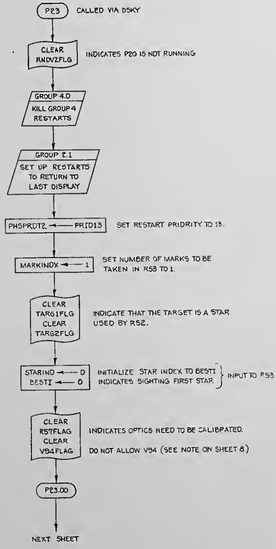
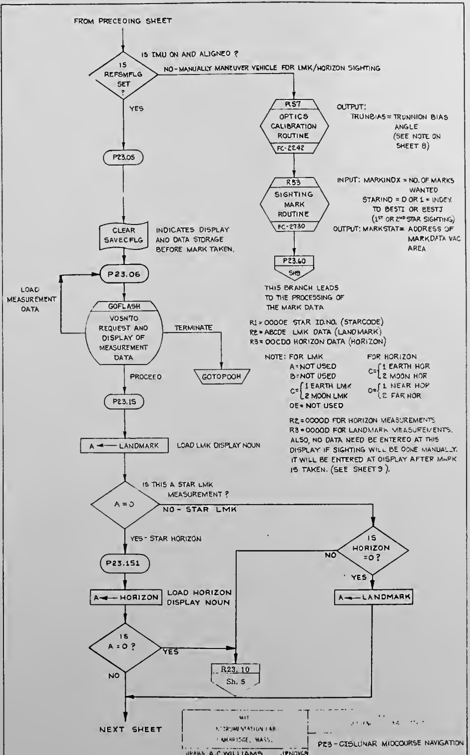
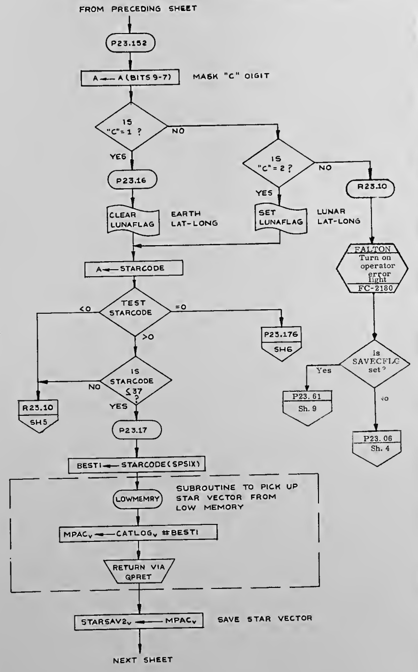
CAMBRIDGE, MASS.
DRAWN
2 MAY 69
W. G. Byrne
5/14/69
P23-CISLUNAR MIDCOURSE NAVIGATION
COLOSSUS 2D
FC-2600
REV 1
2
27



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 8NOV68	P23 - CISLUNAR MIDCOURSE NAVIGATION
PRGMR W. E. Byrne 5/19/69	
ANALST	
DOCMR W C Dogforth 4/23/69	COLOSSUS 2D — FC-2600
APPR'D John A. Moss 21 May 69	REV 1 — 3 — 27



FROM PRECEDING SHEET
IS IMU ON AND ALIGNED ?
IS REFSMFLG SET ?
NO - MANUALLY MANEUVER VEHICLE FOR LMK/HORIZON SIGHTING
YES
R57
OPTICS CALIBRATION ROUTINE
FC-2242
OUTPUT:
TRUNBIAS = TRUNNION BIAS ANGLE (SEE NOTE ON SHEET 8)
P23.05
R53
SIGHTING MARK ROUTINE
FC-2730
INPUT: MARKINDX = NO. OF MARKS WANTED
STARIND = 0 OR 1 = INDEX TO BESTI OR BESTJ (1ST OR 2ND STAR SIGHTING)
OUTPUT: MARKSTAT = ADDRESS OF MARKDATA VAC AREA
CLEAR SAVECFLG
INDICATES DISPLAY AND DATA STORAGE BEFORE MARK TAKEN.
P23.60
SH9
P23.06
THIS BRANCH LEADS TO THE PROCESSING OF THE MARK DATA
LOAD MEASUREMENT DATA
GOFLASH
V06N70 REQUEST AND DISPLAY OF MEASUREMENT DATA
TERMINATE
R1 = 0000E STAR ID. NO. (STARCODE)
R2 = ABCDE LMK DATA (LANDMARK)
R3 = 00CD0 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}
D = {1 NEAR HOR, 2 FAR HOR}
PROCEED
GOTOPOOH
P23.15
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 9).
A ← LANDMARK
LOAD LMK DISPLAY NOUN
IS THIS A STAR LMK MEASUREMENT ?
A = 0
NO - STAR LMK
YES - STAR HORIZON
IS HORIZON = 0 ?
NO
YES
P23.151
A ← HORIZON
LOAD HORIZON DISPLAY NOUN
A ← LANDMARK
IS A = 0 ?
YES
NO
R23.10
Sh. 5
NEXT SHEET
MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.
DRAWN A.C. WILLIAMS 18NOV68
PRGMR W.E. Byrne 5/14/69
ANALYST
DIGMR
APPR'D John A. Moore 21 May 69
P23 - CISLUNAR MIDCOURSE NAVIGATION
COLOSSUS 2D
FC-2600
REV 1
4
27



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DRAWN 16APR69
PROGMR W. E. Byrne 5/6/69
ANALYST
DOCMR 4/23/69
APPR'D

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P23-CISLUNAR MIDCOURSE NAVIGATION

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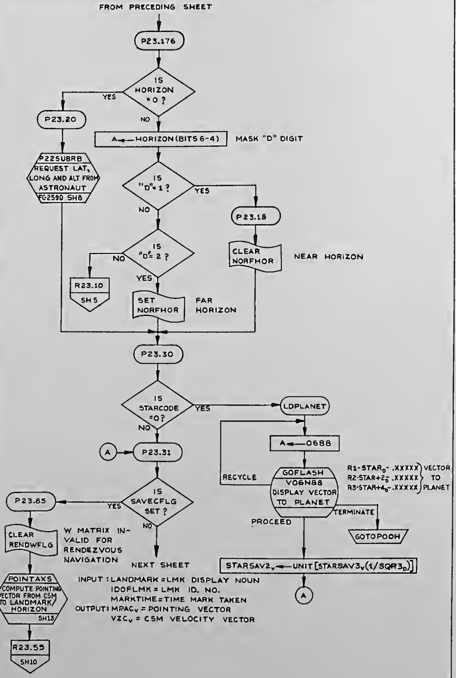
REV 1

SHEET 5 OF 27



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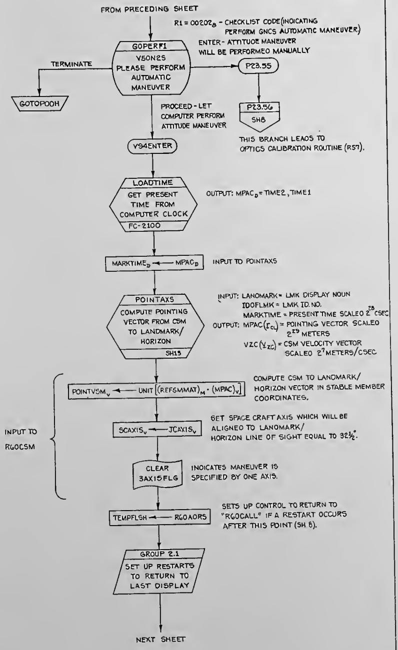
P23- CISLUNAR MIDCOURSE NAVIGATION

COLOSSUS 2D

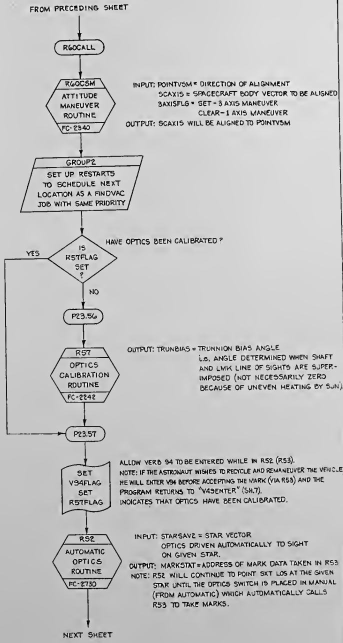
FC-2600

PROGMR W.E. Byrd 5/19/69

6 of 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	13NOV68	P23-CISLUNAR MIDCOURSE NAVIGATION
PRGMR W.E. Byrne	5/14/69	
ANALST		COLOSSUS 2D — DOCUMENT NO. FC-2600
DOCMR M. Digiovanni	4/23/69	
APPR'D John A. Moore	21 May 69	REV 1 — SH 7 OF 27



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

GUIDANCE AND NAVIGATION

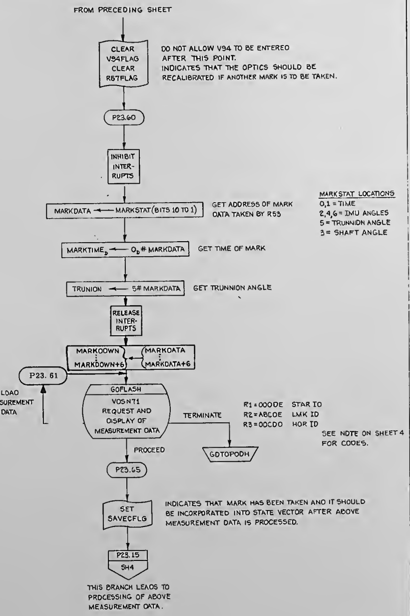
DRAWN A C WILLIAMS 15NOV68
PRGMR W. E. Byrne 5/11/69
ANALST
DOCMR W C Dophitt 4/23/69
APPR'D John A. Moore 24 May 69

P23 - CISLUNAR MIDCOURSE NAVIGATION

COLOSSUS 2D

DOCUMENT NO. FC-2600

REV 1



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DRAWN	A.C.WILLIAMS	13NOV68
PRGMR	W. E. Byrne	5/15/69
ANALYST		
GDCMR	[illegible]	4/23/69
APPR'D	John A. Mo[illegible]	21 May 69

P23 - CISLUNAR MIDCOURSE NAVIGATION

COLOSSUS 2D

FC-2600

9 27

R23.5S

u_{CL} = UNIT(r_{CL})

$POLO_V$ ←— UNIT$(MPAC)_V$

COMPUTE UNIT POINTING VECTOR FROM CSM TO LANDMARK/HORIZON.
GSOP EQU. 2.6.2

POL30 = r_{CL}^2
POL32 = $|r_{CL}|$

$POL30_V$ ←— $POL34_V$

SAVE r_{CL}^2 FOR USE IN COMPUTING THE VARIANCE, α^2.
NOTE: r_{CL}^2 (AND $|r_{CL}|$ IN POL32) ARE FORMED BY THE ABOVE UNIT INSTRUCTION.

$u_{CL}^* = UNIT(u_{CL} + V_C'/c)$

$UCLSTAR_V$ ←— UNIT$(POLO_V + (VZC)_V (ONE/C))$

CORRECT POINTING VECTOR FOR ABERRATION.
GSOP EQU. 2.6.4

$u_S^* = UNIT(u_S + (V_C' - V_{ES})/C)$

$USSTAR_V$ ←— UNIT$(US_V + [(VZC_V - VESO_V)(ONE/C)])$

CORRECT STAR VECTOR FOR ABERRATION.
GSOP EQU. 2.6.3
V_{ES} = VELOCITY OF SUN RELATIVE TO THE EARTH.

$COSQ = u_S^* \cdot u_{CL}^*$

$POLO_D$ ←— $USSTAR_V \cdot UCLSTAR_V$

COMPUTE COSINE OF ESTIMATED ANGLE BETWEEN STAR AND POINTING VECTOR
GSOP EQU. 2.6.21

$b_0 = UNIT(u_S^* - COSQ \cdot u_{CL}^*)$

$BVECTOR_V$ ←— UNIT$(USSTAR_V - (POLO_D \cdot UCLSTAR_V))$

$b_1 = 0$
$b_2 = 0$

$(BVECTOR + 6)_V$ ←— $ZEROVECS_V$
$(BVECTOR + 12)_V$ ←— $ZEROVECS_V$

COMPUTE GEOMETRY OF MEASUREMENT VECTOR (b_0, b_1, b_2)
GSOP EQU. 2.6.21

$POL2 = -COS^{-1}(COSQ)$

$POL2_D$ ←— $-ARCOS(POLO_D)$

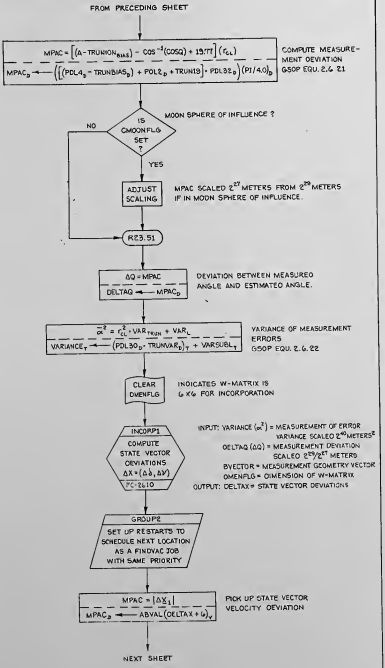
SAVE STAR TO POINTING VECTOR ANGLE

$MPAC_D$ ←— $ZEROVECS_D$
MPAC ←— TRUNION - VARSUBL
$POL4_D$ ←— $MPAC_D$

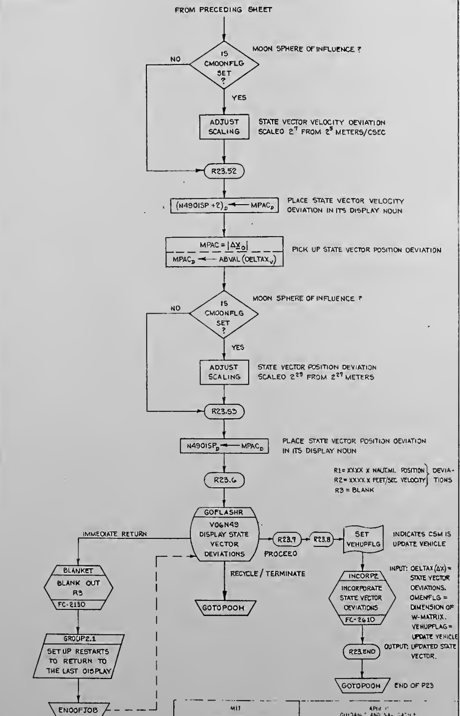
CLEAR MPAC.
CONVERT TRUNNION ANGLE FROM 1'S TO 2'S COMPLEMENT. (BY SPECIAL SUBTRACT INSTRUCTION)
STORE TRUNNION ANGLE FOR LATER USE.

NOTE: VARSUBL IS DEFINED TO BE 3 WORDS, THE FIRST WORD OF WHICH IS ZERO.

NEXT SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	14NOV68	P23 - CISLUNAR MIDCOURSE NAVIGATION
PR. MR W. E. Byrne	5/19/69	
ANALYST		COLOSSUS 2D — DOCUMENT No. FC-2600
DOC MR M C Dogbert	4/29/69	
APPR'D John A. Moore	21 May 69	REV 1 — SHEET 11 OF 27



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

APOLLO GUIDANCE AND NAVIGATION

DRAWN	A.C WILLIAMS	15NOV68
PRGMR	W. R. Byrne	5/19/69
ANAL		
DCLMR	M C Degand	4/23/69
APPR'D	John R. Morse	21 May 69

REV 1

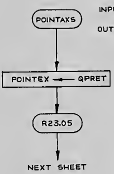
P23-CISLUNAR MIDCOURSE NAVIGATION

COLOSSUS 2D

FC-2600

12 27

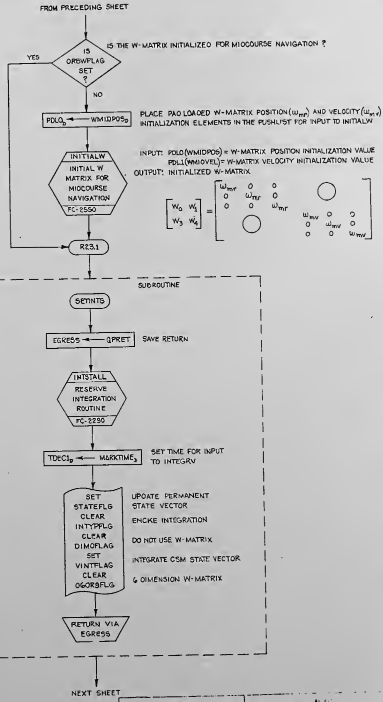
SUBROUTINE WHICH COMPUTES THE CSM TO LANDMARK/HORIZON POINTING VECTOR



INPUT : LANDMARK = LMK DISPLAY NOUN
MARKTIME = TIME MARK TAKEN

OUTPUT: PDLO = MPAC ($\underline{r}_{CL}$) = POINTING VECTOR SCALED 2^{29} METERS
VZC ($\underline{V}_{ZC}$) = CSM VELOCITY VECTOR SCALE 2^{7} METERS/CSEC

SAVE RETURN



$$\begin{bmatrix} W_0 & W_1 \\ W_3 & W_4 \end{bmatrix} = \begin{bmatrix} \omega_{mr} & 0 & 0 & & & \\ 0 & \omega_{mr} & 0 & & \bigcirc & \\ 0 & 0 & \omega_{mr} & & & \\ & & & \omega_{mv} & 0 & 0 \\ & \bigcirc & & 0 & \omega_{mv} & 0 \\ & & & 0 & 0 & \omega_{mv} \end{bmatrix}$$

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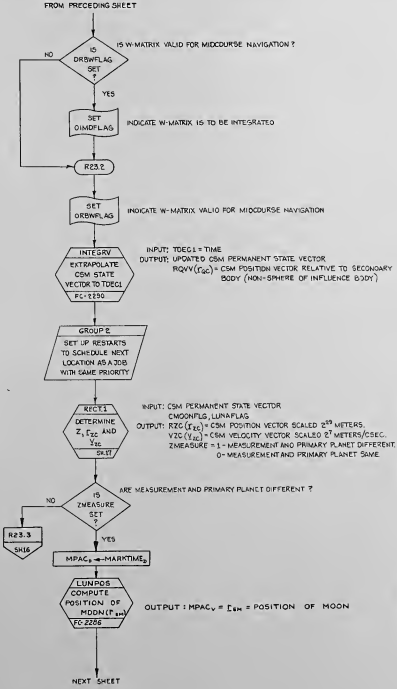
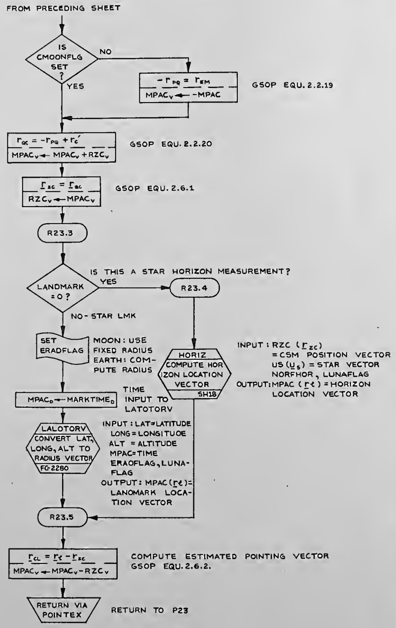
DRAWN A.C. WILLIAMS	25NOV68	P23 - CISLUNAR MIDCOURSE NAVIGATION
PRGMR W.E. Bjune	5/14/69	
ANALST		COLOSSUS 2D FC-2600
DOCMR	4/23/69	
APPR'D	24 May 69	REV 1 SHEET 14 OF 27

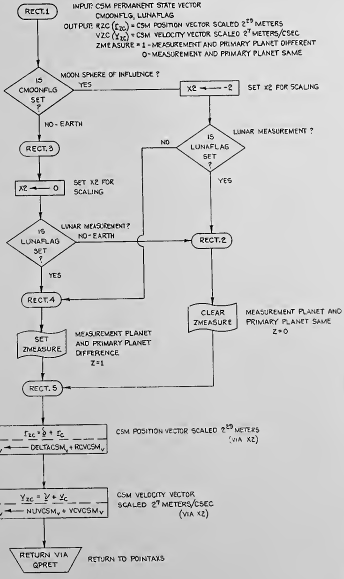


MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 25NOV68	P23 - CISLUNAR MIDCOURSE NAVIGATION
PROG MGR W.E. Bjune 5/19/69	
ANAL	COLOSSUS 2D FC-2600
DEV MGR McDonforth 4/29/69	
APPROVED John R. Moore 21 May 69	REV 1 SHEET 15 OF 27

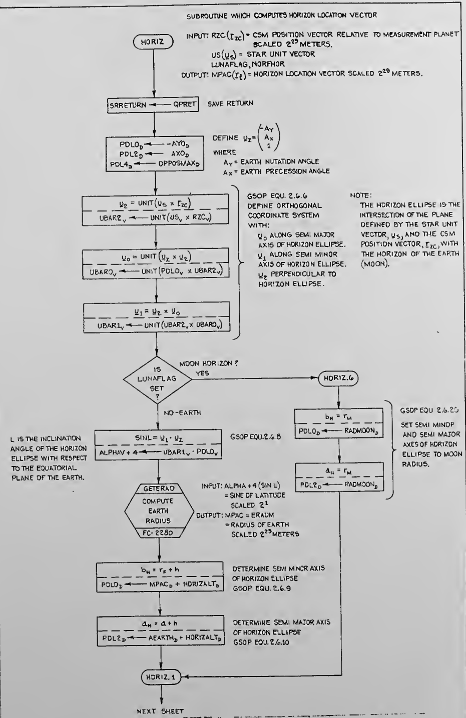


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	P23 CISLUNAR MIDCOURSE NAVIGATION
DRAWN [signature] 5 MAY 69	
CHECKED W. E. Byrne 5/14/69	
ANALYST	
CHECKED [signature] 19 May 69	COLOSSUS 2D FC-2600
APPROVED John A. Morse 21 May 69	REV 1 116 27

SUBROUTINE TO COMPUTE Z, $\underline{r}_{zc}$ AND $\underline{v}_{zc}$



MIT INSTRUMENTATION LAB CAMBRIDGE MASS		
DRAWN A.C. WILLIAMS	25NOV68	P23 - CISLUNAR MIDCOURSE NAVIGATION
CHECKED W.F. Byrne	5/19/69	
ANA		COLOSSUS 2D — FC-2600
DOC MGR McDougald	5/23/69	
APPROVED John A. Norse	21 May 69	REV 1 — 17 — 27



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS

DRAWN A.C. WILLIAMS 26NOV68
PROMP W.E. Byrne 5/14/69
ANALYST
CHKR MC Daybrith 4/23/69
APPR'D John A. Moore 21 May 69

GUIDANCE AND NAVIGATION

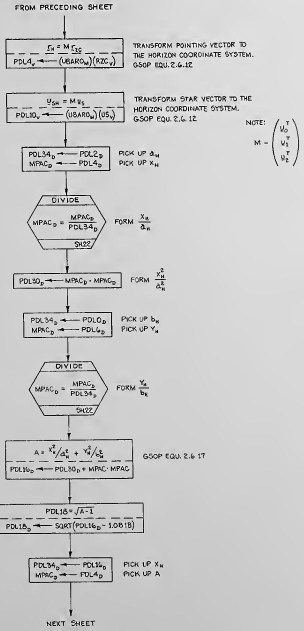
P23-CISLUNAR MIDCOURSE NAVIGATION

COLOSSUS 2D

FC-2600

REV 1

SHEET 18 OF 27



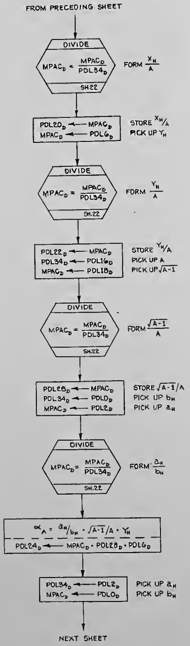
MIT INSTRUMENTATION LAB CAMBRIDGE, MA

A.C. WILLIAMS 26NOV68
W. E. Byrne 5/14/69
McGlothin 4/23/69
John A. Moore 21 May 69

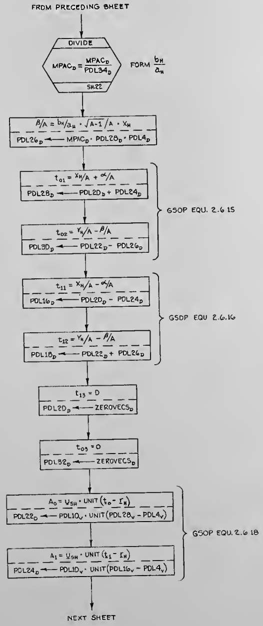
P23 - CISLUNAR MIDCOURSE NAVIGATION

COLOSSUS 2D FC-2600

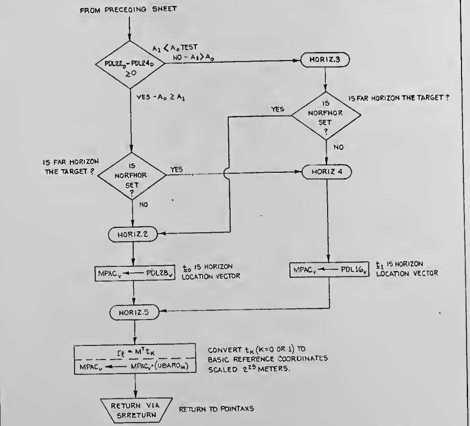
19 27

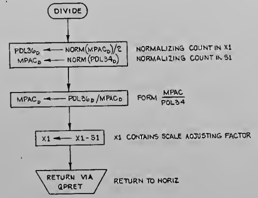


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 26NOV68	P23 - CISLUNAR MIDCOURSE NAVIGATION
PRI MR W.E. Byers 5/19/69	
ANALYST	COLOSSUS 2D
DOCMR W.C. Dogherty 4/23/69	DOCUMENT No. FC-2600
APPR'D John A. Moore 21 May 69	REV 1 SHEET 20 of 27



MIT INSTRUMENTATION LAB CAMBRIDGE MASS	
DRAWN A.C.WILLIAMS 27NOV68	R23-CISLUNAR MIDCOURSE NAVIGATION
W.G. Byrne 5/19/69	COLOSSUS 2D FC-2600
	21 27





MIT AMBR ... MASS	... NAVIGATION
DRAWN A.C. WILLIAMS 27NOV68 PRGMR W.E. Byrne 5/11/69 ANALST DOCMR M C Dygert 4/23/69 APPR'D John A. Norse 21 May 69	R23-CISLUNAR MIDCOURSE NAVIGATION COLOSSUS 2D FC-2600 REV 1 22 27

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	2590	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 TDEC1	SH 15
LUNPOS	2286	COMPUTE POSITION OF MOON	SH 15
LALOTORV	2280	CONVERT LAT, LONG, ALT TO RADIUS VECTOR	SH 16
GETERAD	2280	COMPUTE EARTH RADIUS	SH 18

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	
R57FLAG 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
V94FLAG 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
SAVECFLG 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
LUNAFLAG FLAGWORD 3 BIT 12	LUNAR LAT-LONG	EARTH LAT-LONG	SH 5	SH 5	SH 17, 18
NORFHOR FLAGWORD 0 BIT 11	SIGHTING ON FAR HORIZON	SIGHTING ON NEAR NORIZON	SH 6	SH 6	SH 22
RENDWFLG 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.		APOLLO GUIDANCE AND NAVIGATION
DRAWN G. J. Hengille		P23- CISLUNAR MIDCOURSE NAVIGATION
PRGMR W. S. Bjune	5/1/69	
ANALYST		COLOSSUS 2D · DOCUMENT NO FC-2600
DOCMR W. C. Probst	4/2/69	
APPR'D John R. Moore	21 May 65	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	
VEHUPFLG 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		
INTYPFLG FLAGWORD 3 BIT 4	CONIC INTEGRATION	ENCKE INTEGRATION		SH 14	
DIMOFLAG 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		
D6OR9FLG 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	EARTH: USE FIXED RADIUS	SH 16		
	MOON USE FIXED RADIUS	MOON: USE RLS FOR RADIUS			

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V05N70	FLASHING	R1 = 000DE = STAR ID NO R2 = ABCDE = LMK DATA R3 = 00CD0 = HORIZON DATA REQUEST MEASUREMENT DATA BEFORE MARK IS TAKEN	SH 4
V06N88	FLASHING	R1 = $STAR_D$ - .XXXXX R2 = $STAR{+}2_D$ - .XXXXX R3 = $STAR{+}4_D$ - .XXXXX VECTOR TO PLANET	SH6
V50N25	FLASHING	R1 = 00202 PLEASE PERFORM AUTOMATIC MANEUVER	SH7
V05N71	FLASHING	R1 = 000DE = STAR ID NO R2 = ABCDE = LMK DATA R3 = 000CD0 = HORIZON DATA REQUEST MEASUREMENT DATA AFTER MARK IS TAKEN	SH9
V06N49	FLASHING	R1 = XXXX.X NAUT. MI. POSITION DEVIATION R2 = XXXX.X FEET/SEC VELOCITY DEVIATION R3 = BLANK	SH12

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNIT	AGC UNIT	AGC SCALING
PHSPRDT2		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			$(2^1, 2^1, 2^1)$
SCAXIS		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	$\underline{u}^*_{CL}$	CSM TO LANDMARK/HORIZON UNIT VECTOR CORRECTED FOR ABERRATION			$(2^1, 2^1, 2^1)$
VZC	$\underline{V}'_C$	CSM VELOCITY VECTOR	FEET/SEC	METERS/CSEC	$(2^7, 2^7, 2^7)$
USSTAR	$\underline{u}^*_S$	STAR UNIT VECTOR CORRECTED FOR ABERRATION			$(2^1, 2^1, 2^1)$
US	$\underline{u}_S$	STAR UNIT VECTOR			$(2^1, 2^1, 2^1)$
BVECTOR	$(\underline{b}_0, \underline{b}_1, \underline{b}_2)$	GEOMETRY OF MEASUREMENT MATRIX			VARIABLE
TRUNBIAS		CALIBRATION ANGLE FOR SEXTANT	DEG	REV	2^3
DELTAQ	ΔQ	MEASURED AND ESTIMATED DEVIATION	NAUT. MI.	METERS	$2^{29}, 2^{27}$
VARIANCE	$-\alpha^2$	VARIANCE OF MEASUREMENT ERRORS		METERS^2	2^{40}
DELTAX	$\Delta \underline{x}_0$	STATE VECTOR POSITION DEVIATIONS	NAUT. MI.	METERS	$2^{29}, 2^{27}$
DELTAX+6	$\Delta \underline{x}_1$	STATE VECTOR VELOCITY DEVIATIONS	FEET/SEC	METERS/CSEC	$2^7, 2^5$
N49DISP		DISPLAY NOUN FOR DELTAX	NAUT. MI.	METERS	2^{29}
N49DISP+6		DISPLAY NOUN FOR DELTAX+6	FEET/SEC	METERS/CSEC	2^7
POINTEX		RETURN ADDRESS FROM POINTAXS		(INTEGER)	2^{14}

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}
EGRESS		SUBROUTINE RETURN ADDRESS		(INTEGER)	2^{14}
TDEC1		TIME FOR INTEGRATION	SEC	CSEC	2^{28}
RZC	$\underline{r}_{ZC}$	CSM POSITION VECTOR RELATIVE TO MEASUREMENT PLANET		METERS	2^{29}
RQVV	$\underline{r}_{QC}$	CSM POSITION VECTOR RELATIVE TO SECONDARY PLANET		METERS	2^{29}
RL	$\underline{r}_{\ell}$	LANDMARK/HORIZON LOCATION VECTOR		METERS	2^{29}
RCLL	$\underline{r}_{CL}$	CSM TO LANDMARK/HORIZON VECTOR		METERS	2^{29}
DELTACSM	$\underline{\delta}$	CSM CONIC POSITION DEVIATION		METERS	$2^{22}/2^{18}$
RCVCSM	$\underline{r}_{C}$	CSM REFERENCE CONIC POSITION		METERS/ CSEC	$2^{29}/2^{27}$
NUVCSM	$\underline{\nu}$	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	$\underline{U}_2$				$(2^{1}, 2^{1}, 2^{1})$
ALPHAV+4		SINE OF LATITUDE (FOR GETERAD)			2^{1}

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
PR1013		PRIORITY 13 REGISTER	13	13000	2^{14}
SPSIX		SINGLE PRECISION 6	6	00006	2^{14}
CATLOG		BEGINNING ADDRESS OF STORED STAR VECTORS		(INTEGER)	2^{14}
JCAXIS		TRACK AXIS VECTOR	$57\frac{1}{2}^{\circ}$ 90° $32\frac{1}{2}^{\circ}$	.268649805 0 .421695725	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^{-21}
ZEROVECS		BEGINNING ADDRESS OF 6 REGISTERS OF 0	0	0	2^{14}
VARSUBL		LANDMARK/HORIZON ERROR VARIANCE		3.4299040×10^6	2^{40}
TRUN19		TRUNNION BIAS ANGLE	19.77 DEG	.055 REVS	2^0
P1/4.0		CONVERSION FACTOR REVS TO RADIANS	$2\pi \frac{\text{RAD}}{\text{REV}}$	$.1592 \frac{\text{RAD}}{\text{REV}}$	2^3
TRUNVAR		TRUNNION ERROR VARIANCE		2.5×10^{-9}	2^{-18}
9DWID		DECIMAL 2		(INTEGER)	2^{14}
LATTAB		BEGINNING ADDRESSES OF STORED LANDMARK LATITUDE, LONGITUDE, AND ALTITUDE TABLES		(INTEGER)	2^{14}
LONGTAB					
ALTTAB					
DPPOSMAX		DOUBLE PRECISION REGISTER CONTAINING MAXIMUM VALUE	.999999996	37777 37777	2^0
PADMOON	r_m	RADIUS OF MOON		1738090 METERS	2^{29}
AEARTH	a	A - AXIS OF EARTH		6378166 METERS	2^{29}

PAD LOADS

AGC TAG	GSOP TAG	MEANING
WM1DPOS	w_{mr}	W - MATRIX POSITION INITIALIZATION VALUE
WMIDVEL	w_{vr}	W - MATRIX VELOCITY INITIALIZATION VALUE
VESO	$\underline{V}_{ES}$	VELOCITY OF SUN RELATIVE TO EARTH
-AYO	A_Y	EARTH NUTATION ANGLE
AXO	A_X	EARTH PRECESSION ANGLE
HORIZALT	h	EARTH HORIZON ALTITUDE

NAVIGATION EXTENDED VERBS

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

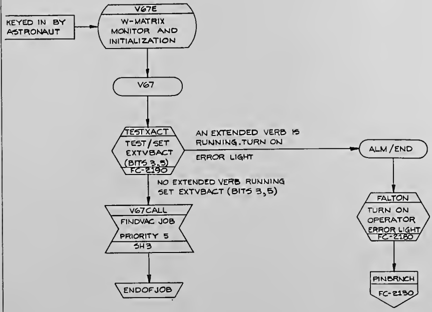
SH. 1-3	REV 0
SH. 4-5	REV. 1
SH. 6-7	REV. 0

DRAWN	F. S. Chmielewski	
PROJ	M. E. Smith	7 JAN 69
CHKR	R. PISCATELLI	7 FEB 69
APPR	John J. Moran	7 FEB 69

NAVIGATION EXTENDED VERBS

COLOSSUS IIA FC-2605

REV 1 1 7

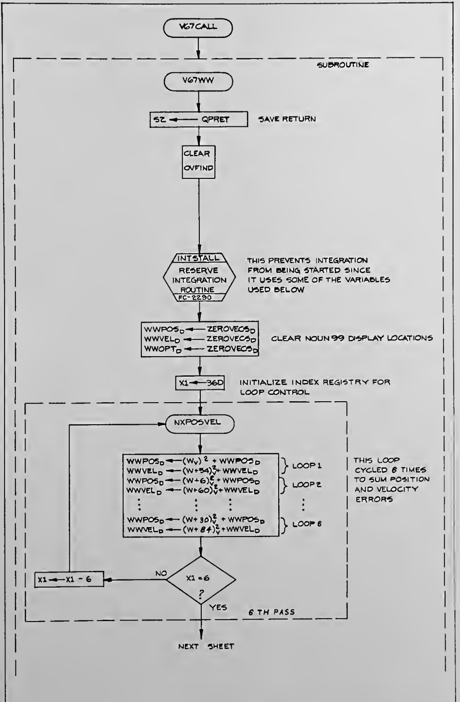


M E Smith 7FEB69
R. PISCATELLI 7FEB69
John A. Moore 7FEB69

NAVIGATION EXTENDED VERBS

COLOSSUS IIA FC-2605

REV 1 2 7



INSTRUMENTATION LAB
CAMBRIDGE, MASS

DRAWN	D. S. Chmielinski	27 DEC 68
PRGMR	M. E. Smith	7 FEB 69
ANALYST		
DOC MPR	R. PISCATELLI	7 FEB 69
APPR'D	John A. Miller	7 FEB 69

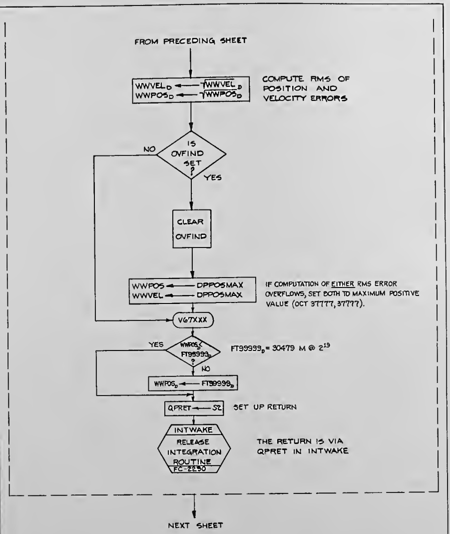
GUIDANCE AND NAVIGATION

NAVIGATION EXTENDED VERBS

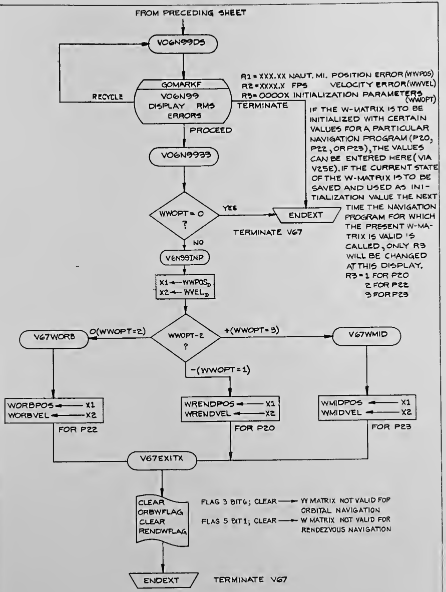
COLOSSUS IIA FC-2605

REV 1

3 of 7



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN Z. L. Chmielinski 27DEC68	NAVIGATION EXTENDED VERBS
PRGMR M. E. Smith 7FEB69	
ANALST	DOCUMENT NO. COLOSSUS IIA FC-2605
DOCMR R. PISCATELLI 7FEB69	
APPR'D John A. Moore 7FEB69	REV 2 SHEET 4 OF 7



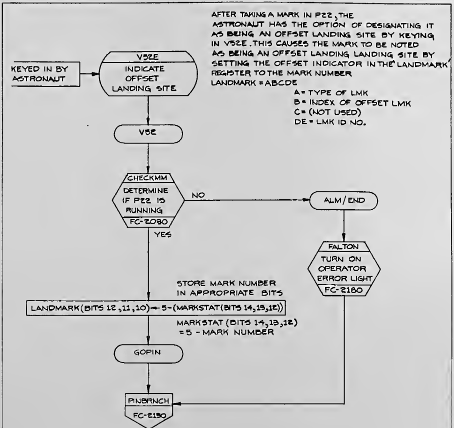
INSTRUMENTATION LAB
CAMBRIDGE MASS

DRAWN T. S. Chojnacki 30DEC68
PRGMR M. E. Smith 7FEB69
ANALST
DOCMR R. PISCATELLI 7FEB69
APPR John A. Moore 7FEB69

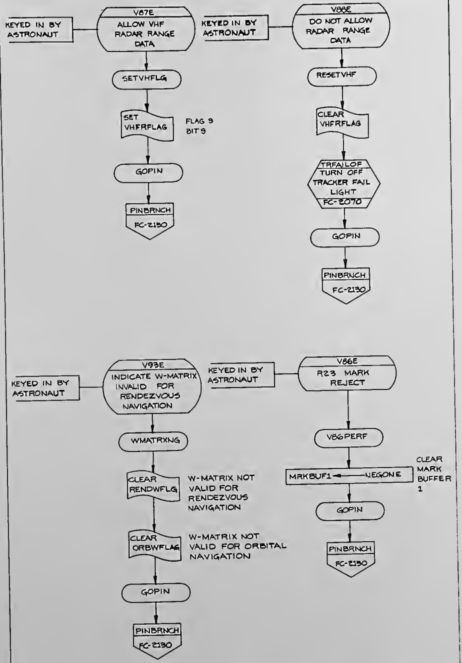
NAVIGATION EXTENDED VERBS

COLOSSUS IIA FC-2605

REV 1 5 7



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN		NAVIGATION EXTENDED VERBS
PRGMR M. E. Smith	7FEB69	
ANALST		COLOSSUS IIA FC-2605
DOCMR R. PISCATELLI	7FEB69	
APPR'D John A. Miller	7FEB69	REV 1 SHEET 6 OF 7



MIT INSTRUMENTATION LAB
CAMBRIDGE MASS.

DRAWN [signature]
PRGMR N. E. Smith 7FEB69
ANALST
DOCMR R. PISCATELLI 7FEB69
APPR'D John A. Miller 7FEB69

NAVIGATION EXTENDED VERBS

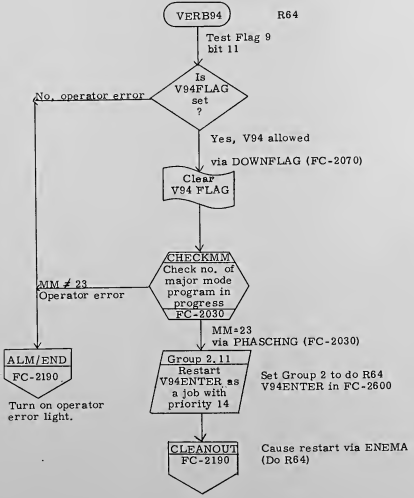
COLOSSUS IIA FC-2605

REV 1 SH. 7 OF 7

V94 (R64)

VERB94 Sh. 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Hunter	10/29/69	V94 (R64)	
PRGMR R. Whittredge	11/25/69	COLOSSUS 2D	DOCUMENT NO. FC-2606
ANALST			
DOCMR Roberta M. Entes	11/25/69		
APPR'D Roberta M. Entes	11/25/69	REV	SHEET 1 OF 3



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Hunter	10/29/69	V94 (R64)	
PRGMR R. Mittledge	11/25/69		DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2606
DOCMR Roberta M. Estes	11/25/69		
APPR'D Roberta M. Estes	11/25/69	REV	SHEET 2 OF 3

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	
DRAWN R. Hunter	10/29/69	V94 (R64)	
PRGMR R. Whittredge	11/25/69	COLOSSUS 2D	DOCUMENT NO. FC-2606
ANALST			
DOCMR Roberta M. Eaton	11/25/69		
APPR'D Roberta M. Eaton	11/25/69	REV	SHEET 3 OF 3

MEASUREMENT INCORPORATION

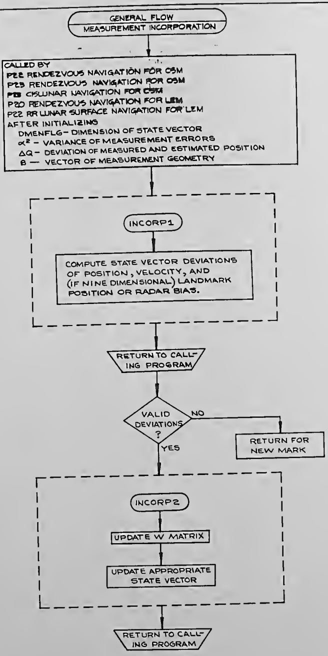
MAJOR SUBROUTINES:

INCORP1 - COMPUTES STATE VECTOR DEVIATIONS

INCORP2 - INCORPORATES STATE VECTOR DEVIATIONS INTO STATE VECTOR

SPECIAL CONVENTIONS:

1. $2^X/2^Y$ 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 SH14)



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	MEASUREMENT INCORPORATION
DRAWN F.W. Scott 30 Aug 68	
PROMP L.R. Jennings 1 Oct 68	COLOSSUS II — FC-2610
ANALST	
DOCMR R. Pucatelli 1 Oct 68	2 — 16
APPR'D John A. Rowe 1 Oct 68	REV

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 6X6 OR 9X9

DELTAQ = ΔQ = DEVIATION BETWEEN ESTIMATED AND ACTUAL TRACKING MEASUREMENT (SCALAR)

VARIANCE = α^2 = VARIANCE INHERENT IN MEASUREMENT AND STATE VECTOR UNCERTAINTIES (SCALAR)

BVECTOR = 6 OR 9 DIMENSIONAL GEOMETRY OF MEASUREMENT VECTOR

DMENFLG = DIMENSION OF W
0 = 6X6   1 = 9X9

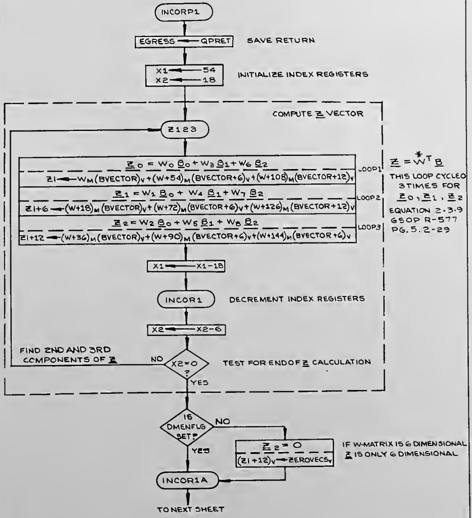
OUTPUT

DELTAX = ΔX = 6 OR 9 DIMENSIONAL STATE VECTOR DEVIATIONS

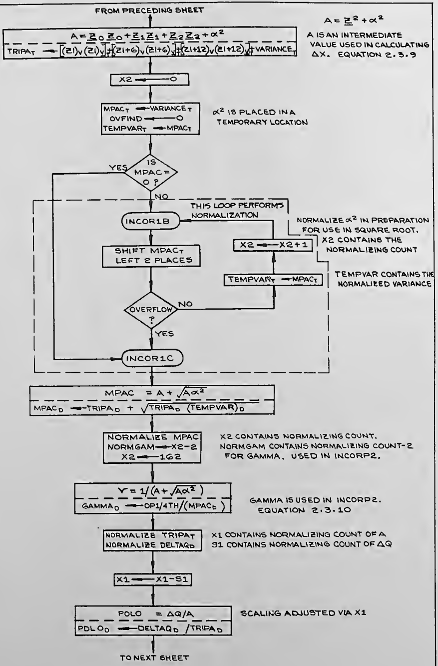
ZI = 6 OR 9 DIMENSIONAL VECTOR USED FOR THE INCORPORATION

OMEGA = ω = 6 OR 9 DIMENSIONAL OMEGA WEIGHTING VECTOR

GAMMA = γ = SCALAR USED FOR INCORPORATION



DRA: J. W. Frost 30 Jul 68	MEASUREMENT INCORPORATION	
CR: S R Jennings 1 Oct 68		
ANALYST: R. Pucalelli 1 Oct 68	COLOSSUS II	FC-2610
APPR: John A. Moore 1 Oct 68		5 16



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

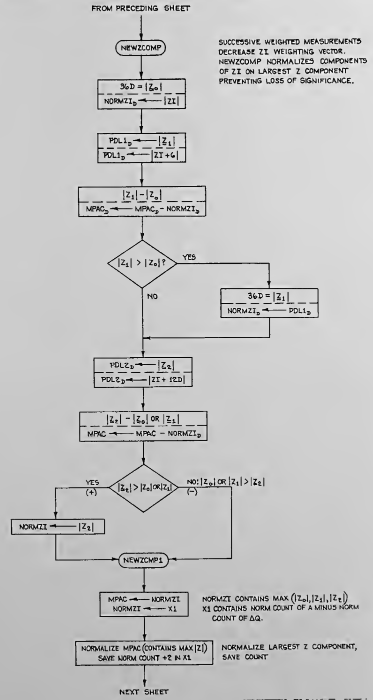
DRAWN 5 July 68
PROGMR S.R. Jennings 1 Oct 68
CHECKED R. Pucatelli 1 Oct 68
APPR'D John A. Moore 1 Oct 68

MEASUREMENT INCORPORATION

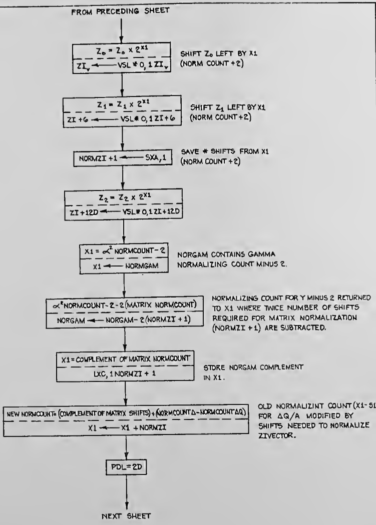
COLOSSUS II

FC-2610

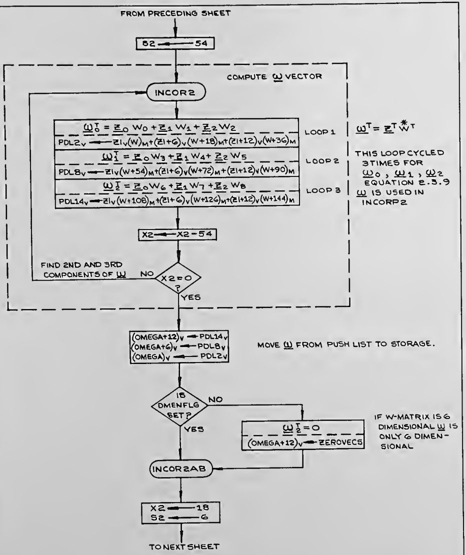
4 16



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 21FEB69 PRGMR A. Bartlett 12 Mar 69 ANALST DOCMP [signature] Mar 12, 69 APPR'D John A. Moore 12 MAR 69	MEASUREMENT INCORPORATION COLOSSUS II FC-2610 REF. 5 16



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	24FEB69	MEASUREMENT INCORPORATION
PRGMR A. Corbett	12 Mar 69	DOCUMENT No.
ANALST		COLOSSUS II — FC-2610
DOCMR [signature]	Mar 12, 69	SHEET 6 OF 16
APPR'D [signature]	12 MAR 69	

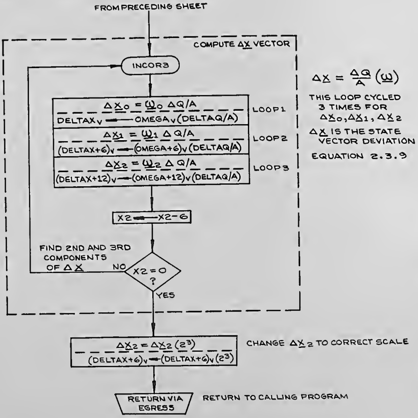


MEASUREMENT INCORPORATION

COLOSSUS II

FC-2610

7 16



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN J. W. Scott 31 July 68
PRGMR P. R. Jennings 1 Oct 68
ANAL
DOCMR R. Fucatelli 1 Oct 68
APPR'D John A. Morse 1 Oct 68

MEASUREMENT INCORPORATION

COLOSSUS II FC-2610

REV 0 16

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 ASTRONAUT OR BY CALLING PROGRAM.

INPUT :

VEHUPFLAG = UPDATE VEHICLE 1=CSM , 0=LEM

W= ERROR TRANSITION MATRIX

DELTAX= ΔX= 6 OR 9 DIMENSIONAL STATE VECTOR DEVIATIONS

DMENFLG= DIMENSION OF W 1=9X9 , 0=6X6

OMEGA = ω = 6 OR 9 DIMENSIONAL OMEGA WEIGHTING VECTOR USED TO MINIMIZE STATISTICAL ERRORS

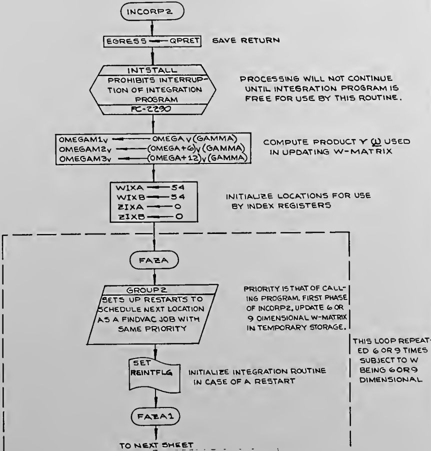
GAMMA = γ = SCALAR USED IN THE INCORPORATION

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

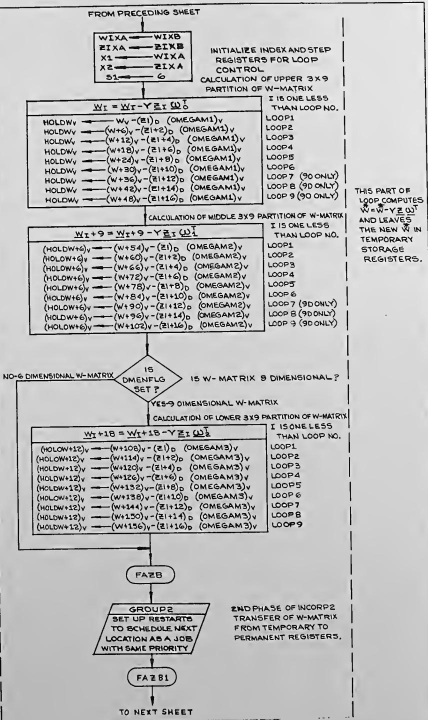


MEASUREMENT INCORPORATION

COLOSSUS II

FC-2610

9 16



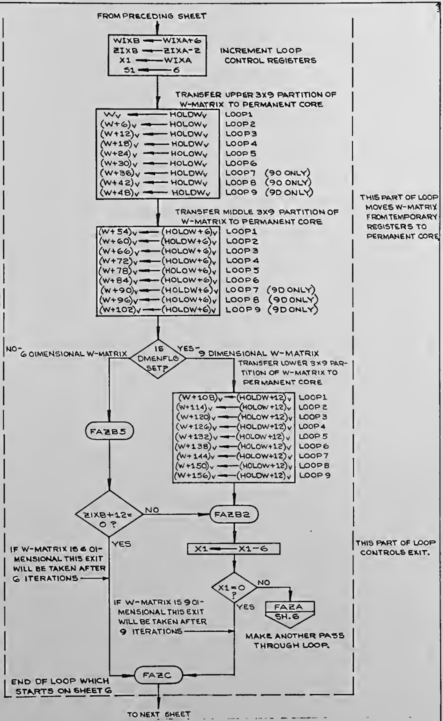
MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

MEASUREMENT INCORPORATION

COLOSSUS II

FC-2610

10 16



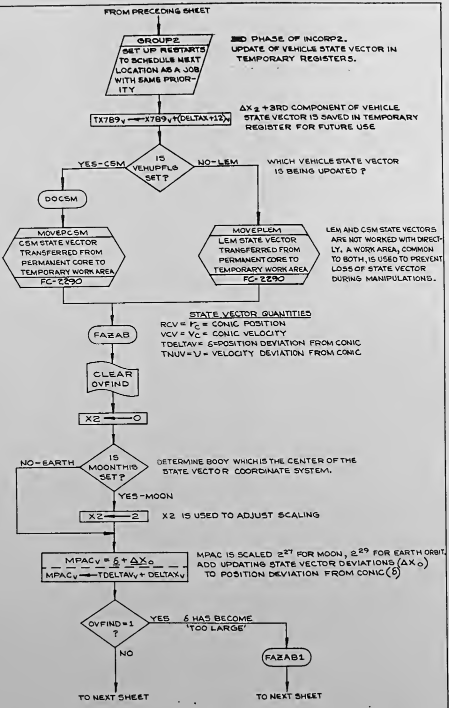
MEASUREMENT INCORPORATION

DRAWN	S.H. Scott	1 Aug 68
PROGMR	L.R. Jennings	1 Oct 68
ANALYST		1 Oct 68
DOCMTR	R. Pusatelli	1 Oct 68
APPRVD	John A. Moore	1 Oct 68

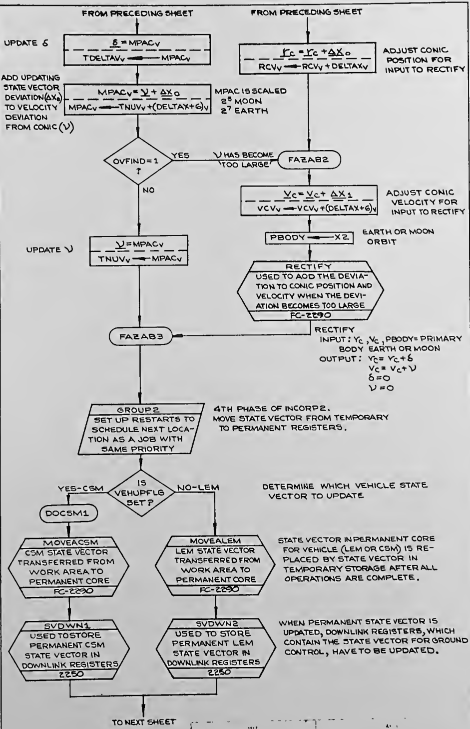
COLOSSUS II

FC-2610

11 16



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN 2AUG68 / PRGMR 1Oct68 / ANALST / DOCMR 1Oct68 / APPR'D 1Oct68 / REV	MEASUREMENT INCORPORATION
COLOSSUS II	DOCUMENT NO. FC-2610 SHEET 12 OF 16



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

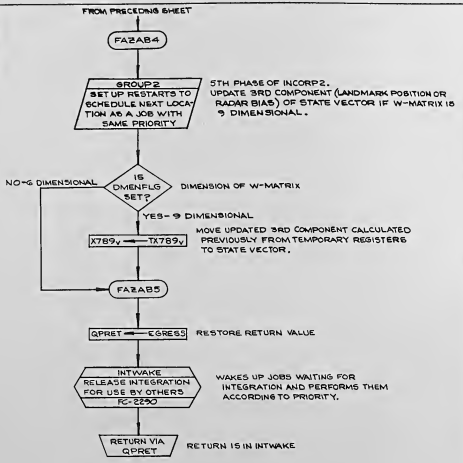
DRAWN / PROGR / ANALYST / APPR [signatures] 10 Oct 68

MEASUREMENT INCORPORATION

COLOSSUS II

FC-2610

13 16



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN
PRGMR
ANALST
DOCMP
APPR'D

MEASUREMENT INCORPORATED

COLOSSUS II

FC-2610

14 of 16

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
SVDWN1	2250	STORES CSM STATE VECTOR IN DOWNLINK REGISTERS	SH11
SVDWN2	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
DMENFLG FLAGWORD 5 BIT 9	W-MATRIX IS 9 DIMENSIONAL	W-MATRIX IS 6 DIMENSIONAL			SH3, 5, 8, 9, 12
REINTFLG 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^{14}
W		W-MATRIX			VARIABLE
ZI	Z	VECTOR USED IN THE INCORPORATION			VARIABLE
TRIPA	A	SCALAR USED IN THE INCORPORATION			VARIABLE
VARIANCE	α^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^{14}
GAMMA	γ	SCALAR USED IN THE INCORPORATION			VARIABLE
DELTAQ	ΔQ	MEASUREMENT TRACKING DEVIATIONS			VARIABLE
OMEGA	ω	STATISTICAL WEIGHTING VECTOR			VARIABLE
DELTAX	ΔX	STATE VECTOR DEVIATIONS			VARIABLE
OMEGAM1, 2, 3		VECTOR USED IN THE INCORPORATION			VARIABLE
WIXA, WIXB		SCALARS USED FOR INDEXING		(INTEGER)	2^{14}
ZIXA, ZIXB		SCALARS USED FOR INDEXING		(INTEGER)	2^{14}
HOLDW		TEMPORARY STORAGE FOR W-MATRIX			VARIABLE

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
TDELTAV	δ	POSITION DEVIATION FROM CONIC		METERS	$2^{29}/2^{27}$
TNUV	ν	VELOCITY DEVIATION FROM CONIC	METERS/SEC	METERS/CSEC	$2^{7}/2^{5}$
RCV	r_c	CONIC POSITION		METERS	$2^{29}/2^{27}$
VCV	v_c	CONIC VELOCITY	METERS/SEC	METERS/CSEC	$2^{7}/2^{5}$
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)	$(2^{28}, 2^{28}, 2^{28})$
DP1/4TH		DOUBLE PRECISION ONE FOURTH	1/4	.25	2^{0}

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN P. M. Dietrich	13SEP68	MEASUREMENT INCORPORATION
PRGMR E.R. Jennings	1 Oct 68	
ANALST		COLOSSUS II — DOCUMENT NO FC-2610
DOCMR R. Piccatelli	1 Oct 68	
APPR'D John A. Moon	1 Oct 68	REV — SHEET 16 OF 16

P30 EXTERNAL ΔV MANEUVER AND
P31 LAMBERT AIM POINT MANEUVER

PRE-THRUST COMPUTATIONS

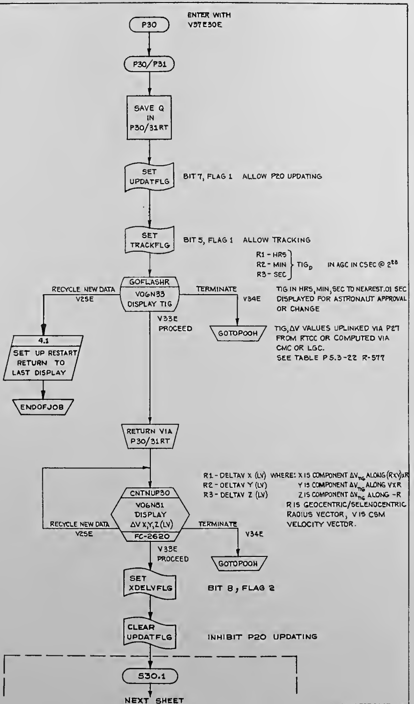
MAJOR SUBROUTINES

P30/P31 (USED BY P30 AND P31)
S30.1 (P30 ONLY)
S31.1 (P31 ONLY)

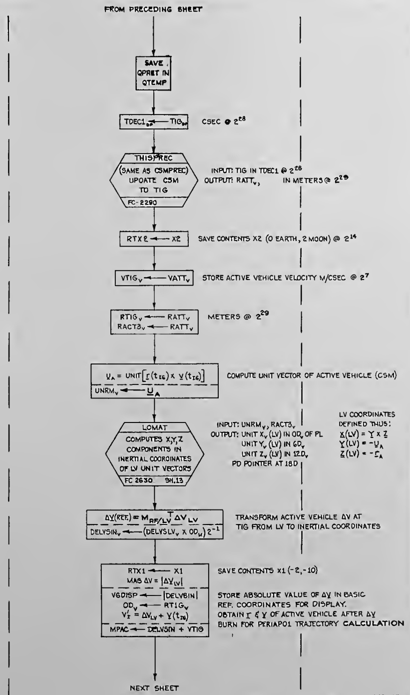
EXTERNAL ENTRY POINTS:

DISPMGA (SH5), CNTNUP30 (SH6)

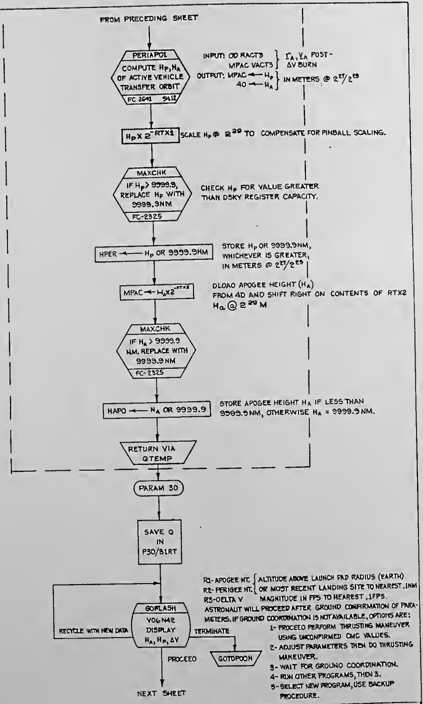
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C WILLIAMS 12DEC68	P30/P31 EXTERNAL DELTA VELOCITY
PRGMR 4-16-69	
ANALYST	COLOSSUS IIC FC-2620
PGMMR 4-16-69	
APPR'D John A. Moore 16 April 69	REV 1 SH 1 OF 12



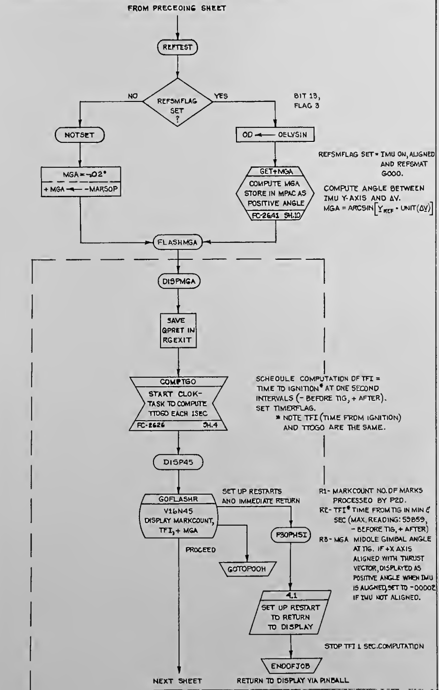
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 12 DEC 68	P30/P31 EXTERNAL DELTA VELOCITY
PRGMR 4-16-69	
ANALYST	COLOSSUS II C — DOCUMENT NO FC-2620
DOCMR 4-16-69	
APPR'D John A. Miller 16 April 69	REV 3 — SHEET 2 OF 12



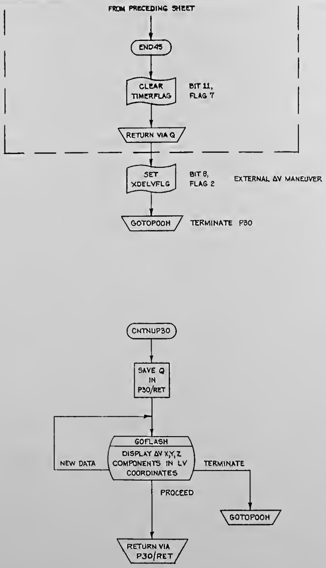
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 15 DEC 68	P30/P31 EXTERNAL DELTA VELOCITY
PRGMR [signature] 4-16-69	
ANALYST	COLOSSUS IIC DOCUMENT № FC-2620
DOCMR [signature] 4-16-69	
APPR'D [signature] 16 April 69	REV 3 SH 3 of 12



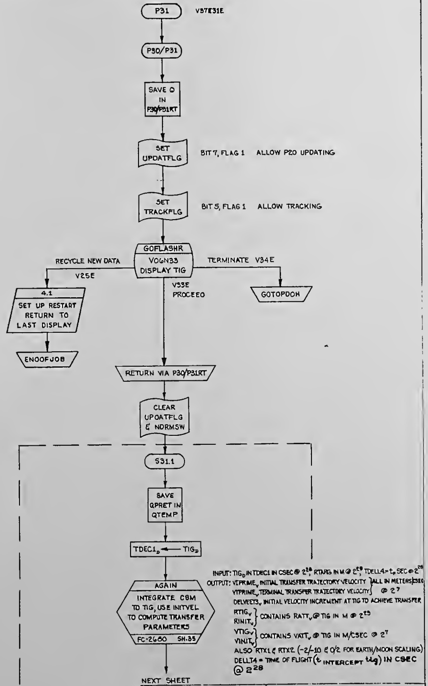
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS 13DEC68	P30/P31 EXTERNAL DELTA VELOCITY	
PRGMR [signature] 4-16-69		
ANALST	COLOSSUS II C	DOCUMENT NO. FC-2620
DOCMR [signature] 4-16-69		SHEET 4 OF 12
APPR'D John A. Moore 16 April 69	REV 2	



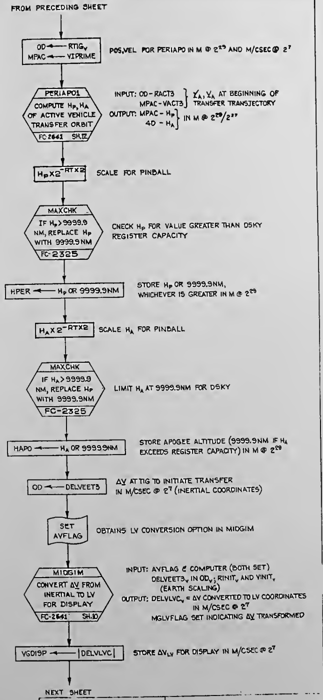
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 16DEC68	P30/P31 EXTERNAL DELTA VELOCITY
PRGMR [signature] 4-16-69	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2620
DOCMR [signature] 4-16-69	
APPR'D [signature] 16 April 69	REV 1 SHEET 5 OF 12



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 16DEC68	P30/P31 EXTERNAL DELTA VELOCITY
PRGMR [signature] 4.11.69	COLOSSUS IIC
ANALST	DOCUMENT NO. FC-2620
DOCMR [signature] 14.6.69	REV 1
APPR'D [signature]	SHEET 6 OF 12



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 16 DEC 68	P30/P31 EXTERNAL DELTA VELOCITY
PRGMR [signature] 4-16-69	
ANALST	COLOSSUS II C — DRAWING NO. FC-2620
DOCMR [signature] 4-16-69	
APPR'D John A. Moore 16 April 69	REV 4 — SHEET 7 OF 12



MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

P30/P31
EXTERNAL DELTA VELOCITY

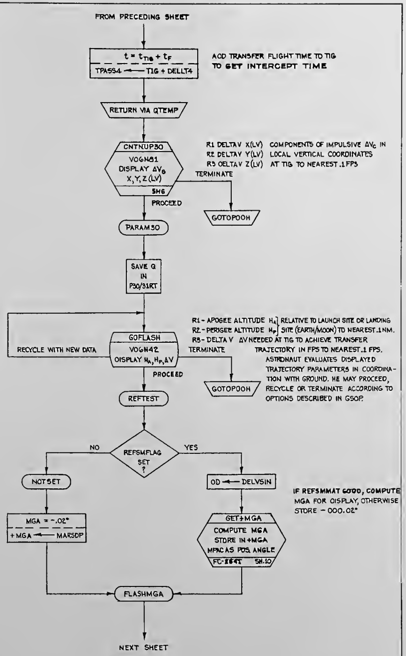
DRAWN	A.C. WILLIAMS	17DEC68
PRGMR	[signature]	4-16-69
ANALST		
DOCMR	[signature]	4-16-69
APPR'D	[signature]	16 April 69

COLOSSUS IIC

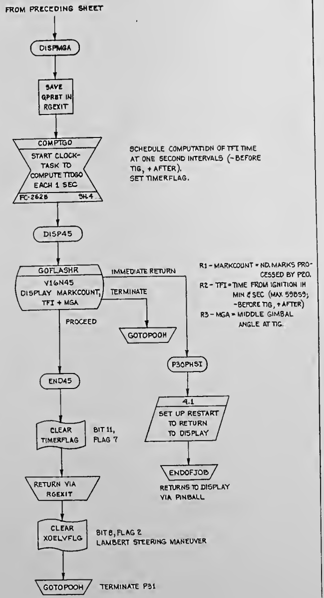
REV 1

DOCUMENT NO. FC-2620

SHEET 8 OF 12



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS	17DEC68	P30/P31 EXTERNAL DELTA VELOCITY
PRGMR [signature]	4.16.69	
ANALST		COLOSSUS II C — DOCUMENT NO. FC-2620
DOCMR [signature]	4.16.69	
APPR'D John A. Moore	16 April 69	REV 1 — SHEET 9 OF 12



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 18DEC68	P30/P31 EXTERNAL DELTA VELOCITY
PRGMR 4-16-69	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2620
DOCMR 14.4.69	
APPR'D John A. Moss 16 April 69	REV 1 — SHEET 10 OF 12

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS			
SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
THISPREC	FC-1350	UPDATES CSM TO TDEC1 TIME	SH. 3
LOMAT	FC-1740	CONVERTS REF TO LV COORDINATES	SH. 3
PERIAPO1	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 CLOCKTASK) AT ONE SEC. INTERVALS	SH. 5, 10
AGAIN	FC-2680	INTEGRATES CSM TO TIG AND USES $\underline{r}(t_{IG})$, $\underline{v}(t_{IG})$ IN INITVEL TO COMPUTE	SH. 7
MIDGIM	FC-1760	CONVERTS $\underline{\Delta V}$ 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 BIT5, 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 CLOCKTASK	STOP COMPUTING TFI	SH. 6, 10	SH. 6, 10	
XDELVFLG BIT8, FLAG2	EXTERNAL ΔV 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 (IN 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
V06N33	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, ΔV FOR TRANSFER TRAJECTORY	SH. 4, 9
V16N45	FLASHING	DISPLAYS MARKCOUNT, TFI & +MGA	SH. 5, 10

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 [illegible] INTEGRATED TO	HRS, MIN, [illegible] SEC	CSEC	2^{28}
$VTIG_V$		ACTIVE VEHICLE VELOCITY AT TIG	FPS	M/CSEC	2^7
$RTIG_V$		ACTIVE VEHICLE POSITION AT TIG	NAUTICAL MILES	METERS	2^{29}
$RACT3_V$		SAME AS RTIG	NAUTICAL MILES	METERS	$2^{27}/2^{29}$
$UNRM_V$	$\underline{u}_{TD}$	UNIT VECTOR OF ACTIVE VEHICLE			2^1
$DELVSIN_V$	$\Delta\underline{v}_{LV}$	STORAGE LOC FOR $\Delta\underline{v}_{LV}$	FPS	M/CSEC	2^7
VGDISP	$\lvert\Delta\underline{v}_{LV}\rvert$	STORAGE LOC FOR $\lvert\Delta\underline{v}_{LV}\rvert$	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	$\underline{r}(t_T)$	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
RINIT		SAME AS RTIG, VTIG ABOVE EXCEPT EARTH SCALING	NM	M	2^{29}
VINIT			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°	IMU/REFSMAT NOT READY FOR MGA COMP.	DEGREES	REV	2^0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN [illegible] 19FEB69
PRGMR [illegible] 4/16/69
ANALST
DOCMR [illegible] Apr 16 69
APPR'D [illegible] 6 Apr 69

APOLLO GUIDANCE AND NAVIGATION

P30/P31 EXTERNAL DELTA VELOCITY

COLOSSUS II

DOCUMENT NO. FC-2620

REV 1

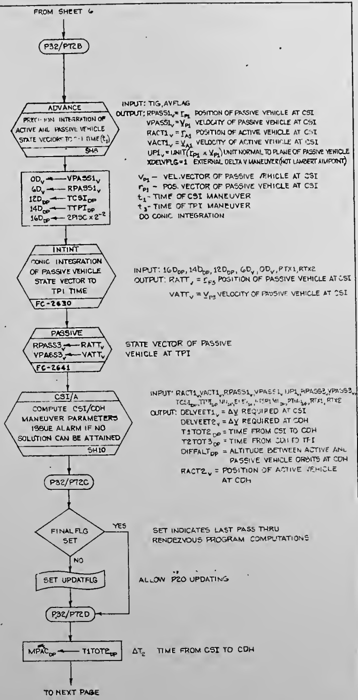
SHEET 12 OF 12

P32, P72 CO-ELLIPTIC SEQUENCE INITIATION

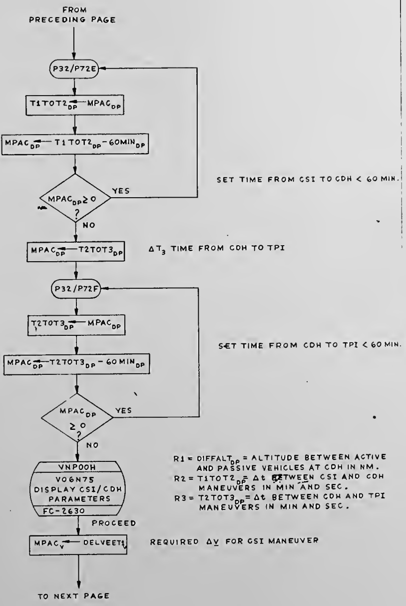
THE ENCLOSED REPLACEMENT SHEET WILL UPDATE THE COLOSSUS II FLOW CHART FC-2626, REV 0 TO THE COLOSSUS IIA FLOW CHART FC-2626 REV 1
THE EFFECTIVE SHEETS FOR COLOSSUS IIA FC-2626 REV. 1

Sheets	Rev.
1 ~ 22	REV. 0
23	REV 1
24 ~ 26	REV 0

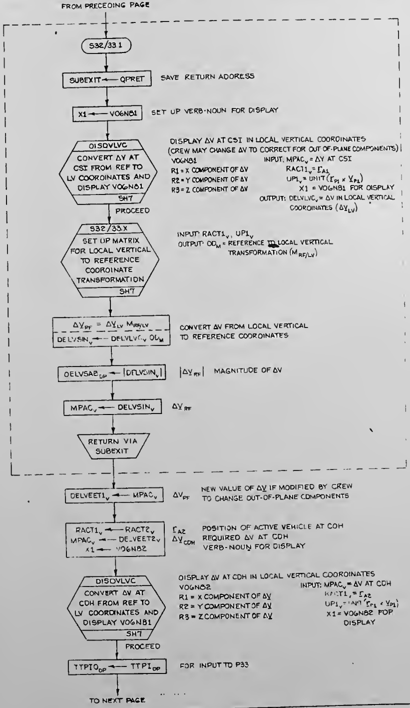
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN L. J. Lavernière 27 MAY 69	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PRGMR	
ANALST W. Tempelman	COLOSSUS II-A
DOCMR	DOCUMENT NO. FC-2626
APPR'D	REV 1 SHEET 1 OF 25



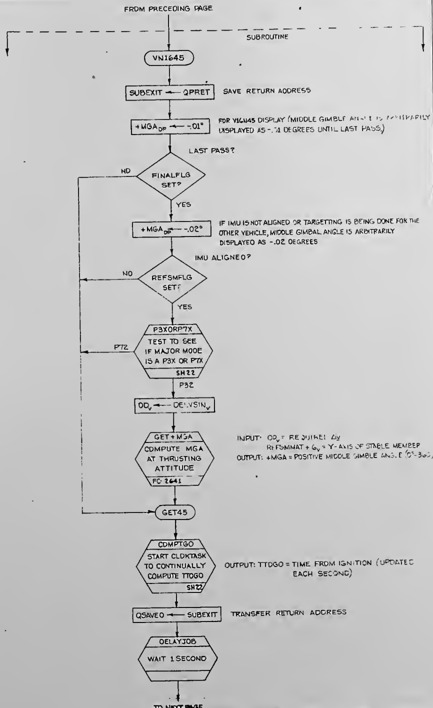
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 4-22-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PROGR [signature] 5-22-68	
ANALST [signature]	COLOSSUS II — DOCUMENT NO. FC-2626
DOCUM [signature]	
APPR'D [signature] 6-7-68	REV 1 — SHEET 2 OF 2



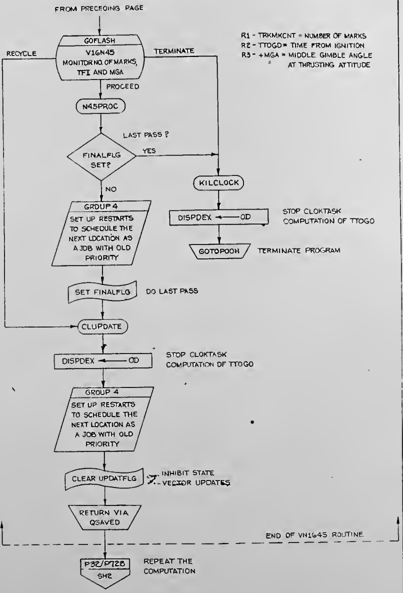
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 11 APR 69	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PRGMR [signature] 14 APR 69	COLOSSUS II
ANALST [signature] 14 Apr 69	DOCUMENT NO. FC-2626
DOCMR [signature] 16 Apr 69	
APPR'D John A. Moore 16 Apr 69	REV — SHEET 3 OF 25



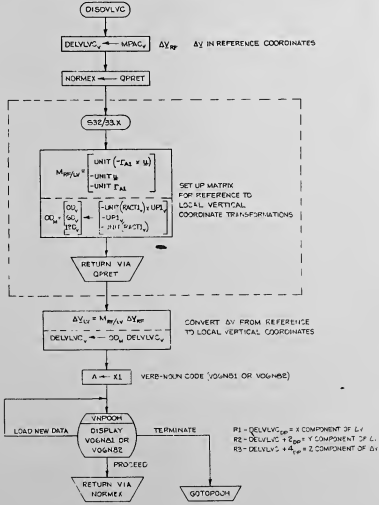
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN A.C. WILLIAMS	4-23-68		
PRGMR [signature]	8-22-68	COLOSSUS II	DOCUMENT NO. FC-2626
ANALST [signature]			
DOCMR [signature]			
APPR'D J. [signature]	6-7-68	REV 1	SHEET 4 OF 25



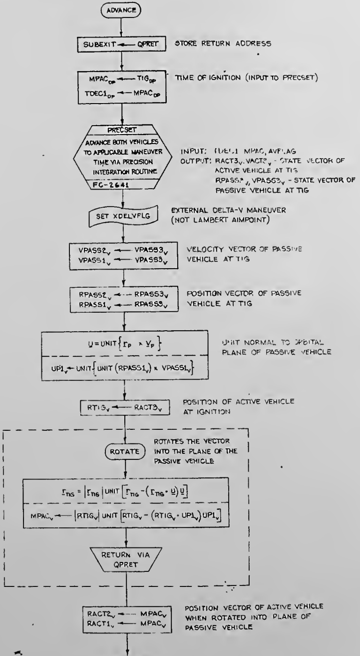
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 4-24-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PRGMR P. White 8-23-68	COLOSSUS II
ANALST W. Tempelman	DOCUMENT NO. FC-2626
DOCMR [signature] 16 April 69	
APPR'D [signature] 6-7-69	REV 1 SHEET 5 OF 26



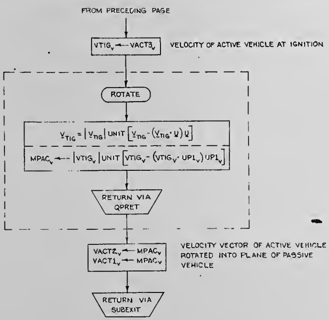
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
DRAWN A.C. WILLIAMS 4-24-68	
PRGMR [signature] 8-22-68	COLOSSUS II — DOCUMENT NO. FC-2626
ANALST [signature]	
DOCMR [signature]	REV 1 — SHEET 6 OF 28
APPR'D [signature]	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS	4-25-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PRGMR	8-22-68	
ANALST		COLOSSUS II — DOCUMENT NO. FC-2626
DOCMR		
APPR'D	6-2-68	REV 1 — SHEET 7 OF 25


ADVANCE
SUBEXIT ← QPRET
STORE RETURN ADDRESS
MPAC_DP ← TIG_DP
TDEC1_DP ← MPAC_DP
TIME OF IGNITION (INPUT TO PRECSET)
PRECSET
ADVANCE BOTH VEHICLES TO APPLICABLE MANEUVER TIME VIA PRECISION INTEGRATION ROUTINE
FC-2641
INPUT: TDEC1 MPAC, AVFLAG
OUTPUT: RACT3_V, VACT3_V - STATE VECTOR OF ACTIVE VEHICLE AT TIG
RPASS3_V, VPASS3_V - STATE VECTOR OF PASSIVE VEHICLE AT TIG
SET XDELVFLG
EXTERNAL DELTA-V MANEUVER
(NOT LAMBERT AIMPOINT)
VPASS2_V ← VPASS3_V
VPASS1_V ← VPASS3_V
VELOCITY VECTOR OF PASSIVE VEHICLE AT TIG
RPASS2_V ← RPASS3_V
RPASS1_V ← RPASS3_V
POSITION VECTOR OF PASSIVE VEHICLE AT TIG
u = UNIT {r_P × v_P}
UP1_V ← UNIT{UNIT (RPASS1_V) × VPASS1_V}
UNIT NORMAL TO ORBITAL PLANE OF PASSIVE VEHICLE
RTIG_V ← RACT3_V
POSITION OF ACTIVE VEHICLE AT IGNITION
ROTATE
ROTATES THE VECTOR INTO THE PLANE OF THE PASSIVE VEHICLE
r_TIG = |r_TIG| UNIT [r_TIG - (r_TIG · u) u]
MPAC_V ← |RTIG_V| UNIT [RTIG_V - (RTIG_V · UP1_V) UP1_V]
RETURN VIA QPRET
RACT2_V ← MPAC_V
RACT1_V ← MPAC_V
POSITION VECTOR OF ACTIVE VEHICLE WHEN ROTATED INTO PLANE OF PASSIVE VEHICLE

TO NEXT PAGE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
DRAWN A.C. WILLIAMS 6-4-68	DOCUMENT NO.
PRGMR [signature] 8-22-68	COLOSSUS II · FC-2626
ANALST [signature]	
DOCMR [signature]	
APPR'D [signature] 6-7-68	REV 1 · SHEET 5 OF 25

CSI/A

CLEAR S32.IF1 / SET S32.IF2 — V_1 DOES NOT EXCEED MAXIMUM ALLOWABLE VALUE; FIRST PASS INDICATOR FOR NEWTON RAPSON ITERATION

CLEAR S32.IF3A / SET S32.IF3B — S3 = 1 FIRST SEARCH

$LOOPCT_{DP} \leftarrow 0$ — CLEAR CSI NEWTON ITERATION COUNTER
$CSIALRM_{DP} \leftarrow 0$ — CLEAR ALARM INDICATER

START OF SECOND SEARCH IN OPPOSITE DIRECTION (FROM SH21) → CSI/B

$$\sqrt{\frac{2\mu}{\left[(r_{A1}/r_{P3})+1\right] r_{A1}}}$$

$$OD_{DP} \leftarrow \sqrt{\frac{2\ RTMU_{DP}}{\left[\frac{|RACT1_V|}{|RPASS3_V|}+1DPB2_{DP}\right] |RACT1_V|}}$$

FIRST GUESS AT MAGNITUDE OF TOTAL VELOCITY REQUIRED AFTER CSI (VELOCITY REQUIRED TO ACHIEVE A RADIUS EQUAL TO r_{P3} IN $\frac{1}{2}$ ORBIT FROM CSI POINT)

$$\underline{h}_1 = UNIT(\underline{u} \times r_{A1})$$

$$MPAC_V \leftarrow UNIT\left[UP1_V \times UNIT(RACT1_V)\right]$$

DIRECTION OF REQUIRED ΔV AT CSI (HORIZONTAL AND PARALLEL TO THE PLANE OF THE PASSIVE VEHICLE) (UP1 = (RPASS1 × VPASS1) = UNIT NORMAL TO PLANE OF PASSIVE VEHICLE)

$$V_1 = \sqrt{\frac{2\mu}{\left[(r_{A1}/r_{P3})+1\right] r_{A1}}} - (\underline{V}_{A1} \cdot \underline{h}_1)$$

$$DELVCSI_{DP} \leftarrow OD_{DP} - \left[VACT1_V \cdot MPAC_V\right]$$

MAGNITUDE OF REQUIRED ΔV AT CSI

$$\Delta V_1 = 10\ FT/SEC$$

$$DELOV_{DP} \leftarrow INITST$$

DECREMENT TO ITERATIVELY MODIFY THE INITIAL GUESS AT VELOCITY REQUIRED AFTER CSI UNTIL ALL CONSTRAINTS ARE SATISFIED (INITST = .03048 M/CS (SCALED 2^7) = 10 FT/SEC)

NEWTON RAPSON ITERATION LOOP (FROM SH17 15,19) → CSI/B1

$LOOPCT_{DP} \leftarrow LOOPCT_{DP} + 1$ — INCREMENT ITERATION COUNTER

$X2 \leftarrow 6$ — INDEX TO ALARM CODE TABLE. #6 REFERS TO ALARM CODE .00605 = # OF ITERATIONS EXCEEDS LOOP MAXIMUM

LOOPCT ≥ 16 ?
- YES → SCNDSOL SH20 — NO SOLUTION AFTER 15 ITERATIONS
- NO ↓

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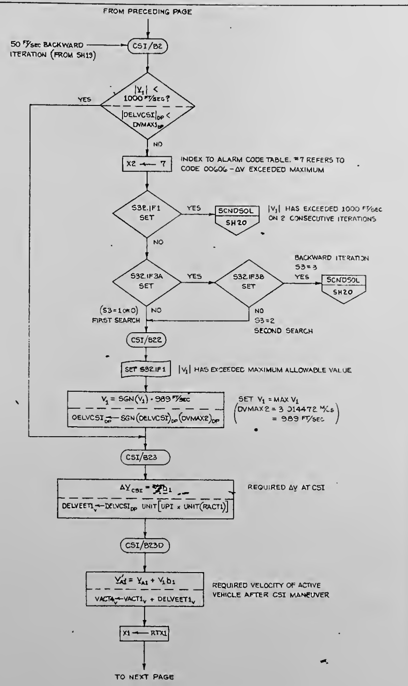
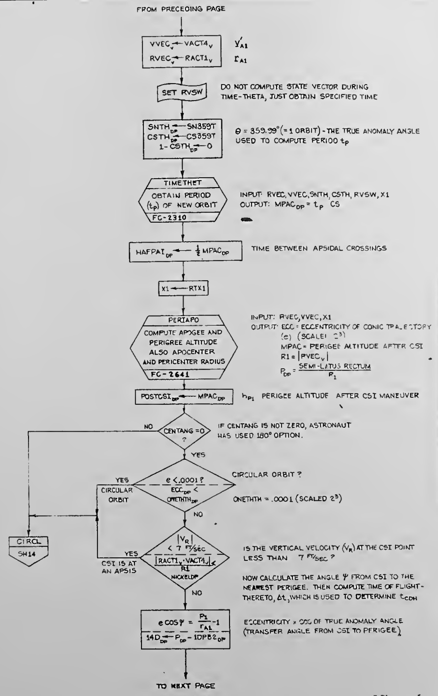
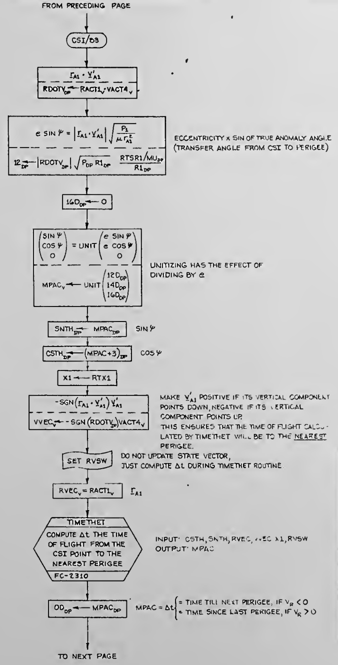
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C.WILLIAMS	4-25-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
PRGMR P. [illegible]	8-22-68	COLOSSUS II	DOCUMENT NO. FC-2626
ANALST [illegible]			
DOCMR [illegible]	[illegible]		
APPR'D J. [illegible]	6-9-68	REV 1	SHEET 10 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 4-26-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PROGR [signature] 8-22-68	
ANALYST [signature]	COLOSSUS II — DOCUMENT NO. FC-2626
DOCMN [signature]	
APPR'D [signature]	REV 1 — SHEET 11 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS	4-23-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PRGMR	8-27-68	
ANALST		COLOSSUS II — DOCUMENT NO. FC-2626
DOCMR		
APPRVD	1-7-69	REV 1 — SHEET 13 OF 28



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS	4-23-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
PRGMR [signature]	8-22-68	COLOSSUS II	DOCUMENT NO. FC-2626
ANALST [signature]			
DOCMR [signature]			
APPR'D J. Henry	6-7-68	REV 1	SHEET 13 OF 25

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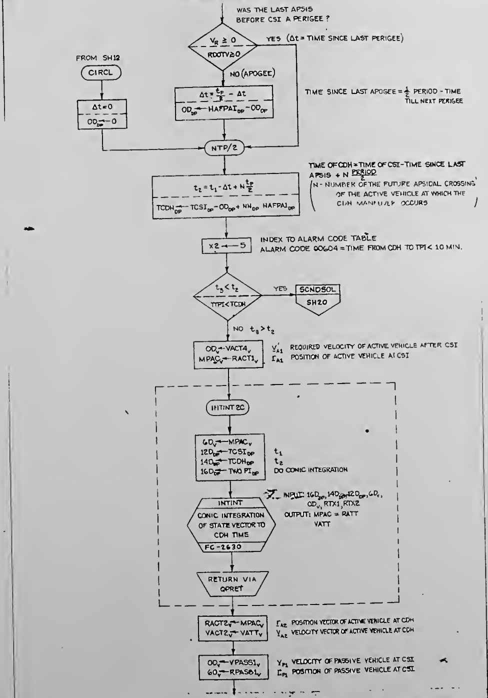

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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P52 AND P72 CO-ELLIPTIC SEQUENCE INIATION	
DRAWN A.C. WILLIAMS	4-30-68	COLOSSUS II	DOCUMENT NO. FC-2630
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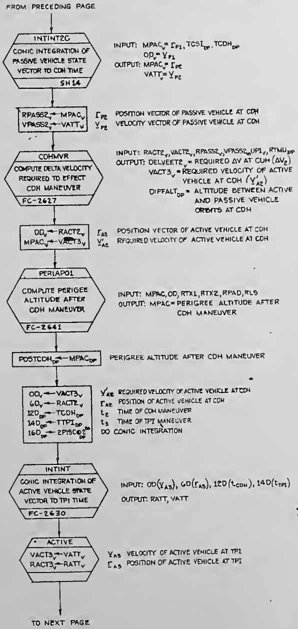
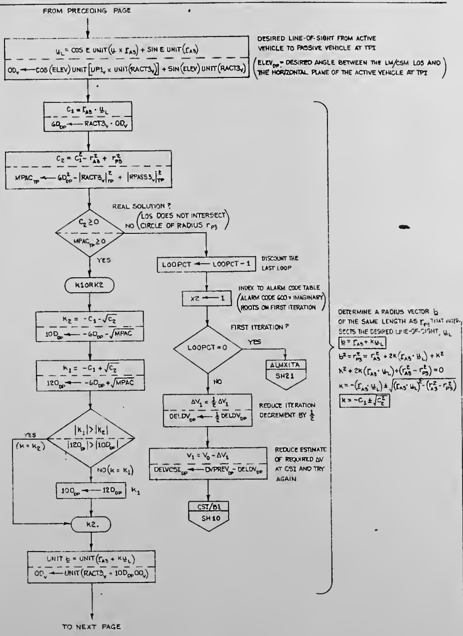
ANALST [signature]			
DOCMR [signature]	[illegible]		
APPR'D [signature]	6-7-68	REV 1	SHEET [illegible] OF [illegible]



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P52 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
DRAWN A.C.WILLIAMS	6-1-68		
PROGMR	8-23-68	COLOSSUS II	DOCUMENT NO. FC-2626
ANALST			
DOCMR		REV 1	SHEET 15 OF 25
APPR'D			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C.WILLIAMS 5-2-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
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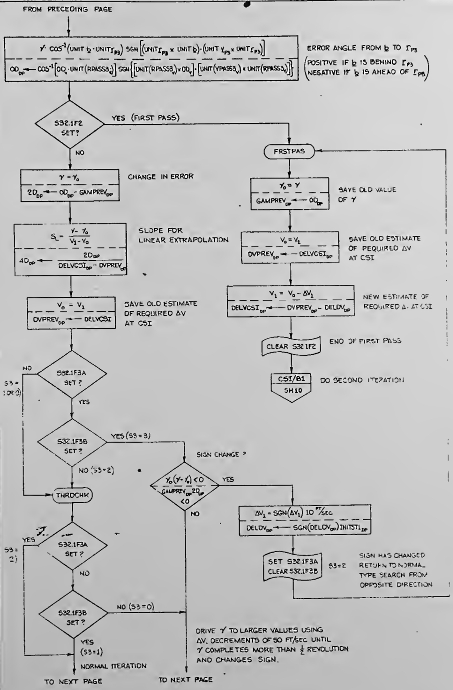
ANALST [signature]		
DOCMR [signature] 11 Apr 69	REV 1	SHEET 16 OF 25
APPR'D J. Henry 6-2-68		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
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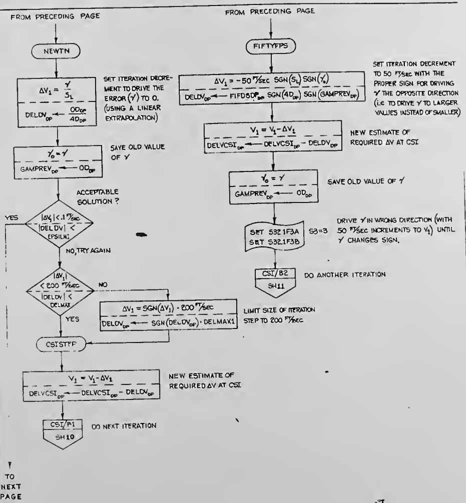
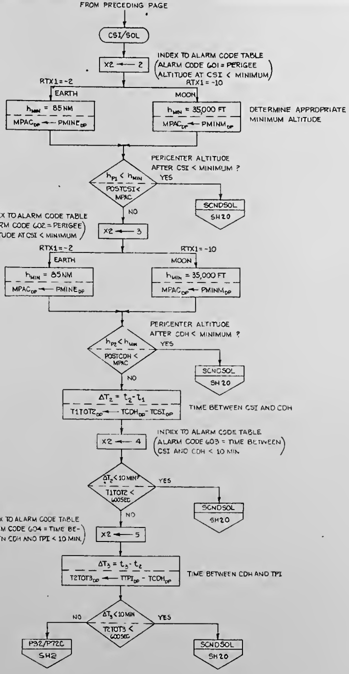
ANALST [signature]			
DOCMR [signature]	4-6-68		
APPR'D J. Henry	6-7-68	REV 1	SHEET 17 OF 25



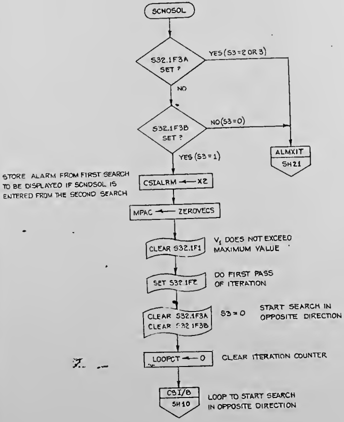
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C.WILLIAMS	5-6-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION	
PRGMR [signature]	8-22-68		DOCUMENT NO.
ANALST [signature]		COLOSSUS II	FC-2626
DOCMR [signature]	4-4-69		
APPR'D J. [signature]	6-7-68	REV 1	SHEET 18 OF 25



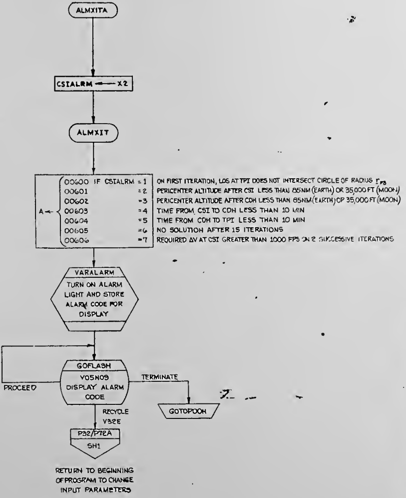
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS	5-6-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PRGMR [signature]	8-22-68	
ANALST [signature]		COLOSSUS II — DOCUMENT NO. FC-2626
DOCMR [signature]	[illegible]	
APPR'D [signature]	[illegible]	REV 1 — SHEET 19 OF 25

ALARM CONDITIONS THAT CAUSE ENTRY OF SCNDSOL ARE:

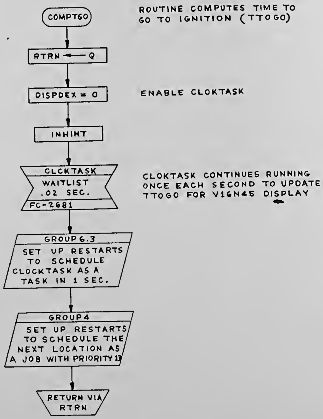
- NO SOLUTION AFTER 15 ITERATIONS
- V_1 > 1000 FT/sec ON 2 SUCCESSIVE ITERATIONS
- $t_3 < t_2$
- h_{p1} < 85 NM OR 35,000 FT
- h_{p2} < 85 NM OR 35,000 FT
- ΔT_2 < 10 MIN
- ΔT_3 < 10 MIN

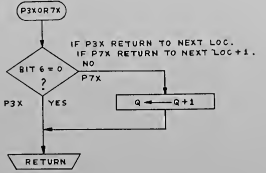


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS	5-6-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INIATION	
PRGMR	5-22-68	COLOSSUS II	DOCUMENT NO. FC-2626
ANALST			
DOCMR		REV 1	SHEET 20 OF 25
APPR'D	6-7-68		

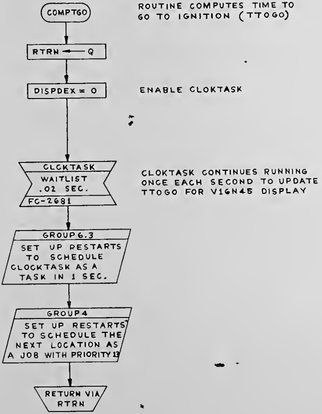


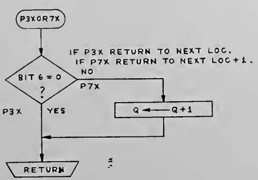
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 5-7-68	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
PRGMR [signature] 8-22-68 ANALST [signature] DOCMR [signature] APPRD [signature]	COLOSSUS II — DOCUMENT NO. FC-2626
	REV. 1 — SHEET 21 OF 25





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN / PRGMR / ANALST / DOCMR / APPR'D	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
	COLOSSUS II — DOCUMENT NO. FC-2626
	SHEET 22 OF 25





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN / PRGMR / ANALST / DOCMR / APPR'D	P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION
COLOSSUS IIA	DOCUMENT NO. FC-2626
REV 1	SHEET 25 OF 25

DISPLAYS	MEANING	USED
V06N30	DISPLAY CSI TIME	SH1
V06N55	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
V06N81	DISPLAY REQUIRED ΔV FOR CSI	SH4,SH7
V06N82	DISPLAY REQUIRED ΔV FOR CDH	
V05N09	DISPLAY APPROPRIATE ALARM CODE	SH21

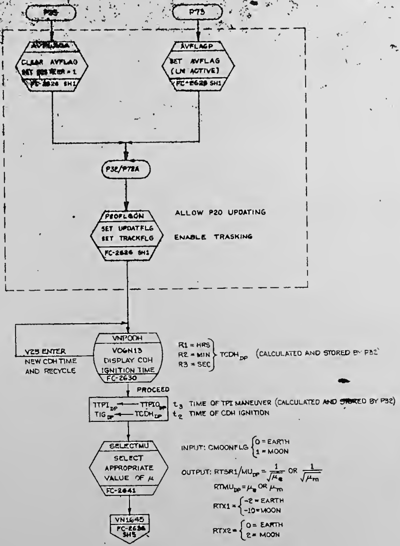
ALARMS	MEANING	USED
00600	ON FIRST ITERATION, LOS AT TPI DOES NOT INTERSECT CIRCLE OF RADIUS r_{P3}	SH17
00601	PERICENTER ALTITUDE AFTER TPI LESS THAN 85 NM (EARTH) OR 35,000 FT (MOON)	SH19
00602	PERICENTER ALTITUDE AFTER CDH LESS THAN 85 NM (EARTH) OR 35,000 FT (MOON)	SH19
00603	TIME FROM CSI TO CDH 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

ERASABLES	MEANING	UNITS	SCALING
CSIALRM	ALARM CODE		B28
CSTH	COS OF θ THE TRUE ANOMALY ANGLE	REVOLUTIONS	B1
DELDV	ΔV STORAGE	M/CSEC	B7
DELVEET1	ΔV FOR CSI MANEUVER	M/CSEC	B7
DELVEET2	ΔV FOR CDH MANEUVER	M/CSEC	B7
DELVCSI	ΔV AT CSI	M/CSEC	B7
DELVLVC	ΔV IN LOCAL VERTICAL COORDINATES	M/CSEC	B7
DELVSAB	MAGNITUDE OF ΔV AT CSI		B7
DELVSIN	ΔV AT CSI IN REFERENCE COORDINATES	M/CSEC	B7
DIFFALT	DISTANCE BETWEEN ACTIVE AND PASSIVE VEHICLE ORBITS AT CDH	METERS	B29
DVPREV	PREVIOUS CSI ΔV VALUE	M/CSEC	B7
ECC	ECCENTRICITY		B3
ELEV	DESIRED LOS ANGLE AT TPI	REVOLUTIONS	B1
GAMPREV	PREVIOUS VALUE OF γ, THE ERROR ANGLE FROM b TO r_{P3}	REVOLUTIONS	B0
HAFPA1	TIME BETWEEN APSIDAL CROSSINGS	CENTISECONDS	B28
LOOPCT	ITERATION COUNTER		B28
NN	NUMBER OF APSIDAL CROSSINGS OF ACTIVE VEHICLE		B28
POSTCDH	PERIGEE ALTITUDE AFTER CDH MANEUVER	METERS	B29
POSTCSI	PERIGEE ALTITUDE AFTER CSI MANEUVER	METERS	B29
RACT1	POSITION OF ACTIVE VEHICLE AT CSI TIME	METERS	B29
RACT2	POSITION OF ACTIVE VEHICLE AT CDH TIME	METERS	B29
RACT3	POSITION VECTOR OF ACTIVE VEHICLE AT TPI	METERS	B29
RATT	POSITION VECTOR OUTPUT FROM INTEGRATION	METERS	B29
RDOTV	$\underline{r}_{A1} \cdot \underline{v}'_{A1}$		B36
RPASS1	POSITION VECTOR OF PASSIVE VEHICLE AT CSI TIME	METERS	B29
RPASS2	POSITION VECTOR OF PASSIVE VEHICLE AT CDH	METERS	B29
RPASS3	POSITION VECTOR OF PASSIVE VEHICLE AT TPI	METERS	B29
RTIG	POSITION OF ACTIVE VEHICLE AT CSI BEFORE ROTATION	METERS	B29
RTMU	μ_e OR μ_m	$M^3/CSEC^2$	B36 OR B30
RTSR1/MU	$1/\sqrt{\mu_e}$ OR $1/\sqrt{\mu_m}$	$CSEC/M^{3/2}$	B17 OR B14
RTX1	SHIFT COUNTER; -2 FOR EARTH ORBIT, -10 FOR LUNAR ORBIT		B14
RTX2	SHIFT COUNTER; 0 FOR EARTH ORBIT, 2 FOR LUNAR ORBIT		B14
RVEC	POSITION VECTOR (INPUT TO CONIC ROUTINES)	METERS	B29
SNTH	SINE OF θ THE TRUE ANOMALY ANGLE	REVOLUTIONS	B1
T1TDT2	TIME FROM CSI TO CDH	CENTISECONDS	B28
T2TDT3	TIME FROM CDH TO TPI	CENTISECONDS	B28

P32 - COELLIPTIC SEQUENCE INITIATION

ERASABLES	MEANING	UNITS	SCALING
TCDH	TIME OF CDH MANEUVER	CENTISECONDS	B28
TCSI	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
UP1	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
VVEC	VELOCITY VECTOR (INPUT TO CONIC ROUTINES)	M/CSEC	B7

CONSTANTS		VALUE	UNITS	SCALING
MUTABLE	μ_e GRAVITATIONAL CONSTANT OF EARTH	3.986032×10^{10}	$M^3/CSEC^2$	B36
MUTABLE+6	$1/\sqrt{\mu_e}$	$.50087529 \times 10^{-5}$	$CSEC/M^{3/2}$	B17
MUTABLE+8	μ_e GRAVITATIONAL CONSTANT OF MOON	4.902778×10^{8}	$M^3/CSEC^2$	B30
MUTABLE-14	$1/\sqrt{\mu_m}$	$.45162595 \times 10^{-4}$	$CSEC/M^{3/2}$	B14

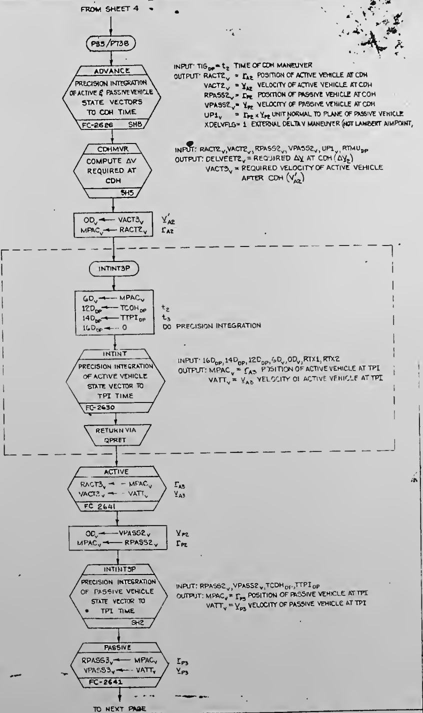


MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

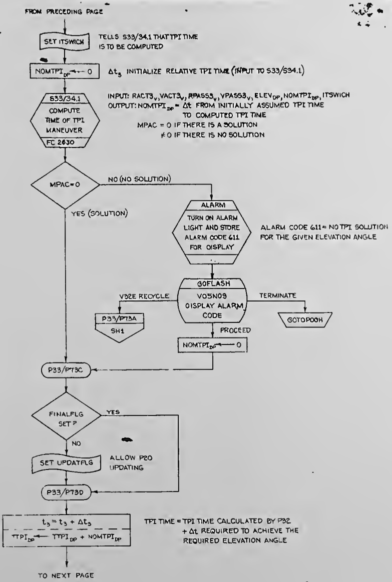
APOLLO GUIDANCE AND NAVIGATION

P33 AND P73
CONSTANT DELTA ALTITUDE TARGETTING

DRAWN R.C. WILLIAMS	6-6-68	COLOSSUS II
PROGR	10-9-69	DOCUMENT NO. FC-2627
ANALST	4-18-69	
DOCMN	4-16-69	
APPRD	4-18-69	REV 1 — SHEET 1 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 6-7-68	P35 AND P73 CONSTANT DELTA ALTITUDE TARGETTING
PRGMR [signature] 6-9-68	
ANALST [signature] 6-18-68	COLOSSUS II — DOCUMENT NO. FC-2627
DOCMR 4-16-68	
APPR'D [signature] 6-18-68	REV 1 — SHEET 2 OF 3



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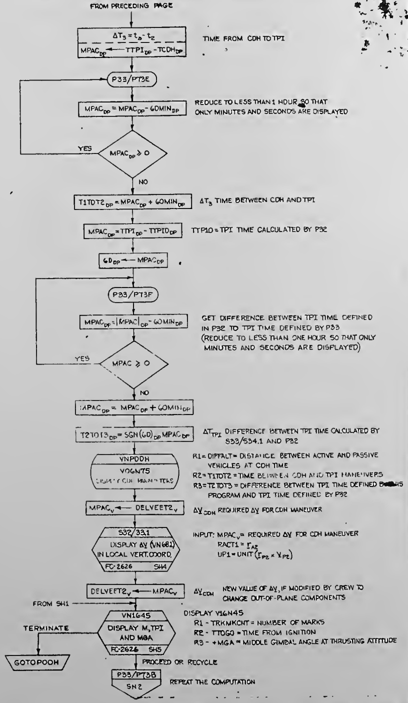
DRAWN A C WILLIAMS	6-7-68	P33 AND P73 CONSTANT DELTA ALTITUDE TARGETTING
PRGMR [signature]	6-4-69	COLOSSUS II — DOCUMENT NO. FC-2627
ANALST [signature]	6-18-69	
DOCMR	6-18-69	
APPR'D [signature]	6-18-69	REV 1 — SHEET 3 OF 7



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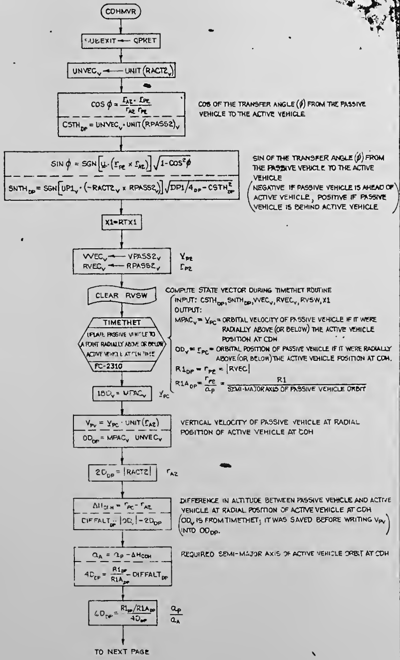
		P33 AND P73 CONSTANT DELTA ALTITUDE TARGETTING	
DRAWN A.C WILLIAMS	6-7-68	COLOSSUS II	DOCUMENT NO. FC-2627
PRGMR			
ANALST			
DOCMR			
APPR'D	6-18-68	REV 1	SHEET 4 OF 7



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DRAWN A.C.WILLIAMS	6-10-68	P33 AND P73 CONSTANT DELTA ALTITUDE TARGETTING	
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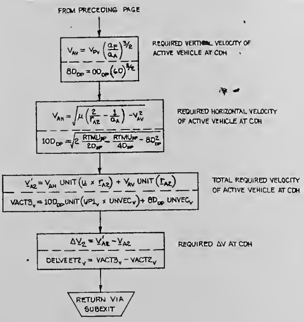
ANALST [signature]	6-18-68	COLOSSUS II	DOCUMENT NO. FC-2627
DOCMR	6-18-68		
APPR'D [signature]	6-18-68	REV 1	SHEET 5 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P33 AND P73 CONSTANT DELTA ALTITUDE TARGETTING	
DRAWN A.C. WILLIAMS	6-11-68	COLOSSUS II	DOCUMENT NO. FC-2627
PRGMR [illegible]	[illegible]		
ANALST [illegible]	[illegible]		
DOCMR	4-16-68		
APPR'D [illegible]	[illegible]	REV 1	SHEET 6 OF 7

P33 - CONSTANT DELTA ALTITUDE

SUBROUTINES

IN THIS CHART

P20FLGON	SET TRACKFLG, UPDATFLG
CDHMVR	COMPUTE REQUIRED ΔV FOR CDH MANEUVER

ON OTHER CHARTS

SELECTMU	SELECTS μ ACCORDING TO LUNAR OR EARTH SPRERE OF INFLUENCE
INTINT	PERFORMS ROUSEKEEPING PRIOR TO INTEGRATION CALL
S33/34.1	COMPUTES EITHER E OR TPI TIME
S32/33.1	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
ITSWICH	SET	TPI TIME TO BE COMPUTED	SH4		
	CLEARED	TPI TIME HAS BEEN COMPUTED			
FINALFLG	SET	LAST PASS TRRU RENDEZVOUS PROGRAM			SR4
	CLEARED	INTERIMPASS THRU RENDEZVOUS PROGRAM			
UPDATFLG	SET	UPDATING VIA MARKS ALLOWED	SH4		
	CLEARED	UPDATING VIA MARKS DISALLOWED			
XDELVFLG	SET	EXTERNAL ΔV MANEUVER	SH6		
	GLEARED	LAMBERT AIM POINT MANEUVER			
RVSW	SET	COMPUTE FINAL STATE VECTOR IN TIMETHET IN ADDITION TO Δt		SH8	
	CLEARED	COMPUTE Δt ONLY			
AVFLAG	SET	LM IS ACTIVE VERICLE	SR1	SH1	
	CLEARED	CSM IS ACTIVE VERICLE			
TRACKFLG	SET	ENABLE TRACKING	SH1		
	CLEARED				

DISPLAYS	MEANING	USED
V06N13	DISPLAY CDH IGNITION TIME	SH1
V05N11	DISPLAY ALARM CODE 00611	SH3
V06N75	DISPLAY CDH PARAMETERS	SR4
V16N45	DISPLAY M, TFI, MGA	SH4
V06N81	DISPLAY ΔV IN LOCAL VERT. COORDINATES	SH14

ALARMS	MEANING	USED
00611	NO TPI SOLUTION FOR TRE GIVEN ELEVATION ANGLE	SH3

ERASABLES	MEANING	UNITS	SCALING
TTPIO	TIME OF TPI MANEUVER FROM P32	CENTISECS	B28
TTPI	TIME OF TPI MANEUVER	CENTISECS	B28
TIG	TIME OF IGNITION	CENTISECS	B28
TCDH	TIME OF CDH MANEUVER	CENTISECS	B28
VACT3	REQUIRED VELOCITY OF ACTIVE VEHICLE AT CDH	M/CSC	B7
RACT2	ACTIVE VEHICLE POSITION VECTOR AT CDH TIME	METERS	B29
VACT2	VELOCITY VECTOR OF ACTIVE VEHICLE AT CDH	METERS	B29
VPASS2	PASSIVE VEHICLE VELOCITY VECTOR AT CDH TIME	M/CSC	B7
RPASS2	PASSIVE VEHICLE POSITION VECTOR AT CDH TIME	METERS	B29
NOMTPI	Δ FROM NOMINAL TPI TO COMPUTED TPI	CENTISECS	B28
T1TOT2	TIME FROM CDH TO TPI	CENTISECS	B28
T2TOT3	TIME FROM TPI (P32) TO TPI (COMPUTED IN P33)	CENTISECS	B28
DELVEET2	ΔV REQUIRED FOR CDH MANEUVER	M/CSC	B7
UP1	$\underline{r}_{P2} \times \underline{V}_{P2}$ UNIT NORMAL TO PLANE OF PASSIVE VEHICLE		
SNTH	SINE φ ANGLE BETWEEN ACTIVE AND PASSIVE VERICLES AT CDR		B1
CSTH	COS φ ANGLE BETWEEN ACTIVE AND PASSIVE VEHICLES AT CDH		B1
RVEC	POSITION VECTOR OUTPUT FROM INTEGRATION	METERS	B29
VVEC	VELOCITY VECTOR OUTPUT FROM INTEGRATION	M/CSC	B7
DH FALT	DIFFERENCE BETWEEN ACTIVE AND PASSIVE VERICLES ALTITUDES	METERS	B29

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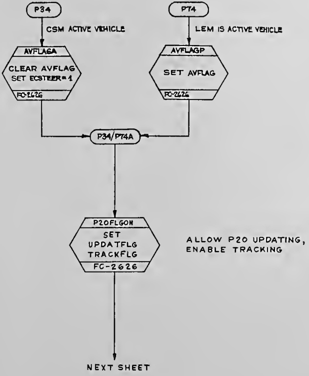
DRAWN	20 AUG 69	P33 AND P73 CONSTANT DELTA ALTITUDE TARGETING
PRGMR		
ANALST		COLOSSUS II — DOCUMENT NO. FC-2627
DOCMR		
APPR'D John A. Morse		REV 1 — SHEET 7 OF 7

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.		APOLLO GUIDANCE AND NAVIGATION
DRAWN	29MAY69	P34, P74 TRANSFER PHASE INITIATION TARGETING
PRGMR		
ANALST		COLOSSUS II A
DOCMR		DOCUMENT NO. FC-2630
APPR'D		REV 1
		SHEET 1 OF 20



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN A.C. WILLIAMS 5APR69
PRGMR
ANALST
DOCMP
APPR'D

APOLLO GUIDANCE AND NAVIGATION

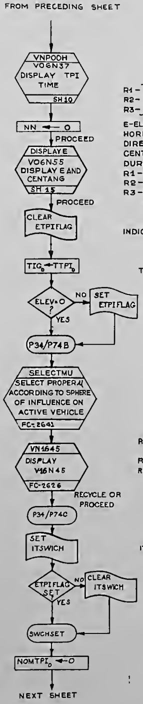
P34, P74 TRANSFER PHASE INITIATION TARGETING

COLOSSUS IIA

DOCUMENT NO. FC-2630

REV 1

SHEET 2 OF 20



R1 – } TTPI_D { 00XX. – HRS } TIME OF TPI
R2 – } TTPI_D { 000XX. – MIN } IGNITION
R3 – } TTPI_D { 0XX.XX – SEC }

E-ELEV. ANGLE BETWEEN CSM/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 TRANSER 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.

TTPI = INPUT TPI TIME

INDICATES ELEV. ANGLE IS SUPPLIED FOR P34

R1 = TRKMKCNT = NO. OF MARKS SINCE LAST MANEUVER OR INITIATION OF P20

R2 = T TOGO = TIME TILL TPI MANEUVER

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. Cahill 11 JULY 68

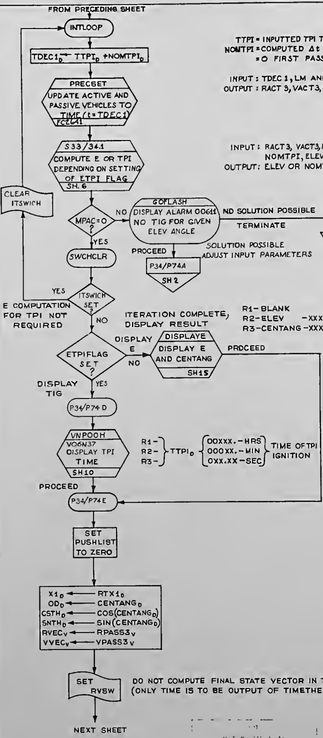
W. Templeman 11 Oct 68

W. C. Thurston 11 SEP 68

John A. Moore 12 Oct 68 5 MAY 69

COLOSSUS II A FC-2630

1 3 20



TTPI = INPUTTED TPI TIME.
NOMTPI = COMPUTED Δt FROM S33/34.1
= 0 FIRST PASS.

INPUT : TDEC 1, LM AND CSM STATE VECTORS
OUTPUT : RACT 3, VACT 3, RPASS 3, VPASS 3

INPUT : RACT3, VACT3, RPASS3, VPASS3, TTPI, NOMTPI, ELEV, ITSWICH
OUTPUT: ELEV OR NOMTPI

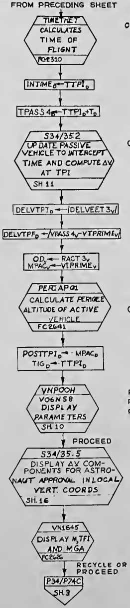
R1 - BLANK
R2 - ELEV -XXX.XX DEG. - ELEVATION ANGLE
R3 - CENTANG -XXX.XX DEG. - ORBITAL CENTRAL ANGLE OF THE PASSIVE VEHICLE DURING TRANSFER FROM TPI TO TIME OF INTERCEPT.

DO NOT COMPUTE FINAL STATE VECTOR IN TIME-THETA.
(ONLY TIME IS TO BE OUTPUT OF TIMETHET ROUTINE)

DRAWN 12 JULY 68
10 Oct 68
11 SEP 68
APPD 12 Oct 68
5 May 69
REV 1

P34, P74 TRANSFER PHASE INITIATION TARGETING

COLOSSUS IIA FC-2630



INPUT: RVEC, VVEC, SNTH, CSTH, OD(CENTANG)

OUTPUT: T_D = TIME FOR THE PASSIVE VEHICLE TO TRAVERSE THE ANGLE (CENTANG) BETWEEN THE TPI AND INTERCEPT POINTS.

FOR INIT VEL

T_D = TIME FROM TPI TO INTERCEPT TIME

INPUT: RPASS3, VPASS3, INTIME, TPASS4, UNRM, RACT3, VACT3

OUTPUT: RTARG, VPASS4, DELVLVC, DELVEET3, VTPRIME VIPRIME

VTPRIME - VELOCITY AT TARGET AFTER RENDEZVOUS MANEUVER

VIPRIME - VELOCITY REQUIRED TO EFFECT RENDEZVOUS

INPUT: OD (POSITION VECTOR OF ACTIVE VEH)
MPAC (VELOCITY VECTOR OF ACTIVE VEH)

OUTPUT: MPAC (PERIGEE ALTITUDE)

POSTTPI = H_P = PERIGEE ALTITUDE DISPLAYED TO INSURE ACTIVE VEHICLE IS A SAFE DISTANCE FROM EARTH.

R1 = POSTTPI = PERIGEE ALTITUDE

R2 = DELVTPI = ΔV_{TPI} = REQUIRED VELOCITY FOR TPI MANEUVER

R3 = DELVTPF = ΔV_{TPF} = REQUIRED VELOCITY FOR FINAL INTERCEPT MANEUVER

INPUT: DELVEET3, DELVLVC

R1 = TRKMKCNT = NO. OF MARKS MADE SINCE THE LAST THRUSTING MANEUVER OR INITIATION OF P20

R2 = TTOGO = TIME TO OR FROM TPI

R3 = + MGA = MIDDLE GIMBAL ANGLE

S33/34.1

NORMEX ← QPRET

SET PUSHLIST TO ZERO

TITER ← 40000_8
$SECMAX_D$ ← $MAX250_D$
$RAPREC_V$ ← $RACT3_V$
$VAPREC_V$ ← $VACT3_V$
$RPPREC_V$ ← $RPASS3_V$
$VPPREC_V$ ← $VPASS3_V$

COMPUTES ONE OF TWO QUANTITIES : ① ELEVATION ANGLE E BETWEEN CSM/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)

ELCALC

CALCULATES THE UNIT LOS VECTOR AND THE UNIT NORMAL VECTOR TO THE LOS VECTOR

S34/35.1

$\underline{u}_L = \text{UNIT}(\underline{r}_P - \underline{r}_A)$
$ULOS_V$ ← $\text{UNIT}(RPASS3_V - RACT3_V)$

LOS UNIT VECTOR

$\underline{u} = \text{UNIT}(\underline{r}_A \times \underline{v}_A)$
$UNRM_V$ ← $\text{UNIT}(RACT3_V \times VACT3_V)$

UNIT VECTOR NORMAL TO LOS VECTOR

RETURN VIA QPRET

$OD_V = ULOS_V = \underline{u}_L$
$MPAC_V = UNRM_V = \underline{u}$

$00 = \underline{u} \times \underline{r}_A$
00_V ← $MPAC_V \times RACT3_V$

$6D = \underline{r}_A / r_A$
$6D_V$ ← $\text{UNIT}(RACT3_V)$

$\underline{u}_P = \text{UNIT}[\underline{u}_L - (\underline{u}_L \cdot \underline{r}_A)\underline{r}_A / r_A^2]$
$MPAC_V$ ← $\text{UNIT}[ULOS_V - (ULOS_V \cdot 6D_V)6D_V]$

$00 = \underline{u}_P \cdot (\underline{u} \times \underline{r}_A)$
00_D ← $MPAC_V \cdot 0D_V$

$E_A = \cos^{-1}[\underline{u}_L \cdot \underline{u}_P \, SGN(\underline{u}_P \cdot \underline{u} \times \underline{r}_A)]$
00_D ← $\cos^{-1}[ULOS_V \cdot MPAC_V \, SGN(00_D)]$

COMPUTED ELEVATION ANGLE

NEXT SHEET

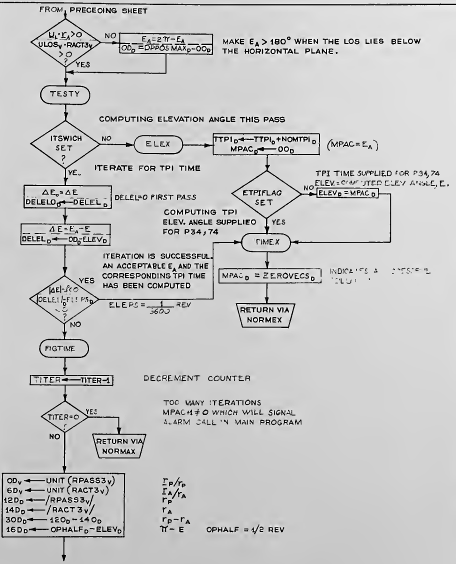
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

DRAWN P.M. Dobrick 29AUG68
ANALYST W. Tempelman 10 Oct 68
DOCMR M. Stephens 11SEP68
APPROVED John A. Moore 12 Oct 68 5 Aug 69

P34, P74 TRANSFER PHASE INITIATION TARGETING

COLOSSUS IIA FC-2630

REV 1



FROM PRECEDING SHEET
$\underline{u}_L \cdot \underline{r}_A > 0$ ULOS$_V$ · RACT3$_V$ > 0 ?
NO
$E_A = 2\pi - E_A$
OD_D = DPPOSMAX$_D$ − 00_D
MAKE $E_A > 180°$ WHEN THE LOS LIES BELOW THE HORIZONTAL PLANE.
YES
TESTY
COMPUTING ELEVATION ANGLE THIS PASS
ITSWICH SET ?
NO
ELEX
TTPI$_D$ ← TTPI$_D$ + NOMTPI$_D$
MPAC$_D$ ← 00_D
(MPAC = E_A)
ITERATE FOR TPI TIME
YES
TPI TIME SUPPLIED FOR P34,74
ELEV = COMPUTED ELEV ANGLE, E.
$\Delta E_o = \Delta E$
DELELO$_D$ ← DELEL$_D$
DELEL=0 FIRST PASS
ETPIFLAG SET
NO
ELEV$_D$ = MPAC$_D$
COMPUTING TPI ELEV. ANGLE SUPPLIED FOR P34, 74
YES
$\Delta E = E_A - E$
DELEL$_D$ ← OD_D − ELEV$_D$
TIMEX
ITERATION IS SUCCESSFUL. AN ACCEPTABLE E_A AND THE CORRESPONDING TPI TIME HAS BEEN COMPUTED
MPAC$_D$ = ZEROVECS$_D$
YES
$|\Delta E| - \epsilon < 0$ DELEL$_D$ − ELEPS$_D$ < 0 ?
ELEPS = $\frac{1}{3600}$ REV
RETURN VIA NORMEX
NO
FIGTIME
TITER ← TITER−1
DECREMENT COUNTER
TOO MANY ITERATIONS
MPAC+1 ≠ 0 WHICH WILL SIGNAL ALARM CALL IN MAIN PROGRAM
TITER=0 ?
YES
NO
RETURN VIA NORMAX
$0D_V$ ← UNIT (RPASS3$_V$)
$6D_V$ ← UNIT (RACT3$_V$)
$12D_D$ ← /RPASS3$_V$/
$14D_D$ ← /RACT3$_V$/
$30D_D$ ← $12D_D$ − $14D_D$
$16D_D$ ← OPHALF$_D$ − ELEV$_D$
$\underline{r}_P / r_P$
$\underline{r}_A / r_A$
r_P
r_A
$r_P - r_A$
$\pi - E$
OPHALF = 1/2 REV

FROM PRECEDING SHEET

Decision: $(\pi - E)\,SGN(r_P - r_A) < 0$ — $16D_D\,SGN(30D_D) < 0$?

YES → RETURN VIA NORMEX

THE ELEVATION ANGLE E, IS INCONSISTENT WITH THE RELATIVE ALTITUDES OF THE TWO VEHICLES: RETURN AND DISPLAY ALARM 00611

NO ↓

$28D = -COS(\pi - E)\, r_A / r_P$

$28D_D \leftarrow MPAC_D \leftarrow -COS(16D_D)\,14D_D / 12D_D$

USED LATER IN CALCULATION OF Δt
$-COS(\pi - E) = COS\ E$

Decision: $1 - |r_A COS\ E / r_P| < 0$ — $DPHALF_D - /MPAC_D/ < 0$?

YES → RETURN VIA NORMEX

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

NO ↓

$\omega_A = [UNIT(\underline{u} \times \underline{r}_A) \cdot \underline{v}_A]\, r_P$

$16D_D \leftarrow [UNIT(UNRM_V \times 6D_V) \cdot VACT3_V]\, 12D_D$

$\omega_P = \{UNIT[(\underline{r}_P \times \underline{v}_P) \times \underline{r}_P] \cdot \underline{v}_P\}\, r_A$

$MPAC_D \leftarrow \{UNIT[(0D_V \times VPASS3_V) \times 0D_V] \cdot VPASS3_V\}\, 14D_D$

$16D = \omega_A - \omega_P$

$16D_D \leftarrow 16D_D - MPAC_D$

DENOMINATOR IN Δt CALCULATION BELOW.

$18D = (\underline{r}_A \times \underline{r}_P) \cdot \underline{u}$

$18D_D \leftarrow (6D_V \times 0D_V) \cdot UNRM_V$

$MPAC = SGN(\underline{r}_A \times \underline{r}_P \cdot \underline{u})\, COS^{-1}(\underline{r}_A \cdot \underline{r}_P / r_A r_P)$

$MPAC_D \leftarrow SGN\, 18D_D\, [COS^{-1}(6D_V \cdot 0D_V)]$

$6D_V$ = UNIT VECTOR = $\underline{r}_A / r_A$
$0D_V$ = UNIT VECTOR = $\underline{r}_P / r_P$

$\alpha - \pi = MPAC + E - \pi$

$18D_D \leftarrow MPAC_D + ELEV_D - DPHALF_D$

USED IN CALCULATION OF Δt
DPHALF = 1/2 REV

$\Delta t = \{[\{\pi - COS^{-1}(r_A COS\ E / r_P)\}\, SGN(r_P - r_A) + (\alpha - \pi)]\, 2\pi / (\omega_A - \omega_P)\}\, r_A r_P$

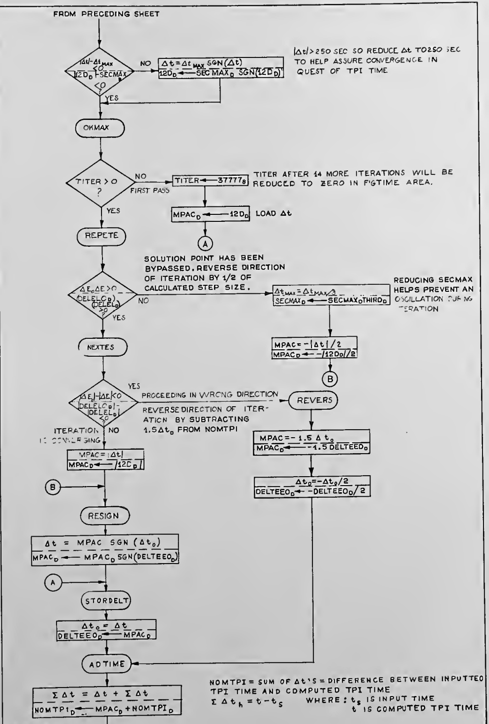
$12D_D \leftarrow \{[\{DPHALF_D - (COS^{-1} 28D_D)\}\, SGN(30D_D) + 18D_D]\, TWOPI_D / 16D_D\}\, 14D_D\, 12D_D$

2π CANCELS REV. UNITS SO THAT THE UNITS OF THE FINAL EXPRESSION WILL BE CSEC.

NEXT SHEET

MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS.
DRAWN D. H. Dietrich 24 SEP 68
CHECKER
ANALYST W. Tempelman 10 Oct 68
DOCMR M. C. Hughes 2 OCT 68
APPR'D John A. Moore 12 Oct 68, 5 May 69
REV 1

P34, P74 TRANSFER PHASE INITIATION TARGETING
COLOSSUS IIA FC-2630
SH 8 OF 20



MIT INSTRUMENTATION LAB, CAMBRIDGE, MASS.

DR J. Cahill 18JUL68

CHK W. Tempelman 30Oct68

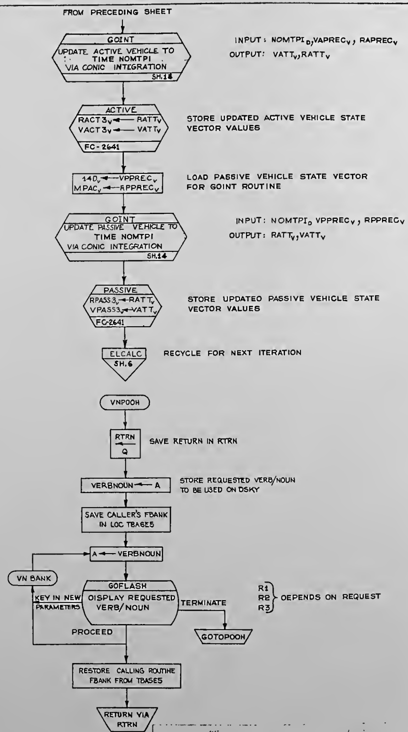
M.C. Forsyth 11SEP68

APPR'D John A. Moore 12Oct68 5 May 69

P34, P74 TRANSFER PHASE INITIATION TARGETING

COLOSSUS IIA FC-2630

1 9 20



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN 18JUL68
PRGMR
ANALST
DOCMR 11SEP68
APPR'D 5 May 69

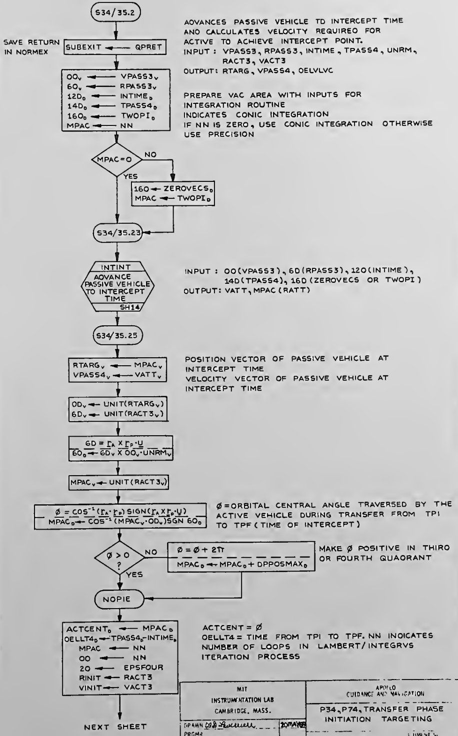
P34, P74 TRANSFER PHASE INITIATION TARGETING

COLOSSUS II A

FC-2630

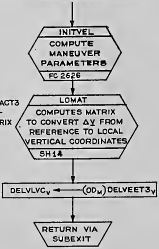
REV 1

10 of 20



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 20MAY68	P34, P74, TRANSFER PHASE INITIATION TARGETING
PRGMR	
ANALST [signature] 13 June 69	COLOSSUS IIA — FC-2630
DOCMR [signature] 13 June 69	
APPR'D [signature] 13 June 69	REV 1 — 11 of 20

FROM PRECEDING SHEET



INPUT: RINIT, VINIT, RTARG, DELLT4, INTIME
OD(NO OF ITERATIONS OF LAMBERT/INT[illegible]), 2D ANGLE TO [illegible]
RTX1 (-2 EARTH, -10 LUNAR), RTX2 (0 EARTH, 2 LUNAR)
OUTPUT: RTARG (OFFSET TARGET POSITION VECTOR), VIPRIME (VELOCITY REQUIRED FROM TPI POINT FOR ACTIVE VEHICLE TO ACHIEVE TPF POINT), VTPRIME (ACTIVE VEHICLE VELOCITY AFTER TPF POINT), DELVEET3 (ΔV FOR TPI MANEUVER)
INITVEL COMPUTES THE REQUIRED MANEUVER AND DELTA VELOCITIES TO TRANSFER THE ACTIVE VEHICLE FROM IT'S INITIAL POSITION (TPI) TO TARGET POSITION (TPF) IN A PRESCRIBE TIME OF FLIGHT.

INPUT: UNRM, RACT3
OUTPUT: TRANSFORMATION MATRIX IN OD_M

ΔV IN LOCAL VERTICAL COORDINATES

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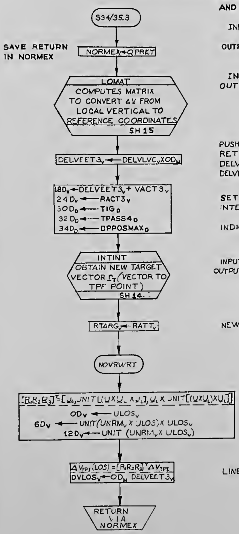
DRAWN [signature] 26SEP68	P34, P74 TRANSFER PHASE INITIATION TARGETING
PRGMR	
ANALST [signature] 10Oct68	COLOSSUS IIA — DOCUMENT № FC-2630
DOCMR [signature] 2OCT68	
APPR'D [signature] 12Oct68 5May69	REV 1 — SHEET 12 OF 20

CALCULATES NEW TARGET VECTOR IF ΔV OVERWRITE AND LINE OF SIGHT ΔV



INPUT: DELVLVC, VACT3, RACT3, TIG, TPASS 4, UNRM, ULOS
OUTPUT: DVLOS, RTARG

INPUT: UNRM, RACT3
OUTPUT: TRANSFORMATION MATRIX IN OD_M

PUSH LIST COUNTER IS 18 UPON RETURN FROM LOMAT
DELVEET3 = ΔV_{TPI} IN REFERENCE COORDS.
DELVLVC = NEW ΔV_{TPI} INPUTTED BY ASTRONAUT OVERWRITE

SET UP VAC AREA FOR INTEGRATION ROUTINE

INDICATES PRECISION INTEGRATION

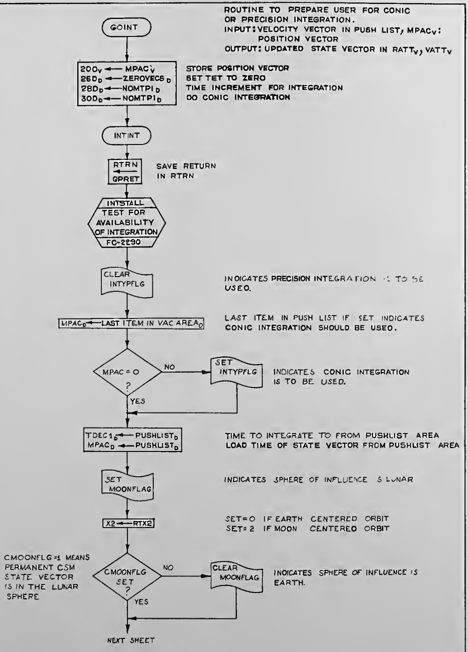
INPUT: SEE PREVIOUS BOX
OUTPUT: $RATT_V$

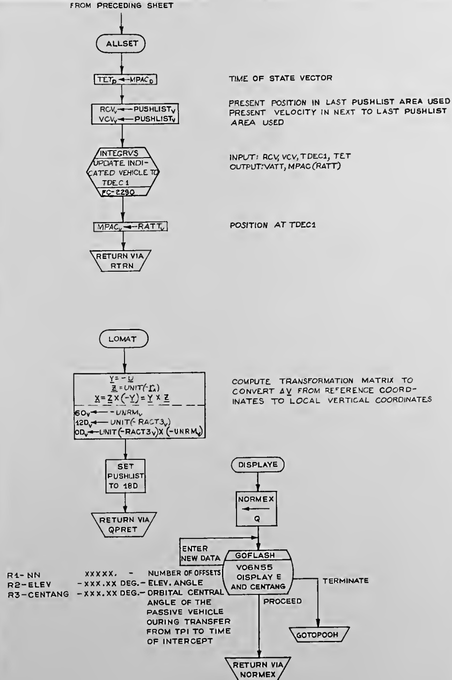
NEW OFFSET TARGET VECTOR

THIS MATRIX IS USED TO CONVERT ΔV FROM REFERENCE COORDINATES TO LINE OF SIGHT COORDINATES

LINE OF SIGHT DELTA VELOCITY

CAMBRIDGE, MASS.	P34, P74 TRANSFER PHASE INITIATION TARGETING
22JUL68 / 10Oct68 / 11SEP68 / 12Oct68 / 5May69	COLOSSUS IIA — FC-2630
	REV 1 — 13 of 20


ROUTINE TO PREPARE USER FOR CONIC
OR PRECISION INTEGRATION.
INPUT: VELOCITY VECTOR IN PUSH LIST, MPACV: POSITION VECTOR
OUTPUT: UPDATED STATE VECTOR IN RATTV, VATTV
GOINT
200V ← MPACV
26DD ← ZEROVEC5D
28DD ← NOMTPID
30DD ← NOMTPID
STORE POSITION VECTOR
SET TET TO ZERO
TIME INCREMENT FOR INTEGRATION
DO CONIC INTEGRATION
INTINT
RTRN ← QPRET
SAVE RETURN IN RTRN
INTSTALL
TEST FOR AVAILABILITY OF INTEGRATION
FC-2290
CLEAR INTYPFLG
INDICATES PRECISION INTEGRATION IS TO BE USED.
MPACD ← LAST ITEM IN VAC AREAD
LAST ITEM IN PUSH LIST IF SET INDICATES CONIC INTEGRATION SHOULD BE USED.
MPAC = 0 ?
NO
YES
SET INTYPFLG
INDICATES CONIC INTEGRATION IS TO BE USED.
TDEC1D ← PUSHLISTD
MPACD ← PUSHLISTD
TIME TO INTEGRATE TO FROM PUSHLIST AREA
LOAD TIME OF STATE VECTOR FROM PUSHLIST AREA
SET MOONFLAG
INDICATES SPHERE OF INFLUENCE IS LUNAR
X2 ← RTX2
SET=0 IF EARTH CENTERED ORBIT
SET=2 IF MOON CENTERED ORBIT
CMOONFLG=1 MEANS PERMANENT CSM STATE VECTOR IS IN THE LUNAR SPHERE
CMOONFLG SET ?
NO
YES
CLEAR MOONFLAG
INDICATES SPHERE OF INFLUENCE IS EARTH.
NEXT SHEET

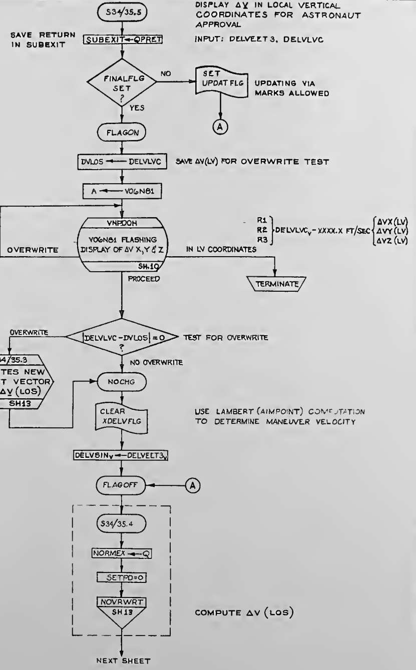


22JUL68
11SEP68
12OCT68
5 May 69

P34, P74 TRANSFER PHASE INITIATION TARGETING

COLOSSUS II A FC-2630

1 15 20



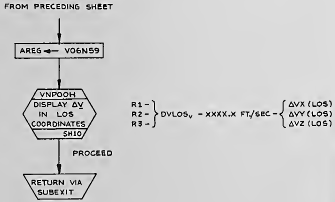
P34, P74 TRANSFER PHASE INITIATION TARGETING

DRAWN 22JUL68
CHKD 11SEP68
APPR'D 12 OCT 68 / 5 May 69

COLOSSUS IIA

FC-2630

1 16 20


FROM PRECEDING SHEET
AREG ← V06N59
VNPOOH
DISPLAY ΔV
IN LOS
COORDINATES
SH10
R1 - ΔVX (LOS)
R2 - DVLOS_V - XXXX.X FT./SEC - ΔVY (LOS)
R3 - ΔVZ (LOS)
PROCEED
RETURN VIA
SUBEXIT

P34 TRANSFER PHASE INITIATION (TPI)

SUBROUTINES

IN THIS CHART		
VNPOOH	DISPLAY REQUESTED VERB/NOUN	SH. 10
DISPLAYE	DISPLAY V06N55	SH. 15
SELECTMU	SELECT μ 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	ΔV(LV) IN REF, NEW TARGET, ΔV IN LOS COORDINATES	SH. 13
S34/35.5	DISPLAY $\Delta \underline{V}$ COMPONENTS	SH. 16
LOMAT	COMPUTES TRANSFORMATION MATRIX	SH. 15

OTHER CHARTS	
AVFLAGA	CLEAR AVFLAG, SET ECSTEER = 1, SET UPDATFLG AND TRACKFLG
AVFLAGP	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
PERIAPO1	CALCULATES PERIGEE ALTITUDE TO ACTIVE VEHICLE
VN1645	DISPLAY M,TFI,MGA
P20FLGON	SETS TRACKFLG, UPDATFLG

FLAGS	MEANING		SET	CLEARED	TESTED
ETPIFLAG	SET	ELEVATION ANGLE IS INPUT	SH2	SH2	SH2,SH3 SH6
	CLEARED	TPI TIME IS INPUT			
ITSWICH	SET	FORCE ANOTHER ITERATION OF S34/35.1 TO COMPUTE TPI TIME	SH2	SH2,SH3	SH3,SH6
	CLEARED	ACCEPT CURRENT TPI TIME/FINAL ITERATION S34/35.1 PRIOR TO COMPUTING ELEV. ANGLE			
RVSW	SET	ONLY TIME IS AN OUTPUT FROM TIMETHET	SH3		
	CLEARED	STATE VECTOR UPDATE AND TIME ARE OUTPUTS FROM TIMETHET			
MOONFLAG	SET	MOON IS SPHERE OF INFLUENCE	SH13	SH13	
	CLEARED	EARTH IS SPHERE OF INFLUENCE			
INTYPFLG	SET	CONIC INTEGRATION	SH13	SH13	
	CLEARED	PRECISION INTEGRATION			
CMOONFLG	SET	PERMANENT CSM STATE VECTOR IN LUNAR SPHERE			SH13,SH15
	CLEARED	PERMANENT CSM STATE VECTOR IN EARTH SPHERE			
FINALFLG	SET	LAST PASS THRU RENDEZVOUS PROGRAM COMPUTATIONS		SH16	SH15
	CLEARED	INTERIM PASS THRU RENDEZVOUS PROGRAM COMPUTATIONS			
UPDATFLG	SET	UPDATING VIA MARKS ALLOWED	SH15		
	CLEARED	UPDATING VIA MARKS DISALLOWED			
AVFLAG	SET	LM ACTIVE VEHICLE			
	CLEARED	CSM ACTIVE VEHICLE			
XDELVFLG	SET	USE EXTERNAL $\Delta \underline{V}$ COMPUTATION FOR MANEUVER VELOCITY		SH15	
	CLEARED	USE LAMBERT COMPUTATION TO DETERMINE MANEUVER VELOCITY			
TRACKFLG	SET	TRACKING ALLOWED			
	CLEARED	TRACKING DISALLOWED			

ALARMS	MEANING		USED	
00611	NO TIME OF IGNITION FOR GIVEN ELEV. ANGLE		SH3	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietrich 4 SEP 68	P34 P74 TRANSFER PHASE INITIATION TARGETING
ANALST W. Tempelman 10 OCT 68	COLOSSUS IIA FC-2630
DOCMR M. Kosbatt 11 SEP 68	
APPR'D John A. Moore 12 OCT 68 5 May 69	REV 1 SHEET 18 OF 20

ERASABLES		UNITS	
TTPI	TIME OF TPI MANEUVER	CENTISECS.	2^{28}
TIG	IGNITION TIME OF MANEUVER	CENTISECS.	2^{28}
ELEV.	DESIRED LOS ANGLE AT TPI	REVOLUTIONS	2^{1}
NN	NUMBER OF INTEGRATION OFFSETS; 0 = CONIC, 2 = PRECISION		
NOMTPI	DELTA TIME BETWEEN ASSIGNED AND COMPUTED TPI TIME	CENTISECS.	2^{28}
TDEC1	INPUT TIME TO INTEGRATION	CENTISECS.	2^{28}
DELVEET3	$\Delta \underline{V}$ FOR TPI MANEUVER	M/CSC	2^{7}
CENTANG	ANGLE TRAVERSED BY PASSIVE VEHICLE FROM TPI TO TPF TIME	REVOLUTIONS	2^{1}
CSTH	COS OF CENTANG	REVOLUTIONS	2^{1}
SNTH	SIN OF CENTANG	REVOLUTIONS	2^{1}
RVEC	STATE VECTOR POSITION VALUE	METERS	2^{29}
RPASS3	PASSIVE VEHICLE POSITION VECTOR AT TPI TIME	METERS	2^{29}
VPASS3	PASSIVE VEHICLE VELOCITY VECTOR AT TPI TIME	M/CSC	2^{7}
VVEC	STATE VECTOR VELOCITY VALUE	M/CSC	2^{7}
INTIME	INPUT TIME TO INITVEL ROUTINE	CENTISECS.	2^{28}
T	TIME FROM TPI TO TPF	CENTISECS.	2^{28}
TPASS4	RENDEZVOUS TIME	CENTISECS.	2^{28}
DELVTPI	MAGNITUDE OF $\Delta \underline{V}$ AT TPI	M/CSC	2^{7}
DELVTPF	MAGNITUDE OF $\Delta \underline{V}$ AT TPF	M/CSC	2^{7}
RPASS4	PASSIVE VEHICLE POSITION VECTOR AT TPF TIME	METERS	2^{29}
VPASS4	PASSIVE VEHICLE VELOCITY VECTOR AT TPF TIME	M/CSC	2^{7}
VTPRIME	VELOCITY AT TARGET AFTER MANEUVER	M/CSC	2^{7}
VIPRIME	MANEUVER VELOCITY REQUIRED	M/CSC	2^{7}
RTARG	OFFSET TARGET POSITION VECTOR	METERS	2^{29}
RTX1	SHIFT COUNTER; -2 FOR EARTH ORBIT, -10 FOR LUNAR ORBIT		2^{14}
RTX2	SHIFT COUNTER; 0 FOR EARTH ORBIT, 2 FOR LUNAR ORBIT		2^{14}
+MGA	MIDDLE GIMBAL ANGLE	REVOLUTIONS	2^{0}
TTOGO	TIME TO IGNITION	CENTISECS.	2^{28}
TRKMKCNT	NO. OF OPTICS MARKS INCORPORATED SINCE LAST MANEUVER OR INITIATION OF P20		2^{14}
TITER	ITERATION COUNTER FOR S33/34.1	B14	
SECMAX	Δt UPPER LIMIT FOR CURRENT ITERATION		2^{28}
RACT3/RINIT	POSITION VECTOR OF ACTIVE VEHICLE AT TPI	METERS	2^{29}
VACT3/VINIT	VELOCITY VECTOR OF ACTIVE VEHICLE AT TPI	M/CSC	2^{7}
ULOS	UNIT LINE OF SIGHT VECTOR	METERS	2^{1}
UNRM	UNIT NORMAL VECTOR TO ACTIVE VEHICLE'S PLANE	METERS	2^{1}
DELEL	DIFFERENCE BETWEEN DESIRED AND COMPUTED ELEVATION ANGLE	REVOLUTIONS	2^{1}
DELEL0	TEMP. STORAGE FOR DELEL	REVOLUTIONS	2^{1}
DELTEE0	CURRENT ITERATION'S VALUE OF Δt	CENTISECS.	2^{28}
RAPREC	POSITION VECTOR OF ACTIVE AT TPI TEMP. STORAGE	METERS	2^{29}
VAPREC	VELOCITY VECTOR OF ACTIVE AT TPI TEMP. STORAGE	M/CSC	2^{7}
RPPREC	POSITION VECTOR OF PASSIVE AT TPI TEMP. STORAGE	METERS	2^{29}
VPPREC	VELOCITY VECTOR OF PASSIVE AT TPI TEMP. STORAGE	M/CSC	2^{7}
VATT	POSITION VECTOR AFTER INTEGRATION UPDATE	M/CSC	2^{7}
RATT	VELOCITY VECTOR AFTER INTEGRATION UPDATE	METERS	2^{29}
ACTCENT	CENTRAL ANGLE TRAVERSED BY ACTIVE FROM TPI TO TPF	REVOLUTIONS	2^{0}
TET	TIME INPUT TO INTEGRATION ROUTINE	CENTISECS.	2^{28}
VCV	PRESENT VELOCITY INPUT TO INTEGRATION ROUTINE	M/CSC	2^{7}
RCV	PRESENT POSITION INPUT TO INTEGRATION ROUTINE	METERS	2^{29}

P34 (CONT'D)

DISPLAYS

VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N37	FLASHING	R1 - / R2 - / R3 - } $TTPI_D$ { 00xxx. HRS. / 000xx. MIN. / 0xx.xx SEC } TIME OF TPI IGNITION	SH2, 3
V06N55	FLASHING	R1 - NN NUMBER OF OFFSETS. 0 = CONIC, 2 = PRECISION R2 - ELEV } xxx.xx DEG. { ELEVATION ANGLE R3 - CENTANG } xxx.xx DEG. { ORBITAL CENTRAL ANGLE OF THE PASSIVE VEH. DURING TRANSFER FROM TPI TO TIME OF INTERCEPT	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 - / R2 - / R3 - } $DELVLVC_V$ xxxx.x FT/SEC { ΔVX (LV) / ΔVY (LV) / ΔVZ (LV) } DELTA V REQUIRED FOR TPI MANEUVER IN LOCAL VERTICAL COORDINATES	SH15
V06N59	FLASHING	R1 - / R2 - / R3 - } $DVLOS_V$ xxxx.x FT/SEC { ΔVX (LOS) / ΔVY (LOS) / ΔVZ (LOS) } DELTA V REQUIRED FOR TPI MANEUVER IN LINE OF SIGHT COORDINATES	SH16

R36: OUT-OF-PLANE RENDEZVOUS ROUTINE

PRELIMINARY

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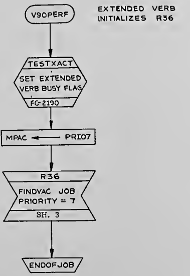
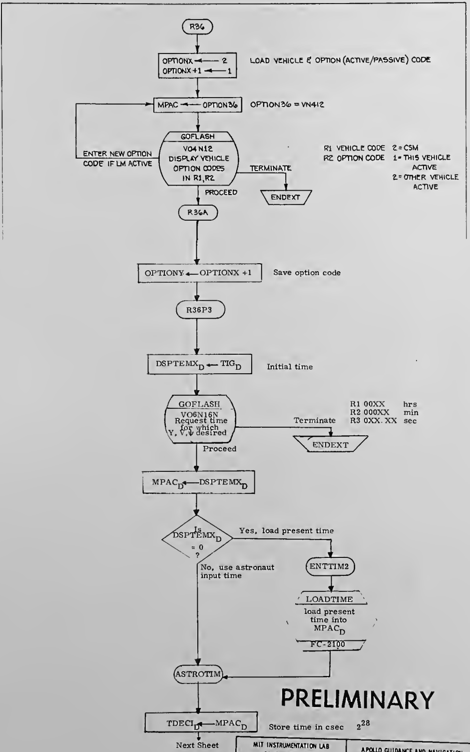
DRAWN L. Valentine	12/6/67	R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2631
DOCMR			
APPR'D		REV 2	SHEET 1 OF 7

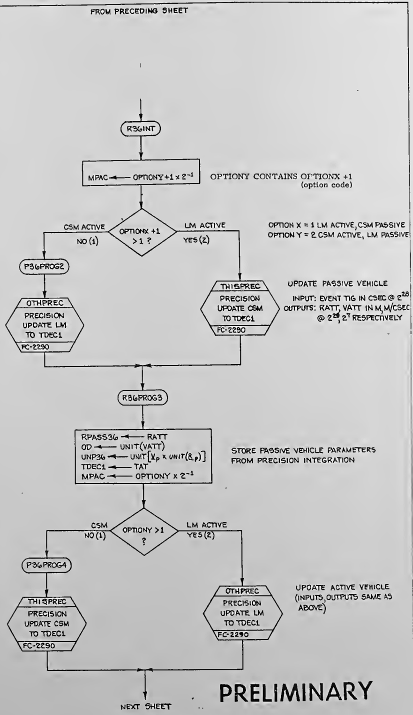


PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2631
ANALST			
DOCMR			
APPR'D		REV 2	SHEET 2 OF 7

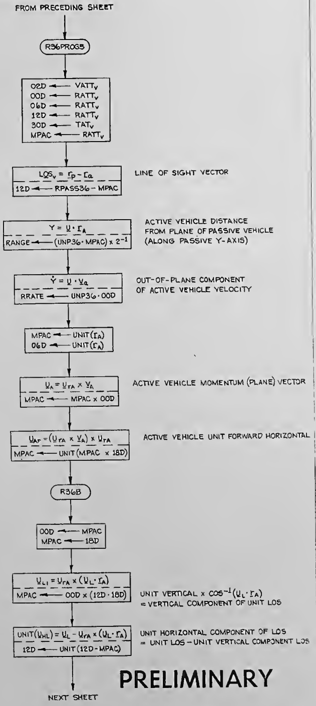


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN	R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PRGMR		
ANALST	COLOSSUS 2D	DOCUMENT NO. FC-2631
DOCMR		
APPR'D	REV	SHEET 3 OF 7



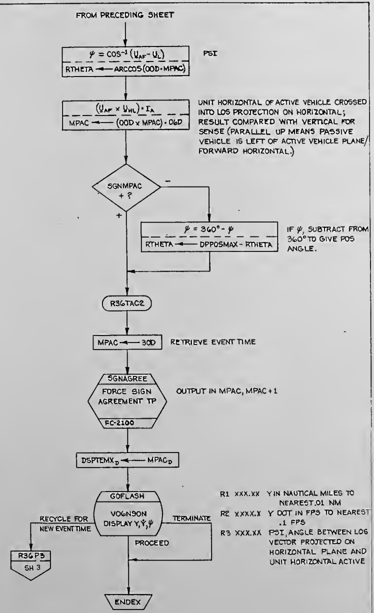
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	11/7/69	R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2631
DOCMR			
APPR'D		REV 2	SHEET 4 OF 7



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2631
DOCMR			
APPR'D		REV 2	SHEET 5 OF 7



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	[illegible]	R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2631
DOCMR			
APPR'D		REV 2	SHEET 6 OF 7

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
SGNAGREE	FC-2100	FORCE SIGN AGREEMENT (TRIPLE PRECISION)	SH 6
TESTXACT	FC-2190	SETS EXTENDED VERB BUSY FLAG	SH 2

DISPLAYS

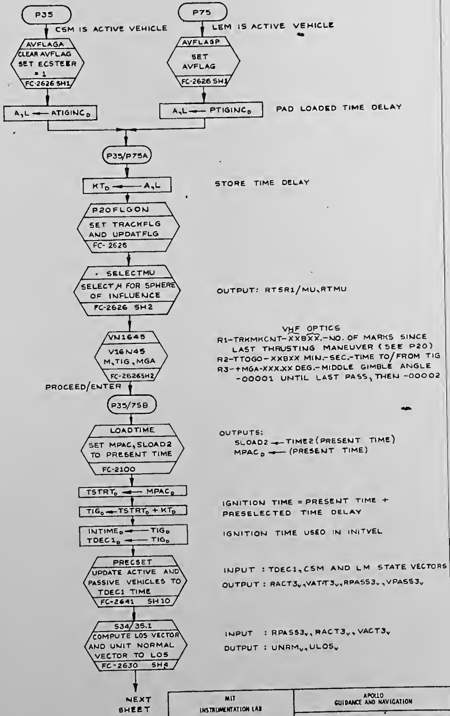
		WHERE
V04N12	DISPLAY VEHICLE CODE (1=LM, 2=CSM) IN R1 AND OPTION CODE (1=THIS VEHICLE ACTIVE, 2 = PASSIVE) IN R2	SH 3
V06N16N	REQUEST TIME FOR WHICH Y, Ẏ, ψ DESIRED	SH 3
V06N90N	DISPLAY Y, Ẏ, ψ	SH 6

ERASABLES

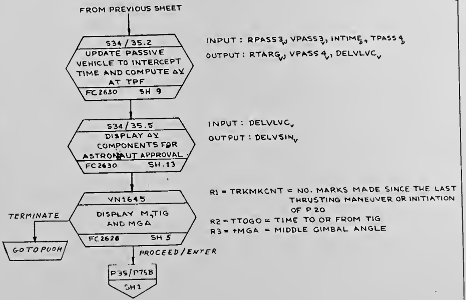
		UNITS	SCALING
OPTIONX	VEHICLE OPTION CODE (LM=1, CSM=2)		2^1
OPTIONX +1	(EQUALS OPTIONY) VEHICLE CODE (1=CSM ACTIVE, 2=LM ACTIVE)		2^1
DSPTEMX	DISPLAY BUFFER AREA (SAME AS OPTIONX)		
TDEC1	TIME STORAGE LOS	CSEC	2^{28}
RPASS36	STORAGE FOR PASSIVE VEHICLE POSITION VECTOR	METERS	2^{29}
UNP36	UNIT VECTOR OF PASSIVE VEHICLE MOMENTUM/ PLANE		
RANGE	Y, ACTIVE VEHICLE DISTANCE FROM PASSIVE VEHICLE PLANE	METERS	
RRATE	Ẏ, ACTIVE VEHICLE VELOCITY COMPONENT NORMAL TO PASSIVE PLANE	M/CSEC	
RTHETA	ψ, ANGLE BETWEEN ACTIVE VEHICLE UNIT FORWARD HORIZONTAL & LOS PROJECTED INTO HORIZONTAL PLANE		

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PRGMR	COLOSSUS 2D	DOCUMENT NO. FC-2631
ANALST		
DOCMR		
APPR'D	REV 2	SHEET 7 OF 7



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P35, P75 TRANSFER PHASE MIDCOURSE TARGETING	
DRAWN [signature]	1APR69		DOCUMENT NO.
PRGMR [signature]	2MAY69		
ANALST		COLOSSUS II-D	FC-2640
DOCMR [signature]	2 May 69		
APPR'D [signature]	2 May 69	REV 1	SHEET 1 OF 3



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	P35, P75 TRANSFER PHASE MIDCOURSE TARGETING
PRGMR	COLOSSUS II-D
ANALST	DOCUMENT NO. FC-2640
DOCMR	REV 1.
APPR'D	SHEET 2 OF 3

P35 TRANSFER PHASE MIDCOURSE

SUBROUTINES

ON OTHER CHARTS

AVFLAGA	CLEAR AVFLAG, SETS ECSTEER = 1
AVFLAGP	SETS AVFLAG
LOADTIME	SETS MPAC TO PRESENT TIME
SELECTMU	SELECT μ 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 ΔV COMPONENTS
VN164 5	DISPLAY M, TFI AND MGA
P20FLGON	SET UPDATFLG, TRACKFLG

FLAGS

AVFLAG
TRACKFLG   FINALFLG
UPDATFLG   AVFLAG

} ALL SET AND, CLEARED ON SH1

USED SH. 2

DISPLAYS

V16N45
R1-TRKMKCNT-XXXXX.-NO OF MARKS
R2-TTOGO-XXBXX MIN.-SEC.-TIME TO/FROM TIG
R3-+MGA-XXX.XX DEG. MIDDLE GIMBAL ANGLE

ALARMS

NONE

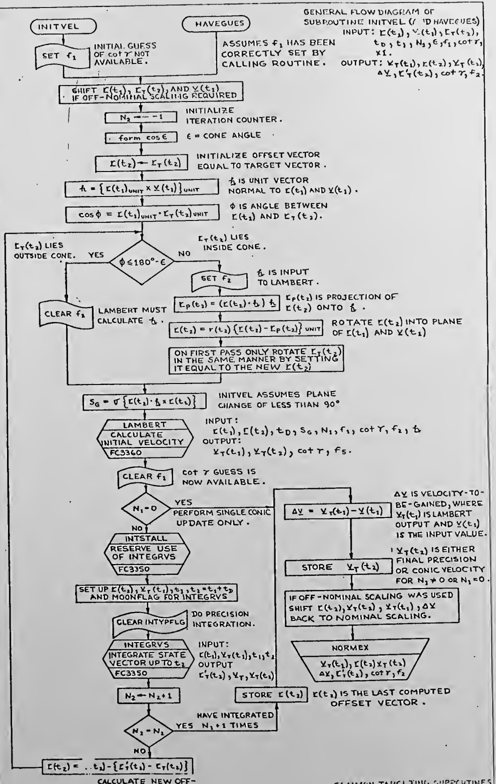
ERASABLES

		UNITS	SCALING
KT	TIMEDELAY STORAGE	CENTISECS	2[illegible]
TSTRT	PRESENT TIME STORAGE	CENTISECS	2[illegible]
TIG	TIME OF MANEUVER	CENTISECS	[illegible]
ATIGINC	PAD LOADED TIME DELAY FOR P35	CENTISECS	[illegible]
PTIGINC	PAD LOADED TIME DELAY FOR P75	CENTISECS	[illegible]
INTIME	INPUT TIME TO INITVEL	CENTISECS	[illegible]
TDEC1	INPUT TIME TO INTEGRATION	CENTISECS	[illegible]

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	2JUL68	P35, P75 TRANSFER PHASE MIDCOURSE TARGETING	
PRGMR [illegible]	19JUL68		
ANALST W. [illegible]	20Sept68	COLOSSUS II-P	DOCUMENT NO. FC-2640
DOCMR W. [illegible]	12JUL68		
APPR'D John A. [illegible]	26 Sept 68 2 May 69	REV 1.	SHEET 3 OF 3

COMMON TARGETING SUBROUTINES

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS



COMMON TARGETING SUBROUTINES
INITVEL MIDGIM
PERIAPO, SELECTMU, ELECT

COLOSSUS 2D FC-2611

G. P. Clark

INITVEL (AND HAVEGUES)

GIVEN THE INITIAL TIME t_1, THE INITIAL POSITION $r(t_1)$, THE FINAL POSITION $r_T(t_2)$ AND THE CORRESPONDING TRANSFER TIME t_D, THIS SUBROUTINE CALCULATES THE FOLLOWING VECTORS:

1) THE INITIAL VELOCITY VECTOR $v_T(t_1)$ WHICH WILL TAKE ONE IN A PRECISION INTEGRATION FROM $r(t_1)$ TO $r_T(t_2)$, AND
2) THE FINAL POSITION VECTOR $r(t_2)$ WHICH ONE WOULD ARRIVE AT IF ONE USED THE ABOVE INITIAL VELOCITY VECTOR $v_T(t_1)$ AND UPDATED USING ONLY A CONIC CALCULATION. THIS VECTOR IS REFERRED TO AS THE OFFSET TARGET VECTOR.

INITVEL IS CALLED BY:
P1Ø (OR P11), CALLIVEL, S4Ø.1, MANUPARM

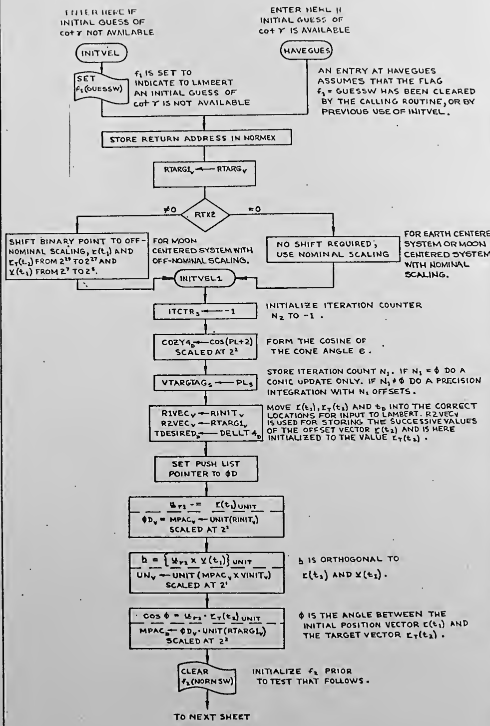
HAVEGUES IS CALLED BY:
S4Ø.9 .

INPUT:

1) $RINIT_v = r(t_1)$, INITIAL POSITION VECTOR, IN METERS, AT 2^{29}.
2) $VINIT_v = v(t_1)$, INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT 2^7. 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) $RTARG_v = r_T(t_2)$, THE TARGET VECTOR, IN METERS, AT 2^{29}. IF $N_1 \neq 0$ IT IS THE TRUE TARGET VECTOR. IF $N_1 = Ø$ IT IS THE OFFSET TARGET VECTOR.
4) $DELLT4 = t_D$, DESIRED TRANSFER TIME FROM $r(t_1)$ TO $r_T(t_2)$, IN CSEC, AT 2^{28}.
5) $INTIME = t_1$, TIME OF VALIDITY OF $r(t_1)$, IN CSEC, AT 2^{28}.
6) $PL_S = N_1$, THE NUMBER OF OFFSETS TO BE USED IN CALCULATING THE OFFSET TARGET VECTOR. IT IS ALSO EQUAL TO THE NUMBER OF ITERATIONS MINUS 1. $N_1 = Ø$ IMPLIES A SINGLE CONIC CALCULATION BUT NO INTEGRATION NOR OFFSET CALCULATION. IN THIS CASE $RTARG_v$ IS ASSUMED TO BE THE OFFSET VECTOR.
7) $PL+2 = \epsilon$, THE CONE ANGLE OF A CONE MEASURED ABOUT $-r(t_1)$, IN REVOLUTIONS, AT 2^0.
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) B29FLAG = 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 μ-TABLE, IS -2 FOR EARTH, IS -10D FOR MOON.
12) AVEGFLAG = A FLAG, IF SET $ITERCTR_S$ IS SET EQUAL TO 5, IF CLEAR $ITERCTR_S$ IS SET EQUAL TO 20D.
13) PUSH LIST POINTER IS AT THE GENERAL VALUE PL, WHERE $Ø \leq PL \leq 38D$.

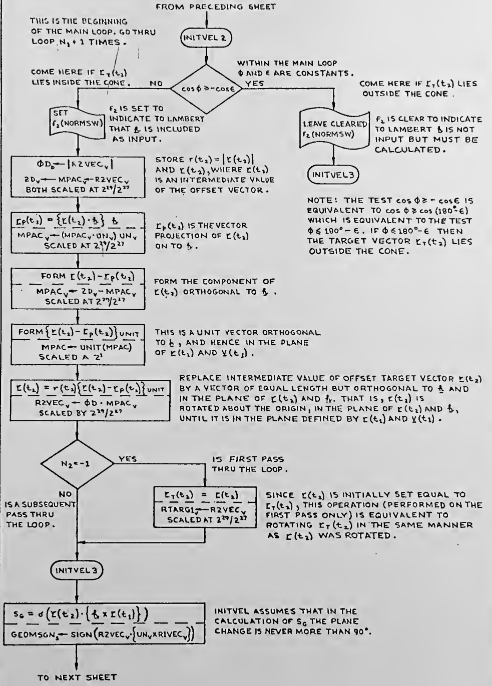
OUTPUT:

1) $VIPRIME_v = v_T(t_1)$, THE VELOCITY REQUIRED AT TIME t_1 IN ORDER TO REACH $r_T(t_2)$ IN A PRECISION MANNER IN TIME INTERVAL t_D, IN METERS/CSEC, AT 2^7. THIS IS THE FINAL VELOCITY OUTPUT FROM LAMBERT AND IS THE VELOCITY USED IN THE VELOCITY-TO-BE-GAINED EQUATIONS.
2) $RTARG_v = r(t_2)$, THE COMPUTED OFFSET TARGET VECTOR, IN METERS, AT 2^{29}.
3) $VTPRIME_v = v_T(t_2)$, THE FINAL PRECISION VELOCITY VECTOR RESULTING FROM A PRECISION UPDATE OF THE INITIAL POSITION VECTOR $r(t_1)$ AND THE REQUIRED INITIAL VELOCITY VECTOR $v_T(t_1)$ IF $N_1 \neq 0$. IT IS THE FINAL CONIC VELOCITY VECTOR RESULTING FROM A CONIC UPDATE OF $r(t_1)$ AND $r(t_2)$ IF $N_1 = Ø$. IT IS IN METERS/CSEC AT 2^7.
4) $DELVEET_v = \Delta v$, THE VELOCITY TO BE GAINED, IN METERS/CSEC, AT 2^7.
5) $RATT1_v = r'_T(t_2)$, THE POSITION VECTOR RESULTING FROM A PRECISION INTEGRATION FROM $r(t_1)$ USING $v_T(t_1)$ AS THE INITIAL VELOCITY, IN METERS, AT $2^{29}/2^{27}$.
6) $COGA = \cot\gamma$, COTANGENT OF FLIGHT PATH ANGLE OF THE VECTORS $r(t_1)$ AND $v_T(t_1)$, MEASURED FROM THE VERTICAL, AT 2^5.
7) $NORMSW = f_2$, A FLAG, IS CLEAR IF THE TARGET VECTOR $r_T(t_2)$ LIES OUTSIDE OF THE CONE, IS SET IF $r_T(t_2)$ LIES INSIDE THE CONE.
8) $ITERCTR_S$ = ITERATION COUNT USED IN LAMBERT.
9) PUSH LIST POINTER IS AT ØD.



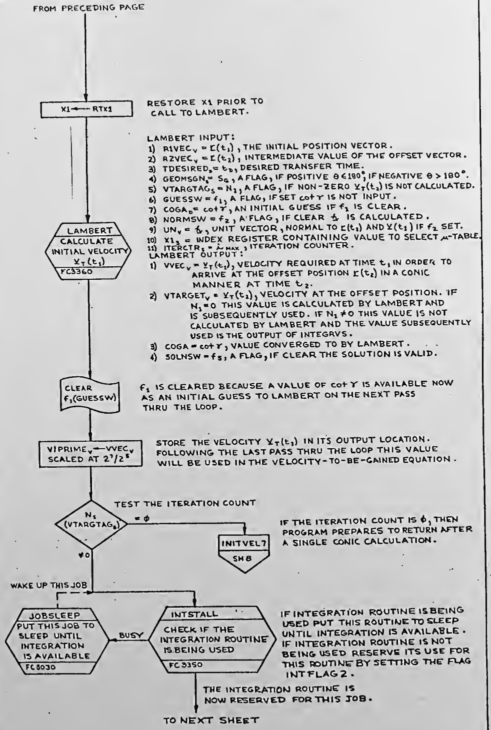
COMMON TARGETING SUBROUTINES INITVEL, MIDGIM PERIAPO, SELECTMU, PRECSET

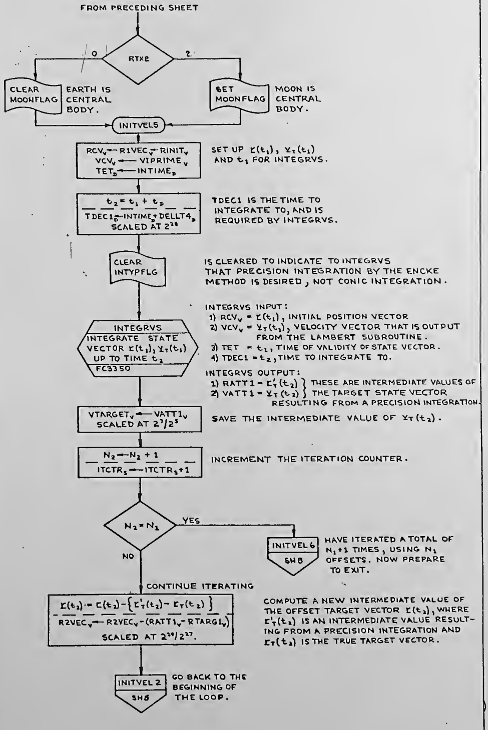
COLOSSUS 2D FC-2541

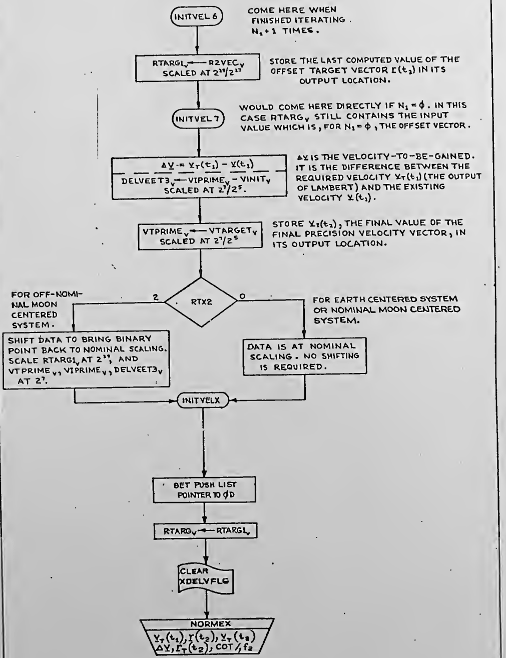


COMMON TARGETING SUBROUTINES
INITVEL, MIDGIM
PERIAPO, SELECTMU, PRECSET
COLOSSUS 2D FC-2541

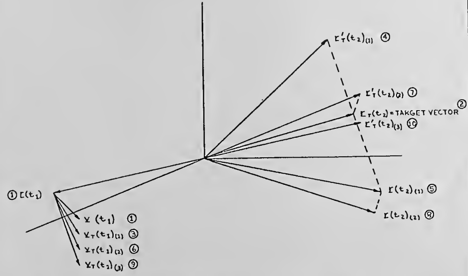
[illegible]	12 APR 69	
[illegible]	6 SEPT 69	
C. A. Clark	12 JUL 68	
John A. Moore	7 Sept 68	


FROM PRECEDING PAGE
X1 ←— RTX1
RESTORE X1 PRIOR TO CALL TO LAMBERT.
LAMBERT INPUT:
1) R1VEC$_V$ = r(t$_1$), THE INITIAL POSITION VECTOR.
2) R2VEC$_V$ = r(t$_2$), INTERMEDIATE VALUE OF THE OFFSET VECTOR.
3) TDESIRED$_D$ = t$_D$, DESIRED TRANSFER TIME.
4) GEOMSGN$_S$ = S$_G$, A FLAG, IF POSITIVE θ ≤ 180°, IF NEGATIVE θ > 180°.
5) VTARGTAG$_S$ = N$_1$, A FLAG, IF NON-ZERO v$_T$(t$_2$) IS NOT CALCULATED.
6) GUESSW = f$_1$, A FLAG, IF SET cot γ IS NOT INPUT.
7) COGA$_D$ = cot γ, AN INITIAL GUESS IF f$_1$ IS CLEAR.
8) NORMSW = f$_2$, A FLAG, IF CLEAR u$_N$ IS CALCULATED.
9) UN$_V$ = u$_N$, UNIT VECTOR, NORMAL TO r(t$_1$) AND v(t$_1$) IF f$_2$ SET.
10) X1$_S$ = INDEX REGISTER CONTAINING VALUE TO SELECT μ-TABLE.
11) ITERCTR$_S$ = λ$_{MAX}$, ITERATION COUNTER.
LAMBERT OUTPUT:
1) VVEC$_V$ = v$_T$(t$_1$), VELOCITY REQUIRED AT TIME t$_1$ IN ORDER TO ARRIVE AT THE OFFSET POSITION r(t$_2$) IN A CONIC MANNER AT TIME t$_2$.
2) VTARGET$_V$ = v$_T$(t$_2$), VELOCITY AT THE OFFSET POSITION. IF N$_1$ = 0 THIS VALUE IS CALCULATED BY LAMBERT AND IS SUBSEQUENTLY USED. IF N$_1$ ≠ 0 THIS VALUE IS NOT CALCULATED BY LAMBERT AND THE VALUE SUBSEQUENTLY USED IS THE OUTPUT OF INTEGRVS.
3) COGA = cot γ, VALUE CONVERGED TO BY LAMBERT.
4) SOLNSW = f$_5$, A FLAG, IF CLEAR THE SOLUTION IS VALID.
LAMBERT
CALCULATE INITIAL VELOCITY v$_T$(t$_1$)
FC3360
CLEAR f$_1$(GUESSW)
f$_1$ IS CLEARED BECAUSE A VALUE OF cot γ IS AVAILABLE NOW AS AN INITIAL GUESS TO LAMBERT ON THE NEXT PASS THRU THE LOOP.
VIPRIME$_V$ ←— VVEC$_V$ SCALED AT $2^7/2^5$
STORE THE VELOCITY v$_T$(t$_1$) 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$_S$ (VTARGTAG$_S$)
= ϕ
≠0
INITVEL7
SH 8
IF THE ITERATION COUNT IS ϕ, THEN PROGRAM PREPARES TO RETURN AFTER A SINGLE CONIC CALCULATION.
WAKE UP THIS JOB
JOBSLEEP
PUT THIS JOB TO SLEEP UNTIL INTEGRATION IS AVAILABLE
FC 8030
BUSY
INTSTALL
CHECK IF THE INTEGRATION ROUTINE IS BEING USED
FC 3350
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
RTX2
0
2
CLEAR MOONFLAG
EARTH IS CENTRAL BODY.
SET MOONFLAG
MOON IS CENTRAL BODY.
INITVEL5
$RCV_v \leftarrow R1VEC_v \leftarrow RINIT_v$
$VCV_v \leftarrow VIPRIME_v$
$TET_D \leftarrow INTIME_D$
SET UP $r(t_1)$, $v_T(t_1)$ AND t_1 FOR INTEGRVS.
$t_2 = t_1 + t_D$
$TDEC1_D \leftarrow INTIME_D + DELLT4_D$
SCALED AT 2^{28}
TDEC1 IS THE TIME TO INTEGRATE TO, AND IS REQUIRED BY INTEGRVS.
CLEAR INTYPFLG
IS CLEARED TO INDICATE TO INTEGRVS THAT PRECISION INTEGRATION BY THE ENCKE METHOD IS DESIRED, NOT CONIC INTEGRATION.
INTEGRVS
INTEGRATE STATE VECTOR $r(t_1)$, $v_T(t_1)$ UP TO TIME t_2
FC3350
INTEGRVS INPUT:
1) $RCV_v = r(t_1)$, INITIAL POSITION VECTOR
2) $VCV_v = v_T(t_1)$, VELOCITY VECTOR THAT IS OUTPUT FROM THE LAMBERT SUBROUTINE.
3) TET $= t_1$, TIME OF VALIDITY OF STATE VECTOR.
4) TDEC1 $= t_2$, TIME TO INTEGRATE TO.
INTEGRVS OUTPUT:
1) RATT1 $= r'_T(t_2)$
2) VATT1 $= v_T(t_2)$
THESE ARE INTERMEDIATE VALUES OF THE TARGET STATE VECTOR RESULTING FROM A PRECISION INTEGRATION.
$VTARGET_v \leftarrow VATT1_v$
SCALED AT $2^7/2^5$
SAVE THE INTERMEDIATE VALUE OF $v_T(t_2)$.
$N_2 \leftarrow N_2 + 1$
$ITCTR_S \leftarrow ITCTR_S + 1$
INCREMENT THE ITERATION COUNTER.
$N_2 = N_1$
YES
INITVEL6
SH8
HAVE ITERATED A TOTAL OF N_1+1 TIMES, USING N_1 OFFSETS. NOW PREPARE TO EXIT.
NO
CONTINUE ITERATING
$r(t_2) \leftarrow r(t_2) - \{r'_T(t_2) - r_T(t_2)\}$
$R2VEC_v \leftarrow R2VEC_v - (RATT1_v - RTARG1_v)$
SCALED AT $2^{29}/2^{27}$.
COMPUTE A NEW INTERMEDIATE VALUE OF THE OFFSET TARGET VECTOR $r(t_2)$, WHERE $r'_T(t_2)$ IS AN INTERMEDIATE VALUE RESULTING FROM A PRECISION INTEGRATION AND $r_T(t_2)$ IS THE TRUE TARGET VECTOR.
INITVEL2
SH8
GO BACK TO THE BEGINNING OF THE LOOP.


INITVEL 6
COME HERE WHEN FINISHED ITERATING . N1+1 TIMES.
RTARG1v ← R2VECv SCALED AT 2^29/2^27
STORE THE LAST COMPUTED VALUE OF THE OFFSET TARGET VECTOR r(t2) IN ITS OUTPUT LOCATION.
WOULD COME HERE DIRECTLY IF N1 = ϕ. IN THIS CASE RTARGv STILL CONTAINS THE INPUT VALUE WHICH IS, FOR N1 = ϕ, THE OFFSET VECTOR.
INITVEL 7
ΔV = VT(t1) − V(t1)
DELVEET3v ← VIPRIMEv − VINITv SCALED AT 2^7/2^5.
ΔV IS THE VELOCITY-TO-BE-GAINED. IT IS THE DIFFERENCE BETWEEN THE REQUIRED VELOCITY VT(t1) (THE OUTPUT OF LAMBERT) AND THE EXISTING VELOCITY V(t1).
VTPRIMEv ← VTARGETv SCALED AT 2^7/2^5
STORE VT(t2), THE FINAL VALUE OF THE FINAL PRECISION VELOCITY VECTOR, IN ITS OUTPUT LOCATION.
RTX2
2
0
FOR OFF-NOMINAL MOON CENTERED SYSTEM.
FOR EARTH CENTERED SYSTEM OR NOMINAL MOON CENTERED SYSTEM.
SHIFT DATA TO BRING BINARY POINT BACK TO NOMINAL SCALING. SCALE RTARG1v AT 2^29, AND VTPRIMEv, VIPRIMEv, DELVEET3v AT 2^7.
DATA IS AT NOMINAL SCALING. NO SHIFTING IS REQUIRED.
INITVELX
SET PUSH LIST POINTER TO ϕD
RTARGv ← RTARG1v
CLEAR XDELVFLG
NORMEX
VT(t1), r(t2), VT(t2)
ΔV, rT(t2), COT/f2

THE FOLLOWING IS A GEOMETRICAL REPRESENTATION OF WHAT OCCURS WHEN THREE PASSES ARE MADE THROUGH THE MAIN LOOP IN INITVEL. 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 $r(t_1)$ IS THE GIVEN POSITION VECTOR, $v(t_1)$ IS THE GIVEN VELOCITY VECTOR.

② $r_T(t_2)$ IS THE GIVEN TARGET VECTOR. FOR COMPLETENESS AND CONSISTENCY IN USE OF SUBSCRIPTS THE TARGET VECTOR $r_T(t_2)$ CAN BE CONSIDERED TO BE THE ZEROETH OFFSET VECTOR $r(t_2)_{(0)}$.

ITERATION 1

③ $v_T(t_1)_{(1)}$ IS CALCULATED BY LAMBERT USING $r(t_1)$ FROM ① AND $r(t_2)_{(0)} = r_T(t_2)$ FROM ②.

④ $r'_T(t_2)_{(1)}$ IS CALCULATED BY PRECISION INTEGRATION USING $r(t_1)$ FROM ① AND $v_T(t_1)_{(1)}$ FROM ③.

⑤ $r(t_2)_{(1)}$ IS THE OFFSET VECTOR RESULTING FROM SUBTRACTING THE MISS VECTOR BETWEEN $r'_T(t_2)_{(1)}$ FROM ④ AND $r_T(t_2)$ FROM ② FROM THE OFFSET VECTOR $r(t_2)_{(0)} = r_T(t_2)$ FROM ②.

ITERATION 2

⑥ $v_T(t_1)_{(2)}$ IS CALCULATED BY LAMBERT USING $r(t_1)$ FROM ① AND $r(t_2)_{(1)}$ FROM ⑤.

⑦ $r'_T(t_2)_{(2)}$ IS CALCULATED BY PRECISION INTEGRATION USING $r(t_1)$ FROM ① AND $v_T(t_1)_{(2)}$ FROM ⑥.

⑧ $r(t_2)_{(2)}$ IS THE OFFSET VECTOR RESULTING FROM SUBTRACTING THE MISS VECTOR BETWEEN $r'_T(t_2)_{(2)}$ FROM ⑦ AND $r_T(t_2)$ FROM ② FROM THE OFFSET VECTOR $r(t_2)_{(1)}$ FROM ⑤.

ITERATION 3

⑨ $v_T(t_1)_{(3)}$ IS CALCULATED BY LAMBERT USING $r(t_1)$ FROM ① AND $r(t_2)_{(2)}$ FROM ⑧.

⑩ $r'_T(t_2)_{(3)}$ IS CALCULATED BY PRECISION INTEGRATION USING $r(t_1)$ FROM ① AND $v_T(t_1)_{(3)}$ FROM ⑨.

⑪ THE ROUTINE NOW PREPARES TO EXIT. IT CALCULATES THE VELOCITY-TO-BE-GAINED AS THE DIFFERENCE $v_T(t_1)_{(3)} - v(t_1)$.

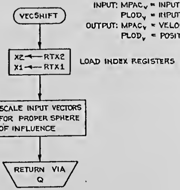
⑫ THERE IS NO CALCULATION OF THE OFFSET VECTOR $r(t_2)_{(3)}$ CORRESPONDING TO $r'_T(t_2)_{(3)}$.

⑬ THE FINAL OUTPUT VECTORS ARE:

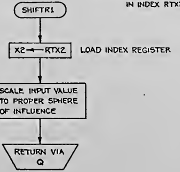
1) $v_T(t_1)_{(3)}$ FROM ⑨
2) $r(t_2)_{(2)}$ FROM ⑧
3) $r'_T(t_2)_{(3)}$ FROM ⑩

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



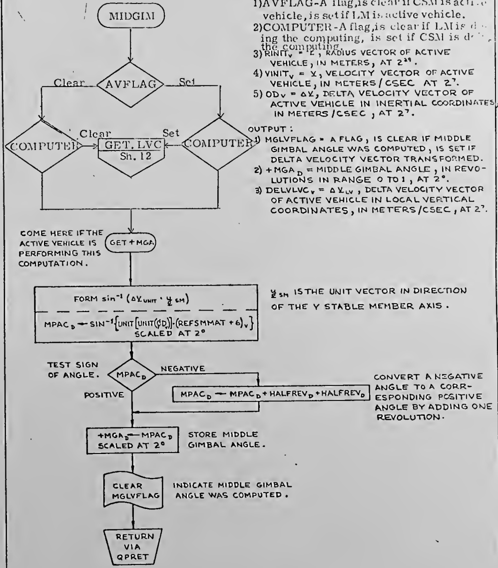
IF THE ACTIVE VEHICLE IS PERFORMING THIS COMPUTATION THIS ROUTINE COMPUTES THE POSITIVE MIDDLE GIMBAL ANGLE FOR THE ACTIVE VEHICLE ASSUMING THE X- AXIS IS ALIGNED WITH THE ΔV IMPULSE THRUST DIRECTION. IF THE PASSIVE VEHICLE IS PERFORMING THIS COMPUTATION THIS ROUTINE TRANSFORMS THE INPUT VELOCITY VECTOR FROM INERTIAL COORDINATES TO LOCAL VERTICAL COORDINATES OF THE ACTIVE VEHICLE.

INPUT:

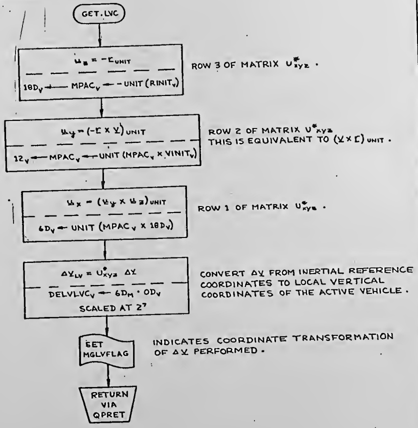
1) AVFLAG - A flag, is clear if CSM is active vehicle, is set if LM is active vehicle.
2) COMPUTER - A flag, is clear if LM is doing the computing, is set if CSM is doing the computing.
3) $RINIT_V$ = r, RADIUS VECTOR OF ACTIVE VEHICLE, IN METERS, AT 2^{29}.
4) $VINIT_V$ = v, VELOCITY VECTOR OF ACTIVE VEHICLE, IN METERS/CSEC AT 2^7.
5) OD_V = Δv, DELTA VELOCITY VECTOR OF ACTIVE VEHICLE IN INERTIAL COORDINATES, IN METERS/CSEC, AT 2^7.

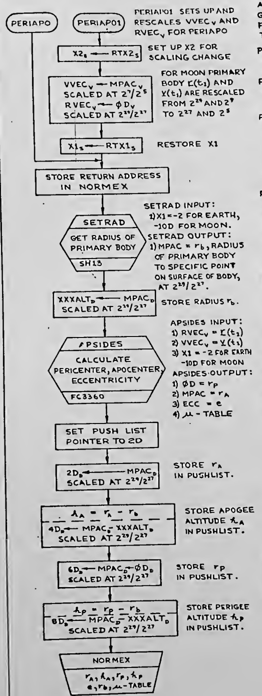
OUTPUT:

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) $DELVLVC_V$ = Δv_{LV}, DELTA VELOCITY VECTOR OF ACTIVE VEHICLE IN LOCAL VERTICAL COORDINATES, IN METERS/CSEC, AT 2^7.



COME HERE IF THE PASSIVE VEHICLE IS PERFORMING THIS CALCULATION.





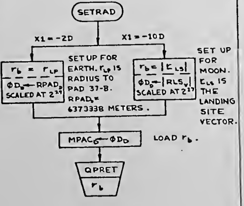
THIS SUBROUTINE COMPUTES THE TWO BODY APOCENTER AND PERICENTER ALTITUDES, GIVEN (1) THE POSITION AND VELOCITY VECTORS FOR A POINT ON THE TRAJECTORY, AND (2) THE PRIMARY BODY INDICATOR.

PERIAPO CALLED BY:
S30.1 (IN P30, P37), CSI (IN P32 - P35, P72 - P75), MANUPARM.
PERIAPO1 CALLED BY:
CSI (IN P32 - P35, P72 - P75), P34 - P35, P74 - P75, P38 - P39.

PERIAPO INPUT:
1) RVEC$_V$ = r(t$_1$), POSITION VECTOR TO POINT ON TRAJECTORY, IN METERS, AT $2^{29}/2^{27}$.
2) VVEC$_V$ = v(t$_1$), VELOCITY VECTOR TO POINT ON TRAJECTORY, IN METERS/CSEC AT $2^7/2^5$.
3) X1$_S$ = PRIMARY BODY INDICATOR IN INDEX REGISTER 1, -2 FOR EARTH, -10D FOR MOON.

PERIAPO1 INPUT:
1) ΦD$_V$ = r(t$_1$), IN METERS, 2^{29}.
2) MPAC$_V$ = v(t$_1$), IN METERS/CSEC, AT 2^7.
3) RTX1$_S$ = PRIMARY BODY INDICATOR, IS -2 FOR EARTH, -10D FOR MOON.
4) RTX2$_S$ = VALVE USED FOR RESCALING r(t$_1$) AND v(t$_1$) FOR OFF-NOMINAL SCALING, IS 0 FOR EARTH, 2 FOR MOON.

OUTPUT:
1) 2D$_D$ = r$_A$, RADIUS OF APOCENTER, IN METERS, AT $2^{29}/2^{27}$.
2) 4D$_D$ = h$_A$, APOCENTER ALTITUDE, IN METERS, AT $2^{29}/2^{27}$.
3) 6D$_D$ = r$_P$, RADIUS OF PERICENTER, IN METERS, AT $2^{29}/2^{27}$.
4) 8D$_D$ = h$_P$, PERICENTER ALTITUDE, IN METERS, AT $2^{29}/2^{27}$.
5) ECC$_D$ = e, ECCENTRICITY, AT 2^3.
6) XXXALT$_D$ = r$_b$, RADIUS OF PRIMARY BODY, IN METERS, AT $2^{29}/2^{27}$.
7) μ - TABLE FOR PRIMARY BODY.
8) PUSH LIST POINTER AT 10D.



COMMON TARGETING SUBROUTINES
INITVEL, MIDGIM
PERIAPO, SELECTMU, PRECSET
COLOSSUS 2D FC-2541

0 15 16

THIS ROUTINE SETS UP VALUES OF μ AND $1/\sqrt{\mu}$ APPROPRIATE FOR EITHER EARTH OR MOON AS PRIMARY BODY AND DEPENDS ON CONDITION OF CMOONFLG.

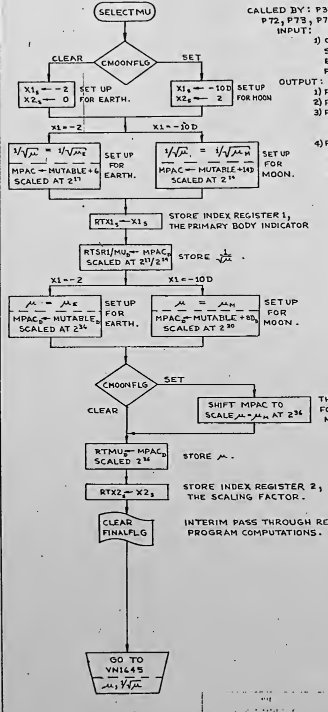
CALLED BY: P32, P33, P34, P35, P38, P39, P72, P73, P74, P75, P78, P79.

INPUT:

1) CMOONFLG = PERMANENT CSM STATE FLAG, IS CLEAR FOR EARTH PRIMARY BODY, IS SET FOR MOON.

OUTPUT:

1) $RTMU_D = \mu$, AT 2^{36}.
2) $RTSR1/MU_D = 1/\sqrt{\mu}$, AT $2^{17}/2^{14}$.
3) $RTX1_S$ = PRIMARY BODY INDICATOR, IS -2 FOR EARTH, -10D FOR MOON.
4) $RTX2_S$ = SCALING FACTOR FOR NOMINAL/OFF-NOMINAL DATA, IS 0 FOR NOMINAL (EARTH), IS 2 FOR OFF-NOMINAL (MOON).



COMMON TARGETING SUBROUTINES INITVEL, MIDGIM PERIAPO, SELECTMU, PRECSET

COLOSSUS 2D FC-2641

0 14 18

THIS ROUTINE PERFORMS A PRECISION UPDATE OF THE ACTIVE AND PASSIVE VEHICLES TO A SPECIFIED TIME.

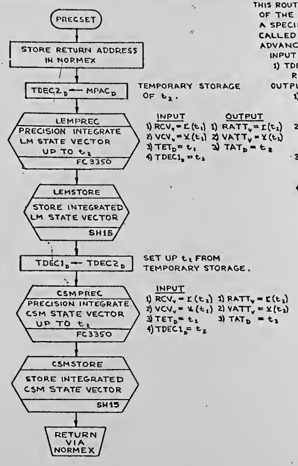
CALLED BY: P34, P35, P39, PREC/TT, ADVANCE

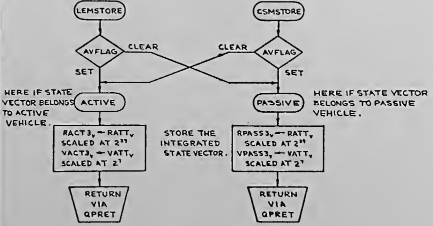
INPUT:

1) $TDEC1_D = MPAC_D = t_2$, TIME TO INTEGRATE TO, IN CSEC AT 2^{28}.

OUTPUT:

1) $RACT3_V = r(t_2)$, POSITION VECTOR OF ACTIVE VEHICLE AT t_2, IN METERS, AT 2^{29}.
2) $VACT3_V = v(t_2)$, VELOCITY VECTOR OF ACTIVE VEHICLE AT t_2, IN METERS/CSEC, AT 2^7.
3) $RPASS3_V = r(t_2)$, POSITION VECTOR OF PASSIVE VEHICLE AT t_2, IN METERS, AT 2^{29}.
4) $VPASS3_V = v(t_2)$, VELOCITY VECTOR OF PASSIVE VEHICLE AT t_2, IN METERS/CSEC, AT 2^7.





GENERAL INFORMATION

SUBROUTINES CALLED ON OTHER CHARTS

NAME	FLOW CHART NUMBER	DESCRIPTION	WHERE CALLED
LAMBERT	FC1360	CALCULATE INITIAL AND FINAL VELOCITIES GIVEN THE INITIAL AND FINAL POSITIONS AND TIME	INITVEL (SH 6)
INTSTALL	FC1350	RESERVE INTEGRATION ROUTINE FOR CALLER	INITVEL (SH 6)
INTEGRVS	FC1350	PERFORM PRECISION INTEGRATION ON STATE VECTOR	INITVEL (SH 7)
APSIDES	FC1360	COMPUTE PERICENTER, APOCENTER, ECCENTRICITY	PERIAPO (SH.13)
LEMPREC	FC1350	PERFORM PRECISION INTEGRATION ON LM STATE VECTOR	PRECSET (SH 15)
CSMPREC	FC1350	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_1)	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		SELECTMU (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_2)	UNIT NORMAL INPUT TO LAMBERT	LAMBERT COMPUTES ITS OWN UNIT NORMAL	INITVEL (SH 5)	INITVEL (SH 4)	

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

A. J. [illegible] 11 JUL 68

12 Aug 69

G. A. Clark

APOLLO GUIDANCE AND NAVIGATION

COMMON TARGETING SUBROUTINES
INITVEL, MIDGIM
PERIAPO, SELECTMU, PRECSET

COLOSSUS 2D FC-2641

AVEGFLAG	AVERAGEG (SERVICER) DESIRED	AVERAGEG (SERVICER) NOT DESIRED			INITVEL (SH 6)
CMOONFLG	CSM STATE VECTOR IN LUNAR SPHERE	CSM STATE VECTOR NOT IN LUNAR SPHERE			SELECTMU (SH 14)
GEOMSGN$_S$ (S_G)	IS PLUS IF TRUE ANOMALY LESS THAN 180°	IS MINUS IF TRUE ANOMALY GREATER THAN 180°	INITVEL (SH 5)		
VTARGTAG$_S$	IF NON-ZERO $\underline{v}_T(t_2)$ IS NOT CALCULATED	IF ZERO $\underline{v}_T(t_2)$ IS CALCULATED	INITVEL (SH 4)		INITVEL (SH 6, SH 7)
GUESSW (t_I)	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$_S$	i_{MAX}, LOOP CONTROL VALUE FOR LAMBERT ROUTINE	2^{14}	22D
TDEC1$_D$	t_2, TIME TO INTEGRATE TO, IN CSEC	2^{28}	32D
TET$_D$	t_1, IN CSEC	2^{28}	E3, 1516
RCV$_V$	$\underline{r}(t_I)$, IN METERS	$2^{29}/2^{27}$	E3, 1534
VCV$_V$	$\underline{v}_T(t_1)$, IN METERS/CSEC	$2^{7}/2^{5}$	E3, 1542
RVEC$_V$	$\underline{r}(t)$, POSITION VECTOR, IN METERS	$2^{29}/2^{27}$	E5, 1654
R1VEC$_V$	$\underline{r}(t_I)$, IN METERS	2^{29}	E5, 1654
R2VEC$_V$	$\underline{r}(t_2)$, IN METERS	$2^{29}/2^{27}$	E5, 1662
TDESIRED$_D$	t_D, IN CSEC	2^{28}	E5, 1670
UN$_V$	$\underline{h}$	2^{1}	E5, 1673
VTARGTAG$_s$	IS THE NUMBER OF OFFSETS USED IN INITVEL ROUTINE	2^{14}	E5, 1701
VTARGET$_v$	$\underline{v}_T(t_2)$	$2^{7}/2^{5}$	E5, 1702
VVEC$_v$	$\underline{v}(t)$, VELOCITY VECTOR, IN METERS/CSEC	$2^{7}/2^{5}$	E5, 1743
NORMEX$_s$	RETURN ADDRESS OF PERIAPO AND PRECSET		E7, 1450
RTRN$_s$	RETURN ADDRESS OF INITVEL		E7, 1452
TDEC2$_D$	TEMPORARY STORAGE OF TDEC1	2^{28}	E7, 1560
XIINPUT$_s$	TEMPORARY STORAGE OF X1		E7, 1564
ITCTR$_s$	ITERATION COUNTER	2^{14}	E7, 1603
COZY4$_D$	COS (ϵ)	2^{2}	E7, 1853

CONSTANTS USED

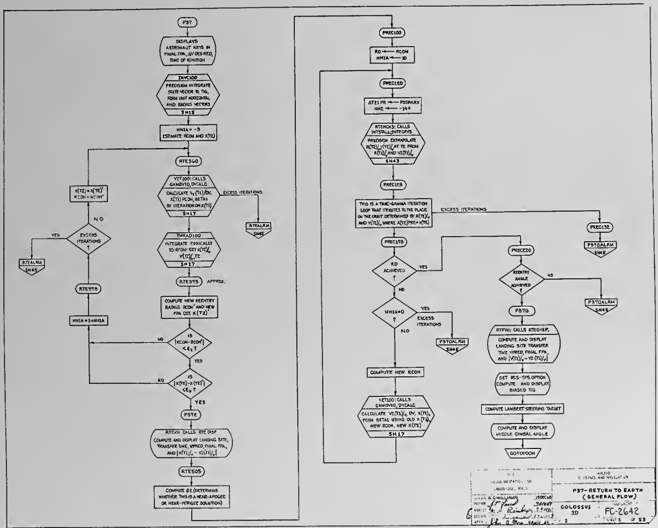
NAME	PHYSICAL MEANING	SCALING	COMPUTER VALUE
$HALFREV_D$	0.5 REVOLUTIONS	2^{0}	1.0 B-1
$EPSFOUR_D$	15/360 REVOLUTIONS (EQUALS 15^{o})	2^{0}	0.0416666666
$RPAD_D$	STANDARD RADIUS OF PAD 37-B IN METERS, EQUALS 20,909,901.57 FT	2^{29}	8373338 B-29
$MUTABLE_D$	μ_E, IN $M^3/CSEC^2$	2^{38}	3.986032 E10 B-36
MUTABLE + 6D	$1/\sqrt{\mu_E}$ IN $CSEC/M^{3/2}$	2^{-17}	0.50087529 E-5 B17
MUTABLE + $8D_D$	μ_M, IN $M^3/CSEC^2$	2^{30}	4.902778 E8 B-30
MUTABLE + $14D_D$	$1/\sqrt{\mu_M}$, IN $CSEC/M^{3/2}$	2^{-14}	0.45162595 E-4 B14

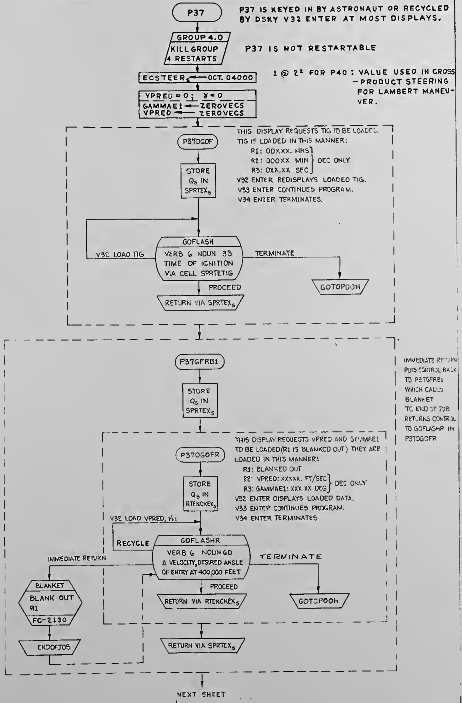
V2T100	Sh. 17
GAMDV10	Sh. 23
PREC100	Sh. 34
RTEVN	Sh. 28
P37	Sh. 3

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 $norm_{X1}(Z)$.

All quantities are double precision unless indicated in this manner: Subscript S for single precision, subscript T for triple, subscript V for vector.


P37
DISPLAYS ASTRONAUT KEYS IN FINAL FPA, ΔV DESIRED, TIME OF IGNITION
INVC100
PRECISION INTEGRATE STATE VECTOR TO TIG, FORM UNIT HORIZONTAL AND RADIUS VECTORS
SH15
NN1A = -9
ESTIMATE RCON AND X(T2)
RTE360
V2T100: CALLS GAMDV10, DVCALC
CALCULATE V2(T1)/DV, X(T1) RCON, BETA1 BY ITERATION ON X(T1)
SH17
EXCESS ITERATIONS
RTEALRM
SH45
TMRAD100
INTEGRATE CONICALLY TO RCON' GET R(T2), V(T2), T2
SH27
RTE373
APPROX.
COMPUTE NEW REENTRY RADIUS RCON' AND NEW FPA COT. X(T2)'
IS |RCON-RCON'| < E2 ?
YES
NO
IS |X(T2)-X(T2)'| < EB ?
YES
NO
NN1A = 1 + NN1A
RTE375
EXCESS ITERATIONS ?
YES
NO
RTEALRM
SH45
X(T2) = X(T2)' RCON = RCON'
P37E
RTEVN CALLS RTE DISP
COMPUTE AND DISPLAY LANDING SITE, TRANSFER TIME, VPRED, FINAL FPA, AND |V(T1)/v - V2(T1)/v|
RTE505
COMPUTE φ2 (DETERMINE WHETHER THIS IS A NEAR-APOGEE OR NEAR-PERIGEE SOLUTION)
PREC100
R0 ← RCON
NN1A ← 10
PREC120
ΔT21 PR ← POSMAX
NN2 ← -144
RTENCK3: CALLS INTSTALL, INTEGRVS
PRECISION EXTRAPOLATE R(T2)/v, V(T2)/v AT T2 FROM R(T1)/v AND V2(T1)/v
SH43
PREC125
THIS IS A TIME-GAMMA ITERATION LOOP THAT ITERATES TO THE PLACE ON THE ORBIT DETERMINED BY R(T2)/v AND V(T2)/v WHERE X(T2)PRE = X(T2)
EXCESS ITERATIONS
PREC132
P37OALRM
SH45
PREC175
RD ACHIEVED ?
YES
NO
NN1A = 0 ?
YES
EXCESS ITERATIONS
NO
P37OALRM
SH45
COMPUTE NEW RCON
V2T100: CALLS GAMDV10, DVCALC
CALCULATE V2(T1)/v, DV, X(T1), RCON BETA1 USING OLD X(T1), NEW RCON, NEW X(T2)
SH17
PREC220
REENTRY ANGLE ACHIEVED ?
NO
P37OALRM
SH45
P37G
RTFVN: CALLS RTEDISP.
COMPUTE AND DISPLAY LANDING SITE TRANSFER TIME VPRED, FINAL FPA, AND |V(T1)/v - V2(T1)/v|
GET RCS-SPS OPTION COMPUTE AND DISPLAY BIASED TIG
COMPUTE LAMBERT STEERING TARGET
COMPUTE AND DISPLAY MIDDLE GIMBAL ANGLE
GOTOPOOH
APOLLO
GUIDANCE AND NAVIGATION
P37-RETURN TO EARTH (GENERAL FLOW)
COLOSSUS
2D
FC-2642
2
OF 53



A.C.WILLIAMS 20DEC68
9 APR 69
9 Apr. 69
9 April 69

P37 - RETURN TO EARTH (MAIN PROGRAM)

COLOSSUS 2D

FC-2642

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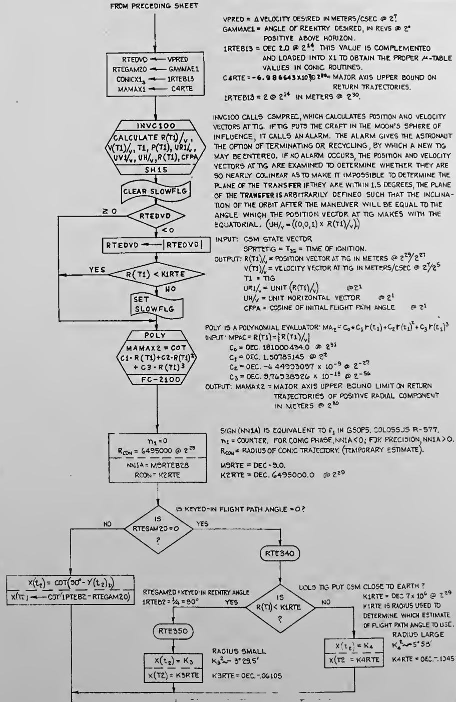


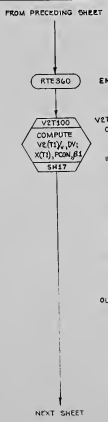
A.C. WILLIAMS 23DEC68
9APR69
9Apr69
John A. Moore 9Apr.69

P37-RETURN TO EARTH (MAIN PROGRAM)

COLOSSUS 2D

FC-2642

2 4 53

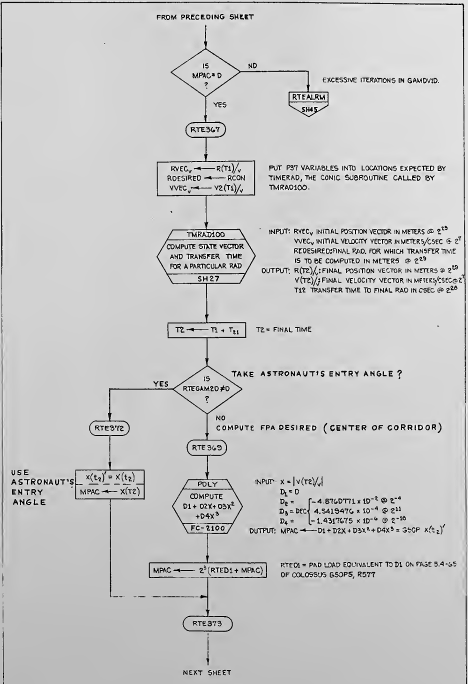


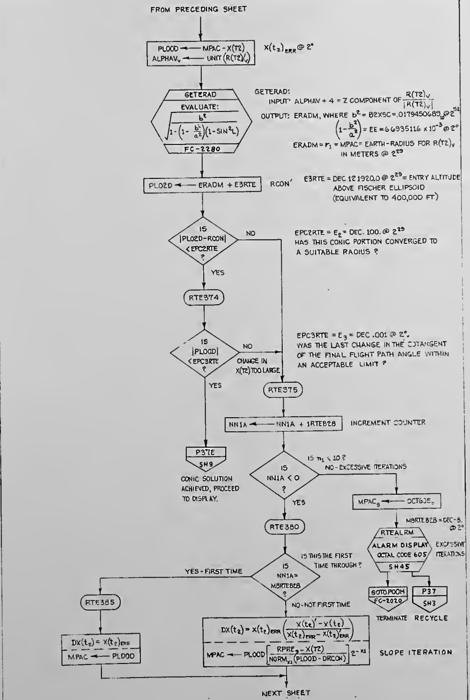
ENTRANCE FROM RTE390

V2T100
CALLS: GAMDV10
XT1LIM
DVCALC

INPUT:
1) R(T1) = MAGNITUDE OF INITIAL POSITION VECTOR IN METERS @ 2^{29}
2) RCON = MAGNITUDE OF FINAL POSITION VECTOR IN METERS @ 2^{29}
3) V(T1)/v = INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
4) RTEDVD = Δ VELOCITY DESIRED IN METERS/CSEC @ 2^7
5) UR1/v = UNIT INITIAL POSITION VECTOR @ 2^1
6) UH/v = 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) MAMAX1
10) MAMAX2 } TEMPORARY { LOWER / UPPER } BOUND ON GAMDV INTERATOR IN METERS @ 2^{30}
11) NN1A = CONIC ITERATION COUNTER. (NN1A <0 IMPLIES THIS IS CONIC PHASE.)

OUTPUT:
1) V2(T1)/v = POST-IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
2) DV = INITIAL DELTA V IN METERS/CSEC @ 2^7
3) X(T1) = COTAN OF INITIAL FPA (POST-IMPULSE) @ 2^5
4) PCON = SEMI-LATUS RECTUM IN METERS @ 2^{25}
5) BETA1 = 1 + $X(T2)^2$
6) MPAC = 0, NORMAL EXIT
MPAC ≠ 0, ALARM CODE OCT 605 - EXCESSIVE ITERATIONS IN GAMDV10
7) ABORT EXIT TO P00D00 : OCT 610


FROM PRECEDING SHEET
IS MPAC = D ?
NO
EXCESSIVE ITERATIONS IN GAMDV1D.
RTEALRM
SH45
YES
RTE367
RVEC_v ← R(T1)/_v
RDESIRED ← RCON
VVEC_v ← V2(T1)/_v
PUT P37 VARIABLES INTO LOCATIONS EXPECTED BY TIMERAD, THE CONIC SUBROUTINE CALLED BY TMRAD100.
TMRAD100
COMPUTE STATE VECTOR AND TRANSFER TIME FOR A PARTICULAR RAD
SH27
INPUT: RVEC_v INITIAL POSITION VECTOR IN METERS @ 2^29
VVEC_v INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
REDESIRED: FINAL RAD. FOR WHICH TRANSFER TIME IS TO BE COMPUTED IN METERS @ 2^29
OUTPUT: R(T2)/_v: FINAL POSITION VECTOR IN METERS @ 2^29
V(T2)/_v: FINAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
T12 TRANSFER TIME TO FINAL RAD IN CSEC @ 2^28
T2 ← T1 + T21
T2 = FINAL TIME
IS RTEGAM20 ≠ 0 ?
TAKE ASTRONAUT'S ENTRY ANGLE ?
YES
NO
COMPUTE FPA DESIRED (CENTER OF CORRIDOR)
RTE372
RTE369
USE ASTRONAUT'S ENTRY ANGLE
x(t2)' = x(t2)
MPAC ← X(T2)
POLY
COMPUTE D1 + D2X + D3X^2 + D4X^3
FC-2100
INPUT: X = |V(T2)/_v|
D1 = D
D2 = DEC −4.876D771 x 10^-2 @ 2^-4
D3 = DEC 4.5419476 x 10^-4 @ 2^11
D4 = DEC −1.4317675 x 10^-6 @ 2^-16
OUTPUT: MPAC ← D1 + D2X + D3X^2 + D4X^3 = GSOP x(t2)'
MPAC ← 2^3 (RTED1 + MPAC)
RTED1 = PAD LOAD EQUIVALENT TO D1 ON PAGE 5.4-65 OF COLOSSUS GSOPS, R577
RTE373
NEXT SHEET



P37 - RETURN TO EARTH (MAIN PROGRAM)

A.C WILLIAMS 26DEC68

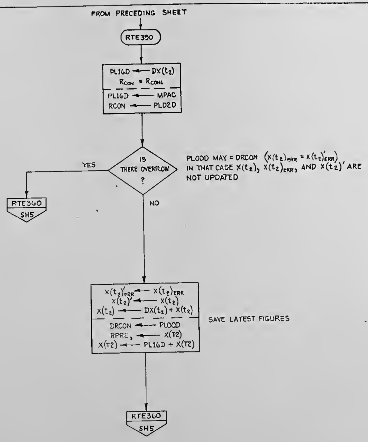
9APR69

9Apr69

9April69

COLOSS. 2D FC-2642

2 7 53

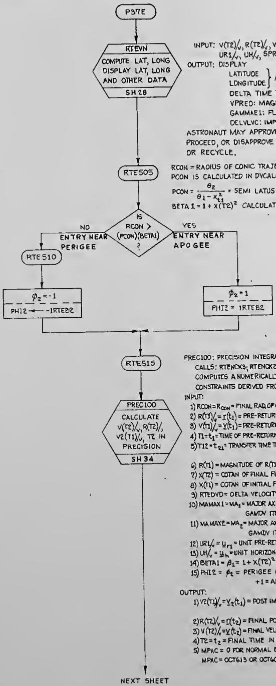


A.C. WILLIAMS 26DEC68
9APR69
10APR69
9Apr69
John A. Moor 9April 69

P37 – RETURN TO EARTH
(MAIN PROGRAM)

COLOSSUS 2D FC-2642

2 8 53



INPUT: V(T2)/v, R(T2)/v, V2(T1)/v, V(T1)/v, UR1/v, UH/v, SPRETIG, T2.

OUTPUT: DISPLAY

LATITUDE } AT 400,000 FT.
LONGITUDE }

DELTA TIME TO 400,000 FT

VPRED: MAGNITUDE OF VELOCITY AT 400,000 FT.

GAMMAE1: FLIGHT PATH ANGLE AT 400,000 FT.

DELVLVC: IMPULSIVE DELTA V

ASTRONAUT MAY APPROVE OF THESE CALCULATIONS AND PROCEED, OR DISAPPROVE AND EITHER TERMINATE OR RECYCLE.

RCON = RADIUS OF CONIC TRAJECTORY.

PCON IS CALCULATED IN DVCALC.

$$PCON = \frac{\theta_2}{\theta_1 - x_{t_1}^2} = \text{SEMI LATUS RECTUM}$$

BETA 1 = $1 + X(T2)^2$ CALCULATED IN V2T100

(THIS OCCURS ONLY FOR NEARLY CIRCULAR ORBITS.)

PREC100: PRECISION INTEGRATION SUBROUTINE

CALLS: RTENCK3; RTENCK2; PARAM; TIMERAD; V2T100, INTSTALL

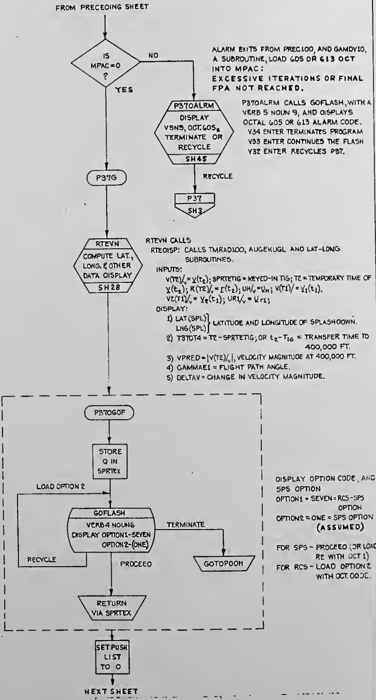
COMPUTES A NUMERICALLY INTEGRATES A TRAJECTORY, USING CONSTRAINTS DERIVED FROM THE CONIC INTEGRATION.

INPUT:

1) RCON = R_{CON} = FINAL RAD. OF CONIC TRAJECTORY IN METERS @ 2^{29}
2) R(T1)/v = $\underline{r}(t_1)$ = PRE-RETURN POS. VECTOR IN METERS @ 2^{29}
3) V(T1)/v = $\underline{v}(t_1)$ = PRE-RETURN VELOCITY VECTOR IN M/CSEC @ 2^7
4) T1 = t_1 = TIME OF PRE-RETURN STATE VECTOR IN CSEC @ 2^{28}
5) T12 = t_{21} = TRANSFER TIME TO T2, THE FINAL POSITION TIME, IN CSEC @ 2^{28}
6) R(T1) = MAGNITUDE OF R(T1)/v, IN METERS @ 2^{29}
7) X(T2) = COTAN OF FINAL FLIGHT PATH ANGLE @ 2^0
8) X(T1) = COTAN OF INITIAL FLIGHT PATH ANGLE @ 2^5
9) RTEDVD = DELTA VELOCITY DESIRED IN METERS/CSEC @ 2^7
10) MAMAX1 = MA_1 = MAJOR AXIS LIMIT ON LOWER BOUND OF GAMDV ITERATOR IN METERS @ 2^{30}
11) MAMAX2 = MA_2 = MAJOR AXIS LIMIT ON UPPER BOUND OF GAMDV ITERATOR IN METERS @ 2^{30}
12) UR1/v = $\underline{u}_{r1}$ = UNIT PRE-RETURN POSITION VECTOR @ 2^1
13) UH/v = $\underline{u}_h$ = UNIT HORIZONTAL VECTOR @ 2^1
14) BETA1 = $\beta_1 = 1 + X(T2)^2$ @ 2^1
15) PHI2 = ϕ_2 = PERIGEE OR APOGEE @ 2^2
+1 = APOGEE -1 = PERIGEE

OUTPUT:

1) V2(T1)/v = $\underline{v}_2(t_1)$ = POST IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
2) R(T2)/v = $\underline{r}(t_2)$ = FINAL POSITION VECTOR IN METERS @ 2^{29}
3) V(T2)/v = $\underline{v}(t_2)$ = FINAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
4) T2 = t_2 = FINAL TIME IN CSEC @ 2^{28}
5) MPAC = 0 FOR NORMAL EXIT
MPAC = OCT613 OR OCT605 FOR ALARM EXIT.



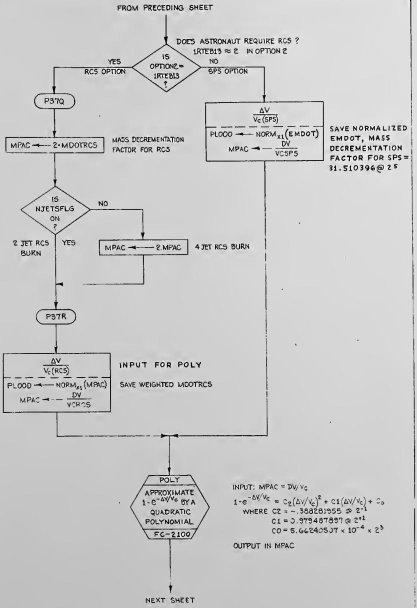
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

DRAWN A.C.WILLIAMS 6JAN69

P37- RETURN TO EARTH
(MAIN PROGRAM)

COLOSSUS 2D FC-2642

REV 2 10 53



A C.WILLIAMS 6JAN69
[signature] 9APR69
[signature] 10APR69
[signature] 7Apr 69
John A. Moore 9April 69

P37- RETURN TO EARTH
(MAIN PROGRAM)

COLOSSUS 2D

FC-2642

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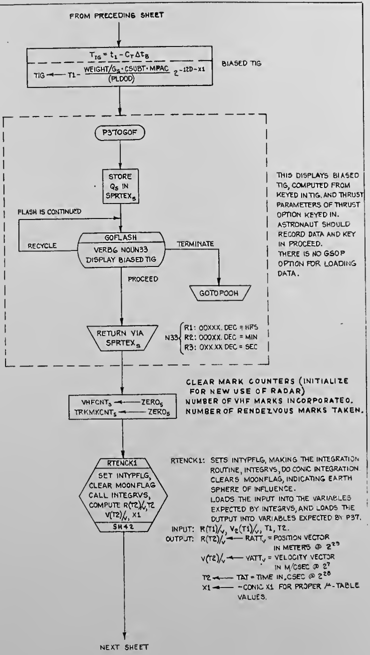

A.C.WILLIAMS 6JAN69

P37- RETURN TO EARTH (MAIN PROGRAM)

COLOSSUS 2D

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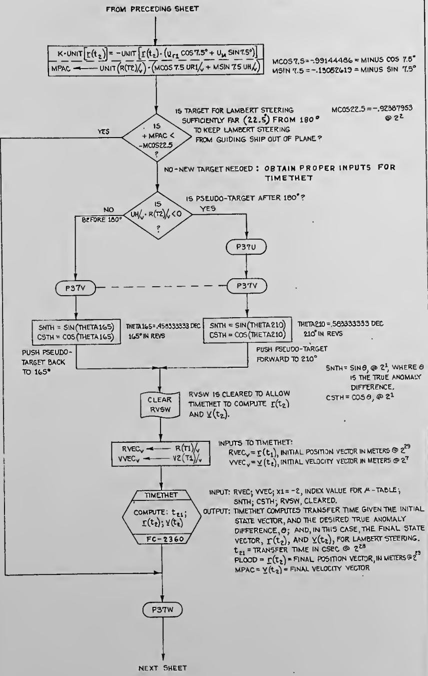

A.C. WILLIAMS 7JAN69
9APR69
10APR69
9Apr 69
9 April 69

P37 - RETURN TO EARTH (MAIN PROGRAM)

COLOSSUS 2D FC-2642

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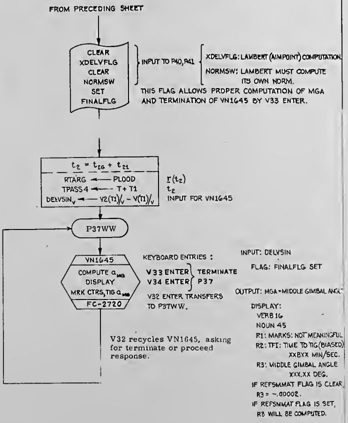

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9Apr69
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P37- RETURN TO EARTH (MAIN PROGRAM)

COLOSSUS 2D

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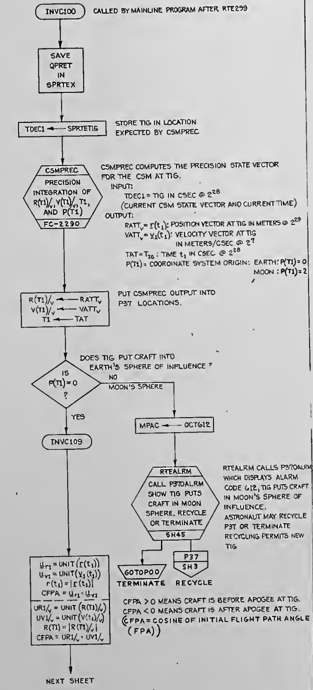

A.C.WILLIAMS 8JAN69

9APR69

10APR69

9April69

9April69

P37 – RETURN TO EARTH (INVC100)

COLOSSUS 2D

FC-2642

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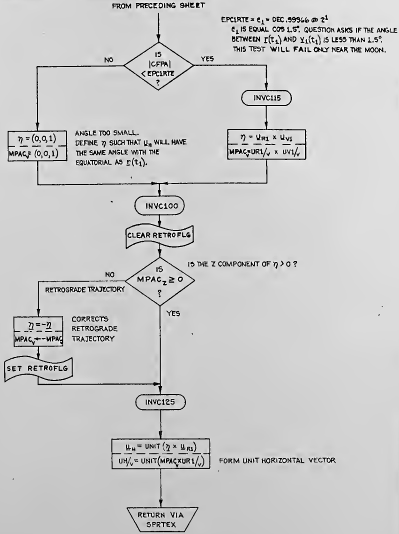

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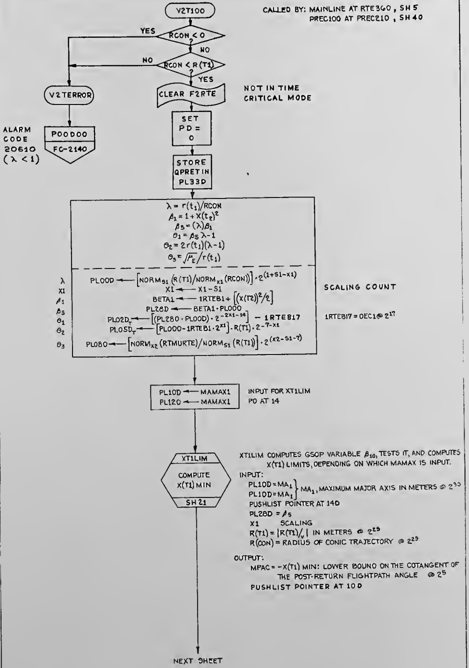
DRAWN A.C.WILLIAMS 9JAN69

P37- RETURN TO EARTH
(INVC100)

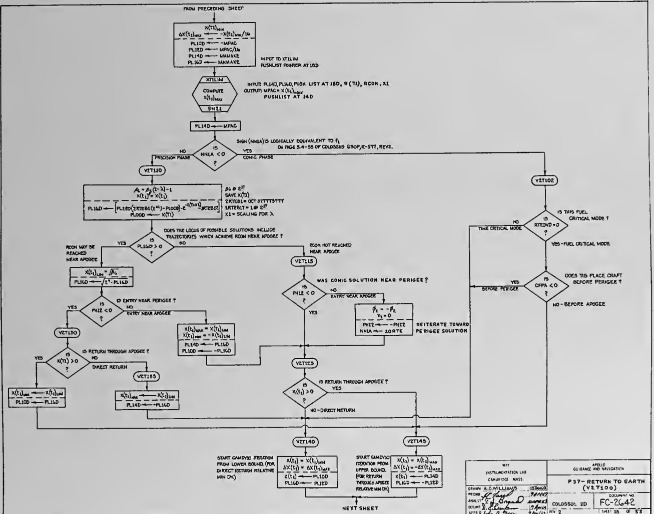
COLOSSUS 2D FC-2642

REV 2

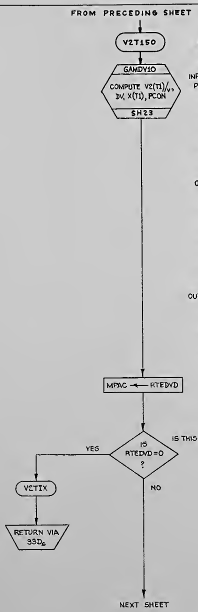
16 53



MIT INSTRUMENTATION LAB CAMBRIDGE MASS		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS	9JAN69	P37 - RETURN TO EARTH (V2T100)
PRGMR [signature]	9APR69	
ANALYST [signature]	10APR69	COLOSSUS 2D FC-2642
PRGMR [signature]	9Apr69	
APPR'D John A. Moore	9April69	REV 2 SHEET 17 OF 53



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 15JAN69	P37 - RETURN TO EARTH (V2T100)
COLOSSUS 2D	DOCUMENT NO FC-2642
REV 2	SHEET 18 OF 53



GAMDV10 CALLS DVCALC BY ITERATION, IT CALCULATES $V2(T1)/_v = \underline{V}_2(t_1)$, $DV = \Delta V$, $X(T1) = X(t_1)$ AND PCON = P_{CON}.

INPUT:

PUSHLIST:

- 02D $\theta_1 = \beta_5 \lambda - 1$
- 05D $\theta_2 = 2r(t_1)(\lambda - 1)$
- 08D $\theta_3 = \sqrt{\mu_E}/r(t_1)$
- 10D $X(t_1)_{MIN}$ = LOWER BOUND ON INDEPENDENT VAR. $X(t_1)$
- 12D $\Delta X(t_1)_{MAX}$ = MAXIMUM $\Delta X(T1)$
- 14D $X(T1)_{MAX}$ = UPPER BOUND ON IND. VAR $X(t_1)$.
- 16D $\Delta X(t_1)$ = CHANGE IN $X(t_1)$

OTHER:

- $V(T1)/_v = \underline{V}(t_1)$ = INITIAL, PRE-IGNITION VELOCITY VECTOR IN METERS/CSEC @ 2^7
- RTEDVD = ΔV_D = KEYED-IN Δ VELOCITY DESIRED IN METERS/CSEC @ 2^7
- $U(R1)/_v = \underline{U}_{R1}$ = UNIT POSITION VECTOR AT T_{IG}.
- $UH/_v = \underline{U}_H$ = UNIT HORIZONTAL VECTOR: UNIT($\eta \times R(T1)/_v$)
- X(T1) = COTANGENT OF INITIAL FLIGHT PATH ANGLE FROM THE VERTICAL.
- F2RTE = FLAG ON MEANS TIME CRITICAL MODE. FLAG OFF MEANS NOT IN TIME CRITICAL MODE.

OUTPUT:

- $V2(T1)/_v = \underline{V}_2(t_1)$ = POST-IMPULSE VELOCITY VECTOP IN METERS/CSEC @ 2^7
- DV = ΔV = CHANGE IN VELOCITY
- X(T1) = COT. OF INITIAL POST-RETURN FLIGHT PATH ANGLE FROM VERTICAL.
- PCON = P_{CON} = SEMI-LATUS RECTUM IN METERS @ $2^{28}/2^{26}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN A.C.WILLIAMS 13JAN69

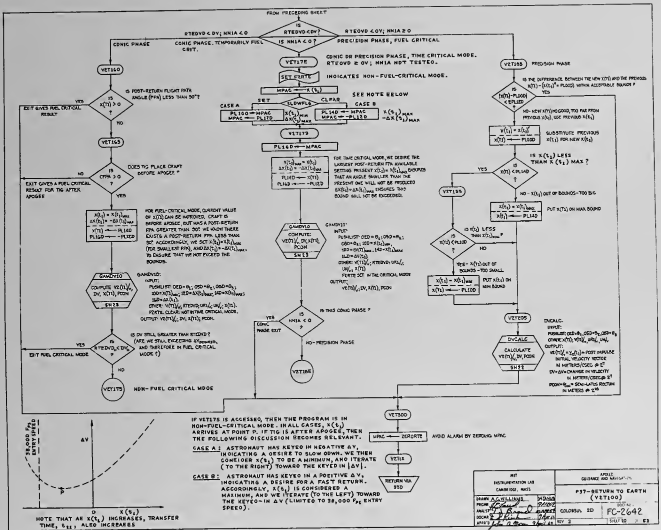
P37 - RETURN TO EARTH (V2T100)

COLOSSUS 2D

FC-2642

REV 2

19 53



FROM PRECEDING SHEET
IS RTEDVD < DV? IS NN1A < 0?
RTEDVD < DV; NN1A < 0
CONIC PHASE
CONIC PHASE, TEMPORARILY FUEL CRIT.
RTEDVD < DV; NN1A ≥ 0
PRECISION PHASE, FUEL CRITICAL
CONIC OR PRECISION PHASE, TIME CRITICAL MODE. RTEDVD ≥ DV; NN1A NOT TESTED.
V2T17E
SET F2RTE
INDICATES NON-FUEL-CRITICAL MODE.
MPAC ← X(t1)
SEE NOTE BELOW
SET
CLEAR
SLOWFLG
CASE A
CASE B
PL10D ← MPAC
MPAC ← PL12D
X(t1)MIN
ΔX(t1)MAX
PL14D ← MPAC
MPAC ← PL12D
X(t1)MAX
-ΔX(t1)MAX
V2T179
PL16D ← MPAC
X(t1)MAX = X(t1)
ΔX(t1) = -ΔX(t1)MAX
PL14D ← X(T1)
PL16D ← -PL12D
FOR TIME CRITICAL MODE, WE DESIRE THE LARGEST POST-RETURN FPA AVAILABLE. SETTING PRESENT X(t1) = X(t1)MAX ENSURES THAT AN ANGLE SMALLER THAN THE PRESENT ONE WILL NOT BE PRODUCED. ΔX(t1) = ΔX(t1)MAX ENSURES THIS BOUND WILL NOT BE EXCEEDED.
GAMDV10
COMPUTE: V2(T1)/V, DV, X(T1), PCON
SN23
GAMDV10:
INPUT:
PUSHLIST: 02D = θ1; 05D = θ2; 08D = θ3; 10D = X(t1)MIN, 12D = ΔV(T1)MAX, 14D = X(t1)MAX, 16D = ΔV(t1)
OTHER: V(T1)/V; RTEDVD; UR1/V; UH/V; X(T1)
F2RTE SET IN THE CRITICAL MODE
OUTPUT:
V2(T1)/V, DV, X(T1), PCON
IS THIS CONIC PHASE?
IS NN1A < 0 ?
YES
CONIC PHASE EXIT
NO-PRECISION PHASE
V2T18E
V2T160
IS POST-RETURN FLIGHT PATH ANGLE (FPA) LESS THAN 90°?
IS X(T1) > 0 ?
YES
EXIT GIVES FUEL CRITICAL RESULT
NO
V2T165
DOES TIG PLACE CRAFT BEFORE APOGEE?
IS CFPA > 0 ?
NO
EXIT GIVES A FUEL CRITICAL RESULT FOR TIG AFTER APOGEE
YES
X(t1) = X(t1)MAX
ΔX(t1) = -ΔX(t1)MAX
X(T1) ← PL14D
PL16D ← -PL12D
FOR FUEL-CRITICAL MODE, CURRENT VALUE OF X(T1) CAN BE IMPROVED. CRAFT IS BEFORE APOGEE, BUT HAS A POST-RETURN FPA GREATER THAN 90°. WE KNOW THERE EXISTS A POST-RETURN FPA LESS THAN 90°. ACCORDINGLY, WE SET X(t1) = X(t1)MAX (FOR SMALLEST FPA), AND ΔX(t1) = -ΔX(t1)MAX, TO ENSURE THAT WE NOT EXCEED THE BOUNDS.
GAMDV10
COMPUTE V2(T1)/V, DV, X(T1), PCON
SN23
GAMDV10:
INPUT:
PUSHLIST: 02D = θ1; 05D = θ2; 08D = θ3; 10D = X(t1)MIN; 12D = ΔX(t1)MAX; 14D = X(t1)MAX; 16D = ΔX(t1).
OTHER: V(T1)/V; RTEDVD; UR1/V; UH/V; X(T1).
F2RTE: CLEAR: NOT IN TIME CRITICAL MODE.
OUTPUT: V2(T1)/V; DV; X(T1); PCON.
IS DV STILL GREATER THAN RTEDVD? (ARE WE STILL EXCEEDING ΔVDESIRED, AND THEREFORE IN FUEL CRITICAL MODE?)
IS RTEDVD < DV ?
YES
EXIT FUEL CRITICAL MODE
NO
V2T175
NON-FUEL CRITICAL MODE
V2T10B
PRECISION PHASE
IS THE DIFFERENCE BETWEEN THE NEW X(T1) AND THE PREVIOUS X(T1) - (X(t1)* = PLOOD) WITHIN ACCEPTABLE BOUNDS?
IS |X(T1)-PLOOD| < 2PL1ED ?
YES
NO - NEW X(T1) NO GOOD, TOO FAR FROM PREVIOUS X(t1), USE PREVIOUS X(t1)
X(t1) = X(t1)*
X(T1) ← PLOOD
SUBSTITUTE PREVIOUS X(t1) FOR NEW X(t1)
IS X(t1) LESS THAN X(t1) MAX ?
IS X(T1) < PL14D ?
YES
V2T155
NO - X(t1) OUT OF BOUNDS - TOO BIG
X(t1) = X(t1)MAX
X(t1) ← PL14D
PUT X(T1) ON MAX BOUND
IS X(t1) LESS THAN X(t1)MIN?
IS X(T1) < PL10D ?
NO
YES - X(T1) OUT OF BOUNDS - TOO SMALL
X(t1) = X(t1)MIN
X(T1) ← PL10D
PUT X(t1) ON MIN BOUND
V2TE05
DVCALC
CALCULATE V2(T1)/V, DV, PCON
SH22
DVCALC.
INPUT:
PUSHLIST: 02D = θ1, 05D = θ2, 08D = θ3
OTHER: X(T1); V(T1)/V, UR1/V, UH/V
OUTPUT:
V2(T1)/V = V2(t1) = POST IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
DV = ΔV = CHANGE IN VELOCITY IN METERS/CSEC @ 2^7
PCON = Rcon = SEMI-LATUS RECTUM IN METERS @ 2^29
V2T300
MPAC ← ZERORTE
AVOID ALARM BY ZEROING MPAC
V2T1X
RETURN VIA 35D
38,000 FPS ENTRY SPEED
ΔV
P
0
X(t1)
NOTE THAT AS X(t1) INCREASES, TRANSFER TIME, t12, ALSO INCREASES
IF V2T175 IS ACCESSED, THEN THE PROGRAM IS IN NON-FUEL-CRITICAL MODE. IN ALL CASES, X(t1) ARRIVES AT POINT P. IF TIG IS AFTER APOGEE, THEN THE FOLLOWING DISCUSSION BECOMES RELEVANT.
CASE A: ASTRONAUT HAS KEYED IN NEGATIVE ΔV, INDICATING A DESIRE TO SLOW DOWN. WE THEN CONSIDER X(t1) TO BE A MINIMUM, AND ITERATE (TO THE RIGHT) TOWARD THE KEYED IN |ΔV|.
CASE B: ASTRONAUT HAS KEYED IN A POSITIVE ΔV, INDICATING A DESIRE FOR A FAST RETURN. ACCORDINGLY, X(t1) IS CONSIDERED A MAXIMUM, AND WE ITERATE (TO THE LEFT) TOWARD THE KEYED-IN ΔV (LIMITED TO 38,000 FPS ENTRY SPEED).
MIT
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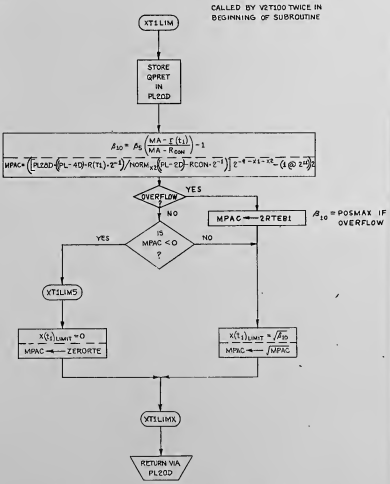
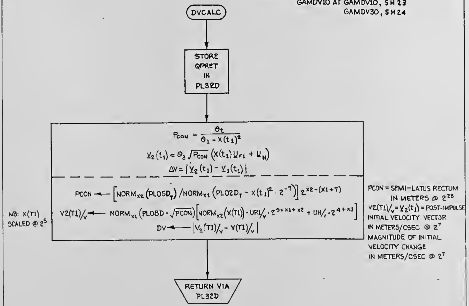
CAMBRIDGE, MASS
APOLLO
GUIDANCE AND NAVIGATION
P37—RETURN TO EARTH (V2T100)
DRAWN A.G. WILLIAMS
PRGMR
ANALST
DOCMR
APPR'D
COLOSSUS 2D
FC-2642
REV 2
SHEET 20 OF 53



XT1LIM IS USED TWICE: ONCE USING MAMAX1 AND ONCE USING MAMAX2.
WHEN MAMAX1 IS USED, XT1LIM 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, XT1LIM 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 FPA IS THEREFORE NOT PERMITTED TO HAVE A POSITIVE RADIAL COMPONENT.

CALLED BY: V2T100 AT V2T205 , SH 20
GAMDV10 AT GAMDV10, SH 23
GAMDV30, SH 24

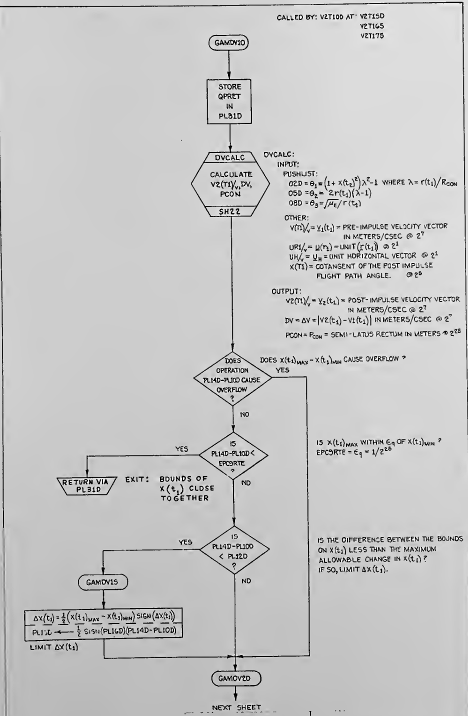


PCON

PCON SATISFIES THE EQUATION: $P_{CON} = \dfrac{2r(t_1)\left(\frac{r(t_1)}{R_{CON}} - 1\right)}{\frac{(r(t_1))^2}{R_{CON}^2}\left(1 + (X(t_1))^2\right) - \left(1 + (X(t_1))^2\right)}$ WHERE

$\theta_2 = 2r(t_1)\left(\frac{r(t_1)}{R_{CON}} - 1\right)$ AND $\theta_1 = \frac{(r(t_1))^2}{R_{CON}^2}\left(1 + (X(t_1))^2\right) - 1$, WHERE $r(t_1)$ = RADIUS

AT T_{IG}; R_{CON} = 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.



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DRAWN A.C.WILLIAMS 17JAN69

P37- RETURN TO EARTH (GAMDV10)

COLOSSUS 2D FC-2642

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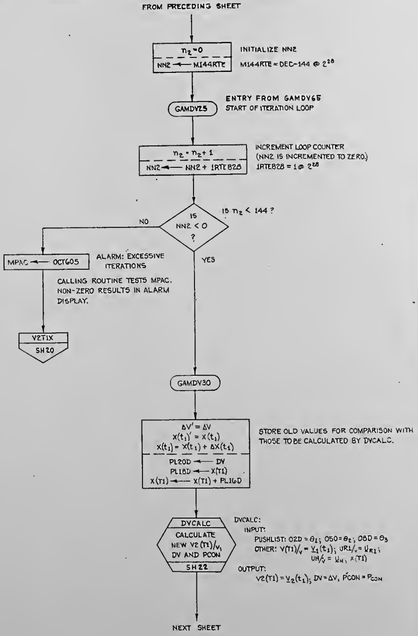

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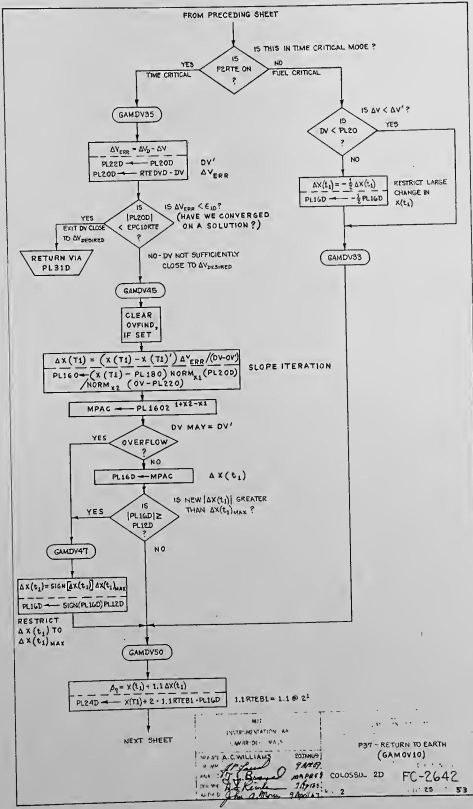
	A.C. WILLIAMS	20 JAN 69
	[signature]	9 APR 69
	[signature]	10 APR 69
	[signature]	9 APR 69
	John A. Miller	9 April 69

P37 - RETURN TO EARTH
(GAMDV10)

COLOSSUS 2D FC-2642

REV 2 24 53


FROM PRECEDING SHEET
IS THIS IN TIME CRITICAL MODE ?
IS F2RTE ON ?
YES
TIME CRITICAL
NO
FUEL CRITICAL
GAMDV35
ΔV_ERR = ΔV_D - ΔV
PL22D ← PL20D
PL20D ← RTEDVD - DV
DV'
ΔV_ERR
IS |PL20D| < EPC10RTE ?
IS ΔV_ERR < ε_10 ?
(HAVE WE CONVERGED ON A SOLUTION ?)
YES
EXIT DV CLOSE TO ΔV_DESIRED
RETURN VIA PL31D
NO - DV NOT SUFFICIENTLY CLOSE TO ΔV_DESIRED
GAMDV45
CLEAR OVFIND, IF SET
ΔX(T1) = (X(T1) - X(T1)') ΔV_ERR/(DV-DV')
PL160 ← (X(T1) - PL180) NORM_X1 (PL20D) /NORM_X2 (DV-PL22D)
SLOPE ITERATION
MPAC ← PL1602 1+X2-X1
DV MAY = DV'
OVERFLOW ?
YES
NO
PL16D ← MPAC
ΔX(t_1)
IS |PL16D| ≥ PL12D ?
IS NEW |ΔX(t_1)| GREATER THAN ΔX(t_1)_MAX ?
YES
NO
GAMDV47
ΔX(t_1) = SIGN[ΔX(t_1)] ΔX(t_1)_MAX
PL16D ← SIGN(PL16D) PL12D
RESTRICT ΔX(t_1) TO ΔX(t_1)_MAX
IS ΔV < ΔV' ?
IS DV < PL20 ?
YES
NO
ΔX(t_1) = -½ ΔX(t_1)
PL16D ← -½ PL16D
RESTRICT LARGE CHANGE IN X(t_1)
GAMDV33
GAMDV50
β_q = X(t_1) + 1.1 ΔX(t_1)
PL24D ← X(T1) + 2 · 1.1RTEB1 · PL16D
1.1RTEB1 = 1.1 @ 2^1
NEXT SHEET
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INSTRUMENTATION LAB
CAMBRIDGE, MASS
A.C.WILLIAMS
20JAN69
9APR69
10APR69
P37 - RETURN TO EARTH
(GAMDV10)
COLOSSUS 2D
FC-2642
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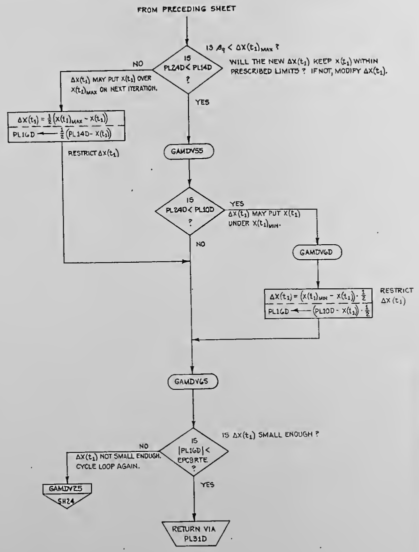


DRAWN A.C. WILLIAMS 20JAN69

P37 – RETURN TO EARTH (GAMDV10)

COLOSSUS 2D

FC-2642

26 53

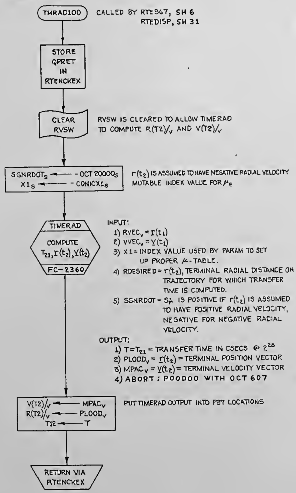
TIME RADIUS CALLING SUBROUTINE

INPUT:

RVEC	INITIAL POSITION VECTOR	VECT. @ 2^{29} MTRS
VVEC	INITIAL VELOCITY VECTOR	VECT. @ 2^{7} MTRS/CSEC
RDESIRED	FINAL RADIUS FOR WHICH TRANSFER TIME IS TO BE COMPUTED	DP. @ 2^{29} METERS

OUTPUT:

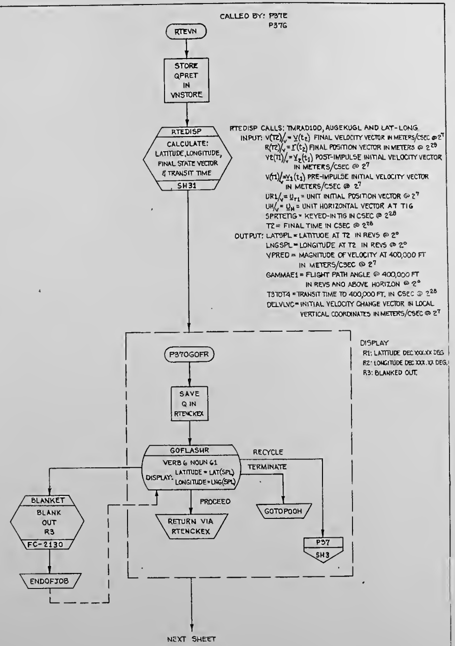
R(T2)/$_v$	FINAL POSITION VECTOR	VECT. @ 2^{29} METERS
V(T2)/$_v$	FINAL VELOCITY VECTOR	VECT. @ 2^{7} MTRS/CSEC
T12	TRANSFER TIME TO FINAL RADIUS	DP. @ 2^{28} CSEC
	ABORT EXIT FOR NO SOLUTION: POODOO, WITH OCT 607	



A.C.WILLIAMS 21JAN69
9APR69
9APR69
9Apr69
9April 69

P37 - RETURN TO EARTH
(TMRAD100)

FC-2642



M.I.T.
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CAMBRIDGE, MASS

DRAWN A.C.WILLIAMS 21JAN69

9JUL69

10APR69

9Apr69

9April 69

P37-RETURN TO EARTH

COLOSSUS 2D

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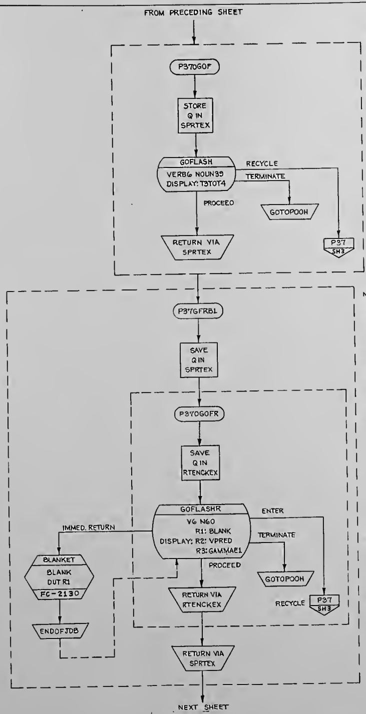


DISPLAY: T3TOT4 TRANSFER TIME TO 400,000 FT.
R1: HRS: 00XXX.
R2: MIN: 000XX.
R3: SEC: 0XX.XX
} DECIMAL

NOTE: P37GFRB1 INTERLOCKS WITH P37OGOFR IN THIS MANNER:
IMMEDIATE RETURN FROM GOFLASHR IN P37OGOFR TO BLANKET, WHICH IS CONTAINED IN P37GFRB1. ENDOFJOB RETURNS DISPLAY FOR ASTRONAUT RESPONSE.

R1: BLANK
R2: VPRED DEC XXXXX. IN FT/SEC = VELOCITY MAGNITUDE AT 400,000 FT.
R3: GAMMAE1 DEC XXX.XX IN DEGREES = FLIGHT PATH ANGLE AT 400,000 FT

DRAWN A.C.WILLIAMS 23JAN69

9APR69

10APR69

9Apr69

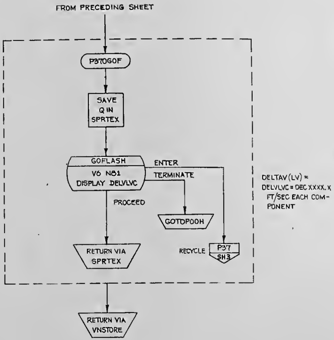
9April69

P37 - RETURN TO EARTH (RTEVN)

COLOSSUS 2D

FC-2642

2 29 53



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DRAWN	A.C. WILLIAMS	24JAN69
PROG	[illegible]	9APR69
ANAL	[illegible]	10APR69
[illegible]	[illegible]	7Apr69
APP'D	John A. Moo[illegible]	9 April 69

P37- RETURN TO EARTH (RTEVN)

COLOSSUS 2D

FC-2642

REV 2

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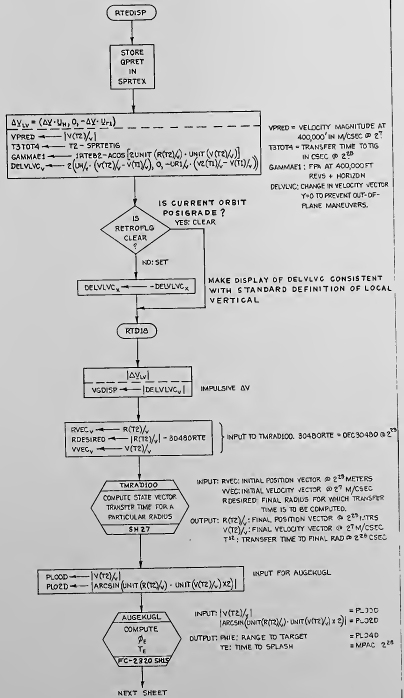


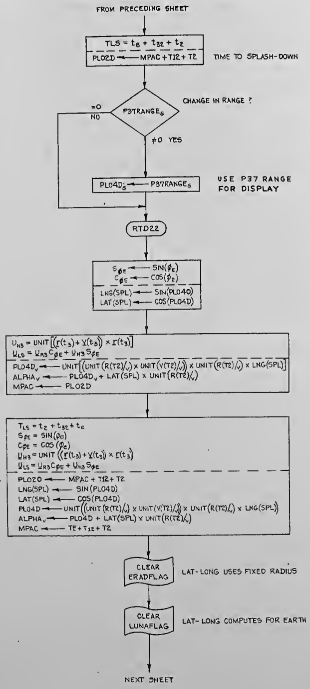
A. C. WILLIAMS 24 JAN 69
9 APR 69
10 APR 69
9 April
9 April 69

P37 - RETURN TO EARTH (RTEDISP)

COLOSSUS 2D

FC-2642

2 31 53

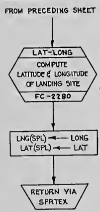


A.C.WILLIAMS 27JAN69

P37-RETURN TO EARTH
(RTEOISP)

COLOSSUS 2D FC-2642

2 32 53



INPUT: MPAC = TIME CSEC @ 2^{27}
ERADFLAG = 0 MEANS FIXED EARTH RAD
LUNAFLAG = 0 MEANS FOR EARTH
ALPHAV = POSITION VECTOR IN METERS @ 2^{29}
OUTPUT: LAT = LATITUDE IN REVS @ 2^0
LONG = LONGITUDE IN REVS @ 2^0

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P37 — RETURN TO EARTH
(RTEDISP)

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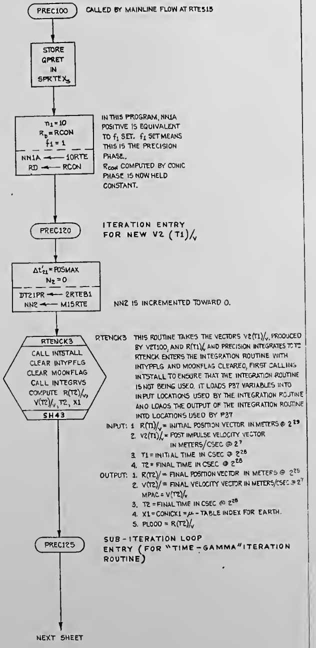

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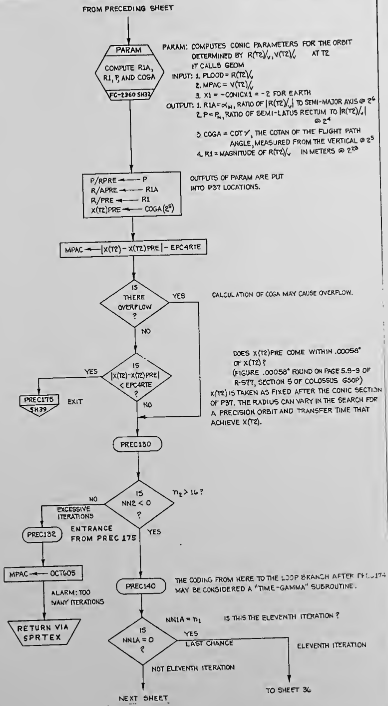
DRAWN A.C. WILLIAMS 28JAN69

P37 - RETURN TO EARTH (PREC100)

COLOSSUS 2D FC-2642

REV 2 — 34 of 53

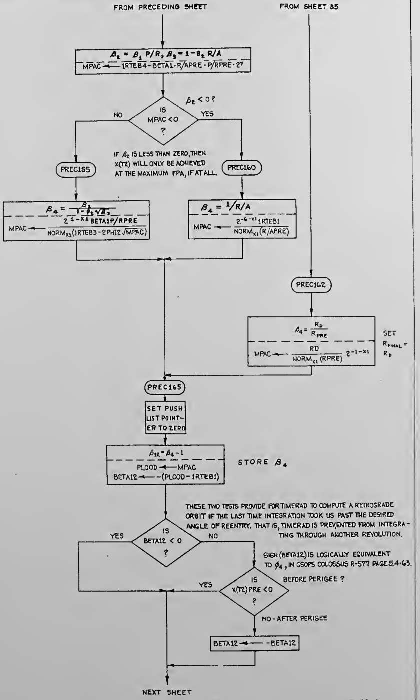


A.C.WILLIAMS 28JAN69
9APR69
10APR69
9Apr 69
9April 69

P37 - RETURN TO EARTH (PREC100)

COLOSSUS 2D FC-2642

2 35 53



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DRAWN A.C. WILLIAMS 25 JAN 69

APOLLO GUIDANCE AND NAVIGATION

P37 – RETURN TO EARTH (PREC100)

COLOSSUS 2D

FC-2642

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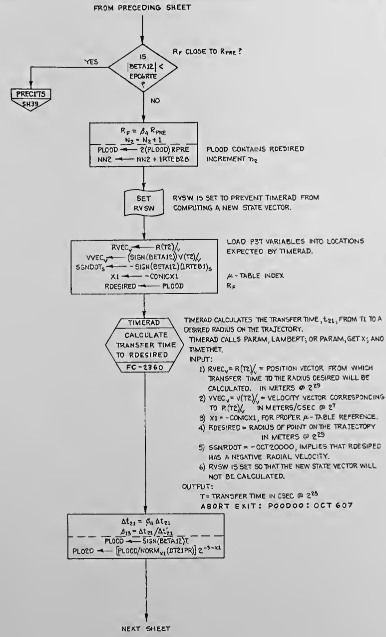

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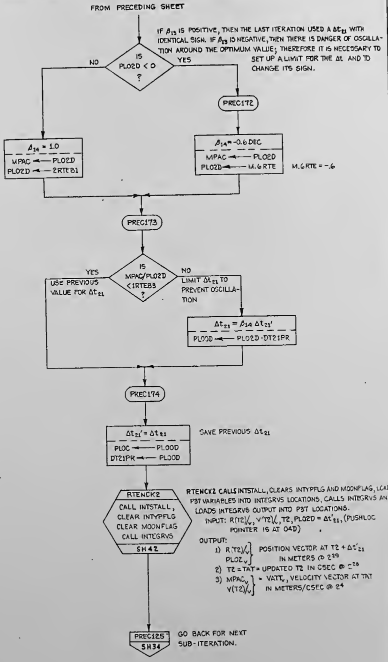
DRAWN A.C.WILLIAMS	29JAN68	P37- RETURN TO EARTH (PREC100)	
CHECKED [signature]	9JAN67		
APPROVED [signature]	9APR69	COLOSSUS 2D	FC-2642
[signature]	9APR69		
APPROVED John A. Moore	9April69	2	37 53



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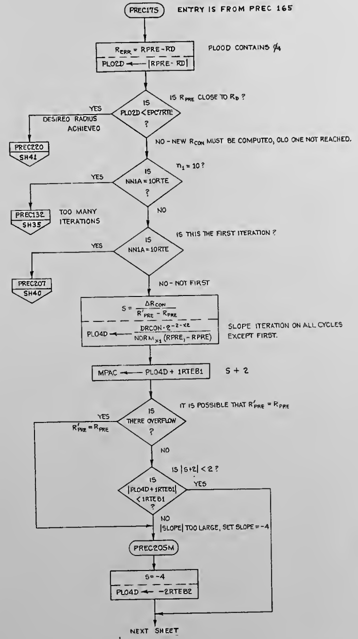
DRAWN A.C.WILLIAMS 30JAN69
CHECKED [signature] 9APR69
APPROVED [signature] 10APR69
APPROVED [signature] 9APR69
APPR [signature] 9April69

P37-RETURN TO EARTH
(PREC100)

COLOSSUS 2D FC-2642

2 38 53



A.C. WILLIAMS 30JAN69

9APR69

10APR69

9APR69

John A. Moore 9Apr69

P37- RETURN TO EARTH (PREC100)

COLOSSUS 2D

FC-2642

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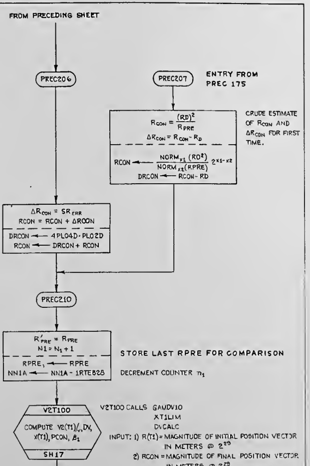

V2T100 CALLS GAMDV10
XT1LIM
DVCALC

INPUT:
1) R(T1) = MAGNITUDE OF INITIAL POSITION VECTOR IN METERS @ 2^{29}
2) RCON = MAGNITUDE OF FINAL POSITION VECTOR IN METERS @ 2^{29}
3) V(T1) = INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
4) RTEDVD = Δ VELOCITY DESIRED IN METERS/CSEC @ 2^7
5) UR1/$_v$ = UNIT INITIAL POSITION VECTOR @ 2^1
6) UH/$_v$ = UNIT HORIZONTAL VECTOR @ 2^1
7) Y(T2) = COTANGENT OF FINAL FLIGHT PATH ANGLE @ 2^0
8) X(T1) = COTANGENT OF INITIAL FLIGHT PATH ANGLE @ 2^5
9) CFPA = COSINE OF INITIAL FLIGHT PATH ANGLE @ 2^1
10) MAMAX1 } TEMPORARY { LOWER } BOUND ON GAMDV
11) MAMAX2 } TEMPORARY { UPPER } ITERATOR IN METERS @ 2^{30}
12) PHI2 = PERIGEE-APOGEE INDICATOR: -1 = PERIGEE, +1 = APOGEE
13) NN1A = PRECISION ITERATION COUNTER (NN1A > 0 IMPLIES THIS IS PRECISION PHASE)

OUTPUT:
1) V2(T1)/$_v$ = POST-IMPULSE VELOCITY VECTORS IN METERS/CSEC @ 2^7
2) DV = INITIAL DELTAV IN METERS/CSEC @ 2^7
3) X(T1) = COTAN OF INITIAL FPA (POST-IMPULSE) @ 2^5
4) PCON = SEMI-LATUS RECTUM IN METERS @ 2^{25}
5) BETA1 = $1 + X(T2)^2$ @ 2^1
6) MPAC = 0 NORMAL EXIT MODE
MPAC ≠ 0, ALARM CODE OCT605
EXCESSIVE ITERATIONS IN GAMDV10

NEXT SHEET

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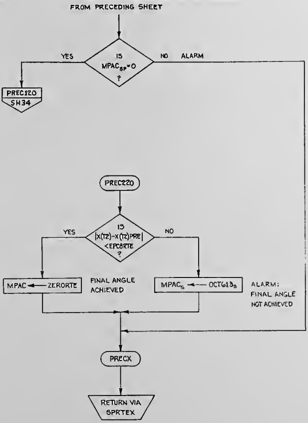
DRAWN A.C.WILLIAMS 31JAN69
PRGMR [signature] 9APR69
ANAL [signature] 10APR69
D CHKR [signature] 1Apr 69
APPR'D John A. Moore 9 Apr 69

P37- RETURN TO EARTH (PREC100)

COLOSSUS 2D FC-2642

REV 2 40 53



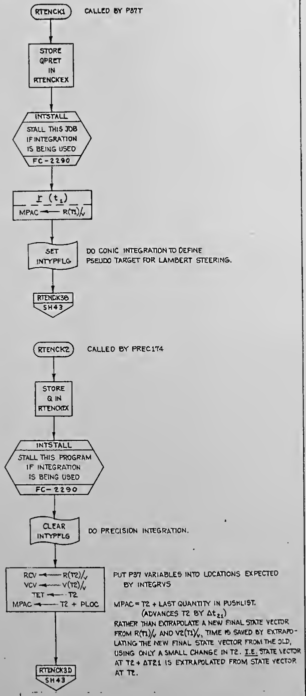
A.C.WILLIAMS 31JAN69

P37- RETURN TO EARTH (PREC100)

COLOSSUS 2D

FC-2642

2 41 53



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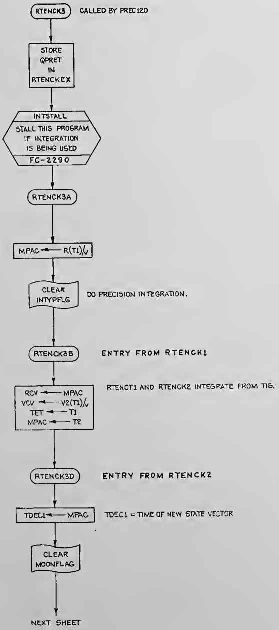
DRAWN A.C.WILLIAMS 3FEB69
PROGMR 9APR69
ANALYST 10APR69
CHECKED 9APR69
APPR'D John A. Moore 9April 69 REV 2

P37 – RETURN TO EARTH (RTENCK)

COLOSSUS 2D

FC-2642

42 53



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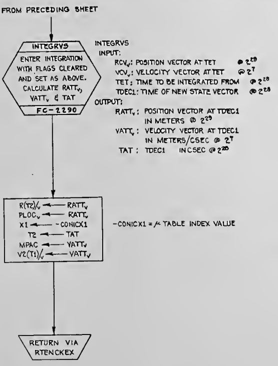
DRAWN A.C.WILLIAMS 13FEB69

P37- RETURN TO EARTH (RTENCK)

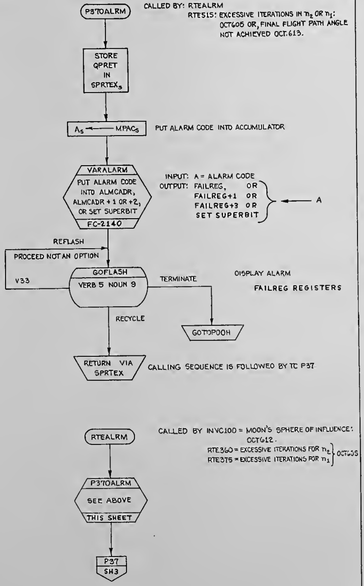
COLOSSUS 2D

FC-2642

2 43 53



FROM PRECEDING SHEET
INTEGRVS
ENTER INTEGRATION WITH FLAGS CLEARED AND SET AS ABOVE. CALCULATE RATT_v, VATT_v & TAT
FC-2290
INTEGRVS
INPUT:
RCV_v: POSITION VECTOR AT TET @ 2^29
VCV_v: VELOCITY VECTOR AT TET @ 2^7
TET: TIME TO BE INTEGRATED FROM @ 2^28
TDEC1: TIME OF NEW STATE VECTOR @ 2^28
OUTPUT:
RATT_v: POSITION VECTOR AT TDEC1 IN METERS @ 2^29
VATT_v: VELOCITY VECTOR AT TDEC1 IN METERS/CSEC @ 2^7
TAT: TDEC1 IN CSEC @ 2^28
R(T2)/_v ← RATT_v
PLOC_v ← RATT_v
X1 ← -CONICX1
T2 ← TAT
MPAC ← VATT_v
V2(T1)/_v ← VATT_v
-CONICX1 = μ TABLE INDEX VALUE
RETURN VIA RTENCKEX



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9APR69
9Apr69
9April 69

P37 – RETURN TO EARTH
(P37OALRM)

COLOSSUS 2D FC-2642

2 45 53

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$ALPHAV_V$	$\underline{r}(t_2)$	INPUT TO GETERAD (UNIT $(R(T2)_V)$			
$BETA1_D$	β_I	$1 + x(t_2)^2$			2^1
$BETA2_D$	φ_4	SIGN INDICATOR FOR TIMERAD			
$CFPA_D$	C_{FPA}	COSINE OF PRE-RETURN FPA			2^1
$COGA_D$	$x(t_2)_{PRE}$	OUTPUT OF PARAM. COT OF PRECISION ORBIT AT T2			2^5
$CSTH_D$		INPUT TO TIMETHET· COS OF 165^o OR 210^o			2^2
$CONICX1_S$		CONICμ -TABLE INDEX			
$DELVSIN_D$	$\underline{V}_2(t_1)$	$\underline{V}_2(t_1) - \underline{V}_1(t_I)$ INPUT TO VN2645	FT/SEC	M/CSEC	2^7
$DRCON_D$	ΔR_{CON}	RCON SLOPE ITERATOR	METERS	METERS	2^{29}
$DT21PR_D$	$\Delta t'_{21}$	PREVIOUS $\Delta t21$	SECONDS	CSEC	2^{28}
DV_D	ΔV	TEMP ABSOLUTE VALUE OF ΔVELOCITY AT TIG	FT/SECOND	M/CSEC	2^7
$ECSTEER_S$ *		STEERING CONSTANT FOR LAMBERT STEERING	EQUALS 1@ 2^1		.5@ 2^2
$ERADM_D$		RADIUS OF FISCHER ELLIPSOID FOR T2	METERS	METERS	2^{29}
$GAMMAE1_D$		DISPLAY LOCATION FOR NOUN 60-FINAL FPA	DEGREES	REVS	2^0
$MAMAx1_D$	MA_1	MAJOR AXIS CLOSE TO PARABOLIC TRAJECTORY USED TO COMPUTE LOWER BOUND ON x(T1), COT OF POST IMPULSE FPA	METERS	METERS	2^{30}
$MAMAx2_D$	MA_2	MAXIMUM MAJOR AXIS USED FOR COMPUTING UPPER BOUND ON x(T1)	METERS	METERS	2^{30}
$NN1A_D$	n_1	COUNTER #1 FOR ITERATION			
SIGN(NNIA)	f_1	POSITIVE = PRECISION PHASE NEGATIVE = CONIC PHASE			
$NN2_D$	n_2	COUNTER #2 FOR ITERATION			
$P/RPRE_D$	P/R_{PRE}	RATIO OF SEMI-LATUS RECTUM TO $\|R(T2)/_V\|$			2^4
$PCON_D$	P_{CON}	TEMPORARY SEMI-LATUS RECTUM	METERS	METERS	2^{29}
$PHIE_D$	φ_E	RANGE FROM 400,000 FT ENTRY ALTITUDE TO SPLASHDOWN	NAUTICAL MILES	METERS	2^{29}
$PH12_D$	φ_2	PERIGEE-APOGEE INDICATOR: +1=APOGEE -1=PERIGEE			
*EMDOT	$\dot{M}$	MASS DECREMENTATION FACTOR FOR CSM	LB/SEC	KG/CSEC	2^3

P37RANGE		RANGE FROM 300 K FT TO SPLASH IF ≠ 0. IF = 0, USE AUGEKUGL COMPUTATION.	NAUTICAL MILES	REVS	2^0
$P(T1)_D$	$P(t_1)$	PRIMARY BODY AT TIG 1 = MOON 0 = EARTH			
$R/APRE_D$	σR_{PRE}	RATIO OF $\|R(T2)/V\|$ TO SEMI-MAJOR AXIS			2^6
$RATT_V$		RADIUS VECTOR OUTPUT OF INTEGRATION ROUTINES	METERS	METERS	2^{29}
$RCON_D$	R_{CON}	TEMP FINAL RADIUS OF CONIC TRAJECTORY	METERS	METERS	2^{29}
RCV_V		RADIUS VECTOR INPUT TO INTEGRVS	METERS	METERS	2^{29}
RD_D	R_D	FINAL RADIUS DESIRED	METERS	METERS	2^{29}
$RDESIRED_D$	R_F	TEMPORARY FINAL RADIUS	METERS	METERS	2^{29}
$RPRE_D$	R_{PRE}	TEMP FINAL RADIUS OF A PRECISION TRAJECTORY	METERS	METERS	2^{29}
$RPRE'_D$	$x(t_2)$ R'_{PRE}	LAST $x(t_2)$ COT (FINAL FPA) (FOR CONIC) LAST R_{PRE} (FOR PRECISION)			2^0
$RTARG_D$	$r(t_2)_D$	INPUT TO VN1645 RADIUS VECTOR AT FINAL TIME	METERS	METERS	2^{29}
$RTEDVD_D$	ΔV_D	Δ VELOCITY DESIRED	METERS/SEC	M/CSEC	2^7
$RTEGAM2D_D$	$\tau(t_2)_D$	FINAL FPA DESIRED	DEGREES	REVS	2^0
$RTENCKEX_S$		RETURN ADDRESS STORAGE			
$RVEC_V$		INPUT TO CONIC SUBROUTINES (RADIUS VECTOR)	METERS	METERS	2^{29}
$R(T1)_D$	$r(t_1)$	RADIUS MAGNITUDE AT TIG	METERS	METERS	2^{29}
$R(T1)/_V$	$\underline{r}(t_1)$	RADIUS VECTOR AT TIG	METERS	METERS	2^{29}
$R(T2)/_V$	$\underline{r}(t_2)$	RADIUS VECTOR AT T_2	METERS	METERS	2^{29}
$SGNRDOT_S$		INPUT TO TIMERAD POSITIVE FOR POSITIVE RADICAL VELOCITY NEGATIVE FOR NEGATIVE RADICAL VELOCITY			
$SNTH_D$		INPUT TO TIMETHET SINE OF 165° OT 210°			2^1
$SPRTETIG_D$	T_{IG}	TIME OF IGNITION	SECONDS	CSEC	2^{28}
$SPRTEX_S$		RETURN ADDRESS STORAGE			
TAT_D		TIME OF OUTPUT VECTORS OF CONIC SUBROUTINES	SECONDS	CSEC	2^{28}

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. 15
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	INTERIM 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	
LUNAFLAG	LUNAR LAT-LONG	EARTH LAT-LONG		SH. 32	
INTYPFLG	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. 20

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DRAWN A. J. Fanello 12NOV68
PR. MR T. P. Flaris 9JAN69
ANA T. Brand 10APR69
LOCMR D. S. Kimbe 7Apr69
APPR'D John A. Moore 9April 69

P37
RETURN TO EARTH

COLOSSUS 2D

FC-2643

2 48 53

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$TDEC1_D$		INPUT TO INTEGRVS: TIME TO BE INTEGRATED TO	SECONDS	CSEC	2^{28}
TE_D	t_e	TIME FROM ENTRY TO SPLASHDOWN	SECONDS	CSEC	2^{28}
TET_D		TIME INPUT TO INTEGRVS	SECONDS	CSEC	2^{28}
$TPASS4_D$		TIME INPUT TO S40.9	SECONDS	CSEC	2^{28}
$TRKMKCNT_S$		TRACKING MARK COUNTER			
$T1_D$	t_1	INITIAL VECTOR TIME (TIG)	SECONDS	CSEC	2^{28}
$T12_D$	t_{12}	TRANSFER TIME TO FINAL RADIUS	SECONDS	CSEC	2^{28}
$T2_D$	t_2	TIME OF RE-ENTRY	SECONDS	CSEC	2^{28}
UH_V	$\underline{u}_H$	UNIT HORIZONTAL VECTOR			
$UR1/_V$	$\underline{u}_{R1}$	UNIT RADIUS VECTOR AT t_1			
$UV1_V$	$\underline{u}_{V1}$	UNIT VELOCITY VECTOR AT t_1			
$V(T1)/_V$	$\underline{v}_1(t_1)$	VELOCITY VECTOR AT t_1 (PRE-IMPULSE)	FT/SEC	M/CSEC	2^7
$V2(T1)/_V$	$\underline{v}_2(t_1)$	VELOCITY VECTOR AT t_1 (POST-IMPULSE)	FT/SEC	M/CSEC	2^7
$V(T2)_V$	$\underline{v}(t_2)$	VELOCITY VECTOR AT t_2	FT/SEC	M/CSEC	2^7
$VHFCNT_S$		VHFMARK COUNTER			
$VNSTORE_S$		RETURN ADDRESS STORAGE			
$VPRED_D$		KEYED IN ΔV DESIRED, OR FINAL VELOCITY	FT/SEC	M/CSEC	2^7
$VVEC_V$		INPUT TO CONIC ROUTINES $(V(T1)/_V)$	FT/SEC	M/CSEC	2^7
$WEIGHT\ G_D$		MASS OF VEHICLE	POUNDS	KG	2^{16}
$X(T1)_D$	$x(t_1)$	COTAN (INITIAL POST-IMPULSE FPA)			2^5
$X(T2)_D$	$x(t_2)$	COTAN (FINAL FPA)			2^0
$X(T2)PRE_D$	$x(t_2)_{PRE}$	COTAN OF FINAL FPA OF PRECISION TRAJECTORY			2^0

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N33	GOFLASH	R1 00XXX. HRS R2 000XX. MIN R3 0XX.XX SEC — DEC ONLY. TIG	SH. 3
V06N60	GOFLASHR	R1. BLANKED OUT R2 VPRED XXXXX. FT/SEC — DEC ONLY ΔV DESIRED R3 GAMMAE1 (FLIGHT PATH ANGLE) — FINAL FPA DESIRED	SH. 3
V04N06	GOFLASH	R1 OPTION CODE R2 ASSUMED OPTION — OCTAL: RCS-SPS OPTION R3 NOT USED	SH. 10
V06N33	GOFLASH	R1 00XXX. HRS R2 000XX. MIN R3 0XX.XX SEC — DEC ONLY BIASED TIG	SH. 12
V06N61	GOFLASHR	R1 XXX.XX — LATITUDE } DEGREES R2. XXX.XX — LONGITUDE } DEGREES R3 BLANKED OUT	SH. 28
V06N39	GOFLASH	R1 00XXX. HRS R2 000XX. MIN R3 0XX.XX SEC — DECIMAL TRANSFER TIME	SH. 29
V06N60	GOFLASHR	R1 BLANKED OUT — PREDICTED V R2 VPRED XXXXX. FT/SEC — DEC ONLY R3 GAMMAE1 XXX.XX DEGREES — PREDICTED FINAL FPA	SH. 29
V06N81	GOFLASH	R1 XXXX.X FT/SEC R2 XXXX.X FT/SEC R3 XXXX.X FT/SEC — $\Delta \underline{V}$ VECTOR	SH. 30
V05N09	GOFLASH	R1, R2, R3: OCTAL ALARM CODE FROM MPAC, 00XXX, IN ONE REGISTER	SH. 45

PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
$RTEDI_D$	D_I	X^o COEFFICIENT IN COMPUTATION OF $x(t_2)$	.2075330	1.6602637	2^3	

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$CSUBT_P$	C_T	VALUE USED IN CALCULATING BIASED TIG	1/2	.5	2^0
$C4RTE_D$	MAI	MAXIMUM MAJOR AXIS FOR R(TI)/V WITH NEGATIVE RADIAL COMPONENT	8. x 10^8 METERS	8 x 10^8 METERS	2^{30}
$EPC1RTE_D$	ε_1	VALUE USED TO TEST WHETHER RADIUS AND VELOCITY VECTORS ARE NEARLY COLINEAR	COS(1.5°)	.99966	2^1

P37
RETURN TO EARTH

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PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$EPC2RTE_D$	ε_2	CRITERION USED TO DETERMINE WHETHER CONIC PORTION HAS CONVERGED TO A SUITABLE REENTRY RADIUS	100 METERS	100 METERS	2^{29}
$EPC3RTE_D$	ε_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 $.058^{o}$)	.001	.001	2^0
$EPC4RTE_D$	ε_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 $.00058^{o}$)	.00001	.00001	2^0
$EPC6RTE_D$	ε_6	CRITERION USED TO DETERMINE WHETHER FINAL STATE VECTOR COMPUTATION HAS ALREADY REACHED THE DESIRED REENTRY ANGLE	.000007	.000007	2^1
$EPC7RTE_D$	ε_7	CRITERION USED TO DETERMINE WHETHER PRECISION SECTION HAS CONVERGED UPON THE REENTRY RADIUS SELECTED IN CONIC PORTION	1000 METERS	1000 METERS	2^{29}
$EPC8RTE_D$	ε_8	CRITERION USED TO MAKE FINAL CHECK ON REENTRY ANGLE REACHED IN PRECISION PORTION (TEST ON COTANGENT, EQUIVALENT TO $.116^{o}$)	.002	.002	2^0
$EPC9RTE_D$	ε_9	CRITERION USED TO DETERMINE IF GAMDV10 ITERATOR HAS REACHED A MINIMUM	2^{-20}	2^{-20}	2^5
$EPC10RTE_D$	ε_{10}	CRITERION USED TO DETERMINE WHETHER GAMDV10 ITERATOR HAS REACHED DESIRED ΔV	0.01 M SEC	0.0001 M CSEC	2^7
$E3RTE_D$	E_3	REENTRY ALTITUDE ABOVE FISCHER ELLIPSOID	121920 M	121420 M	2^{29}
$KIRTE_D$	K_I	RADIUS USED TO DETERMINE WHICH ESTIMATE OF REENTRY ANGLE TO BE USED	7.0×10^6 M	7.0×10^6 M	2^{29}
$K2RTE_D$	K_2	INITIAL ESTIMATE OF REENTRY RADIUS	6.495×10^6 M	6495000 M	2^{29}
$K3RTE_D$	K_3	INITIAL ESTIMATE OF COTANGENT OF REENTRY ANGLE USED WHEN $\lvert R(TI), V \rvert < KI$ (EQUIVALENT TO $-3^{o}29.5'$)	-.06105	-.06105	2^0

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$K4RTE_D$	K_4	INITIAL ESTIMATE OF COTANGENT OF REENTRY ANGLE USED WHEN $\lvert R(TI)/V \rvert >$ KI (EQUIVALENT TO $-5^{o}58'$	-.10453	-.10453	2^0
$MCOS7.5_D$	$-COS\ 7.5^o$	USED IN DETERMINING GSOP QUANTITY K	-.99144486	-.99144486	2^0
$MCOS22.5_D$	$-COS\ 22.5^o$	CRITERION USED TO DETERMINE WHETHER TARGET FOR LAMBERT STEERING IS TOO CLOSE TO 180^o	-.92387953	-.92387953	2^2
$MDOTIII_D$	$\dot{m}$(SPS)	MASS DECREMENTATION FACTOR FOR SPS BURN	63.8 LB/SEC	.289391932 KG/CSEC	2^3
$MDOTRCS_D$	$\dot{m}$(RCS)	MASS DECREMENTATION FACTOR FOR RCS BURN	.16375 KG/SEC	.0016375 KG/CSEC	2^3
$MSIN7.5_D$	$-SIN\ 7.5^o$	USED IN DETERMINING GSOP QUANTITY K	-.13052619	-.13052619	2^0
$RTMURTE_D$	$\sqrt{\mu_E}$	SQUARE ROOT OF EARTH GRAVITATIONAL CONSTANT	19965050.1 $M^{3/2}$/SEC	199650.501 $M^{3/2}$/CSEC	2^{18}
$THETA165_D$	165^o	165^o = POSITION OF NEW TARGET FOR LAMBERT STEERING	165^o	.458333333 REVS	2^0
$THETA210_D$	210^o	210^o = POSITION OF ALTERNATE NEW TARGET FOR LAMBERT STEERING	210^o	.58333333 REVS	2^0
$VCRCS_D$	V_C(RCS)	THRUST VELOCITY OF RCS JETS	2706.64 METERS/SEC	27.0664 METERS/CSEC	2^5
$VCSPS_D$	V_C(SPS	THRUST VELOCITY OF SPS ENGINE	3088.11 METERS/SEC	30.8811 METERS/CSEC	2^5
$2RTEB1_D$	POSMAX	INITIAL SETTING OF Δt_{21}	3777737777 OCT	3777737777 OCT	2^0
$30480RTE_D$	30480	INPUT TO TIMERAD = R(T2)/V - 30480	30480 METERS	30480 METERS	2^{29}

THE FOLLOWING ARE INPUTS TO THE POLY SUBROUTINE. CALLED TO COMPUTE MAMAX2, X(t2)', AND $(1-e^{-\Delta v/v_e})$, IN THE ORDER THEY APPEAR. (ALL VALUES DP; NO AGC TAGS - POLY USES INDEXED ADDRESSING.)

		ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
C_o	COEFFICIENTS USED TO COMPUTE MA_2	1.81000434×10^8 M	181000434 M	2^{31}
C_1		1.50785145	1.50785145	2^2
C_2		$-6.49993057 \times 10^{-9}$ M^{-1}	$-6.49993057 \times 10^{-9}$ M^{-1}	2^{-27}
C_3		$9.76938926 \times 10^{-18}$ M^{-2}	$9.76938926 \times 10^{-18}$ M^{-2}	2^{-56}

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
	D_1	COEFFICIENTS USED TO COMPUTE x(T2)'		0	
	D_2		$-4.8760771 \times 10^{-4}$ S/M	$-4.8760771 \times 10^{-2}$ CSEC/M	2^{-4}
	D_3		4.5419476×10^{-8} S^2/M^2	4.5419476×10^{-4} $CSEC^2/M^2$	2^{11}
	D_4		$-1.4317675 \times 10^{-12}$ S^3/M^3	$-1.4317675 \times 10^{-8}$ $CSEC^3/M^3$	2^{-18}
–	C_0	COEFFICIENTS USED TO COMPUTE $(1-e^{-\Delta v/vc})$		$5.68240507 \times 10^{-4}$	2^3
–	C_1			0.979487897	2^1
–	C_2			-.388281955	2^{-1}

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DRAWN 12 NOV 68
PRGMR 9 APR 69
ANALST 10 APR 69
DOCMR 9 Apr 69
APPR'D 9 April 69

P37
RETURN TO EARTH

COLOSSUS 2D FC-2642

2 53 53

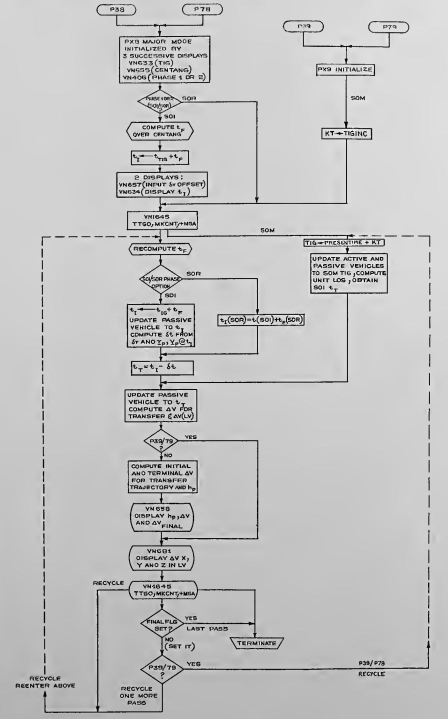
P38 - P78 STABLE ORBIT RENDEZVOUS

(PHASE 1 SOI STABLE ORBIT INITIATION (SOI)
AND PHASE 2 STABLE ORBIT RENDEZVOUS (SOR))

P39 - P79 STABLE ORBIT MIDCOURSE (SOM)

EXTERNAL ENTRY POINT: PREC/TT (SH. 11)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN	1 APR 69	P38 - P78 STABLE ORBIT RENDEZVOUS
APPROVED	7 APR 69	
	16 July 69	COLOSSUS IIA FC-2644
	17 April 69	
	7 May 69	REV 1 — 1 — 15



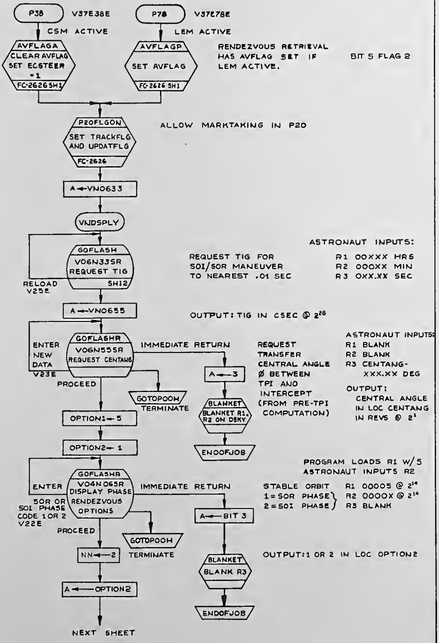
MIT INSTRUMENTATION LABORATORY

P38, P39 GENERAL FLOW DIAGRAM

COLOSSUS IIA

FC-2644

2 . 15



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P38-P78

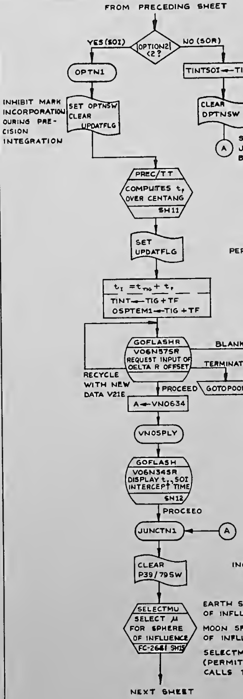
STABLE ORBIT RENDEZVOUS

COLOSSUS IIA

FC-2644

REV 1

3 15



IF OPTION2 = 2 PERFORM SOR STEPS

SAVE TINT FOR SOR PHASE

OPTNSW: CLEAR = SOR, SET = SOI

PREC/TT UPDATES $\underline{r}_P$, $\underline{v}_P$ TO TIG THEN USES THESE VALUES AND SPECIFIED CENTANG IN TIMETHET TO CALCULATE t_F. ALSO UPDATES $\underline{r}_A$, $\underline{v}_A$ TO TIG
INPUTS: RACT3, RPASS3, VACT3, VPASS3, AND TDEC1 (= TIG)
OUTPUT: t_F IN CSEC @ 2^{28}

PERMIT MARK INCORPORATION

t_I IN CSEC @ 2^{28}

REQUEST ASTRONAUT LOAD DELTA R (δr), THE OFFSET OF THE STABLE ORBIT POINT ALONG THE PASSIVE VEHICLE ORBIT TO NEAREST .1NM. (+ IF STABLE ORBIT POINT BEHIND PASSIVE VEHICLE, - IF AHEAD) STORED IN ERASABLE LOC DELTAR IN METERS @ $2^{27}/2^{29}$
R1 XXXX.XNM
R2 BLANK
R3 BLANK

DISPLAY t_I (FINAL) TIME OF ARRIVAL AT STABLE ORBIT POINT TO NEAREST .01 SEC
R1 00XXX HRS
R2 000XX MIN
R3 0XX.XX SEC
OUTPUT IN CSEC @ 2^{28}

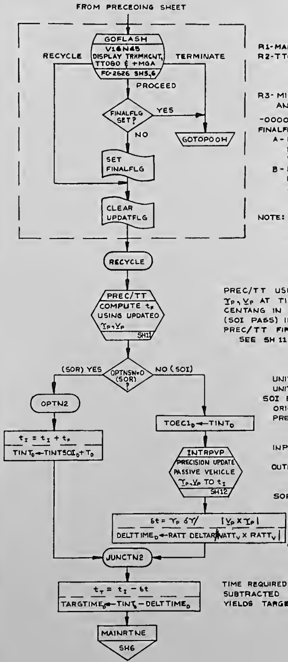
INDICATES P38/P78 OPERATING (P39/P79 WHEN SET)

EARTH SPHERE OF INFLUENCE: RTX1 ← 2, RTX2 ← 0, RTSR1/MU$_D$ ← $1/\sqrt{\mu_E}$ = .50087529 × 10^{-5}, RTMU$_D$ ← μ_E = 3.986032 × 10^{10}

MOON SPHERE OF INFLUENCE: RTX1 ← -10, RTX2 ← -2, RTSR1/MU$_D$ ← $1/\sqrt{\mu_M}$ = .45162595 × 10^{-4}, RTMU$_D$ ← μ_M = 4.902778 × 10^{8}

SELECTMU CLEARS FINALFLG AND SETS UPDATFLG (PERMITTING MARKTAKING IN VN1645 DISPLAY) THEN CALLS THE VN1645 DISPLAY ON NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 8APR69	P38 – P78 STABLE ORBIT RENDEZVOUS
PRGMR [signature] 7 APR 69	
ANALYST [signature] 8 Jul 69	COLOSSUS IIA — DOCUMENT FC-2644
DOCMR [signature] 7 Apr 69	
APPR'D [signature] 7 May 69	REV 1 — SHEET 4 OF 15



VHF OPTICS
R1-MARK COUNT XXBXX
R2-TTOGO/TFI XXBXX (- = BEFORE TIG, + = AFTER TIG) IN MINUTES, SECONDS
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 VERSION IN FC-2626 SH5,6

PREC/TT USES PRECSET TO RECOMPUTE $\underline{r}_A, \underline{v}_A, \underline{r}_P, \underline{v}_P$ AT TIG, THEN OBTAINS NEW t_F USING CENTANG IN TIMETHET. t_F WILL BE DIFFERENT (SOI PASS) IF MARKS WERE TAKEN SINCE PREC/TT FIRST USED

SEE SH 11 FOR INPUTS, OUTPUT IS t_F IN REVS @ 2^1
RPASS3 IN RVEC IN M @ $2^{27}, 2^{24}$
VPASS3 IN VVEC IN M/CSEC @ $2^5, 2^7$
CENTANG IN CSTH, SNTH IN REVS @ 2^1
UNIT LINE OF SIGHT IN ULOS } IN METERS
UNIT NORMAL LOS IN UNRM } @ 2^1

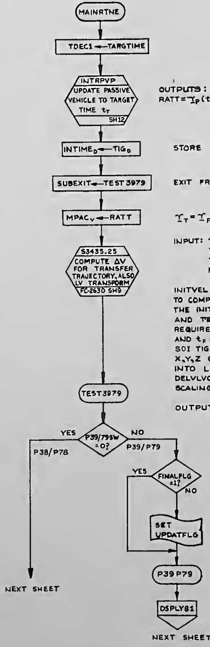
SOI BRANCH:
ORIGINAL t_I FOR SOI t_{IG} PLUS t_F FROM PREC/TT GIVES t_I, INTERCEPT TIME

INPUT: PASSIVE STATE VECTOR & t_I IN CSEC @ 2^{28}
OUTPUT: RPASS3, VPASS3 IN RATT, VATT WITH STANDARD MOON/EARTH SCALING

SOR BRANCH:
$t_I(SOI) + t_F(SOR)$ YIELDS $t_I(SOR)$
CONVERT δr TO δt USING $\underline{r}_P, \underline{v}_P$ AT t_I AND CIRCULAR APPROXIMATION
OUTPUT: δt IN CSEC @ 2^{28}

TIME REQUIRED TO TRAVERSE δr OFFSET SUBTRACTED FROM INTERCEPT TIME (SOI OR SOR) YIELDS TARGET TIME t_T IN CSEC @ 2^{28}

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	GUIDANCE AND ... P38-P78
H. D. Laverriere 11APR68; J. F. Goode 17 APR 68; W. Tempelman 8 July 68; ... 17 Jul 68; John A. Moore 1 Aug 68	STABLE ORBIT RENDEZVOUS
	COLOSSUS IIA FC-2644
REV 1	15 OF 15



OUTPUTS:
RATT = $\underline{r}_P(t_T)$, VATT = $\underline{V}_P(t_T)$

STORE TIG IN CSEC @ 2^{28}

EXIT FROM 53435.25

$\underline{r}_T = \underline{r}_P(t_T)$

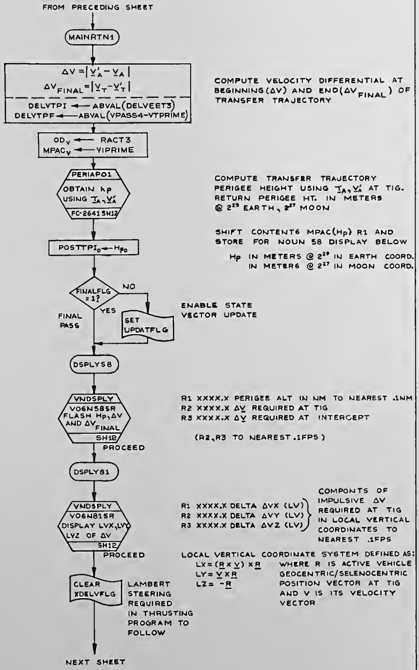
INPUT: $\underline{r}_P, \underline{V}_P$ AT t_T IN MPAC, VATT RESPECTIVELY; TIG$_D$ IN INTIME; t_T IN TARGTIME; $\underline{r}_A, \underline{V}_A$ AT TIG IN RPASS3$_D$, VPASS3$_D$ [FROM FIRST (SH4) PREC/TT CALC]

INITVEL IS CALLED (WITH $N_1 = 2, \epsilon = 15°$) BY 53435.25 TO COMPUTE A TRANSFER TRAJECTORY BETWEEN THE INITIAL AND TERMINAL POINTS, THE INITIAL AND TERMINAL VELOCITIES AND THE TOTAL $\Delta\underline{V}$ REQUIRED. CENTANG IS RETURNED IN ACTCENT$_D$ AND $t_F = t_I - t_{IG}$ IS RETURNED IN DELLT4$_D$. $\Delta\underline{V}$ AT SOI TIG IS RETURNED IN DELVEET3$_V$ IN REFERENCE X, Y, Z COMPONENTS, THEN CONVERTED INTO LOCAL VERTICAL COORDINATES. OUTPUT IN DELVLVC$_V$ (STD. AGC POSITION, VELOCITY, TIME SCALING THROUGHOUT)

OUTPUT: RTARG ($\underline{r}_P$ @ t_T), VIPRIME ($\underline{V}_A$ @ SOI); VTPRIME ($\underline{V}_A$ @ SOR); DELVEET3 ($\Delta\underline{V}$ @ SOI); VPASS4 ($\underline{V}_P$ @ SOR); ACTCENT (ϕ); DELLT4 (t_F); DELVLVC ($\Delta\underline{V}_{LV}$ @ SOI)

IF NOT FINAL PASS (RECYCLE @ PRIOR VN1645), SET UPDATFLG, PERMITTING STATE VECTOR UPDATE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
		P38-P78
DRAWN	8APR69	STABLE ORBIT RENDEZVOUS
PRGMR	7 May 69	
ANALYST	16 Jul 69	COLOSSUS IIA — DOCUMENT FC-2644
DOCMR	7 May 69	
APPR'D	7 May 69	REV 1 — SHEET 6 OF 15

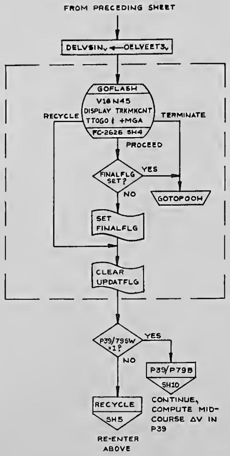


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

P38-P78 STABLE ORBIT RENDEZVOUS

COLOSSUS IIA FC-2644

REV 1 SHEET 7 OF 15



STORE ΔV_{TPI} REF COORD

R1 MARK COUNT XXBXX (VHF OPTICS)

R2 TTOGO/TFI XXBXX MIN BSEC (−=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

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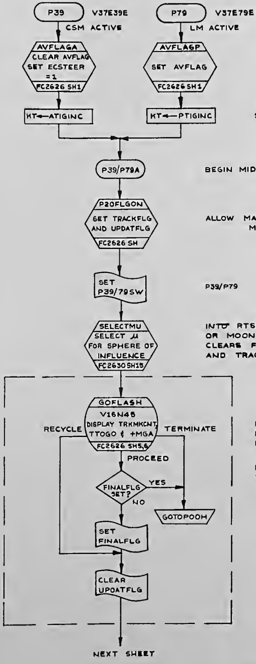
DRAWN	3APR69	P38-P78	
PRGMR	7 May 69	STABLE ORBIT RENDEZVOUS	
ANALST	6 May 69	COLOSSUS IIA	DOCUMENT NO. FC-2644
DOCMR	7 May 69		
APPR'D	7 May 69	REV 1	SHEET 8 OF 15



SELECT PREPARATION TIME δT FOR THRUST MANEUVER PAD LOADED OR ASSIGNED BY ASTRONAUT IN P27

BEGIN MIDCOURSE INITIAL CONDITIONS DISPLAY

ALLOW MARKTAKING IN P20 AND MARK INCORPORATION

P39/P79

LOADS VALUES OF $1/\sqrt{\mu}$ AND μ INTO RTSR1/MU AND RTRNMU FOR EARTH OR MOON SPHERE OF INFLUENCE ALSO CLEARS FINALFLG AND SETS UPDATFLG AND TRACKFLG

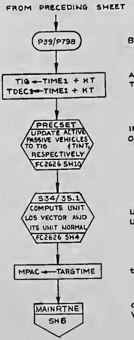
R1 XXBXX TRKMKCNT
R2 XXBXX TTOGO
R3 XXX.XX MGA

-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

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	P38-P78
DRAWN [signature] 9APR69	STABLE ORBIT RENDEZVOUS
PRG MGR [signature] 7 May 69	DOCUMENT NO
ANALYST [signature] 14 July 69	COLOSSUS IIA — FC-2644
DOC MGR [signature] 7 May 69	
APPR'D [signature] 9 May 69	REV 1 — SHEET 9 OF 15



BEGIN MIDCOURSE CORRECTION ΔV COMP.

ADD PREP. TIME TO PRESENT TIME TO GET TIME OF MIDCOURSE CORRECTION TIG

INPUT: TDEC1, CSM & LM STATE VECTORS, TINT
OUTPUT: RACT3, VACT3, RPASS4, VPASS4

UNIT LOS $\underline{U}_L$ = UNIT($\underline{r}_P - \underline{r}_A$) RET. VIA PLOO
UNIT LOS NORMAL $\underline{U}$ = UNIT ($\underline{r}_A \times \underline{V}_A$) RET VIA MPAC

t_T FOR INTERVP FROM SOI

COMPUTE $\underline{r}_P, \underline{V}_P$ AT t_T, THEN OBTAIN DELVLVC$_0$ WITH INITVEL AND DISPLAY IN LV COORDINATES

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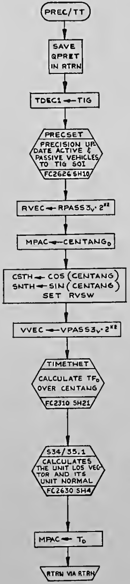
DRAWN / PRGMR / ANALST / DOCMR / APPR'D	P38-P78 STABLE ORBIT RENDEZVOUS
	COLOSSUS IIA — DOCUMENT NO. FC-2644
REV 1	SHEET 10 OF 15



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 SOI/SOR TIME OF IGNITION (SOM TIG OFFSET BY δT)

INPUT: TDEC1, CSM & LM STATE VECTORS
OUTPUT: $RACT3_V$, $VACT3_V$, $RPASS3_V$, $VPASS3_V$, $TDEC1_D$ IN CSEC @ 2^{28}, RACT, RPASS IN METERS @ 2^{29}, VACT, VPASS IN M/CSEC @ 2^7

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 @ 2^1

SCALE VVEC 2^7 EARTH, 2^5 MOON.

GIVEN CENTANG OF PASSIVE VEHICLE BETWEEN TIG & TINT AND RPASS, VPASS AT TIG. CALCULATE TF TIME OF FLIGHT FOR SOR
INPUT: RPASS3, VPASS3 IN METERS @ $2^{27}/2^{29}$ AND M/CSC $2^5/2^7$, RESPECTIVELY CENTANG CSTH & SNTH IN REVOLUTION @ 2^1
OUTPUT: t_F IN CSEC @ 2^{28}

INPUT: RPASS3, RACT3, VACT3 STD. SCALING

LOS OF ACTIVE VEHICLE VIEWED FROM PASSIVE VEHICLE AT TIG: $\underline{U}_L$ = UNIT $(\underline{r}_P - \underline{r}_A)$, $\underline{U}$ = UNIT $(\underline{r}_A \times \underline{V}_A)$
OD_V ← $ULOS_V$ ← $\underline{U}_L$
$MPAC_V$ ← $UNRM_V$ ← $\underline{U}$

$\underline{U}_L$, $\underline{U}$ ARE RETURNED VIA PUSH LIST LOC 00 AND MPAC, RESPECTIVELY, IN METERS @ 2^1

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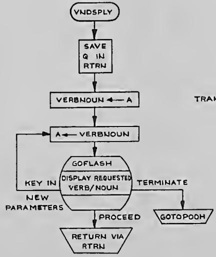
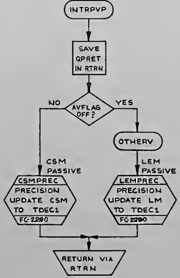
DRAWN [signature]	10APR69	P38-P78
PRGMR [signature]	7 May 69	STABLE ORBIT RENDEZVOUS
ANALYST [signature]	[illegible]	COLOSSUS IIA — DOCUMENT NO FC-2644
GDLMR [signature]	7 May 69	REV 1
APPR'D [signature]	7 May 69	SHEET 11 OF 16



TRANSFER VN CODE TO DISPLAY LOC VERBNOUN

R1
R2 } DEPENDS ON REQUEST
R3



INPUT: t_I IN CSEC @ 2^{28}
VEHICLES STATE VECTORS FOR LM, CSM

OUTPUT: $\underline{r}_P$, $\underline{V}_P$ IN RATT, VATT AT t_I OR t_T

STANDARD AGC SCALING

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P38-P78	
DRAWN [signature]	10APR69	STABLE ORBIT RENDEZVOUS	
PRGMR [signature]	7 May 69		DOCUMENT NO
ANALST [signature]	11 July 69	COLOSSUS IIA	FC-2644
DOCMR [signature]	7 May 69		
APP'D John A. [signature]	7 May 69	REV 1	SHEET 12 OF 15

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
AVFLAGA	FC-2626	CLEARS AVFLAG (CSM ACTIVE), SETS ECSTEER	SH. 3, 9
AVFLAGP	FC-2626	SETS AVFLAG	SH. 3, 9
P20FLGON	FC-2626	SETTRACK & UPDATFLG	SH. 3, 9
SELECTMU	FC-2630 SH. 15	SELECTS PROPER $1/\sqrt{\mu}$, μ 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 $\underline{R}_A$ & $\underline{V}_A$ AT TIG AND RETURNS H_p, PERIGEE HEIGHT	SH. 7
CSMPREC	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
XDELVFLG	LAMBERT STEERING NOT REQUESTED	LAMBERT STEERING IN THRUSTING MANEUVER TO FOLLOW		SH. 7	
P39/79SW	MIDCOURSE COMPUTATION	NOT MIDCOURSE	SH. 9		SH. 6, 8

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N33SR	GOFLASH	R1 00XXX HRS R2 000XX MIN R3 0XX.XX SEC } REQUEST TIG	SH. 3
V06N55SR	GOFLASHR	R1 BLANK R2 BLANK R3 XXX.XX DEG. REQUEST CENTANG, CENTRAL ANGLE OF TRANSFER	SH. 3
V04N06SR	GOFLASHR	R1 00005 R2 0000X X = 1 FOR SOI R3 BLANK X = 2 FOR SOR	SH. 3
V06N57SR	GOFLASHR	R1 XXXX.X NM R2 BLANK R3 BLANK STABLE ORBIT POINT OFFSET δr REQUEST	SH. 4
V06N34SR	GOFLASH	R1 00XXX HRS R2 000XX MIN R3 0XX.XX SEC t_1 TIME OF INTERCEPT	SH. 4

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature]	1 APR 69	P38 – P78 STABLE ORBIT RENDEZVOUS
PRGMR [signature]	7 May 69	
ANALYST [signature]	6 June	COLOSSUS IIA DOCUMENT NO FC-2644
DOCMR [signature]	7 May 69	
APPR'D [signature]	7 May 69	REV 1 SHEET 13 OF 15

DISPLAYS (CONTINUED)

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V16N45	GOFLASH	R1 XXBXX R2 XXBXX TTOGO/TFI { TIME TO IGNITION/TIME FROM IGNITION IN MINUTES, SECONDS (MAXIMUM 60 B 60) R3 MIDDLE GIMBAL ANGLE IN DEGREES	SH. 5, 8, 9
V06N58SR	GOFLASH	R1 0000.1 PERIGEE ALT. IN N.M. R2 0000.0 ΔV_{TIG} IN FPS } IN REFERENCE COORDINATES R3 0000.0 ΔV_{TPF} IN FPS }	SH. 7
V06N81SR	GOFLASH	R1 0000.0 ΔVX R2 0000.0 ΔVY } IN LOCAL VERTICAL COORDINATES R3 0000.0 ΔVZ	SH. 7

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
OPTION1	5	STABLE ORBIT CODE			2^{14}
OPTION2	1 OR 2	PHASE 1 (SOI) OR PHASE 2 (SOR)			2^{14}
TINT	t_I	TIME OF INTERCEPT FOR SOI	MIN B SEC	CSEC	2^{28}
TINTSOI	t_I	SOI INTERCEPT TIME STORED FOR SOR=t_{IG}(SOR)		CSEC	2^{28}
TDEC1		STORAGE LOC FOR t_I, t_T FOR INTEGRATION		CSEC	2^{28}
T	t_F	TIME OF FLIGHT, T_{IG} TO t_I		CSEC	2^{28}
DELTAR	δr	OFFSET OF STABLE ORBIT (INTERCEPT) POINT FROM PASSIVE VEHICLE	NM	METERS	2^{29}
DELTTIME	δt	TIME TO TRAVERSE δr		CSEC	2^{28}
TARGTIME	t_T	TIME ACTIVE VEHICLE REACHES STABLE ORBIT POINT		CSEC	2^{28}
INTIME	t_{IG}	IGNITION TIME FOR S3435.25 (CALLS INITVEL)		CSEC	2^{28}
DELVTPI	ΔV	MAGNITUDE OF ΔV REQUIRED FOR BURN	FPS	M/CSEC	2^{7}
DELVTPF	ΔV_{FINAL}	MAGNITUDE OF ΔV REQUIRED AT INTERCEPT	FPS	M/CSEC	2^{7}
POSTTPI	H_p	MIN PERIGEE ALT.	NM	METERS	2^{29}
DELVSIN	ΔV	VALUE OF VELOCITY INCREMENT IN REFERENCE INERTIAL COORDINATES FOR EXTERNAL ΔV BURNS	FPS	M/CSEC	2^{7}
KT	$\delta\tau$	STORAGE LOC FOR ATIGINC, PTIGINC (BELOW)		CSEC	2^{28}
ATIGINC PTIGINC	$\delta\tau$ $\delta\tau$	ACTIVE } THRUST MANEUVER PASSIVE } PREP. TIME		CSEC	2^{28}
VERBNOUN	VXXNXX	STORE VERBNOUN COMBINATIONS			2^{14}
TIG	t_{IG}	IGNITION TIME FOR MANEUVER		CSEC	2^{28}

PROGRAM CONSTANTS

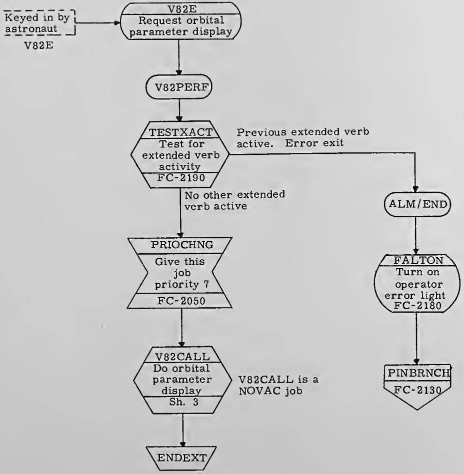
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
MUTABLE	μ_e(MUE)	EARTH GRAVITATIONAL CONSTANT	3.986032×10^{10}	$M^3/CSEC^2$	2^{36}
MUTABLE+6	$1/\sqrt{\mu_e}$	RECIPROCAL SQRT OF μ_e	$.50087529 \times 10^{-5}$	$CSEC/M^{3/2}$	2^{-17}
MUTABLE+8	μ_M(MUM)	MOON GRAVITATIONAL CONSTANT	4.902778×10^8	$M^3/CSEC^2$	2^{30}
MUTABLE+14	$1/\sqrt{\mu_M}$	RECIPROCAL SQRT OF μ_M	$.45162595 \times 10^{-4}$	$CSEC/M^{3/2}$	2^{-14}

PAD LOADS

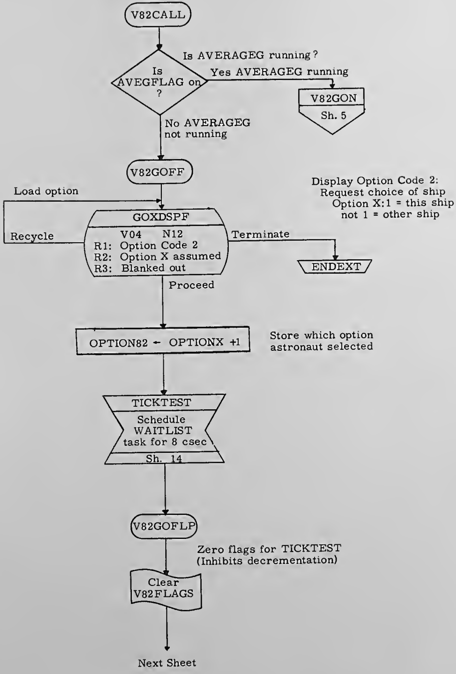
AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
ATIGINC	$\delta\tau$	CSM PREP. TIME FOR MIDCOURSE MANEUVER PREPARATION				
PTIGINC	$\delta\tau$	LM PREP. TIME FOR MIDCOURSE MANEUVER PREPARATION				

ORBITAL PARAMETERS DISPLAY

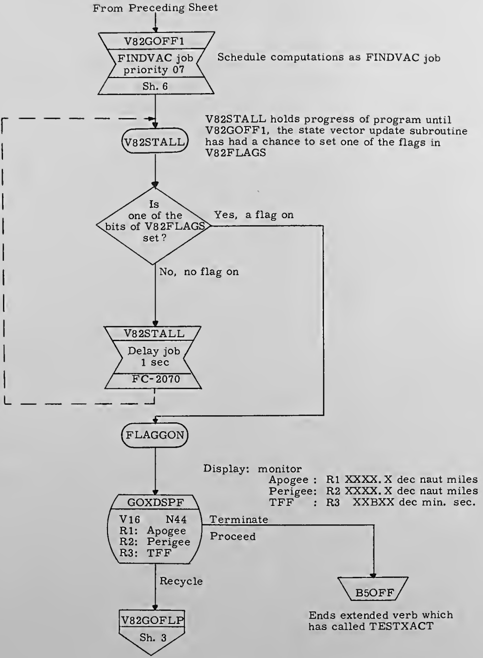
Major Subroutines and External Entry Points:



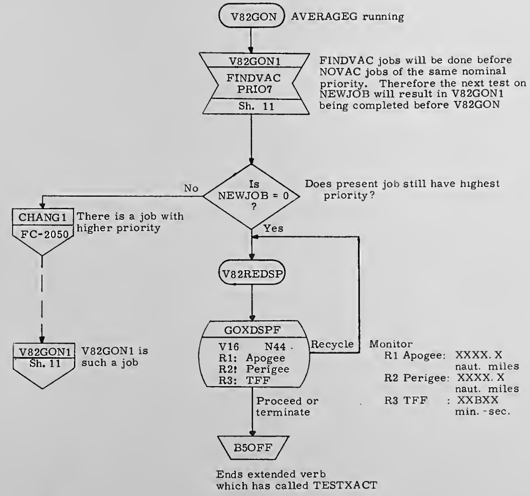
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cincotta 8-5-69	Orbital Parameters Display	
PRGMR T. Crocker 8-29-69		
ANALST	Colossus IIC	DOCUMENT NO. FC-2650
DOCMR Roberta M. Sutey 8/29/69		
APPR'D [signature]	REV 1	SHEET 2 OF 25



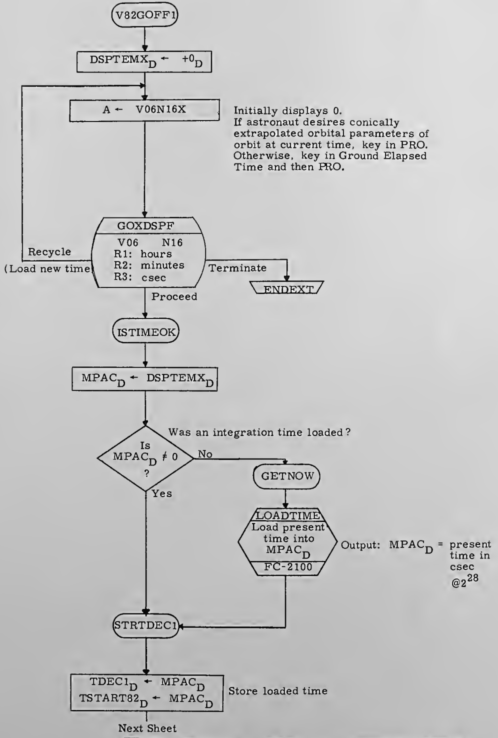
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		Orbital Parameters Display	
PRGMR	8-29-69		
ANALST		Colussus IIC	DOCUMENT NO. FC-2650
DOCMR	8/29/69		
APPR'D	8/29/69	REV 1	SHEET 3 OF 25



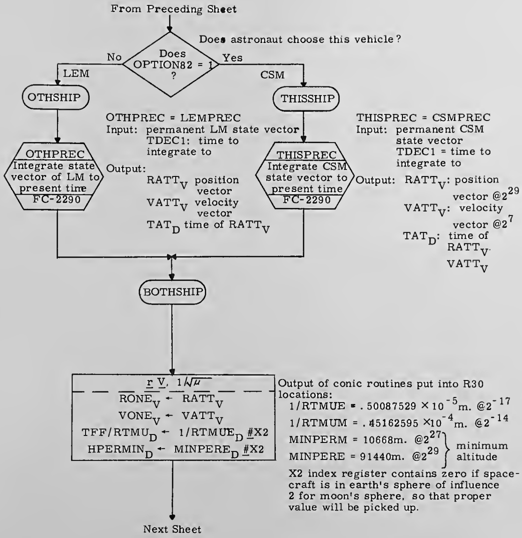
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		Orbital Parameters Display	
PRGMR	8-24-69		
ANALST		Colossus IIC	DOCUMENT NO. FC-2650
DOCMR	8/25/69		
APPR'D	8/29/69	REV 1	SHEET 4 OF 25



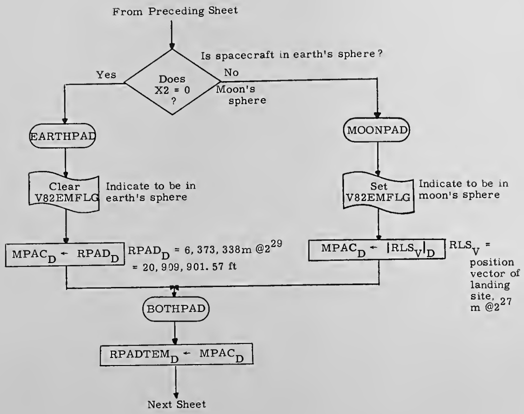
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	[illegible]	Orbital Parameters Display	
PRGMR [illegible]	8-21-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR [illegible]	8/29/69		
APPR'D [illegible]	8/29/69	REV 1	SHEET 5 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	[illegible]	Orbital Parameters Display	
PRGMR [illegible]	[illegible]	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR [illegible]	[illegible]		
APPR'D [illegible]	[illegible]	REV 1	SHEET 6 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Crocetta	4 Aug 68	Orbital Parameters Display	
PRGMR T. Crocker	8-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR Roberta M. Sutter	8/29/69		
APPR'D RM Sweet	8/29/69	REV 1	SHEET 7 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Ciocotia	8-28-69	Orbital Parameters Display	
PRGMR T. Cuccia	8-28-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR Roberta M. Entes	8/29/69		
APPR'D	8/29/69	REV 1	SHEET 8 OF 25

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

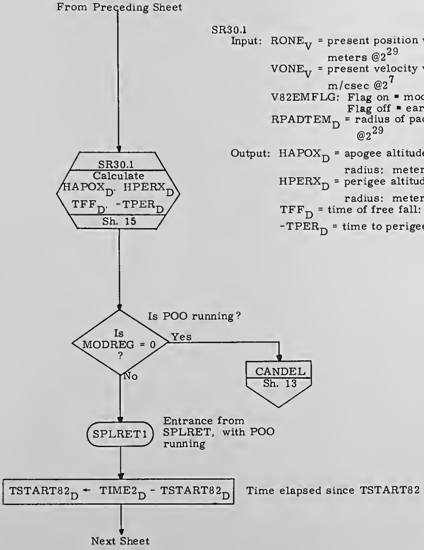
$RPADTEM_D$ = radius of pad: meters @2^{29}

Output: $HAPOX_D$ = apogee altitude above pad radius: meters @2^{29}

$HPERX_D$ = perigee altitude above pad radius: meters @2^{29}

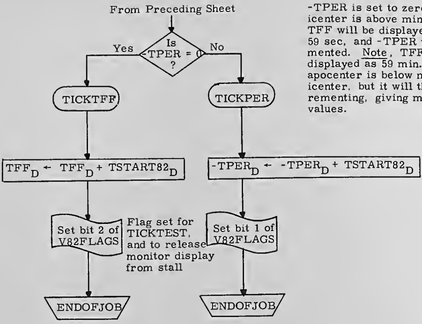
TFF_D = time of free fall: csec @ 2^{28}

$-TPER_D$ = time to perigee: csec @2^{28}

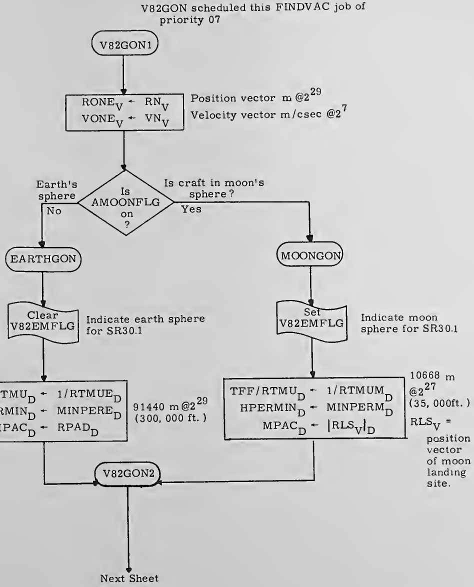


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Covolla	[illegible]	Orbital Parameters Display	
PRGMR I. Gocker	8-29-69		
ANALST		COLOSSUS IIC	DOCUMENT NO. FC-2650
DOCMR Robert M. [illegible]	8/29/69		
APPR'D [illegible]	[illegible]	REV 1	SHEET 9 OF 25

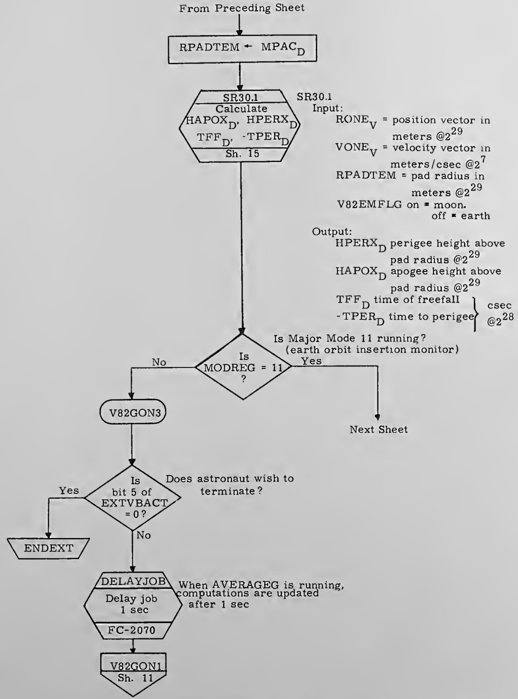
-TPER is set to zero when pericenter is above minimum. If so, TFF will be displayed as 59 min. 59 sec, and -TPER will be decremented. Note, TFF will also be displayed as 59 min. 59 sec when apocenter is below minimum pericenter, but it will then start decrementing, giving meaningless values.



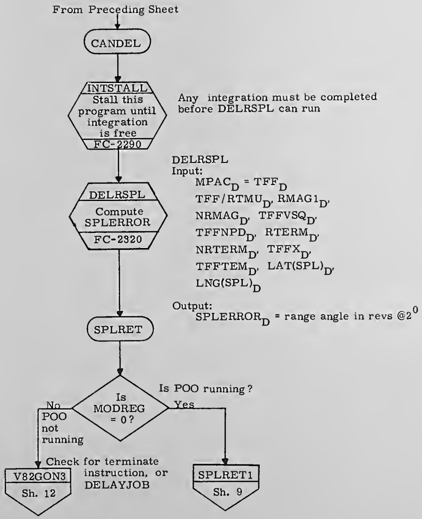
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cincotta	1Aug68	Orbital Parameters Display	
PRGMR T. Crocker	8-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR Roberta M. Estes	8/29/69		
APPR'D [signature]		REV 1	SHEET 10 OF 25



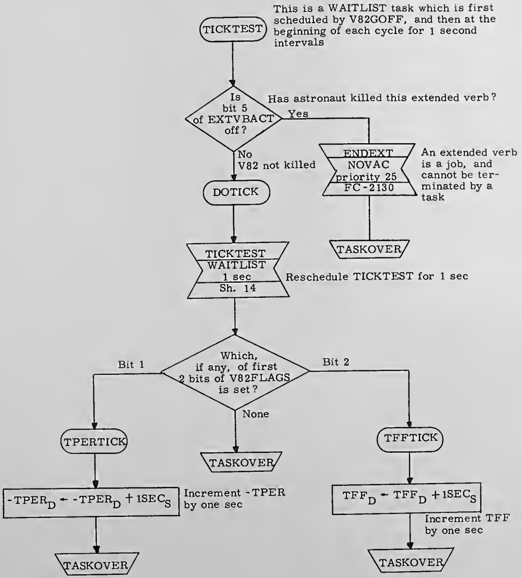
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cincotta	7Aug69	orbital Parameters Display	
PRGMR T. Crellin	8-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR Roberta M. Ems	8/29/69		
APPR'D AM Sarant	8/29/69	REV 1	SHEET 11 OF 25



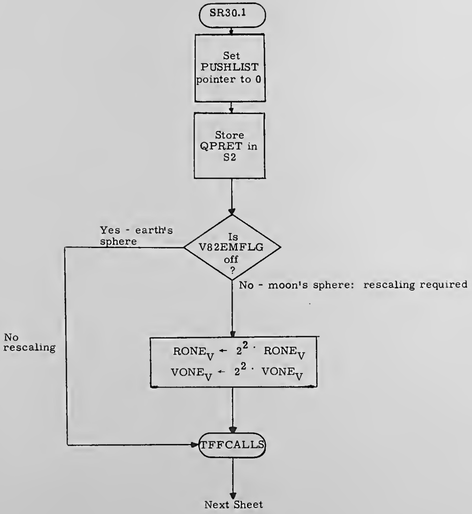
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Ciccotta	1 Aug 69	Orbital Parameters Display	
PRGMR T. Crowell	8-29-69		
ANALST		COLOSSUS IIC	DOCUMENT NO. FC-2650
DOCMR Roberta M. Easter	8/29/69		
APPR'D Alvin M. Shaw		REV 1	SHEET 12 OF 25



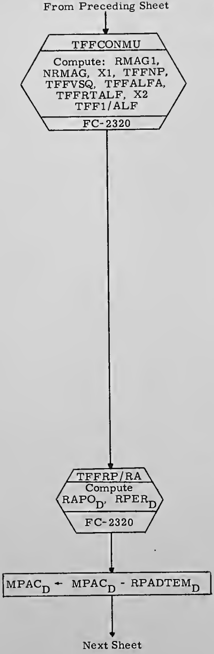
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	7Aug69	Orbital Parameters Display	
PRGMR [illegible]	8-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR [illegible]	8/29/69		
APPR'D [illegible]	8/29/69	REV 1	SHEET 13 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Circotta	1 Aug 69	Orbital Parameters Display	
PRGMR J. Circotta	8-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR Roberta M. Eiss	8/29/69		
APPR'D	8/29/69	REV 1	SHEET 14 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	2Aug69	Orbital Parameters Display	
PRGMR [signature]	8-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR [signature]	8/29/69		
APPR'D [signature]	8/29/69	REV 1	SHEET 15 OF 25



TFFCONMU:

Input:

$RONE_V$ = position vector in meters E@ 2^{29} M@2^{27}

$VONE_V$ = velocity vector in m/csec E@ 2^7 M@2^5

TFF/RTMU = $1/\sqrt{\mu}$ E@2^{-17} M@2^{-14}

Output:

$RMAG1_D$ = radius at time of RONE in meters E@2^{29}, M@2^{27}

$NRMAG_D$ = normalized RMAG, nrom count in X1 meters E@2^{29-NR} M@2^{27-NR}

NR = -X1 = -norm count for NRMAG

$TFFNP_D$: semilatus rectum, weighed by NR: meters E@2^{38-2NR} M@2^{36-2NR}

$TFFVSQ_D$: $\frac{V}{\sqrt{\mu}} \frac{V}{\sqrt{\mu}}$ present velocity, normalized 1/meters E@2^{-20} M@2^{-18}

$TFFALFA_D$: α weighted by NR, in 1/meters E@2^{-26+NR} M@2^{-24+NR}

$TFFRTALF_D$: $\sqrt{\alpha}$ normalized E@2^{-10-NA} M@2^{-9-NA}

X2 = -NA, norm count for $\sqrt{\alpha}$

$TFF1/ALF_D$ = signed, semi-major axis weighted by NA. In meters E@$2^{+22+2NA}$ M@2^{20+2NA}M

$VONE'_V$ = VONE•TFF/RTMU in 1/(M 1/2) @$2^{-10}/2^{-9}$

TFFRP/RA:

Input:

$TFFALFA_D$ = α = (semi-major axis)$^{-1}$ in meters^{-1} @$2^{-26+NR}/2^{-24+NR}$

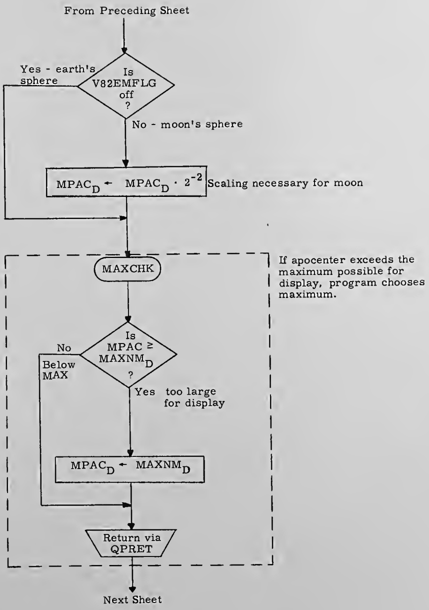
$TFFNP_D$ = semi-latus rectum in meters @$2^{38-2NR}/2^{36-2NR}$ X1, X2 set by TFFCONMU

Output:

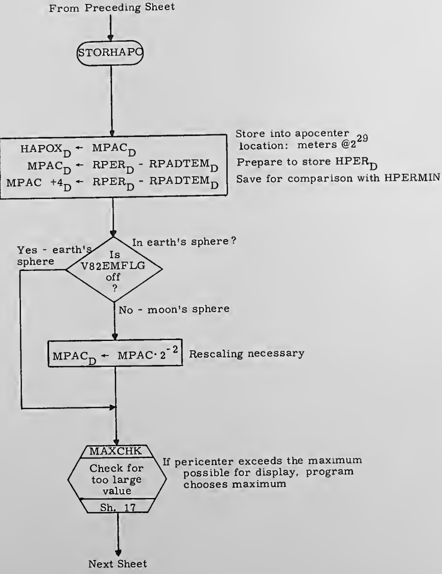
$RPER_D$ = perigee radius in meters @$2^{29}/2^{27}$

$RAPO_D$ = apogee radius in meters @$2^{29}/2^{27}$

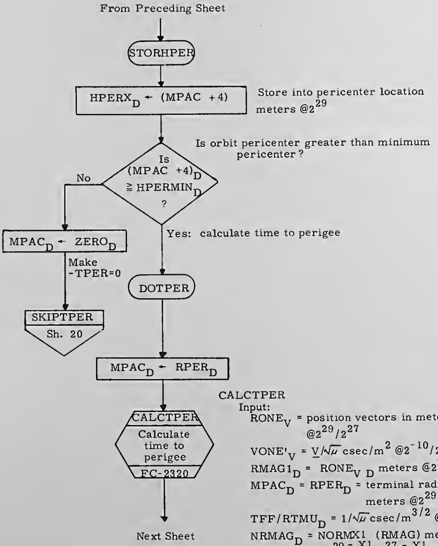
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cincotta	12Aug69	Orbital Parameter Display	
PRGMR J. Cincotta	8-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR Robert M. Estes	8/29/69		
APPR'D [signature]	[illegible]	REV 1	SHEET 16 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN I. Ciocotta	3Aug69	Orbital Parameters Display	
PRGMR I. Gordon	7-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR Roberta M. Eaton	8/29/69		
APPR'D [illegible]		REV 1	SHEET 17 OF 25



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cocotto	8 Aug 69	Orbital Parameters Display	
PRGMR T. Cocker	8-29-69	COLOSSUS IIC	DOCUMENT NO. FC-2650
ANALST			
DOCMR Roberta M. Eusui	8/29/69		
APPR'D [signature]	8/29/69	REV 1	SHEET 18 OF 25



CALCTPER

Input:

$RONE_V$ = position vectors in meters @$2^{29}/2^{27}$

$VONE'_V$ = $\underline{V}/\sqrt{\mu}$ csec/m^2 @$2^{-10}/2^{-9}$

$RMAG1_D$ = $RONE_{V\ D}$ 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$^{3/2}$ @$2^{-17}/2^{-14}$

$NRMAG_D$ = NORMX1 (RMAG) meters @$2^{29-X1}/2^{27-X1}$

X1 = Norm factor for RMAG

$TFFNP_D$ = semilatus rectum meters @$2^{38-2X}/2^{36-2X}$

TFFALFA = α meters @$2^{-26+X1}/2^{-24+X1}$

TFFRTALF = $\sqrt{\alpha}$ meters$^{1/2}$ @$2^{10-X2}/2^{9-X2}$

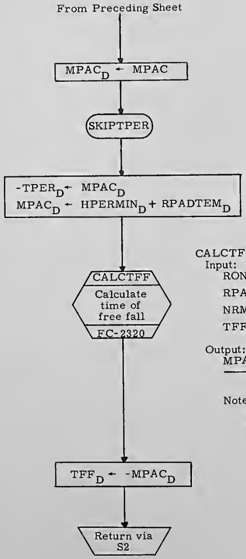
X2 = Norm count for TFFRTALF

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 J. Covelli	13Aug69	Orbital Parameters Display	
PRGMR T. Cuck	8-29-69		DOCUMENT NO.
ANALST		COLOSSUS IIC	FC-2650
DOCMR [signature]	8/29/69		
APPR'D [signature]	8/29/69	REV 1	SHEET 19 OF 25



CALCTFF

Input:

$RONE_V$, $VONE_V$, $RMAG1_D$, MPAC = RPADTEM + HPERMIN, $TFF/RTMU_D$, $NRMAG_D$, X1, $TFFNP_D$, $TFFALFA_D$, $TFFRTALF_D$, X2, TFF1/ALF

Output:

$\underline{MPAC_D}$ = TFF = time of free-fall, in csec @2^{28}

Note:

If the trajectory fails to reach HPERMIN + RPADTEM (300, 000' or 35, 000') then TFF will be displayed as 59B59

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	[date]	Orbital Parameters Display	
PRGMR [signature]	8-29-69		DOCUMENT NO.
ANALST		COLOSSUS IIC	FC-2650
DOCMR [signature]	8/29/69		
APPR'D [signature]		REV 1	SHEET 20 OF 25

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 R2: 000XX. minutes R3: 0XX. XX seconds } time of event	SH. 6

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
AVEGFLAG	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 J. Ciccolella	8 Aug 69	Orbital Parameters Display	
PRGMR T. Cadden	8-28-69		DOCUMENT NO.
ANALST		COLOSSUS IIC	FC-2650
DOCMR Robert M. Eaton	8/29/69		
APPR'D [signature]	8/29/69	REV 1	SHEET 21 OF 25

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
CALCTFF	2370	Calculates time of free fall to a particular radius	SH. 20
CALCTPER	2320	Calculates time of free fall to pericenter	SH. 19
DELAYJOB	2070	Delays a job for a particular time period	SH. 12
DELRSPL	2320	Calculates error in splashdown between calculated and predicted	SH. 13
ENDEXT	2130	Ends an extended verb	SH. 14
FALTON	2130	Turns on operator error light	SH. 2
LOADTIME	2100	Loads present time into $MPAC_D$	SH. 6
OTHPREC	2300	Update LM vector to a particular time	SH. 7
PRIOCHNG	2050	Change calling job's priority	SH. 2
TESTXACT	2190	Test for extended verb activity	SH. 2
TFFCONMU	2320	Computes various parameters used in the TFF routines, and establishes them in the push list area	SH. 16
TFFRP/RA	2320	Calculates perigee and apogee radius for a given conic	SH. 16
THISPREC	2300	Update CSM state vector to a particular time	SH. 7
INTSTALL	2300	Stall calling program until integration is not in use. Then inhibit any other program from using integration until INTWAKE is called.	SH. 13

ERASABLE LOCATIONS USED					
AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$-TPER_D$	t_{PER}	Negative of time from pericenter	min/sec	csec	2^{28}
$HAPOX_D$	h_a	Apocenter altitude	feet	meters	$2^{29}/2^{27}$
$HPERMIN_D$		Minimum perigee	feet	meters	$2^{29}/2^{27}$
$HPERX_D$	h_p	Pericenter altitude	feet	meters	$2^{29}/2^{27}$
MODREG		Major mode indication			
NEWJOB		Points to coreset of active job of highest priority			
$NRMAG_D$		Normalized RMAG	feet	meters	$2^{27+X1}/2^{24+X1}$
$RAPO_D$		Apogee radius	feet	meters	$2^{29}/2^{27}$
$RATT_V$		Radius vector output of integration	feet	meters	2^{29}
$\|RLS_V\|_D$	r_{LS}	Lunar landing site radius	feet	meters	2^{27}
$RMAG1_D$	r	Magnitude of radius vector	feet	meters	$2^{27}/2^{29}$
RN_V	$\underline{r}$	Radius vector as given by AVERAGEG	feet	meters	2^{29}
$RONE_V$	$\underline{r}$	Radius vector input to integration	feet	meters	$2^{29}/2^{27}$
$RPADTEM_D$		Location for storing pad radius	feet	meters	$2^{29}/2^{27}$

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$RPER_D$	r_p	Magnitude of pericenter	feet	meters	$2^{27}/2^{29}$
TFF_D	t_{ff}	Time of free fall to a certain altitude	seconds	csec	2^{28}
$TFF/RTMU_D$	$1/\sqrt{\mu}$	Inverse of the square root of mu	$sec/feet^{3/2}$	$csec/m^{3/2}$	$2^{14}/2^{17}$
$TFFALFA_D$		Inverse of the semimajor axis of a conic	1/feet	1/meters	$2^{-26 - X1}/2^{-24 - X1}$
$TFFNP_D$	p	Semilatus rectum, normalized	feet	meters	$2^{28 + X1}/2^{36 + X1}$
$TFFRTALF_D$	$\sqrt{\alpha}$	Square root of alpha	$1/feet^{1/2}$	$1/m^{1/2}$	$2^{-10 - X1}/2^{-9 - X1}$
$TFFVSQ_D$	$(v')^2$	Velocity/$\sqrt{u}$	$1/feet^{1/2}$	$1/m^{1/2}$	$2^{-20}/2^{-18}$
$TFF1/ALF_D$		Signed, semi-major axis, weighted by X2	feet	meters	$2^{22 - 2 \cdot X2}/2^{20 - 2 \cdot X2}$
$TIME2_D$		Timing registers	seconds	csec	2^{28}
$TSTART82_D$		Storage for TIME2 input	seconds	csec	2^{28}
$TDEC1_D$		Time to be integrated to	seconds	csec	2^{28}

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DRAWN J. Cuccolo 8Aug68
PRGMR T. Cuellar 8-29-68
ANALST
DOCMR Roberto M. Estrada 8/29/68
APPR'D [illegible] 8/29/68

APOLLO GUIDANCE AND NAVIGATION
Orbital Parameters Display
COLOSSUS IIC
DOCUMENT NO. FC-2650
REV 1
SHEET 24 OF 25

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$VATT_V$		Velocity output of integration routines	feet/sec	meters/csec	2^7
VN_V		Velocity vector, output of AVERAGEG	feet/sec	m/csec	2^7
$VONE_V$		Velocity vector	feet/sec	m/csec	2^7
$VONE'_V$		VONE,	$feet^{-1/2}$	$m^{-1/2}$	$2^{-10}/2^{-9}$

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	$01065\ 05603_8$	2^0
MINPERE	r_{pMIN}	300,000 ft reference alt for earth	300.000 ft	91440 meters	2^{29}
MINPERM	$r_p{}^{MIN}$	35,000 ft reference alt for moon	35,000 ft	1068 meters	2^{27}
RPAD		Standard pad radius	20910922 ft	6373338 meters	2^{29}
1/RTMUE	$1/\sqrt{\mu}_e$	Inverse of the square root of mu for earth	.0008427916 $\times 10^{-5}$	50087529 $\times 10^{-5}$	2^{-17}
1/RTMU	$1/\sqrt{\mu}_M$	Inverse of the square root of mu for moon	.007599228 $\times 10^{-4}$ sec/ft$^{3/2}$	.45162595 $\times 10^{-4}$ csec/m$^{3/2}$	2^{-14}

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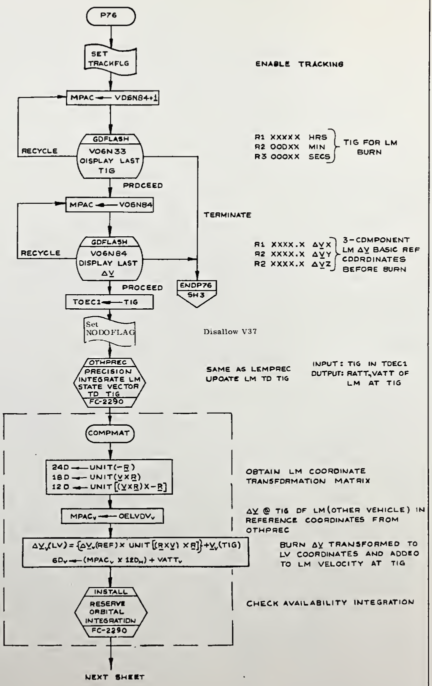
DRAWN J. Lincoln [illegible]	Orbital Paramenters Display
PRGMR [illegible] [illegible]	DOCUMENT NO.
ANALST	COLOSSUS IIC — FC-2650
DOCMR [illegible] [illegible]	REV 1
APPR'D [illegible] [illegible]	

P76 TARGET DELTA VELOCITY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkewich	1/24/69	P-76 Target Delta V	
PRGMR T. E. Crocker	12/3/69		DOCUMENT NO.
ANALST			
DOCMR Roberta M. Eaton	12/3/69	COLOSSUS 2D	FC-2670
APPR'D Roberta M. Eaton	12/3/69	REV 2	SHEET 1 OF 6



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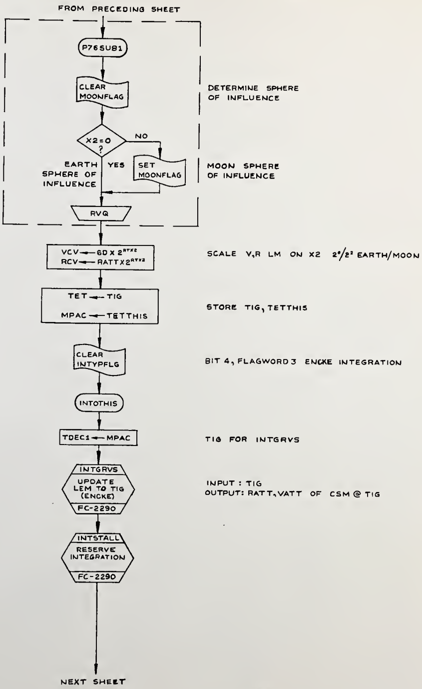
P-76
TARGET DELTA V

COLOSSUS 2D

FC-2670

REV 12

2 6



P76

TARGET DELTA V

COLOSSUS 2D

FC-2670

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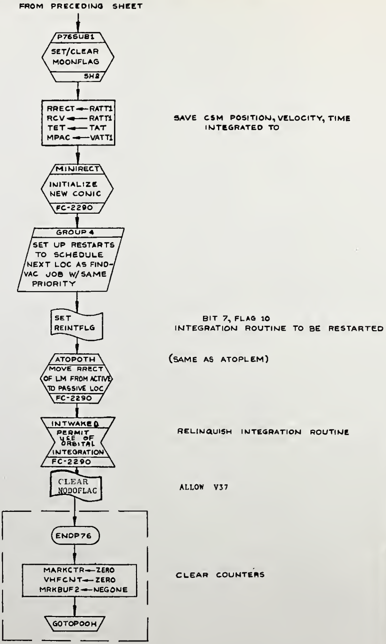

MIT INSTRUMENTATION LAB CAMBRIDGE MASS	APOLLO GUIDANCE AND NAVIGATION
DRAWN 31MAR69	P76
CHECKED 15APR69	TARGET DELTA V
ANALYST	COLOSSUS 2D — FC-2670
DOC MGR 2 May 69	REV 2 — SHEET 4 OF 6
APPR'D 8 May 69	

SUBROUTINES CALLED

SUBROUTINE NAME	WHERE FLOWED	DESCRIPTION	WHERE CALLED
OTHPREC	FC-2290	(SAME AS LEMPREC) PRECISION INTEGRATION OF LM	Sh. 2
INTSTALL	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	4
INTWAKE 0	FC-2290	RELEASES ORBITAL INTEGRATION ROUTINES	4

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. 3	Sh. 3	
INTYPFLAG	ENKE INTEGRATION	CONIC INTEGRATION		Sh. 3	
REINTFLAG	RESTART INTEGRATION	DO NOT RESTART INTEGRATION	Sh. 4		
NODOFLAG	V37 NOT PERMITTED	V37 PERMITTED	Sh. 2	Sh. 4	

VARIABLE ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TDEC1		STORAGE LOC FOR INTEGRATION TIME		CSEC	2^{28}
TIG		STORAGE LOC FOR IGNITION TIME		CSEC	2^{28}
DELVOV		ΔV OTHER VEHICLE (LM)		M/CSEC	2^{7}
VCV		TEMPORARY CONIC VELOCITY		M/CSEC	2^{7}
RCV		TEMPORARY CONIC POSITION		M	2^{29}
TET		TEMPORARY TIME OF STATE VECTOR		CSEC	2^{28}
TETTHIS		TEMPORARY TIME OF CSM STATE VECTOR		CSEC	2^{28}
RRECT		TEMPORARY POSITION AT RECT TIME		M	2^{29}
MARKCTR		MARK COUNTER (USED BY R32)			2^{0}
VHFCNT		VHF MARK COUNTER			2^{0}
MRKBUF2		TEMP MARK COUNTER FOR R21			2^{0}
NEGONE		NEGATIVE 1			2^{14}

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DRAWN J. D. Laurence 11 APR 69
J E Conlin 15 APR 69
2 May 69
2 May 69

P76
TARGET DELTA V
COLOSSUS 2D
FC-2670
2 5 6

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N84		DISPLAY LAST $\Delta \underline{V}$	Sh. 2
V06N33		DISPLAY LAST TIG	Sh. 2

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	
DRAWN		P40, P41 THRUS PROGRAMS	
PRGMR S. M. Beals	10/23/69		
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2680
DOCMR Robert M. Estes	10/23/69		
APPR'D Robert M. Estes	10/23/69	REV 3	SHEET OF

THRUST PROGRAMS (P40 AND P41)

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS·

P40CSM:	HANDLES TIMING OF AN SPS MANEUVER INPUTS (FROM PRE-THRUST PROGRAMS): TIG_D = TIME OF INITIATION OF MANEUVER, IN CSEC @ 2^{28} XDELVFLG - INDICATES WHETHER EXTERNAL ΔV OR LAMBERT MANEUVER IF EXTERNAL ΔV: $DELVSIN_V$ = DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES, IN M/CSEC @ 2^7 $WEIGHT/G_D$ = MASS OF TOTAL VEHICLE (INCLUDING LM IF APPROPRIATE), IN KG @ 2^{16} $RTIG_V$ = POSITION VECTOR AT TIME OF IGNITION IN REFERENCE COORDINATES, IN M @ 2^{29} $VTIG_V$ = VELOCITY VECTOR AT TIME OF IGNITION IN REFERENCE COORDINATES, IN M/CSEC @ 2^7 OR IF LAMBERT: ECSTEER = CROSS-PRODUCT STEERING CONSTANT @ 2^2 $RTARG_V$ = AIMPOINT POSITION VECTOR IN REFERENCE COORDINATES, IN M @ 2^{29} $TPASS4_D$ = TIME OF ARRIVAL AT AIMPOINT IN CSEC @ 2^{28}	SH. 4
P41CSM:	HANDLES TIMING OF AN RCS MANEUVER INPUTS (FROM PRE-THRUST PROGRAMS): ALL THOSE FOR P40 (EXTERNAL Δ V CASE), AS WELL AS NJETSFLG — INDICATES 2- 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
ENGINOFF:	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
TTG/0:	ENDS DISPLAY; SETS UP END OF PROGRAM	SH. 31

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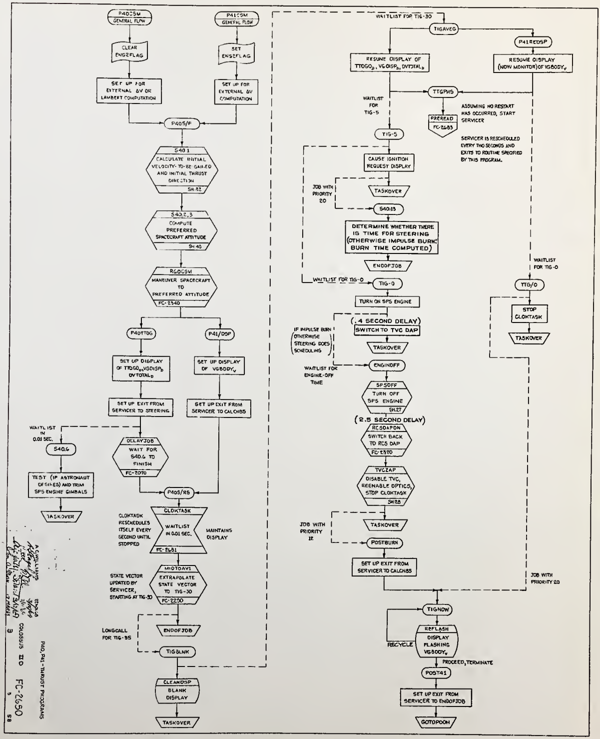
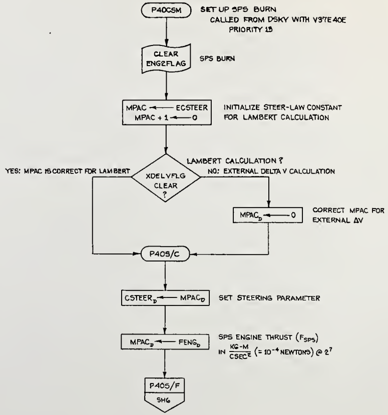
DRAWN A.C.WILLIAMS 13NOV68	P40, P41-THRUST PROGRAMS	
PRGMR [signature] 2/14/69		DOCUMENT NO.
ANALST [signature] 3/11/69	COLOSSUS II D	FC-2680
DOCMR [signature] 3/12/69		
APPR'D [signature] 17 MAR 69	REV 3	SHEET 1 OF 58

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
PRE40.6	RESTART ENTRY TO S40.6	SH.44



P40CSM GENERAL FLOW
P41CSM GENERAL FLOW
CLEAR ENGZFLAG
SET ENGZFLAG
SET UP FOR EXTERNAL ΔV OR LAMBERT COMPUTATION
SET UP FOR EXTERNAL ΔV COMPUTATION
P40S/F
S40.1 CALCULATE INITIAL VELOCITY-TO-BE-GAINED AND INITIAL THRUST DIRECTION SH 32
S40.2,3 COMPUTE PREFERRED SPACECRAFT ATTITUDE SH 40
R60CSM MANEUVER SPACECRAFT TO PREFERRED ATTITUDE FC-2340
P40TTOG
P41/DSP
SET UP DISPLAY OF TTOGO, VGDISP, DVTOTAL
SET UP DISPLAY OF VGBODY
SET UP EXIT FROM SERVICER TO STEERING
SET UP EXIT FROM SERVICER TO CALCN85
WAITLIST IN 0.01 SEC.
S40.6
DELAYJOB WAIT FOR S40.6 TO FINISH FC-2070
TEST (IF ASTRONAUT DESIRES) AND TRIM SPS ENGINE GIMBALS
TASKOVER
P40S/R5
CLOKTASK RESCHEDULES ITSELF EVERY SECOND UNTIL STOPPED
CLOKTASK WAITLIST IN 0.01 SEC. FC-2681
MAINTAINS DISPLAY
STATE VECTOR UPDATED BY SERVICER, STARTING AT TIG-30
MIDTOAV1 EXTRAPOLATE STATE VECTOR TO TIG-30 FC-2250
ENDOFJOB
LONGCALL FOR TIG-35
TIG35LNK
CLEANDSP BLANK DISPLAY
TASKOVER
WAITLIST FOR TIG-30
TIGAVEG
P41REDSP
RESUME DISPLAY OF TTOGO, VGDISP, DVTOTAL
RESUME DISPLAY (NOW MONITOR) OF VGBODY
TTGPHS
WAITLIST FOR TIG-5
PREREAD FC-2683
ASSUMING NO RESTART HAS OCCURRED, START SERVICER
SERVICER IS RESCHEDULED EVERY TWO SECONDS AND EXITS TO ROUTINE SPECIFIED BY THIS PROGRAM.
TIG-5
CAUSE IGNITION REQUEST DISPLAY
JOB WITH PRIORITY 20
TASKOVER
S40.13
DETERMINE WHETHER THERE IS TIME FOR STEERING (OTHERWISE IMPULSE BURN: BURN TIME COMPUTED)
ENDOFJOB
WAITLIST FOR TIG-0
TIG-0
WAITLIST FOR TIG-0
TIG/0
TURN ON SPS ENGINE
STOP CLOKTASK
TASKOVER
(.4 SECOND DELAY)
SWITCH TO TVC DAP
IF IMPULSE BURN (OTHERWISE STEERING DOES SCHEDULING)
TASKOVER
WAITLIST FOR ENGINE-OFF TIME
ENGINOFF
SPSOFF TURN OFF SPS ENGINE SH 27
(2.5 SECOND DELAY)
RCSDAPON SWITCH BACK TO RCS DAP FC-2370
TVCZAP DISABLE TVC, REENABLE OPTICS, STOP CLOKTASK SH 28
JOB WITH PRIORITY 12
TASKOVER
POSTBURN
SET UP EXIT FROM SERVICER TO CALCN85
JOB WITH PRIORITY 20
TIGNOW
RECYCLE
REFLASH DISPLAY FLASHING VGBODY
PROCEED, TERMINATE
POST41
SET UP EXIT FROM SERVICER TO ENDOFJOB
GOTOPOOH
P40, P41-THRUST PROGRAMS
COLOSSUS IIE
FC-2650



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PRGMR
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APPR'D

APOLLO
GUIDANCE AND NAVIGATION

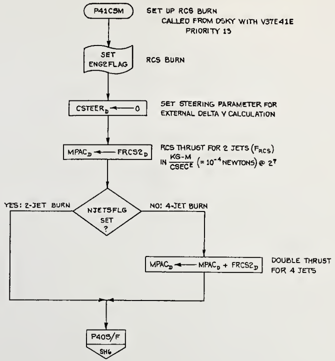
P40, P41 - THRUST PROGRAMS

COLOSSUS 2D

DOCUMENT NO FC-2680

REV B

SHEET 4 OF 58



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DRAWN A.C. WILLIAMS 17OCT68	P40, P41 - THRUST PROGRAMS
PRGMR [signature] 3/1/69	
ANALST [signature] 3/11/69	COLOSSUS IID
SUPVR [signature] 3/12/69	DOCUMENT NO FC-2680
APPR'D [signature] 17 MAR 69	REV B SHEET 5 OF 58

P40S/F

CALLED BY P40CSM, P41CSM
WITH APPROPRIATE THRUST IN $MPAC_D$

F_D ← $MPAC_D$ — SAVE THRUST IN $\frac{KG\text{-}M}{CSEC^2}$ ($=10^{-4}$ NEWTONS) @ 2^7

$NOMTIG_D$ ← TIG_D — SAVE NOMINAL TIME OF IGNITION - ACTUAL TIME MAY BE CHANGED IN CSEC @ 2^{28}
(UPLINKED FROM GROUND OR KEYED IN BY ASTRONAUT)

R02BOTH
CHECK IMU STATUS
FC-2210

RETURNS HERE ONLY IF OKAY.
OTHERWISE DISPLAYS ALARM AND TERMINATES PROGRAM.

P40PVA

S40.1
CALCULATE INITIAL VELOCITY-TO-BE-GAINED AND INITIAL THRUST DIRECTION
SH32

INPUT:
- $VTIG_V$ = VELOCITY VECTOR AT TIG IN REFERENCE COORDINATES IN M/CSEC @ 2^7
- $RTIG_V$ = POSITION VECTOR AT TIG IN REFERENCE COORDINATES IN M @ 2^{29}
- $DELVSAB_D$ = MAGNITUDE OF DESIRED IMPULSIVE VELOCITY CHANGE IN M/CSEC @ 2^7
- $DELVSIN_V$ = DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES IN M/CSEC @ 2^7

OR

- $RTARG_V$ = AIMPOINT POSITION VECTOR IN REFERENCE COORDS. @ 2^{29}
- $TPASS4_D$ = TIME SHOULD ARRIVE AT AIMPOINT IN CSEC @ 2^{28}

OUTPUT:
- $VGTIG_V$ = VELOCITY-TO-BE-GAINED AT TIG IN REFERENCE COORDINATES IN M/CSEC @ 2^7
- DELVLVC = VELOCITY-TO-BE-GAINED AT TIG IN L.V. COORDINATES IN M/CSEC @ 2^7
- UT_V = UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST IN REFERENCE COORDINATES @ 2^1

S40.2,3
COMPUTE PREFERRED SPACECRAFT ATTITUDE
SH40

INPUT: UT_V, $RTIG_V$, $VTIG_V$
- PACTOFF = PITCH OFFSET ANGLE } FROM TVC DAP
- YACTOFF = YAW OFFSET ANGLE } FROM TVC DAP

OUTPUT:
- $POINTVCSM_V$ = UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST IN S.M. COORDINATES @ 2^1
- $SCAXIS_V$ = UNIT VECTOR IN DIRECTION OF THRUST IN SPACECRAFT COORDINATES @ 2^1
- $XSCREF_V$, $YSCREF_V$, $ZSCREF_V$ = DESIRED SPACECRAFT AXES IN REFERENCE COORDINATES @ 2^1 = PREFERRED IMU ORIENTATION (SEE SH.42)

SET PFRATFLG — PREFERRED ATTITUDE HAS BEEN COMPUTED.

NEXT SHEET

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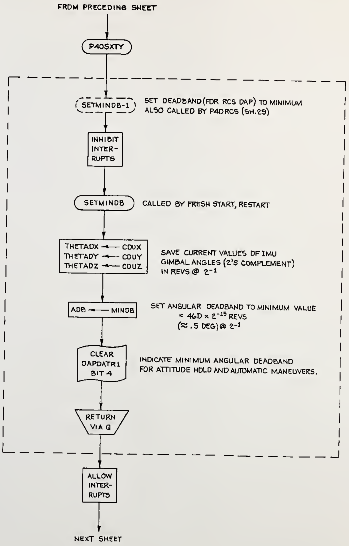
DRAWN A.C. WILLIAMS	18OCT68	P40, P41-THRUST PROGRAMS
PRGMR [signature]	3/10/69	DOCUMENT NO.
ANALST [signature]	3/11/69	COLOSSUS IID FC-2680
DOCMR [signature]	3/12/69	REV 3
APPR'D [signature]	[date]	SHEET 6 OF 58



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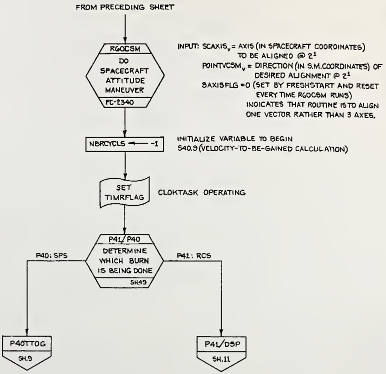
DRAWN A.C.WILLIAMS	18OCT68	P40, P41 - THRUST PROGRAMS
PRGMR [illegible]	3/6/69	
ANALST [illegible]	3/11/69	COLOSSUS IID — DOCUMENT NO. FC-2680
DOCMR [illegible]	3/12/69	
APPR'D [illegible]	[illegible]	REV 2 — SHEET 7 OF 58



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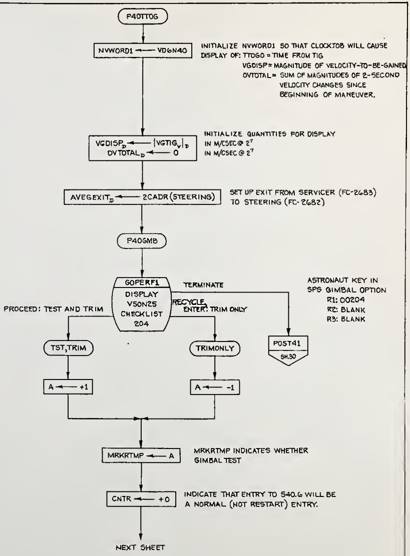
DRAWN A.C.WILLIAMS	10OCT68	P40, P41 - THRUST PROGRAMS
PRGMR		
ANALST		COLOSSUS IID — DOCUMENT NO. FC-2680
DOCMR		
APPR'D	19MAR69	REV 3 — SHEET 8 OF 58



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS

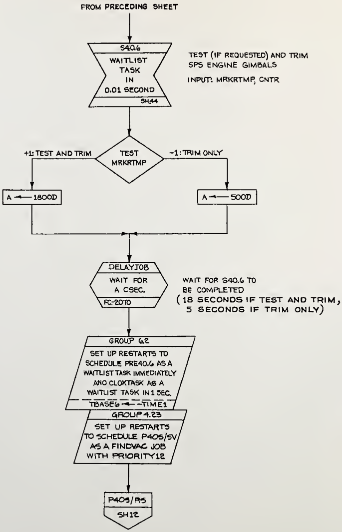
APOLLO GUIDANCE AND NAVIGATION

P40, P41 - THRUST PROGRAMS

DRAWN A.C. WILLIAMS	22OCT68
PRGMR (signature)	3/4/69
ANALST (signature)	3/4/69
DOC (signature)	3/12/69
APPR'D (signature)	

COLOSSUS IIO — DOCUMENT NO. FC-2680

REV 3 — SHEET 9 OF 58



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 22OCT68	P40, P41 - THRUST PROGRAMS
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DOCMR	SHEET 10 OF 58
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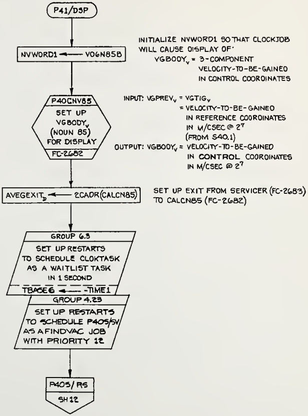

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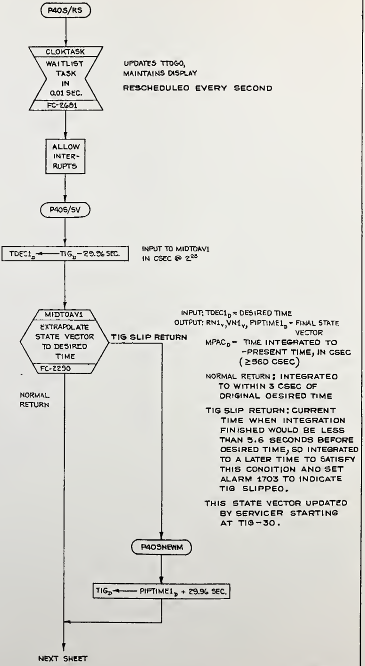

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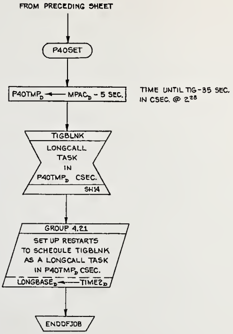

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DOCMR
APPR'D

APOLLO GUIDANCE AND NAVIGATION

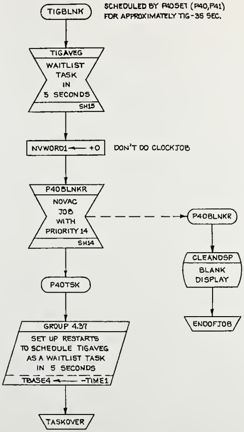
P40,P41-THRUST PROGRAMS

COLOSSUS II D

DOCUMENT NO. FC-2680

REV 3

SHEET 15 OF 58



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DRAWN A.C. WILLIAMS	28OCT68	P40, P41 - THRUST PROGRAMS	
PRGMR			DOCUMENT NO.
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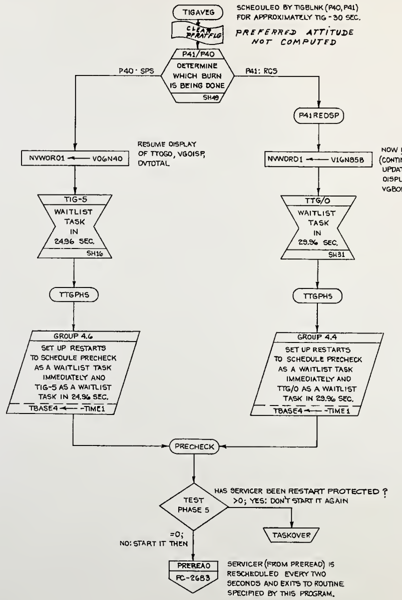
DOCMR	3/12/69		
APPR'D	13 MAR 69	REV 3	SHEET 14 OF 58



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DRAWN A.C. WILLIAMS 23OCT68	P40, P41 - THRUST PROGRAMS
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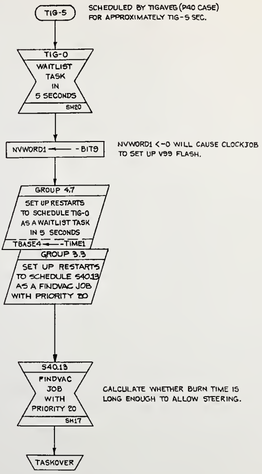
APPR'D 13 MAR 69	REV 5 SHEET 15 OF 58



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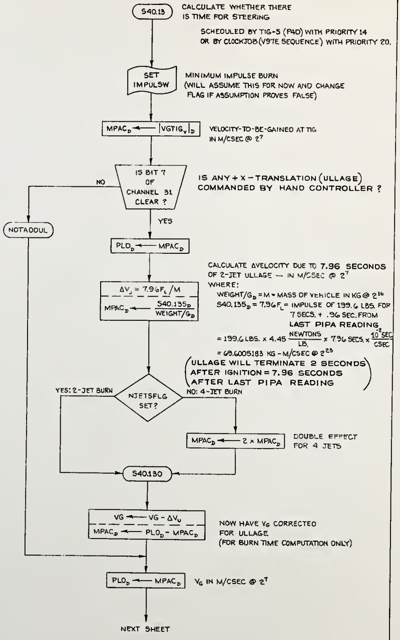
DOCMR 3/12/69	
APPR'D 12MAR69	REV 3 · SHEET 16 OF 58



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

DRAWN A.C WILLIAMS 24OCT68
CHECKED A.S. Engel Jr. 3/10/69
ANALYST Peter J. Volante 3/11/69
DES. ENGR. Alex K. Forant 3/12/69
APPROVED John A. Moore 17MAR69

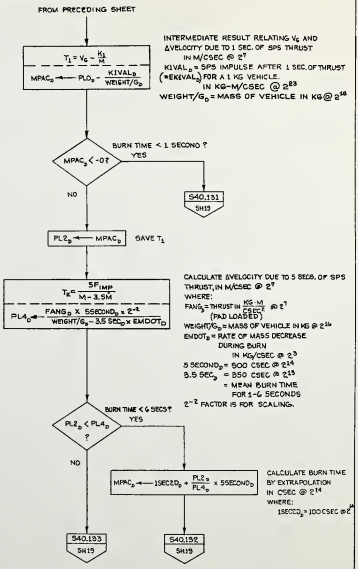
APOLLO GUIDANCE AND NAVIGATION

P40, P41 - THRUST PROGRAMS

COLOSSUS IID

DOCUMENT NO. FC-2680

REV 3



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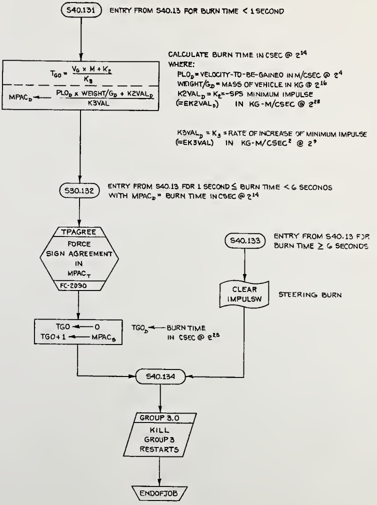
DOCMR [signature] 3/12/69		
APPR'D [signature] 12MAR69	REV 3	SHEET 18 OF 58



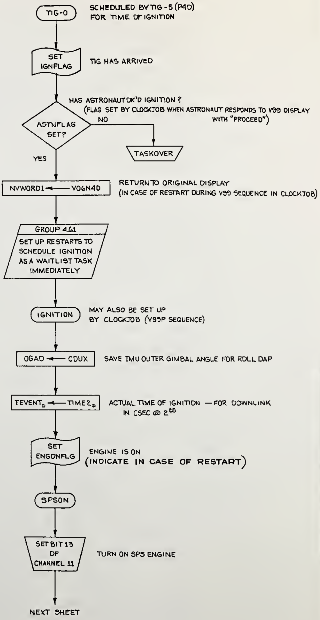
NOTE: BURN TIME COMPUTATIONS (ABOVE) FOLLOW
THE EMPIRICALLY DERIVED EXPRESSION FOR IMPULSE:

FOR 0 SEC. < Δt < 1 SEC: $MV_G = -K_2 + K_3 \Delta t$

FOR 1 SEC. < Δt < 6 SEC: $MV_G = K_1 + F_{IMP}(\Delta t - 1 SEC.)$

[K1, K2, K3, F_{IMP} STORED IN ERASABLE MEMORY]

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS	25OCT68	P40, P41 - THRUST PROGRAMS
PRGMR [signature]	3/ /69	
ANALST [signature]	3/11/69	COLOSSUS IID — DOCUMENT NO. FC-2680
DOCMR [signature]	3/12/69	
APPR'D [signature]	12 MAR 69	REV 3 — SHEET 19 OF 58



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DRAWN A.C.WILLIAMS 25OCT68
PRGMR
ANALST
DOCMR
APPR'D

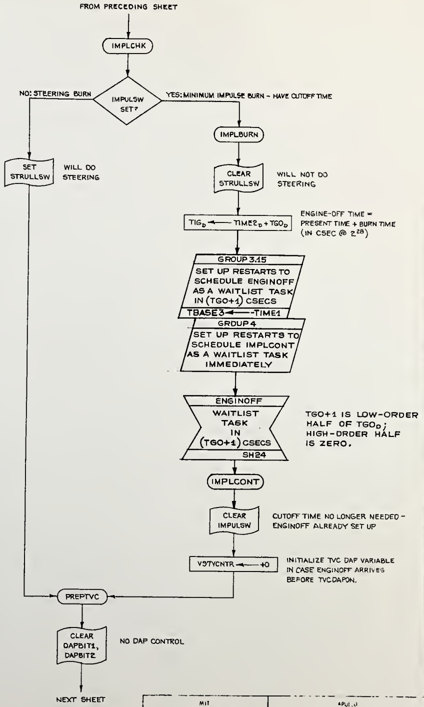
APOLLO GUIDANCE AND NAVIGATION

P40, P41 - THRUST PROGRAMS

COLOSSUS IID

DOCUMENT NO. FC-2680

REV 3



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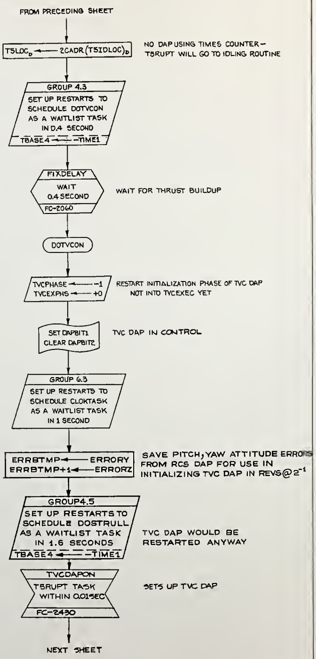
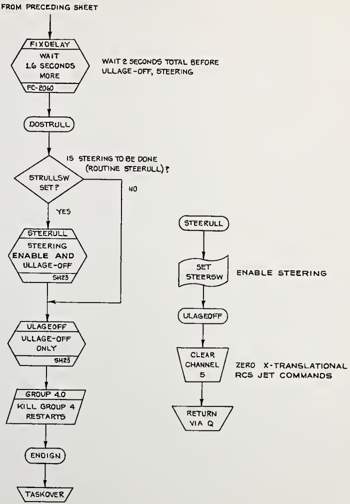
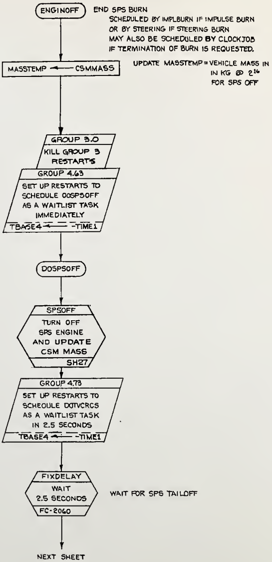
DRAWN A.C.WILLIAMS 28OCT68	P40, P41 - THRUST PROGRAMS
PRGMR [signature] 3/10/69	
ANALST [signature] 3/10/69	COLOSSUS II D — DOCUMENT NO FC-2680
DOCM [signature] 3/12/69	
APPR'D [signature] 3/12/69	REV 3 — SHEET 21 OF 58



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	28OCT68	P40,P41-THRUST PROGRAMS
PRGMR A. Engel	3/10/69	DOCUMENT NO
ANALST A. Engel	3/10/69	COLOSSUS II D FC-2680
DOCMR Alecia M. Grant	3/12/69	
APPR'D John A. Moore	3/13/69	REV 3 SHEET 22 OF 58



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS	28OCT68	P40, P41 - THRUST PROGRAMS
PRGMR	2/10/69	
ANALST	2/6/69	COLOSSUS II D — DOCUMENT No. FC-2680
DOCMR	3/12/69	
APPR'D	12 MAR 69	REV 3 — SHEET 23 OF 58



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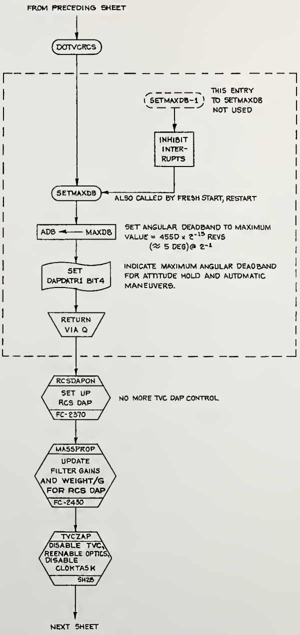
DRAWN A.C.WILLIAMS 28OCT68	P40, P41 - THRUST PROGRAMS
PRGMR 3/10/69	
ANALST 3/10/69	COLOSSUS IID — DOCUMENT NO FC-2680
DO. 3/12/69	
APPR'D 10 MAR 69	REV 3 — SHEET 24 OF 58



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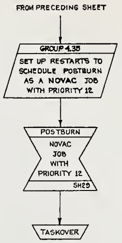
DRAWN A.C.WILLIAMS 29OCT68	
PRGMR A.G. Engel Jr. 3/10/69	
ANALST A.G. Engel Jr. 3/10/69	COLOSSUS II D FC-2680
DOCMR 3/12/69	
APPR'D John A. [illegible]	REV 3 SHEET 25 58



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DRAWN A.C.WILLIAMS	29OCT68	P40, P41 - THRUST PROGRAMS
PRGMR	3/10/69	
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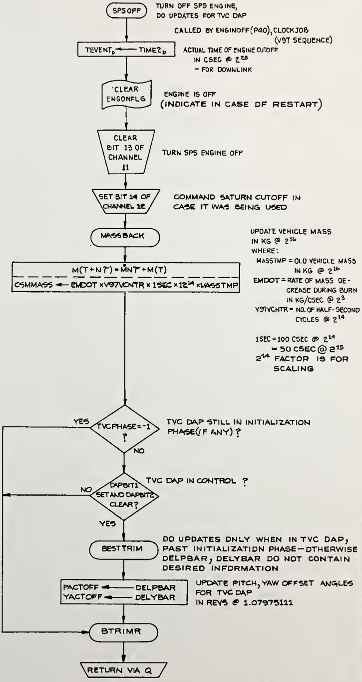

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C. WILLIAMS 6DEC68	P40, P41 - THRUST PROGRAMS
PRGMR A.J. Engel Jr. 3/10/69	
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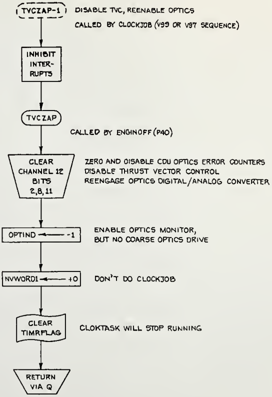
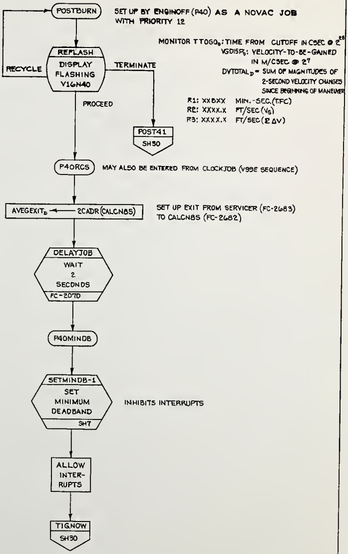
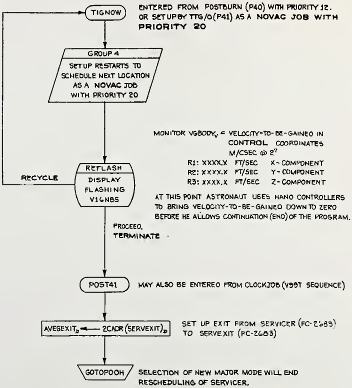
DOC MR Aleta M. Grant 3/12/69	
APPR'D John A. Moore 12 MAR 69	REV 3 27 58



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 29OCT68 PRGMR A.J. Engel Jr. 3/10/69 ANALST Peter J. Volante 3/11/69 DOCMR Gloria M. Swart 3/12/69 APPR'D John A. Rowe 12 MAR 69	P40, P41 - THRUST PROGRAMS COLOSSUS IID — DOCUMENT NO. FC-2680
	REV. B — SHEET 28 OF 58



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 30OCT68 PRGMR A.G. Engel Jr. 3/4/69 ANALST Peter Weill 3/4/69 DOCMR Ollie M. Swan 3/12/69 APPR'D John A. Mar 12 MAR 69	P40, P41 - THRUST PROGRAMS COLOSSUS IID DOCUMENT NO. FC-2680 REV 3 SHEET 29 OF 58



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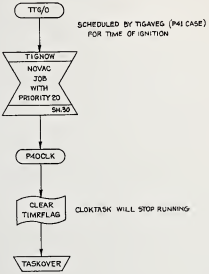
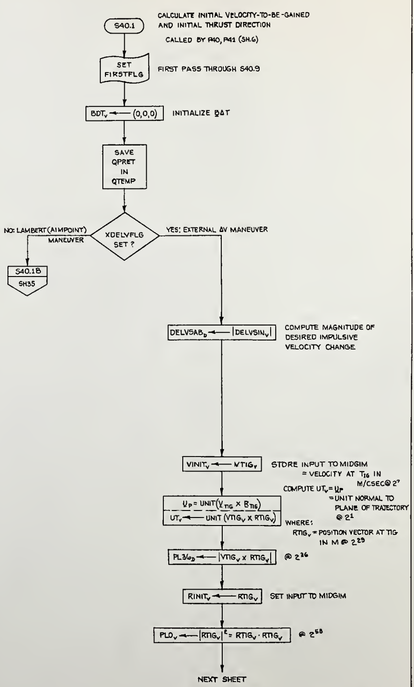

TTG/0
SCHEDULED BY TIGAVEG (P41 CASE)
FOR TIME OF IGNITION
TIGNOW
NOVAC
JOB
WITH
PRIORITY 20
SH.30
P40CLK
CLEAR
TIMRFLAG
CLOKTASK WILL STOP RUNNING
TASKOVER



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DRAWN A.C.WILLIAMS 30OCT68	P40, P41 - THRUST PROGRAMS
PRGMR A.H. Engel Jr. 3/10/69	
ANALST S. Zeldin 3/12/69	COLOSSUS IID DOCUMENT № FC-2680
DOCMR Alice M. Dinant 3/13/69	
APPR'D John A. Moore 19 MAR 69	REV 3 SHEET 32 OF 58

FROM PRECEDING SHEET

$$\frac{\theta_T}{2} = \frac{1}{2} \times \frac{1}{2\pi} \times \frac{|\underline{V}_{TIG} \times \underline{R}_{TIG}| \times |\Delta \underline{V}_{LV}| \times M}{|\underline{R}_{TIG}|^2 \times F}$$

$$PL14_D \leftarrow \frac{THETACON_D \times PL36_D \times DELVSAB_D \times WEIGHT/G_D}{PLO_D \times F_D}$$

CALCULATE $\frac{\theta_T}{2}$ = ONE-HALF THE ESTIMATED CENTRAL ANGLE TRAVELED DURING MANEUVER IN REVS @ 2^0 (SEE GSOP SECT. 5 FIGURE 3.3-7)

WHERE:

$THETACON_D = \frac{1}{2} \times \frac{1}{2\pi}$ @ 2^6 (FOR CONVERSION OF RADS TO REVS)

$DELVSAB_D$ = MAGNITUDE OF DESIRED IMPULSIVE VELOCITY CHANGE IN M/SEC @ 2^7

$WEIGHT/G_D$ = MASS OF VEHICLE IN KG @ 2^{16}

F_D = NOMINAL THRUST IN $\frac{KG\text{-}M}{CSEC^2}$ ($=10^{-4}$ NEWTONS) @ 2^7 (SET BY P40 OR P41)

$$(\Delta \underline{V} \cdot \underline{U}_P)\underline{U}_P$$

$$PLO_V \leftarrow (DELVSIN_V \cdot UT_V) \times UT_V \times 2^2$$

CALCULATE OUT-OF-PLANE COMPONENT IN M/CSEC @ 2^7

WHERE: $DELVSIN_V$ = DESIRED IMPULSIVE VELOCITY CHANGE IN M/CSEC @ 2^7 IN REFERENCE COORDINATES

UT_V = UNIT NORMAL TO PLANE OF TRAJECTORY @ 2^1

2^2 FACTOR IS FOR SCALING.

$$\Delta \underline{V}_P = \Delta \underline{V} - (\Delta \underline{V} \cdot \underline{U}_P)\underline{U}_P$$

$$PL6_V \leftarrow DELVSIN_V - PLO_V$$

CALCULATE $\Delta \underline{V}_P$ = IN-PLANE COMPONENT OF DESIRED VELOCITY CHANGE IN M/SEC @ 2^7 IN REFERENCE COORDINATES

$$\underline{V}_G(T_{IG}) = \left[\cos\left(\frac{\theta_T}{2}\right) UNIT(\Delta \underline{V}_P) + \sin\left(\frac{\theta_T}{2}\right) UNIT(\Delta \underline{V}_P \times \underline{U}_P)\right] |\Delta \underline{V}_P| + (\Delta \underline{V} \cdot \underline{U}_P)\underline{U}_P$$

$$VGTIG_V \leftarrow \left[\cos(PL14_D) UNIT(PL6_V) + \sin(PL14_D) UNIT(PL6_V \times UT_V)\right] |PL6_V| \times 2^2 + PLO_V$$

CALCULATE VELOCITY-TO-BE-GAINED AT TIME OF IGNITION IN M/CSEC @ 2^7 IN REFERENCE COORDINATES WHERE 2^2 FACTOR IS FOR SCALING

[ROTATE IN-PLANE COMPONENT BY $\frac{\theta_T}{2}$ (TO COMPENSATE FOR FINITE DURATION OF BURN) AND ADD THE OUT-OF-PLANE COMPONENT]

$$\underline{U}_{TD} = UNIT(\underline{V}_G(T_{IG}))$$

$$UT_V \leftarrow UNIT(VGTIG_V)$$

UNIT VECTOR IN THE DIRECTION OF DESIRED INITIAL THRUST IN REFERENCE COORDINATES @ 2^1

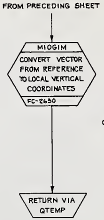
$$PLO_V \leftarrow VGTIG_V$$

INPUT TO MIDGIM IN M/CSEC @ 2^7 IN REFERENCE COORDINATES

SET AVFLAG

INPUT TO MIDGIM INDICATING THAT IT IS TO CONVERT A VECTOR FROM REFERENCE TO LOCAL VERTICAL COORDINATES.

NEXT SHEET



INPUT: AVFLAG (INDICATING SUBROUTINE OPTION)
COMPUTER (ALWAY SET IN COLOSSUS - INDICATES CGC (NOT LGC) COMPUTER)
PLO_V = VECTOR IN REFERENCE COORDINATES
$RINIT_V$ = POSITION VECTOR FOR SAME TIME AS PLO_V IN REFERENCE COORDINATES IN M @ 2^{29}
$VINIT_V$ = VELOCITY VECTOR FOR SAME TIME AS PLO_V IN REFERENCE COORDINATES IN M/CSEC @ 2^7

OUTPUT: MGLVFLAG (INDICATING WHICH SUBROUTINE OPTION WAS USED; IN THIS CASE, SET)
$DELVLVC_V$ = VECTOR IN LOCAL VERICAL COORDINATES (CONVERTED FROM PLO_V)

∴ HERE, $DELVLVC_V$ = VELOCITY-TO-BE-GAINED AT TIME OF IGNITION IN M/CSEC @ 2^7

S40.18 — LAMBERT BRANCH OF S40.1

$TDEC1_D \leftarrow TIG_D - TWODT_D$
$DELLT4_D \leftarrow TPASS4_D - TDEC1_D$

SET UP INPUTS TO AGAIN:
$TDEC1_D$ = TWO SECONDS BEFORE TIME OF IGNITION IN CSEC @ 2^{28}
WHERE TWODT = 200 CSEC @ 2^{28}
$DELLT4_D$ = TIME FROM $TDEC1_D$ UNTIL TIME AIMPOINT IS TO BE REACHED IN CSEC @ 2^{28}
WHERE $TPASS4_D$ = TIME THAT AIMPOINT IS TO BE REACHED IN CSEC @ 2^{28}

AGAIN
CALCULATE REQUIRED VELOCITY AND Δ VELOCITY FOR MANEUVERED BEGINNING AT DESIRED TIME
SH.38

INPUT: $TDEC1_D$, $DELLT4_D$, $RTARG_V$ = AIMPOINT POSITION VECTOR IN REFERENCE COORDINATES IN M @ 2^{29}
OUTPUT: $VIPRIME_V$ = INITIAL VELOCITY REQUIRED FOR MANEUVER AT $TDEC1_D$, IN M/SEC @ 2^7
$RINIT_V$, $RTIG_V$ = POSITION VECTOR AT $TDEC1_D$ IN M @ 2^{29} IN REFERENCE COORDINATES
$VINIT_V$, $VTIG_V$ = VELOCITY VECTOR AT $TDEC1_D$, IN M/CSEC @ 2^7 IN REFERENCE COORDINATES
$DELVEET3_V$ = CHANGE IN VELOCITY REQUIRED FOR MANEUVER AT $TDEC1_D$, IN M/CSEC @ 2^7 IN BASIC REFERENCE COORDINATES

$UT_V \leftarrow VIPRIME_V$

TEMPORARY STORAGE FOR $V_R(T_{IG}-2)$ IN M/CSEC @ 2^7

$TDEC1_D \leftarrow TIG_D$
$DELLT4_D \leftarrow TPASS4_D - TDEC1_D$

SET UP INPUTS TO AGAIN (IN CSEC @ 2^{28})
WHERE $TDEC1_D$ = TIME OF IGNITION THIS TIME.

AGAIN
CALCULATE REQUIRED VELOCITY AND Δ VELOCITY FOR MANEUVERED BEGINNING AT DESIRED TIME
SH.38

INPUT: $TDEC1_D$, $DELLT4_D$, $RTARG_V$
OUTPUT: $VIPRIME_V$,
$RINIT_V$, $RTIG_V$,
$VINIT_V$, $VTIG_V$,
$DELVEET3_V$

$PLO_V \leftarrow DELVEET3_V$
$VGTIG_V \leftarrow DELVEET3_V$

SAVE REQUIRED VELOCITY CHANGE AT T_{IG} IN PLO_V AS INPUT TO MIDGIM AND IN $VGTIG_V$ FOR FUTURE REFERENCE IN REFERENCE COORDINATES IN M/CSEC @ 2^7

NEXT SHEET

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 CGC COMPUTER)
PLO_v = VECTOR IN REFERENCE COORDINATES
$RINIT_v$ = POSITION VECTOR FOR SAME TIME AS PLO_v IN REFERENCE COORDINATES IN M @ 2^{29}
$VINIT_v$ = VELOCITY VECTOR FOR SAME TIME AS PLO_v IN REFERENCE COORDINATES IN M/CSEC @ 2^7
OUTPUT: MGLVFLAG (INDICATING WHICH SUBROUTINE OPTION WAS USED; IN THIS CASE, SET)
$DELVLVC_v$ = VECTOR IN LOCAL VERTICAL COORDINATES (CONVERTED FROM PLO_v)
∴ HERE, $DELVLVC_v$ = VELOCITY-TO-BE-GAINED AT TIME OF IGNITION IN M/CSEC @ 2^7

CALCUT

$MPAC_v \leftarrow RTIG_v$

INPUT TO CALCGRAV:
POSITION VECTOR AT DESIRED TIME IN REFERENCE COORDINATES IN M @ 2^{29}

CALCGRAV
CALCULATE GRAVITATIONAL ACCELERATION
FC-2663

INPUT: $MPAC_v$ = POSITION VECTOR
OUTPUT: $MPAC_v$ = $GDT1/2_v$ = ½ THE DIFFERENCE IN VELOCITY DUE TO GRAVITATIONAL ACCELERATION, AT SPECIFIED POSITION, OVER 2 SECONDS IN REFERENCE COORDINATES IN M/CSEC @ 2^7

$$C\underline{B} = C\left(\frac{\underline{V}_R(T_{IG}) - \underline{V}_R(T_{IG}-2) - 2 \times \frac{1}{2} G(\underline{R}(T_{IG}))\Delta T}{2\ SECS}\right)$$

$$PL12_v \leftarrow CSTEER\left(\frac{VIPRIME_v - UT_v}{200CS_D} - \frac{2 \times GDT1/2_v}{200CS_D}\right) \times 2^2$$

CALCULATE $C\underline{B}$ = INTERMEDIATE RESULT IN REFERENCE COORDINATES IN M/CSEC² @ 2^{-5}

WHERE:
$VIPRIME_v = \underline{V}_R(T_{IG})$ = REQUIRED VELOCITY AT TIG IN M/CSEC @ 2^7
$UT_v = \underline{V}_R(T_{IG}-2)$ = REQUIRED VELOCITY AT TIG-2 IN M/CSEC @ 2^7
$200CS_D$ = 200 CSEC @ 2^{12}
CSTEER = STEER-LAW CONSTANT @ 2^2 (SET BY P40, P41)
2^2 FACTOR IS FOR SCALING.

NEXT SHEET

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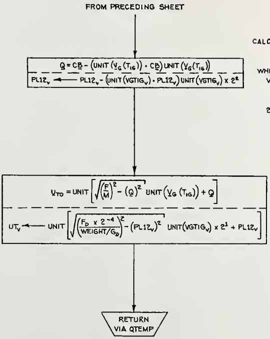
DRAWN A.C. WILLIAMS 1NOV68	P40, P41 - THRUST PROGRAMS	
PRGMR S. Zeldin 3/10/69		
ANALYST [signature] 3/11/69	COLOSSUS IID	DOCUMENT NO FC-2680
DOCMR [signature] 3/12/69		
APPR'D [signature] 12 MAR 69	REV 3	SHEET 36 OF 58



CALCULATE Q = INTERMEDIATE RESULT IN REFERENCE COORDINATES IN M/CSEC @ 2^{-5}

WHERE:

$VGTIG_V$ = VELOCITY-TO-BE-GAINED AT TIG IN REFERENCE COORDINATES IN M/CSEC @ 2^7

2^2 FACTOR IS FOR SCALING.

CALCULATE

$\underline{U}_{TD}$ = UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST @ 2^1 (IN REFERENCE COORDINATES)

WHERE:

F_D = ENGINE THRUST IN KG-M/CSEC^2 (=10^{-4}NEWTONS) @ 2^7 (FROM P40 OR P41)

$WEIGHT/G_D$ = MASS OF VEHICLE IN KG @ 2^{16}

$2^{-4}, 2^1$ FACTORS ARE FOR SCALING

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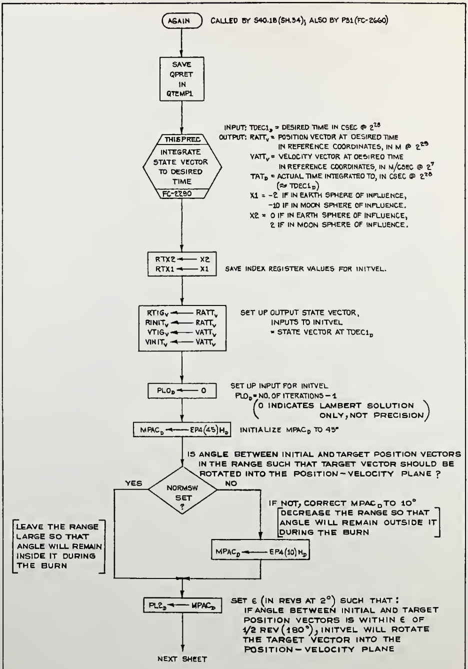

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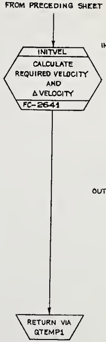


INPUT: $RINIT_V$ = INITIAL POSITION VECTOR IN REFERENCE COORDINATES IN M @ 2^{25}

$VINIT_V$ = INITIAL VELOCITY VECTOR IN REFERENCE COORDINATES IN M/CSEC @ 2^7

$RTARG_V$ = OFFSET TARGET VECTOR IN REFERENCE COORDINATES IN M @ 2^{29}

$DELLT4_D$ = TIME OF FLIGHT FROM $RINIT_V$ TO $RTARG_V$ IN CSEC @ 2^{28}

$PL0_D$ = NO. OF ITERATIONS-1 (0 INDICATES LAMBERT)

$PL2_D$ = ANGLE ε (IN REVS @ 2^0) WHICH DETERMINES SITUATION IN WHICH TARGET VECTOR MUST BE ROTATED

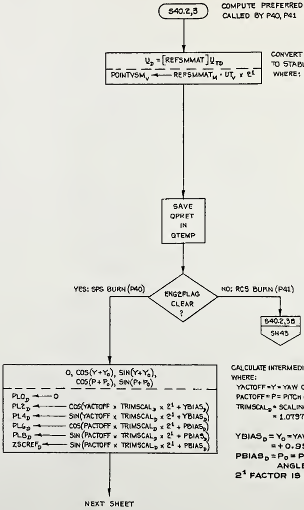
RTX1 = −2 IF IN EARTH SPHERE OF INFLUENCE, −10 IF IN MOON SPHERE OF INFLUENCE.

RTX2 = 0 IF IN EARTH SPHERE OF INFLUENCE, 2 IF IN MOON SPHERE OF INFLUENCE.

OUTPUT: $VIPRIME_V$ = INITIAL VELOCITY REQUIRED FOR MANEUVER IN REFERENCE COORDINATES IN M/CSEC @ 2^7

$VTPRIME_V$ = FINAL VELOCITY (AT $RTARG_V$) AFTER MANEUVER IN REFERENCE COORDINATES IN M/CSEC @ 2^7

$DELVEET3_V$ = INITIAL CHANGE IN VELOCITY REQUIRED FOR MANEUVER IN REFERENCE COORDINATES IN M/CSEC @ 2^7



COMPUTE PREFERRED SPACECRAFT ATTITUDE
CALLED BY P40, P41

CONVERT INITIAL THRUST DIRECTION VECTOR TO STABLE MEMBER COORDINATES @ 2^1
WHERE:

$REFSMMAT_M$ = TRANSFORMATION MATRIX BETWEEN REFERENCE AND S.M. COORDINATE SYSTEMS @ 2^1

$UT_V = U_{TD}$ = UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST IN REFERENCE COORDINATES @ 2^1 (FROM S40.1)

2^1 FACTOR IS FOR SCALING.

CALCULATE INTERMEDIATE RESULTS @ 2^1
WHERE:

YACTOFF = Y = YAW OFFSET ANGLE IN REVS @ 1.07975111
PACTOFF = P = PITCH OFFSET ANGLE IN REVS @ 1.07975111
$TRIMSCAL_D$ = SCALING CONSTANT FOR YACTOFF, PACTOFF = 1.07975111 @ 2^1

$YBIAS_D = Y_0$ = YAW MECHANICAL BIAS ANGLE = +0.95° IN REVS @ 2^0
$PBIAS_D = P_0$ = PITCH MECHANICAL BIAS ANGLE = −2.15° IN REVS @ 2^0
2^1 FACTOR IS FOR SCALING

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APPR'D John A. Moss 12 MAR 69	REV 3	SHEET 40 OF 58

FROM PRECEDING SHEET

$\underline{X}_{SC(EB)} = (\cos(P+P_o)\cos(Y+Y_o), -\cos(P+P_o)\sin(Y+Y_o), \sin(P+P_o))$

$\underline{Y}_{SC(EB)} = (\sin(Y+Y_o), \cos(Y+Y_o), 0)$

$\underline{Z}_{SC(EB)} = (-\sin(P+P_o)\cos(Y+Y_o), \sin(P+P_o)\sin(Y+Y_o), \cos(P+P_o))$

$XSCREF_v \leftarrow (PL6_D \times PL2_D \times 2^1, -PL6_D \times PL4_D \times 2^1, PL8_D)$

$YSCREF_v \leftarrow (PL4_D, PL2_D, PL0_D)$

$ZSCREF_v \leftarrow (-ZSCREF_D \times PL2_D \times 2^1, ZSCREF_D \times PL4_D \times 2^1, PL6_D)$

CALCULATE $[M]^T = \begin{bmatrix} \underline{X}_{SC(EB)} \\ \underline{Y}_{SC(EB)} \\ \underline{Z}_{SC(EB)} \end{bmatrix}$

GIVING SPACECRAFT AXES IN ENGINE BELL COORDINATES @ 2^1

WHERE $[M] = \begin{bmatrix} \underline{X}_{EB(SC)} \\ \underline{Y}_{EB(SC)} \\ \underline{Z}_{EB(SC)} \end{bmatrix}$ GIVES ENGINE BELL AXES IN SPACECRAFT COORDINATES

$X_{EB(SC)} = (\cos(P+P_o)\cos(Y+Y_o), \sin(Y+Y_o), -\sin(P+P_o)\cos(Y+Y_o))$

$SCAXIS_v \leftarrow (XSCREF_D, YSCREF_D, ZSCREF_D)$

CALCULATE UNIT VECTOR IN DIRECTION OF ENGINE BELL (X AXIS OF ENGINE BELL COORDINATE SYSTEM) IN SPACECRAFT COORDINATES @ 2^1 (FOR R60CSM)

$\underline{X}_{EB(RF)} = \underline{U}_{TD}$

$PL0_v \leftarrow UT_v$

$\underline{Y}_{EB(RF)} = \underline{U}_{TD} \times UNIT(\underline{R}(T_{IG}))$

$PL6_v \leftarrow UNIT(PL0_v \times UNIT(RTIG_v))$

INITIALIZE VALUE OF $\underline{Y}_{EB(RF)}$ - MAY BE CHANGED BY TSTRXUT

$PL36_D \leftarrow |PL0_v \times UNIT(RTIG_v)|$

INPUT TO TSTRXUT @ 2^2

TSTRXUT

MAKE SURE THAT $\underline{U}_{TD}$ AND $\underline{R}_{TIG}$ ARE NOT COLLINEAR

SH43

INPUT: $PL36_D = |\underline{U}_{TD} \times UNIT(R(T_{IG}))|$

OUTPUT: IF $\underline{U}_{TD}, \underline{R}(T_{IG})$ NOT COLLINEAR:

$\underline{Y}_{EB(RF)} = MPAC_v = PL6_v = UNIT(\underline{U}_{TD} \times UNIT(\underline{R}(T_{IG})))$

IF $\underline{U}_{TD}, \underline{R}(T_{IG})$ COLLINEAR:

$\underline{Y}_{EB(RF)} = MPAC_v = PL6_v = UNIT(\underline{U}_{TD} \times [UNIT(\underline{R}(T_{IG})) + \frac{1}{8} UNIT(\underline{V}(T_{IG}))])$

$\underline{Z}_{EB(RF)} = \underline{X}_{EB(RF)} \times \underline{Y}_{EB(RF)}$

$PL12_v \leftarrow PL0_v \times MPAC_v \times 2^1$

2^1 FACTOR IS FOR SCALING

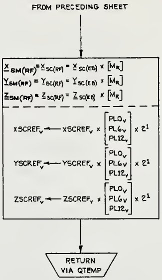
CALCULATE $[M_R] = \begin{bmatrix} \underline{X}_{EB(RF)} \\ \underline{Y}_{EB(RF)} \\ \underline{Z}_{EB(RF)} \end{bmatrix}$ GIVING DESIRED ENGINE BELL COORDINATE AXES IN REFERENCE COORDINATES @ 2^1

NEXT SHEET

A.C. WILLIAMS 4NOV68

P40, P41 - THRUST PROGRAMS

FC 2.30



CALCULATE

$$\begin{bmatrix} X_{SC(RF)} \\ Y_{SC(RF)} \\ Z_{SC(RF)} \end{bmatrix} = [M]^T \times [M_R]$$

GIVING DESIRED SPACECRAFT AXES IN REFERENCE COORDINATES @ 2^1

WHERE 2^1 FACTOR IS FOR SCALING

NOTE: THESE AXES ALSO GIVE THE PREFERRED IMU ALIGNMENT, IN CASE ASTRONAUT CHOOSES TO REALIGN IMU (P52)

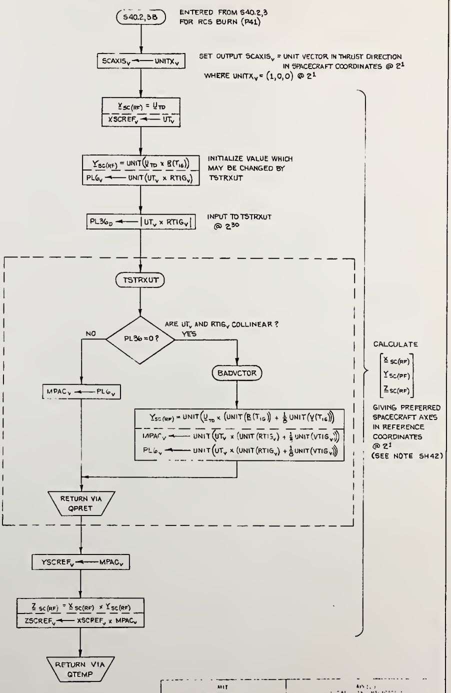
NOTE: THE COMPUTATION ABOVE IS DERIVABLE FROM THE EQUATION:

$$\left[M_{EB(RF)}\right] = \left[M_{EB(SC)}\right] \times \left[M_{SC(RF)}\right]$$

$\left[M_{EB(RF)}\right]$ AND $\left[M_{EB(SC)}\right]$ ARE KNOWN,

$$\text{SO } \left[M_{SC(RF)}\right] = \left[M_{SC(EB)}\right] \times \left[M_{EB(RF)}\right]$$

$$= \left[M_{EB(SC)}\right]^T \times \left[M_{EB(RF)}\right]$$



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S. Zeldin 4/10/69
Peter J Mull 3/11/69
Alexa M. Soranko 3/12/69
John A. Moore 10 MAR 69

P40, P41 - THRUST PROGRAMS

COLOSSUS IID

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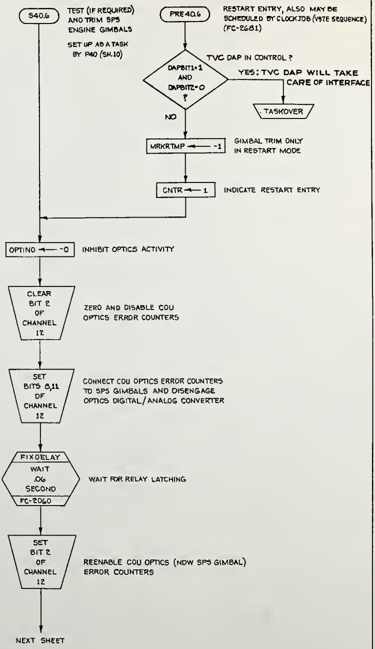

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DOCMR Albert M. Soaut	3/12/69	
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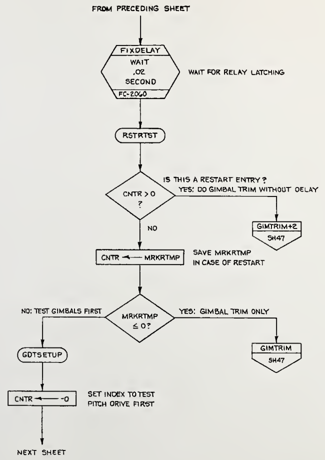

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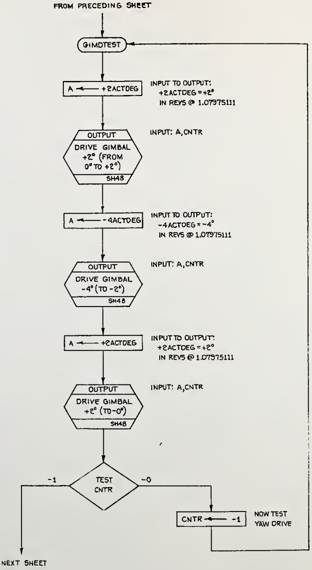

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DOCMR 3/12/69	
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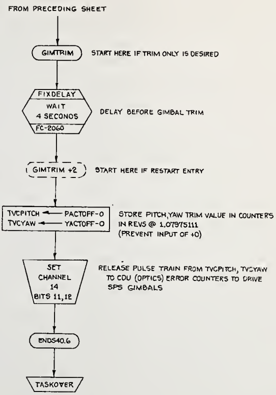

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DOCMR [illegible]
APPR'D [illegible]

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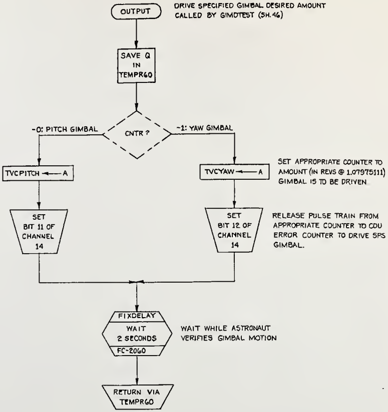
P40, P41 - THRUST PROGRAMS

COLOSSUS [illegible]

DOCUMENT NO. FC-2680

REV 3

SHEET 47



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DOCUMENT NO. FC-2680
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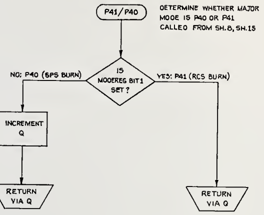
SHEET 48 OF 58



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DPGMR [illegible] 3/10/69
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GUIDANCE AND NAVIGATION

P40, P41 - THRUST PROGRAMS

COLOSSUS IID

DOCUMENT NO FC-2680

REV 3

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 TTOGO, MAINTAIN DISPLAY	SH. 12
INITVEL	2641	CALCULATE VELOCITY AND Δ VELOCITY REQUIRED FOR MANEUVER	SH. 39
MASSPROP	2430	UPDATE MASS PROPERTIES FOR DAPS (& FILTER GAIN VALUES FOR TVC DAP)	SH. 25
MIDGIM	2830	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 ($VGBODY_V$) FOR DISPLAY	SH. 11
RCSDAPON	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
TVCDAPON	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 FLAGWRD5 BIT 8	COMPUTER IS CGC	COMPUTER IS LGC	FRESH START AND RESTART		

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DOCMR [signature] 3/6/69	
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FLAGS (CONTINUED)

NAME					WHERE SET	WHERE CLEARED	WHERE TESTED
DAPBIT1 FLAGWRD6 BIT 15 / DAPBIT2 FLAGWRD6 BIT 14	BOTH SET SATURN DAP IN CONTROL	DAPBIT1=1 DAPBIT2=0 TVC DAP IN CONTROL	DAPBIT1=0 DAPBIT2=1 RCS DAP IN CONTROL	BOTH CLEAR NO DAP CONTROL	SH. 22	SH. 21 SH. 21, 22	SH. 27, 44 SH. 27, 44

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DAPDATR1 BIT 4	ANGULAR DEADBAND IS MAXIMUM	ANGULAR DEADBAND IS MINIMUM	SH. 25	SH. 7	
ENGONFLG 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
PFRATFLG 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		
STRULLSW FLAGWRD6 BIT 13	DO ROUTINE STEERULL (STEERING IS TO BE DONE)	DO ONLY ROUTINE ULAGEOFF (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	

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 IV B CUTOFF COMMANDED	S IV 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

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. XXBXX MIN-SEC TTOGO=TIME FROM TIG 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 R2 XXXX.X FT/SEC R3· XXXX.X FT/SEC $VGBODY_V$ = VELOCITY-TO-BE-GAINED IN CONTROL COORDINATES (X, Y, Z COMPONENTS)	SH. 30

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
ADB		ANGULAR DEADBAND FOR AUTOPILOT	DEGREES	REVS	2^{-1}
$AVEGEXIT_D$		VARIABLE ADDRESS OF EXIT FROM SERVICER (FC#2683)			
BDT_V	$\underline{B}\Delta T$	INTERMEDIATE QUANTITY IN STEERING COMPUTATIONS; EQUAL TO $(\underline{\dot{V}}_R - G)\Delta T$ IN REFERENCE COORDINATES	M/SEC^2	$M/CSEC^2$	2^7
CDUX		OUTER IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-1}
CDUY		INNER IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-1}
CDUZ		MIDDLE IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2^{-1}
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^{16}
$CSTEER_D$	C	CROSS PRODUCT STEERING CONSTANT			2^2
$DELLT4_D$		LENGTH OF TIME TO REACH TARGET	SEC	CSEC	2^{28}
DELPBAR		TVC PITCH OFFSET-TRACKER-FILTER OUTPUT	DEGREES	REVS	1.07975111
$DELVEET3_V$		CHANGE IN VELOCITY REQUIRED FOR A MANEUVER, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
$DELVLVC_V$	$\Delta \underline{V}_{LV}$	VELOCITY-TO-BE-GAINED AT TIME OF IGNITION, IN TIME-OF-IGNITION LOCAL VERTICAL COORDINATES	M/SEC	M/CSEC	2^7

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
$DELVSAB_D$	V_{LV}	MAGNITUDE OF VELOCITY-TO-BE-GAINED AT TIME OF IGNITION	M/SEC	M/CSEC	2^7
$DELVSIN_V$	$\underline{V}$	DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
$DVTOTAL_D$		SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE THE BEGINNING OF THE MANEUVER (FOR DISPLAY)	M/SEC	M/CSEC	2^7
ERRBTMP		TEMPORARY STORAGE FOR ERRORY (BELOW) - USED BY TVC DAP	DEGREES	REVS	2^{-1}
ERRBTMP+1		TEMPORARY STORAGE FOR ERRORZ (BELOW) - USED BY TVC DAP	DEGREES	REVS	2^{-1}
ERRORY		PITCH ATTITUDE ERROR (CONTROL COORDS.) - FROM RCS DAP	DEGREES	REVS	2^{-1}
ERRORZ		YAW ATTITUDE ERROR (CONTROL COORDS.) - FROM RCS DAP	DEGREES	REVS	2^{-1}
F_D	F	NOMINAL THRUST (USED IN CENTRAL ANGLE COMPUTATION)	POUNDS OR NEWTONS	$KG\text{-}M/CSEC^2$	2^7
$GDT1/2_V$	$(1/2)G\Delta T$	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	2^7
MASSTMP		TEMPORARY STORAGE FOR UPDATED CSM VEHICLE MASS	KG	KG	2^{16}
MODREG		MAJOR MODE, OR PROGRAM, NUMBER			
MRKRTMP		USED HERE TO INDICATE TO S40.6 WHETHER ENGINE GIMBALS ARE TO BE TESTED, OR ONLY TRIMMED			
NBRCYCLS	N	USED TO INDICATE WHETHER S40.9 IS TO BEGIN ANEW, AND IF NOT, THE NUMBER OF 2-SECOND CYCLES SINCE S40.9 WAS LAST STARTED			2^{14}
$NOMTIG_D$		NOMINAL TIME OF IGNITION (ACTUAL TIME OF IGNITION MAY BE CHANGED)	SEC	CSEC	2^{28}
NVWORD1		USED TO INDICATE TO CLOKTASK 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^{-1}
OPTIND		INDICATES WHAT, IF ANY, OPTICS ACTIVITY IS TO BE ALLOWED			
PACTOFF		PITCH OFFSET ANGLE	DEGREES	REVS	1.07975111
PHASE5		INDICATES WHETHER CERTAIN ROUTINES ARE TO BE RESTARTED AND, IF SO, AT WHAT POINT			
$PIPTIME1_D$		TIME CORRESPONDING TO SOME UPDATED STATE VECTOR	SECS	CSECS	2^{28}

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$POINTVCSM_V$	$\underline{U}_D$	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			2^1
$RATT_V$	R(T)	POSITION VECTOR, IN REFERENCE COORDINATES, COMPUTED BY INTEGRATION ROUTINE FOR A SPECIFIED TIME	M	M	2^{29}
$REFSMMAT_M$	[REFSMMAT]	TRANSFORMATION MATRIX FOR CONVERSION BETWEEN REFERENCE AND STABLE MEMBER COORDINATE SYSTEMS			2^1
$RINIT_V$		POSITION VECTOR AT A SPECIFIED TIME, IN REFERENCE COORDINATES	M	M	2^{29}
$RTARG_V$	$\underline{R}(T_2)$	AIMPOINT POSITION VECTOR, IN REFERENCE COORDINATES	M	M	2^{29}
$RTIG_V$	$\underline{R}(T_{IG})$	POSITION VECTOR AT TIME OF IGNITION, IN REFERENCE COORDINATES	M	M	2^{29}
RTX1		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			
$SCAXIS_V$		UNIT VECTOR (IN THIS CASE, IN DIRECTION OF THRUST) IN SPACECRAFT COORDINATES, TO BE ALIGNED WITH ANOTHER VECTOR			2^1
$TDEC1_D$	T	SPECIFIED TIME CORRESPONDING TO STATE VECTOR TO BE COMPUTED	SECS	CSECS	2^{28}
$TEVENT_D$		ACTUAL TIME OF RELEVANT EVENT, FOR DOWNLINK	SECS	CSECS	2^{28}
TGO_D	T_{GO}	TIME UNTIL ENGINE CUTOFF (IF KNOWN)	SECS	CSECS	2^{28}
THETADX		SNAPSHOT OF OUTER IMU GIMBAL ANGLE	DEGREES	REVS	2^{-1}
THETADY		SNAPSHOT OF INNER IMU GIMBAL ANGLE	DEGREES	REVS	2^{-1}

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
THETADZ		SNAPSHOT OF MIDDLE IMU GIMBAL ANGLE	DEGREES	REVS	2^{-1}
TIG_D	T_{IG}	TIME OF IGNITION OR OF CUTOFF, WHICHEVER IS RELEVANT	SECS	CSECS	2^{28}
TIME1		LOW-ORDER HALF OF $TIME2_D$=CURRENT TIME	SECS	CSECS	2^{28}
$TIME2_D$		CURRENT TIME	SECS	CSECS	2^{28}
$TPASS4_D$	T_2	TIME OF ARRIVAL AT TARGET	SECS	CSECS	2^{28}
TVCEXPHS		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_V	$\underline{U}_{TD}$	UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST, IN REFERENCE COORDINATES			2^1
$VATT_V$	V(T)	VELOCITY VECTOR, IN REFERENCE COORDINATES, COMPUTED BY INTEGRATION ROUTINE FOR A SPECIFIED TIME	M/SEC	M/CSEC	2^7
$VGBODY_V$		VELOCITY-TO-BE-GAINED IN CONTROL COORDINATES	M/SEC	M/CSEC	2^7
$VGDISP_D$		MAGNITUDE OF VELOCITY-TO-BE-GAINED (FOR DISPLAY)	M/SEC	M/CSEC	2^7
$VGPREV_V$	$\underline{V}_G$	LAST COMPUTED VELOCITY-TO-BE-GAINED, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
$VGTIG_V$	$\underline{V}_G(T_{IG})$	VELOCITY-TO-BE-GAINED AT TIME OF IGNITION, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
$VINIT_V$		VELOCITY VECTOR AT A SPECIFIED TIME, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$VIPRIME_V$	$\underline{V}_R$	VELOCITY REQUIRED AT BEGINNING OF A MANEUVER, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
$VTIG_V$	$\underline{V}(T_{IG})$	VELOCITY VECTOR AT TIME OF IGNITION, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
V97VCNTR		USED BY TVC DAP TO COUNT NUMBER OF HALF-SECOND INTERVALS			2^{14}
$WEIGHT/G_D$	M	MASS OF VEHICLE (INCLUDING LM IF APPROPRIATE)	KG	KG	2^{16}
$XSCREF_V$	$\underline{X}_{SC(RF)}$	SPACECRAFT X AXIS IN REFERENCE COORDINATES			2^1
YACTOFF		YAW OFFSET ANGLE	DEGREES	REVS	1.07975111
$YSCREF_V$	$\underline{Y}_{SC(RF)}$	SPACECRAFT Y AXIS IN REFERENCE COORDINATES			2^1
$ZSCREF_V$	$\underline{Z}_{SC(RF)}$	SPACECRAFT Z AXIS IN REFERENCE COORDINATES			2^1

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$EP4(10)H_D$	10^o	POSSIBLE VALUE FOR MINIMUM ANGLE BETWEEN INITIAL AND FINAL POSITION VECTORS SUFFICIENT TO DEFINE A PLANE OF FLIGHT	10 DEGREES	.027777777 REV	2^0
$EP4(45)H_D$	45^o	POSSIBLE VALUE FOR MINIMUM ANGLE BETWEEN INITIAL AND FINAL POSITION VECTORS SUFFICIENT TO DEFINE A PLANE OF FLIGHT	45 DEGREES	.125 REV	2^0
$FENG_D$	F_{SPS}	SPS ENGINE THRUST (USED IN CENTRAL ANGLE COMPUTATION FOR P40)	20500 LBS	9.1188544 $KG\text{-}M/CSEC^2$	2^7
$FRCS2_D$	F_{RCS}	RCS THRUST FOR 2 JETS (USED IN CENTRAL ANGLE COMPUTATION FOR P41)	199.6 (COS 10) LBS	.087437837 $KG\text{-}M/CSEC^2$	2^7
MAXDB		MAXIMUM VALUE FOR ANGULAR DEADBAND (FOR AUTOPILOT)	4 998779 DEGREES	455×2^{-15} REVS	2^{-1}
MINDB		MINIMUM VALUE FOR ANGULAR DEADBAND (FOR AUTOPILOT)	.505371 DEGREES	46×2^{-15} REVS	2^{-1}

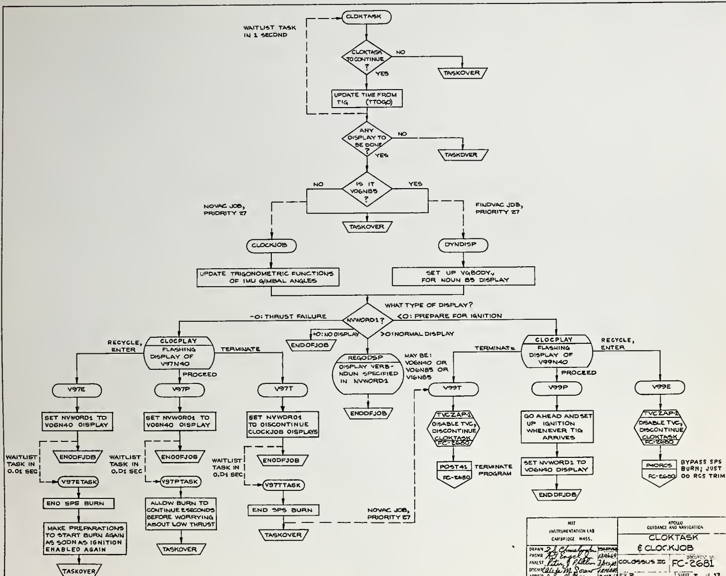
PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$PBIAS_D$	P_O	BIAS IN PITCH OFFSET ANGLE	-2.15 DEGREES	-.0059722222 REV	2^0
$S40.135_D$	$7.98F_L$	IMPULSE OF ULLAGE THRUST DUE TO 2-JET BURN FOR 7.98 SECONDS	1588.818 LB-SEC	89.6005183 KG-M/CSEC	2^{23}
$TRIMSCAL_D$		SCALING FACTOR FOR SPS ENGINE GIMBAL OFFSET ANGLES	1.07975111	1.07975111	2^1
$YBIAS_D$	Y_O	BIAS IN YAW OFFSET ANGLE	+0.95 DEGREES	+.00263888889 REV	2^0
+2ACTDEG		AMOUNT OF ROTATION USED IN TESTING ENGINE GIMBALS	+1.9928 DEGS	+.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	2^2	10000
EMDOT	$\dot{M}$	RATE OF MASS DECREASE DURING SPS BURN			2^3	
$K1VAL_D$ (=$EK1VAL_D$)	K_1	1-SECOND SPS IMPULSE	LB-SEC	KG-M/CSEC	2^{23}	
$FANG_D$	F_{IMP}	EFFECTIVE THRUST DURING 1-6 SECOND INTERVAL OF BURN (USED IN IMPULSIVE BURN TIME COMPUTATIONS)	POUNDS OR NEWTONS	KG-M/CSEC^2	2^7	
$K2VAL_D$ (=$EK2VAL_D$)	K_2	-SPS MINIMUM IMPULSE	LB-SEC	KG-M/CSEC	2^{23}	
K3VAL (=EK3VAL)	K_3	EFFECTIVE THRUST DURING 0-1 SECOND INTERVAL OF BURN (USED IN IMPULSIVE BURN TIME COMPUTATIONS)	LB-SEC/SEC	KG-M/CSEC^2	2^9	

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	TURNS OFF SPS ENGINE, SETS UP RE-IGNITION (FROM ENTER RESPONSE TO V97 FLASH)	SH. 11



CLOKTASK
WAITLIST TASK IN 1 SECOND
CLOKTASK TO CONTINUE ?
NO
YES
TASKOVER
UPDATE TIME FROM TIG (TTOGO)
ANY DISPLAY TO BE DONE ?
NO
YES
TASKOVER
IS IT V06N85 ?
NO
YES
NOVAC JOB, PRIORITY 27
FINDVAC JOB, PRIORITY 27
TASKOVER
CLOCKJOB
DYNDISP
UPDATE TRIGONOMETRIC FUNCTIONS OF IMU GIMBAL ANGLES
SET UP VGBODY, FOR NOUN 85 DISPLAY
WHAT TYPE OF DISPLAY?
NVWORD1 ?
-0: THRUST FAILURE
<0: PREPARE FOR IGNITION
+0: NO DISPLAY
>0: NORMAL DISPLAY
ENDOFJOB
CLOCPLAY FLASHING DISPLAY OF V97N40
RECYCLE, ENTER
PROCEED
TERMINATE
REGODSP DISPLAY VERB-NOUN SPECIFIED IN NVWORD1
MAY BE: V06N40 OR V06N85 OR V16N85
ENDOFJOB
CLOCPLAY FLASHING DISPLAY OF V99N40
TERMINATE
RECYCLE, ENTER
PROCEED
V97E
V97P
V97T
SET NVWORD1 TO V06N40 DISPLAY
SET NVWORD1 TO V06N40 DISPLAY
SET NVWORD1 TO DISCONTINUE CLOCKJOB DISPLAYS
WAITLIST TASK IN 0.01 SEC
WAITLIST TASK IN 0.01 SEC
WAITLIST TASK IN 0.01 SEC
ENDOFJOB
ENDOFJOB
ENDOFJOB
V97ETASK
V97PTASK
V97TTASK
END SPS BURN
ALLOW BURN TO CONTINUE 2 SECONDS BEFORE WORRYING ABOUT LOW THRUST
END SPS BURN
MAKE PREPARATIONS TO START BURN AGAIN AS SOON AS IGNITION ENABLED AGAIN
TASKOVER
TASKOVER
TASKOVER
NOVAC JOB, PRIORITY 27
V99T
V99P
V99E
TVCZAP-1 DISABLE TVC, DISCONTINUE CLOKTASK FC-2680
GO AHEAD AND SET UP IGNITION WHENEVER TIG ARRIVES
TVCZAP-1 DISABLE TVC, DISCONTINUE CLOKTASK FC-2680
POST41 FC-2680
TERMINATE PROGRAM
SET NVWORD1 TO V06N40 DISPLAY
P40RCS FC-2680
BYPASS SPS BURN; JUST DO RCS TRIM
ENDOFJOB
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APOLLO GUIDANCE AND NAVIGATION
CLOKTASK & CLOCKJOB
COLOSSUS IIC
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REV 2
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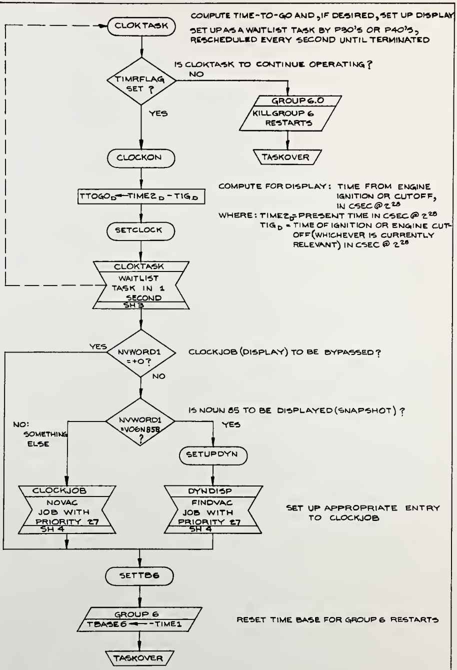

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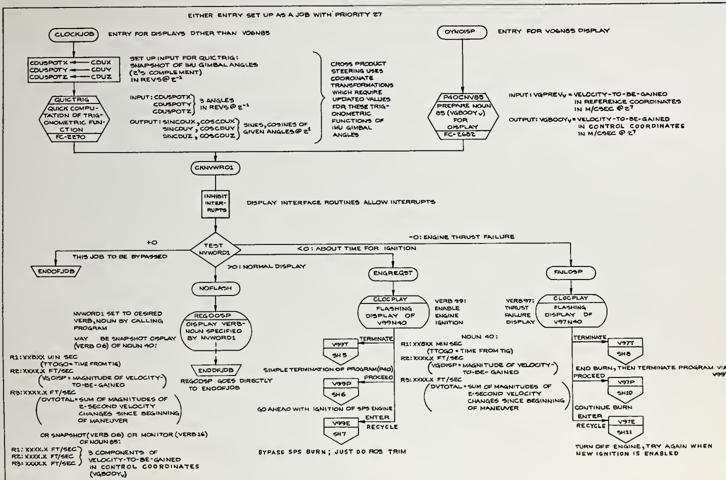

CLOKTASK
& CLOCKJOB

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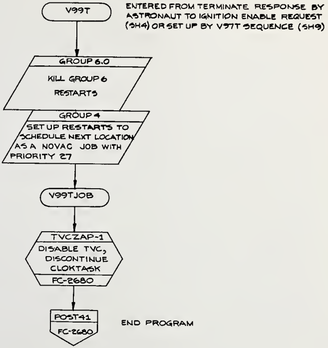

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CLOKTASK & CLOCKJOB

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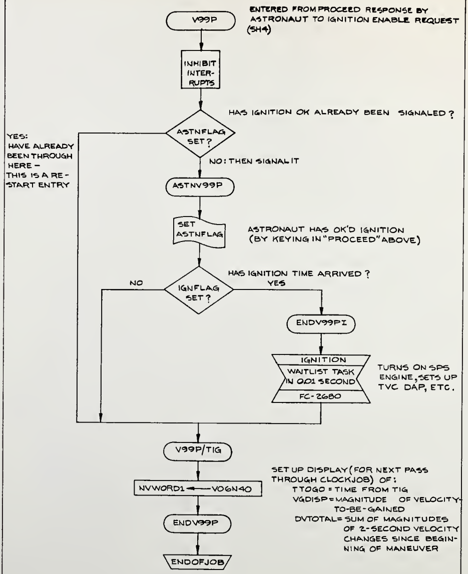

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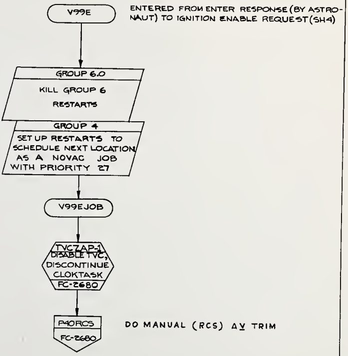

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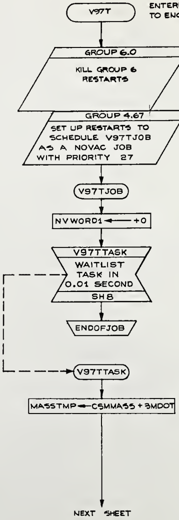

ENTERED FROM TERMINATE RESPONSE (BY ASTRONAUT) TO ENGINE FAILURE DISPLAY (SH4)

DISCONTINUE CLOCKJOB

SET UP INPUT TO SPSOFF:
VEHICLE MASS IN KG @ 2^{16}
WHERE: CSMMASS = LAST VALUE FOR VEHICLE MASS IN KG @ 2^{16}
3MDOT = $\dot{M}$ × 3 SECONDS
= 3-SECOND MASS LOSS NOT ALREADY ACCOUNTED FOR (BECAUSE OF ENGINE FAILURE)
= 86.8175796 KG @ 2^{16}
NOTE:
3 SECONDS IS AVERAGE OF 2-4 SECOND LOW-THRUST DETECTION PERIOD

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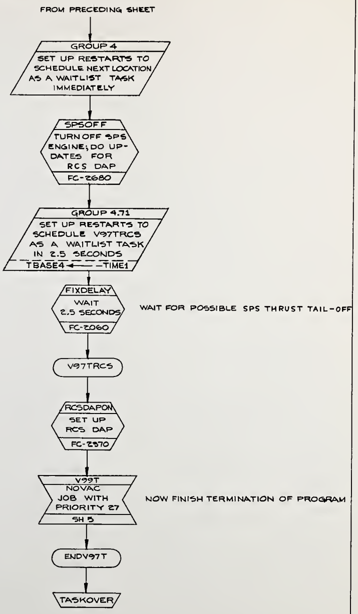
DOCMR [signature] 12 FEB 69	
APPR'D [signature] 13 FEB 69	REV 2 — SHEET 8 OF 17



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APOLLO GUIDANCE AND NAVIGATION

CLOKTASK & CLOCKJOB

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PRGMR	[signature]	13Feb69
ANALYST	[signature]	Feb 12, 69
DOCMR	[signature]	12FEB69
APPR	[signature]	13FEB69

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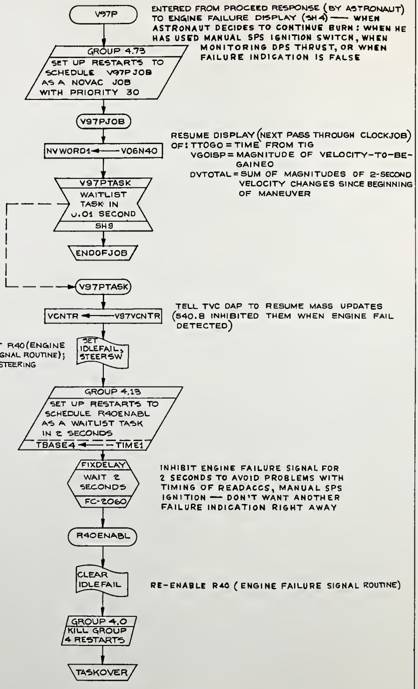
REV 2

SH 9 OF 17



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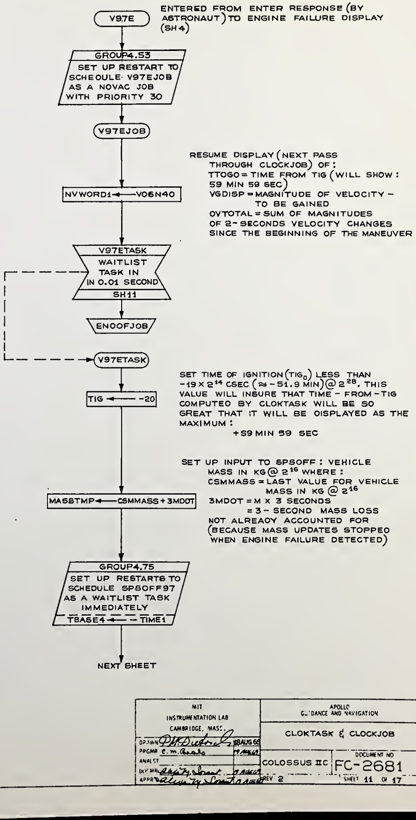

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APOLLO GUIDANCE AND NAVIGATION

CLOKTASK & CLOCKJOB

COLOSSUS IIC

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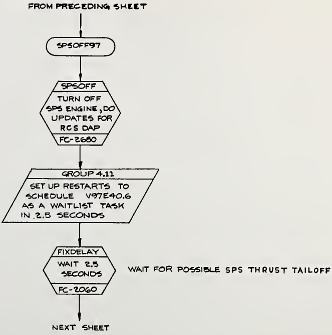

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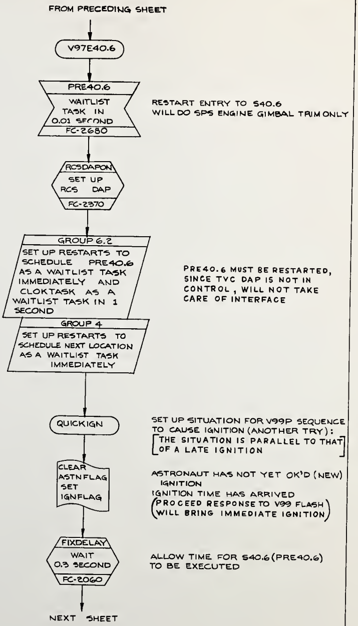

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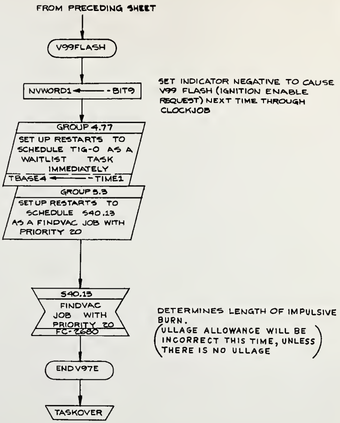
APPR'D 13FEB69	REV 2 — SHEET 13 OF 17



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 18 NOV 68	CLOKTASK & CLOCKJOB
PRGMR [signature] 13 Feb 69	
ANALST [signature] Feb 17 69	COLOSSUS IIC — DOCUMENT NO FC-2681
DOCMR [signature] 20 FEB 69	
APPR'D [signature] 19 FEB 69	REV 2 — SHEET 14 OF 17

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
RCSDAPON	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		
TIMRFLAG FLAGWRD7 BIT 11	CLOKTASK TO CONTINUE	CLOKTASK NOT TO RUN			SH.3

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 30 OCT 68	CLOKTASK & CLOCKJOB
PRGMR [signature] 13 JAN 69	
ANALYST [signature] 2/11/69	COLOSSUS IIC FC-2681
DOCMR [signature]	
APPR'D [signature] 3 FEB 69	REV 2 SHEET 15 OF 17

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N40	NORMAL	R1 XXBXX MIN-SEC TTOGO = TIME FROM TIG R2 XXXX.X FT/SEC VGDISP = MAGNITUDE OF VELOCITY-TO-BE-GAINED R3: XXXX.X FT/SEC DVTOTAL = SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE BEGINNING OF MANEUVER	SH. 4
V06N85	NORMAL	R1: XXXX.X FT/SEC R2: XXXX.X FT/SEC R3: XXXX.X FT/SEC 3 COMPONENTS OF $VGBODY_V$ = VELOCITY-TO-BE GAINED IN CONTROL COORDINATES	SH. 4
V16N85	MONITOR	SAME AS ABOVE	SH. 4
V99N40	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^{-1}
CDUSPOTY		SECOND ANGLE INPUT TO QUICTRIG — IN 2'S COMPLEMENT	DEGREES	REVS	2^{-1}
CDUSPOTZ		THIRD ANGLE INPUT TO QUICTRIG — IN 2'S COMPLEMENT	DEGREES	REVS	2^{-1}
CDUX		OUTER IMU GIMBAL ANGLE IN 2'S COMPLEMENT	DEGREES	REVS	2^{-1}
CDUY		INNER IMU GIMBAL ANGLE IN 2'S COMPLEMENT	DEGREES	REVS	2^{-1}
CDUZ		MIDDLE IMU GIMBAL ANGLE IN 2'S COMPLEMENT	DEGREES	REVS	2^{-1}
COSCDUX		COSINE OF FIRST ANGLE INPUT TO QUICTRIG			2^{1}
COSCDUY		COSINE OF SECOND ANGLE INPUT TO QUICTRIG			2^{1}
COSCDUZ		COSINE OF THIRD ANGLE INPUT TO QUICTRIG			2^{1}
CSMMASS		MASS OF CSM	KG	KG	2^{16}
DVTOTAL		SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE BEGINNING OF MANEUVER	M/SEC	M/CSEC	2^{16}
MASSTMP		TEMPORARY UPDATED VERSION OF CSMMASS (ABOVE)	KG	KG	2^{16}

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
NVWORD1		INDICATES WHETHER ANY DISPLAY IS TO BE SET UP BY CLOCKJOB AND, IF SO, WHICH ONE			
SINCDUX		SINE OF FIRST ANGLE INPUT TO QUICTRIG			2^1
SINCDUY		SINE OF SECOND ANGLE INPUT TO QUICTRIG			2^1
SINCDUZ		SINE OF THIRD ANGLE INPUT TO QUICTRIG			2^1
TBASE6		LOW ORDER HALF OF TIME FROM WHICH GROUP 6 WAITLIST TASK RESTART ΔT'S ARE MEASURED	SEC	CSEC	2^{14}
TIG_D	T_{IG}	TIME OF ENGINE IGNITION OR CUTOFF, WHICHEVER IS CURRENTLY RELEVANT	SEC	CSEC	2^{28}
$TIME2_D = \begin{pmatrix} TIME2, \\ TIME1 \end{pmatrix}$		PRESENT TIME	SEC	CSEC	2^{28}
$TTOGO_D$		TIME FROM TIG (ABOVE)	SEC	CSEC	2^{28}
$VGBODY_V$		VELOCITY-TO-BE-GAINED IN CONTROL COORDINATES (DISPLAYED AS NOUN 85)	M/SEC	M/CSEC	2^7
$VGDISP_D$		MAGNITUDE OF VELOCITY-TO-BE-GAINED (DISPLAYED AS PART OF NOUN 40)	M/SEC	M/CSEC	2^7
$VGPREV_V$	$\underline{V}_G$	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
3MDOT	$\dot{M}$ x 3 SEC	3-SECOND MASS LOSS DUE TO SPS BURN	86.8175796 KG	86.8175796 KG	2^{16}

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. 12
QUIKREAD:	Takes Quick Accelerometer Readings for Downlink Telemetry	Sh. 15
SERVICER:	Checks Δ Velocity Values Read In, Does Permanent State Vector Update Using Sensed Δ 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

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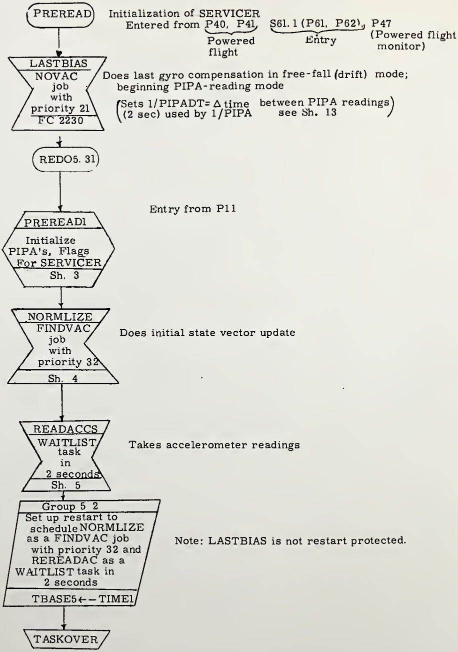
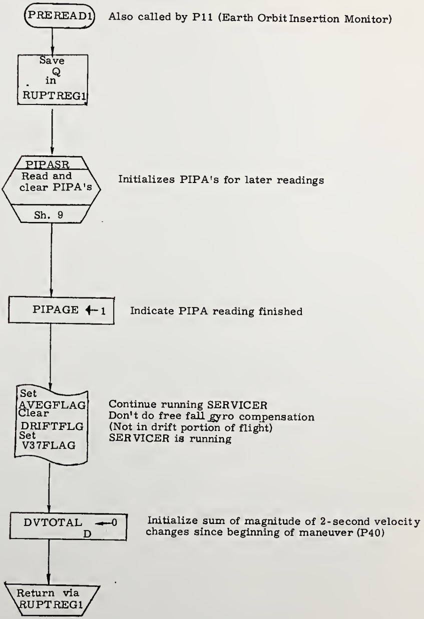
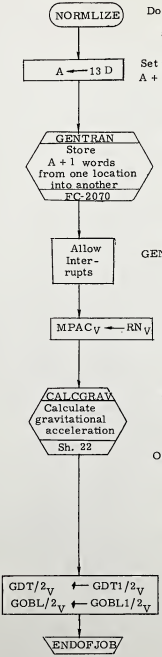
RAWN R. Welch	5/22/69	SERVICER	
PRGMR			
ANALST Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D [illegible]	11/11/69	REV 1	SHEET 1 OF 37



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	5/27/66	SERVICER	
PRGMR			
ANALST Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D [signature]	11/11/69	REV 1	SHEET 2 OF 37


PREREAD1
Also called by P11 (Earth Orbit Insertion Monitor)
Save Q in RUPTREG1
PIPASR
Read and clear PIPA's
Sh. 9
Initializes PIPA's for later readings
PIPAGE ← 1
Indicate PIPA reading finished
Set AVEGFLAG
Clear DRIFTFLG
Set V37FLAG
Continue running SERVICER
Don't do free fall gyro compensation
(Not in drift portion of flight)
SERVICER is running
DVTOTAL D ← 0
Initialize sum of magnitude of 2-second velocity changes since beginning of maneuver (P40)
Return via RUPTREG1



Do initial state-vector update
set up by PREREAD with priority 32;
also called by P11

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: $RN_V \leftarrow RN1_V$

$VN_V \leftarrow VN1_V$

$PIPTIME_D \leftarrow PIPTIME1_D$

(Update powered flight permanent state vector)

GENTRAN inhibits interrupts

Set up input to CALCGRAV

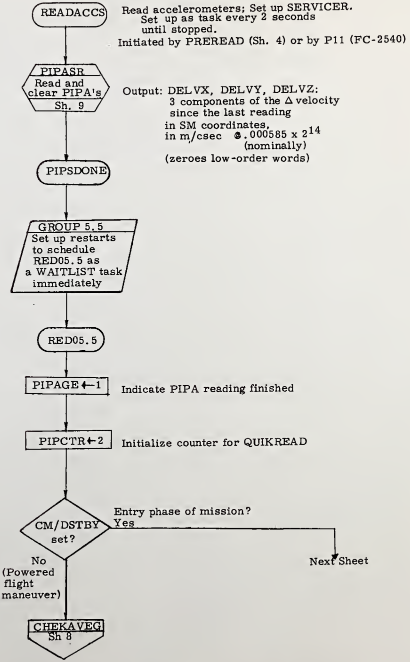
Input: $MPAC_V$= Position vector in reference coordinates in M ⊛ 2^{29}

RTX2 Indicates whether in earth or moon sphere of influence, by value of 0 or 2 respectively

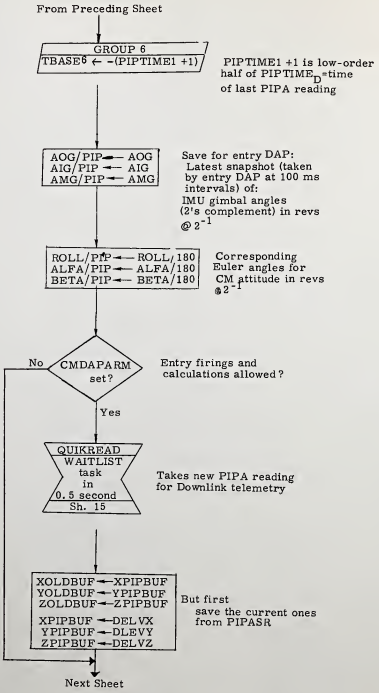
Output: $MPAC_V$ = $GDT1/2_V$ = One-half the velocity change due to gravitational acceleration at the specified position over a two-second interval, in reference coordinates in m/csec ⊛ 2^7

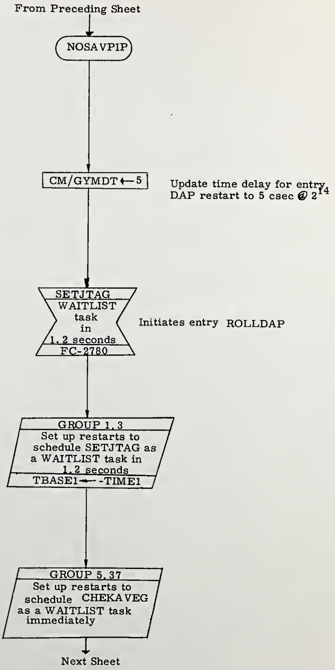
And if in earth's sphere of influence:
$GOBL1/2_V$= correction term for gravitational anomaly due to earth oblateness ⊛ 2^1

Store new values from CALCGRAV

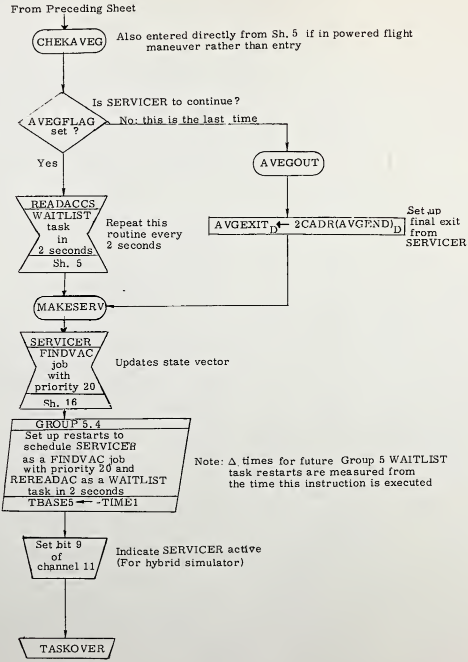


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN B. Welch	8/27/69	SERVICER	
PRGMR			
ANALST Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D Roberta M. Eustis	11/11/69	REV 1 1	SHEET 5 OF 37

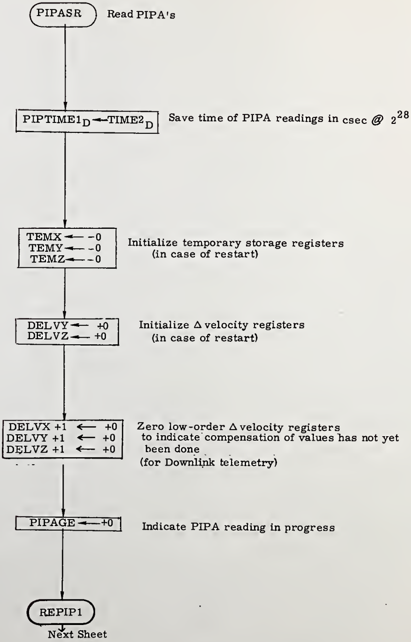

From Preceding Sheet
GROUP 6
TBASE6 ← −(PIPTIME1 +1)
PIPTIME1 +1 is low-order half of PIPTIME$_D$=time of last PIPA reading
AOG/PIP ← AOG
AIG/PIP ← AIG
AMG/PIP ← AMG
Save for entry DAP: Latest snapshot (taken by entry DAP at 100 ms intervals) of: IMU gimbal angles (2's complement) in revs @ 2^{-1}
ROLL/PIP ← ROLL/180
ALFA/PIP ← ALFA/180
BETA/PIP ← BETA/180
Corresponding Euler angles for CM attitude in revs @ 2^{-1}
CMDAPARM set?
No
Yes
Entry firings and calculations allowed?
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	
DRAWN	C. Welch	8/7/69	SERVICER	
PRGMR				
ANALST	Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR				
APPR'D	Robert M. Estes	11/11/69	REV 1	SHEET 7 OF 37



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	[illegible]	SERVICER	
PRGMR			
ANALST Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D [signature]	11/11/69	REV 1	SHEET 8 OF 37


PIPASR
Read PIPA's
PIPTIME1$_D$ ← TIME2$_D$
Save time of PIPA readings in csec @ 2^{28}
TEMX ← -0
TEMY ← -0
TEMZ ← -0
Initialize temporary storage registers
(in case of restart)
DELVY ← +0
DELVZ ← +0
Initialize Δ velocity registers
(in case of restart)
DELVX +1 ← +0
DELVY +1 ← +0
DELVZ +1 ← +0
Zero low-order Δ velocity registers
to indicate compensation of values has not yet
been done
(for Downlink telemetry)
PIPAGE ← +0
Indicate PIPA reading in progress
REPIP1
Next Sheet

From Preceding Sheet

TEMX ←-PIPAX
TEMY ←-PIPAY

Temporary storage of X and Y PIPA readings

Set DELV$_V$ [=(DELVX$_D$, DELVY$_D$, DELVZ$_D$] =ΔV
=Change in velocity since last reading in stable member coordinates in m/csec @.000585 x 2^{14} (Nominally)

Where:

PIPAX=X-component of $\Delta\underline{V}$
$= \int_{t-2}^{t \text{ secs}} A_x dt$
Where t=2

PIPAY=Y-component of $\Delta\underline{V}$
$\int_{t-2}^{t \text{ secs}} A_y dt$
Where t=2

PIPAZ=Z-component of $\Delta\underline{V}$
$\int_{t-2}^{t \text{ secs}} A_z dt$
Where t=2

All in SM coordinates in m/csec @.000585 x 2^{14} (Nominally)

DELVX←PIPAX
DELVY←PIPAY

Final storage of X and Y PIPA readings

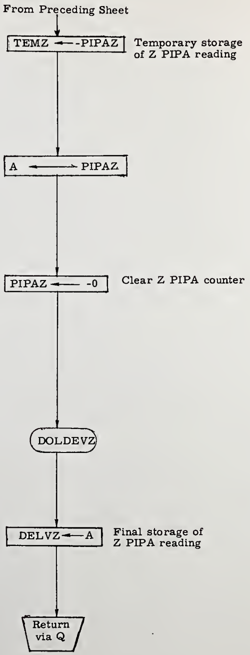
PIPAX ← -0
PIPAY ← -0

Clear X and Y PIPA counters

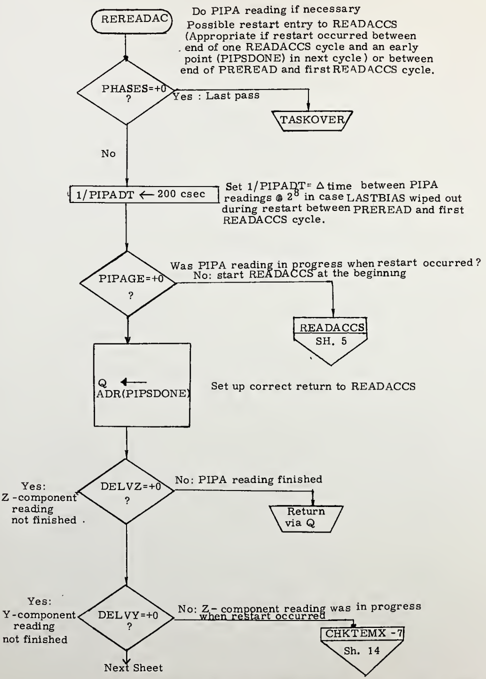
Note: Scaling of $\Delta\underline{V}$ increments, as measured by PIPA's, is inaccurate due to bias and scale factor errors in the hardware. These errors are compensated for (making scale factor accurate and removing bias) in 1/PIPA (See Sh. 17)

REPIP3

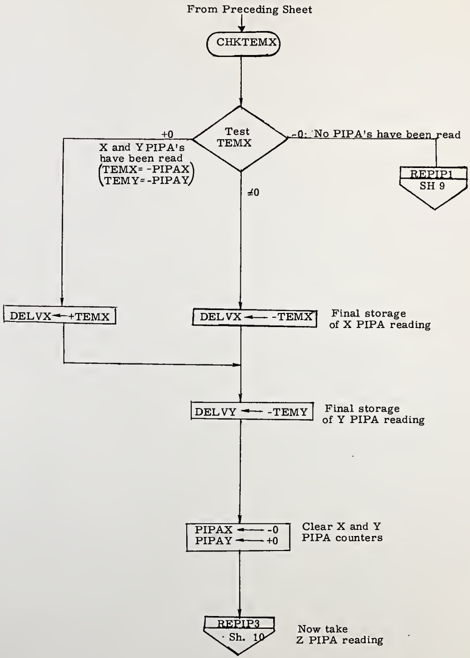
Next Sheet



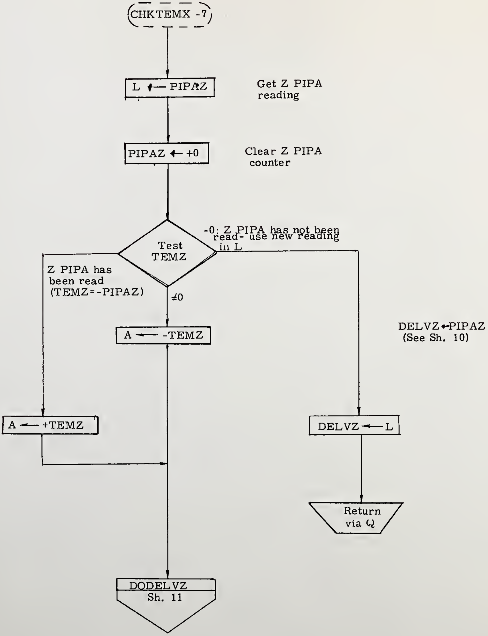
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Welch	8/23/69	SERVICER	
PRGMR			
ANALST Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D Roberta M. Eaton	11/11/69	REV 1	SHEET 11 OF 37



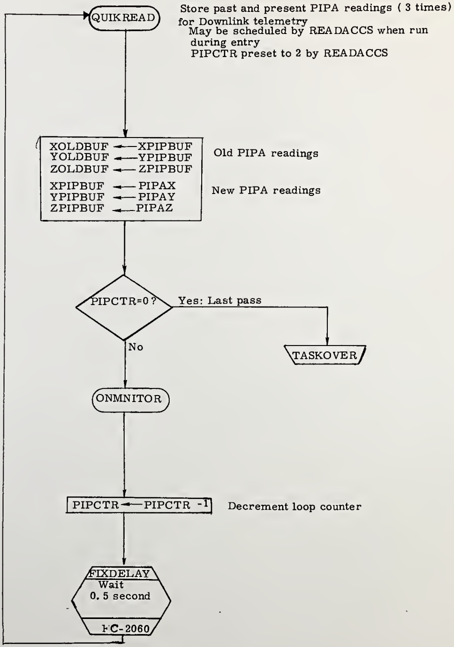
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	5/21/69	SERVICER	
PRGMR			
ANALST Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D [signature]	12/1/69	REV 1	SHEET 12 OF 37



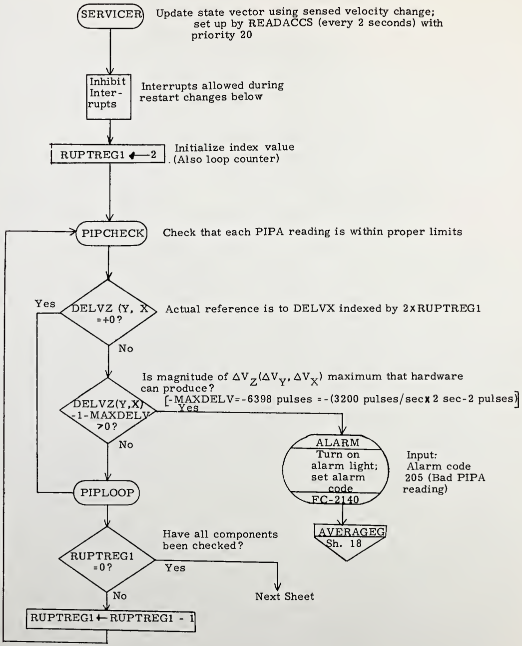
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Welch	8/20/69	SERVICER	
PRGMR			
ANALST Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D Robert M. Estes	11/11/69	REV 1	SHEET 13 OF 37



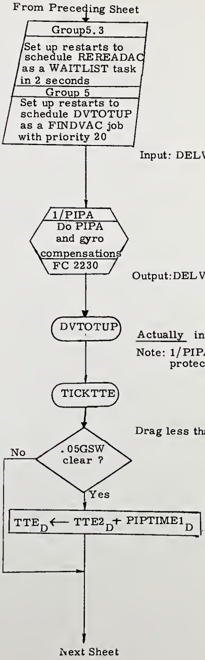
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Welch	8/20/69	SERVICER	
PRGMR			
ANALST Al Engel	11/10/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D Robert M. Eaton	11/11/69	REV 1	SHEET 14 OF 37



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN R. Welch 8/27/69	SERVICER
PRGMR	
ANALST Al Engel 11/10/69	COLOSSUS 2D / DOCUMENT NO. FC-2683
DOCMR	
APPR'D Roberta M Ester 11/11/69	REV 1 / SHEET 15 OF 37



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. Welch	5/21/69	SERVICER	
PRGMR			
ANALST Al Engel	8/14/69	COLOSSUS 2D	DOCUMENT NO. FC-2683
DOCMR			
APPR'D Robert M. Ester	11/11/69	REV 1	SHEET 16 OF 37



Input: DELVX, DELVY, DELVZ= 3 components of Δ velocity as read from PIPA's in SM coordinates

Nominally in m/csec @ $.000585 \times 2^{14}$

1/PIPADT = Δ 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 ($\Delta \underline{V}$) 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}

From Preceding Sheet

$DVTOTAL_D \leftarrow DVTOTAL_D + KPIP1 \times |DELV_V|$

Update $DVTOTAL_D$ = sum of the magnitudes of 2-second velocity changes since beginning of the maneuver in m/csec @ 2^7
Where KPIP1 = $.000585 \times 2^7$ scaling factor for $DELV_V$

(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: $DELV_V$ = 2-second velocity change in SM coordinates in m/csec @ $.000585 \times 2^{14}$

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 change in velocity due to gravitational acceleration at RN_V over an interval of 2-secs. in reference coordinates, in m/csec @ 2^7

RTX2 - Indicates whether in earth or moon sphere of influence, by value of 0 or 2, respectively

Output: $DELVREF_V$ = Sensed velocity change in reference coordinates in m/csec @ 2^7

$RN1_V$ = Updated position vector in reference coordinates in m @ 2^{29}

$VN1_V$ = Updated velocity vector in reference coordinates in m/csec @ 2^7

$GDT1/2_V$ = 1/2 the change in velocity due to gravitational acceleration at $RN1_V$ over an interval of 2 secs in reference coordinates, in m/csec @ 2^7

And if in earth's sphere of influence:

$GOBL1/2_V$ = Gravitational anomaly due to earth oblateness @ 2^1

CALCRVG
Update state vector
Sh. 20

Next Sheet

From Preceding Sheet

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

A ← 25D

Set parameter for GENTRAN:
A + 1 = number of words to be moved

GENTRAN
Store A + 1 words from one location to another
FC-2070

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

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

Location specified in $AVGEXIT_D$

$AVGEXIT_D$ 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

CALCRVG — Update state vector

Convert $\Delta \underline{V}$ sensed into reference coordinates in m/csec @ 2^7

$\Delta \underline{V}_{REF} = \Delta \underline{V}_{SM}$ [REFSMMAT]

$DELVREF_V \leftarrow KPIP1 \times DELV_V \times REFSMMAT_M \times 2^1$

Where: $DELV_V = \Delta V$ in SM coordinates in m/csec @ $.000585 \times 2^{14}$

$KPIP1 = .000585 \times 2^7$ (for scaling $DELV_V$)

$REFSMMAT_M$ = 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: $1/2\ \Delta \underline{V}$ (in reference coords, in m/csec @ 2^7

$PL6_V \leftarrow GDT/2_V + DELVREF_V$

in reference coords $1/2\ \underline{G}\ (T)\Delta T + 1/2 \Delta \underline{V}$ in m/csec @ 2^7

Compute new position vector in reference coords, in m @ 2^{29}

$\underline{R}\ (T+\Delta T) = \underline{R}\ (T) + \Delta T\ \underline{V}\ (T) + \underline{G}\ (T)\ \Delta T/2 + \Delta V/2$

$MPAC_V \leftarrow RN_V + 2SEC(22)_D\ [VN_V + GDT/2_V + \tfrac{1}{2}\ DELVREF_V]$

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 gravitational acceleration at RN_V over a 2-second interval in reference coordinates in m/csec @ 2^7

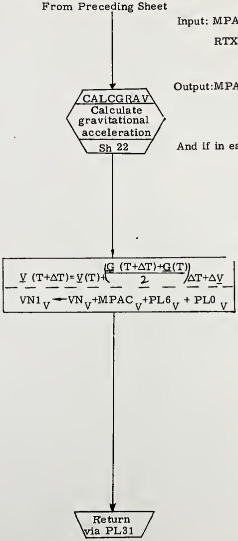
$2SEC(22)_D$ = 200 csec @ 2^{22}

Save QPRET in PL 31

$RN1_V \leftarrow MPAC_V$

Save new position vector

Next Sheet



Input: MPAC V = Position vector in reference coordinates in m @2^{29}

RTX2 - Indicates whether in earth or moon sphere of influence, by value of 0 or 2, respectively

Output: MPAC V = GDT1/2 V = 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^{7}

And if in earth's sphere of influence:

GOBL1/2 V = Gravitational anomaly due to earth oblateness @2^{1}

Compute new velocity vector in reference coords, in m/csec @2^{1}

Where: VN V =Old velocity vector in reference coordinates in m/csec @2^{7}

PL6 V, PL0 V } Intermediate results saved above

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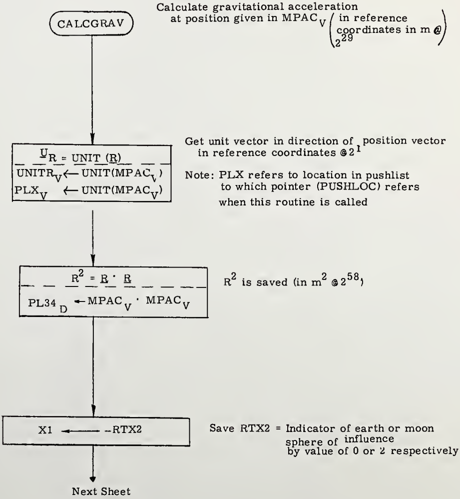

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From Preceding Sheet

X1 = 0 ?

In earth's sphere of influence ?

Yes : must make correction for earth oblateness

No: Moon

$\cos\phi = \underline{U}_R \cdot \underline{U}_Z$

$PLX_D \leftarrow PLX_V \cdot UNITW_V$

Compute cos ϕ at 2^1
Where: ϕ = angle between position vector and earth polar axis
$UNITW_V = \underline{U}_Z$ = Unit vector in direction of $\underline{Z}$ = Earth rotation vector (Polar axis) in reference coordinates @ 2^0

$\frac{R^2}{4 R_E} \underline{G}_B = 3/2\ J_{2E}\ (R_E/R)^2 \left[(1-5\ \cos^2\phi)\ \underline{U}_R + 2\ \cos\phi\ \underline{U}_Z\right]$

$GOBL1/2_V \leftarrow 20J_D \frac{RESQ_D}{PL34_D} (DP1/20_D - PLX_D^2)\ UNITR_V + 2J_D \frac{RESQ_D}{PL34_D} PLX_D\ UNITW_V$

Compute gravitational anomaly due to earth oblateness @ 2^1 (Reference coords.)
Where: $20J_D = 20 \times 3/2\ J_{2E}$ @ 2^{-1}
Where $J_{2E} = .10823067 \times 10^{-2}$
= 2nd harmonic of earth's potential function
$2J_D = 2 \times 3/2\ J_{2E}$ @ 2^{-1}
$RESQ_D = R_E^2$ = Square of equatorial radius of the earth = $40.6809913 \times 10^{12}\ m^{-2}$ @ 2^{59}
$DP1/20_D = .05 = 1/20$

$PLX_V \leftarrow UNITR_V + GOBL1/2_V$

When in earth sphere of influence, must correct for earth oblateness by adding in $\underline{G}_B$ (@ 2^1)

Next Sheet

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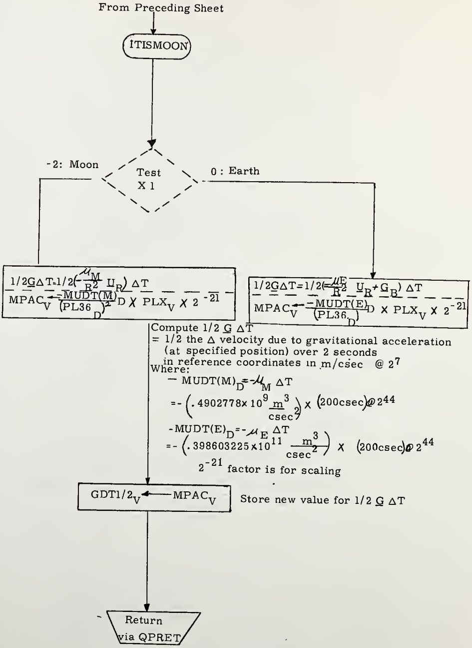

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AVGEND — Entered from SERVICER last time through: final exit

OLDBT1 ← PIPTIME +1

Set OLDBT1= (1/PIPADT) = Time of last PIPA compensation to low-order half of $PIPTIME_D$ = time of last PIPA reading in csec @ 2^{28}

Set DRIFTFLG

Do gyro compensation (resuming drifting flight)

Group 5. 0
Kill Group 5 restarts

Group 2
Set up restarts to schedule next location as a FINDVAC job with priority 20

AVETOMID
Perform transition from powered flight to coasting state vector maintenance
FC-2290

Input: RN_V, VN_V, $PIPTIME_D$ = Final state vector from AVERAGEG computation

Result: Updates variables used in coasting flight integration, updates state vector of other vehicle (LM)
Does W matrix if RENDWFLG or ORBWFLAG is set

VHFCNT ← O
TRKMKCNT ← O

Clear mark counters (initialize for new use of radar, optics)
Number of VHF ranging marks incorporated
Number of optics marks incorporated

Next Sheet

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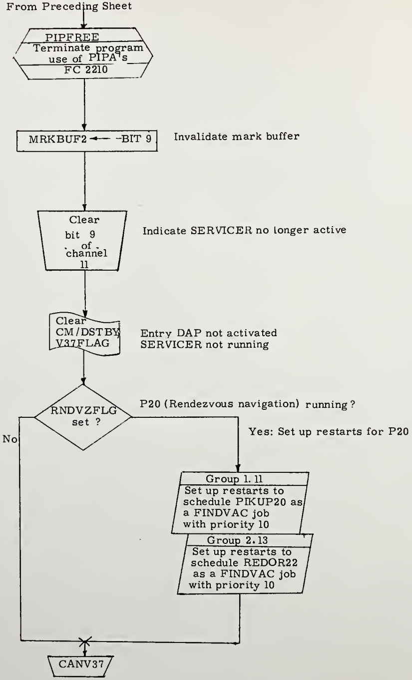

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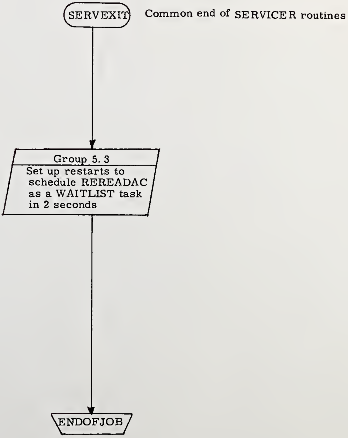

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SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

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 $\Delta \underline{V}$ 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 ROLLDAP	Sh. 7
STEERING	2682	Updates velocity-to-be-gained, computes steering rate commands for TVC DAP and time-to-SPS-cutoff	Sh. 19
VHHDOT	2540	Updates and displays inertial V, rate of change of V, altitude above pad (Noun 62)	Sh. 19
1/PIPA	2230	Does PIPA compensation and powered flight gyro compensation; corrects sensed $\Delta \underline{V}$ values for scale-factor, bias errors	Sh. 17

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
AVEGFLAG 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	
.05GSW 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	

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DOCMR			
APPR'D [signature]	11/11/69	REV 1	SHEET 29 OF 37

DISPLAYS

Verb Noun	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^{-1}
AIG/PIP		Value of AIG (above) at time of last PIPA reading (used by entry DAP)	degrees	revs	2^{-1}
ALFA/PIP		Value of ALFA/180 (below) at time of last PIPA reading (used by entry DAP)	degrees	revs	2^{-1}
ALFA/180		Third Euler angle for CM attitude	degrees	revs	2^{-1}
AMG		Snapshot of middle IMU gimbal angle (2's complement)	degrees	revs	2^{-1}
AMG/PIP		Value of AMG (above) at time of last PIPA reading (used by entry DAP)	degrees	revs	2^{-1}
AOG		Snapshot of outer IMU gimbal angle (2's complement)	degrees	revs	2^{-1}
AOG/PIP		Value of AOG (above) at time of last PIPA reading (used by entry DAP)	degrees	revs	2^{-1}

ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
$AVGEXIT_D$		2CADR of location which begins routine to run after SERVICER			
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	degrees	revs	2^{-1}
$DELVREF_V$	$\Delta \underline{V}_{REF}$	Sensed velocity change in reference coordinates	m/sec	m/csec	2^7
$DELV_V$	$\Delta \underline{V}$	Sensed velocity change in stable member coordinates	m/sec	m/csec	$.000585 \times 2^{14}$
$DELVX_D$	ΔV_X	X-component of sensed velocity change in SM coordinates	m/sec	m/csec	$.000585 \times 2^{14}$
$DELVY_D$	ΔV_Y	Y-component of sensed velocity change in SM coordinates	m/sec	m/csec	$.000585 \times 2^{14}$
$DELVZ_D$	ΔV_Z	Z-component of sensed velocity change in SM coordinates	m/sec	m/csec	$.000585 \times 2^{14}$

ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
$DVTOTAL_D$		Sum of the magnitudes of 2-second velocity changes since beginning of the maneuver	m/sec	m/csec	2^7
$GDT/2_V$	$1/2\ \underline{G}\ (T)\ \Delta T$	1/2 The change in velocity due to gravitational acceleration over a 2-second interval, in reference coordinates	m/sec	m/csec	2^7
$GDT1/2_V$	$1/2\ \underline{G}(T+\Delta T) \times \Delta T$	Temporary storage for updated version of $GDT/2_V$ (above)	m/sec	m/csec	2^7
$GOBL/2_V$	$\frac{-R^2}{\mu_E}\ \underline{G}_B\ (T)$	Correction term (in reference coordinates) for gravitational anomaly due to earth oblateness - satisfies the equation: $\underline{G}(\text{at } \underline{R}) = \frac{\mu_E}{R^2}\ \text{UNIT}(\underline{R}) + \underline{G}_B$			2^1
$GOBL1/2_V$	$\frac{-R^2}{\mu_E}\ \underline{G}_B\ (T+\Delta T)$	Temporary storage for updated version of $GOBL/2_V$ (above)			2^1
MRKBUF2		Temporary storage for marks used in rendezvous tracking; invalid if negative			
OLDBT1 =1/PIPADT		Δ Time between PIPA readings or time of last PIPA compensation	sec	csec	2^8 or 2^{14}
PHASE5		Indicates whether certain routines are to be restarted and, if so, at what point			

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			
PIPAX		Counter accumulating X-component velocity change (in SM coordinates) since last reading	m/sec	m/csec	.000585 x 2^{14}
PIPAY		Counter accumulating Y-component velocity change (in SM coordinates) since last reading	m/sec	m/csec	.000585 x 2^{14}
PIPAZ		Counter accumulating Z-component velocity change (in SM coordinates) since last reading	m/sec	m/csec	.000585 x 2^{14}
$PIPTIME_D$		Time of last PIPA reading	sec	csec	2^{28}
$PIPTIME1_D$		Temporary updated version of $PIPTIME_D$ (above)	sec	csec	2^{28}
$REFSMMAT_M$	[REFSMMAT]	Transformation matrix for conversion between SM and reference coordinate systems			2^{1}
RN_V	$\underline{R}(T)$	Position vector in reference coordinates	m	m	2^{29}
$RN1_V$	$\underline{R}(T+\Delta T)$	Temporary updated version of RN_V (above)	m	m	2^{29}

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		First Euler angle for CM attitude	degrees	revs	2^{-1}
RTX2		Indicator of whether vehicle is in earth or moon sphere of influence, by value of 0 or 2, respectively			
TEMX		Temporary storage for PIPA reading (PIPAX above)	m/sec	m/csec	$-.000585 \times 2^{14}$
TEMY		Temporary storage for PIPA reading (PIPAY above)	m/sec	m/csec	$-.000585 \times 2^{14}$
TEMZ		Temporary storage for PIPA reading (PIPAZ above)	m/sec	m/csec	$-.000585 \times 2^{14}$
$TIME2_D = \begin{pmatrix} TIME2 \\ TIME1 \end{pmatrix}$		Present time	sec	csec	2^{28}
TRKMKCNT		Number of optics marks incorporated			
TTE_D	$-T_{FF}$	Negative of time of free fall from latest PIPA reading	seconds	csec	2^{28}
$TTE2_D$		Negative of absolute time of arrival at EMS altitude	seconds	csec	2^{28}

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_V	$\underline{V}(T)$	Velocity vector in reference coordinates	m/sec	m/csec	2^7
$VN1_V$	$\underline{V}(T+\Delta T)$	Temporary updated version of VN_V (above)	m/sec	m/csec	2^7
XOLDBUF		Old PIPAX (see above) reading for Downlink telemetry	m/sec	m/csec	$.000585 \times 2^{14}$
XPIPBUF		New PIPAX (see above) reading for Downlink telemetry	m/sec	m/csec	$.000585 \times 2^{14}$
YOLDBUF		Old PIPAY (see above) reading for Downlink telemetry	m/sec	m/csec	$.000585 \times 2^{14}$
YPIPBUF		New PIPAY (see above) reading for Downlink telemetry	m/sec	m/csec	$.000585 \times 2^{14}$
ZOLDBUF		Old PIPAZ (see above) reading for Downlink telemetry	m/sec	m/csec	$.000585 \times 2^{14}$
ZPIPBUF		New PIPAZ (see above) reading for Downlink telemetry	m/sec	m/csec	$.000585 \times 2^{14}$

PROGRAM CONSTANTS

AGC Tag	GSOP Symbol	Meaning	Engineering Value and Units	AGC Value And Units	AGC Scaling
KPIP1		Scaling factor for converting $\Delta \underline{V}$ sensed to nominal velocity scaling	$.000585 \times 2^7$	$.000585 \times 2^7$	2^0
-MAXDELV		$-\left(\text{Maximum } \Delta V \text{ component hardware can sense - 2}\right)$	-6398 Pulses	-6398 Pulses	2^{14}
-MUDT(E)_D	$-\mu_E \Delta T$	-(Earth gravitational constant) x (2 seconds)	$-.79720645 \times 10^{15}$ m^3/sec	$-.79720645 \times 10^{13}$ $m^3/csec$	2^{44}
-MUDT(M)_D	$-\mu_M \Delta T$	-(Moon gravitational constant) x (2 seconds)	$-.9805556 \times 10^{13}$ m^3/sec	$-.9805556 \times 10^{11}$ $m^3/csec$	2^{44}
RESQ_D	$R_E{}^2$	Square of equatorial radius of the earth	$40.6809913 \times 10^{12}$ m^2	$40.6809913 \times 10^{12}$ m2	2^{59}
$2J_D$	$2 \times (3/2\ J_{2E})$	2 x 3/2 x the 2nd harmonic of earth's potential function	3.2469201×10^{-3} $\times 10^{-3}$	3.2469201	2^{-1}
$20J_D$	$20 \times (3/2\ J_{2E})$	20 x 3/2 x the 2nd harmonic of earth's potential function	3.2469201×10^{-2}	3.2469201×10^{-2}	2^{-1}

PROGRAM CONSTANTS (CONTINUED)

AGC Tag	GSOP Tag	Meaning	Engineering Value And Units	AGC Value And Units	AGC Scaling	Octal Value
$UNITW_V$	$\underline{u}_Z$	Unit vector in the direction of earth rotation vector (Z) in reference coordinates	$-3.32402568949 \times 10^{-6}$ $4.18407084553 \times 10^{-5}$ $9.99999998 \times 10^{-1}$	Same	2^0	77777 76203 00000 25740 37777 37777

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 (ΔV IN CONTROL COORDINATES) AND NOUN 62 (V, H, $\dot{H}$) 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

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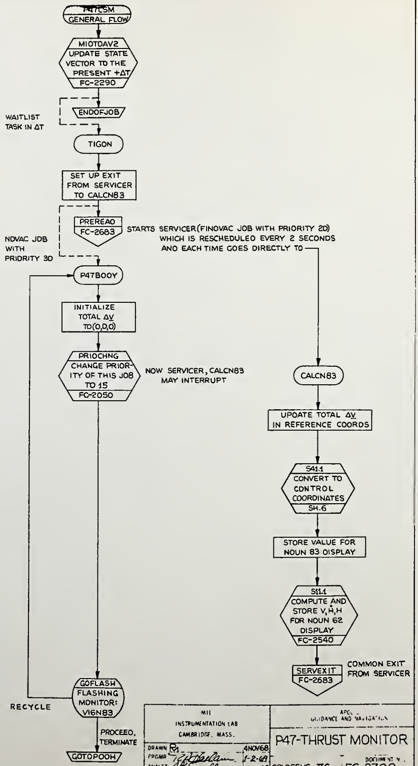
ANALST	A. G. Engel Jr. 1-2-69	COLOSSUS IIC — DOCUMENT NO. FC-2700
DOCMR	[signature] 1-2-69	
APPR'D	John A. Moor 2 JAN 69	REV 2 — SHEET 1 OF 10



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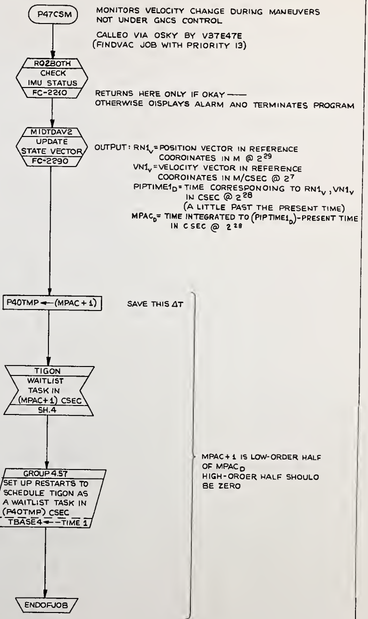
COLOSSUS IIC

DOCUMENT NO. FC-2700

REV 2

SHEET 2 OF 10



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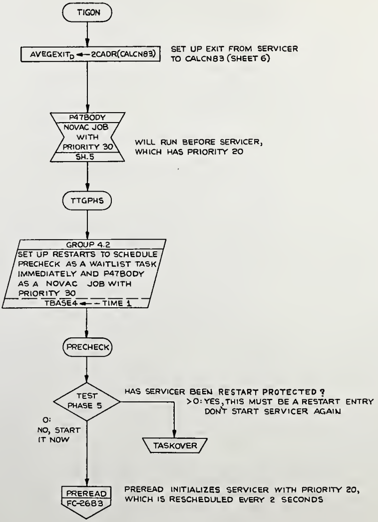
P47-THRUST MONITOR

COLOSSUS IIC FC-2700

REV 2 3 10



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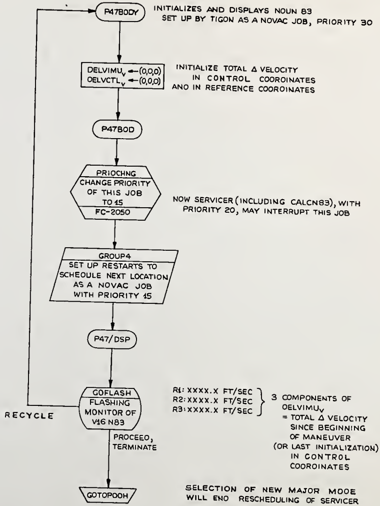
REV 2

SHEET 4 OF 10



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COLOSSUS IIC

REV 2

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SHEET 5 OF 10

CALCN83 — UPDATES VALUES FOR NOUN 83 AND NOUN 62 DISPLAYS

ENTERED DIRECTLY FROM SERVICER EVERY 2 SECONDS WITH PRIORITY 20

$DV47TEMP_V \leftarrow DELVCTL_V + DELVREF_V$
$PLO_V \leftarrow DELVCTL_V + DELVREF_V$

UPDATE TOTAL VELOCITY CHANGE IN REFERENCE COORDINATES IN M/CSEC @ 2^7

WHERE: $DELVCTL_V$ = OLD TOTAL $\Delta \underline{V}$ IN REFERENCE COORDINATES IN M/CSEC @ 2^7

$DELVREF_V$ = LAST 2-SECOND VELOCITY CHANGE IN REFERENCE COORDINATES IN M/CSEC @ 2^7

S41.1 — CONVERT VECTOR FROM REFERENCE TO CONTROL COORDINATE SYSTEM — SH. 8

INPUT: PLO_V = VECTOR IN REFERENCE COORDINATES

OUTPUT: $MPAC_V$ = VECTOR IN CONTROL COORDINATES (SAME SCALING)

$DELVIMU_V \leftarrow MPAC_V$

STORE $\Delta \underline{V}$ IN S.C. COORDINATES, IN M/CSEC @ 2^7

S11.1 — COMPUTE VALUES FOR NOUN 62 DISPLAY — FC-2540

INPUT: RN_V = POSITION VECTOR IN REFERENCE COORDINATES IN M @ 2^{29}

VN_V = VELOCITY VECTOR IN REFERENCE COORDINATES IN M/CSEC @ 2^7

OUTPUT: $VMAGI_D$ = MAGNITUDE OF VELOCITY, IN M/CSEC @ 2^7

$HDOT_D$ = RATE OF CHANGE OF ALTITUDE (COMPONENT OF VN_V ALONG RN_V) IN M/CSEC @ 2^7

$ALTI_D$ = DISTANCE OF VEHICLE FROM EARTH OR MOON SURFACE, AS APPROPRIATE IN M @ 2^{29}

NOTE: NOUN 62 DISPLAY WILL NOT BE DONE AUTOMATICALLY, BUT MAY BE REQUESTED BY ASTRONAUT

GROUP 5.3 — SET UP RESTARTS TO SCHEDULE REREADAC AS A WAITLIST TASK IN 2 SECONDS

NOTE: THIS Δ TIME IS MEASURED FROM THE LAST TIME READACCS WAS SCHEDULED

GROUP 5 — SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINDVAC JOB WITH PRIORITY 20

NEXT SHEET

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DRAWN RJ	14 NOV 68	P47-THRUST MONITOR
PRGMR [signature]	1-2-69	
ANALST [signature]	1-2-69	COLOSSUS IIC — DOCUMENT NO. FC-2700
DOCMR [signature]	1-2-69	
APPR'D [signature]	2 JAN 69	REV 2 — SHEET 6 OF 10

FROM PRECEDING SHEET

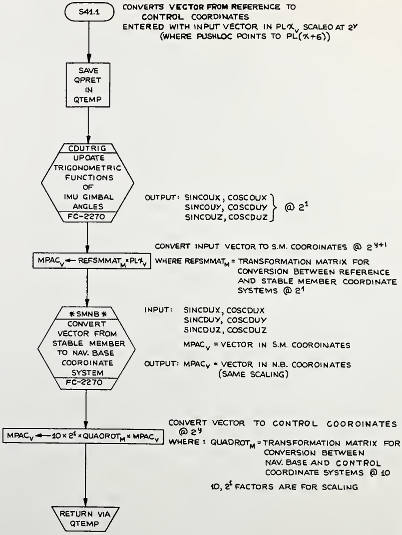
SET PARAMETER FOR GENTRAN
A+1 = NUMBER OF WORDS TO BE MOVED

INPUT: DV47TEMP = FIRST WORD TO BE STORED
DELVCTL = FIRST WORD TO BE STORED INTO

RESULT: $DELVCTL_V \leftarrow DV47TEMP_V$

(STORE UPDATED VERSION OF TOTAL $\Delta\underline{V}$
IN REFERENCE COORDINATES, IN M/CSEC @ 2^7)

COMMON EXIT FROM SERVICER



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P47-THRUST MONITOR

DRAWN RJ	13NOV68	
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APPR'D [signature]	2 JAN 69	REV 2

DOCUMENT NO FC-2700

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 GIMBAL 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	2683	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	2683	COMMON END OF SERVICER ROUTINES	SH.7
S11.1	2540	COMPUTES MAGNITUDE OF VELOCITY, ALTITUDE AND ALTITUDE CHANGE RATE FOR NOUN 62 DISPLAY	SH.6
SMNB	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
V16N83	FLASHING MONITOR	R1 XXXX.X FT/SEC R2: XXXX.X FT/SEC R3· XXXX.X FT/SEC } 3 COMPONENTS OF $DELVIMU_V$ = TOTAL $\Delta \underline{V}$ SENSED SINCE BEGINNING OF MANEUVER (OR LAST INITIALIZATION) IN CONTROL COORDINATES	SH.5

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$ALTI_D$	H	DISTANCE OF VEHICLE FROM EARTH OR MOON SURFACE, AS APPROPRIATE	M	M	2^{29}
$AVEGEXIT_D$		VARIABLE 2CADR ADDRESS OF EXIT FROM SERVICER (FC-2683)			
COSCDUX		COSINE OF OUTER IMU GIMBAL ANGLE			2^1
COSCDUY		COSINE OF INNER IMU GIMBAL ANGLE			2^1
COSCDUZ		COSINE OF MIDDLE IMU GIMBAL ANGLE			2^1

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$DELVCTL_V$		TOTAL ΔV SENSED SINCE BEGINNING OF MANEUVER (OR SINCE LAST INITIALIZATION) IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
$DELVIMU_V$		TOTAL ΔV SENSED SINCE BEGINNING OF MANEUVER (OR SINCE LAST INITIALIZATION) IN CONTROL COORDINATES	M/SEC	M/CSEC	2^7
$DELVREF_V$	$\Delta \underline{V}_{REF}$	SENSED 2-SECOND VELOCITY CHANGE IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
$DV47TEMP_V$		TEMPORARY UPDATED VERSION OF $DELVCTL_V$ (ABOVE) FOR COPY CYCLE	M/SEC	M/CSEC	2^7
$HDOT_D$	$\dot{H}$	RATE OF CHANGE OF ALTITUDE (ABOVE LAUNCH PAD)	M/SEC	M/CSEC	2^7
PHASE5		INDICATES WHETHER CERTAIN ROUTINES ARE TO BE RESTARTED AND, IF SO, AT WHAT POINT			
$PIPTIME_D$		TIME OF LAST ACCELEROMETER READING (CORRESPONDS TO RN_V, VN_V)	SEC	CSEC	2^{28}
$REFSMMAT_M$	[REFSMMAT]	TRANSFORMATION MATRIX FOR CONVERSION BETWEEN REFERENCE AND STABLE MEMBER COORDINATE SYSTEMS			2^1
RN_V	$\underline{R}$	POSITION VECTOR IN REFERENCE COORDINATES	M	M	2^{29}
RNI_V		TEMPORARY UPDATED VERSION OF RN_V (ABOVE)	M	M	2^{29}
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
$VMAGI_D$	VI	INERTIAL VELOCITY (MAGNITUDE)	M/SEC	M/CSEC	2^7
VN_V	$\underline{V}$	VELOCITY VECTOR IN REFERENCE COORDINATES	M/SEC	M/CSEC	2^7
VNI_V		TEMPORARY UPDATED VERSION OF VN_V (ABOVE)	M/SEC	M/CSEC	2^7

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING AND AGC VALUE	AGC SCALING
$QUADROT_M$		TRANSFORMATION MATRIX FOR CONVERSION BETWEEN NAVIGATION BASE AND CONTROL COORDINATE SYSTEMS (A 7.25 DEGREE ROTATION)	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & .99200 & -.12620 \\ 0 & .12620 & .99200 \end{bmatrix}$	10

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DRAWN A. J. Smith	30OCT68	P47 THRUST MONITOR
PRGMR	1-2-69	
ANALST	1-2-69	COLOSSUS IIC — DOCUMENT NO. FC-2700
DOCMR	1-2-69	
APPR'D John A. Moore	2 JAN 69	REV 2 — SHEET 10 OF 10

P52: 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-2720, REV. 1.

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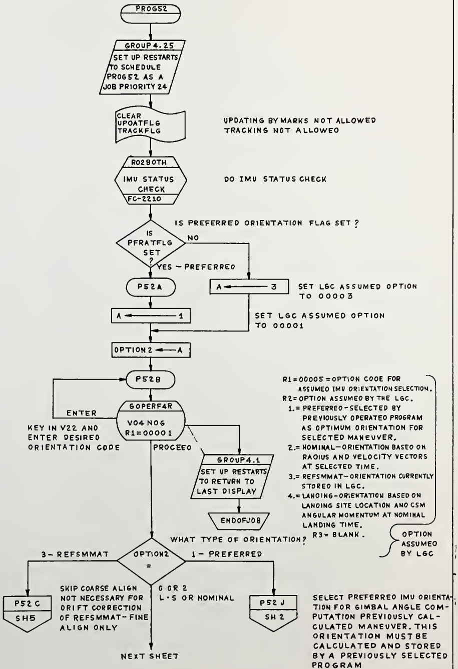
DRAWN	11 AUG 69	P52 IMU REALIGNMENT	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS IIC	FC-2720
DOCMR G. S. NALLY			
APPR'D [signature]	12 AUG 69	REV 1	SHEET OF



19AUG68
7NOV68

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COLOSSUS IIC FC-2720

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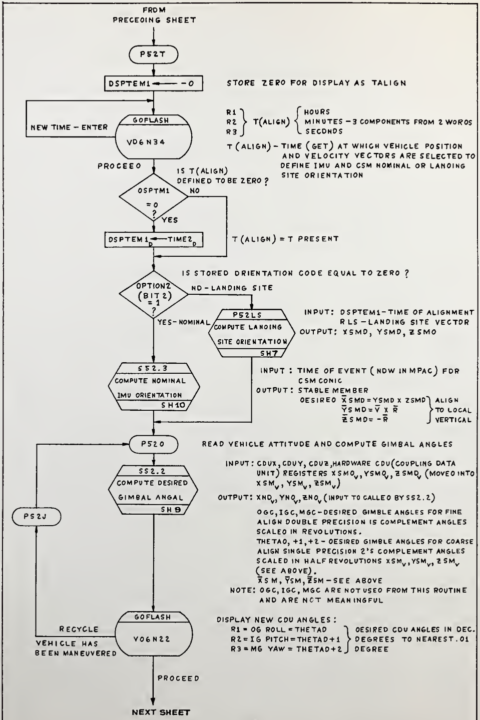

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DRAWN	[signature]	19AUG68
CHECKED	R. Vincent	7NOV68
ANALYST		
APPROVED	[signature]	7Nov68
APPROVED	John A. [signature]	19MAR69

P52
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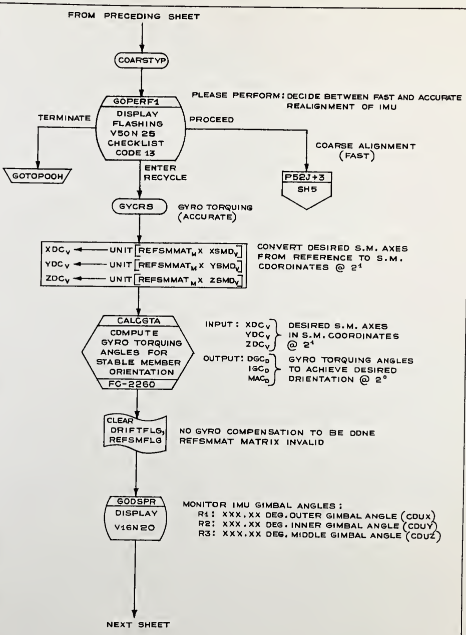
COLOSSUS II FC-2720

1 2 32



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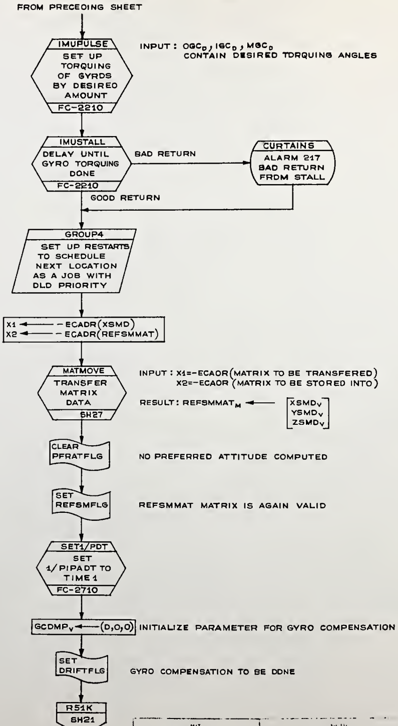
DRAWN [signature] 6FEB69
PROGRAMMED S. Albert 19MAR69
ANALYST
DOCUMENTED G.S. NALLY 19MAR69
APPROVED John A. Moore 19MAR69

P52
IMU REALIGNMENT

COLOSSUS IIC FC-2720

SH. 1 3 32



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DRAWN [signature] 6FEB69
PRGMR [signature] 20MAR69
ANALST
DOCMR Q. S. NALLY 19MAR69
APPR'D [signature] 19MAR69

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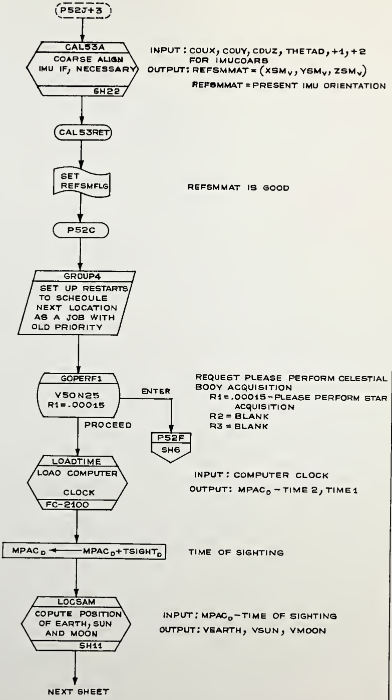
COLOSSUS IIC
DOCUMENT NO. FC-2720
REV 1
SH 4 OF 32



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DRAWN P.M. Dietz 11FEB69

S. Albert

APPROVED G.S. NALLY 19MAR69

John T. Moore 19MAR69

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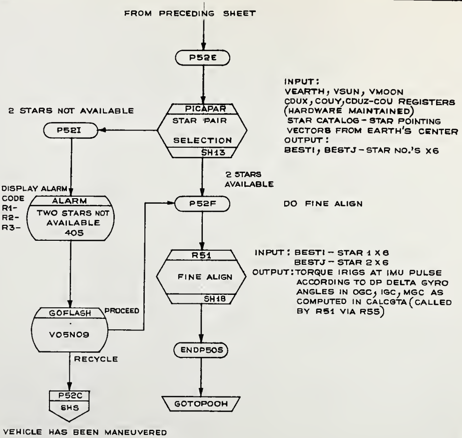
COLOSSUS IIC FC-2720

REV 1 5 32



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IMU REALIGNMENT

COLOSSUS IIC
DOCUMENT NO. FC-2720
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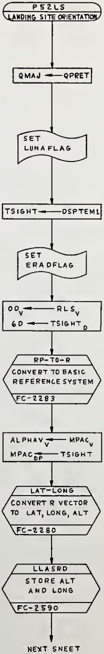


DISPLAY THE LANDING SIGNT LATITUDE, LONGITUDE AND ALTITUDE COMPUTE THE LANDING SITE ORIENTATION FOR P52 OR P54.
INPUT: DSPTEM1 - TIME OF ALIGNMENT
RLS - LANDING SITE VECTOR IN MOON FIXED COORDINATES
OUTPUT: XSMD, YSMD, ZSMD

LUNAR LAT AND LONG

TIME IS ALIGNMENT

USE FIXED RADIUS

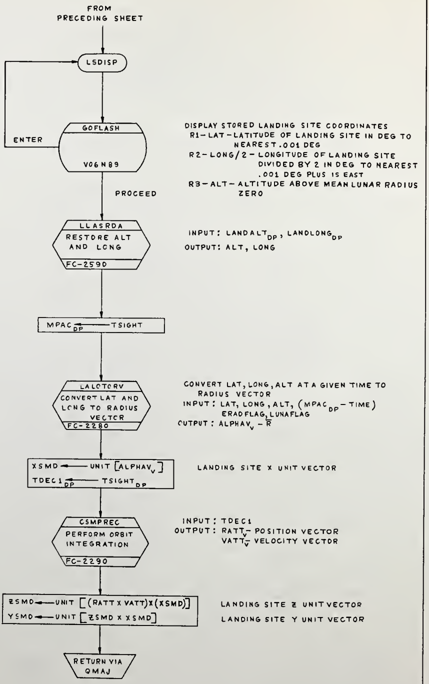
LANDING SITE VECTOR
TIME OF ALIGNMENT

CONVERT RP (VECTOR IN PLANETARY COORDINATE SYSTEM MOON FIXED) TO R (SAME VECTOR IN BASIC REF. SYSTEM)
INPUT: MPAC - NON ZERO = MOON
0 - 5D - RP VECTOR
6 - 7D - TIME
OUTPUT: $MPAC_V$ - R VECTOR B27 FOR MOON

R VECTOR B29
TIME OF ALIGNMENT

CONVERT RAD VECTOR AT GIVEN TIME TO LAT, LONG, AND ALT
INPUT: ALPHAV - POSITION VECTOR
$MPAC_{DP}$ - TIME
ERADFLAG, LUNAFLAG
OUTPUT: LAT - LATITUDE
LONG - LONGITUDE
ALT - ALTITUDE

STORE IN LOCATIONS FOR N89 DISPLAY
INPUT: ALT_{DP}, $LONG_{DP}$
OUTPUT: $LANDALT_{DP}$, $LANDLONG_{DP}$
NDTE: LAT AND LANDLAT ARE TNE SAME



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21AUG68

19 MAR 69

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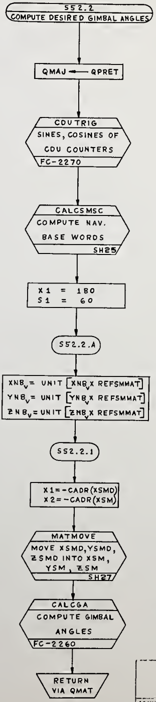


COMPUTES THE GIMBAL ANGLES FOR DESIRED STABLE MEMBER AND PRESENT VEHICLE

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: SINCDUX, SINCDUY, SINCDUZ
COSCDUX, COSCDUY, COSCDUZ

INPUT: SINCDUX, SINCDUY, SINCDUZ
COSCDUX, COSCDUY, 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

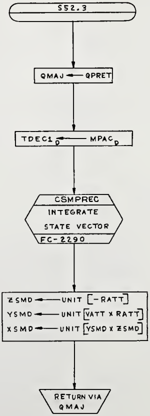
INPUT TO MATMOVE

INPUT: X1, X2

OUTPUT: MOVE MATRIX FROM X1 LOCATION TO X2 LOCATION

INPUT: XNB_V, YNB_V, ZNB_V - PRESENT NAV. BASE COORDS - UNIT VECTOR
XSM_V, YSM_V, ZSM_V - DESIRED IMU ORIENTATION - UNIT VECTOR

OUTPUT: THETAD, +1, +2 - SINGLE PRECISION 2'S COMPLEMENT VALUES OF DESIRED GIMBAL ANGLES



COMPUTES NOMINAL ORIENTATION BASED ON $\bar{R}$ AND $\bar{V}$ (POSITION AND VELOCITY VECTORS)

INPUT: TIG (IN MPAC) - TIME OF IGNITION

OUTPUT: $XSMD_v$, $YSMD_v$, $ZSMD_v$ - DESIRED GIMBAL AXES IN BASIC REFERENCE COORDINATES

TIME OF IGNITION (IF KOWN) OR CURRENT TIME

INPUT: TDEC1 - TIME OF INTEGRATION

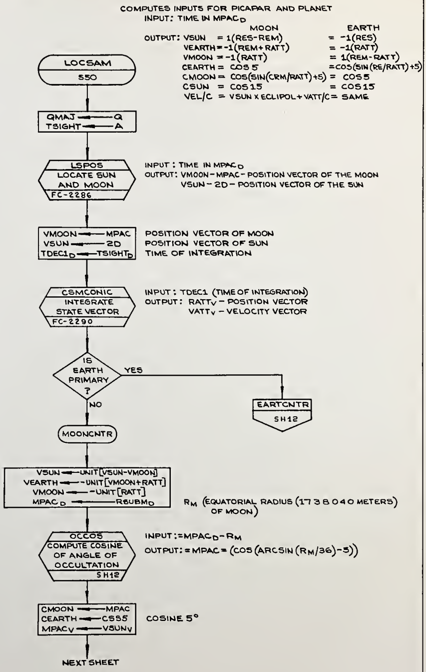
OUTPUT: $RATT_v$, $VATT_v$, - POSITION AND VELOCITY VECTORS

DESIRED GIMBAL AXES

ZSMD = UNIT R

YSMD = UNIT (V+R)

XSMD = UNIT (YSMD X ZSMD)

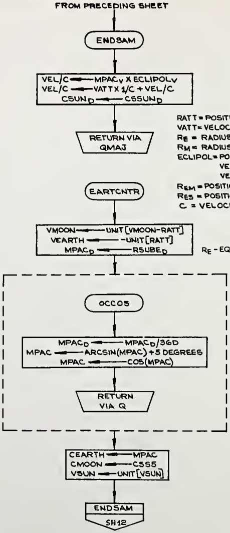


P52
IMU REALIGNMENT

COLOSSUS IIC FC-2720

29AUG
7NOV
12MAR69

1 11 32



RATT = POSITION VECTOR OF CM W.R.T. MOON
VATT = VELOCITY VECTOR OF CM W.R.T. MOON
R_E = RADIUS OF EARTH
R_M = RADIUS OF MOON
ECLIPOL = POLE OF ECLIPTIC SCALED BY TANGENTIAL VELOCITY OF EARTH W.R.T. SUN OVER THE VELOCITY OF LIGHT
R_{EM} = POSITION OF MOON W.R.T. EARTH
R_{ES} = POSITION OF SUN W.R.T. EARTH
C = VELOCITY OF LIGHT

R_E - EQUATORIAL RADIUS (6378166 METERS) OF EARTH

COMPUTE COSINE OF ANGLE OF OCCULTATION

COS (ARCSIN(MPAC/36) + 5)

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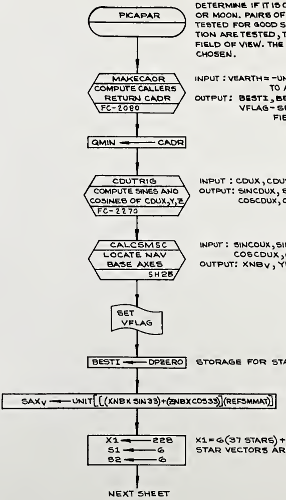
DRAWN J.W. Scott 29AUG	
PRGMR R. Warbel 7NOV58	
ANALYST	
DOCMR E.J. Nelly	COLOSSUS IIC FC-2720
APPR'D John A. Nevins 19MAR69	REV 1 SHEET 12 OF 32

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.



INPUT: VEARTH = -UNIT(R) WHERE R HAS BEEN UPDATED TO APPROX. TIME OF SIGHTING.
OUTPUT: BESTI, BESTJ – STAR NO. 5 X 6
VFLAG – SET IMPLIES NO. OF STARS IN FIELD OF VIEW

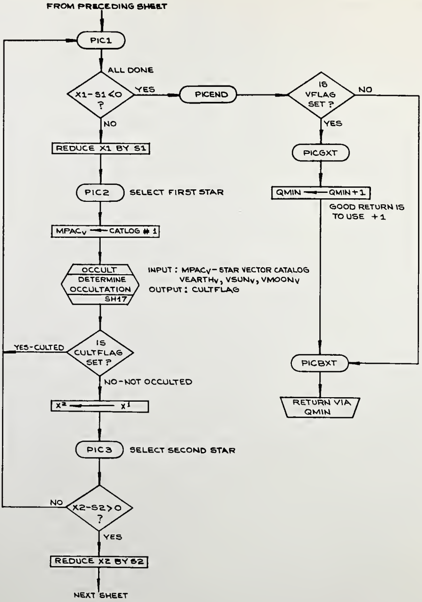
INPUT: CDUX, CDUY, CDUZ
OUTPUT: SINCDUX, SINCDUY, SINCDUZ
COSCDUX, COSCDUY, COSCDUZ

INPUT: SINCDUX, SINCDUY, SINCDUZ
COSCDUX, COSCDUY, COSCDUZ
OUTPUT: XNB_V, YNB_V, ZNB_V

STORAGE FOR STAR NUMBERS

SHAFT AXIS IS DEFINED IN THE BASIC REFERENCE SYSTEM
IT HAS NOW BEEN TRANSLATED TO THE CENTER OF THE EARTH

X1 = 6(37 STARS) + 6 = 228 = PRIMARY STAR
STAR VECTORS ARE 6 WORDS APART



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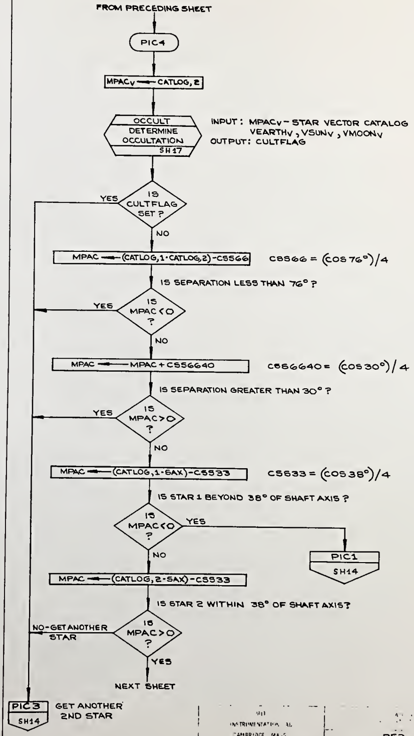
FC-2720

REV 1

14 of 32



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DRAWN: 30 AUG
CHECKED: 7 NOV 68
DOCMK: 6-69

P52
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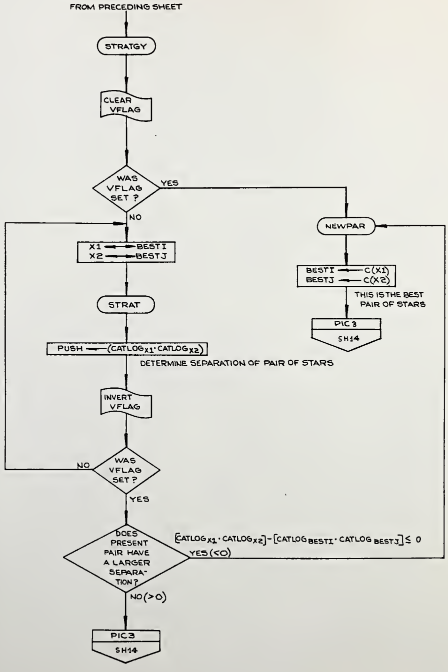
FC-2720

1 — SHEET 15 OF 32

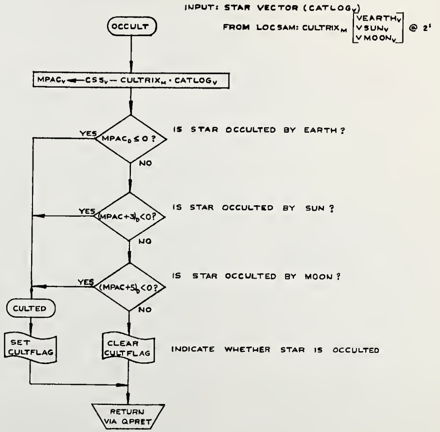


P52
IMU REALIGNMENT

COLOSSUS IIC FC-2720

30 AUG
7 NOV 68
7 Mar 69
19 MAR 69

15 32



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DRAWN F.D.LAVERRIERE	P52 IMU REALIGNMENT
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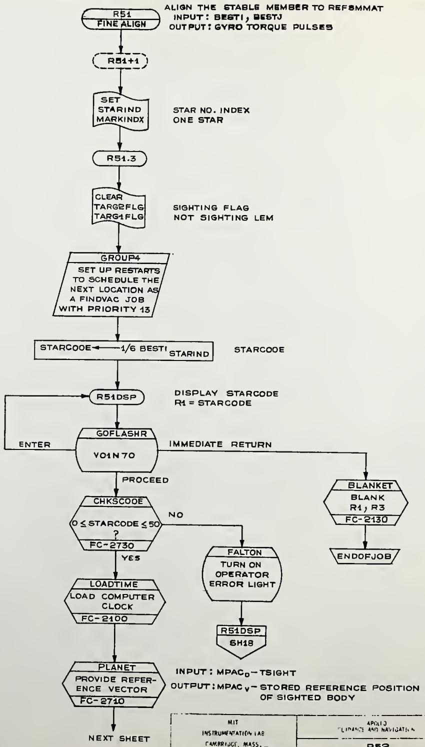
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2720
DOCMR G. S. NALLY	
APPR'D [signature]	REV 1 — SHEET 17 OF 32



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DRAWN P. M. Dixon 13 FEB 69
CHKR S. [illegible] 17 MAR 69
ANALYST
DOC. MR G. S. NALLY 19 MAR 69
APP'D John A. Miller 19 MAR 69

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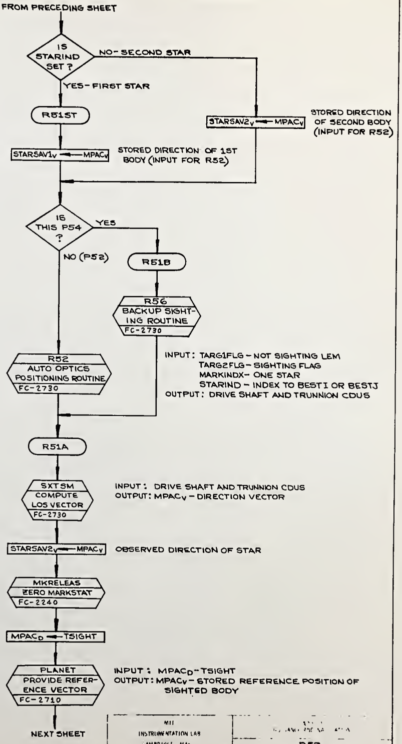
SHEET 18 32



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PRGMR 7 NOV 66
ANALST
DOCMR 7 Nov 66
APPR'D 17 MAR 67

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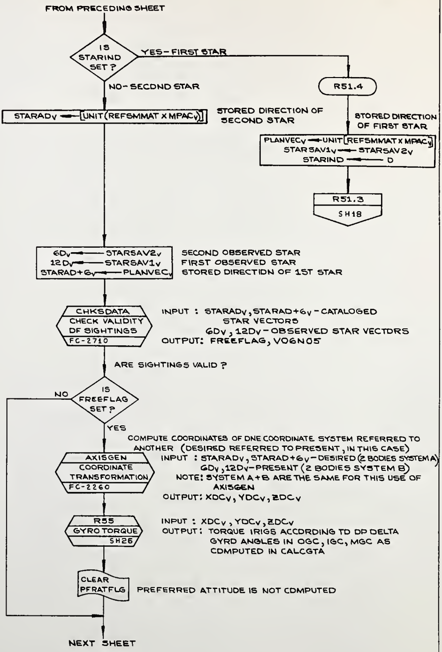

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ANALYST
DOC MGR
APP'D — 19 MAR 69

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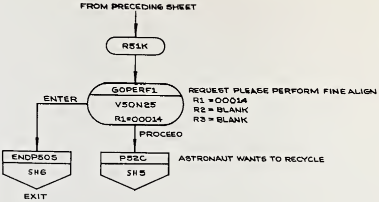

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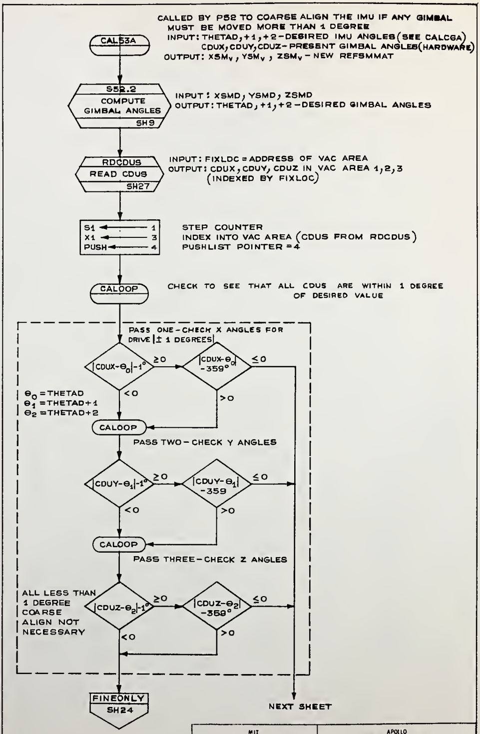

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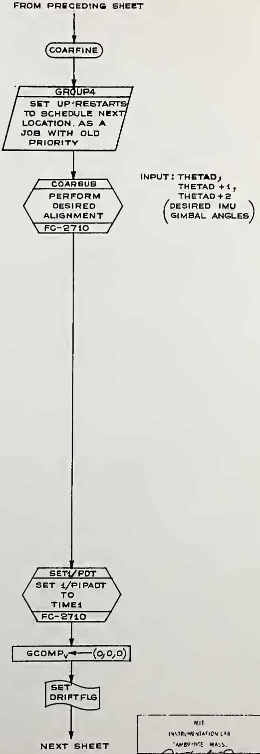
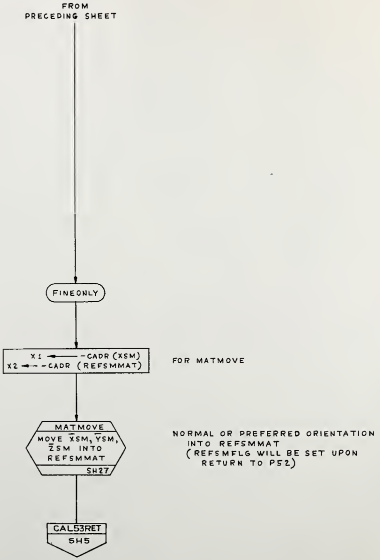
PRGMR S. Weiss 19MAR69	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2720
DOCMR G.S. NALLY 19MAR69	
APPR'D John A. Moore 19MAR69	REV 1 SHEET 22 OF 32



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN P.M. Dietz 14FEB68	P52 IMU REALIGNMENT
PRGMR S. [illegible]	
ANALST	COLOSSUS IIC FC-2720
PRGMR G.S NALLY	
APPR'D John A. Moore 19MAR68	REV 1 SHEET 23 OF 32



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature] 2 OCT 68	P52 IMU REALIGNMENT
PRGMR [signature] 7 NOV 68	DOCUMENT NO
ANALST	COLOSSUS IIC FC-2720
DOC MR [signature] 7 Nov 68	
APPR'D [signature] 19 Mar 69	REV 1 SHEET 24 OF 32

CALCSMSC
COMPUTE NAV. BASE AXES

CALLED BY PICAPAR, S52.2

INPUT: SINCDUX, SINCDUY, SINCDUZ, COSCDUX, COSCDUY, COSCDUZ – SINES, COSINES OF OUTER, INNER, MIDDLE GIMBAL ANGLES

OUTPUT: XNB_V, YNB_V, ZNB_V – CONSIDER THESE THREE VECTORS AS THE TRANSFORMATION MATRIX $[SMNB] = Q_3 Q_2 Q_1$ STABLE MEMBER TO NAV BASE WHERE:

$$XNB_V = 2 \begin{bmatrix} (COSCDUY)(COSCDUZ) \\ (SINCDUZ)/2 \\ -(SINCDUY)(COSCDUZ) \end{bmatrix}$$

$$Q_1 = \begin{bmatrix} COSCDUY & 0 & -SINCDUY \\ 0 & 1 & 0 \\ SINCDUY & 0 & COSCDUY \end{bmatrix} \text{(INNER)}$$

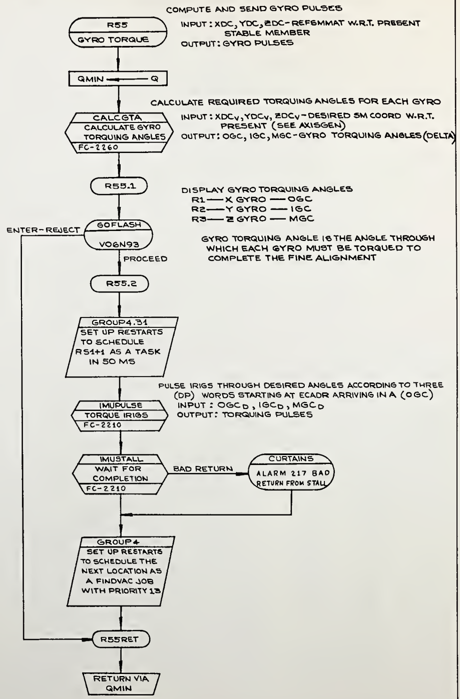
$$ZNB_V = 2 \begin{bmatrix} 2(COSCDUY)(SINCDUX)(SINCDUZ) + (COSCDUX)(SINCDUY) \\ -(SINCDUX)(COSCDUZ) \\ (COSCDUX)(COSCDUY) - 2(SINCDUX)(SINCDUZ)(SINCDUY) \end{bmatrix}$$

$$Q_2 = \begin{bmatrix} COSDUZ & SINCDUZ & 0 \\ -SINCDUZ & COSCDUZ & 0 \\ 0 & 0 & 1 \end{bmatrix} \text{(MIDDLE)}$$

$$YNB_V = 2 \begin{bmatrix} ZNB_V \times XNB_V \end{bmatrix}$$

$$Q_3 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & COSCDUX & SINCDUX \\ 0 & -SINCDUX & COSCDUX \end{bmatrix} \text{(OUTER)}$$

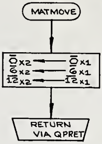
RETURN VIA QPRET



P52
IMU REALIGNMENT

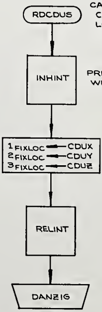
COLOSSUS IIC FC-2720

REV 1 SHEET 26 OF 32



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 CAL53A (BY RTB CALL) TO READ CDUS INTO VAC AREA WHOSE ADDRESS IS LOCATED IN FIXLOC

PREVENT CDU'S FROM CHANGING WHILE READING

SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
R02BOTH	FC-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-2290	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 CHKSCODE R56	FC-2130 FC-2730 FC-2730	CLEAR R1, R2 CHECK STARCODE BACKUP SIGHTING ROUTINE	SH. 18 SH. 18 SH. 19
R52	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
SETI/PDT	FC-2710	SET 1/PIPADT TO TIME1	SH. 23
CALCGTA	FC-2260	CALCULATE GYRO TORQUING ANGLES	SH. 26
IMUPULSE	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	

FLAGS (CONTINUED)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
LUNAFLG	LUNAR LAT-LONG	EARTH LAT-LONG	SH. 7		
ERADFLAG	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
CULTFLAG	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	T3RUPT CALLS GYRO COMPENSATION	T3RUPT 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

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
OPTION2		ORIENTATION CODE			
DSPTEMI		DISPLAY WORD			
TIME2		PRESENT TIME			
TSIGHT		TIME OF SIGHTING	CENTISECONDS		B-28
$ALPHAV_V$	R	RADIUS VECTOR			I/2 UNIT VECTOR
XSMD		STABLE MEMBER DESIRED COORDINATES X-ROW			1/2 UNIT VECTOR
YSMD-		STABLE MEMBER DESIRED COORDINATES Y-ROW			I/2 UNIT VECTOR
ZSMD		STABLE MEMBER DESIRED COORDINATES Z-ROW			I/2 UNIT VECTOR
VATT		CONIC VELOCITY VECTOR			
RATT		CONIC POSITION VECTOR			
TDEC1		PRESENT TIME			
VEARTH	$\bar{u}_E$	UNIT VECTOR SPECIFYING LINE OF SIGHT TO EARTH			1/2 UNIT VECTOR
VSUN	$\bar{u}_S$	UNIT VECTOR SPECIFYING LINE OF SIGHT TO SUN			1/2 UNIT VECTOR
VMOON	$\bar{u}_M$	UNIT VECTOR SPECIFYING LINE OF SIGHT TO MOON			I/2 UNIT VECTOR
VEL/C		ABERRATION CORRECTION			
CEARTH					
CSUN					
CMOON					
BESTI		STAR NUMBER TIMES 6	INTEGER	REVS	I
BESTJ		STAR NUMBER TIMES 6	INTEGER	REVS	I
XNB_V	$\underline{X}_{NB}$	PRESENT NAV BASE X COORDINATE			I/2 UNIT VECTOR
YNB	$\underline{Y}_{NB}$	PRESENT NAV BASE Y COORDINATE			1/2 UNIT VECTOR
ZNB	$\underline{Z}_{NB}$	PRESENT NAV BASE Z COORDINATE			I/2 UNIT VECTOR
REFSMMAT	REFSMMAT				I/2 UNIT VECTOR
SAX		SHAFT AXIS			1/2 UNIT VECTOR
STARCODE					
STARSAV1		STAR NO I UNIT VECTOR			
STARSAV2		STAR NO 2 UNIT VECTOR			

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
MODREG					
STARAD					
PLANVEC		REFERENCE VECTOR			
STARAD+6		SIGHTED DIRECTION OF 2ND BODY			
THETAD		GIMBAL ANGLES			
CDUX					
CDUY					
CDUZ					
SINCDUX					
SINCDUY					
SINCDUZ					
COSCDUX					
COSCDUY					
COSCDUZ					
MARKSTAT					
XSM	$\underline{X}_{SM}$	STABLE MEMBER DESIRED COORDINATE X-ROW			1/2 UNIT VECTOR
YSM	$\underline{Y}_{SM}$	STABLE MEMBER DESIRED COORDINATE Y-ROW			1/2 UNIT VECTOR
ZSM	$\underline{Z}_{SM}$	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°	
DEGREE1				1°	
SIN33		SINE $32^{\circ}31'23.19''$		.5376381241	
COS33		COSINE $32^{\circ}31'23.19''$		.8431756920	
CSS66		COSINE $76^{\circ}/4$		.060480472	
CSS6640		(COSINE 76° - COSINE 30°)/4		-.15602587	
CSS33		(COSINE 38°)/4		.197002688	
CSS5		(COSINE 5°)/4		.2490475	
CSSUN		(COSINE 15°)/4		.24148	
RSUBM	R_M	RADIUS OF MOON		1738090 METERS	

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, .00016209 VECTOR	
TSIGHTI		TIME DELAY TO STAR SIGHTINGS		240 SECS	

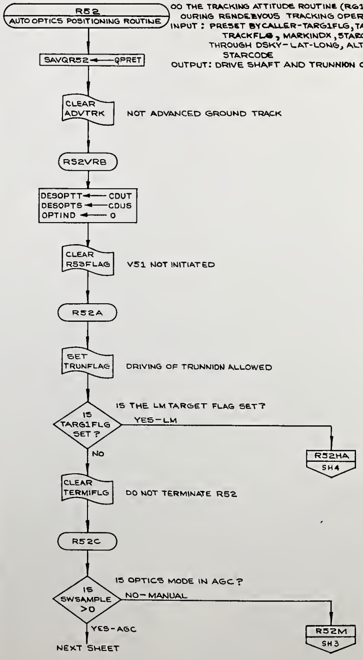
R52, R53, R56

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Lutkevich	11-26-69	R52, R53, R56	
PRGMR Sharon Albert	12/1/69		DOCUMENT NO
ANALST			
DOCMR Roberta M. Eutes	11/26/69	COLOSSUS 2D	FC-2730
APPR'D Roberta M. Eutes	12/1/69	REV 3	SHEET 1 OF

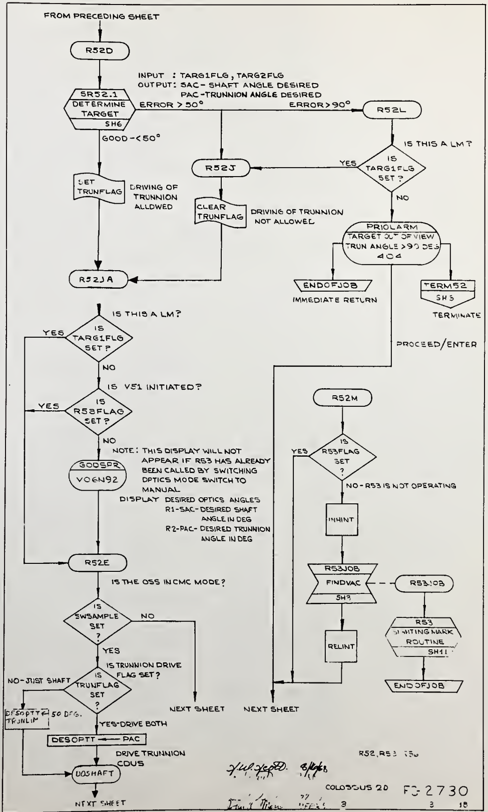
POINT THE STAR LOS OF THE OPTICS AT A STAR OR LANDMARK DEFINED BY THE PROGRAM OR BY DSKY INPUT
POINT THE STAR LOS OF THE OPTICS AT THE LM DURING RENDEZVOUS TRACKING OPERATION
DO THE TRACKING ATTITUDE ROUTINE (R61) EVERY 16 SEC. DURING RENDEZVOUS TRACKING OPERATIONS

INPUT: PRESET BY CALLER-TARG1FLG, TARG2FLG, RNDVZFLG, TRACKFLG, MARKINDX, STARCODE
THROUGH DSKY-LAT-LONG, ALT OF LANDMARK, STARCODE

OUTPUT: DRIVE SHAFT AND TRUNNION CDUS



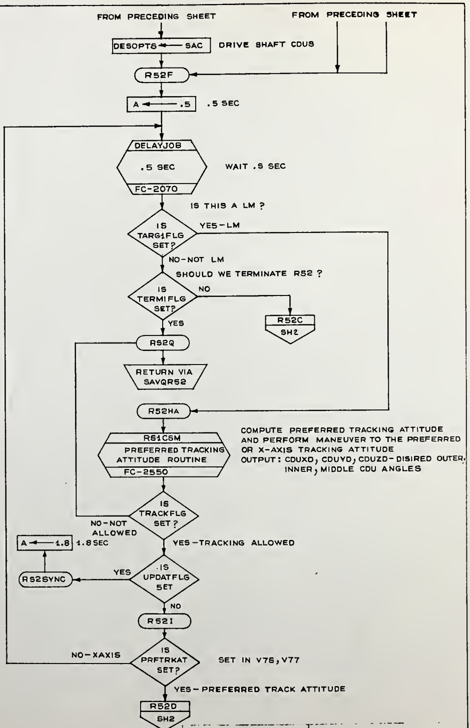
R52, R53, R56



R52, R53 15b

COLOSSUS 2D FC-2730

3 3 18



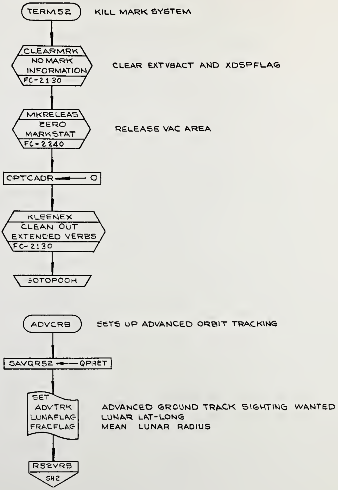
MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS

16 AUG 68
7 FEB 69

R52, R53, R56

COLOSSUS 2D FC-2730

REV 3 4 18

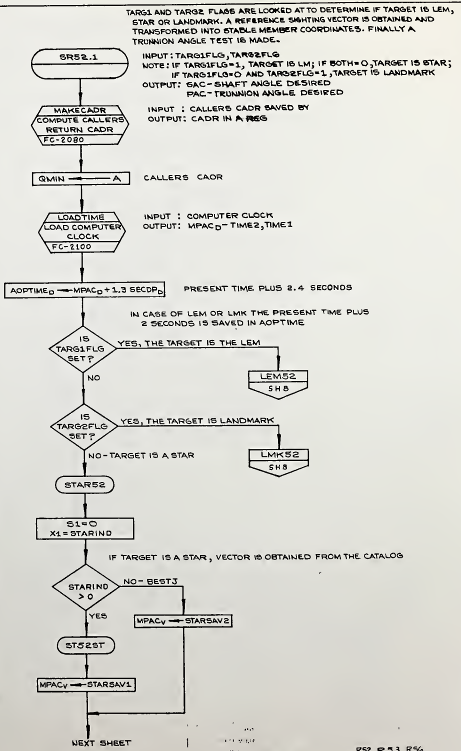


R52, R53, R56

COLOSSUS 2D FC-2730

3

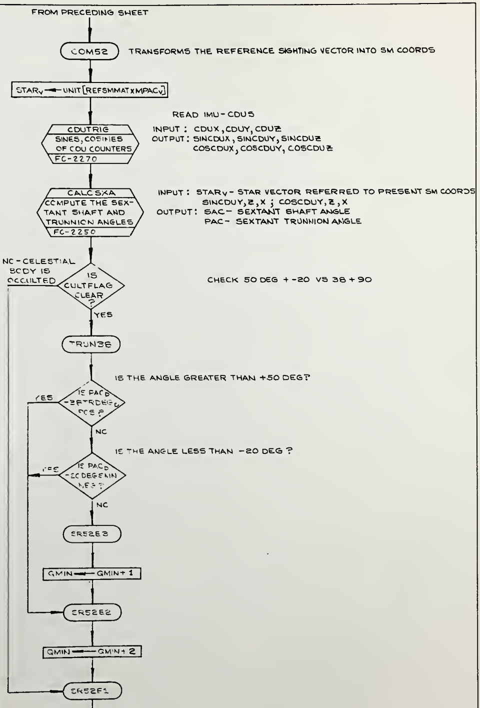
5 13

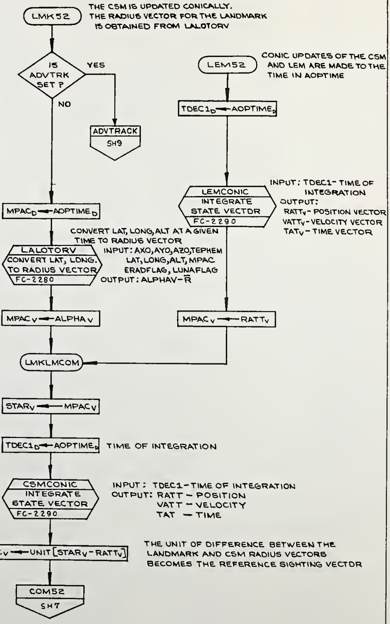


R52, R53, R56

COLOSSUS 20 FC-2730

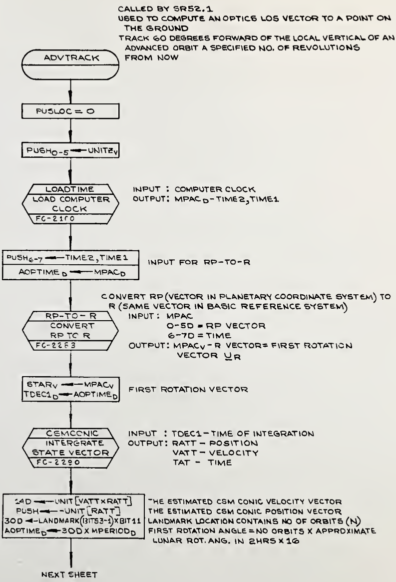
3 6 18


FROM PRECEDING SHEET
COM52
TRANSFORMS THE REFERENCE SIGHTING VECTOR INTO SM COORDS
STARV ← UNIT [REFSMMAT x MPACV]
READ IMU-CDUS
CDUTRIG
SINES, COSINES OF CDU COUNTERS
FC-2270
INPUT: CDUX, CDUY, CDUZ
OUTPUT: SINCDUX, SINCDUY, SINCDUZ
COSCDUX, COSCDUY, COSCDUZ
CALCSXA
COMPUTE THE SEXTANT 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
NO - CELESTIAL BODY IS OCCULTED
IS CULTFLAG CLEAR ?
YES
CHECK 50 DEG + -20 VS 38 + 90
TRUN38
IS THE ANGLE GREATER THAN +50 DEG?
YES
IS PACD -38TRDEGD POS ?
NO
IS THE ANGLE LESS THAN -20 DEG ?
YES
IS PACD -20 DEGSMIN NEG ?
NO
SR52E3
GMIN ← GMIN + 1
SR52E2
QMIN ← GMIN + 2
SR52F1
A ← GMIN
RETURN VIA SWCALL



R52, R53, R56

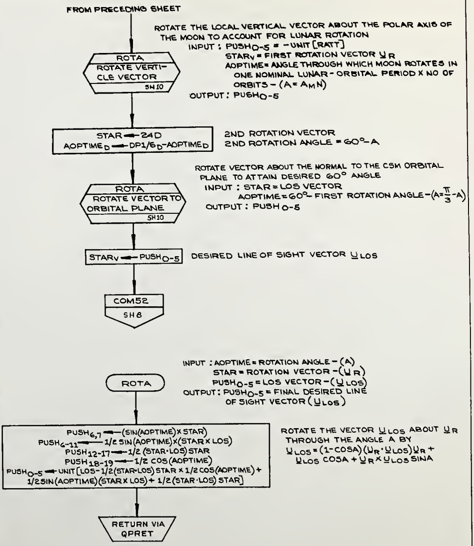
COLOSSUS 2D FC-2730



R52, R53, R56

COLOSSUS 2D FC-2730

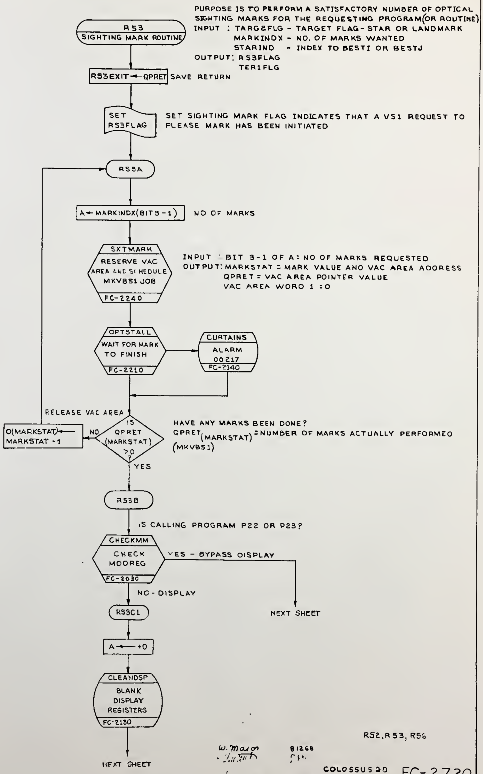
3 9 18



R52, R53, R56

COLOSSUS 2D FC-2730

3 10 18

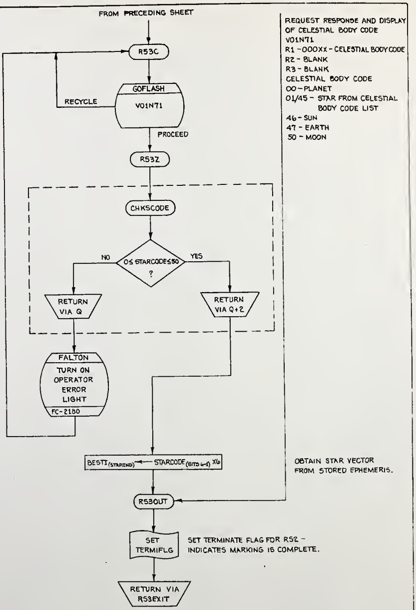


R52, R53, R56

W. Mason 81268

COLOSSUS 20 FC-2730

7FEB69 3 11 18



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS

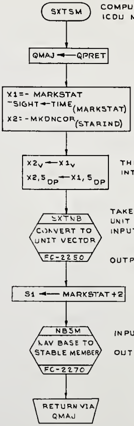
DRAWN A.C. WILLIAMS 5FEB69
PRGMR K. Vincent 7FEB69
ANALYST
SUPVR G.S. NALLY 2 7 69
APPROVED John A. Moore 7FEB69

R52, R53, R56

COLOSSUS 2D

FC-2730

3 12 18



SXTSM: COMPUTES AN LOS VECTOR IN SM COORD FROM OCDU AND ICDU MARK DATA

X1 = - MARKSTAT: ADDRESS OF VAC AREA
WORD 0 IS TIME

X2 : - MKDNCOR (STARIND): DOWNLINK (EITHER CADR(MARKDOWN) OR CADR(MARK2DWN))

$X2_V \leftarrow X1_V$, $X2,5_{DP} \leftarrow X1,5_{DP}$: THIS MOVES 7 REGISTER MARKDATA TABLE INTO DOWNLINK

SXTNB: TAKES SHAFT AND TRUNNION ANGLES AND CONVERTS THEM TO A UNIT VECTOR REFERENCED TO THE NB COORD SYSTEM
INPUT : VAC AREA LOC3 - SHAFT ANGLE
VAC AREA LOC5 - TRUNNION ANGLE
X1 - BASE ADDRESS
OUTPUT : 32D, MPAC = 1/2 UNIT VECTOR IN NB COORDS

S1 ← MARKSTAT + 2: BASE ADDRESS OF ICDU

NBSM:
INPUT : S1 = BASE ADDRESS OF CDU
$32D_V$ = VECTOR TO BE TRANSFORMED IN NB
OUTPUT : $32D_V$ = VECTOR IN SM
$MPAC_V$ = VECTOR IN SM

MARK DATA TABLE CONSISTS OF 2 WORDS FOR THE TIME AND 5 WORDS FOR THE 2 SXT AND 3 IMU ANGLES

WORD 0 $TIME_{DP}$
1
2 CDUY
3 CDUS
4 CDUZ
5 CDUT
6 CDUX

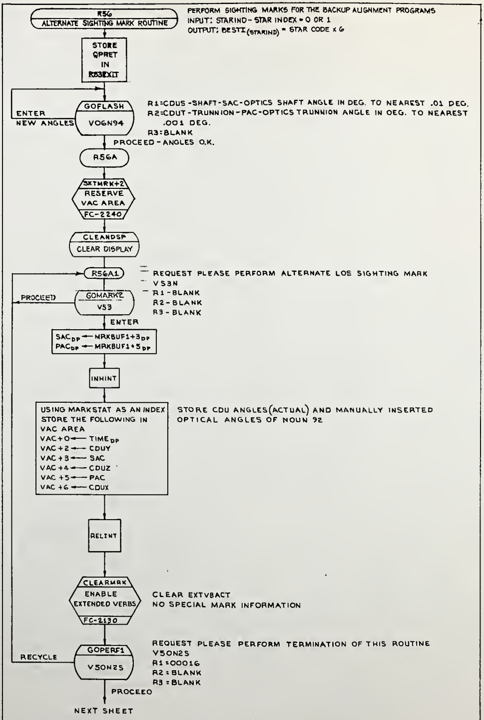
R52, R53, R56

W Mayon 81369
[illegible]

COLOSSUS 2D

FC-2730

[illegible] 7/4/69
John [illegible] 7/28/69 3

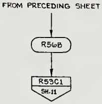


R52,R53,R56

COLOSSUS 2D

FC-2730

14 18



A.C.WILLIAMS 5FEB69

R52, R53, R56

COLOSSUS 2D

FC-2730

3

15 18

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 CDU 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

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
TERMIMFLG	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		
ERADFLAG	USE FIXED RADIUS	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
		PRIOLARM – 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

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
CDUT		OPTICS TRUNNION ANGLE	DEGREES	REVS	2^{-3}
CDUS		OPTICS SHAFT ANGLE	DEGREES	REVS	2^{-1}
DESOPTT		DISPLAY NOUN FOR TRUNNION ANGLE	DEGREES	REVS	2^{-1}
DESOPTS		DISPLAY NOUN FOR SHAFT ANGLE	DEGREES	REVS	2^{+1}
STARSAV2		STAR2 UNIT VECTOR			2^{1}
STARSAV1		STAR1 UNIT VECTOR			2^{1}
$RATT_V$		CONIC POSITION VECTOR	M	M	2^{29}
$VATT_V$		CONIC VELOCITY VECTOR	M/SEC	M/CSEC	2^{7}
TAT_D		TIME OF $RATT_V$, $VATT_V$	SEC	CSEC	2^{28}
$ALPHAV_V$		RADIUS VECTOR	M	M	2^{29}
LANDMARK		NO OF REVOLUTIONS			
AOPTIME		TEMPORARY			
$STAR_V$		TEMPORARY			
STARIND		STAR INDICATOR			
$TDEC1_D$		TIME VARIABLE	SEC	CSEC	2^{28}
$TSIGHT_D$		TIME OF SIGHTING	SEC	CSEC	2^{28}
CDUX		OUTER IMU GIMBAL ANGLE	DEGREES	REVS	2^{-1}
CDUY		INNER IMU GIMBAL ANGLE	DEGREES	REVS	2^{-1}
CDUZ		MIDDLE IMU GIMBAL ANGLE	DEGREES	REVS	2^{-1}

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
38TRDEG		50° TO 65° ANGLE CHECK	60 DEGS	.16666667 REV	2^{-2}
20DEGSMN		65° TO 90° ANGLE CHECK	-38 DEGS	-.1098 REV	2^{-2}
MPERIOD		LUNAR ANGULAR ROTATION IN 2 HOURS	1.071432 DEGS	.0029762 REV	2^{-4}
DP1/6		1/6 REVOLUTION = 60°	60 DEGS	.16666666 REV	2^{0}
TRUNLIM		MAXIMUM TRUNNION = 50°	50 DEGS		

MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS.

17JAN69
Ken Vincent
G.S. NALLY 2 7 69
John A. Flore 3FEB69

R52, R53, R56

COLOSSUS 2D FC-2730

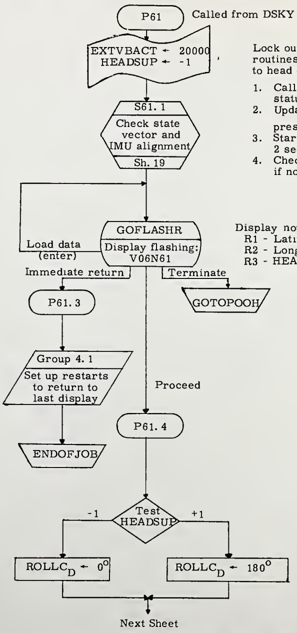
18 of 18

P60's - ENTRY PROGRAMS

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cimarillo	20 Aug 69	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 1 OF 35

P61: Maneuver to CM/SM Separation Attitude



Called from DSKY via V37E61E

Lock out extended verbs (protect TFF routines from V82) Set HEADSUP flag to head down (lift up)

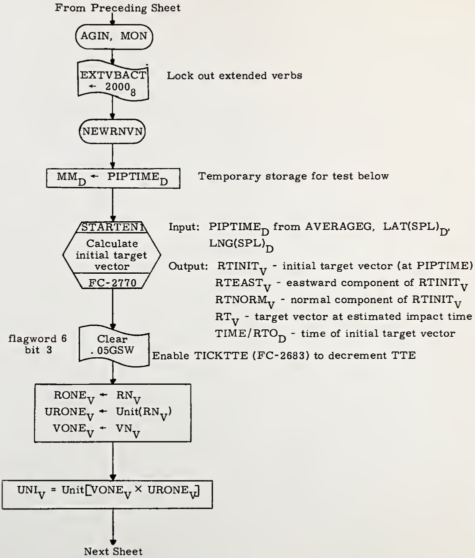
1. Call R02 check REFSMMAT & IMU status. Set IMUSE flag
2. Update state vectors VN_V, RN_V, to present time + a small tolerance
3. Start AVERAGEG as part of servicer 2 sec. update sequence
4. Check IMU alignment and do alarm if not satisfactory (10 sec display)

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)

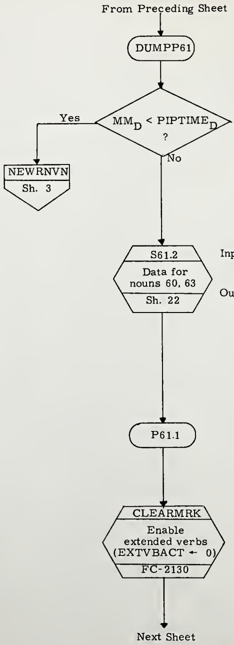
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN J. Cirvotta (date illegible)	P60's
PRGMR	COLOSSUS 2D — DOCUMENT NO. FC-2760
ANALST	
DOCMR	
APPR'D	REV 1 — SHEET 2 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Ciocotta	20Aug68	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 3 OF 35



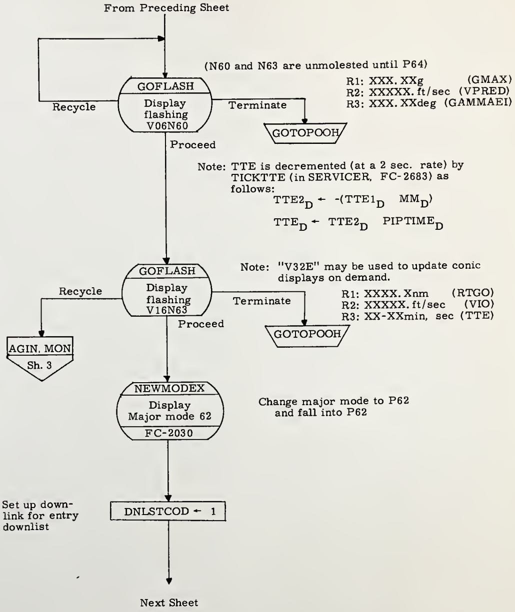
If PIPTIME has been updated, it means that AVERAGEG has run, so above calculations are invalid and must be redone using new state vector

Input: $RONE_V$, $VONE_V$, $URONE_V$, UNI_V, $UNITW_V$, EMSALT

Output:
- GMAX = maximum predicted deceleration during entry (in g's) } noun 60
- VPRED = predicted inertial velocity at 400,000 ft } noun 60
- GAMMAEI = predicted flight path angle (γ) at 400,000 ft } noun 60
- RTOGO = range from EMS altitude to splash } noun 63
- VIC = predicted inertial velocity at EMS altitude } noun 63
- 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 63

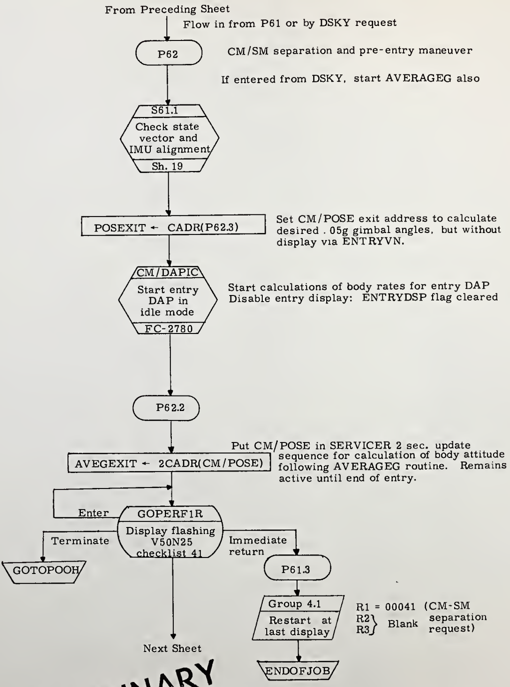
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cvrotla	8Aug69	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 4 OF 35



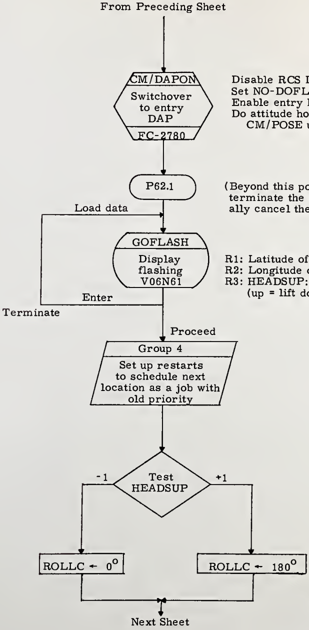
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cacciatore	28 Aug 69	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 5 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J.C. Cincotta	29 Aug 68	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 6 OF 35



Disable RCS DAP
Set NO-DOFLAG to inhibit further V37's
Enable entry DAP
Do attitude hold, beginning after first CM/POSE update

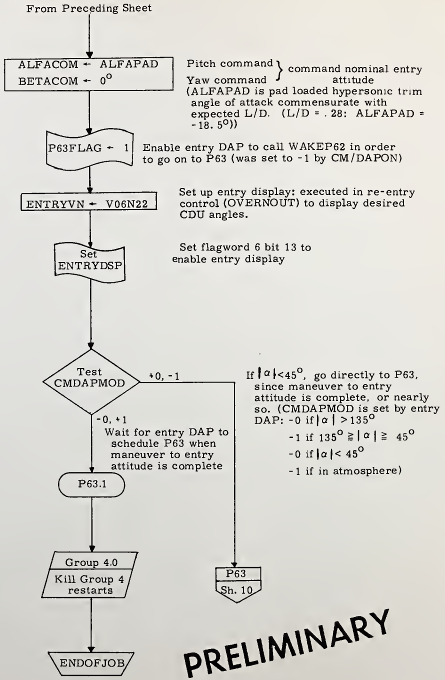
(Beyond this point, "terminate" will not terminate the entry sequence. To unconditionally cancel the P60's, V37E 00E must be used.)

R1: Latitude of splashpoint XXX. XX deg
R2: Longitude of splashpoint XXX. XX deg
R3: HEADSUP: +1 → up; -1 → down ±0000X
(up = lift down, and vice versa)

Command appropriate entry DAP roll angle for configuration requested.
If HEADSUP = +1, ROLLC = 180° (lift down)
If HEADSUP = -1, ROLLC = 0° (lift up)

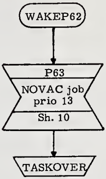
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	[date]	P60's	
PRGMR			DOCUMENT NO.
ANALST			
DOCMR		COLOSSUS 2D	FC-2760
APPR'D		REV 1	SHEET 7 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN JCiccotta	25Sep68	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 8 OF 35

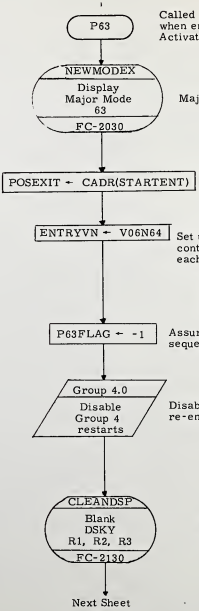


Called from entry DAP at transition from $|\alpha| > 45^o$ to $|\alpha| < 45^o$ _if_ P63 flag = +0 (P63 flag must first become +1 which it does when $|\alpha| > 45^o$) (See FC-2780)

Schedule P63

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J Ciocotto	25 Sept 69	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 9 OF 35



Called from WAKEP62, or flow in from P62, when entry attitude has been achieved. Activate entry guidance.

Major Mode display: P63

Put STARTENT into 2 sec update sequence following CM/POSE to initialize entry steering. (STARTENT will set POSEXIT to CADR (SCALEPOP) for subsequent passes) (STARTENT omits display)

Set up entry display executed in re-entry control (OVERNOUT) to display noun 64 each 2 sec:

R1: XXX.XX g drag acceleration
R2: XXXXX fps velocity
R3: XXXX.X nm distance to splash point (negative if will fall short)

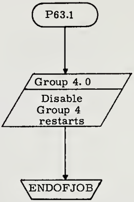
Assure that P63 will not be called out of sequence by skip phase is P66 or P67

Disable Group 4 - display is restarted in re-entry control (Group 5)

Remove V06N22, if present. P63 display begins on second pass thru entry steering

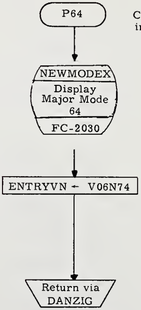
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cinotta	6 Sep 68	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 10 OF 35



Disable Group 4 - display is restarted in re-entry control (Group 5)

PRELIMINARY



Called from re-entry control when 0.05g is initially exceeded.

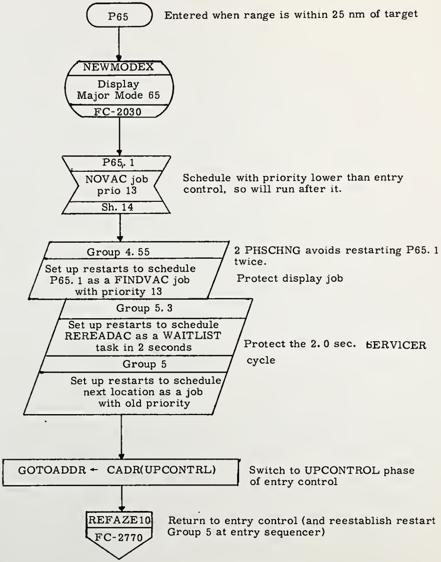
Major Mode display P64

Set up entry display executed in re-entry control (OVERNOUT) to display noun 74 each 2 sec:

R1: XXX.XX deg roll command (ROLLC)
R2: XXXXX. fps velocity (VMAGI)
R3: XXX.XX g drag (D)

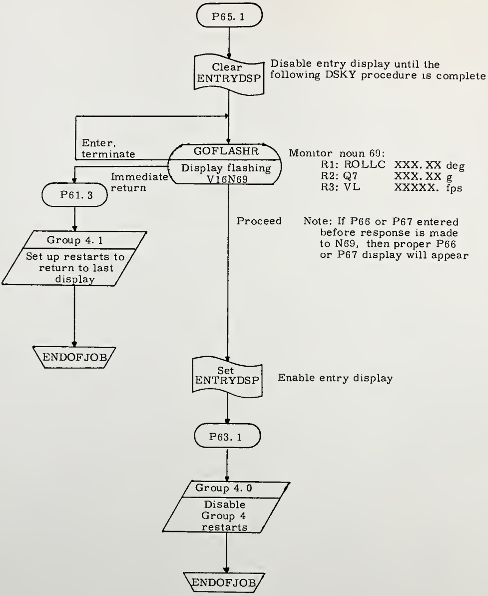
(Noun 68 display may still be called up)

PRELIMINARY



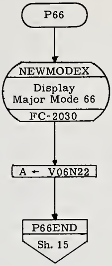
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN JCmcESD	3Sept 68	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 13 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN I. Concotta	3 Sept 69	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 14 OF 35



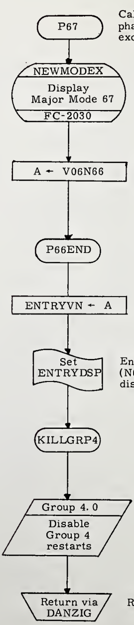
Entered when drag <Q7

Set up entry display to display desired gimbal 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 J. C McCOTA	3 Sept 69	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 15 OF 35



Called from re-entry control when final phase trajectory is entered (when drag level exceeds 0. 2 g)

Set up entry display executed in re-entry control (OVERNOUT) to display noun 66:
R1: XXX. XX deg roll command (ROLLC)
R2: XXXX. X nm cross-range error
R3: XXXX. X nm down-range error

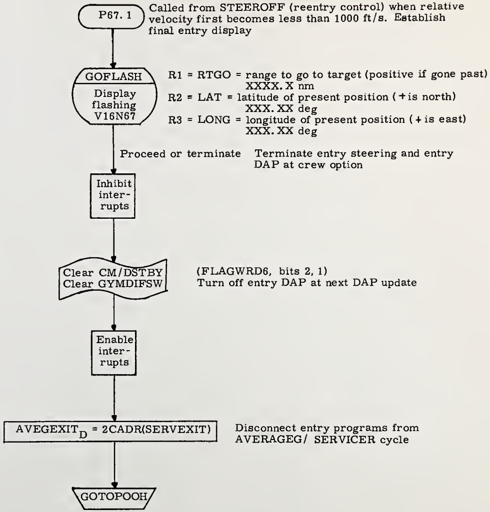
Enable entry displays in case came from P65. (N69 if still active, will be replaced by current display noun)

Disable GRP 4 in case come from HUNTEST (side tracked iteration) or from P65 (flashing display)

Return to caller in interpretive language

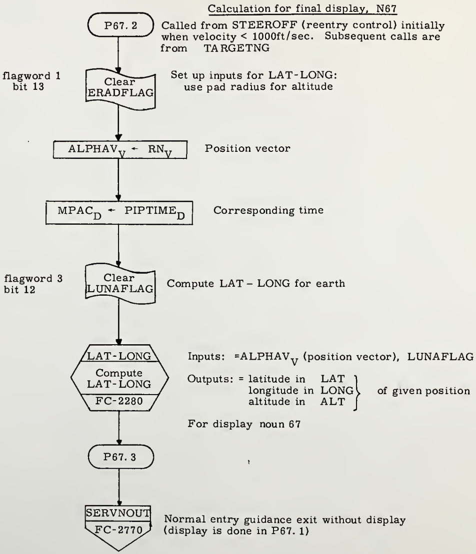
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cwotta	3 Sep 71	P60's	
PRGMR			DOCUMENT NO.
ANALST			
DOCMR		COLOSSUS 2D	FC-2760
APPR'D		REV 1	SHEET 16 OF 35



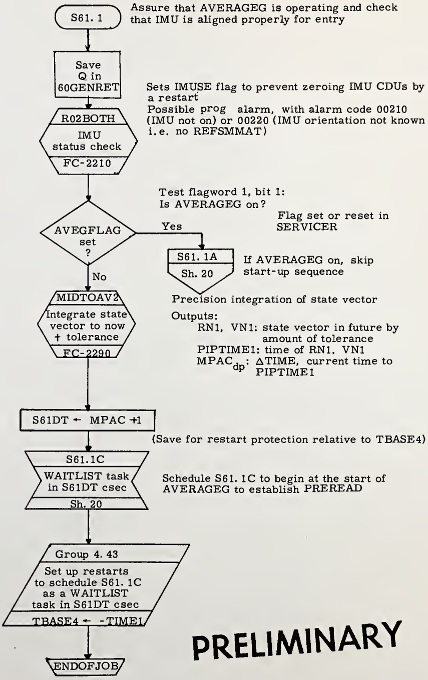
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Crosta	15 Sep 69	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 17 OF 35



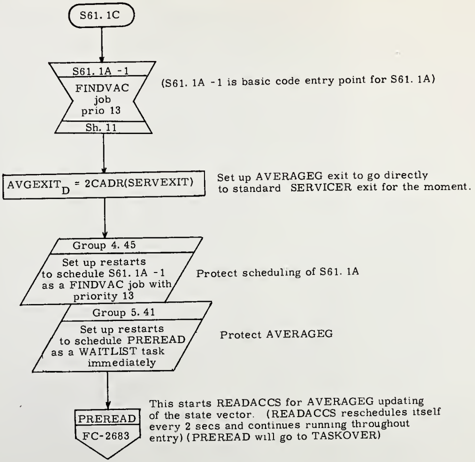
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Cinotta	4 Sept 69	P60's	
PRGMR			DOCUMENT NO.
ANALST			
DOCMR		COLOSSUS 2D	FC-2760
APPR'D		REV 1	SHEET 18 OF 35



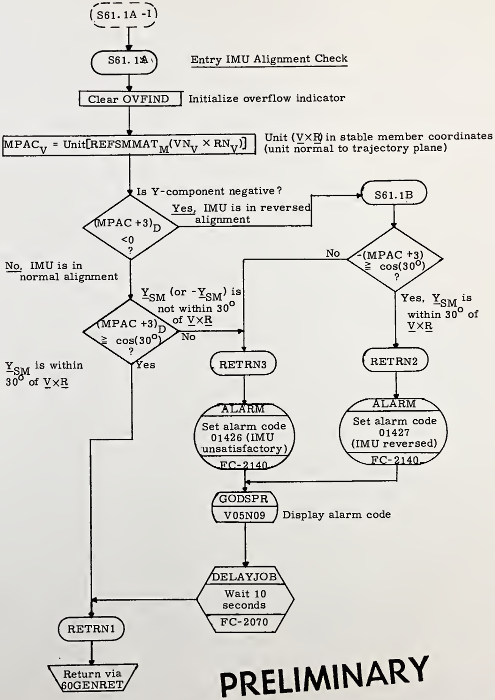
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Ciocoita		P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 19 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Acosta	5 Sept 68	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APPR'D		REV 1	SHEET 20 OF 35

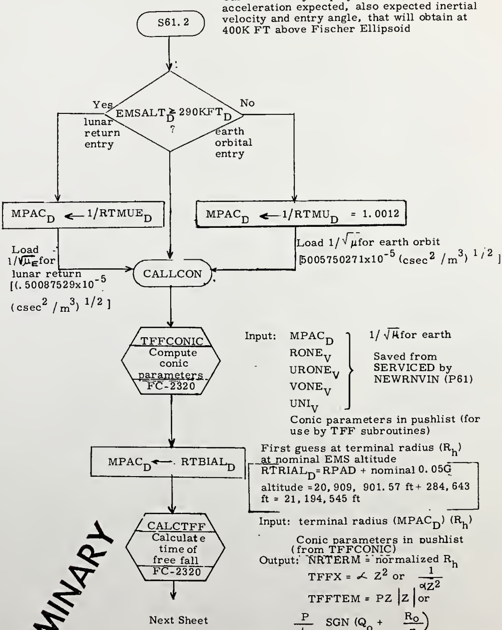


PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Crocetta	5 Sep 68	P60's	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2760
DOCMR			
APPR'D		REV 1	SHEET 21 OF 35

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



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	9/4/69	P60'S	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2760
DOCMR			
APPR'D		REV 1	SHEET 22 OF 35

From Preceding Sheet

TFF/TRIG — Calculate sin, cos transfer angle — FC-2320

Input: NRTERM, TFFX, TFFTEM — From CALCTFF
NRMAG — From TFFCONIC

Output: MPAC = sin (δf), where (δf) is transfer angle from present to EMS altitude.
CDELF/2 = cos (δf)

FISHCALC — Calculate Fischer radius — FC-2320

Input: $MPAC_D$ = sin (δf), UNI_v = unit (V_o x R_o)
CDELF/2 = cos (δf)

Output: $MPAC_D$ = ERADM = Radius of earth (R_e) at latitude of estimated terminal radius (R_h)

$MPAC_D \leftarrow MPAC_D + EMSALT_D$

Corrected estimate of terminal radius (R_h)
$EMSALT_D$=284, 643 ft (pad loaded, earth orbital)
$EMSALT_D$=297, 431 ft (pad loaded, lunar return)

CALCTFF — Recalculate time of free fall — FC-2320

Input: $MPAC_D$= terminal radius (R_h)

Output: $MPAC_D$= time of flight to EMS altitude from present position.
NRTERM = normalized R_h
TFFX $= \alpha Z^2$ or $\frac{1}{\alpha Z^2}$
TFFTEM = $PZ|Z|$ or $\frac{P}{\alpha} SGN\left(Q_0 + \frac{R_0}{2}\right)$

$TTE1_D \leftarrow MPAC_D$
$TTE2_D \leftarrow -(MPAC_D + MM_D)$
$TTE_D \leftarrow PIPTIME_D - (MPAC_D + MM_D)$

Time till entry (. 05g) stored positive
Negative for N63 display

TFF/TRIG — Calculate sin cos — FC-2320

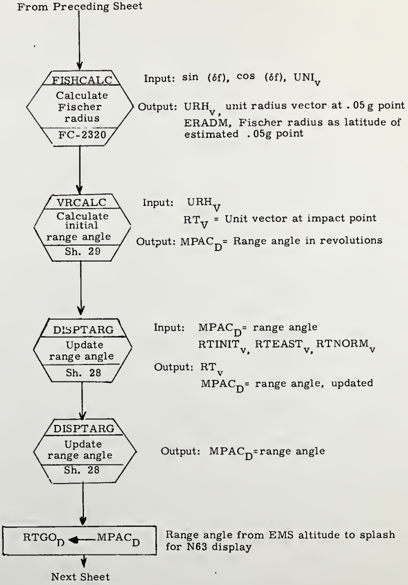
Input: NRTERM, TFFX, TFFTEM — From CALCTFF
NRMAG — From TFFCONIC

Output: $MPAC_D$ = sin (δf)
CDELF/2 = cos (δf)

Next Sheet

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstein	7/12/69	P60'S	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 23 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	9/11/69	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 24 OF 35

From Preceding Sheet

VGAMCALC
Calculate velocity magnitude and flight path angle
FC-2320

Input: NRTERM (from CALCTFF)
Conic parameters in Pushlist from TFFCONIC

Output: $PDL0_D$ = terminal velocity (V_h)
$MPAC_D$ = flight path angle (δ_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)

$$V10_D \leftarrow PL0_D + \frac{VEMSCON_D}{PL0_D \cdot MPAC_D}$$

Obtain V_δ 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 $PL0_D$ = terminal velocity (V_h)
$MPAC_D$ = flight path angle (δ_e)

Calculation of maximum G for display (noun 60)

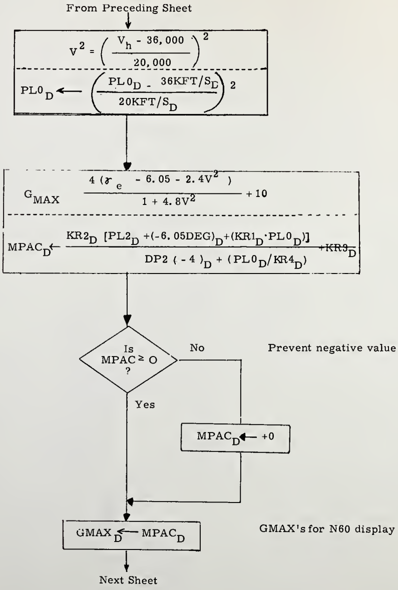
$PL2_D \leftarrow MPAC_D$

Predicted flight path angle at 300,000 feet (δ_e)

Next Sheet

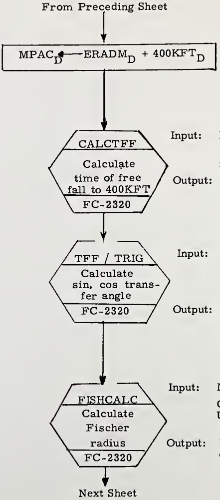
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Albstone	9/11/69	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 25 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone 7/23/69	P60'S	
PRGMR		
ANALST	COLOSSUS 2D	DOCUMENT NO. FC-2760
DOCMR		
APPR'D	REV 1	SHEET 26 OF 35



First guess of terminal radius at 400,000 ft
$ERADM_D$ = earth radius at EMS latitude (from FISHCALC)

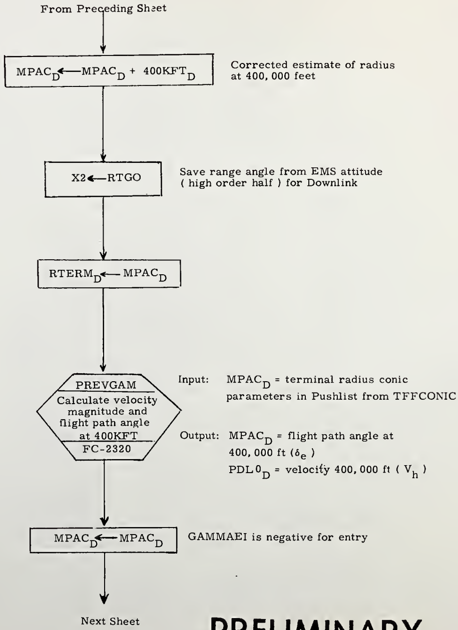
Input: $MPAC_D$ = terminal radius
Conic parameters in Pushlist from TFFCONIC
Output: NRTERM, TFFX, TFFTEM

Input: NRTERM, TFFX, TFFTEM } From CALCTFF
NRMAG From TFFCONIC
Output: $MPAC_D$ = sin (δf) where (δf) is the transfer angle
CDELF/2 = cos (δf) from present position to 400,000 ft

Input: $MPAC_D$ = sin (δf)
CDELF/2 = cos (δf)
UNI_V = unit V_o × R.
Output: MPAC = radius of earth at latitude of 400,000 ft. Terminal radius = ERADM

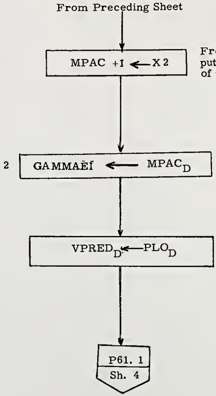
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	7/12/68	P60'S	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 27 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	9/12/68	P60's	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2760
DOCMR			
APPR'D		REV 1	SHEET [illegible] OF 35



From packed word for Downlink: put RTGO (high - word) into low-word of GAMMAEI

Flight path angle at 400, 000 ft for N60 Downlink quantity:

high-word = γ_e

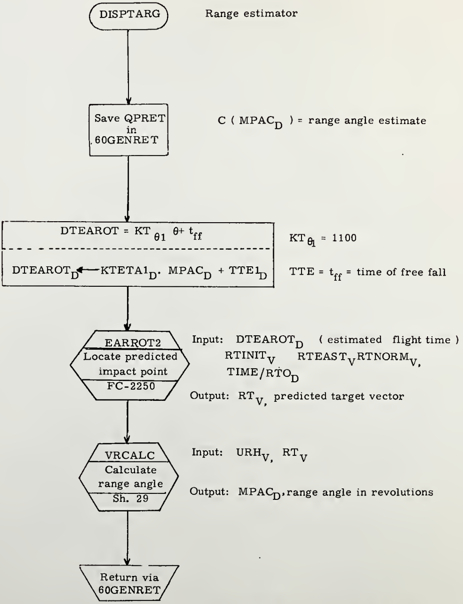
low-word = range to go

Conic velocity at 400, 000 ft for noun 60 display

Note: Effect of RTGO in low-word GAMMAEI on DSKY is negligible (≈0. 005 deg)

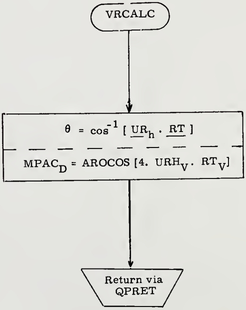
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Gilstone	7/2/69	P60's	
PRGMR			
ANALST		COLOSSUS 2D	DOCUMENT NO. FC-2760
DOCMR			
APPR'D		REV 1	SHEET 29 OF 35



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	8/1/69	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 30 OF 35



Input: URH_V (Unit radius at .05g point)
RT_V (Unit target vector)

Output: $MPAC_D$, range angle in revolutions

PRELIMINARY

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_V = desired body Y axis in reference coordinates

$UYA/2_V$ = normal to trajectory plane in reference coordinates from CM/POSE

$YNB_V \leftarrow UYA/2_V \cdot COS\ (ROLLC_D) + UZA/2_V \cdot SIN\ (ROLLC_D)$

$ROLLC_D$ = roll command

$UZA/2_V$ = trajectory triad Z axis in reference coordinates (from CM/POSE)

$XNB_V \leftarrow UXA/2_V \cdot COS\ (ALFAPAD) + (YNB_V \times UXA/2_V) \cdot SIN\ (ALFAPAD)$

$UXA/2_V$ = trajectory triad X axis in reference coordinates from (from CM/POSE)

ALFAPAD = pad loaded pitch trim angle

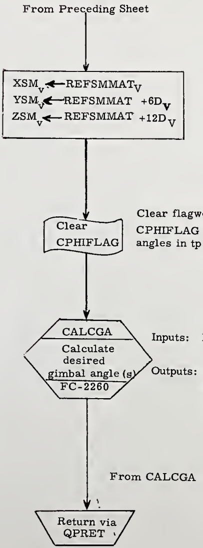
$ZNB_V \leftarrow XNB_V \times YNB_V$

Z axis to complete the triad

Next Sheet

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	7/17/69	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 32 OF 35



Reference coordinate system to stable member transformation matrix, for use by CALCGA

Clear flagword 0, bit 15:
CPHIFLAG causes CALCGA to store resulting angles in tp in CPHI

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

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature]	7/7/69	P60's	
PRGMR		COLOSSUS 2D	DOCUMENT NO. FC-2760
ANALST			
DOCMR			
APPR'D		REV 1	SHEET 33 OF 35

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 traget 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

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	4 Sept 69	P60's	
PRGMR			DOCUMENT NO.
ANALST		COLOSSUS 2D	FC-2760
DOCMR			
APP'D		REV 1	SHEET 34 OF 35

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
AVEGFLAG Flagword 1 bit 1	AVERAGEG(SERVICER) to continue	AVERAGEG(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 Flagwood 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	

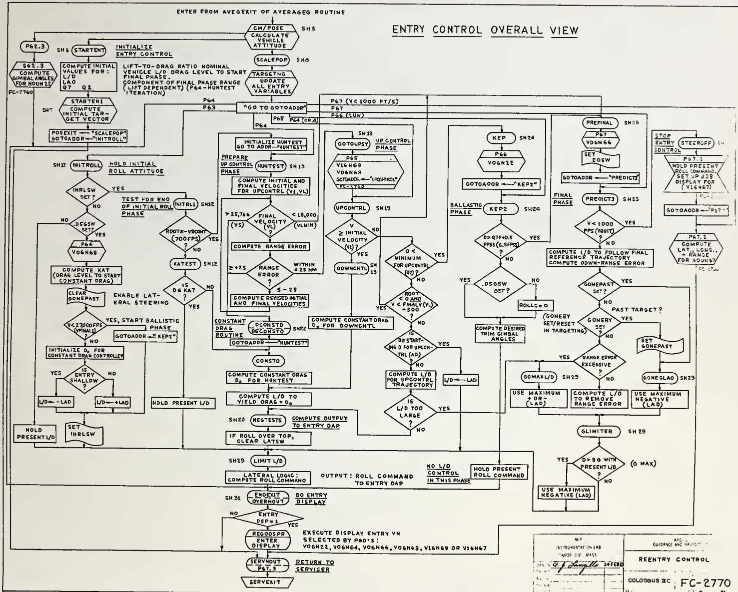
PRELIMINARY

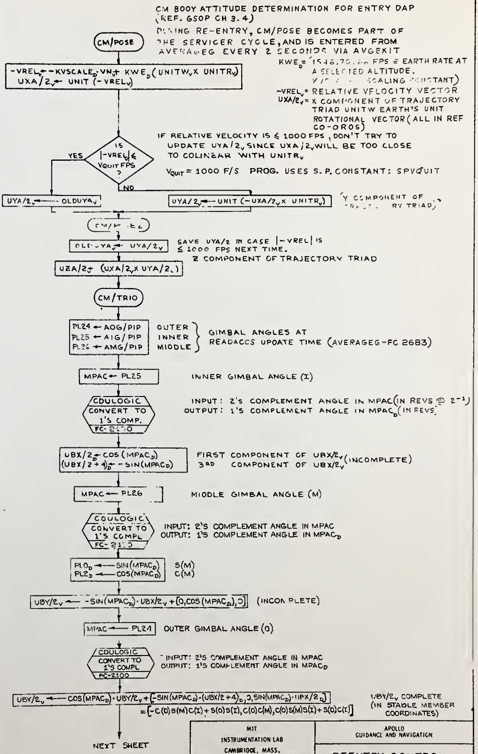
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstein 4 Sept	P60's	
PRGMR		DOCUMENT NO.
ANALST	COLOSSUS 2D	FC-2760
DOCMR		
APPR'D	REV 1	SHEET 35 OF 35

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
ENDEXIT OVERNOUT }	DISPLAY ENTRYVN AND EXIT	SH. 31
SERVNOUT	EXIT FROM SERVICER CYCLE	SH. 31

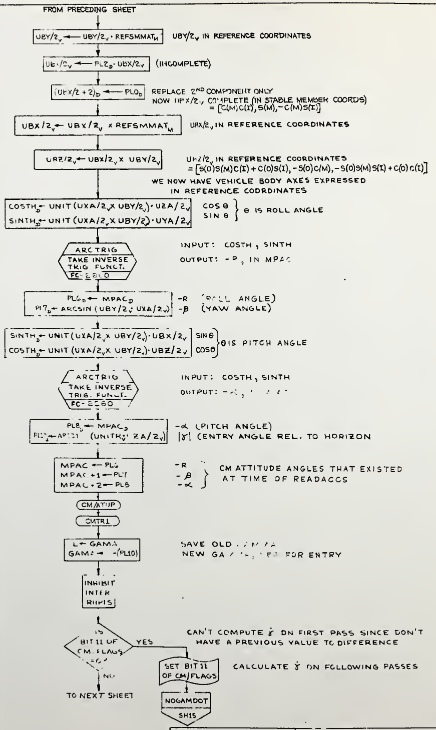
PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN H. De Hart	REENTRY CONTROL
PRGMR	
ANALST	COLOSSUS IIC — DOCUMENT NO. FC-2770
DOCMR	
APPR'D	REV — SHEET 1 OF 31

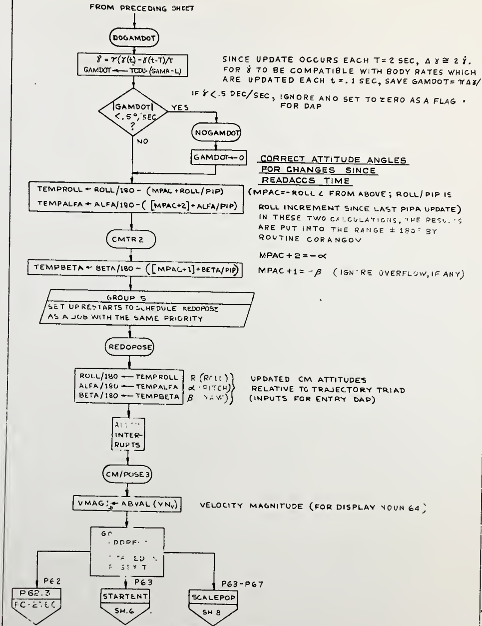

ENTRY CONTROL OVERALL VIEW
ENTER FROM AVEGEXIT OF AVERAGEG ROUTINE
CM/POSE
CALCULATE VEHICLE ATTITUDE
SH3
SCALEPOP
SH8
TARGETNG
UPDATE ALL ENTRY VARIABLES
"GO TO GOTOADDR"
P64
P63
P65
P64 (OR 8)
P67 (V< 1000 FT/S)
P67
P66 (LUN)
P62.3
S62.3
COMPUTE GIMBAL ANGLES FOR NOUN 22
FC-2760
SH6
STARTENT
INITIALIZE ENTRY CONTROL
COMPUTE INITIAL VALUES FOR: L/D LAD Q7 Q2
LIFT-TO-DRAG RATIO NOMINAL
VEHICLE L/D DRAG LEVEL TO START FINAL PHASE.
COMPONENT OF FINAL PHASE RANGE (LIFT DEPENDENT) (P64-HUNTEST ITERATION)
SH7
STARTEN1
COMPUTE INITIAL TARGET VECTOR
POSEXIT ←— "SCALEPOP"
GOTOADDR ←— "INITROLL"
SH12
INITROLL
HOLD INITIAL ROLL ATTITUDE
INRLSW SET?
YES
NO
.05GSW SET?
P64
V06N68
COMPUTE KAT (DRAG LEVEL TO START CONSTANT DRAG)
CLEAR GONEPAST
ENABLE LATERAL STEERING
V< 27000FPS (VFINAL1)
YES, START BALLISTIC PHASE
GOTOADDR ←— "KEP2"
INITIALIZE D0 FOR CONSTANT DRAG CONTROLLER
IS ENTRY SHALLOW?
L/D ←— -LAD
L/D ←— +LAD
HOLD PRESENT L/D
SET INRLSW
TEST FOR END OF INITIAL ROLL PHASE
INITRL1
SH12
RDOTZ-VRCONT (700FPS)?
KATEST
SH12
IS D≤KAT?
HOLD PRESENT L/D
P64
INITIALIZE HUNTEST GO TO ADDR ←— "HUNTEST"
PREPARE UP CONTROL PHASE
HUNTEST
SH13
COMPUTE INITIAL AND FINAL VELOCITIES FOR UPCONTRL (V1, VL)
>25,766 (VS)
FINAL VELOCITY (VL)?
<18,000 (VLMIN)
COMPUTE RANGE ERROR
≥+25
RANGE ERROR?
WITHIN ±25 NM
≤-25
COMPUTE REVISED INITIAL AND FINAL VELOCITIES
CONSTANT DRAG ROUTINE
DCONSTD
BECONSTO
SH22
GOTOADDR ←— "HUNTEST"
CONSTD
COMPUTE CONSTANT DRAG D0 FOR HUNTEST
COMPUTE L/D TO YIELD DRAG = D0
SH23
NEGTESTS
COMPUTE OUTPUT TO ENTRY DAP
IF ROLL OVER TOP, CLEAR LATSW
SH29
LIMIT L/D
LATERAL LOGIC: COMPUTE ROLL COMMAND
OUTPUT: ROLL COMMAND TO ENTRY DAP
SH31
ENDEXIT
OVERNOUT
DO ENTRY DISPLAY
ENTRY DSP=1
REGODSPR
ENTER DISPLAY
EXECUTE DISPLAY ENTRY VN SELECTED BY P60'S: V06N22, V06N64, V06N66, V06N68, V16N69 OR V16N67
SERVNOUT
P67.3
RETURN TO SERVICER
SERVEXIT
SH19
GOTOUPSY
UP CONTROL PHASE
P65
V16N69
V06N68
GOTOADDR ←— "UPCONTROL"
FC-2760
UPCONTRL
SH19
V ≥ INITIAL VELOCITY (V1)?
DOWNCNTL
SH19
COMPUTE CONSTANT DRAG D0 FOR DOWNCNTL
0 < MINIMUM FOR UPCONTRL (Q7)?
ROOT < 0 AND V < FINALV (VL) +500
D≥ STARTING D FOR UPCONTRL (AD)
COMPUTE L/D FOR UPCONTRL TRAJECTORY
L/D ←— LAD
IS L/D TOO LARGE?
NO L/D CONTROL IN THIS PHASE
HOLD PRESENT ROLL COMMAND
KEP
SH24
P66
V06N22
GOTOADDR ←— "KEP2"
BALLASTIC PHASE
KEP2
SH24
D> Q7F+0.5 FPSS (6.5FPSS)?
.05GSW SET?
ROLLC = 0
COMPUTE DESIRED TRIM GIMBAL ANGLES
PREFINAL
SH25
P67
V06N66
SET EGSW
GOTOADDR ←— "PREDICT3"
FINAL PHASE
PREDICT3
SH25
V< 1000 FPS (VQUIT)?
COMPUTE L/D TO FOLLOW FINAL REFERENCE TRAJECTORY
COMPUTE DOWN-RANGE ERROR
GONEPAST SET?
PAST TARGET?
GONEBY SET?
(GONEBY SET/RESET IN TARGETING)
SET GONEPAST
RANGE ERROR EXCESSIVE?
GOMAXL/D
SH29
USE MAXIMUM + OR - (LAD)
COMPUTE L/D TO REMOVE RANGE ERROR
GONEGLAD
SH29
USE MAXIMUM NEGATIVE (LAD)
GLIMITER
SH29
D> 8G WITH PRESENT L/D?
(G MAX)
USE MAXIMUM NEGATIVE (LAD)
STOP ENTRY CONTROL
STEEROFF
P67.1
HOLD PRESENT ROLL COMMAND. SET UP JOB DISPLAY FOR (V16N67)
GOTOADDR ←— "P67"
P67.2
COMPUTE LAT., LONG., + RANGE FOR NOUN67
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.
APOLLO GUIDANCE AND NAVIGATION
REENTRY CONTROL
COLOSSUS IIC
FC-2770
14FEB



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Langille	FEB 1968	REENTRY CONTROL
PRGMR		
ANALST		COLOSSUS IIC — DOCUMENT NO. FC-2170
DOCMR		
APPR'D		REV — SHEET 3 OF 31



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN G. J. Lavzille	REENTRY CONTROL
PRGMR	
ANALST	DOCUMENT NO.
DOCMR	COLOSSUS IIC — 70
APPR'D	REV — SHEET 4 OF 31



POSEXIT MAY POINT TO ONE OF THE FOLLOWING:
... DESIRED GIMBAL ANGLES.
... SERVICER CYCLE, WITHOUT THE ENTRY DISPLAY (ENTRYVN-FC2760)*

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:
NOUN 22 MAY BE DISPLAYED MANUALLY. AFTER CREW ACCEPTS N61, ENTRYDSP FLAG IS SET AND NOUN 22 IS DISPLAYED AUTOMATICALLY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN [signature]	18JUL68	REENTRY CONTROL
PRGMR		
ANALST		DOCUMENT NO. FC 2770
DOCMR		
APPR'D		REV — SHEET 5 OF 31

ENTRY INITIALIZATION

REFERENCES:
GSDP, SECT. 5.7

STARTENT — FOLLOWS CM/POSE AFTER P63 HAS SET POSEXIT = CADR (STARTENT)

INHIBIT INTERRUPTS

INITIALIZE SWITCHES

CM/FLAGS:

Flag action	Switch	Meaning
SET BIT 13	ENDRYDSP	ENABLE ENTRY DISPLAYS
SET BIT 10	GONEPAST*	OMIT LATERAL CALCULATIONS
CLEAR BIT 9	RELVELSW	TARGETING USES INERTIAL VELOCITY
CLEAR BIT 8	EGSW	NOT IN FINAL PHASE
CLEAR BIT 7	NOSWITCH	ALLOW LATERAL SWITCH OF ROLL ANGLE
CLEAR BIT 6	HIND	DON'T ITERATE HUNTEST AFTER RANGER
CLEAR BIT 5	INRLSW	HOLD INITIAL ROLL ATTITUDE UNTIL .05g EXCEEDED
SET BIT 4	LATSW	DOWNLIFT NOT INHIBITED
CLEAR BIT 3	.05GSW	DRAG < .05G

* GONEPAST IS INITIALLY SET TO OMIT LATERAL STEERING. THUS ROLLC WILL REMAIN 0 OR 180° AS DEFINED BY HEADSUP UNTIL ONSET OF .05g (P64)

ALLOW INTERRUPTS

Assignment	Comment
LOD_D ← LOOPAD,0	[USE PAD LOAD] FINAL PHASE L/D
LAD_D ← LADPAD,0	[USE PAD LOAD] MAXIMUM L/D (MINIMUM ACTUAL VEHICLE L/D)
$L/DCMINR_D$ ← LAD · $COS15_D$	L/D FOR MIN · ROLL ANGLE WHEN LATERAL STEERING IS DESIRED
$KLAT_D$ ← LAT_D · $LATSLOPE_D$	LATERAL SWITCHING SLOPE = LATSLOPE = 1/24
$Q7_D$ ← $Q7F_D$	MINIMUM DRAG FOR UPCONTROL = Q7F = 6 FPSS
$FACTOR_D$ ← OCT 37777, 37777	UPCONTROL FACTOR, INITIAL VALUE = $POSMAX_D = 1 - 2^{-28}$
L/D_D ← − SIGN (HEADSUP) LAD_D	INITIAL L/D COMMAND: ROLL = 0°, OR ROLL = 180°

STARTEN1 — CALCULATE INITIAL TARGET VECTOR (SH7)

INITIALIZE TARGET AT PRESENT TIME

OUTPUT: $RTINIT_V$ − INITIAL TARGET VECTOR

RT_V − TARGET VECTOR { $RTEAST_V$, $RTNORM_V$ }

THETAH − RANGE ANGLE

(ALL VECTORS IN REF COORD.)

Assignment	Comment
$LATANG_D$ ← UNIT (VN_V X $UNITR_V$) · RT_V	$LATANG_D$ = LATERAL RANGE AT TARGET
$K2ROLL_D$ ← − SIGN ($LATANG_D$)	$K2ROLL_D$ = INDICATOR FOR LATERAL SWITCH OF ROLL COMMAND
$Q2_D$ ← 500 LAD_D − 1152	$Q2_D$ = COMPONENT OF FINAL PHASE RANGE (LIFT DEPENDENT)
GOTOADDR ← CADR (INITROLL)	SET FOR INITIAL ENTRY PHASE (SEE SCALEPOP SH8)
POSEXIT ← CADR (SCALEPOP)	HEREAFTER, SCALEPOP TO FOLLOW CM/POSE IN SERVICER SEQUENCE

SERVNOUT (SH31) — OMIT ENTRY DISPLAY ON INITIAL PASS AND EXIT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

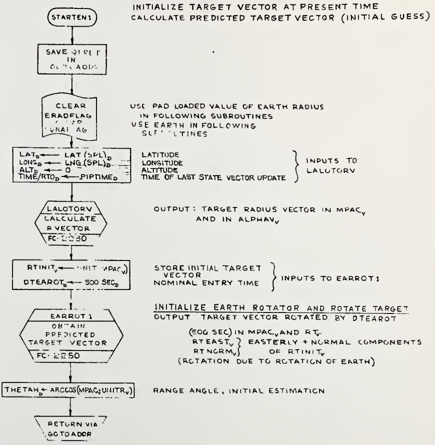
DRAWN / CHECKED / ANALYST / DOC'MR / APPR'D — 6 SEP 68

REENTRY CONTROL

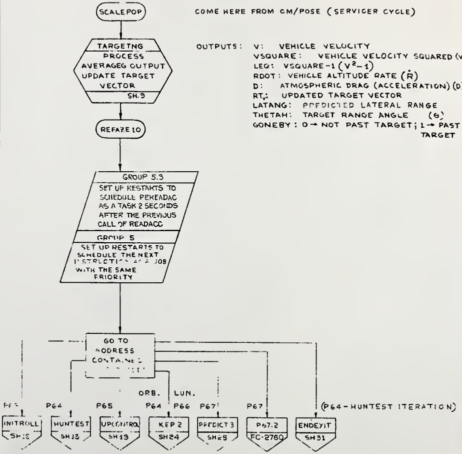
COLOSSUS IIC — DOCUMENT NO. FC-2770

REV — SHEET 6 OF 31

INITIAL TARGETING



ENTRY CONTROL

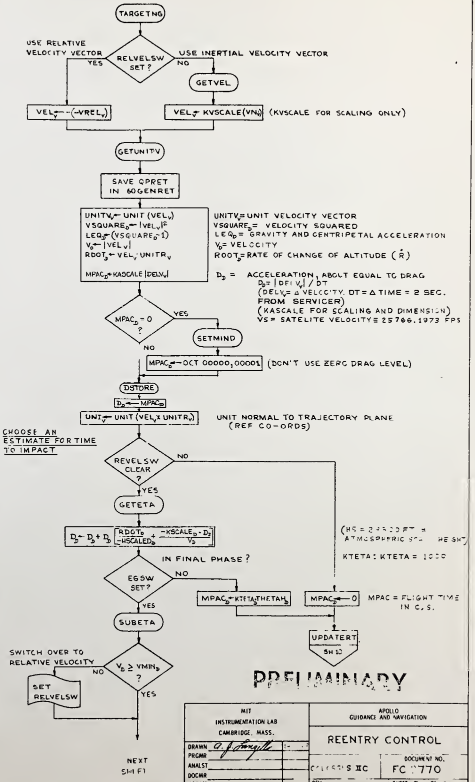


OUTPUTS:

- V: VEHICLE VELOCITY
- VSQUARE: VEHICLE VELOCITY SQUARED (V^2)
- LEQ: VSQUARE-1 (V^2-1)
- RDOT: VEHICLE ALTITUDE RATE ($\dot{R}$)
- D: ATMOSPHERIC DRAG (ACCELERATION) (D)
- RT_v: UPDATED TARGET VECTOR
- LATANG: PREDICTED LATERAL RANGE
- THETAH: TARGET RANGE ANGLE (θ)
- GONEBY: 0 → NOT PAST TARGET; 1 → PAST TARGET

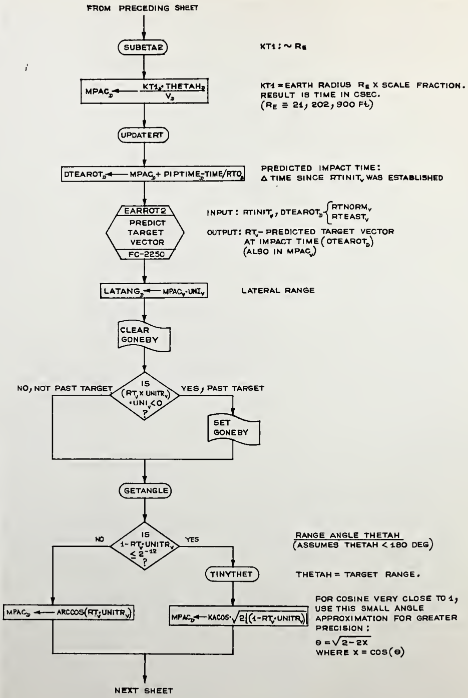
INITROLL: HOLDS EARLY ROLL ATTITUDES
HUNTEST: CHECKS IF ESTIMATED RANGE AT NOMINAL L/D IS LESS THAN DESIRED RANGE
UPCONTRL: CONTROLS ROLL DURING SEMI-CIRCULAR PHASE OF ENTRY
KEP 2: MONITORS DRAG
PREDICT3: FINAL SUB-ORBITAL CONTROL
P67.2: MAINTAINS LAST COMPUTED ROLL ANGLE
ENDEXIT: EXIT

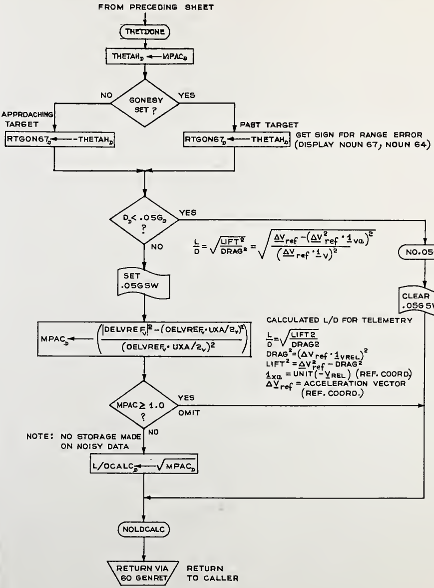
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN O. J. Langlle	REENTRY CONTROL
PRGMR	DOCUMENT NO. FC 2770
ANALST	
DOCMR	
APPR'D	REV — SHEET 8 OF 31



PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN A. J. Lungelle	REENTRY CONTROL
PRGMR	DOCUMENT NO.
ANALST	CALCULUS IIC — FC 770
DOCMR	
APPR'D	REV — SHEET 9 OF 31


FROM PRECEDING SHEET
SUBETA2
KT1 : ~ R_E
MPAC_D ← KT1_D · THETAH_D / V_D
KT1 = EARTH RADIUS R_E X SCALE FRACTION.
RESULT IS TIME IN CSEC.
(R_E ≡ 21, 202, 900 Ft)
UPDATERT
DTEAROT_D ← MPAC_D + PIPTIME_D - TIME/RTO_D
PREDICTED IMPACT TIME:
Δ TIME SINCE RTINIT_V WAS ESTABLISHED
EARROT2
PREDICT TARGET VECTOR
FC-2250
INPUT : RTINIT_V, DTEAROT_D {RTNORM_V, RTEAST_V}
OUTPUT: RT_V - PREDICTED TARGET VECTOR AT IMPACT TIME (DTEAROT_D) (ALSO IN MPAC_V)
LATANG_D ← MPAC_V · UNI_V
LATERAL RANGE
CLEAR GONEBY
IS (RT_V X UNITR_V) · UNI_V < 0 ?
NO, NOT PAST TARGET
YES, PAST TARGET
SET GONEBY
GETANGLE
IS 1 - RT_V · UNITR_V ≤ 2^-12 ?
NO
YES
RANGE ANGLE THETAH
(ASSUMES THETAH < 180 DEG)
TINYTHET
THETAH = TARGET RANGE.
MPAC_D ← ARCCOS(RT_V · UNITR_V)
MPAC_D ← KACOS · √2[(1 - RT_V · UNITR_V)]
FOR COSINE VERY CLOSE TO 1, USE THIS SMALL ANGLE APPROXIMATION FOR GREATER PRECISION :
θ = √(2 - 2X)
WHERE X = COS(θ)
NEXT SHEET

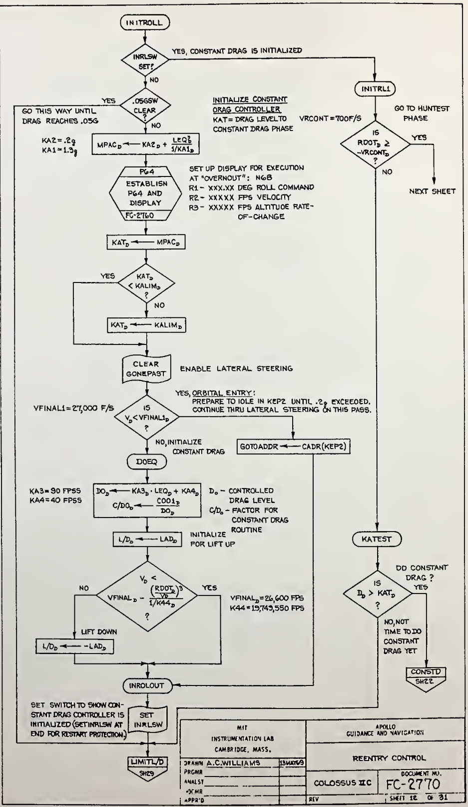


REENTRY CONTROL

COLOSSUS IIC FC-2770

DRAWN Q.H. Dati 30SEP68

11 31


INITROLL
INRLSW SET?
YES, CONSTANT DRAG IS INITIALIZED
NO
INITRL1
YES
.05GSW CLEAR ?
GO THIS WAY UNTIL DRAG REACHES .05G
NO
INITIALIZE CONSTANT DRAG CONTROLLER
KAT= DRAG LEVEL TO CONSTANT DRAG PHASE
VRCONT = 700F/S
GO TO HUNTEST PHASE
IS RDOT_D ≥ -VRCONT_D ?
YES
NO
NEXT SHEET
KA2 = .2g
KA1 = 1.3g
MPAC_D ← KA2_D + LEQ²_D / 1/KA1_D
P64
ESTABLISH P64 AND DISPLAY
FC-2760
SET UP DISPLAY FOR EXECUTION AT "OVERNOUT": N68
R1- XXX.XX DEG ROLL COMMAND
R2- XXXXX FPS VELOCITY
R3- XXXXX FPS ALTITUDE RATE-OF-CHANGE
KAT_D ← MPAC_D
YES
KAT_D < KALIM_D ?
NO
KAT_D ← KALIM_D
CLEAR GONEPAST
ENABLE LATERAL STEERING
YES, ORBITAL ENTRY:
PREPARE TO IDLE IN KEP2 UNTIL .2g EXCEEDED.
CONTINUE THRU LATERAL STEERING ON THIS PASS.
VFINAL1 = 27,000 F/S
IS V_D < VFINAL1_D ?
NO, INITIALIZE CONSTANT DRAG
GOTOADDR ← CADR(KEP2)
DOEQ
KA3 = 90 FPSS
KA4 = 40 FPSS
DO_D ← KA3_D · LEQ_D + KA4_D
C/DO_D ← C001_D / DO_D
D_o - CONTROLLED DRAG LEVEL
C/D_o - FACTOR FOR CONSTANT DRAG ROUTINE
L/D_D ← LAD_D
INITIALIZE FOR LIFT UP
KATEST
DO CONSTANT DRAG ?
IS D_D > KAT_D ?
YES
NO, NOT TIME TO DO CONSTANT DRAG YET
CONSTD
SH22
NO
V_D < VFINAL_D - (RDOT_D / V_D)³ / 1/K44_D ?
YES
VFINAL_D = 26,600 FPS
K44 = 19,749,550 FPS
LIFT DOWN
L/D_D ← -LAD_D
INROLOUT
SET SWITCH TO SHOW CONSTANT DRAG CONTROLLER IS INITIALIZED (SET INRLSW AT END FOR RESTART PROTECTION.)
SET INRLSW
LIMITL/D
SH29
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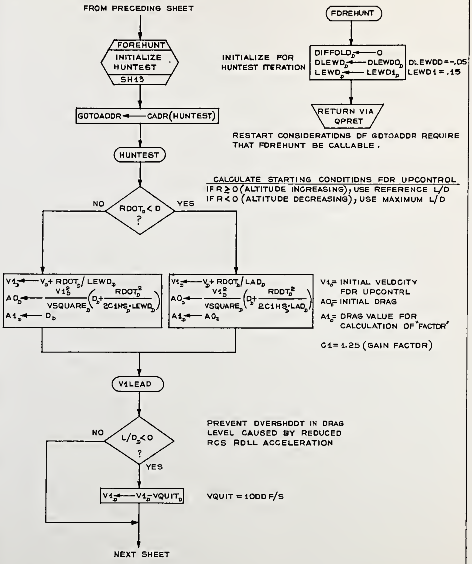
GUIDANCE AND NAVIGATION
DRAWN A.C.WILLIAMS 13MAY69
PRGMR
ANALST
CMR
APPR'D
REENTRY CONTROL
COLOSSUS IIC
DOCUMENT NO.
FC-2770
REV
SHEET 12 OF 31



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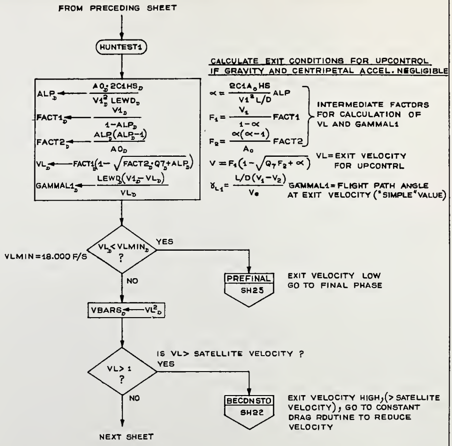
DRAWN D.M. Dietrich 3 OCT 68	REENTRY CONTROL
PRGMR	
ANALST	COLOSSUS IIC DOCUMENT NO. FC-2770
DOCMR	
APPR'D	REV SHEET 13 OF 31



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DRAWN [signature] 3 OCT 68	REENTRY CONTROL
PRGMR	DOCUMENT NO.
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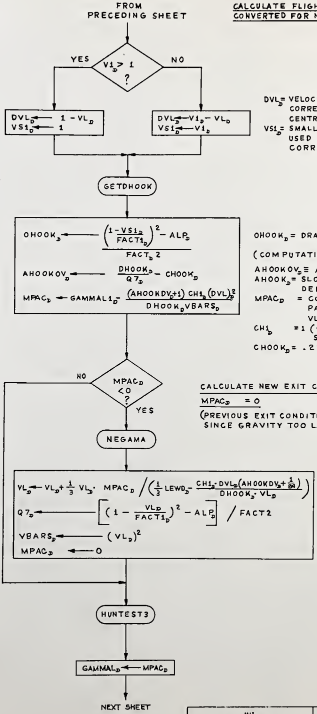
CALCULATE FLIGHT PATH ANGLE (ALTITUOE RATE) CONVERTED FOR NEGLECTEO ACCELERATIONS



DVL_D = VELOCITY CHANGE FOR WHICH THE CORRECTION FOR GRAVITY AND CENTRIPETAL ACCELERATION IS APPLIED

$VS1_D$ = SMALLER OF 1 OR $V1_D$, USED TO LIMIT THE CORRECTION

$OHOOK_D$ = DRAG AT VELOCITY VS1

(COMPUTATION USES OHOOKYQ7 ROUTINE)

$AHOOKOV_D \equiv$ AHOOK OVL

$AHOOK_D$ = SLOPE FOR ASSUMED LIHEAR DENSITY VARIATION

$MPAC_D$ = CORRECTED VALUE OF FLIGHT PATH ANGLE AT EXIT VELOCITY VL FOR UPCONTRL

$CH1_D$ = 1 (CONSIOER THAT $_D$ IS PART OF SYMBOL CH1)

$CHOOK_D$ = .25

CALCULATE NEW EXIT CONDITIONS (VL AND Q7) FOR $MPAC_D$ = 0

(PREVIOUS EXIT CONDITIONS CANNOT BE REACHEO, SINCE GRAVITY TOO LARGE)

VL_D = EXIT VELOCITY

$Q7_D$ = EXIT DRAG LEVEL MINIMUM ORAG FOR UPCONTRL (COMPUTATION USES OHOOKYQ7 ROUTINE)

$MPAC_D$ = EXIT FLIGHT PATH ANGLE

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DRAWN G. J. Levy [signature] 10CT68	REENTRY CONTROL
PRGMR / ANALST / DOCMR / APPR'D	COLOSSUS IIC — FC-2770
	REV — SHEET 15 OF 31

FROM PRECEDING SHEET

$GAMMAL1_D \leftarrow GAMMAL1_D + Q19_D(GAMMAL_D - GAMMAL1_D)$

USE WEIGHTED AVERAGE FOR UP-RANGE

Q19 = .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°)

$COSG/2_D \leftarrow 1 - \frac{(GAMMAL_D)^2}{2}$ — TRUNCATED COSINE SERIES (APPROXIMATION)

$ASKEP_D \leftarrow 2\,SIN^{-1}\left(\frac{VBARS_D \cdot COSG/2_D \cdot GAMMAL_D}{\sqrt{(VBARS_D^2 - VBARS_D)(COSG/2)^2 + 1/16}}\right)$ — KEPLER RANGE = $ASKEP_D$

$ASP1_D \leftarrow Q3_D \cdot VL_D + Q2_D$ — FINAL PHASE RANGE = $ASP1_D$

$ASPUP_D \leftarrow -\left(\frac{C12_D}{GAMMAL1_D}\right) LOG\left(\frac{Q7_D \cdot V1_D^2}{AO_D \cdot VBARS_D}\right)$ — UP PHASE RANGE = $ASPUP_D$

$ASPDWN_D \leftarrow \frac{V_D \cdot RDOT_D}{AO_D \cdot LAD_D} KC3_D$ — RANGE TO PULLOUT = $ASPDWN_D$

$ASP3_D \leftarrow Q5_D\,(Q6_D - GAMMAL_D)$ — GAMMA CORRECTION = $ASP3_D$

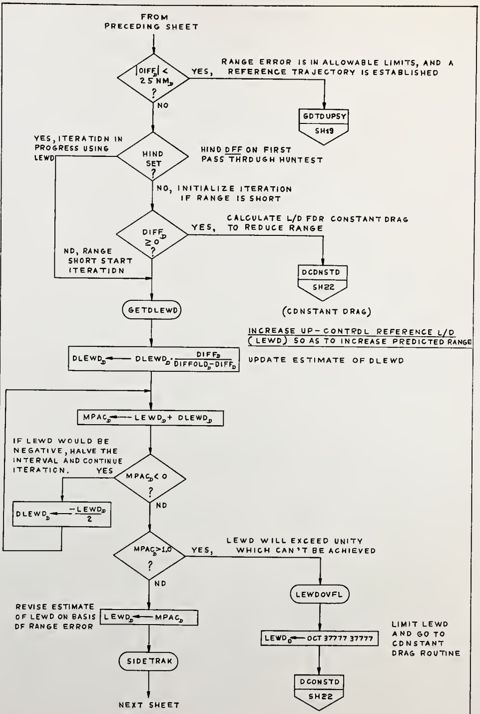
ASPS (TM) ← $ASKEP_S$
ASPS (TM) +1 ← $ASP1_S$
ASPS (TM) +2 ← $ASPUP_S$
ASPS (TM) +3 ← $ASPWN_S$
ASPS (TM) +4 ← $ASP3_O$

HIGH ORDER HALF FOR DOWN TELEMETRY

$DIFF_D \leftarrow ASP3_D + ASPDWN_D + ASPUP_D + ASP1_D + ASKEP_D - THETAH_D$

$DIFF_D$ = PREDICTED RANGE − DESIRED RANGE (THETAH CALCULATED IN TARGETNG

NEXT SHEET



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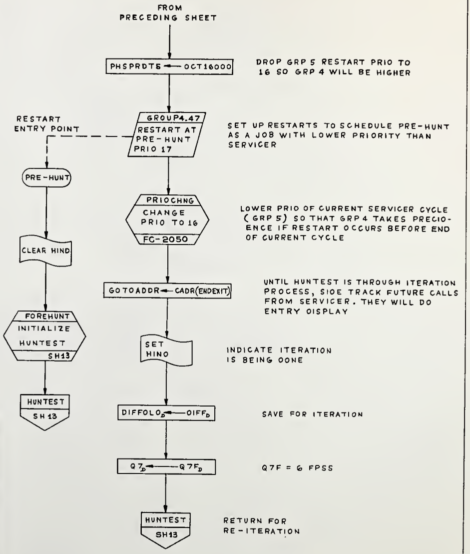
DRAWN [signature] 2OCT68	REENTRY CONTROL
PRGMR	
ANALST	COLOSSUS IIC — FC-2770
DOCMR	
APPR'D	REV — SHEET 17 OF 31



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DRAWN A. J. Longillo 2 OCT 68 / PRGMR / ANALYST / DOCMR / APPR'D	REENTRY CONTROL
	COLOSSUS IIC — DOCUMENT NO. FC-2770
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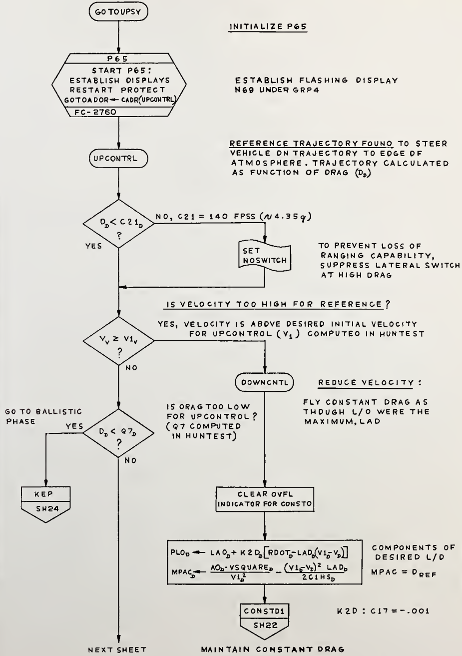

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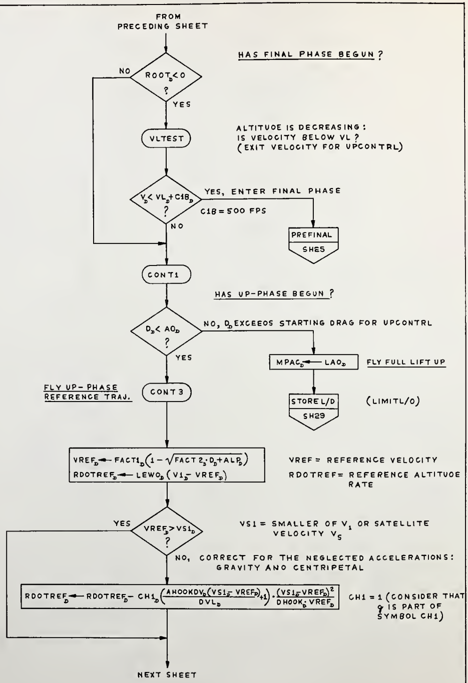
DRWN 4 OCT 68	REENTRY CONTROL
CHKD / ANALYST / DOC MP / APPR'D	COLOSSUS IIC — DOCUMENT No. FC-2770
REV	SHEET 19 OF 31



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APOLLO GUIDANCE AND NAVIGATION

REENTRY CONTROL

DRAWN	A. J. Fangillo	4 OCT 68
PRGMR		
ANALST		
DOCMR		
APPR'D		

COLOSSUS IIC

DOCUMENT NO. FC-2770

REV

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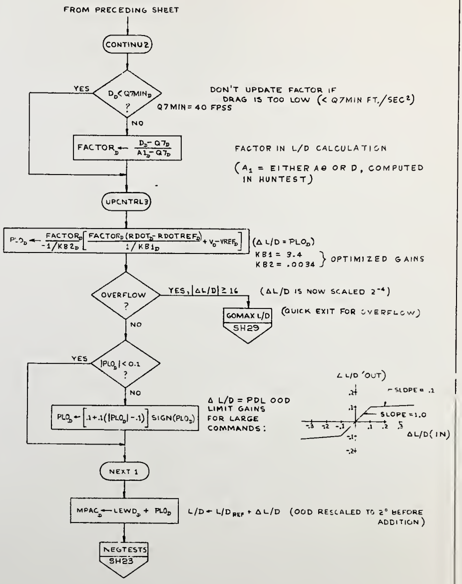

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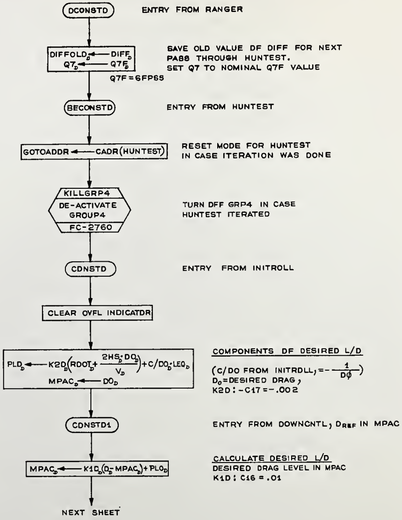
DRAWN PRGMR ANALST DOCMR APPR'D/	REENTRY CONTROL	
	COLOSSUS IIC	DOCUMENT NO. FC 2770
	REV	SHEET 21 OF 31



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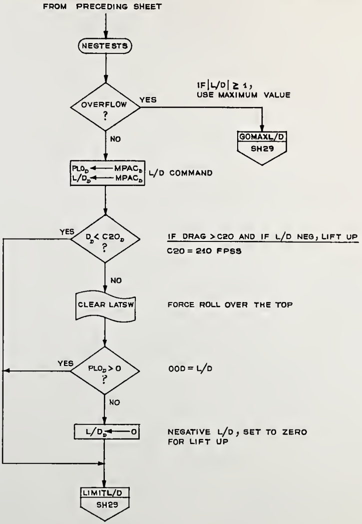
DRAWN R. M. Dietrich 4 OCT 68 PRGMR ANALST DOCMR APPR'D	REENTRY CONTROL COLOSSUS IIC — DOCUMENT NO. FC-2770 REV — SHEET 22 OF 31



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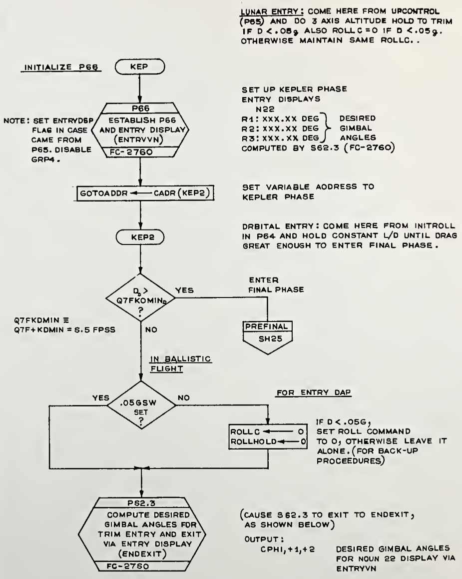
DRAWN [signature] 7 OCT 66 PRGMR ANALST DOCMR APPR'D	REENTRY CONTROL COLOSSUS IIC DOCUMENT NO. FC-2770 REV SHEET 23 OF 31



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DRAWN D.M. Didn... 8 OCT 68	REENTRY CONTROL
PRGMR	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2770
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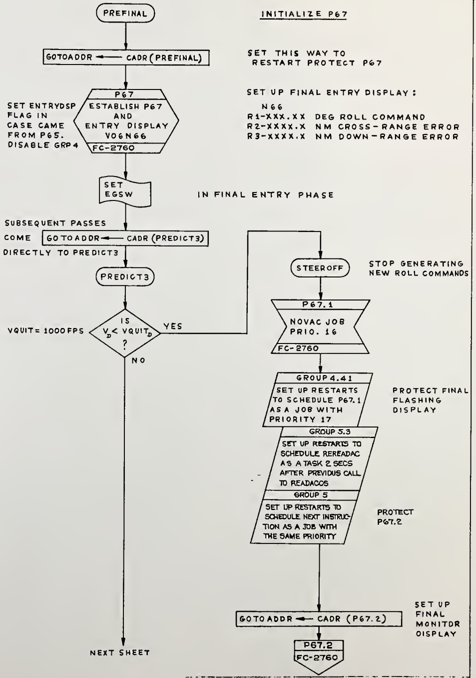
APPR'D	REV SHEET 24 OF 31



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DRAWN 18 OCT 68

APOLLO GUIDANCE AND NAVIGATION

REENTRY CONTROL

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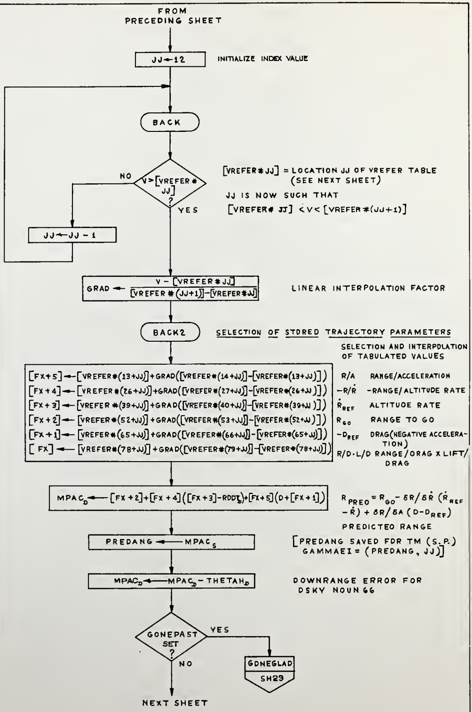

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DRAWN G. J. [signature] 8 OCT 68	REENTRY CONTROL
PRGMR	DOCUMENT NO.
ANALST	COLOSSUS IIC FC-2770
DOCMR	
APPR'D	REV SHEET 26 OF 31

	V_{REF} FPS	dR/dD NM/FPSS	-dR/d$\dot{R}$ NM/FPS	$\dot{R}_{REF}$ FPS	R_{TOGO} NM	$-D_{REF}$ FPSS	dR/dL/D NM
VREFER:	994	VREFER +13 -.0346	VREFER +26 -.0025[illegible]7	VREFER +39 -690.9	VREFER +52 3.7	VREFER +65 -41.15	VREFER +78 12.20
	2103	-.05551	— .003582	-719	10.4	-60.0	21.82
	3922	-.09034	— .007039	-694	23.6	-81.5	43.28
	6295	-.1410	— .01446	-609	46.3	-93.9	96.70
	8531	-.1978	— .02479	-493	75.4	-98.5	187.44
	10101	-.2372	— .03391	-416	99.9	-102.3	282.2
VREFER+6:	14014	-.3305	— .06139	-352	170.9	-118.7	329.4
	15951	-.3605	— .07683	-416	210.3	-125.2	465.5
	18357	-.4956	— .09982	-566	266.8	-120.4	682.7
	20829	-.6483	— .1335	-781	344.3	-95.4	980.5
	23090	-2.021	— .2175	-927	504.8	-28.1	1385
	23500	-3.354	— .3046	-820	643.0	-6.4	1508
VREFER+12:	35000	-3.354	— .3046	-820	794.3	-6.4	1508

THIS TABLE IS STORED SEQUENTIALLY BEGINNING AT LOCATION "VREFER"

V_{REF} = VELOCITY, THE INDEPENDENT VARIABLE

dR/dD = CHANGE IN RANGE VS CHANGE IN ATMOSPHERIC DRAG

-dR/d$\dot{R}$ = CHANGE IN RANGE VS CHANGE IN ALTITUDE RATE (NEGATED)

$\dot{R}_{REF}$ = ALTITUDE RATE OF REFERENCE TRAJECTORY

R_{TOGO} = RANGE TO GO OF REFERENCE TRAJECTORY

$-D_{REF}$ = ATMOSPHERIC DRAG OF REFERENCE TRAJECTORY

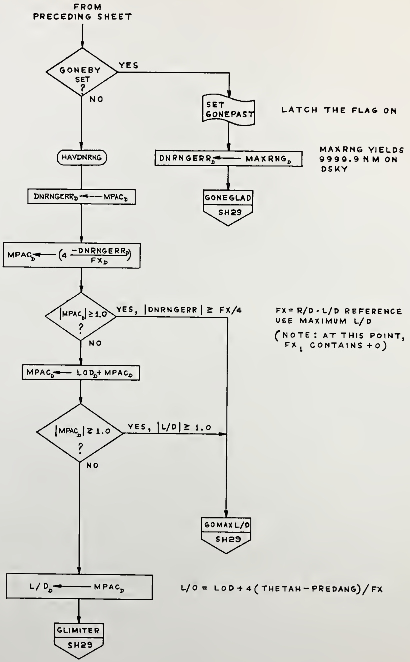
dR/dL/D = CHANGE IN RANGE VS CHANGE IN LIFT/DRAG

LOCATIONS VREFER — VREFER + 12
LOCATIONS VREFER + 13 — VREFER + 25
LOCATIONS VREFER + 26 — 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/d$\dot{R}$ IS JJ + 26, ETC.

FOR INSTANCE: IF V = 14014, JJ = 6 SINCE VREFER + 6 = 14014. THEN dR/dD = VREFER + 13 + 6 = -.3305;
-dR/d$\dot{R}$ = VREFER + 26 + 6 = -.06139, $\dot{R}_{REF}$ = VREFER + 39 + 6 = -352, R_{TOGO} = VREFER + 52 + 6 = 170.9
D_{REF} = VREFER + 65 + 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.



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DRAWN [signature] 9OCT68	REENTRY CONTROL
PPGMR	
ANALYST	DOCUMENT NO.
DOC MR	COLOSSUS IIC FC-2770
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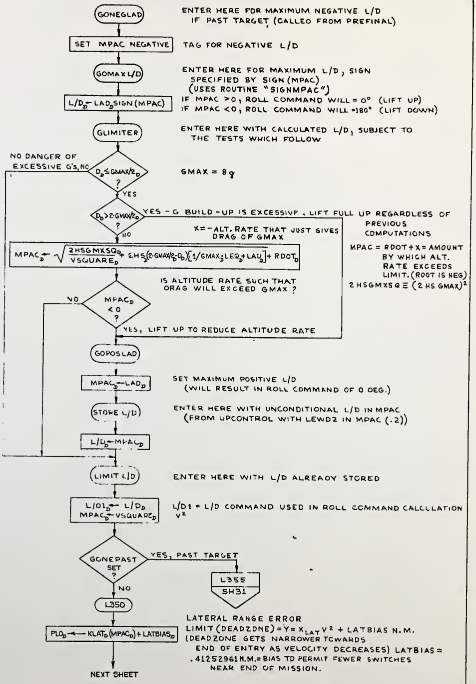

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DRAWN A. J. Lanzillo 19 JUL 68	REENTRY CONTROL
PRGMR	
ANALST	COLOSSUS II C — DOCUMENT NO. FC 2770
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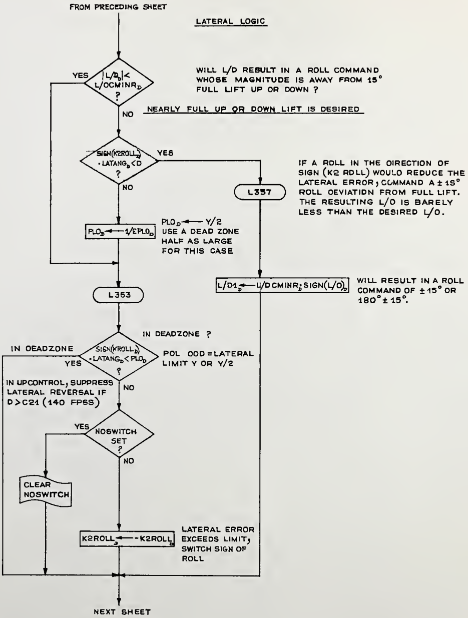
LATERAL LOGIC



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DRAWN D.M. Dietrich 8 OCT 68	REENTRY CONTROL
PRGMR	
ANALST	DOCUMENT NO.
DOCMR	COLOSSUS IIC FC-2770
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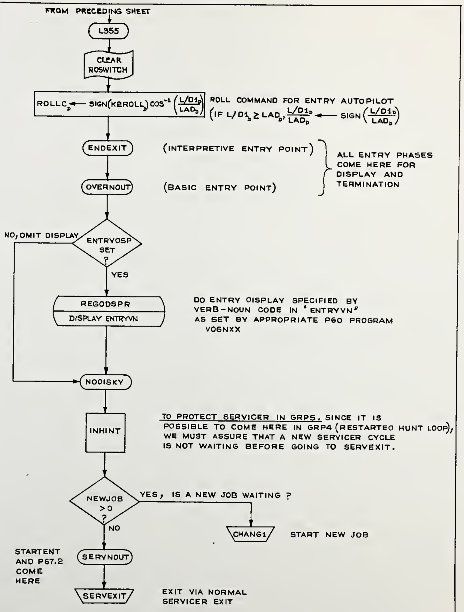

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REENTRY CONTROL

COLOSSUS IIC FC-2770

31 31

ENTRY DIGITAL AUTOPILOT

PRELIMINARY

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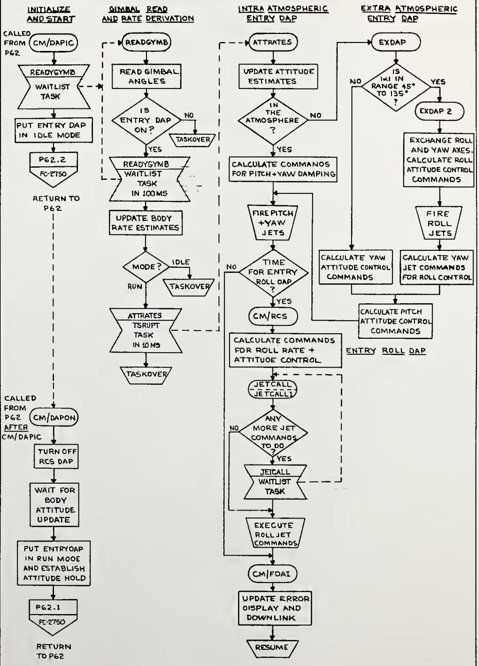
DRAWN A.C.WILLIAMS	6MAY69	ENTRY DIGITAL AUTOPILOT	
PRGMR			
ANALST		COLOSSUS II C	DOCUMENT NO. FC-2780
DOCMR			
APPR'D		REV	SHEET 1 OF 24

ENTRY DIGITAL AUTOPILOT — OVERALL VIEW



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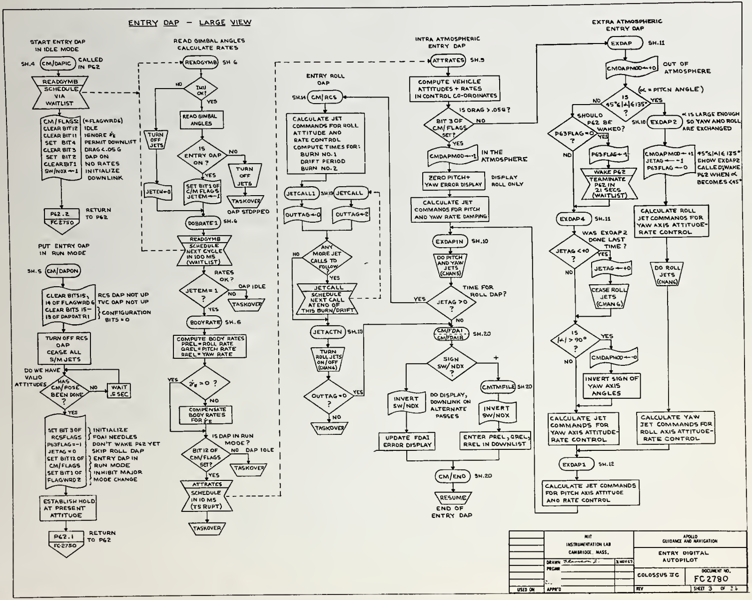
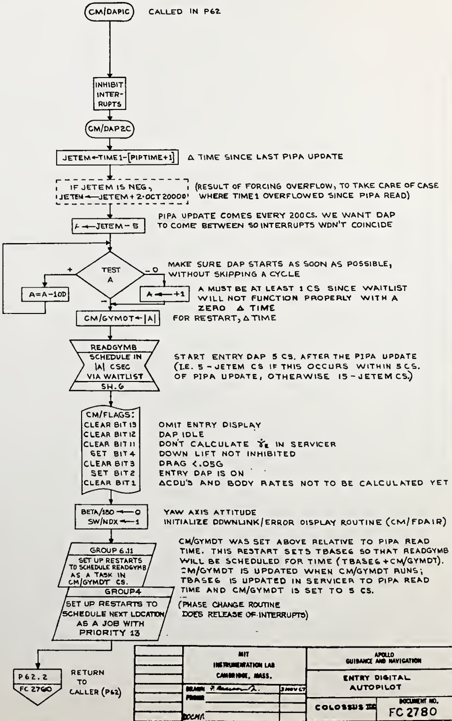
	DRAWN F. Reason Jr. 31 OCT 67	ENTRY DIGITAL AUTOPILOT
	PRGMR	COLOSSUS IIC — DOCUMENT NO. FC 2780
USED ON	APPR'D	REV — SHEET 2 OF 24



ENTRY DAP – LARGE VIEW
START ENTRY DAP IN IDLE MODE
SH.4 CM/DAPIC CALLED IN P62
READGYMB SCHEDULE VIA WAITLIST
CM/FLAGS: (=FLAGWRD6) CLEAR BIT12 IDLE; CLEAR BIT11 IGNORE; SET BIT4 PERMIT DOWNLIFT; CLEAR BIT3 DRAG < .05 G; SET BIT2 DAP ON; CLEARBIT1 NO RATES; SW/NDX ← 1 INITIALIZE DOWNLINK
P62.2 FC2750 RETURN TO P62
PUT ENTRY DAP IN RUN MODE
SH.5 CM/DAPON
CLEAR BITS15, 14 OF FLAGWRD6 RCS DAP NOT UP; TVC DAP NOT UP; CLEAR BITS 15-13 OF DAPDATR1 CONFIGURATION BITS = 0
TURN OFF RCS DAP CEASE ALL S/M JETS
DO WE HAVE VALID ATTITUDES
HAS CM/POSE BEEN DONE ?
NO
WAIT .5 SEC
YES
SET BIT 3 OF RCSFLAGS INITIALIZE FDAI NEEDLES; P63FLAG=-1 DON'T WAKE P62 YET; JETAG = 0 SKIP ROLL DAP; SET BIT12 OF CM/FLAGS ENTRY DAP IN RUN MODE; SET BIT1 OF FLAGWRD2 INHIBIT MAJOR MODE CHANGE
ESTABLISH HOLD AT PRESENT ATTITUDE
P62.1 FC-2750 RETURN TO P62
READ GIMBAL ANGLES CALCULATE RATES
READGYMB SH 6
IMU OK?
NO
YES
READ GIMBAL ANGLES
TURN OFF JETS
IS ENTRY DAP ON ?
NO
YES
TURN OFF JETS
TASKOVER
DAP STOPPED
JETEM ← 0
SET BIT1 OF C/M FLAGS JETEM ← 1
DOBRATE1 SH.6
READGYMB SCHEDULE NEXT CYCLE IN 100 MS (WAITLIST)
RATES OK?
JETEM = 1 ?
NO
DAP IDLE
TASKOVER
YES
BODYRATE SH.6
COMPUTE BODY RATES PREL = ROLL RATE QREL = PITCH RATE RREL = YAW RATE
YES
$\dot{\gamma}_E = 0$?
NO
COMPENSATE BODY RATES FOR $\dot{\gamma}_E$
IS DAP IN RUN MODE?
BIT 12 OF CM/FLAGS SET?
NO
DAP IDLE
TASKOVER
YES
ATTRATES SCHEDULE IN 10 MS (T5 RUPT)
TASKOVER
ENTRY ROLL DAP
SH.14 CM/RCS
CALCULATE JET COMMANDS FOR ROLL ATTITUDE AND RATE CONTROL COMPUTE TIMES FOR: BURN NO.1 DRIFT PERIOD BURN NO.2
JETCALL1 SH.15 JETCALL
OUTTAG ← 0
OUTTAG ← 2
ANY MORE JET CALLS TO FOLLOW ?
NO
YES
JETCALL SCHEDULE NEXT CALL AT END OF THIS BURN/DRIFT
JETACTN SH.15
TURN ROLL JETS ON/OFF (CHAN6)
OUTTAG = 0 ?
YES
NO
TASKOVER
INTRA ATMOSPHERIC ENTRY DAP
ATTRATES SH.5
COMPUTE VEHICLE ATTITUDES + RATES IN CONTROL CO-ORDINATES
IS DRAG > .05G ?
BIT 3 OF CM/FLAGS SET ?
NO
YES
CMDAPMOD ← -1 IN THE ATMOSPHERE
ZERO PITCH + YAW ERROR DISPLAY
DISPLAY ROLL ONLY
CALCULATE JET COMMANDS FOR PITCH AND YAW RATE DAMPING
EXDAPIN SH.10
DO PITCH AND YAW JETS (CHAN5)
TIME FOR ROLL DAP?
YES
JETAG > 0 ?
NO
CM/FDAI CM/FDAIR SH.20
SIGN SW/NDX ?
+
CMTMFILE SH 20
INVERT SW/NDX
DO DISPLAY, DOWNLINK ON ALTERNATE PASSES
INVERT SW/NDX
UPDATE FDAI ERROR DISPLAY
ENTER PREL, QREL, RREL IN DOWNLIST
CM/END SH.20
RESUME
END OF ENTRY DAP
EXTRA ATMOSPHERIC ENTRY DAP
EXDAP SH.11
CMDAPMOD ← +0 OUT OF ATMOSPHERE
(α = PITCH ANGLE)
IS 45° ≤ |α| ≤ 135° ?
NO
YES
SHOULD P62 BE WAKED?
P63FLAG = 0 ?
YES
NO
P63FLAG ← 1
WAKE P62 TERMINATE P62 IN 21 SECS (WAITLIST)
SH.10 EXDAP2
α IS LARGE ENOUGH SO YAW AND ROLL ARE EXCHANGED
CMDAPMOD ← +1 JETAG ← -1 P63FLAG ← 0
45° ≤ |α| ≤ 135° SHOW EXDAP2 CALLED; WAKE P62 WHEN α BECOMES < 45°
CALCULATE ROLL JET COMMANDS FOR YAW AXIS ATTITUDE-RATE CONTROL
DO ROLL JETS (CHAN6)
EXDAP4 SH.11
WAS EXDAP2 DONE LAST TIME ?
JETAG < +0 ?
YES
NO
JETAG ← +0
CEASE ROLL JETS (CHAN 6)
IS |α| > 90° ?
YES
NO
CMDAPMOD ← -0
INVERT SIGN OF YAW AXIS ANGLES
CALCULATE JET COMMANDS FOR YAW AXIS ATTITUDE-RATE CONTROL
CALCULATE YAW JET COMMANDS FOR ROLL AXIS ATTITUDE-RATE CONTROL
EXDAP1 SH.12
CALCULATE JET COMMANDS FOR PITCH AXIS ATTITUDE AND RATE CONTROL
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.
DRAWN 2 NOV 67
PRGMR
APPR'D
USED ON
APOLLO GUIDANCE AND NAVIGATION
ENTRY DIGITAL AUTOPILOT
COLOSSUS IIC
DOCUMENT NO. FC2780
REV
SHEET 3 OF 24

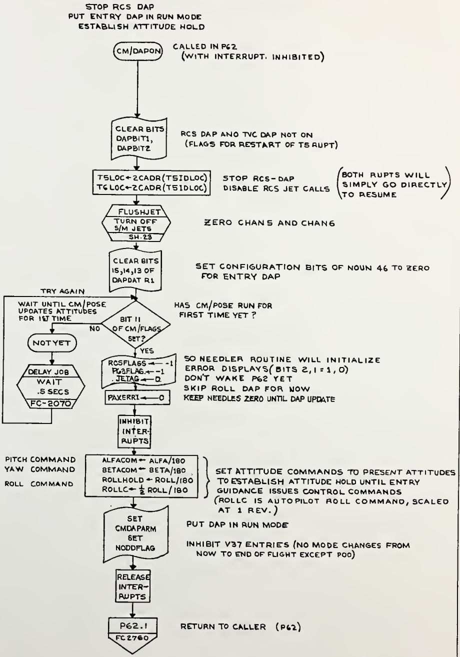
ENTRY DAP START ROUTINE

START ENTRY DAP IN IDLE MODE
TO INITIALIZE ATTITUDES AND RATES

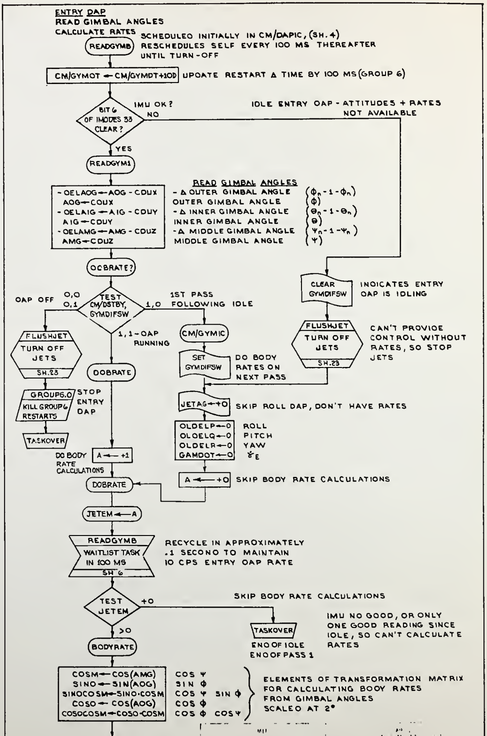


	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	DRAWN [signature] 3 NOV 67	ENTRY DIGITAL AUTOPILOT
	CHECKED	COLOSSUS IIC — DOCUMENT NO. FC 2780
	DOCMR	
USED ON	APPR'D	REV — SHEET 4 OF 24

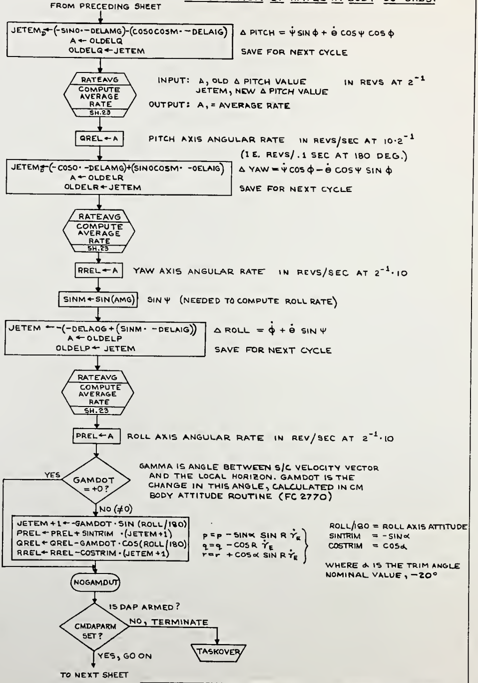
RCS DAP TO ENTRY DAP CHANGEOVER ROUTINE



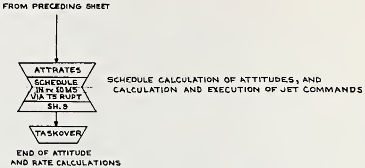
	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
	DRAWN F. Pearson Jr.	7 NOV 67	ENTRY DIGITAL AUTOPILOT
	PROGMR		COLOSSUS IIC · DOCUMENT NO. FC2780
	DOCMR		
USED ON	APPR'D		REV · SHEET 5 OF 24


ENTRY DAP
READ GIMBAL ANGLES
CALCULATE RATES
READGYMB
SCHEDULED INITIALLY IN CM/DAPIC, (SH. 4)
RESCHEDULES SELF EVERY 100 MS THEREAFTER
UNTIL TURN-OFF
CM/GYMDT ← CM/GYMDT+10D
UPDATE RESTART Δ TIME BY 100 MS (GROUP 6)
BIT 6 OF IMODES 33 CLEAR?
IMU OK?
NO
IDLE ENTRY DAP - ATTITUDES + RATES NOT AVAILABLE
YES
READGYM1
READ GIMBAL ANGLES
- DELAOG ← AOG - CDUX
AOG ← CDUX
- DELAIG ← AIG - CDUY
AIG ← CDUY
- DELAMG ← AMG - CDUZ
AMG ← CDUZ
- Δ OUTER GIMBAL ANGLE (Φn-1 - Φn)
OUTER GIMBAL ANGLE (Φ)
- Δ INNER GIMBAL ANGLE (θn-1 - θn)
INNER GIMBAL ANGLE (θ)
- Δ MIDDLE GIMBAL ANGLE (Ψn-1 - Ψn)
MIDDLE GIMBAL ANGLE (Ψ)
DOBRATE?
TEST CM/DSTBY, GYMDIFSW
DAP OFF
0,0
0,1
1,0
1ST PASS FOLLOWING IDLE
1,1 - DAP RUNNING
FLUSHJET
TURN OFF JETS
SH.23
GROUP6.0
KILL GROUP 6 RESTARTS
STOP ENTRY DAP
TASKOVER
DOBRATE
CM/GYMIC
SET GYMDIFSW
DO BODY RATES ON NEXT PASS
CLEAR GYMDIFSW
INDICATES ENTRY DAP IS IDLING
FLUSHJET
TURN OFF JETS
SH.23
CAN'T PROVIDE CONTROL WITHOUT RATES, SO STOP JETS
JETAG ← +0
SKIP ROLL DAP, DON'T HAVE RATES
OLDELP ← 0
OLDELQ ← 0
OLDELR ← 0
GAMDOT ← 0
ROLL
PITCH
YAW
γE
DO BODY RATE CALCULATIONS
A ← +1
A ← +0
SKIP BODY RATE CALCULATIONS
DOBRATE
JETEM ← A
READGYMB
WAITLIST TASK IN 100 MS
SH 6
RECYCLE IN APPROXIMATELY .1 SECOND TO MAINTAIN 10 CPS ENTRY DAP RATE
TEST JETEM
+0
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
>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
MIT
INSTRUMENTATION LA
CAMBRIDGE, MASS.
W. Mayer
8768
ENTRY DIGITAL AUTOPILOT
COLOSSUS IIC
FC-2780
6 - 24

CALCULATION OF RATES IN BODY CO-ORDS.

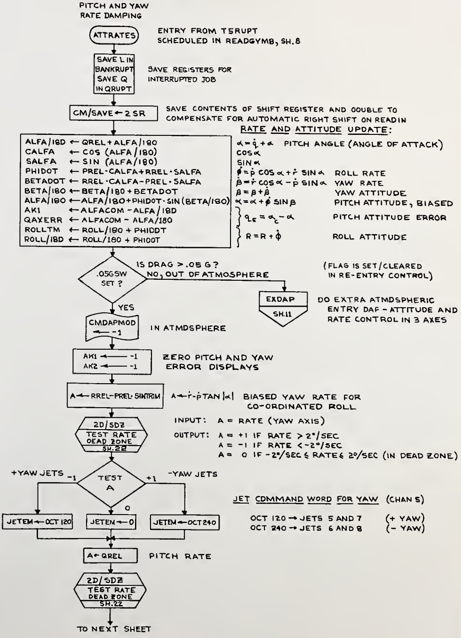


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN [signature] 8 NOV 67	ENTRY DIGITAL AUTOPILOT	
PROJ		
DOCMR	COLOSSUS IIC	DOCUMENT NO. FC 2780
USED ON / APPR'D	REV	SHEET 7 OF 24



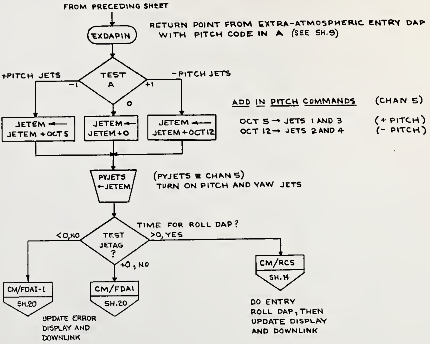
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN F. Raamm J.	ENTRY DIGITAL AUTOPILOT	
PROMR	COLOSSUS IIC	DOCUMENT NO. FC 2780
DOCMR		
USED ON / APPR'D	REV	SHEET 8 OF 24

INTRA ATMOSPHERIC DAP



TO NEXT SHEET

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
	DRAWN [illegible]	9 NOV 67	ENTRY DIGITAL AUTOPILOT
	PRGMR		COLOSSUS IIC — DOCUMENT NO. FC2780
USED ON	APPR'D		REV — SHEET 9 OF 24



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN 7 Pearson 9NOV67
PROJ'R
DOC'MR
APPR'D
USED ON

APOLLO
GUIDANCE AND NAVIGATION

ENTRY DIGITAL
AUTOPILOT

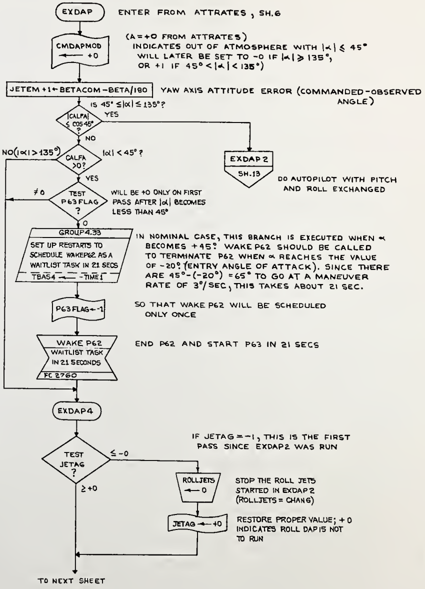
COLOSSUS IIC

DOCUMENT NO. FC2780

REV

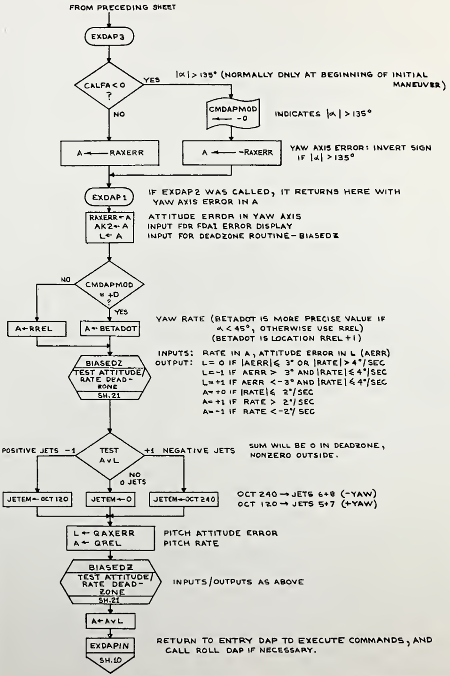
SHEET 10 OF 24

EXTRA ATMOSPHERIC DAP

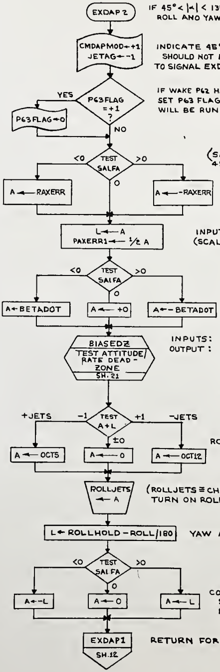


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.
DRAWN F. Pearson J. 10 NOV 67
PROJ'R
APPR'D
USED ON
REV

APOLLO GUIDANCE AND NAVIGATION
ENTRY DIGITAL AUTOPILOT
COLOSSUS IIC
DOCUMENT NO. FC 2790
SHEET 11 OF 24



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN *[signature]* 10 NOV 67	ENTRY DIGITAL AUTOPILOT	
PRGMR	COLOSSUS IIE	DOCUMENT NO. FC 2780
APPR'D	REV	SHEET 22 OF 24
USED ON		



IF 45° < |α| < 135° COME HERE, EXCHANGE ROLL AND YAW, PROVIDE ROLL CONTROL

INDICATE 45° < |α| < 135°, AND THAT ROLL DAP SHOULD NOT BE CALLED
TO SIGNAL EXDAP2 HAS RUN (TESTED IN EXDAP 4, SH8)

IF WAKE P62 HAS NOT BEEN RUN, SET P63 FLAG TO 0 SO WAKE P62 WILL BE RUN WHEN α BECOMES ≤ 45°

(SALFA = SIN(α)) SINCE |α| IS IN THE RANGE 45° TO 135°, SALFA CANNOT BE 0.

ROLL ERROR - COMPLEMENT IF α IS IN RANGE +45° TO +135°
SINCE + YAW IN TRAJECTORY TRIAD ≈ - ROLL FOR S/C

INPUT FOR DEADZONE ROUTINE
(SCALED FOR ERROR DISPLAY ROUTINE)

ROLL RATE - COMPLEMENT IF α IS IN RANGE +45° - +135°

INPUTS: RATE IN A, ATTITUDE ERROR IN L (AERR)
OUTPUT: L = 0 IF |AERR| ≤ 3° OR |RATE| > 4°/SEC
L = -1 IF AERR > 3° AND |RATE| ≤ 4°/SEC
L = +1 IF AERR < -3° AND |RATE| ≤ 4°/SEC
A = +0 IF |RATE| ≤ 2°/SEC
A = +1 IF RATE > 2°/SEC
A = -1 IF RATE < -2°/SEC

ROLL JET CODE:
OCT 12 → JETS 10 + 12, (-ROLL)
OCT 5 → JETS 9 + 11, (+ROLL)
0 → NO JETS

(ROLLJETS ≡ CHAN 6)
TURN ON ROLL JETS

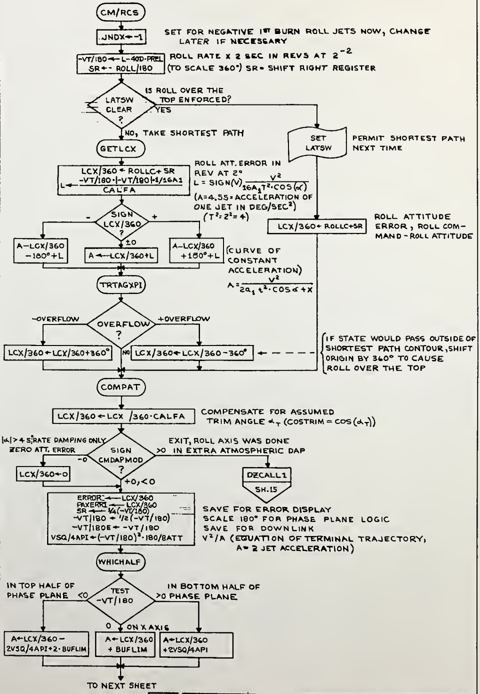
YAW ATTITUDE ERROR

COMPLEMENT IF α IN RANGE -135° TO -45°
SINCE + ROLL IN TRAJECTORY TRIAD ≈ - YAW FOR S/C

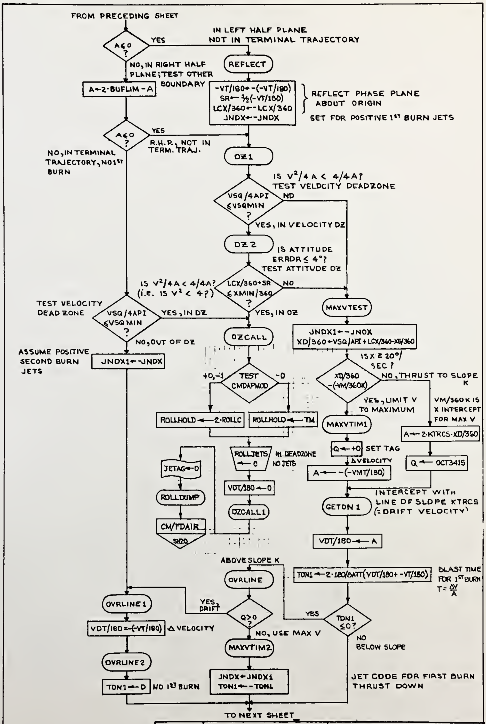
RETURN FOR YAW JETS AND PITCH CONTROL

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN R. Ramsay J. 13 NOV 67	ENTRY DIGITAL AUTOPILOT
PROGR	
DOC/MR	COLOSSUS IIC — DOCUMENT NO. FC 2780
USED ON — APPR'D — REV	SHEET 13 OF 24

ENTRY ROLL DAP



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN T. Reaves 1. 13 NOV 67	ENTRY DIGITAL AUTOPILOT	
PROJECT		
APPR'D	COLOSSUS IIC	DOCUMENT NO. FC 2780
USED ON	REV	SHEET 14 OF 24



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN [illegible] 14 NOV 67
PROG'R
[illegible]
APPR'D
USED ON

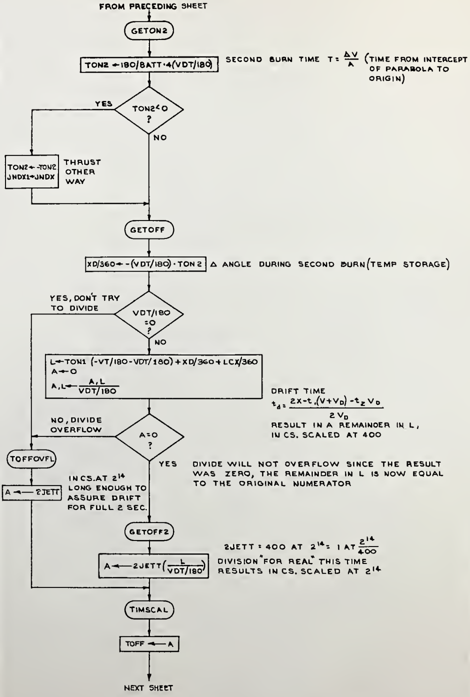
APOLLO
GUIDANCE AND NAVIGATION

ENTRY DIGITAL AUTOPILOT

COLOSSUS II
REV

DOCUMENT NO.
FC 2780

SHEET 15 OF 24



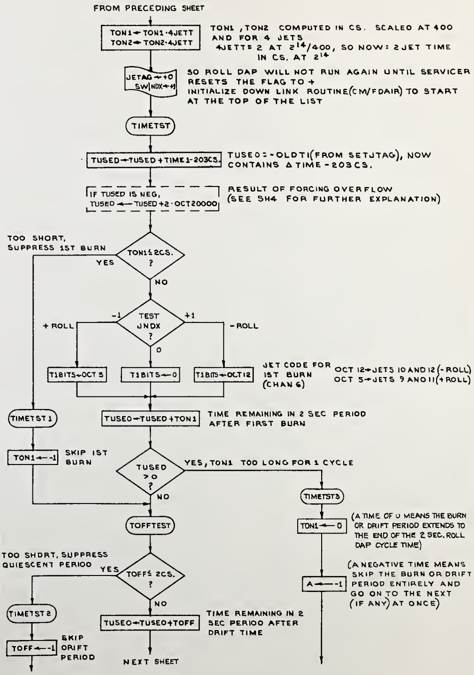
MIT INSTRUMENTATION LAB
W. Mayer 8568

ENTRY DIGITAL AUTO PILOT

COLOSSUS IIC

FC-2780

16 of 24



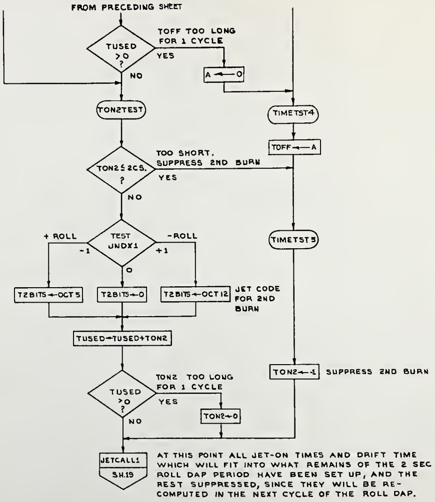
W. Mason

ENTRY DIGITAL AUTOPILOT

COLOSSUS IIC

FC-2780

17 24



DRAWN W. Major 8668
CHKD
APPR'D

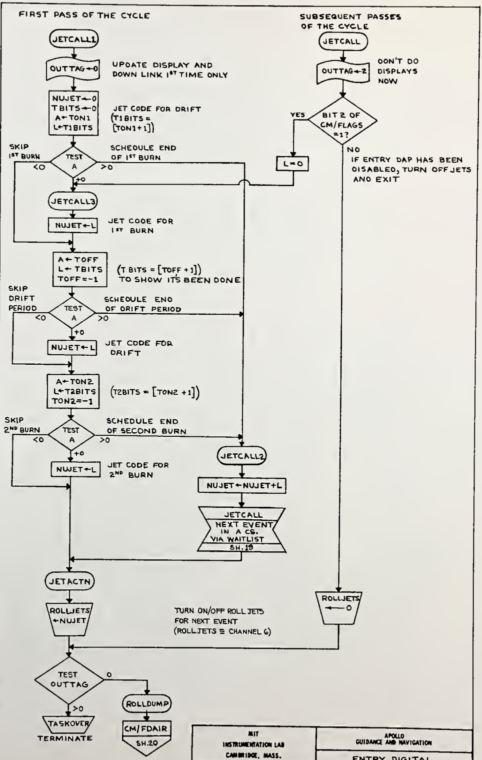
ENTRY DIGITAL AUTO PILOT

COLOSSUS IIC

FC-2780

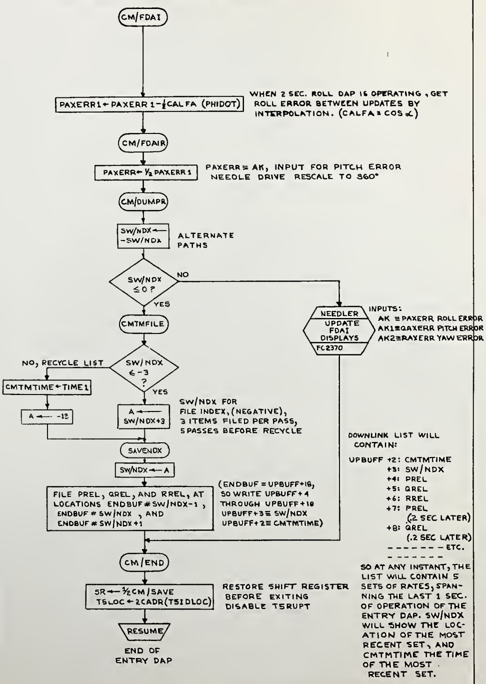
REV

SHEET 18 OF 24



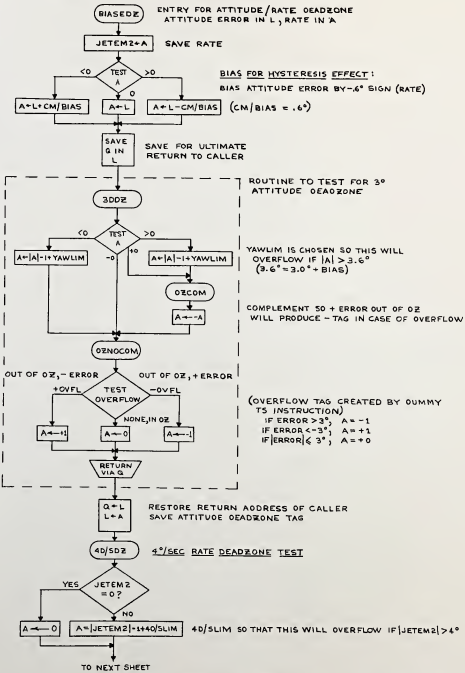
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN P. Peterson Jr. 16 NOV 67	ENTRY DIGITAL AUTOPILOT	
PROGR		
DCMP	COLOSSUS 2C	DOCUMENT NO. FC 278 0
USED ON / APPR'D	REV	SHEET 19 OF 24

FDAI ERROR DISPLAY AND DOWNLINK

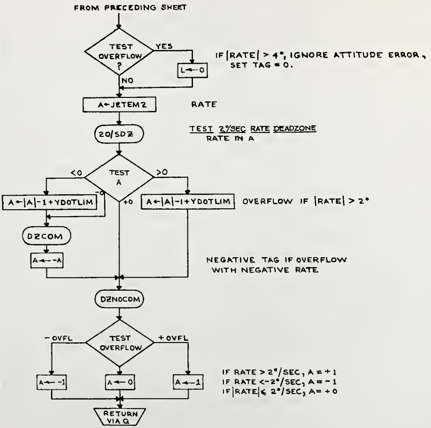


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN F. Ramsey Jr. 17 JAN 67	ENTRY DIGITAL AUTOPILOT	
CHECKED	COLOSSUS 3A	DOCUMENT NO. FC 2780
APP'D	REV	SHEET 20 OF 24
USED ON		

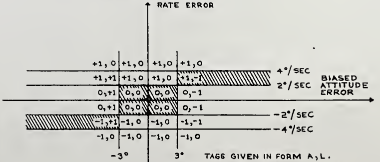
DEADZONE TEST ROUTINE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN *[signature]* 20 Nov 67	ENTRY DIGITAL AUTOPILOT	
PROGR		
DCCMR APPR'D	COLOSSUS IIC	DOCUMENT NO. FC2780
USED ON	REV	SHEET 21 OF 24



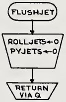
PHASE PLANE LOGIC



TAGS GIVEN IN FORM A, L.
IF SUM OF TAGS = 0, STATE IS IN DEADZONE.
ABOVE OR TO THE LEFT, SUM > 0, NEGATIVE JETS FIRED.
BELOW OR TO THE RIGHT, SUM < 0, POSITIVE JETS FIRED.

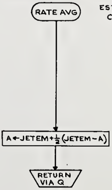
	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
	DRAWN	ENTRY DIGITAL AUTOPILOT
	FROM	COLOSSUS · DOCUMENT NO. FC 2780
USED ON	APPR'D	REV · SHEET 22 OF 24

JET TURN OFF ROUTINE



CHAN 6 } TURN OFF ALL
CHAN 5 } RCS JETS

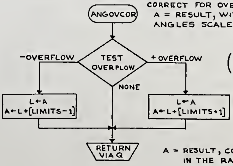
AVERAGE RATE ROUTINE



ESTIMATE AVERAGE RATE ASSUMING CONSTANT ACCELERATION

A = OLD RATE : $\Delta\theta_0$
JETEM = NEW $\Delta\theta$: $\Delta\theta_1$
$$RATE = \Delta\theta_1 + \left(\frac{\Delta\theta_1 - \Delta\theta_0}{2}\right)$$

ANGLE OVERFLOW CORRECTION ROUTINE



CORRECT FOR OVERFLOW ON ANGLE COMPUTATIONS
A = RESULT, WITH POSSIBLE OVERFLOW.
ANGLES SCALED 180°

$\left(\begin{array}{l} LIMITS - 1 = POSMAX \approx +180° \\ LIMITS + 1 = POSMAX = -180° \end{array} \right)$

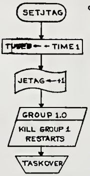
ON + OVERFLOW, $L = A - 180°$
$A = L - 180° = A - 360°$

ON − OVERFLOW, $L = A + 180°$
$A = L + 180° = A + 360°$

A = RESULT, CORRECTED FOR OVERFLOW (I.E., EXPRESSED IN THE RANGE $-180° < A < +180°$)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN F. Bowman Jr. 24 NOV 67	ENTRY DIGITAL AUTOPILOT	
PROGMR		
DCCMR	COLOSSUS IIC	DOCUMENT NO. FC2780
USED ON / APPR'D	REV	SHEET 23 OF 24

ROUTINE TO ENABLE
ENTRY ROLL DAP



CALLED BY SERVICER EVERY 2 SECONDS DURING RE-ENTRY TO REQUEST ROLL DAP

SAVE CURRENT TIME FOR USE BY ENTRY ROLL DAP

ENTRY ROLL DAP TO BE DONE IN NEXT CYCLE OF ENTRY DAP (SEE SH.7)

DON'T RESTART GROUP 1 (SET JTAG WAS PROTECTED IN GROUP 1.3 BY SERVICER)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN F. Pearson Jr.	24 NOV 67	ENTRY DIGITAL AUTOPILOT
CHECKED		COLOSSUS IIC — DOCUMENT NO. FC 2780
DCMR APPR'D		REV — SHEET 24 OF 24
USED ON		

12 DECEMBER 1969

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-8		
	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	T-12
	FC-2680	Thrust Programs (P40, P41) S-33,36		
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		
AVWMIDSW	FC-2300	Orbital Integration	C-40	
AXISGEN	FC-2720	P52 IMU Realignment Program CALLED 20		
AZMTHCG1	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		
BAILOUT	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		
BDP2Z	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		

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         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
CALCTFF  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 TFFConics 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
CDHMVR   FC-2626 P32, P72--CSI CALLED 16
         FC-2627 P33, P73--CDH ENTRY  5
CDRVE    FC-2200 T4RUPT 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
CDUTOCSM 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 Insertation 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
CHAZFOGC FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY  33
CHECKCTP 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 SXTMARK 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-2360 R64 (R05)--S-Band Antenna CALLED 2
         FC-2361 V89 (R63) CALLED 2
         FC-2190 Extended Verbs CALLED 2
CHKSCODE FC-2720 P52 IMU Realignment Program CALLED 18
         FC-2730 R52, R53, R56 ENTRY  12
CHKSDATA FC-2720 P52 IMU Realignment Program CALLED 20
CKMID2   FC-2300 Orbital Integration ENTRY  36
CKOPTVP  FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY  26
CLEANDSP FC-2760 P60's Entry Programs CALLED 10
CLEARMRK FC-2020 Fresh Start and Restart CALLED 24,36
         FC-2240 SXTMARK CALLED 8
         FC-2730 R52, R53, R56 CALLED 5,14
         FC-2760 P60's Entry Programs CALLED 4
CLOCKJOB FC-2681 Cloktask and Clockjob ENTRY  4
CLOKTASK FC-2626 P32, P72--CSI CALLED 23
         FC-2680 Thrust Programs (P40, P41) CALLED 12
         FC-2681 Cloktask and Clockjob ENTRY  3
CMDAPARM FC-2070 Service Routines            C-6
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	FC-2683	Servicer		T-6
	FC-2780	CM Entry Digital Autopilot S-5		T-7
CMDSOUT	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		
CNTNUP30	FC-2620	P30, P31 ENTRY 6		
CNTRCHK	FC-2120	AGC Block Two Selfcheck ENTRY 7		
COAALIGN	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 36		
COGAFLAG	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		
COMPTGO	FC-2620	P30, P31 CALLED 5,10		
	FC-2626	P32, P72--CSI ENTRY 22		
COMPUTER	FC-2070	Service Routines	C-6	
COMPVER	FC-2530	Prelaunch Initialization and Gyro Compassing ENTRY 26		
CPHIFLAG	FC-2070	Service Routines	C-6	
	FC-2760	P60's Entry Programs	C-33	
CREWMANU	FC-2330	R62 Crew Defined Maneuver (V49) ENTRY 2		
CRS61.1	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	V89 (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-2642	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	C-17	T-14,15
	FC-2730	R52, R53, R56		T-7
CURTAINS	FC-2140	Alarm 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		T-10
	FC-2020	Fresh Start and Restart	C-6	T-20,21,30
	FC-2680	Thrust Programs (P40, P41) S-22	C-21	T-27,44
	FC-2780	CM Entry Digital Autopilot	C-5	

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GOODEND  FC-2550 P20 Rendezvous Navigation CALLED 34
GOPERF1  FC-2220 P06 GNCS Power Down CALLED 3
GOPIN    FC-2370 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
GRRBKFLG FC-2070 Service Routines                C-6
GTSCPSS1 FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY  2
GUESSW   FC-2310 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
HAVEGUES FC-2641 Common Targeting Subroutines ENTRY  4
         FC-2641 Common Targeting Subroutines ENTRY  4
HIENERGY FC-2310 Conic Subroutines ENTRY  21
HIND     FC-2070 Service Routines                C-6
         FC-2770 Reentry Control S-18           C-6,18        T-17
HORIZ    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
IMUBAD   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
IMUFIN20 FC-2720 P52 IMU Realignment Program CALLED 23
IMUMON   FC-2200 T4RUPT ENTRY  25
IMUOP    FC-2200 T4RUPT ENTRY  32
IMUPULSE 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
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         FC-2070 Service Routines              C-6
INCORP1  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
INCORP2  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          T-12,18,22
         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          T-12
INSTALL  FC-2580 P21 Ground Track Determination CALLED 3
         FC-2610 Measurement Incorporation CALLED 7
INTEGREV 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
INTEGRVS 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
INTEGRV2 FC-2290 Integration Initialization ENTRY  8
         FC-2300 Orbital Integration CALLED 35
INTFLAG  FC-2290 Integration Initialization S-11        C-13          T-10
         FC-2020 Fresh Start and Restart           C-18,20,6
INTGRATE FC-2300 Orbital Integration ENTRY  8
INTGRVS  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
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          FC-2300 Orbital Integration CALLED 40
          FC-2320 TFFConics CALLED 14
          FC-2605 Navigation Extended Verbs CALLED 4
          FC-2610 Measurement Incorporation CALLED 12
INTWAKEO  FC-2290 Integration Initialization ENTRY  12
          FC-2670 P76 Target Delta V Program CALLED 4
INTWAKEU  FC-2290 Integration Initialization ENTRY  14
INTWAKE0  FC-2320 TFFConics CALLED 14
INTYPFLG  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
ISWRETRN  FC-2080 Inter-bank Communication ENTRY  4
ITERATOR  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 Subrontines ENTRY  4
KEPPREP   FC-2290 Integration Initialization CALLED 9
          FC-2300 Orbital Integration ENTRY  29
KEYCOM    FC-2150 Keyrnpt 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
KMATRIX   FC-2390 RCS DAP Phase 2 CALLED 6
KNOWNFLG  FC-2590 P22 Orbital Navigation S-6          C-6           T-7,13
          FC-2070 Service Routines              C-6
LALOTORV  FC-2320 TFFConics 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
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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
LEMCONIC 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
LEMPREC  FC-2290 Integration Initialization ENTRY  6
         FC-2325 Rendezvous Parameters Displays CALLED 7,10
         FC-2641 Common Targeting Subroutines CALLED 15
LEMSTOFF FC-2545 P17/P77--TPI Search Programs CALLED 3
         FC-2641 Common Targeting Subroutines ENTRY  15
LETFLGON FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY  33
LINUS    FC-2340 R60 Attitude Maneuver CALLED 8
LINVEL   FC-2300 Orbital Integration CALLED 44
LISTINGO FC-2550 P20 Rendezvous Navigation ENTRY  1
         FC-2580 P21 Ground Track Determination ENTRY  1
         FC-2605 Navigation Extended Verbs ENTRY  1
LITTLSUB 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
LMOONFLG 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
LOADCOFF FC-2430 TVC Start-up, Executive, and Service Routines ENTRY  31
LOADTIME 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
LOCSAM   FC-2720 P52 IMU Realignment Program ENTRY  11
LODSAMPT FC-2150 Keyrupt 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
LOWMEMRY FC-2600 P23 Cislunar Midcourse Navigation ENTRY  5
LSPOS    FC-2300 Orbital Integration CALLED 11
         FC-2720 P52 IMU Realignment Program CALLED 11
LUMPOS   FC-2300 Orbital Integration CALLED 45
LUNAFLAG 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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Symbol	Listing	Description		
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	FC-2070	Service Routines	C-6	
	FC-2642	P37 Return To Earth	C-32	
	FC-2730	R52, R53, R56 S-5		
	FC-2760	P60's Entry Programs	C-18	
	FC-2770	Reentry Control	C-7	
LUNAFLG	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		
MARKCONT	FC-2240	SXTMARK ENTRY 5		
MARKDIF	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		
MARKRUPT	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 Insertation Monitor ENTRY 7		
MAXCHK	FC-2620	P30, P31 CALLED 4,8		
MAXDBFLG	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	
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MIDAVFLG	FC-2290	Integration Initialization S-20		
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	FC-2650	Orbital Parameters Display CALLED 7		
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         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
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         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
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PREREAD1 FC-2540 P11 Earth Orbit Insertation Monitor CALLED 4
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         FC-2070 Service Routines              C-6
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PRIOCHNG 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
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PROG20   FC-2550 P20 Rendezvous Navigation ENTRY  3
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PROUT    FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY  37
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PTOACSM  FC-2290 Integration Initialization ENTRY  5
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P17.2    FC-2545 P17/P77--TPI Search Programs ENTRY  5
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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                     T-3
         FC-2020 Fresh Start and Restart              C-8,26,6
P22MKFLG FC-2590 P22 Orbital Navigation S-9          C-4
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P22SUBRB FC-2600 P23 Cislunar Midcourse Navigation CALLED 6
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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
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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
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P47BODY  FC-2700 P47 Thrust Monitor ENTRY  5
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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
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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 (R05)--S-Band Antenna CALLED 4
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         FC-2190 Extended Verbs CALLED 4
         FC-2700 P47 Thrust Monitor CALLED 8
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         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
RCSDAPON 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
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RCSFLAGS FC-2350 Maneuver Calculations and Steering S-10         C-26
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RCSUP    FC-2380 DAP Interface Initialization and Phase I ENTRY  2
RDCDUS   FC-2720 P52 IMU Realignment Program ENTRY  27
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