

APOLLO

GUIDANCE, NAVIGATION AND CONTROL

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APOLLO GUIDANCE AND NAVIGATION PROGRAM

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APOLLO GUIDANCE AND NAVIGATION PROGRAM

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APOLLO GUIDANCE AND NAVIGATION PROGRAM

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INSTRUMENTATION LABORATORY

E-2456

APOLLO GUIDANCE AND NAVIGATION
FLOW CHARTS
PROGRAM COLOSSUS 2C
COMANCHE 67

NOVEMBER 1969

MIT INSTRUMENTATION
LABORATORY
CAMBRIDGE 39, MASSACHUSETTS

ACKNOWLEDGEMENT

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

FOREWORD

This document comprises all flowcharts completed by the date of publication for COLOSSUS 2C programs, routines, and subroutines. (Reference Exhibit D, paragraph 3.3, of M.I.T. Statement of Work, NAS 9-4065, period 1 January 1968-30 June 1970.) Those flowcharts completed and included within the current edition are denoted by an asterisk on the table of contents. As they become available, newly completed flowcharts will be forwarded for inclusion, with an updated contents and index. 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

CONTENTS

<u>Section</u>	<u>Pages</u>
1.0 <u>INTRODUCTION</u>	none
2.0 <u>GENERAL MANAGEMENT AND SERVICE ROUTINES</u>	total (1 + 167)
*FC-2020-FRESH START AND RESTART	1-50
*FC-2030-PHASE TABLE MAINTENANCE	1-16
FC-2041-V69-CAUSE HARDWARE RESTART	none
*FC-2050-EXECUTIVE	1-20
*FC-2060-WAITLIST	1-24
*FC-2070-SERVICE ROUTINES	1-14
*FC-2080-INTER-BANK COMMUNICATION	1- 5
FC-2090-INTERPRETER	none
*FC-2100-RTB OP CODES	1-16
*FC-2110-SINGLE PRECISION SUBROUTINES	1- 4
*FC-2120-AGC BLOCK TWO SELF-CHECK	1-18
	total
3.0 <u>INPUT-OUTPUT ROUTINES</u>	(1 + 73)
FC-2130-DISPLAY INTERFACE ROUTINES	none
*FC-2140-ALARM AND ABORT	1- 9
*FC-2150-KEYRUPT AND UPRUPT	1- 9
FC-2160-UPDATE PROGRAM (P27)	none
FC-2165-V55-ALIGN TIME	none
FC-2170-DOWN-TELEMETRY PROGRAM	none
FC-2176-V74-INITIALIZE ERASABLE DUMP VIA DOWNLINK	none
FC-2190-EXTENDED VERBS	none
FC-2180-PINBALL GAME BUTTONS AND LIGHTS	none
*FC-2200-T4RUPT	1-55
	total
4.0 <u>IMU AND OPTICS ROUTINES</u>	(1 + 11)
FC-2210-IMU MODE SWITCHING ROUTINES	none
FC-2220-PO6 GNCS POWER DOWN	none

FC-2230-IMU COMPENSATION PACKAGE	none
FC-2235-IMU EXTENDED VERBS (V40, V41, V42)	none
*FC-2240-SXTMARK	(+1) 1- 9
*FC-2242-R57 OPTICS CALIBRATION ROUTINE	1
5.0 <u>GEOMETRY TRANSFORMATIONS</u>	total(1 + 3)
FC-2250-CSM GEOMETRY	none
FC-2260-INFLIGHT ALIGNMENT ROUTINES	none
FC-2270-POWERED FLIGHT SUBROUTINES	none
FC-2280-LATITUDE LONGITUDE SUBROUTINES	none
FC-2283-PLANETARY INERTIAL ORIENTATION	none
*FC-2286-LUNAR AND SOLAR EPHEMERIDES	3
6.0 <u>CONIC AND INTEGRATION ROUTINES</u>	total(1 + 153)
*FC-2290-INTEGRATION INITIALIZATION	1-26
*FC-2300-ORBITAL INTEGRATION	1-50
*FC-2310-CONIC SUBROUTINES	(+1) 1-42
FC-2315-INTEGRATION EXTENDED VERBS	none
*FC-2320-TFFCONICS	1-20
*FC-2325-RENDEZVOUS PARAMETERS DISPLAYS	1-14
7.0 <u>MANEUVER ROUTINES</u>	total(1 + 53)
*FC-2330-R62 CREW DEFINED MANEUVER (V49)	1- 4
*FC-2340-R60 ATTITUDE MANEUVER	1- 9
*FC-2350-MANEUVER CALCULATIONS AND STEERING	1-27
*FC-2360-R64 (R05)-S-BAND ANTENNA	1- 6
*FC-2361-V89 (R63)	1- 7
FC-2363-V76, V77 (MANIPULATE PREFERRED ATTITUDE FLAG)	none
8.0 <u>RCS AUTOPILOT</u>	total(1 + 57)
*FC-2370-DAP INTERFACE AND SERVICE ROUTINES	1-20
*FC-2380-RCS DAP INITIALIZATION AND PHASE I	1- 8
*FC-2390-RCS DAP PHASE 2	1-10
*FC-2400-RCS DAP JET SELECTION LOGIC	1-19

9.0	<u>TVC AUTOPILOT</u>	total	(1 + 42)
	*FC-2430-TVC START-UP, EXECUTIVE, AND SERVICE ROUTINES		1-22
	*FC-2440-TVC DAP		1-11
	*FC-2450-STROKE TEST PACKAGE		1- 2
	*FC-2460-ROLL AUTOPILOT		1- 7
10.0	<u>ALIGNMENT AND TEST ROUTINES</u>	total	(1 + 95)
	FC-2520-SYSTEM TEST EXTENDED VERBS (V43,V91)	(+ 1)	1-47
	*FC-2530-PRELAUNCH INITIALIZATION AND GYRO COMPASSING		1-47
11.0	<u>BOOST PROGRAMS</u>		(1 + 48)
	*FC-2540-P11 EARTH ORBIT INSERTION MONITOR		1-27
	*FC-2545-P17/P77-TPI SEARCH PROGRAMS		1-18
12.0	<u>NAVIGATION PROGRAMS</u>	total	(1 + 168)
	*FC-2550-P20 RENDEZVOUS NAVIGATION		1-46
	*FC-2580-P21 GROUND TRACK DETERMINATION		1- 7
	*FC-2590-P22 ORBITAL NAVIGATION		1-44
	*FC-2595-R35 LUNAR LANDMARK SELECTION ROUTINE		1-18
	*FC-2600-P23 Cislunar MIDCOURSE NAVIGATION		1-27
	*FC-2605-NAVIGATION EXTENDED VERBS		1- 7
	*FC-2606-V94 (R64)		1- 3
	*FC-2610-MEASUREMENT INCORPORATION		1-16
13.0	<u>PRE-THRUST TARGETING PROGRAMS</u>	total	(1 + 163)
	*FC-2620-P30, P31		1-12
	*FC-2626-P32, P72-CSI		1-26
	*FC-2627-P33, P73-CDH		1- 7
	*FC-2630-P34-74 TPI TARGETING		1-20
	*FC-2631-R36 (V90)		1- 7
	FC-2640-P35-P75 TPM TARGETING		none
	FC-2641-COMMON TARGETING SUBROUTINES		none
	*FC-2642-P37 RETURN TO EARTH		1-53
	*FC-2644-P38-P78; P39-P79		1-15
	*FC-2650-ORBITAL PARAMETERS DISPLAY		1-17
	*FC-2670-P76 TARGET DELTA V PROGRAM		1- 6

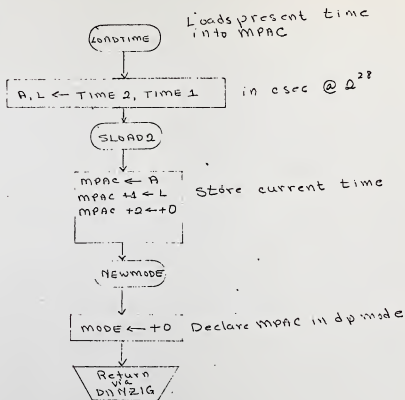
14.0	<u>THRUST PROGRAMS</u>	total (1 + 133)
	*FC-2680-THRUST PROGRAMS (P40, P41)	(+1) 1-58
	*FC-2681-CLOKTASK AND CLOCKJOB	1-17
	*FC-2682-STEERING	1-21
	*FC-2683-SERVICER	1-26
	*FC-2700-P47 THRUST MONITOR	1-10
15.0	<u>ALIGNMENT PROGRAMS</u>	total (1 + 62)
	*FC-2710-P51, P53 IMU ORIENTATION DETERMINATION	1-11
	*FC-2720-P52 IMU REALIGNMENT PROGRAM	(+1) 1-32
	*FC-2730-R52, R53, R56	1-18
16.0	<u>ENTRY PROGRAMS</u>	total (1 + 72)
	*FC-2760-P60'S-ENTRY PROGRAMS	1-17
	*FC-2770-REENTRY CONTROL	1-31
	*FC-2780-CM ENTRY DIGITAL AUTOPILOT	1-24
17.0	<u>INDEX</u>	1-48

RTB Op Codes

LOADTIME	sh. 2
COLOGIC	sh. 3
READPIPS	sh. 4
SGNAGREE	sh. 5
1S TO 2S	sh. 5
V1S TO 2S	sh. 6
2V1S TO 2S	sh. 7
1 TO 2 SUB	sh. 8
INCRCDUS	sh. 9
CDU INC	sh. 10
PULSE IMU	sh. 12
VECS&NAG	sh. 12
TRANSP 1	sh. 13
TRANSP 2	sh. 13
SIGNMPC.	sh. 14
NORMONX1	sh. 15
NORMONIT	sh. 15

PRELIMINARY

RTB Op Codes
 COLOSSUS
 II C FC-2100



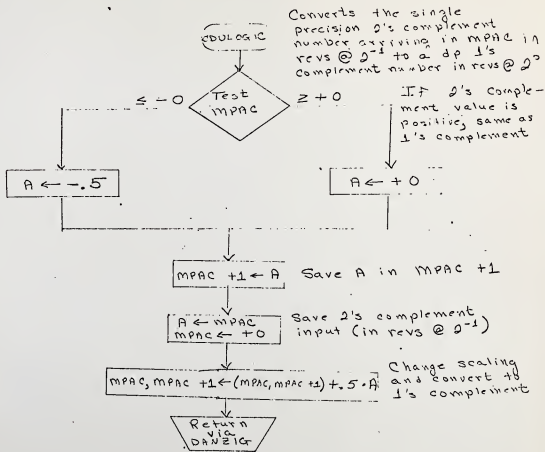
PRELIMINARY

RTB Op Codes

COLOSSUS
IC

FC-2100

sh. 2. of 16



PRELIMINARY

RTB Dp Codes
 COLOSSUS FC-2100
 IC

READPIPS

Reads the PIPA's into MPAC without changing them.

inhibit
interrupts

MPAC ← PIPAX
MPAC +3 ← PIPAY
A ← PIPAZ

in m/csc. @ .000585 x 2¹⁴

release
interrupts

MPAC +5 ← PIPAZ

MPAC +1 ← 0
MPAC +4 ← 0
MPAC +6 ← 0

clear least significant part of each dp component

VECMODE

VMODE

A ← -1

NEWMODE

MODE ← -1

PRELIMINARY

declare MPAC in vector mode

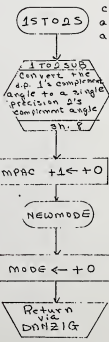
return
via
DANZIG

RTB of Codes
COLOSSUS
IIC . FC-2103

sh. 4 of 16



Forces sign agreement
in MPACT



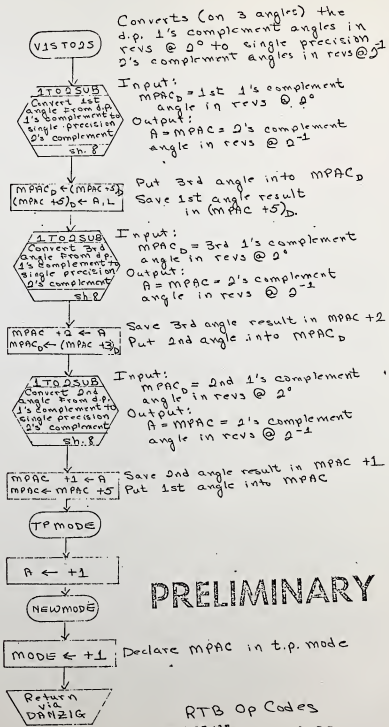
Converts the d.p. 1's
complement angle in revs @ 2^0 to
a single precision 2's complement
angle in revs @ 2^{-1}

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

Declare MPAC in d.p. mode

PRELIMINARY

RTB Op Codes
COLOSSOS FC-2100
IC



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}

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

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

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

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

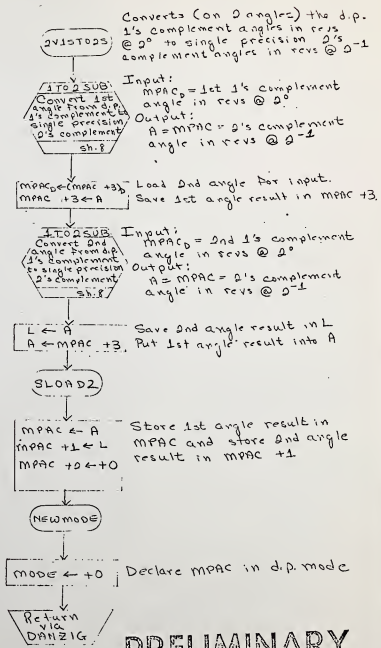
Input:
MPAC_D = 2nd 1's complement angle in revs @ 2^0
Output:
A = MPAC = 2's complement angle in revs @ 2^{-1}

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

PRELIMINARY

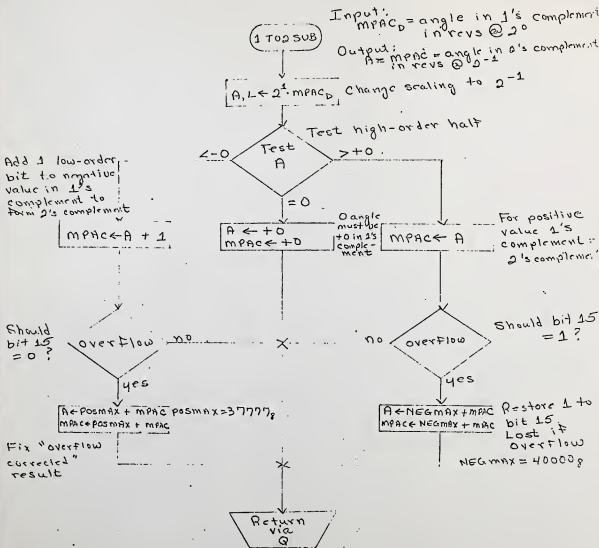
Declare MPAC in t.p. mode

RTB Op Codes
COLOSSUS FC-2100
IIC



PRELIMINARY

RTB Op Codes
 COLOSSUS FC-2100
 II C



PRELIMINARY

RTB Op Codes
 COLOSSUS IIC FC-2100

INCREMENT

Increment: EDU's
Input: angles in MPAC, +3, +5 in 1's complement
@ 2's in 1's complement
THE7AD, +1, +2 in 2's complement

BUF ← ADR(THE7AD)
A ← MPAC

EDU INC
Increment
THE7AD in 2's
complement by
1's complement
quantity in A
sh.10

Input: A = MPAC
BUF = address of quantity to be
incremented (here = address of THE7AD)
Result: $ADR^{-1}(BUF) = THE7AD$
incremented in 2's complement by
1's complement quantity in MPAC

BUF ←
ADR(THE7AD + 1)
A ← MPAC + 3

EDU INC
Increment
THE7AD + 1 in 2's
complement by
1's complement
quantity in A
sh.10

Input: A = MPAC + 3
BUF = address of quantity to be
incremented (here = address of
THE7AD + 1)
Result: $ADR^{-1}(BUF) = THE7AD + 1$
incremented in 2's complement by
1's complement quantity in MPAC + 3

BUF ←
ADR(THE7AD + 2)
A ← MPAC + 5

EDU INC
Increment
THE7AD + 2 in 2's
complement by
1's complement
quantity in A
sh.10

Input: A = MPAC + 5
BUF = address of quantity to be
incremented (here = address of
THE7AD + 2)
Result: $ADR^{-1}(BUF) = THE7AD + 2$
incremented in 2's complement by
1's complement quantity in MPAC + 5

next sheet

PRELIMINARY

RTB Op Codes
COLOSSUS IIC FC-2100

from preceding sheet

YECMODE

YMODE

$A \leftarrow -1$

HEWMODE

MODE $\leftarrow -1$

Declare THETAD in vector mod.

Return
via
DANZIG

COUINC

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

TEM2 $\leftarrow A$

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

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

$= +0$

≤ -0

$> +0$

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

$A \leftarrow +0$

$A \leftarrow ADR^{-1}(BUF)$

$A \leftarrow ADR^{-1}(BUF) - 1$

$A \leftarrow A + TEM2$

Increment by input value

next sheet

RTB Op Codes

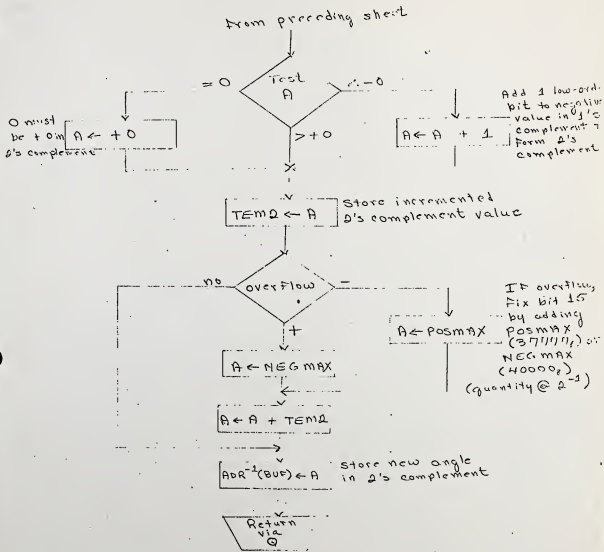
COLOSSUS
IC

FC - 2100

PRELIMINARY

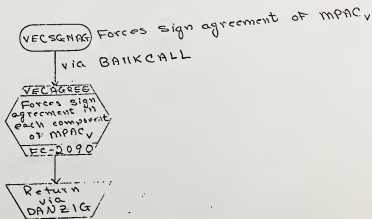
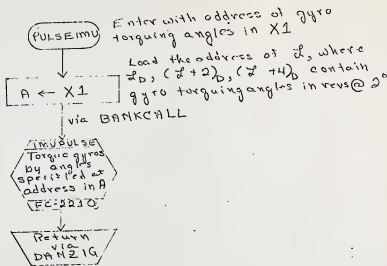
R. Enters

sh. 10 of 16



PRELIMINARY

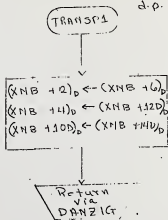
RTB Op Codes
 COLOSSUS FC-D100
 IIC



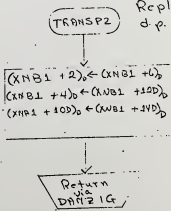
PRELIMINARY

RTB Op Codes
 COLOSSUS FC-2100
 IC

Replaces a 3x3 matrix in
d.p. with the transpose matrix

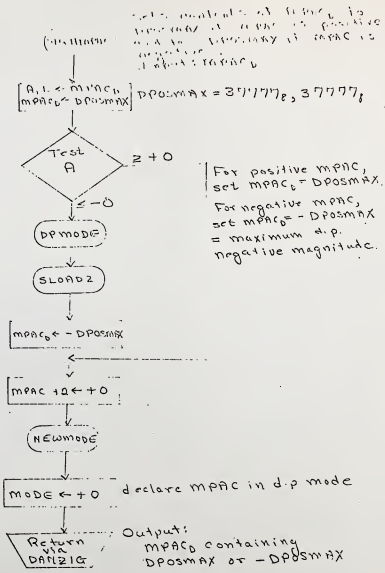


Replaces a 3x3 matrix in
d.p. with the transpose matrix



PRELIMINARY

RTB Op Codes
COLOSSUS IC FC-2100

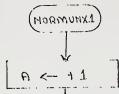


PRELIMINARY

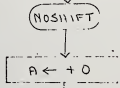
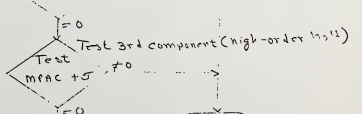
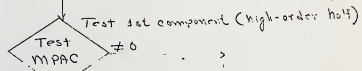
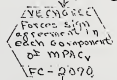
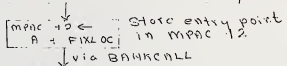
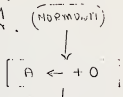
RTB op Codes
 COLOSSUS II FC-2100

R. Entes

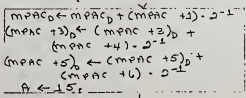
sh. 14 of 1.



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



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



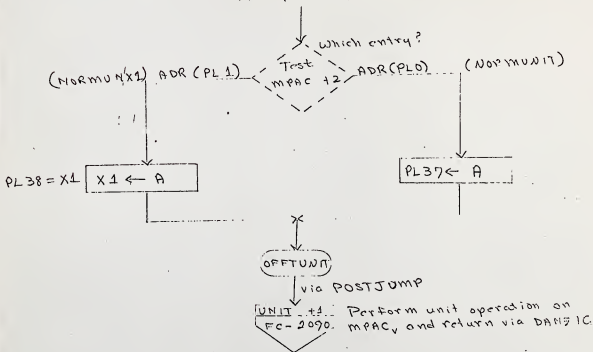
RTB Op Codes
COLLOSSUS FC-2100
II C

PRELIMINARY next sheet

REntos

sh. 15 of 16

from preceding sheet



PRELIMINARY

RTB of Codes
COLOSSUS FC-2100
IC

R. Entes

sh. 16 of 16

ALARM AND ABORT

THE ALARM ROUTINE AND ITS ASSOCIATED ENTRIES ARE USED FOR SETTING THE ALARM CODE INTO ONE OF FAILREG REGISTERS. IT TURNS ON THE PROGRAM ALARM LIGHT (BY SETTING BIT-POSITION 9 OF REGISTER DSPTAB+1D TO ONE) IF THIS IS THE FIRST ALARM SINCE THE FAILREG REGISTERS WERE LAST CLEARED BY DEPRESSING THE ERROR LIGHT RESET KEY OR BY A FRESH START. 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 REGISTER FAILREG, THE SECOND ALARM CODE IS SET INTO REGISTER FAILREG+1 AND THE LAST (3RD OR MORE) IS SET INTO REGISTER FAILREG+2. SUBSEQUENT ALARM CODES (4TH OR MORE) WILL REPLACE THE EXISTING ALARM CODE IN REGISTER FAILREG+2 AND ALSO SET BIT-POSITION 15 OF 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 ECOUNT 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 ALL THE FAILREG REGISTERS AND TURN OFF THE PROGRAM ALARM LIGHT. A FRESH START WILL ALSO DO THIS. 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, AND ALARM. FAILURES WHICH ARE SERIOUS USE THE FOLLOWING ENTRIES BAILOUT, POODOO, AND CCSHOLE.

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 AT THE TOP OF THE NEXT SHEET.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		ALARM AND ABORT	
DESIGN FROM <i>R. J. ...</i>	DATE <i>1/12/68</i>	COLOSSUSS-IA	DOCUMENT NO. FC-2140
ANALYST <i>R. J. ...</i>	<i>4/1/68</i>		
DOCS <i>R. J. ...</i>	<i>4/1/68</i>		
APPROV <i>R. J. ...</i>	REV 1	SHEET 1 OF 9	

BESIDES TURNING ON THE PROGRAM ALARM LIGHT (BY OFF) AND MAKING THE ALARM CODE AVAILABLE FOR DISPLAY, OTHER FUNCTIONS OF EACH ENTRY ARE

CRALARM	DISPLAYS THE ALARM CODES VIA PRODS/PR (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.
CTERAINS	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.
RAHOUT	TERMINATES IN A SOFTWARE RESTART. USED BY ALARM CONDITIONS SUCH AS NO VAC AREAS AVAILABLE, TOO MANY TASKS, ETC.
COOODO	CLEARNS AVEGFLAG AND V3TFLAG. INACTIVATES ALL RESTART GROUPS AND TERMINATES IN A SOFTWARE RESTART. AND GOTOPOOH AND FLASH VEBB ST 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.
UCSHOLE	ALARM CODE OCT 1103 IS ONLY CODE USED. CLEARNS AVEGFLAG AND V3TFLAG, INACTIVATES ALL RESTART GROUPS AND TERMINATES IN A SOFTWARE RESTART, AND GOTOPOOH AND FLASH VEBB ST 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.

UNIT INSTRUMENT IDENTIFICATION PART NUMBER	PART NUMBER AND QUANTITY
45 <i>Q. J. Smith</i> <i>PARRO</i> <i>Nensmore</i> <i>REPRO</i>	ALARM AND ABORT
4-14-69 <i>C. N. Beck</i>	COLOSSUS III FC-2140
APPROVED BY <i>a. Beck</i> 22 April 69	2 - 9

ALARM AND ABORT ROUTINE

FROM PRECEDING SHEET

NOTE: SYMBOL "L" MEANS "CONTAINS" IN THIS FLOWCHART

RETURN ADDRESS TO EITHER THE ENTRY CALLING SEQUENCE OR THE BORTENT (OR PRIORIT) CALLING SEQUENCE. ITEMP1 CONTAINS ONE OF THE FOLLOWING RETURN ADDRESSES DEPENDING UPON WHICH ENTRY WAS USED:

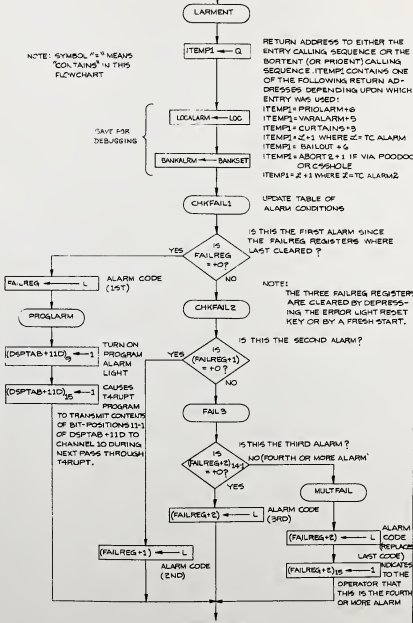
- ITEMP1 = PRIALARM + 6
- ITEMP1 = VARALARM + 5
- ITEMP1 = CURTAIN + 5
- ITEMP1 = Z + 1 WHERE Z = TC ALARM
- ITEMP1 = BAILOUT + 6
- ITEMP1 = ABORT 2 + 1 IF VIA P00000 OR C55HOLE
- ITEMP1 = Z + 1 WHERE Z = TC ALARM 2

SAVE FOR DEBUGGING

UPDATE TABLE OF ALARM CONDITIONS

IS THIS THE FIRST ALARM SINCE THE FAILREG REGISTERS WERE LAST CLEARED?

NOTE: THE THREE FAILREG REGISTERS ARE CLEARED BY PRESSING THE ERROR LIGHT RESET KEY OR BY A FRESH START.

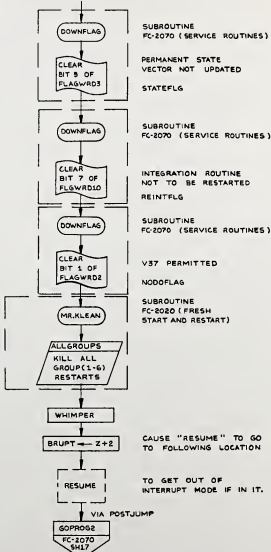


NEXT SHEET

J. J. Chisholm
W. J. Moore
P. H. Beck
 4-16-67
 22 April 67

ALARM AND ABORT
 COLLOSSUS IIA FC-2140
 Rev 1
 4 of 9

FROM PRECEDING SHEET



SEE NOTE A

NOTE A:
GO TO ROUTINE GOTOPROG
AND DISPLAY FLASHING VERB 37
UNLESS NO MAJOR MODE WAS
ACTIVE IN WHICH CASE CONTROL
GOES TO DUMMYJOB+2 (SEE
RESTART, SHEET 20 OF FC-2020.)

TO: DIRECTOR, FBI WASHINGTON, D.C.	DATE: 10/11/68
FROM: SAC, NEW YORK NEW YORK, N.Y.	RE: ALARM AND ABORT
SUBJECT: [REDACTED]	FILE NO. FC-2140
APPROVED: [REDACTED]	DATE: 10/11/68

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
00113	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 CMC	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	PI7, 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 TURNON REQUEST NOT PRESENT FOR 90 SEC	T4RUPT	ALARM
00210	IMU NOT OPERATING	IMU MODE SWITCH, IMU-2, R02, P51	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	VARALARM
00401	DESIRED GIMBAL ANGLES YIELD GIMBAL LOCK	INF ALIGN, IMU-2	ALARM
00404	TARGET OUT OF VIEW - TRUN ANGLE >90 DEG	R52	PRIALARM
00405	TWO STARS NOT AVAILABLE	P52, P54	ALARM
00406	REND NAVIGATION NOT OPERATING	R21, R23	ALARM

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	PROJECT GUIDANCE AND NAVIGATION
DRAWN <i>J. J. ...</i> DESIGNED <i>J. J. ...</i> CHECKED <i>J. J. ...</i> APPROVED <i>J. J. ...</i>	ALARM AND ABORT COLLOSSUS II REV 2
30-10000-1 FC-2140 1967-7-16-9	

ALARM CODE	ALARM CONDITION	SET BY	ALARM ENTRY USED
00407	A1 TO OPTIC'S REQUEST THRU ANGLE > 50 DEG (TARGET OUT OF VIEW)	R52	ALARM
00421	W-MATRIX OVERFLOW	INTEGRV	ALARM
00440	INTRJ, ABORT DUE TO SUBSURFACE S, V.	ALL CALLS TO INTEGRATION	POODOO
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	CDS TO CDU TIME LT PMIN22	P32, P33, P72, P73	VARALARM
00604	CDU TO TPI TIME LT PMIN23	P32, P72	VARALARM
00605	NUMBER OF ITERATIONS EXCEEDS LOOP MAXIMUM	P32, P37, P72	VARALARM
00606	DA EXCEEDS MAXIMUM	P32, P72	VARALARM
00607	* NO SOLUTION FROM TIME THETA OR TIME RADIUS ROUTINE	TIMETHET, TITERAD	POODOO
00610	* LAMDA LESS THAN UNITY	P37	POODOO
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
01103	* UNLSED CCS BRANCH EXECUTED	CCSHOLE	ABORT2
01104	* DELAY ROUTINE BUSY	SERVICE ROUTINES	BAILOUT
01105	DOWNLINK TOO FAST	T4RUPT	ALARM
01106	UPLINK TOO FAST	T4RUPT	ALARM
01107	PHASE TABLE FAILURE. ASSUME ERASABLE MEMORY IS DESTROYED	RESTART	ALARM
01201	* EXECUTIVE OVERFLOW - NO VAC AREAS	EXEC	BAILOUT
01202	* EXECUTIVE OVERFLOW - NO CORE SETS	EXEC	BAILOUT
01203	* WAITLIST OVERFLOW - TOO MANY TASKS	WAITLIST	BAILOUT
01204	* NEGATIVE OR ZERO DELTA TIME - WAITLIST CALL	WAITLIST	POODOO
01206	* SECOND JOB ATTEMPTS TO GO TO SLEEP VIA KEYBOARD AND DISPLAY PROGRAM	PINBALL	POODOO
01207	* NO VAC AREA FOR MARKS	SXTMARK	BAILOUT
01210	* TWO PROGRAMS USING DEVICE AT SAME TIME	IMU MODE SWITCH	POODOO
01211	* ILLEGAL INTERRUPT OF EXTENDED VERB	SXTMARK	BAILOUT
01301	ARCSIN-ARCCOS INPUT ANGLE TOO LARGE	INTERPRETER	ALARM
01302	* SQRT CALLED WITH NEGATIVE ARGUMENT. ABORT	INTERPRETER	POODOO
01407	VG INCREASING	S40.8	ALARM
01426	IMU UNSATISFACTORY	P61, P62	ALARM
01427	IMU REVERSED	P61, P62	ALARM

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
NAME <i>R. J. Smith</i> TAGNO TITLE <i>Mathematical Engineer</i>	ALARM AND ABORT
DATE <i>10/16/69</i>	COLOSSUS III FC-2140
APPROVED <i>John A. ...</i>	SHEET 8 OF 9

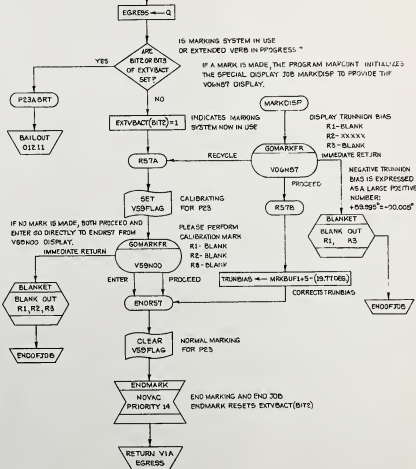
ALARM CODE	ALARM CONDITION	SET BY	ALARM ENTRY USED
01501 *	KEYBOARD AND DISPLAY ALARM DURING INTERNAL USE (NVSUB), ABORT	PINBALL	POO100
01502 *	ILLEGAL FLASHING DISPLAY	GOPLAY	POO100
01520	V37 REQUEST NOT PERMITTED AT THIS TIME	V37	ALARM
01521 *	P01 OR P07 ILLEGALLY SELECTED	P01, P07	POO100
01600	OVERFLOW 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	INSUP. 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
07777	IMU FAIL CAUSED THE ISS WARNING	T4RUPT	VARALARM
10777	IMU, PIPA FAILS CAUSED THE ISS WARNING	T4RUPT	VARALARM
13777	IMU, ICPU FAILS CAUSED THE ISS WARNING	T4RUPT	VARALARM
14777	IMU, ICPU, PIPA FAILS CAUSED THE ISS WARNING	T4RUPT	VARALARM

*INDICATES ABORT TYPE. ALL OTHERS ARE NON-ABORTIVE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		ALARM AND ABORT	
SYMBOL	<i>Ch. Smith</i>	DATE	<i>7/19/69</i>
PICTURE	<i>W. S. Smith</i>	DATE	<i>7/19/69</i>
ANALYST			
DRAWN	<i>D. H. Beebe</i>		<i>4-18-69</i>
APPROVED	<i>John A. DeW</i>	REV	<i>1</i>
		COLOSSUS II-A	DOCUMENT NO. FC-2140
			SHEET 9 0 9

R57
OPTICS CALIBRATION ROUTINE

MEASURES THE EFFECT OF SOLAR RADIATION ON THE SIX TRUNNION ANGLE AND STORES THE MEASURED TRUNNION BIAS FOR P23.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		R57 OPTICS CALIBRATION	
DRAWN A.C. WILLIAMS	DOCTO	FC-2242	
PROG. N.W. BRESLER	W. JAMES	COL00005	
ANALYST			
DYKES			
APPROV. J. J. Kelly			

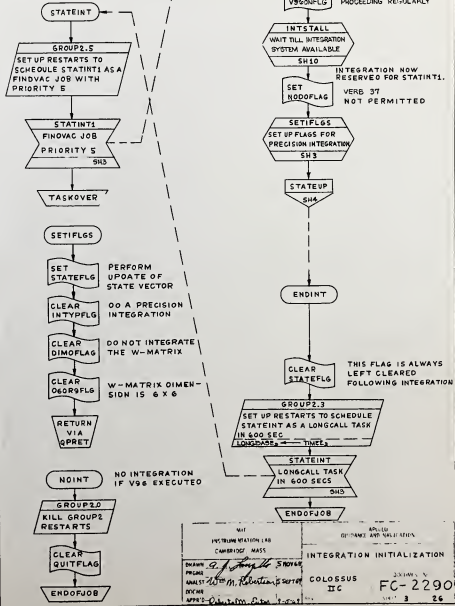
INTEGRATION INITIALIZATION

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
LEMFPREC	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
INTEGRV3	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.	OSTANEX, W. P., USER'S GUIDE FOR ORBITAL INTEGRATION ROUTINE FOR FLIGHT 504, FLIGHT 504 MEMO 3, REV 1, JUNE, 1967.
3.	OSTANEX AND KEFAUVER, LEVEL II TEST PACKAGE FOR COASTING INTEGRATION SUBROUTINE, MIT/IL, NOVEMBER, 1967.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC ENGINEERING AND RESEARCH	
DRAWN <i>L. E. Hester</i>		INTEGRATION INITIALIZATION	
PROGRAM	ANALYST <i>W. P. Ostanex</i>	COLOSSUS IIC	DOCUMENT NO FC-2290
DOCS	APPROVED <i>W. P. Ostanex</i>	REV	VOL 1 OF 28

STATEINT IS SCHEDULED TO BE EXECUTED EVERY 600 SECONDS DURING THE IOLING PROGRAM POO. THUS BOTH STATE VECTORS ARE PRECISION INTEGRATED AND UPDATED TO WITHIN 600 SECONDS OF CURRENT TIME



MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS

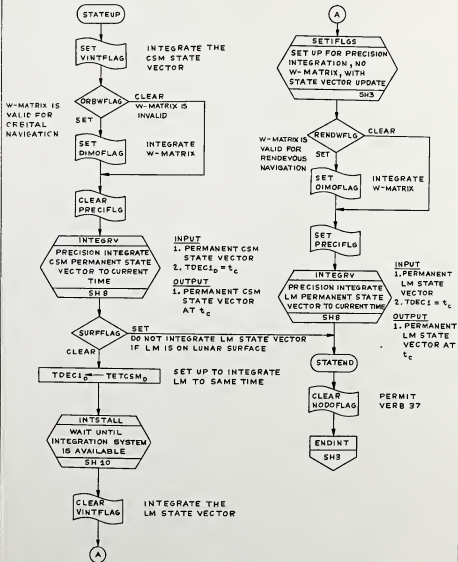
OWNER: *G. P. ...*
 PRINCIPAL: *G. P. ...*
 ANALYST: *W. M. Robertson*
 REVIEW: *...*
 APPROVED: *...*

INTEGRATION INITIALIZATION

COLLOSSUS
IIC

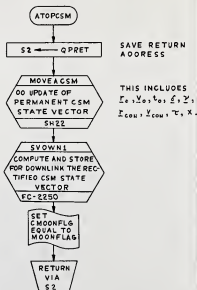
EX-100
FC-2290
3 26

STATEUP DOES THE POO INTEGRATION. IT PRECISION INTEGRATES BOTH CSM AND LM STATE VECTORS TO CURRENT TIME WITH A PERMANENT UPDATE OF BOTH VECTORS. IT INTEGRATES THE W-MATRIX IF IT IS VALID.

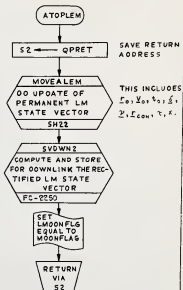


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARC10 GUIDANCE AND NAVIGATION	
DRAWN: <i>[Signature]</i> JUN 68		INTEGRATION INITIALIZATION	
PROGRAM: <i>[Signature]</i>	APPROVED: <i>[Signature]</i>	COLOSSUS IIC	DOCUMENT NO. FC-2290
APPROVED: <i>[Signature]</i>	DATE: 6-27-68	REV	SHEET: 4 of 26

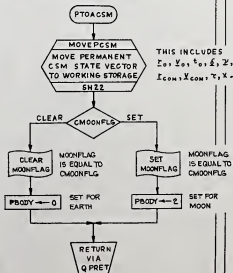
PERFORM AN UPDATE OF PERMANENT
CSM STATE VECTOR AND FLAG
CMOONFLG



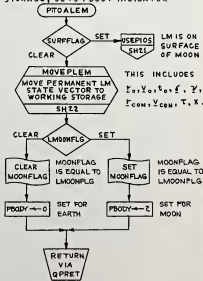
PERFORMS AN UPDATE OF PERMANENT
LM STATE VECTOR AND FLAG
LMOONFLG



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



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



MIL
INSTRUMENTATION LAB
CAMBRIDGE, MASS

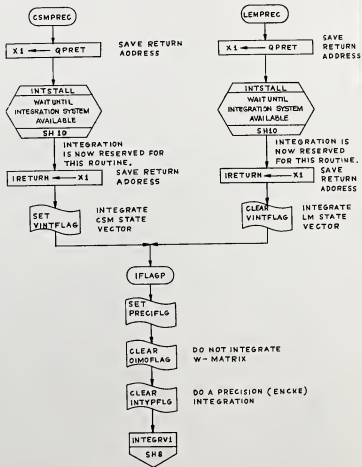
DRYDEN *A. J. England* 15 NOV 66
PROGRAM
ANALYST *E. M. Robinson* 15 NOV 66
DOC NO
APPROVED *John M. Day* 15 NOV 66

AVIATION
GUIDANCE AND NAVIGATION

INTEGRATION INITIALIZATION

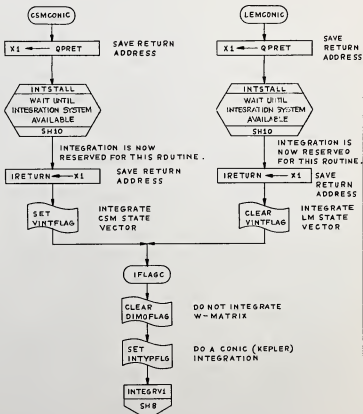
COLOSSUS IIC DOCUMENT NO
FC-2290
SERIAL 5 OF 24

C SMPREC 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 TDC10 = T₁. THE ENTRIES AUTOMATICALLY LOAD THE APPROPRIATE STATE VECTOR AND TIME OF VALIDITY FROM PERMANENT STORAGE INTO RCV_v, YCV_v AND TET₀. THESE ENTRIES SET UP ALL THE FLAGS REQUIRED BY THE INTEGRATION ROUTINE AND PERFORM THE CALL TO INST_{ALL}. 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 TAT₀.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARIEL GUIDANCE AND NAVIGATION	
DEVELOPER: <i>A. J. ...</i>		INTEGRATION INITIALIZATION	
PROGRAM:	ANALYST: <i>M. E. ...</i>	COLOSSUS IIC	FC-2290
DATE:	APPD: <i>...</i>	REV: <i>...</i>	6 of 26

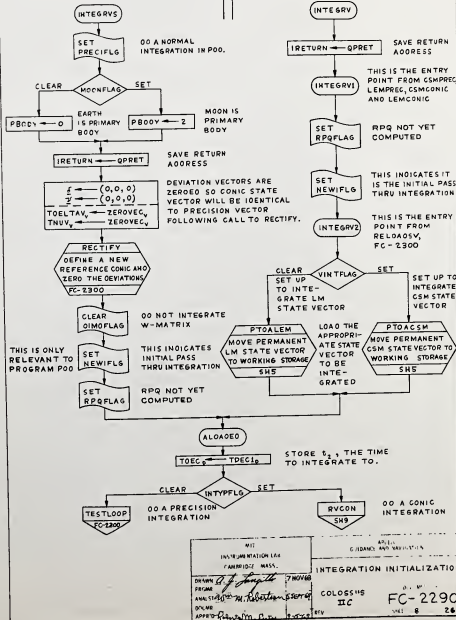
CSMCONIC AND LEMCONIC ARE ENTRIES TO THE INTEGRATION ROUTINE FOR PERFORMING ORBIT INTEGRATION BY THE CONIC (KEPLER) METHOD OF THE PERMANENT STATE VECTOR OF THE CSM AND LM RESPECTIVELY. NO DISTURBING ACCELERATIONS ARE INCLUDED. THE STATE VECTOR IS RECTIFIED IMMEDIATELY PRIOR TO THE KEPLER SOLUTION. THE CALLER MUST STORE THE TIME TO INTEGRATE TO IN TDEC1 = t_0 . THE ENTRIES AUTOMATICALLY LOAD THE APPROPRIATE STATE VECTOR AND TIME OF VALIDITY FROM PERMANENT STORAGE INTO RCV_V, VCV_V AND TET₀. THESE ENTRIES SET UP ALL THE FLAGS REQUIRED BY THE INTEGRATION ROUTINE AND PERFORM THE CALL TO INTSTALL. OUTPUT INCLUDES THE INTEGRATED STATE VECTOR STORED IN THE PUSH LIST IN LOCATIONS RATT_V, VATT_V AND THE TIME ACTUALLY INTEGRATED TO IN PUSH LIST LOCATION TAT_P.



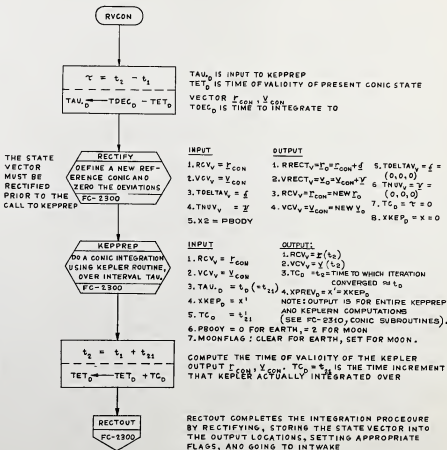
INSTRUMENTATION UNIT CAMBRIDGE, MASS	APPLE DEPARTMENT AND SALES DIV.
DESIGNED BY <i>A. J. Sample</i> SNOYNE	INTEGRATION INITIALIZATION
PROGRAM ANALYST <i>W. M. Johnston</i> SNOYNE	COLOSSUS IIC
DOORMAN APPROVED <i>W. M. Johnston</i> 3-2-58	REVISION NUMBER FC-2290 7 26

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 RCV₀, VCV₀ AND TET₀. THE TIME TO INTEGRATE TO MUST BE LOADED IN TOEC1₀ = t₂.

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, O6OR9FLG AND STATEFLG. THE TIME TO INTEGRATE TO MUST BE LOADED IN TOEC1₀ = t₂. THIS ENTRY LOADS THE APPROPRIATE STATE VECTOR AND TIME FROM PERMANENT STORAGE INTO RCV₀, VCV₀ AND TET₀. THIS IS THE ONLY ENTRY THAT PERMITS W-MATRIX INTEGRATION AS AN OPTION. THIS ENTRY IS USED GENERALLY BY THE NAVIGATION PROGRAMS.

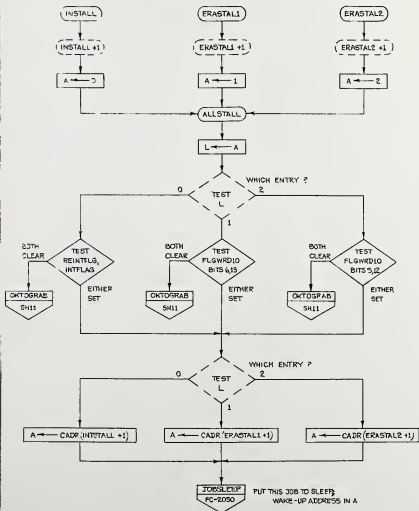


RVCON SETS UP ORBIT INTEGRATION TO DO A CONIC SOLUTION FOR POSITION AND VELOCITY OVER THE TIME INTERVAL FROM TET TO TOEC. IT CALLS THE KEPPREP SUBROUTINE WHICH IN TURN CALLS THE KEPLER SUBROUTINE. RVCON IS ENTERED IF CSMCONIC OR LEMCONIC WAS CALLED OR IF INTEGRVS OR INTEGRV WAS CALLED WITH INTYPFLG SET.

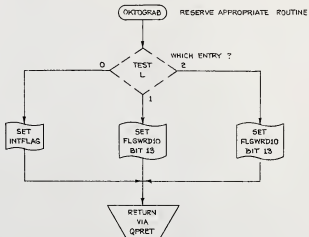


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ANALYSIS DESIGN & INVESTIGATION
INTEGRATION INITIALIZATION	
DRAWN BY <i>[Signature]</i> 7 NOV 67 PREPARED BY <i>[Signature]</i> CHECKED BY <i>[Signature]</i> INCHES APPROVED BY <i>[Signature]</i>	COLOSSUS IIC DRAWING NO. FC-2290 SHEET 9 OF 26

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.

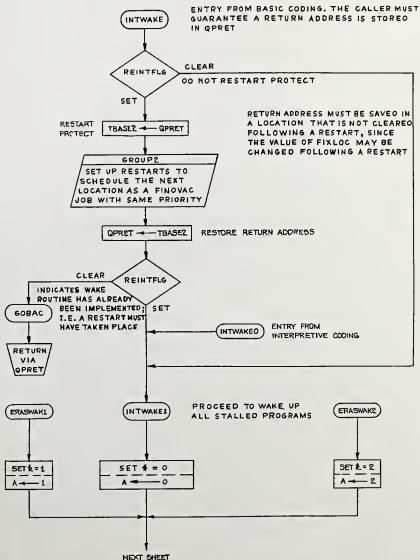


MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		PROJECT GUIDANCE AND NAVIGATION	
DRAWN A. E. WILLIAMS		INTEGRATION INITIALIZATION	
DATE	APPROVED	COLLOSSUS IIC	DOCUMENT NO. FC-2250
APPROVED	DATE	REV	SHEET 30 OF 26



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		INTEGRATION INITIALIZATION	
DESIGNED BY A. C. WILLIAMS	DATE 02/24/68		
APPROVED BY M. Robinson	DATE 5/2/68	CLOSSUS IIC	DOCUMENT # FC-2290
APPROVED BY C. S. ...	DATE 11-2-68	REV	SHEET 11 OF 26

THE INTEGRATION WAKE ROUTINE WAKES UP ALL PROGRAMS THAT HAVE BEEN PUT TO SLEEP (I. E. STALLED) BY THE INTEGRATION STALL ROUTINE INSTSTALL.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN: <i>[Signature]</i> PROGRAM: <i>[Signature]</i> ANALYST: <i>[Signature]</i> CHECKED: <i>[Signature]</i> APPROVED: <i>[Signature]</i>	INTEGRATION INITIALIZATION COLOSSUS IIC DEPARTMENT NO. FC-2290 SHEET 12 OF 26

FROM PRECEDING SHEET

WAKE

STORE ξ
STALTEM ← A

THE VALUE ξ IS USED FOR INDEXING

WAKE1

TEST STALTEM

A ← CADR(ERASTAL1+1)

A ← CADR(INTSTALL+1)

A ← CADR(ERASTAL2+1)

INHINT LOCK OUT INTERRUPTS

A MATCH WAS MADE AND THE STALLED PROGRAM WAS AWAKENED. GO BACK AND WAKE THE NEXT STALLED PROGRAM IN THE LIST OF SLEEPING PROGRAMS

JOBWAKE
WAKE UP A STALLED PROGRAM
FC-2050

INPUT
A = CADR OF AWAKING ADDRESS OF JOB TO BE AWAKENED
OUTPUT
LOCCTR = RELATIVE ADDRESS (0, 120, .. 720) OF CORE SET IF A CADR MATCH IS MADE AND JOB IS AWAKENED; 15-1 IF NO MATCH IS MADE

LOCCTR = -1

NO MATCH WAS MADE AND HENCE THERE ARE NO INTEGRATION STALLED PROGRAMS REMAINING IN THE LIST TO BE AWAKENED

TEST STALTEM

CLEAR REINTFLG
INTEFLAG

CLEAR FLGWRD10
BITS 6, 13

CLEAR FLGWRD10
BITS 5, 12

RELINT ALLOW INTERRUPTS

GOBAC

RETURN VIA QPRET
RETURN TO THE CALLING PROGRAM AT THE INTERPRETER LEVEL

UNIT INSTRUMENTATION OR "AMBERIDGE" UNIT PROJECT NAME DATE BY CHECKED BY APPROVED BY DATE	TITLE INTEGRATION INITIALIZATION COLOSSUS II C FC-2290 13 26
--	--

THIS ROUTINE IS CALLED ONCE BY P27
(THE UPDATE PROGRAM) TO RELEASE
ITS GRAB(MADE VIA INTSTALL) OF THE
INTEGRATION ROUTINE

ALLOW INTERRUPTS

SAVE RETURN ADDRESS

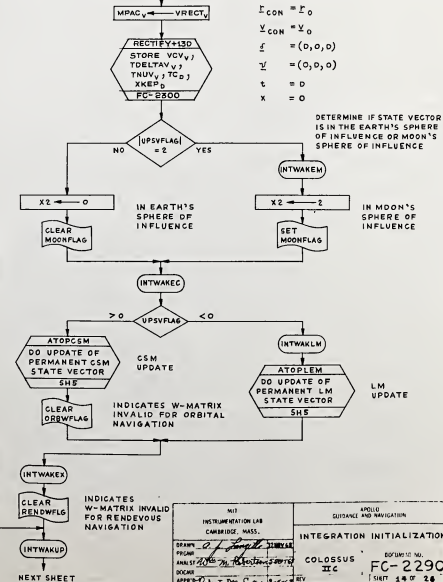
THIS FLAG IS SET IF A CSM/LM STATE
VECTOR UPDATE IS REQUESTED

PREPARE FOR UPDATING
BY SETTING :

$I_{CON} = I_0$
 $Y_{CON} = Y_0$
 $f = (D, 0, 0)$
 $\underline{y} = (0, 0, 0)$
 $t = D$
 $x = 0$

DETERMINE IF STATE VECTOR
IS IN THE EARTH'S SPHERE
OF INFLUENCE OR MOON'S
SPHERE OF INFLUENCE

DO NOT
UPDATE
STATE
VECTOR



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY <i>J. Smith</i>		INTEGRATION INITIALIZATION	
CHECKED BY <i>J. Smith</i>		COLOSSUS IIC	
APPROVED BY <i>J. Smith</i>		FORM NO. FC-2290	
		SHEET 14 OF 26	

FROM
PRECEDING SHEET

UPSVFLAG ← 0

CLEAR THE WORD TO ZERO
TO INDICATE AN UPDATING
IS NOT REQUESTED

INTWAKE0

WAKE UP ALL
STALLED
PROGRAMS

SHIB

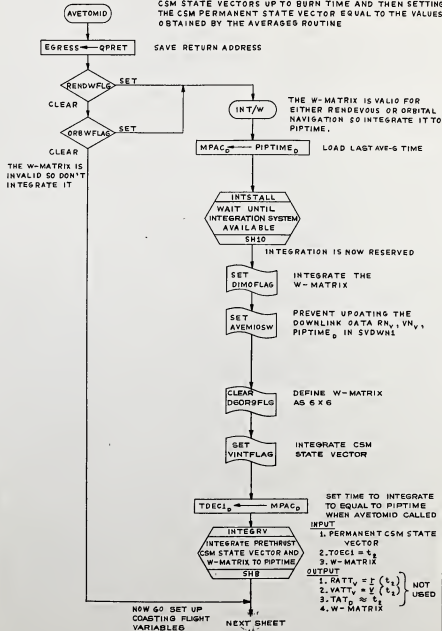
GROUP6

SET UP RESTARTS
TO SCHEDULE THE
NEXT LOCATION AS
A JOB WITH THE
SAME PRIORITY

RETURN
VIA
INTWAK06

NOV 12 1958	INTEGRATION INITIALIZATION
RECEIVED <i>C. J. Smith</i> 12 NOV 1958	COLOSSUS II C
ANALYST <i>M. Robinson</i>	FC-2290
DATE 11/12/58	11 16 26

AVETOMID PERFORMS THE TRANSITION FROM A THRUSTING PHASE TO A COASTING PHASE BY INTEGRATING THE LM AND CSM STATE VECTORS UP TO BURN TIME AND THEN SETTING THE CSM PERMANENT STATE VECTOR EQUAL TO THE VALUES OBTAINED BY THE AVERAGES ROUTINE



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN *A. J. ...*
PROGRAM
ANALYST
CHECKED
APPROVED

APOLLO
GUIDANCE AND NAVIGATION

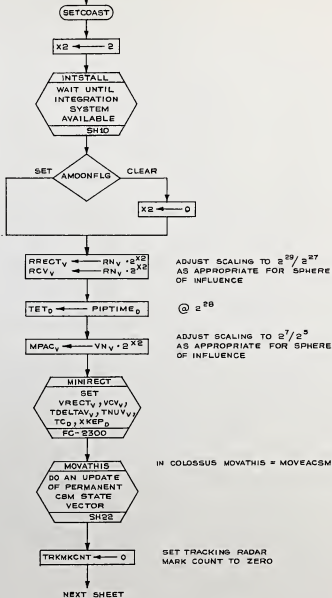
INTEGRATION INITIALIZATION

COLOSSUS
IIC

FC-2290

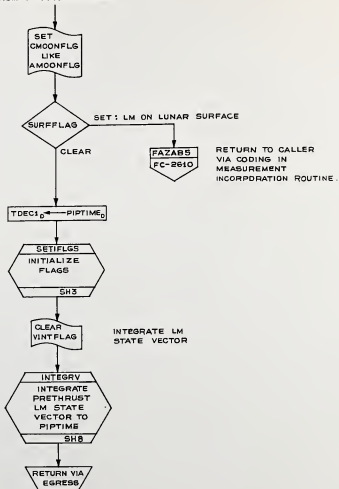
DEC 16 1967

FROM PRECEDING SHEET



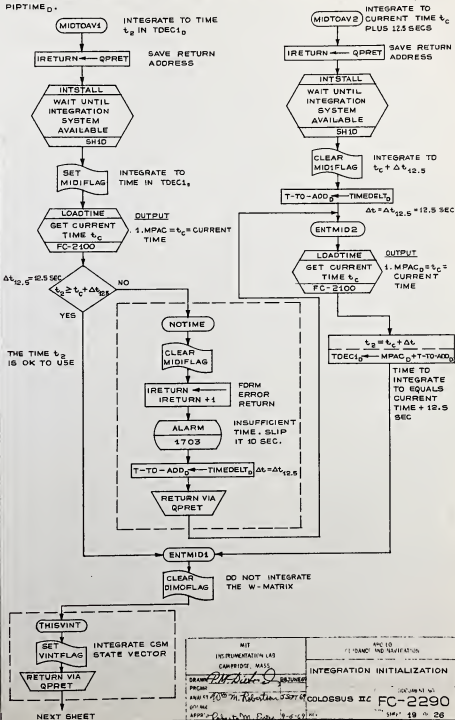
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	AFIELD C. DANCE AND ASSOCIATES
DESIGNED BY <i>[Signature]</i> 1574818	INTEGRATION INITIALIZATION
PROGRAM <i>[Signature]</i>	DOCUMENT NO.
ANALYST <i>[Signature]</i> 1574818	COLOSSUS IIC FC-2290
DATE <i>[Signature]</i> 1-2-63	17 OF 26

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>[Signature]</i>		INTEGRATION INITIALIZATION	
PROGRAM APOLLO	DATE: 21 JUL 68	DOCUMENT NO COLOSSUS IIC	FC-2290
APPROVED: <i>[Signature]</i>	REV	SHEET	18 OF 26

MIDTDAV1 DOES PRECISION INTEGRATION OF THE CSM PERMANENT STATE VECTOR TO THE TIME t_2 SPECIFIED IN TDEC1₀. 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. MIDTDAV2 DOES A PRECISION INTEGRATION OF CSM PERMANENT STATE VECTOR TO CURRENT TIME PLUS 12.5 SECONDS. IN EITHER CASE THE INTEGRATED STATE VECTOR AND TIME ARE STORED IN RN_{Vj}, YN_j, PIPTIME₀.



MIT
 INSTRUMENTATION LAB
 CAMBRIDGE, MASS.
 DRAWN BY *[Signature]*
 CHECKED BY *[Signature]*
 APPROVED BY *[Signature]*

APC 10
 PROGRAM AND REVISIONS
 INTEGRATION INITIALIZATION
 COLLOSSUS II FC-2290
 19 11 26

FROM PRECEDING SHEET

CLEAR
INTYPLFG

DO PRECISION
INTEGRATION

SET
MIOAVFLG

INDICATE TO INTEGRATION THAT IT
WAS CALLED BY THE MIOGAVE ROUTINE

INTEGRV
INTEGRATE CSM
STATE VECTOR TO
TIME t_2
SHB

INPUT

1. PERMANENT CSM STATE VECTOR
2. $TDEC1_0 = t_2$
3. INTERPRETIVE FLAGS

OUTPUT

1. $RATT_v = f(t_2)$
2. $VATT_v = \int f(t_2)$
3. $TAT_0 \approx t_2$

RTX2 ← X2
RTX1 ← X1

CLEAR
AMOODFLG

RTX2

SET
AMOODFLG

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

RN1_v ← RATT_v
VN1_v ← VATT_v
PIPTIME₀ ← TAT₀

STORE THE OUTPUT
OF INTEGRV

INHINT

INHIBIT INTERRUPTS

$\Delta t = t_2 - t_c$
MPAC₀ ← TAT₀ - TIME_{2_0}

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

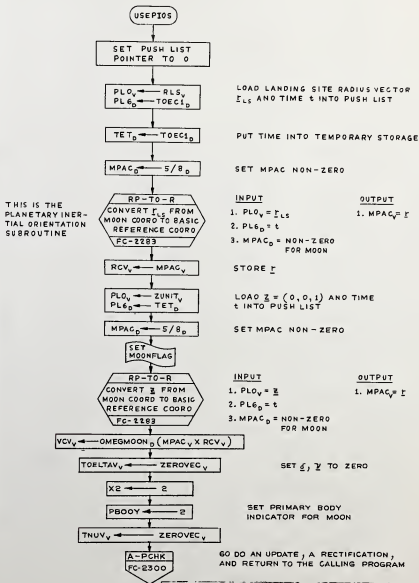
TRAGREE
FORCE SIGN
AGREEMENT IN
MPAC₀
FC-2090

RETURN VIA
IRETURN1

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

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.	APR 62 C. DANCE AND W. J. KILBIA
DRAWN <i>P. H. Dietrich</i>	INTEGRATION INITIALIZATION
DESIGNED <i>P. H. Dietrich</i>	COLOSSUS IIC
DATE <i>10/10/61</i>	FC-2290
APPROVED <i>W. M. ...</i>	REV 20 78 26

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 SITE 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.)	APPROVED DATE: 10/10/68
SPRINK PROGRAM ANALYST DESIGNED APPROVED	INTEGRATION INITIALIZATION COLOSSUS IIc DOCUMENT NO. FC-2290 MAY 28 1968

IN COLOSSUS
MOVATHIS =
MOVEACSM

MOVEACSM

SET BRANK REGISTER FOR
INTEGRV ROUTINE AND DATA

RRECTCSM _V ← RRECT _V	MOVE CSM
VRECTCSM _V ← VRECT _V	STATE VECTOR
TETCSM _D ← TET _D	$I_0, Y_0, T_0,$
DELTA _V CSM _V ← TDELTA _V	$\xi, \gamma, I_{CON},$
NUCSM _V ← TNUV _V	Y_{CON}, T, X
RCVCSM _V ← RCV _V	FROM WORKING
VCVCSM _V ← VCV _V	STORAGE TO
TC _D CSM _D ← TC _D	PERMANENT
XKEPCSM _D ← XKEP _D	STORAGE

RETURN
VIA
DANZIG

MOVEALEM

SET BRANK REGISTER FOR
INTEGRV ROUTINE AND DATA

RRECTLEM _V ← RRECT _V	MOVE LM
VRECTLEM _V ← VRECT _V	STATE VECTOR
TETLEM _D ← TET _D	$I_0, Y_0, T_0,$
DELTALEM _V ← TDELTA _V	$\xi, \gamma, I_{CON},$
NULEM _V ← TNUV _V	Y_{CON}, T, X
RCVLEM _V ← RCV _V	FROM WORKING
VCVLEM _V ← VCV _V	STORAGE TO
TCLEM _D ← TC _D	PERMANENT
XKEPLEM _D ← XKEP _D	STORAGE

RETURN
VIA
DANZIG

MOVEPCSM

SET BRANK REGISTER FOR
INTEGRV ROUTINE AND DATA

RRECT _V ← RRECTCSM _V	MOVE CSM
VRECT _V ← VRECTCSM _V	STATE VECTOR
TET _D ← TETCSM _D	$I_0, Y_0, T_0,$
TDELTA _V ← DELTACS _V	$\xi, \gamma, I_{CON},$
TNUV _V ← NUCSM _V	Y_{CON}, T, X
RCV _V ← RCVCSM _V	FROM
VCV _V ← VCVCSM _V	PERMANENT
TC _D ← TC _D CSM _D	STORAGE TO
XKEP _D ← XKEPCSM _D	WORKING
	STORAGE

RETURN
VIA
DANZIG

MOVEPLEM

SET BRANK REGISTER FOR
INTEGRV ROUTINE AND DATA

RRECT _V ← RRECTLEM _V	MOVE LM
VRECT _V ← VRECTLEM _V	STATE VECTOR
TET _D ← TETLEM _D	$I_0, Y_0, T_0,$
TDELTA _V ← DELTALEM _V	$\xi, \gamma, I_{CON},$
TNUV _V ← NULEM _V	Y_{CON}, T, X
RCV _V ← RCVLEM _V	FROM
VCV _V ← VCVLEM _V	PERMANENT
TC _D ← TCLEM _D	STORAGE TO
XKEP _D ← XKEPLEM _D	WORKING
	STORAGE

RETURN
VIA
DANZIG

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		MIT GUIDANCE AND NAVIGATION	
DRAWN <i>D. J. Farrell</i> 6 JUN 54		INTEGRATION INITIALIZATION	
DESIGNED <i>W. M. Burt</i> 5 SEPT 54		COLOSSUS IIC	
APPROVED <i>W. M. Burt</i> 7-5-54		DELIVERY NO. FC-2290	
		REV. 22 OF 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. 4, 19
JOHNSLEEP	2050	PUT CALLING PROGRAM TO SLEEP	SH. 10
SVDOWN1	2250	GET RECTIFIED CSM STATE VECTOR FOR DOWNLINK	SH. 5
SVDOWN2	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 - 1310	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
KEPHEP	2300	ENTRY POINT FOR CONIC (KEPLER) INTEGRATION	SH. 9
RECTOCT	2300	ENTRY POINT FOR COMPLETING AN INTEGRATION	SH. 9
JOBWAKE	2050	WAKE UP A SLEEPING JOB	SH. 13
FAZABS	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-PCIK	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
INTYFLG (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
DMOFLAG (1, 3)	INTEGRATE THE W-MATRIX	DO NOT INTEGRATE THE W-MATRIX	SH. 4, 16	SH. 3, 6, 7, 8, 19	
DSOR9FLG (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

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
INTEGRATION INITIALIZATION			
DRANK	<i>[Signature]</i>	DATE	1/28/68
FROM	<i>[Signature]</i>	ANALYST	<i>[Signature]</i>
DOC#		COLLOSSUS IIC	DOCUMENT NO. FC-2290
APPROV	<i>[Signature]</i>	REV	SHEET 23 OF 26

FLAGS (CONTINUED)

NAME (BIT, FLAG, WRD)	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE Cleared	WHERE TESTED
PRECIPLG (8, 3)	CSMPREC OR LEMPREC WAS CALLED	INTRGRV OR INTRGRVS WAS CALLED	SH, 4, 6, 8	SH, 4	
MOONFLAG (12, 9)	INSIDE LUNAR SPHERE OF INFLUENCE	OUTSIDE LUNAR SPHERE OF INFLUENCE	SH, 5, 14, 21	SH, 5, 14	SH, 5, 8
CMOONFLAG (12, 8)	(PERMANENT CSM REPRESENTATION OF MOONFLAG)		SH, 5, 18	SH, 5, 18	SH, 5
LMOONFLAG (11, 8)	(PERMANENT LM REPRESENTATION OF MOONFLAG)		SH, 5	SH, 5	SH, 5
NEWIFLG (13, 8)	INITIAL PASS THROUGH INTEGRATION LOOP	SUBSEQUENT PASS THROUGH INTEGRA- TION LOOP	SH, 8		
RPQFLAG (15, 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		
MIDIFLAG (8, 9)	INTEGRATE TO TIME IN TDEC1	INTEGRATE TO CURRENT TIME PLUS 10 SECONDS	SH, 19	SH, 19	
V86ONFLG (5, 8)	POO INTEGRATION INHIBITED BY V86	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		
UPSIFLAG	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
AMOONFLAG (2, 0)	STATE VECTOR IN LUNAR SPHERE AT MIDTOAVE	STATE VECTOR IN EARTH SPHERE AT MIDTOAVE	SH, 20	SH, 20	SH, 17, 18

DISPLAYS

VERB- NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
	ALARM	ALARM CODE = 1703 INSUFFICIENT TIME FOR INTEGRATION, TIG WAS SLIPPED	SH, 19

SET INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
SPARE: <i>R. B. Shaw</i> 197004 PROGRAM: <i>W. M. Robertson</i> 197004 ANALYST: <i>W. M. Robertson</i> 197004 DATE: <i>12-5-71</i> APPROVED: <i>Robert M. Carter</i> 12-5-71		INTEGRATION INITIALIZATION COLLOSSUS IIC SIX-REV 93 FC-2290 24 26	

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TDEC _{1D}	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
TDELTA _V	$\underline{\delta}$	POSITION DEVIATION VECTOR	M	M	2 ²² 2 ¹⁸
TNUV _V	\underline{u}	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
TRMKCNT		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-OTHER _V	\underline{r}_{con}	POSITION VECTOR OF LM FOR DOWNLINK	M	M	2 ²⁹ 2 ²⁷
V-OTHER _V	\underline{v}_{con}	VELOCITY VECTOR OF LM FOR DOWNLINK	M/CSEC	M/CSEC	2 ⁷ 2 ⁵

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APR 11 1964 V. J. HANLEY AND A. W. H. H. S.
REVISION: <i>X-10</i> ANALYST: <i>W. M. Robertson</i> DATE: <i>5/20/64</i> DRAWN: <i>Robertson</i>	INTEGRATION INITIALIZATION COLOSSUS IIC FC-2290 REV: 25 26

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)	ANY
(PAINS)CD _D		INTEGER 2	2	2	2^{14}
TIMDEL _T _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}
$5 \delta_D$		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	\bar{L}_S	LUNAR LANDING SIGHT VECTOR				

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		ATL G. IBAKIS AND NAVIGATION	
DRAWN <i>W. A. Blaine</i> 29 NOV 68		INTEGRATION INITIALIZATION	
PROJ. <i>APOLLO</i>		DOCUMENT NO. FC-2290	
ANALYST <i>W. A. Blaine</i> 5 APR 69		COLLOSSUS IIC	
DOLMP		SHEET 26 OF 26	
APPROVED <i>Robert M. Carter</i> 8-26-63		REV	

ORBITAL INTEGRATION

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

TESTLOOP	ENTRY TO ACTUAL INTEGRATION LOOP	SII. 1
TIMESTEP	INTERMEDIATE ENTRY POINT IN INTEGRATION LOOP	SII. 6
INTEGRATE	INTERMEDIATE ENTRY POINT IN INTEGRATION LOOP THAT INITIALIZES LOCATIONS FOR FIRST PASS THROUGH LOOP	SII. 8
ACCOMP	COMPUTES THE ACCELERATION COMPONENTS FOR EARTH AND MOON	SII. 9
GAMCOMP	SUBROUTINE THAT COMPUTES ACCELERATION a_p DUE TO THE ATTRACTION OF THE PRIMARY BODY	SII. 23
DIFEQ*0	EVALUATE \dot{x} AND \dot{y} AT THE LEFT HAND POINT	SII. 27
DIFEQ*1	EVALUATE \dot{x} AND \dot{y} AT THE MID-POINT	SII. 27
FHR3	CALCULATE TIME AND CONIC STATE VECTOR AT MIDPOINT AND RIGHT HAND POINT	SII. 28
KEPPREP	SUBROUTINE COMPUTES ESTIMATE OF x AND THEN CALLS KEPLER SUBROUTINE TO CALCULATE CONIC STATE VECTOR	SII. 29
DIFEQ*2	EVALUATE \dot{x} AND \dot{y} AT THE RIGHT HAND POINT AND THEN CALCULATE THE FUNCTION \dot{x} AND ITS DERIVATIVE \ddot{x} AT RIGHT HAND POINT	SII. 32
NEXTCOL	INTERMEDIATE ENTRY POINT FOR INTEGRATING A COLUMN OF THE W-MATRIX	SII. 35
CKMID2	ROUTINE ENTERED BY INTEGRATION IF CALLED BY MIDTOAV	SII. 36
A-PCHK	WRAPS UP THE INTEGRATION ROUTINE WITH A STATE VECTOR UPDATE IF REQUESTED AND A RECTIFICATION	SII. 38
RECTOUT	DOES RECTIFICATION AND STORES OUTPUT IN PUSHLIST	SII. 40
DOW..	ROUTINE THAT CONTROLS THE CALCULATION OF THE ACCELERATION TERMS USED FOR INTEGRATING THE W-MATRIX	SII. 41
DOW..1	SUBROUTINE THAT CALCULATES THE ACCELERATIONS a_p AND a_q	SII. 42
RECTIFY	DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS	SII. 43
MINIRECT	ENTRY POINT IN RECTIFY IF δ_x \neq 0 MUST BE INITIALLY ZERO	SII. 43
RECTIFY *13D	ENTRY POINT IN MINIRECT IF VRECT _v ALREADY STORED	SII. 43
ORIGCHNG	CHANGE ORIGIN OF COORDINATE SYSTEM	SII. 44

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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		ORBITAL INTEGRATION	
DRAWN	<i>A. S. K. S. K.</i>		
PROG#			DOCUMENT NO.
ANALYST	<i>W. P. OstaneK</i>		17C-2300
DOCK#		COLOSSUS IIC	
APPROV	<i>W. P. OstaneK</i>	REV	SHEET 1 OF 50

THE TIME TO INTEGRATE TO t_2 IS STORED IN TDEG_D

TESTLOOP

THE INITIAL ENTRY INTO TESTLOOP IS FROM INTEGRV, (FC-2290) IT IS SUBSEQUENTLY REENTERED FROM DIFFERENT POINTS IN THE ROUTINE AS INTEGRATION CONTINUES IN 4E INTERVALS TO THE UPPER LIMIT

QUITFLAG

SET

STOP THE INTEGRATION BECAUSE FLAG IS SET AS A RESULT OF REQUESTING MORE THAN STATEFLG MUST BE LEFT IN A CLEAR CONDITION UPON RETURN FROM INTEGRATE !!

CLEAR

CLEAR STATEFLG

CONTINUE THE INTEGRATION

SET PUSH LIST POINTER TO PL10

INTEXT
SH 40

THIS CLEARS SEVERAL FLAGS AND GOES TO INTWAKE, FC-2290

XZ ← PBODY

PRIMARY BODY INDICATOR IS STORED IN XZ

$$\begin{array}{l} \frac{r_{CON}}{PL10_D} = \frac{r_{CON}}{RCV_V} \\ \frac{r_{CON}}{PL10_D} = \frac{r_{CON}}{RCV_V} \\ \frac{r_{CON}}{PL10_D} = \frac{r_{CON}}{RCV_V} \\ \frac{r_{CON}}{PL10_D} = \frac{r_{CON}}{RCV_V} \end{array}$$

@ 2²⁹/₂ 27
@ 2³⁰/₂ 24

CON ≥ r_{MP}

YES

SINCE r_{MP} EQUALS THE LARGEST NUMBER POSSIBLE THIS TEST WILL ALWAYS FAIL, HENCE GUIDANCE NEVER TAKES THIS PATH

NO

CLEAR MIDFLAG

NOT IN MIDCOURSE

SET MIDFLAG

IN MIDCOURSE, SO INCLUDE MIDCOURSE PERTURBATIONS

NORFINAL

$$\frac{\sqrt{r_{CON}}}{MPAC_D} = \frac{r_{CON}^{3/2}}{\sqrt{\mu_p}}$$

SHIFTED @ 2²⁶

BEGIN CALCULATION OF Δt_{MAX} = MIN(4000SEC, $.3 r_{CON}^{3/2} / \sqrt{\mu_p}$)

Δt_{MAX} IS THE MAXIMUM ALLOWABLE INTERVAL FOR ONE NYSTRON INTEGRATION CYCLE

$$\Delta t = \frac{.3 r_{CON}^{3/2}}{\sqrt{\mu_p}}$$

MPAC_D ← .3D₀ · MPAC_D @ 2²⁶

$.3D_0 = 0.3 @ 2^2$

NEXT SHEET

NO. 1
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DR: *J.S. Chelmsford* 17 OCT 68
PRGRM
ANALY: *M. Robertson* 23 NOV 68
DOCTR
APPRO: *Walter J. ...* 7-21-68

ORBITAL
INTEGRATION
COLOSSUS
IC FC-2300

5 2

FROM PRECEDING SHEET

SHIFT AND LOAD MPAC SUCH THAT $\Delta F \frac{3/2}{CON} / \sqrt{P}$ IS TRUNCATED TO A MULTIPLE OF 120 C SECS, SCALED AT 2^{20}

$$\frac{\Delta t \text{ MAX}}{PL120} \leftarrow \frac{\Delta F \frac{3/2}{CON} / \sqrt{P}}{MPAC_D} @ 2^{20}$$

OVERFLOW
YES
NO

$DT/2 \text{ MAX}_D = 4000$
SECS AT 2^{20}

$\Delta t \text{ MAX} > 4000$
SECS
YES
NO

MAXDT

$$\frac{\Delta t \text{ MAX}}{PL120} \leftarrow \frac{4000 \text{ SEC}}{DT/2 \text{ MAX}_D} @ 2^{20}$$

LIMIT $\Delta t \text{ MAX}$ TO THE MAXIMUM VALUE ALLOWED

AT THIS POINT
 $\Delta t \text{ MAX} = \text{MIN}$
 $(\Delta F \frac{3/2}{CON} / \sqrt{P}, 4000 \text{ SEC})$

DT/2 COMP

CALCULATE Δt , GUARANTEEING THAT
 $\Delta t \leq \Delta t \text{ MAX}$

$$\frac{\Delta t}{MPAC_D} \leftarrow \frac{t_2 - t_1}{TOEC_D - TET_D} @ 2^{20}$$

Δt IS THE TIME INTERVAL BETWEEN t_1 THE CURRENT TIME AS USED IN INTEGRATION LOOP AND t_2 THE UPPER LIMIT. THE VALUE t_1 IN TET_D IS INCREMENTED BY $\frac{\Delta t}{2}$ TWICE CORRESPONDING TO POINTS $j = 2 \text{ AND } 3$. SEE SH. 24

SIGNAGREE
FORCE SIGN
AGREEMENT
FC-2100

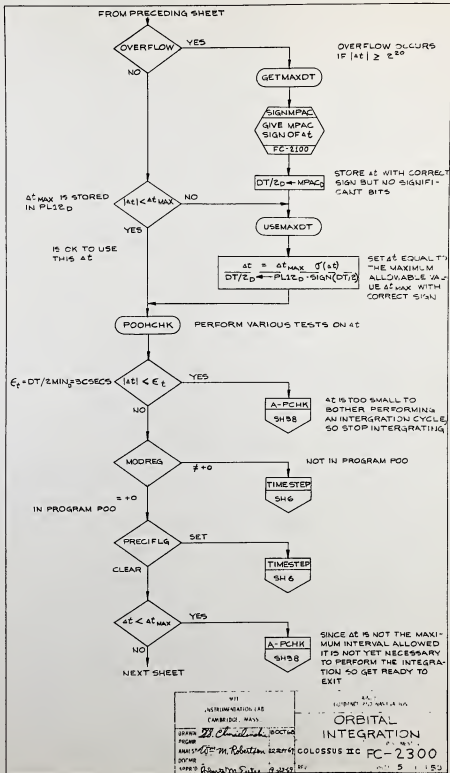
THE SUBROUTINE TAKES THE DOUBLE PRECISION VALUE IN MPAC AND FORCES SIGN AGREEMENT

SHIFT MPAC LEFT 8 PLACES TO SCALE Δt AT 2^{20} AND STORE IN $DT/2_D$

STORE Δt AT 2^{20} . THIS CAN ALSO BE CONSIDERED AS $\Delta t/2$ AT 2^{19}

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARMED GUIDANCE AND NAVIGATION	
DRAWN <i>J. J. Chmel</i>		ORBITAL INTEGRATION	
FROM <i>FC-2100</i>		DOCUMENT NO.	
ANALYST <i>W. M. Johnston</i>		COLOSSUS IIC	
DOCKED		FC-2300	
APPROVED <i>W. M. Johnston</i>		SHEET 4 of 50	



FROM PRECEDING SHEET

CLEAR

NEWIFLG

THIS IS FIRST PASS THROUGH INTEGRATION.

SET

CLEAR

NEWIFLG

CLEAR FLAG TO INDICATE ON SUBSEQUENT TESTS THAT ROUTINE HAS ALREADY MADE THE FIRST PASS THROUGH INTEGRATION.

$t_2 \geq t_1$

NO

INTEEXIT
SH40

DO NOT INTEGRATE

FORM $t_2 - t_1$
 $PLD \leftarrow TDEC - TETD$
 @ 2^{20}

$t_2 - t_1$ IS THE TIME INTERVAL BETWEEN PRESENT TIME AS USED IN INTEGRATION LOOP (TET) AND UPPER LIMIT (TDEC). IN POO, t_2 EQUALS CURRENT REAL TIME, APPROX

FORM $4 \Delta t$
 $MPACD \leftarrow DT / 2D$
 SHIFTED AND ROUNDED
 @ 2^{20}

$DT/2D$ CONTAINS Δt @ 2^{20}

$t_2 > t_1 + 4\Delta t$

NO

INTEEXIT
SH40

IT HAS NOT BEEN AT LEAST 4 TIME STEPS SINCE LAST INTEGRATION SO EXIT WITHOUT DOING ANY INTEGRATION

CURRENT TIME IS NOW AT LEAST $4\Delta t$ SINCE LAST INTEGRATION SO PROCEED WITH INTEGRATION

TIME STEP

PERFORM A SERIES OF TESTS TO DETERMINE IF RECTIFICATION IS REQUIRED

MIDFLAG

SET

CHKSWTCH
CHECK FOR SPHERE OF INFLUENCE
SH45

OUTPUT :
MPAC_s = DISTANCE FROM LUNAR SPHERE

CLEAR

SKIP ORIGIN CHANGE LOGIC

NO

MPAC_s < 0

YES

NO SOLAR PERTURBATIONS

RECTEST

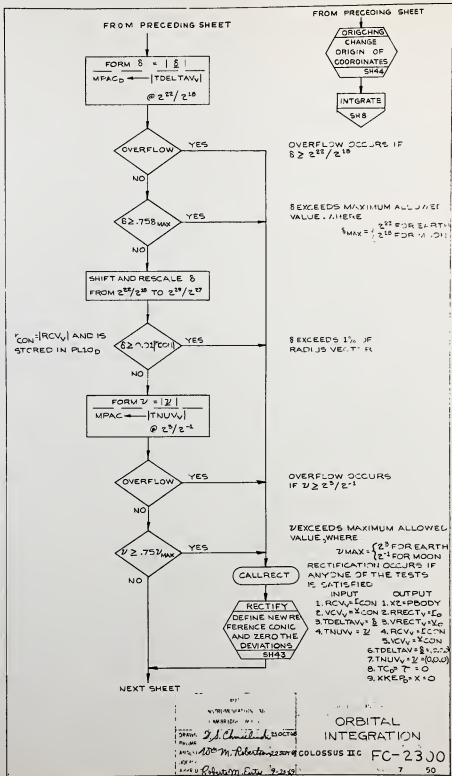
NEXT SHEET

IN LUNAR SPHERE SO CHANGE ORIGIN OF COORDINATES

DOSWITCH

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		ORBITAL INTEGRATION	
PESHW <i>[Signature]</i>		DOCUMENT NO.	
ANALYST <i>[Signature]</i>		COLOSSUS IIC FC-2300	
DOCNR		SHEET 6 OF 50	
APPROV <i>[Signature]</i>		REV	



FROM PRECEDING SHEET

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

ZW ← TNUW
@ Z²/Z⁻¹
YW ← TDELTA VV
@ Z²/Z¹⁸

STORE U, S IN WORKING STORAGE PRIOR TO INTEGRATING THE STATE VECTOR

CLEAR
J SWITCH

INITIALIZE TO INDICATE THE STATE VECTOR AND NOT THE W-MATRIX IS BEING INTEGRATED

DIFEQO

THIS IS THE ENTRY POINT FOR INITIALIZING LOCATIONS PRIOR TO MAKING THREE PASSES THROUGH THE INTEGRATION LOOP (FOR J = 1, 2, 3). THE VECTOR BEING INTEGRATED OVER A TIME INTERVAL OF Δt IS EITHER A STATE VECTOR OR A VECTOR IN THE W-MATRIX

J = 1
DIFEQCNT ← 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, 180, -240

α_j = β
ALPHA VV ← YV_j
@ Z²/Z¹⁸

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

A = 0
H₀ ← DPZEROD

INITIALIZE A_j
A_j TAKES ON THE VALUES 0, Δt, Δt CORRESPONDING TO THE LEFT POINT, MID POINT, AND RIGHT POINT VALUE OF THE INTERVAL Δt.

CLEAR
J SWITCH

SET

ACCOMP
5H9

INTEGRATE THE STATE VECTOR

DOW.
5H41

INTEGRATE A VECTOR FROM THE W-MATRIX

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. J. ...</i>		ORBITAL INTEGRATION	
PROGRAM <i>...</i>		DOCUMENT NO. FC-2300	
DESIGN <i>...</i>		SHEET 8 OF 150	
APPROVED <i>...</i>		REV <i>...</i>	

ACCOMP COMPUTES THE ACCELERATION COMPONENTS. IT IS ENTERED ON EACH OF THE THREE PASSES THROUGH THE INTEGRATION LOOP, CORRESPONDING TO $J=1, 2, 3$

ACCOMP

$X1 \leftarrow PBODY$
 $X2 \leftarrow PBODY$

$PBODY = \begin{cases} 0 & \text{FOR EARTH} \\ 2 & \text{FOR MOON} \end{cases}$

$\frac{f_j}{FW} \leftarrow \frac{0}{ZEROVEC_V}$
 $@ 2^{14}/2^{20}$

INITIALIZE f_j
 f_j IS THE VALUE OF THE SECOND DERIVATIVE, AT POINT j .

SHIFT AND RESCALE $\alpha_j =$
 $ALPHAV_V$ FROM $2^{22}/2^{18}$
TO $2^{27}/2^{27}$

α_j IS THE ESTIMATE OF δ
AT POINT j .

$\frac{\beta_j}{BETAV_V} \leftarrow \frac{\beta_j + ICON}{ALPHAV_V - ICON}$
 $@ 2^{29}/2^{27}$

β_j IS AN ESTIMATE OF THE PRECISION VECTOR β (BASED ON THE LATEST ESTIMATE OF δ (EQUAL TO α_j) AND THE LATEST VALUE OF $ICON$)

DIMOF LAA

SET

THE W-MATRIX IS TO BE INTEGRATED SO STORE β_j IN TEMPORARY STORAGE FOR LATER USE IN SUBROUTINE DOW..1.

CLEAR

THE W-MATRIX IS NOT TO BE INTEGRATED SO DON'T BOTHER TO STORE β_j

$X2 \leftrightarrow DIFEGCNT$

PUT VECTOR POINTER (CORRESPONDING TO A VALUE OF j) INTO $X2$

STORE β_j
VECTAB_V * $X2 \rightarrow BETAV_V$

STORE $\beta_j = I$ INTO PROPER SPOT IN VECTOR TABLE

$DIFEGCNT \leftrightarrow X2$

RESTORE BOTH LOCATIONS

$\frac{u_{joc}}{\alpha_j} = (\beta_j) \text{ UNIT}$
 $\alpha_j = |\alpha_j|$
 $ALPHAV_V \leftarrow \text{UNIT}(ALPHAV_V)$
 $@ 2^1$
 $ALPHAMD \leftarrow |ALPHAV_V|$
 $@ 2^{29}/2^{27}$

$u_{joc} = u_8$
 $\alpha_j = \delta = |\delta|$

NEXT SHEET

REVISION 10 70
AUTHOR: MRS
DATE: 27 October 1960
NAME: W. M. Robertson, 2200 H
COLUSSUS IIC
APPRO: G. M. Datta, 2-255, 21

ORBITAL
INTEGRATION

FC-2300

9 03

FROM PRECEDING SHEET

β_p IS THAT PORTION OF THE SECOND DERIVATIVE \ddot{x}_j DUE TO THE ATTRACTION OF THE PRIMARY BODY, CONSIDERED AS A POINT MASS



INPUT
 1. $BETA_{V_j} = \beta_j = \dot{x}_j^2$
 2. $ALPHA_{V_j} = \alpha_j = \dot{x}_j \dot{y}_j$
 3. $ALPHA_{M_j} = \alpha_j = \dot{x}_j^2$

OUTPUT
 1. $F_{V_j} = G_p$
 2. $BETA_{V_j} = \beta_j = \dot{x}_j^2$ UNIT = $\frac{L}{T^2}$
 3. $BETA_{M_j} = \beta_j = \dot{x}_j^2$

ALPHA_{Vj} ← MPAC_{Vj} ← BETA_{Vj}

SAVE $\alpha_j = (\beta_j)$ UNIT = $\frac{L}{T^2}$

S2 ← X1

SAVE X1

ALPHA_{Mj} ← MPAC_{Mj} ← BETA_{Mj}

SAVE B_j



SET: INCLUDE SOLAR PERTURBATIONS

CLEAR

NO SOLAR PERTURBATIONS



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DEVELOPER: <i>James R. ...</i>		ORBITAL INTEGRATION	
PROGRAM:	DATE: <i>11/10/66</i>	COLLOSSUS II C	DOCUMENT NO. FC-2300
DOCS:	APP'S: <i>...</i>	REV	SHEET 10 OF 50

FROM PRECEDING SHEET

CALCULATE THE DISTURBING ACCELERATIONS
 $\ddot{Q}_{d4} + \ddot{Q}_{d5}$

MPAC₀ ← TET₀

LSPOS
 CALCULATE
 POSITION OF
 SUN AND MOON
 FC-2286

X1 ← S2

INPUT:

1. MPAC₀ = GROUND ELAPSED TIME

OUTPUT:

1. MPAC_v = \int_{em}^v , POSITION OF MOON, Z²⁹

2. PLZ_v = \int_{rs}^v , POSITION OF SUN, Z²⁸

CLEAR MOONFLAG

SET

X2 ← 2

SET UP FOR
 EARTH PRIMARY
 $\int_{rs} = \int_{em}$

$\int_{rs} = - \int_{em}$
 MPAC_v ← -(MPAC_v)

SET UP
 FOR MOON
 PRIMARY
 EQ 2.2.19,
 PAGE

X2 ← 0

STORE \int_{rs}

RPQV_v ← BETAV_v ← MPAC_v
 @ Z²⁹

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		APPLIED OPTICS AND METROLOGY	
DRAWN: <i>John Hennessey</i>		ORBITAL INTEGRATION	
PROJ: <i>2-11-68</i>	CHKD: <i>M. P. Robertson</i>	COLOSSUS IIC	PLC/MS/RS
DATE: <i>2-11-68</i>	APP'D: <i>John S. Dyer</i>	REV	FC-2300
2-22-68		SHEET 11 OF 50	

FROM
PRECEDING SHEET

STORE r_{bc}
RPSV_v ← PL 2_v
@ 2¹⁸

DIMOFLAG
CLEAR
SET

NO W-MATRIX
INTEGRATION

$r_{bc} = r - r_{pd}$
MPAC_v ← ALPHA_v · ALPHA_m - BETAV_v
@ 2¹⁸

EQ 2.2.21,
PAGE 5.2-19

X2 ← DIFEQNT

LOAD X2 WITH POINTER

STORE r_{bc} IN TABLE
(VECTAB + 6 # X2)_v ← MPAC_v

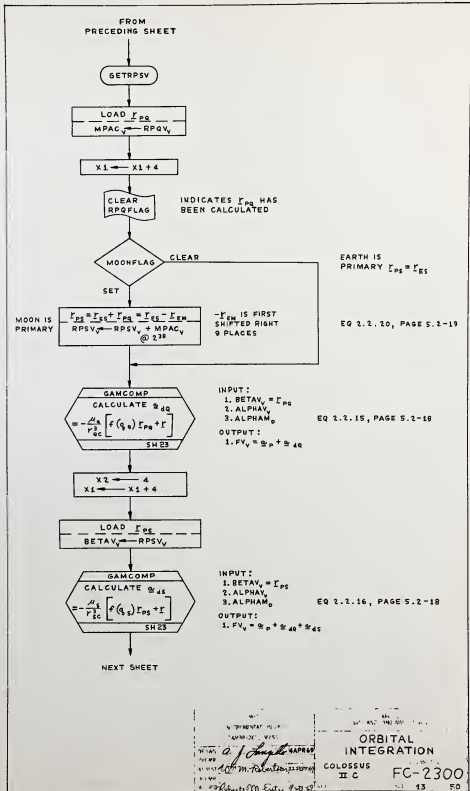
X2 = 0, -12D, -24D

X2 ← DIFEQNT

RESTORE VALUES

NEXT SHEET

MIL INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLO GUIDANCE AND NAVIGATION	
DRAWN <i>G. J. Sargent</i>		ORBITAL INTEGRATION	
FIGURE	SCALE	COLOSSUS IIC	DOCUMENT NO.
ANALYST <i>R. M. Johnson</i>	DATE	FC-2300	SHEET 12 OF 50
APPROVED <i>R. M. Johnson</i>	REV		



FROM PRECEDING SHEET

OBLATE

X2 ← PBODY

PBODY = $\begin{cases} 0 & \text{FOR EARTH} \\ 2 & \text{FOR MOON} \end{cases}$

SET PUSH LIST
POINTER TO ZERO

r IS THE MAGNITUDE OF THE LATEST ESTIMATE OF THE PRECISION POSITION, IT EQUALS R ; r_{op} IS THE RADIUS OF RELEVANCE OF THE PRIMARY BODY. IF THE SPACECRAFT IS OUTSIDE OF THIS SPHERE THEN THE ACCELERATION a_{dp} IS IGNORED.

$r \geq r_{op}$

YES

SPACECRAFT IS
OUTSIDE SPHERE
OF RELEVANCE

NBRANCH
SH21

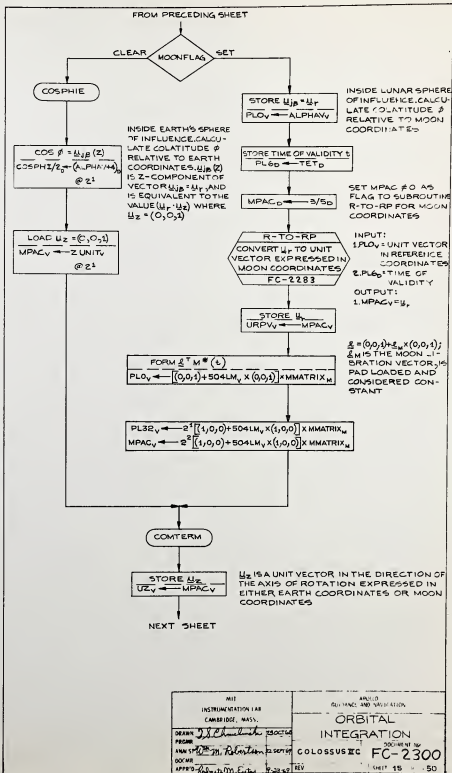
DO NOT
CALCULATE a_{dp}

NO

SPACECRAFT IS INSIDE
SPHERE OF RELEVANCE
SO CALCULATE a_{dp}

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		ORBITAL INTEGRATION	
DR/MR <i>James H. ...</i>	<i>July 67</i>		
PROGRAM			DOCUMENT NO.
ANALYST <i>W. L. ...</i>	<i>22 SEP 66</i>	COLOSSUS II C	FC-2300
DCM			
APPROVED <i>W. L. ...</i>	<i>12-22-69</i>	REV	SHEET 24 OF 50



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN BY *J. Chandra* 250266

PROGRAM

ANALYST *M. R. Chandra* 250266

DOC NO.

APPROVED BY *M. R. Chandra* 250266

ORBITAL
INTEGRATION

COLLOSSUS IIC DOCUMENT NO. FC-2300

REV 15 - 50

FROM PRECEDING SHEET

$$\frac{P_2'}{PL0_D} = \frac{3 \cos \phi}{\cos \phi H I / E_D} \cdot \frac{3/32_D}{@ 2^6}$$

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

$$\frac{\text{FORM } 15 \cos^2 \phi}{MPAC_D} = \frac{15 \cos^2 \phi}{(\cos \phi H I / E_D)^2 \cdot \frac{15/16_D}{@ 2^6}}$$

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

$$\frac{P_3'}{PL2_D + MPAC_D} = \frac{\frac{1}{2} (15 \cos^2 \phi - 3)}{MPAC_D + (MPAC_D - \frac{3/64_D}{@ 2^5})/2}$$

$$3/64_D = 3.0 @ 2^4$$

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

$$\frac{\text{FORM } \frac{7}{8} \cos \phi P_3'}{PL4_D} = \frac{7/12_D \cdot \cos \phi H I / E_D \cdot MPAC_D}{\text{SHIFTED } @ 2^7}$$

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

$$\frac{\text{FORM } \frac{2}{3} P_3'}{MPAC_D} = \frac{2/30_D \cdot PL2_D}{@ 2^7}$$

$$2/30_D = \frac{1}{3} @ 2^1$$

$$\frac{P_4'}{PL4_D} = \frac{\frac{2}{3} \cos \phi P_3' - \frac{1}{3} P_2'}{MPAC_D + PL4_D - MPAC_D @ 2^7}$$

$$\frac{\text{FORM } \frac{9}{16} \cos \phi P_4'}{PL6_D} = \frac{9/16_D \cdot \cos \phi H I / E_D \cdot MPAC_D}{@ 2^{10}}$$

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

$$\frac{P_5'}{MPAC_D} = \frac{\frac{9}{16} \cos \phi P_4' - \frac{2}{3} P_3'}{PL6_D - 5/120_D \cdot PL2_D @ 2^{10}}$$

$$5/120_D = \frac{5}{4} @ 2^5$$

$$\frac{\text{FORM } \frac{J_{4E} P_D}{J_{3E}} P_5'}{MPAC_D} = \frac{J_{4E} P_D}{J_{3E}} \cdot \frac{P_5'}{MPAC_D} @ 2^{26}$$

$$J_{4E} P_D = \begin{cases} \frac{J_{4E} E}{J_{3E}} = 4991607.391 @ 2^{26} \\ \text{FOR EARTH} \\ \frac{J_{4M} E}{J_5} = -176236.02 @ 2^{26} \\ \text{FOR MOON} \end{cases}$$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J.F. Chubbuck</i> 200046		ORBITAL INTEGRATION	
FROM <i>W.M. Robertson</i> 200045		COLOSSUS II	
DIMS		REVISION NO. FC-2300	
APPROV. <i>W.M. Robertson</i> 200045		SHEET 16 OF 50	

FROM PRECEDING SHEET

$$\text{FORM } \frac{J_{2P} P_2' / r + P_4'}{J_{2P}} = \frac{J_{2P} (P_2')}{J_{2P} (r)} P_2' + P_4'$$

$$\text{MPAC}_D \rightarrow \text{MPAC}_D / \text{ALPHAM}_D + \text{PL4}_D @ 2^7$$

$$\text{FORM } \frac{J_{2P} (P_2')}{J_{2P} (r)} P_4' + P_4' = \frac{J_{2P} P_4'}{J_{2P} (r)}$$

$$= \frac{J_{2P} (P_2')^2}{J_{2P} (r)} P_4' + \frac{J_{2P} (P_4')}{J_{2P} (r)} P_4'$$

$$\text{MPAC}_D \rightarrow \text{MPAC}_D \cdot (2J_{2P} R_E^2 / X_2^2) / \text{ALPHAM}_D @ 2^8$$

$$J_{2P} P_4' = \begin{cases} J_{2P} P_4' = 13554.263 \omega_3 @ 2^7 \\ \text{FOR EARTH} \\ J_{2P} P_4' = .3067493346 \times 10^{18} \\ \text{FOR MOON} \\ @ 2^{+10} \end{cases}$$

$$\text{FORM } K_{12} V = \left[\frac{J_{2P} (P_2')^2}{J_{2P} V} P_4' + \frac{J_{2P} (P_4')}{J_{2P} V} P_4' \right] \omega_3$$

$$\text{TVEL}_V \rightarrow [\text{MPAC}_D + \text{PL2}_D] \text{ALPHAV}_V @ 2^6$$

$$\text{FORM } \frac{J_{2P} P_4'}{J_{2P}}$$

$$\text{MPAC}_D \rightarrow (4RE/3X_2) \text{PL4}_D$$

SHIFTED @ 2⁸

$$\text{FORM } \frac{J_{2P} P_4'}{J_{2P}} P_4' / r + P_4' = \frac{J_{2P} (P_4')}{J_{2P}} P_4' + P_4'$$

$$\text{MPAC}_D \rightarrow \text{MPAC}_D / \text{ALPHAM}_D + \text{PL2}_D @ 2^5$$

$$\text{FORM } \frac{J_{2P} (P_4')}{J_{2P}} P_4' + P_4' = \frac{J_{2P} P_4'}{J_{2P} (r)}$$

$$= \frac{J_{2P} (P_4')^2}{J_{2P} (r)} P_4' + \frac{J_{2P} (P_4')}{J_{2P} (r)} P_4'$$

$$\text{MPAC}_D \rightarrow \text{MPAC}_D \cdot (2J_{2P} R_E^2 / X_2^2) / \text{ALPHAM}_D$$

SHIFTED @ 2⁶

$$\text{FORM } K_{12} V = \left[\frac{J_{2P} (P_4')^2}{J_{2P} V} P_4' + \frac{J_{2P} (P_4')}{J_{2P} V} P_4' \right] \omega_3$$

$$\text{MPAC}_V \rightarrow [\text{MPAC}_D + \text{PL0}_D] \text{LIZ}_V$$

SHIFTED @ 2⁶

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	AREA 2-DRAWING AND METROLOGY
DRAWN: <i>J. Chouhade</i> CHECKED: <i>M. Robertson</i> APPROVED: <i>J. Chouhade</i>	ORBITAL INTEGRATION COLUSSUS IIC FC-2300
DATE: 11/17/60 REV: 1	DRAWING NO. 5011 17 - 50

FROM PRECEDING SHEET

$$\text{FORM } K_1 \underline{U}_r - K_2 \underline{U}_z$$

$$\text{TVEC}_v \rightarrow \text{TVEC}_v - \text{MPAC}_v$$

@ 2¹⁶

$$\text{NORMALIZE } \underline{r}$$

$$\text{MPAC}_0 \rightarrow \text{ALPHAD}$$

$$\text{NORMALIZE AT } 2^{22-10}/2^{27-10}$$

THE NORMALIZING VALUE - m
IS STORED IN X1

$$\text{FORM } \underline{r}^4$$

$$\text{MPAC}_0 \rightarrow (\text{MPAC}_0)^4$$

@ 2^{16-4m}/2^{102-4m}

$$\text{NORMALIZE AND STORE } \underline{r}^4$$

$$\text{PLOC} \rightarrow \text{MPAC}_0$$

$$\text{NORMALIZED AT } 2^{16-4m}/2^{102-4m}$$

THE NORMALIZING VALUE - n
IS STORED IN S1

$$\text{FORM } \frac{\sum_{i=1}^3 \underline{r}_i^2 \text{MPAC}_0 / \underline{r}^4}{\text{MPAC}_0 \rightarrow (\sum_{i=1}^3 \text{REQSQ} \times X_2)_0 / \text{MPAC}_0}$$

$\sum_{i=1}^3 \underline{r}_i^2 \text{MPAC}_0 = 1.75501139 \times 10^{23}$
B-7E FOR EARTH
 $\sum_{i=1}^3 \underline{r}_i^2 \text{MPAC}_0 = 0.3067493816 \times 10^{20}$
B-6O FOR MOON

$$\text{FORM } \frac{[K_1 \underline{U}_r - K_2 \underline{U}_z] \sum_{i=1}^3 \underline{r}_i^2 \text{MPAC}_0}{\text{MPAC}_v \rightarrow \text{TVEC}_v \cdot \text{MPAC}_0}$$

THIS IS \underline{U}_{ic} FOR THE
EARTH OR THE MAJOR
PART OF \underline{U}_{icm} FOR THE
MOON

CLEAR
OVPIND
IF SET

$$\text{FORM } -376-n$$

$$X1 \leftarrow 3 \cdot X1 + S1$$

NEXT SHEET

$$\{K_1 \underline{U}_r - K_2 \underline{U}_z\} \frac{\sum_{i=1}^3 \underline{r}_i^2 \text{MPAC}_0}{\underline{r}^4}$$

$$= \left\{ \left[\frac{\text{JAP}(\underline{r}_0)}{\text{JAP}(\underline{r})} P_5' + \frac{\text{JAP}(\underline{r}_0)}{\text{JAP}(\underline{r})} P_4' + P_5' \right] \underline{U}_r - \left[\frac{\text{JAP}(\underline{r}_0)}{\text{JAP}(\underline{r})} P_4' + \frac{\text{JAP}(\underline{r}_0)}{\text{JAP}(\underline{r})} P_5' + P_4' \right] \underline{U}_z \right\} \frac{\sum_{i=1}^3 \underline{r}_i^2 \text{MPAC}_0}{\underline{r}^4}$$

$$= \frac{\text{MPAC}_0}{\underline{r}^4} \left\{ \left[\frac{\text{JAP}(\underline{r}_0)}{\text{JAP}(\underline{r})} P_5' + \frac{\text{JAP}(\underline{r}_0)}{\text{JAP}(\underline{r})} P_4' + P_5' \right] \underline{U}_r - \left[\frac{\text{JAP}(\underline{r}_0)}{\text{JAP}(\underline{r})} P_4' + \frac{\text{JAP}(\underline{r}_0)}{\text{JAP}(\underline{r})} P_5' + P_4' \right] \underline{U}_z \right\}$$

$$= \frac{\text{MPAC}_0}{\underline{r}^4} \sum_{i=1}^3 \frac{\underline{r}_i^2}{\underline{r}^4} \left[P_4' + P_5' \underline{U}_r - P_4' \underline{U}_z \right]$$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J.P. Chappel</i>		ORBITAL INTEGRATION	
PROGRAM <i>APOLLO 11</i>		COLLOSSUS IIC	
DOCSM <i>11-11-68</i>		DRAWING NO. FC-2300	
APPROV <i>J.P. Chappel</i>		SHEET 18 OF 30	

FROM PRECEDING SHEET

$$\frac{\xi_j = \xi_j + \frac{\sigma d_M}{MPAC_y} \left[-FV_y + MPAC_y \frac{2 - 2SD - XI}{2} \right]}$$

$\alpha_{LOMP} + \text{ZONAL OBLATE}$

OVERFLOW

YES

NO

GOBAQUE
SH 22

IF OVERFLOW OCCURS DUE TO EXCESSIVELY LARGE ACCELERATIONS, GO BACK, DO A KEPLER UPDATE, RECTIFY, AND TRY AGAIN

$$FV_y \leftarrow MPAC_y$$

MOONFLAG

CLEAR

SET

NBRANCH
SH 21

THE FOLLOWING CALCULATIONS VALID FOR MOON ONLY

$$\text{form } \frac{5(X_M^2 - Y_M^2)}{r^3} \underline{U}_r$$

$$PL2_y \leftarrow \frac{5}{2} \left[(URPV_0 + 2) \frac{2 - URPV_0^2}{2} - URPV_0^2 \right] \text{ALPHAV}$$

$$\text{SCALED } @ 2^3$$

$$\text{equivalent to } \frac{2X_M}{r} \underline{U}_M + \frac{5(X_M^2 - Y_M^2)}{r^2} \underline{U}_r$$

$$PL2_y \leftarrow PL2_y + URPV_0 + PL32_y$$

$$\text{SCALED } @ 2^3$$

$$\text{equivalent to } \frac{5(X_M^2 - Y_M^2)}{r^3} \underline{U}_r + \frac{2X_M}{r} \underline{U}_M + \frac{2Y_M}{r} \underline{U}_N$$

$$PL2_y \leftarrow PL2_y + 2^2 (URPV_0 + 2) (PL32_y \times UZ_y)$$

$$MPAC_0 \leftarrow \text{COSPHI}/2_0$$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLD DYNAMICS AND TRAJECTORY
PROJECT <i>W. M. Robertson</i>	ORBITAL INTEGRATION
DOC NO. <i>Robert M. Carter 2-23-61</i>	DOCUMENT # COLOSSUS IICFC-2300
	UNIT 19 - 50

FROM PRECEDING SHEET

$$\text{form } 5 \cos^2 \phi$$

$$PLB_D \leftarrow 5 MPAC_D^2$$

$$\text{SCALED @ } 2^8$$

$$\text{form } 1 - 7 \cos^2 \phi$$

$$MPAC_D \leftarrow 1 - (ZMPAC_D^2 + PLB_D)$$

$$\text{SCALED @ } 2^8$$

$$\text{form } \frac{5XM}{r} (1 - 7 \cos^2 \phi) U_r$$

$$MPAC_V \leftarrow SMPAC_D URPV_0 \text{ ALPHAV}$$

$$\text{SCALED @ } 2^5$$

$$MPAC_V \leftarrow PLB_V$$

VECTOR IN MPAC EXCHANGED WITH DP VALUE ($5 \cos^2 \phi$) IN PLB

$$\frac{5XM}{r} (1 - 7 \cos^2 \phi) U_r + (5 \cos^2 \phi - 1) i_M$$

$$PLB_V \leftarrow MPAC_V + (PLB_D - 1) PL32_V$$

$$\text{SCALED @ } 2^5$$

$$\frac{5XM}{r} (1 - 7 \cos^2 \phi) U_r + (5 \cos^2 \phi - 1) i_M + \frac{10XM Z_M - K_M}{r^2}$$

$$PLB_V \leftarrow PLB_V + 10 \cdot URPV_0 (URPV + 4)_0 \cdot UZ_V$$

$$\text{SCALED @ } 2^5$$

$$5U_{z0} \left(\frac{r_M}{r} \right)^2 \left[-\frac{5(XM_V - Y_M)}{r^2} U_r + \frac{2XM}{r} i_M - \frac{2YM}{r} j_M \right]$$

$$+ \frac{3}{2} \text{ALPHAV} C_{31} \left[\frac{5XM}{r} (1 - 7 \cos^2 \phi) U_r + (5 \cos^2 \phi - 1) i_M + \frac{10XM Z_M - K_M}{r^2} \right]$$

$$MPAC_V \leftarrow 2 + \left(\frac{5 \text{E} 3 \text{I} 3 \text{I} 1 \text{R} \text{M}}{\text{ALPHAV}} \cdot \frac{PLB_V + PL2_V}{PLD_0} \right) \text{ SCALED @ } 2^{10}$$

Z_{22} TERM ADDED TO C_{31} TERM,
STORED IN PLO

$$MPAC_V \leftarrow MPAC_V + FV_V$$

OVERFLOW

YES

NO

GOBAQUE
SH22

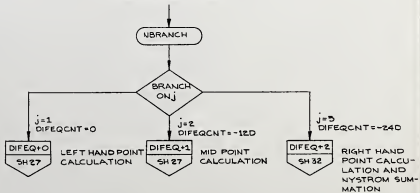
$$FV_V \leftarrow MPAC_V$$

$$X2 \leftarrow PBODY$$

NEXT SHEET

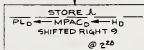
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFSLO GUIDANCE AND NAVIGATION	
ORBITAL INTEGRATION		DOCUMENT NO.	
DR AWN <i>PLB</i>	DR <i>PLB</i>	COLOSSUS IIC	FC-2300
PR CAM	ANNA SP <i>PLB</i>	REV	SHEET 20 OF 50
USCNR	APR 20 1964		

FROM PRECEDING SHEET

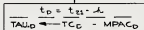


MIL INTERLATION LAB LAWRENCE, MASS		STELL CORVY - MA 01901 4110
DRAWN <i>J. J. Chubb</i>		ORBITAL INTEGRATION
APP'D <i>W. M. Roberts</i>	COLOSSUS IIC	FC-2300
DATE <i>12-28-67</i>	REV	21 - 50

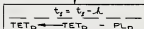
GOBAQUE IS ENTERED IF EITHER:
 1. OVERFLOW OCCURRED IN GAMCOMP WHEN THE SECOND DERIVATIVE INCREMENT WAS ADDED TO f_j , OR,
 2. OVERFLOW OCCURRED IN OBLATE WHEN g_{dp} WAS ADDED TO g_p .
 IN EITHER CASE DO A KEPLER UPDATE, RECTIFY, AND GO BACK AND INTEGRATE AGAIN, BUT NOW WITH A NEW REFERENCE CONIC, HAVING 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_2 IS REDUCED BY λ TO MAKE IT AGREE WITH TIME OF VALIDITY OF RCV_2, VCV_2



INPUT OUTPUT

1. PBODY = (0 FOR EARTH, 1 FOR MOON)

2. $RCV_2 = \mathbf{r}'(t_{21})$

3. $VCV_2 = \mathbf{v}'(t_{21})$

4. $KK EP_D = X'$

5. $TAU_2 = t_{21}$ DESIRED TIME

6. $TC_D = t_{21}$ CLEAR FOR EARTH

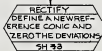
7. MOONFLAG SET FOR MOON

1. $RCV_2 = \mathbf{r}(t_2)$

2. $VCV_2 = \mathbf{v}(t_2)$

3. $TC_D = t_2$ TIME CONVERGED TO t_D

4. $XPREV_2 = X + KKEP_D$



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

THE NEW REFERENCE CONIC IS BASED ON THE OUTPUT OF THE KEPLER UPDATE OF THE STATE VECTOR AND THE DEVIATIONS CALCULATED BY PREQIBN INTEGRATION



THIS INDICATES THE VECTOR RPQ MUST BE CALCULATED

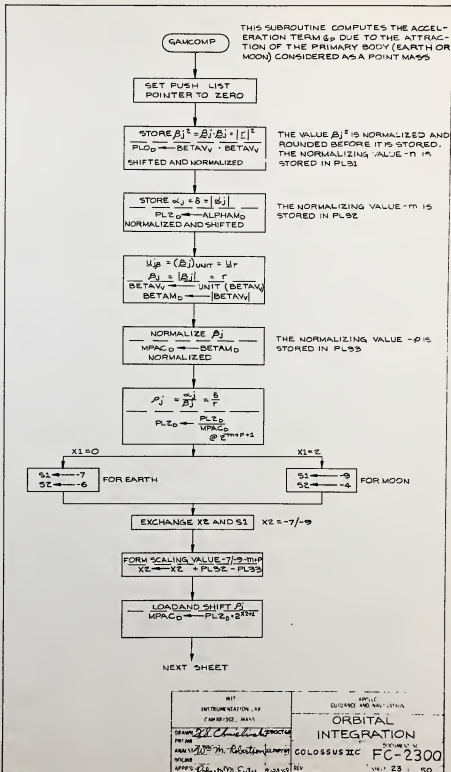


GO BACK AND INTEGRATE AGAIN USING THE NEW REFERENCE CONIC AND ZERO DEVIATIONS



POO000 CLEANS OUT ALL RESTARTS (EXCEPT THOSE ASSOCIATED WITH SERVICE, IF RUNNING); DOES A RESTART, RESULTING IN POO LIGHTS ALARM LIGHT, SETS ALARM CODE (OCT 20430: POSITION DEVIATION VECTOR = 0)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>R. Chubb</i>		ORBITAL INTEGRATION	
PROB: <i>FC-2440</i>		COLLOSSUS II	
ANAL: <i>W. M. Roberts</i>		SOUTH W. 30 FC-2300	
DOCNO: <i>FC-2440</i>		REV: <i>1</i>	
APPR: <i>Robert D. S. ...</i>		MAY 22 19 50	



REF INSTRUMENTATION, AF FANAP/3CE, WASH	APPLIC GUIDANCE AND MANEUVERING
DRAWN BY <i>[Signature]</i> CHECKED BY <i>[Signature]</i> ANALYSIS BY <i>[Signature]</i> SCALE APPROVED BY <i>[Signature]</i> 9-24-53	ORBITAL INTEGRATION COLOSSUS IIC DOCUMENT NO FC-2300 SHEET 23 OF 50

FROM PRECEDING SHEET

EXCHANGE S1 AND X2

STORE P_j
 $PLA_0 \leftarrow MPAC_0$
 @ z^1

STORE P_j^2
 $PL6_0 \leftarrow MPAC_0$
 SHIFTED @ z^1

FORM $z \cdot u_j \cdot u_{jB}$
 $MPAC_0 \leftarrow 2ALPHA \cdot BETA \cdot V$
 @ z^2

MULTIPLICATION BY Z IS ACCOMPLISHED BY A LEFT SHIFT OF ONE PLACE

FORM $P_j^2 - z \cdot u_j \cdot u_{jB} = \frac{q_j}{P_j}$
 $PL6_0 \leftarrow MPAC_0 \leftarrow PL6_0 - MPAC_0$
 @ z^2

$q_j = (P_j^2 - z \cdot u_j \cdot u_{jB}) / P_j$
 $PL6_0 \leftarrow MPAC_0 \leftarrow MPAC_0 \cdot PLA_0$
 SHIFTED @ z^2

FORM $1 + q_j$
 $PL10_0 \leftarrow MPAC_0 \leftarrow DQUARTER_0 \cdot MPAC_0$
 @ z^2

DQUARTER₀ = 1.0 @ z^2

FORM $(1 + q_j)^{3/2}$
 $PL12_0 \leftarrow MPAC_0 \leftarrow PL10_0 \cdot (MPAC_0)$
 @ z^3

FORM $1 + (1 + q_j)^{3/2}$
 $PL14_0 \leftarrow DQUARTER_0 + MPAC_0$
 @ z^2

MPAC IS FIRST SHIFTED LEFT 1 TO A SCALING OF z^2

FORM $\frac{(1 + q_j + 2)q_j + 3}{1 + (1 + q_j)} = \frac{3 + 3q_j + q_j^2}{1 + (1 + q_j)} = \frac{f(q_j)}{g_j}$
 $MPAC_0 \leftarrow \frac{(PL10_0 + HALFDP_0) \cdot PL6_0 + THREE_0}{PL14_0}$
 @ z^1

EQ 2.2.10, REF 1
 HALFDP₀ = 2.0 @ z^1
 THREE₀ = 3.0 @ z^3
 THE NUMERATOR IS SHIFTED LEFT 1 PLACE PRIOR TO ADDING THREE/8₀

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN BY <i>J. Chelak</i>		ORBITAL INTEGRATION	
PREPARED BY <i>M. Robertson</i>		DOCUMENT NO. COLOSSUS IIC FC-2300	
ANALYSED BY <i>M. Robertson</i>		REV	
CHECKED BY <i>M. Robertson</i>		SHEET 24 OF 50	

FROM PRECEDING SHEET

$$\text{FORM } \frac{f(q_j)}{P_j} \cdot P_j = \frac{f(q_j)}{P_j}$$

$$\text{MPAC}_D \leftarrow \text{MPAC}_D \cdot \text{PL} \text{ @ } Z^3$$

$$\text{FORM } \frac{f(q_j)}{P_j} \frac{1}{2} j_B + \frac{1}{2} j_C$$

$$\text{PL} \text{ @ } V \leftarrow \text{MPAC}_D \cdot \text{BETA} V_1 + \text{ALPHA} V_2$$

$$\text{ @ } Z^4$$

$$\text{FORM } \frac{\Delta_j^2 (1+q_j)^{3/2}}{\text{MPAC}_D \rightarrow \text{PL} \text{ @ } D \cdot \text{PL} \text{ @ } C}$$

NORMALIZED AND ROUNDED

NORMALIZING FACTOR - 5 IS STORED IN PL30

$$\text{FORM } \frac{P_j}{\Delta_j^2 (1+q_j)^{3/2}}$$

$$\text{MPAC}_D \leftarrow \frac{\text{PL} \text{ @ } D}{\text{MPAC}_D}$$

$$\text{FORM } \mu_P \frac{P_j}{\Delta_j^2 (1+q_j)^{3/2}}$$

$$\text{MPAC}_D \leftarrow -(\text{MUEARTH} \times XZ)_D \cdot \text{MPAC}_D$$

$$\text{FORM } \frac{\mu_P P_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[\frac{f(q_j)}{P_j} \frac{1}{2} j_B + \frac{1}{2} j_C \right]$$

$$\text{MPAC}_V \leftarrow \text{MPAC}_D \cdot \text{PL} \text{ @ } V$$

EXCHANGE XZ AND S1

LOAD -7/-9 INTO XZ

$$\text{FORM } (-7/-9) \times (-6/-4) - (-5) - (-7) = -13.5 \text{ @ } XZ$$

$$XZ \leftarrow XZ + 3Z - \text{PL} \text{ @ } 30 - \text{PL} \text{ @ } 31$$

THIS IS THE UNNORMALIZING VALUE

CLEAR
OV FIND

TURN OFF OVERFLOW INDICATOR

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED DYNAMICS AND MECHANICS
DRAWN BY <i>J. J. Chalmers</i>	ORBITAL INTEGRATION
FORMER	COLLOSSUS IIC
ANALYST <i>W. M. Robertson</i>	FC-2300
DESIGNED	REV
APPROVED <i>J. J. Chalmers</i>	MAR 25 1950

FROM PRECEDING SHEET

SHIFT MPAC RIGHT -X2-1 PLACES
TO A SCALING OF F_V

EXCHANGE X2 AND S1 RESTORE X2

$$I_j = I_j - \frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[\frac{f(q_j)}{\rho_j} \omega_j \Delta_j + \omega_j \omega_j \right]$$

$$FV_j \leftarrow FV_j + MPACV$$

THIS ADDS TO THE SECOND
DERIVATIVE $\frac{d^2}{dt^2} \xi(t)$ THE

$$\text{AMOUNT} = \frac{H \rho_j}{F V_j} \left[f(q_j) I(t) + \xi(t) \right]$$

EQ 2.2.7

OVERFLOW

YES

NO
RETURN
VIA
QPRET

GOBACK
SH22

GO BACK AND DO A
KEPLER UPDATE, REC-
TIFY AND ATTEMPT
INTEGRATING AGAIN

THE DIFFERENTIAL EQUATION FOR THE ENCKE VARIABLE $\xi(t)$ CAN BE WRITTEN AS

$$\frac{d^2}{dt^2} \xi(t) = -\frac{H \rho_j}{F V_j} \left[f(q_j) I(t) + \xi(t) \right] + 2j_p(t) \quad (2.2.7)$$

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

$$\gamma_j = -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[\frac{f(q_j)}{\rho_j} \omega_j \Delta_j + \omega_j \omega_j \right], \text{ FOR A GIVEN } j.$$

THE FOLLOWING SHOWS THAT γ_j IS EQUIVALENT TO THE FIRST TERM IN 2.2.7. LET
 $\xi(t) = \omega_j = \omega_j \omega_j \Delta_j$ AND $I(t) = \omega_j = \omega_j \omega_j \Delta_j$, WHERE ω_j AND Δ_j ARE MAGNITUDES OF
THE RESPECTIVE VECTORS. DEFINE $\rho_j = \omega_j / \Delta_j$. THEN γ_j CAN BE WRITTEN AS

$\gamma_j = -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[f(q_j) \omega_j + \omega_j \omega_j \right]$, WHERE $F V_j$ HAS BEEN
REPLACED BY $\Delta_j^2 (1+q_j)^{3/2}$. CONTINUING,

$$\begin{aligned} \gamma_j &= -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[f(q_j) \omega_j \Delta_j + \omega_j \omega_j \Delta_j \right] \\ &= -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[f(q_j) \omega_j \Delta_j + \frac{\omega_j \omega_j}{\Delta_j} \Delta_j \right] \\ &= -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[\frac{f(q_j)}{\rho_j} \omega_j \Delta_j + \omega_j \omega_j \right] \end{aligned}$$

THE VARIABLE q_j IS EVALUATED AS,

$$\begin{aligned} q_j &= \frac{(\omega_j - z \omega_j) \cdot \omega_j}{\Delta_j^2} = \frac{(\omega_j \omega_j \Delta_j - z \omega_j \omega_j \Delta_j) \cdot \omega_j \omega_j \Delta_j}{\Delta_j^2} \\ &= \left[\frac{\omega_j}{\Delta_j} \omega_j \Delta_j - z \omega_j \Delta_j \right] \frac{\omega_j \omega_j \Delta_j}{\Delta_j^2} = \rho_j \left[\rho_j - z \omega_j \Delta_j \cdot \omega_j \Delta_j \right] \end{aligned}$$

THE DIFFERENTIAL EQUATION FOR THE ENCKE VARIABLE $\xi(t)$ CAN BE WRITTEN AS

$$\frac{d^2}{dt^2} \xi(t) = -\frac{H \rho_j}{F V_j} \left[f(q_j) I(t) + \xi(t) \right] + 2j_p(t) \quad (2.2.7)$$

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

$$\gamma_j = -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[\frac{f(q_j)}{\rho_j} \omega_j \Delta_j + \omega_j \omega_j \right], \text{ FOR A GIVEN } j.$$

THE FOLLOWING SHOWS THAT γ_j IS EQUIVALENT TO THE FIRST TERM IN 2.2.7. LET
 $\xi(t) = \omega_j = \omega_j \omega_j \Delta_j$ AND $I(t) = \omega_j = \omega_j \omega_j \Delta_j$, WHERE ω_j AND Δ_j ARE MAGNITUDES OF
THE RESPECTIVE VECTORS. DEFINE $\rho_j = \omega_j / \Delta_j$. THEN γ_j CAN BE WRITTEN AS

$\gamma_j = -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[f(q_j) \omega_j + \omega_j \omega_j \right]$, WHERE $F V_j$ HAS BEEN
REPLACED BY $\Delta_j^2 (1+q_j)^{3/2}$. CONTINUING,

$$\begin{aligned} \gamma_j &= -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[f(q_j) \omega_j \Delta_j + \omega_j \omega_j \Delta_j \right] \\ &= -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[f(q_j) \omega_j \Delta_j + \frac{\omega_j \omega_j}{\Delta_j} \Delta_j \right] \\ &= -\frac{H \rho_j}{\Delta_j^2 (1+q_j)^{3/2}} \left[\frac{f(q_j)}{\rho_j} \omega_j \Delta_j + \omega_j \omega_j \right] \end{aligned}$$

THE VARIABLE q_j IS EVALUATED AS,

$$\begin{aligned} q_j &= \frac{(\omega_j - z \omega_j) \cdot \omega_j}{\Delta_j^2} = \frac{(\omega_j \omega_j \Delta_j - z \omega_j \omega_j \Delta_j) \cdot \omega_j \omega_j \Delta_j}{\Delta_j^2} \\ &= \left[\frac{\omega_j}{\Delta_j} \omega_j \Delta_j - z \omega_j \Delta_j \right] \frac{\omega_j \omega_j \Delta_j}{\Delta_j^2} = \rho_j \left[\rho_j - z \omega_j \Delta_j \cdot \omega_j \Delta_j \right] \end{aligned}$$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>John Chouinard</i>		ORBITAL	
PROGRAM		INTEGRATION	
ANALYST <i>John Chouinard</i>		220104	
DOCNR		CGLLOSSUS IIC	
APPROV <i>John Chouinard</i>		FC-2300	
REV		SHEET 26 OF 50	

EVALUATE THE RUNNING FUNCTIONS ψ AND ϕ AT THE LEFT HAND POINT, FOR $j=1$

DIFEQ=0

SET $\psi = \psi_0 = \frac{A_1}{z}$
 $PHIV_0 \leftarrow FV_0$
 SHIFTED @ $2^{19}/z^{17}$

ψ AND ϕ ARE INITIALLY EQUAL TO $\frac{A_1}{z}$
 $A_1 = f(\frac{1}{2}, \frac{1}{2}) f(B_1, t_1)$,
 WHERE $\frac{1}{2}$ IS ESTIMATE OF ψ AT THE LEFT POINT

EVALUATE THE RUNNING FUNCTIONS ψ AND ϕ AT THE MID-POINT. FOR $j=2$

DIFEQ=1

FORM A_2
 $PLV_0 \leftarrow MPAC_0 \leftarrow FV_0$
 SHIFTED AT $2^{19}/z^{17}$

MULTIPLICATION BY $1/z$ IS ACCOMPLISHED BY A CHANGE IN SCALING FACTOR. $\frac{1}{z} = (\frac{1}{2} + \frac{1}{2}i) + \frac{1}{2} \frac{A_1}{z} (\frac{1}{2}i) = \frac{1}{2} (\frac{1}{2} + \frac{1}{2}i) + \frac{1}{2} \frac{A_1}{z} (\frac{1}{2}i)$, WHERE $\frac{1}{2}$ IS ESTIMATE OF ψ AT THE MIDPOINT

$\psi = \psi_0 + \frac{1}{2} A_2$
 $PHIV_0 \leftarrow PHIV_0 + MPAC_0$
 @ $2^{19}/z^{17}$

CALCULATE RUNNING ψ IN $PHIV_0$
 $\psi = \frac{1}{2} + \frac{1}{2} A_2$

$\phi = \phi_0 + \frac{1}{2} A_2$
 $PHIV_0 \leftarrow PHIV_0 + \frac{1}{2} PLV_0$
 @ $2^{19}/z^{17}$

CALCULATE ϕ FROM $PHIV_0$ SUM $\frac{1}{2} + \frac{1}{2} A_2 = \frac{1}{2} + \frac{1}{2} A_2$, WHERE $\frac{1}{2} + \frac{1}{2} A_2$ IS FORMED FROM $\frac{1}{2} + \frac{1}{2} A_2$ BY SHIFTING IT RIGHT ONE PLACE

DIFEQ=COM

COMPUTE VALUES OF λ_j, A_j AT THE MID-POINT AND RIGHT HAND POINT IN PREPARATION FOR THE NEXT PASS THRU THE INTEGRATION LOOP

$\lambda = \lambda_0 + \frac{A_1}{z}$
 $MPAC_0 \leftarrow H_0 + \frac{A_1}{z}$
 @ 2^{19}

λ TAKES ON THE VALUES $\frac{A_1}{z}, \frac{A_2}{z}$

$j = j + 1$
 $DIFEQ=COM \leftarrow X_1 - X_0$

j TAKES ON THE VALUES 2,3 CORRESPONDING TO DIFEQ=1,2

$H_0 \leftarrow MPAC_0$ STORE NEW λ

$\Delta \lambda_j = \lambda + \frac{A_1}{z}$
 $ALPHA_j \leftarrow YV_0 + H_0 (ZV_0 + \frac{H_0 \cdot FV_0}{z})$
 @ $2^{22}/z^{18}$

DIVISION BY z IS ACCOMPLISHED BY A RIGHT SHIFT OF ONE PLACE. $\Delta \lambda_j$ IS AN ESTIMATE OF ψ AT THE MIDPOINT AND RIGHT HAND POINT CALCULATED BY USING A TAYLOR EXPANSION ABOUT THE KNOWN VALUE OF ψ AT THE LEFT HAND POINT

CLEAR TEST J=SWITCH

SET

FBR3
 SH2B

CONTINUE WITH STATE VECTOR INTEGRATION FOR $j=2,3$

DOW.
 SH4E

CONTINUE WITH A VECTOR OF W-MATRIX INTEGRATION FOR $j=2,3$

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FC-2300

27 50

FBR3 IS ENTERED FOR STATE VECTOR INTEGRATION ONLY. IT SETS UP VALUES OF TIME CORRESPONDING TO THE MIDPOINT AND RIGHT HAND POINT (j = 2, 3) AND CALLS THE KEPLER ROUTINE TO CALCULATE THE CONIC STATE VECTOR FOR THESE TIMES

FBR3

X1 ← DIFEGCNT
S1 ← -130

j = 2, 3 CORRESPONDS TO X1 = -12, -24

LOAD AND SHIFT $\frac{\Delta t}{2}$
MPACD ← DT/2D
SHIFTED @ 2²⁰

DT/2D CONTAINS $\frac{\Delta t}{2}$ @ 2¹⁹

X1 ≤ -13 ?
YES
X1 = -24 (j = 3)
NO
X1 = -12 (j = 2)

ROUND MPACD

THE VALUE $\frac{\Delta t}{2}$ IS ROUNDED FOR THE RIGHT POINT (j = 3) ONLY.

STORE $\frac{\Delta t}{2}$
P ← MPACD
@ 2²⁰

STORE $\frac{\Delta t}{2}$ IN TEMPORARY STORAGE

$T = t + \frac{\Delta t}{2}$
TAUD ← TC0 + MPACD

COMPUTE TIMES FOR USE BY THE KEPLER ROUTINE FOR THE MIDPOINT AND RIGHT HAND POINT

$t_1 = t_1 + \frac{\Delta t}{2}$
TETD ← TETD + PLD

t₁ IS INCREMENTED BY $\frac{\Delta t}{2}$ FOR j = 2 AND 3 CORRESPONDING TO THE MIDPOINT AND RIGHT HAND POINT

CALCULATE CONIC STATE VECTOR AT MID POINT AND RIGHT HAND POINT

KEPPREP
KEPLER INTEGRATION OF STATE VECTOR I, Y, Z TO TIME t₀
SH 29

INPUT OUTPUT
1. PBODY = 0 OR 8 1. RCV_v = I (t₁) } FOR NEW
2. TAU₀ = t₀ 2. VCV_v = Y (t₁) } VALUE
3. RCV_v = I (t₁) 3. TC₀ = t₂₁ } OF t₁
4. VCV_v = Y (t₁) 4. XPREV₀ = X
5. XKEP₀ = X } FOR PREVIOUS
6. TC = t₁ } VALUE OF t₁
7. MOONFLAG: CLEAR OR SET

NOTE: OUTPUT IS FOR ENTIRE KEPPREP AND KEPLER COMPUTATIONS (SEE FC-2310; CONIC SUBROUTINES)

ACCOMP
SH 9

GO THRU INTEGRATION LOOP AGAIN FOR j = 2, 3 FOR STATE VECTOR INTEGRATION

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ORBITAL INTEGRATION	DOCUMENT NO. FC-2300
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FROM ANALYST ...	SHEET 26 OF 30
DOCS	
APPROV ...	

KEPREP

LOAD X2 WITH PRIMARY BODY INDICATOR

X2 ← BODY

SET PUSH LIST POINTER TO 0

FORM $\frac{Y}{Z}$
 $PLD_0 \leftarrow \frac{X_2}{Z^{1.5}}$

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

$\frac{Y}{r'} = \frac{r'_{UNIT}}{UNIT} \left(\frac{r'}{RCV_0} \right)$
 $PL3_0 \leftarrow |RCV_0|$
 NORMALIZED @ $Z^{1.5}/Z^{1.5}$

THIS SUBROUTINE COMPUTES AN ESTIMATE OF THE VARIABLE X AT TIME t_0 BASED ON THE VALUES $X_1, r', t(t_0), y, t(t_0)$ AT TIME t_1 FROM THE PREVIOUS COMPUTATION CYCLE. THIS INITIAL ESTIMATE OF X IS USED AS INPUT TO KEPLER TO SPEED UP CONVERGENCE.

- INPUT:
1. BODY - J FOREARTH PRIMARY, 2 FOR MOON
 2. RCV₀ = $r' \cdot \cos(\tau - \frac{t_0}{Z})$ THE STATE VECTOR
 3. VCV₀ = $r' \cdot \sin(\tau - \frac{t_0}{Z})$ RESPONDING TO PREVIOUS
 4. XKEP₀ = $X_1(t - \frac{t_0}{Z})$ CYCLE
 5. TAU₀ = t_0 DESIRED TRANSFER TIME
 6. TC₀ = $t_0 - t_1$ PREVIOUS TRANSFER TIME
 7. MOONFLAG: CLEAR FOR EARTH, SET FOR MOON
- OUTPUT: (OUTPUT FOR KEPLER ONLY)
1. XKEPNEW = X_0 FIRST ESTIMATE OF X CORRESPONDING TO THE TRANSFER TIME t_0
 2. X1 ← X-TABLE POINTER, 2 FOREARTH, 1 FOR MOON
 3. PUSH LIST POINTER AT PL4

r' IS STORED IN NORMALIZED FORM AND THE NORMALIZING VALUE -m IS STORED IN X2. THE UNIT OPERATION ALSO STORES r' IN PL36 @ $Z^{1.5}/Z^{1.5}$

FORM $\frac{Y}{Z} \cdot \frac{V'}{Z}$
 $PL4_0 \leftarrow \frac{MPACV \cdot VCV_0}{Z^2}$

$\frac{\Delta t}{Z} = t_0 - t_1$
 $MPAC_0 \leftarrow \frac{TAU_0 - TC_0}{Z^{2.5}}$
 NORMALIZED @ $Z^{2.5}/Z^{2.5}$

A COMPLETE INTEGRATION STEP CORRESPONDS TO TWO $\frac{\Delta t}{Z}$ INCREMENTS. THE VALUE $\frac{\Delta t}{Z}$ IS NORMALIZED AND THE NORMALIZING VALUE -n IS STORED IN X2

FORM $\frac{\Delta t}{Z} / r'$
 $MPAC_0 \leftarrow \frac{MPAC_0}{PL3_0}$
 @ $Z^{-1.5}/Z^{1.5}$

EXCHANGE MPAC AND PL4

$PL4_0 \leftarrow \frac{1}{r'} \left(\frac{\Delta t}{Z} \right)$
 $MPAC_0 \leftarrow \frac{Y}{r'} \cdot \frac{V'}{Z}$

$\gamma_0 = \frac{Y}{r'} \cdot \frac{V'}{Z} \left(\frac{\Delta t}{Z} \right)$
 $PL6_0 \leftarrow MPAC_0 \cdot PL4_0$
 @ $Z^{1.5} \cdot m \cdot n$

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

FORM $\frac{Z(\gamma_0)^2}{Z^2}$
 $PLD_0 \leftarrow \frac{(MPAC_0)^2}{Z^{1.5} \cdot (m \cdot n)}$

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

NEXT SHEET

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 NAME *John M. Peterson*
 TITLE
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 29 - 50

FROM PRECEDING SHEET

$$\text{FORM } \frac{1}{(P)^2} \left(\frac{\Delta E}{Z} \right)^2$$

$$\text{PL10}_0 \leftarrow \frac{(PL4_0)^2}{(PL4_0)^2}$$

$$\text{SHIFTED @ } Z^{2(m-n)/2 + 2z(m-n)}$$

$$\text{STORE } \frac{H_p}{PL12_0} \leftarrow \frac{(MUEARTH \oplus XE)_0}{\text{SHIFTED @ } Z^{2n}/Z^{27}}$$

$$\text{FORM } \frac{H_p \sqrt{r^3}}{r^2}$$

$$\text{MPAC}_0 \leftarrow \frac{PL12_0 - (VCV_p \cdot VCV_p) PL36_0}{PL2_0}$$

$$\text{SHIFTED @ } Z^{2(m+n)}/Z^{2(m+n)}$$

$$\text{FORM } -\frac{2}{3} \left(\frac{1}{P} - \alpha \right) S^2 = \frac{2}{3} \left(\frac{H_p \sqrt{r^3}}{r^2} \right) \left(\frac{1}{P} \right) \left(\frac{\Delta E}{Z} \right)^2$$

$$\text{VPAC}_0 \leftarrow \text{DPZ/3}_0 \cdot \text{MPAC}_0 \cdot \text{PL10}_0$$

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

$$\text{DPZ/3} = \frac{2}{3} @ Z^{-2}$$

$$\text{FORM } \frac{(-m) - (-n)}{X1} = \frac{n-m}{S1}$$

$$\text{FORM } Z(Y5)^2 - \frac{2}{3} \left(\frac{1}{P} - \alpha \right) S^2$$

$$\text{MPAC}_0 \leftarrow \text{PL6}_0 + \text{MPAC}_0$$

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

$$\text{FORM } -Y5 + Z(Y5)^2 - \frac{2}{3} \left(\frac{1}{P} - \alpha \right) S^2$$

$$\text{MPAC}_0 \leftarrow \frac{-\text{PL6}_0 + \text{MPAC}_0}{\text{SHIFTED @ } Z^{2^7+m-n}}$$

$$\text{FORM } X' + 5 \left[-Y5 + Z(Y5)^2 - \frac{2}{3} \left(\frac{1}{P} - \alpha \right) S^2 \right]$$

$$\text{MPAC}_0 \leftarrow \text{XKEP}_0 + \text{PL0}_0 \cdot \text{PL4}_0 \cdot \text{MPAC}_0$$

$$\text{SHIFTED @ } Z^{27}/Z^{26}$$

$$\text{PL0}_0 \cdot \text{PL4}_0 = \sqrt{P} \cdot \frac{2}{P} \left(\frac{\Delta E}{Z} \right) = 5$$

EXCHANGE
VPAC₀ AND PL4₀

STORE PRECEDING CALCULATION IN PL4₀
LOAD MPAC₀ WITH $\frac{1}{P} \left(\frac{\Delta E}{Z} \right)^2$

NEXT SHEET

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PROGRAM <i>...</i>		DOCUMENT NO. FC-2300	
APPROVED <i>...</i>		SHEET 30 OF 50	

FROM PRECEDING SHEET

$$\Phi = \frac{\sqrt{\mu p}}{r} \left(\frac{\Delta t}{2} \right)$$

$$MPAC_0 \leftarrow MPAC_0 - MPAC_0$$

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

EQ. 2.2.5, PAGE 5.2-10

TURN OFF
OVERFLOW INDICATOR

$$X_0 = X' - S \left[1 - 7S + 2(7S)^2 - \frac{1}{6} \left(\frac{1}{7} - \alpha \right) S^2 \right]$$

$$X_{KEPNEW_0} \leftarrow MPAC + PL_0 @ 2^{17}/2^{16}$$

THIS ADDS S TO INTERMEDIATE CALCULATION IN PL₀. X₀ IS AN ESTIMATE OF THE CORRECT VALUE OF X AT TIME t₀ = T BASED ON X', Y' AT TIME t₀₁ = T - $\frac{\Delta t}{2}$ EQ. 2.2.4, PAGE 5.2-10

KEPTRN ← QPRET

THE RETURN ADDRESS IS STORED IN KEPTRN FOR USE BY KEPLER ROUTINE IN RETURNING TO CALLING ROUTINE.

CLEAR

MOONF_AS

SET

X1 ← -2

EARTH IS
PRIMARY BODY

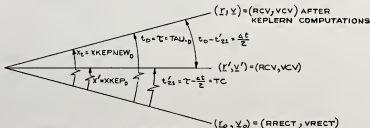
X1 ← -100

MOON IS
PRIMARY BODY

KEPLRN
FC-2310

CALCULATE
CONIC STATE
VECTOR AT
TIME TAU₀
= t₀ = T

THE KEPLER ROUTINE KEPLRN RETURNS CONTROL TO THE CALLING ROUTINE DIRECTLY VIA KEPTRN. SEE CONIC SUBROUTINES, FC-2310



X₀, Y₀, Y₀' CORRESPOND TO THE PREVIOUS TIME t₀₁. A VALUE OF X FOR TIME t₀ IS CALCULATED BY A TAYLOR EXPANSION TYPE METHOD FOR AN INTERVAL OF TIME $\frac{\Delta t}{2} = t_0 - t_{01}$ TO GET AN ESTIMATE X₀ FOR TIME t₀.

APPROVED: *[Signature]*
DATE: 10/1/68
BY: M. S. B. / M. S. B.
FOR: M. S. B. / M. S. B.
APP: [Signature] / M. S. B. / M. S. B.

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EVALUATE THE RUNNING FUNCTIONS ψ AND ϕ AT THE RIGHT HAND POINT, FOR $j=0$. THEN USE THEM TO EVALUATE THE FUNCTION ψ_{n+1} AND ITS DERIVATIVE ϕ_{n+1} AT THE RIGHT HAND POINT.

DIFFEQ+Z

$$\text{FORM } \frac{1}{\sigma} \dot{X} = \frac{\Delta E}{\sigma}$$

$$P_{L0} = -MPAC_0 \rightarrow DPZ/B_0 \cdot H_0 @ z^1$$

FOR $j=0, k = \Delta t$

$$DPZ/B_0 = \frac{1}{\sigma} @ z^2$$

$$\dot{X} = \phi_n \cdot \frac{\Delta E}{\sigma} (\dot{X}_1 + z \dot{X}_2)$$

$$MPAC_V \rightarrow ZV_V + MPAC_0 \cdot PHIV @ z^0/z^2$$

HAVE COMPLETED RUNNING SUM FOR ϕ .
EQ. 2.2.26, PAGE 5.2-19

$$\psi_{n+1} = \psi_n + \phi \cdot \Delta t$$

$$YV_V \rightarrow YV_V + MPAC_V \cdot H_0$$

CALCULATE FUNCTION AT RIGHT HAND POINT
EQ. 2.2.26, PAGE 5.2-19

$$\dot{X} \cdot \Delta t = \frac{\Delta E}{\sigma} (\dot{X}_1 + 4 \dot{X}_2 + \dot{X}_3)$$

$$MPAC_V \rightarrow P_{L0} \cdot (PSIV_V + FV_V)$$

SHIFTED @ z^0/z^2

HAVE COMPLETED RUNNING SUM FOR ψ
PSIV CONTAINS $\dot{X}_2 + 4 \dot{X}_3$
EQ. 2.2.26, PAGE 5.2-19

$$\phi_{n+1} = \phi_n + \psi \cdot \Delta t$$

$$ZV_V \rightarrow ZV_V + MPAC_V$$

CALCULATE FIRST DERIVATIVE OF FUNCTION AT RIGHT HAND POINT
EQ. 2.2.26, PAGE 5.2-19

JSWITCH

SET

CLEAR

A
SH34

THIS INDICATES THE PRECEDING INTEGRATION PASS WAS FOR A STATE VECTOR

THIS INDICATES WE ARE IN THE PROCESS OF INTEGRATING THE W-MATRIX

ENDSTATE

OVERFLOW

YES

NO

GOBAQUE
SH22

GO BACK AND UPDATE, RECTIFY AND INTEGRATE AGAIN WITH NEW REFERENCE CONIC

$$\frac{Z}{\sigma} \rightarrow \phi_{n+1}$$

$$\frac{Y}{\sigma} \rightarrow \psi_{n+1}$$

$$TNLV_V \rightarrow ZV_V @ z^0/z^2$$

$$TDeltaV_V \rightarrow YV_V @ z^0/z^2$$

STORE RESULTS OF INTEGRATION

MIDAVFLAG

SET

CLEAR

THIS FLAG IS SET BY THE MIDTAV ROUTINE ONLY

CKMIDZ
SH96

CKMIDZ TRANSFERS DIRECTLY TO TESTLOOP THUS PRECLUDING ANY W-MATRIX INTEGRATION

DIMOFFLAG

SET

CLEAR

NEXT SHEET

W-MATRIX IS NOT TO BE INTEGRATED SO CONTINUE IMMEDIATELY WITH STATE VECTOR INTEGRATION OVER NEXT TIME INTERVAL &C

TESTLOOP
SH3

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PROGRAM ANALYSIS <i>M. J. Roberts</i>		DOCUMENT NO. FC-2300	
DESIGN <i>M. J. Roberts</i>		SHEET 32 OF 50	
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FROM PRECEDING SHEET

GROUP 2
SET UP RESTARTS TO SCHEDULE
NEXT LOCATION AS A
JOB WITH SAME PRIORITY

BEGIN INTEGRATION OF THE
W-MATRIX FOR A TIME INTERVAL
OF Δt

SET
REINTFLG

SETTING THIS FLAG INDICATES THAT THIS ROUTINE
IF STALLED, IS TO BE RESTARTED AT THIS POINT
IF A PHASE CHANGE OCCURS BETWEEN INSTALL
AND INTWAKE

QPRET ← CADR(AMVED)

SET UP RETURN LINKAGE IN QPRET
TO BE USED BY SUBROUTINES ATOPLEM
OR ATOPCSM

CLEAR VINTFLAG SET

ATOPLEM
DO UPDATE OF
LM STATE VECTOR
FC-2290

LM STATE VECTOR
WAS INTEGRATED

ATOPCSM
DO UPDATE OF
CSM STATE VECTOR
FC-2290

CSM STATE VECTOR
WAS INTEGRATED

AMVED

SET
JSWITCH

THIS INDICATES TO THE INTEGRATION ROUTINE
THAT THE NEXT PASS IS FOR W-MATRIX DATA

CLEAR D6OR9FLG SET

W-MATRIX IS 6x6

W-MATRIX IS 9x9

INITIALIZE I TO 5
COLREG ← 30D

I IS THE COLUMN POINTER
USED FOR SELECTING THE
PROPER VECTOR IN THE
W-MATRIX

INITIALIZE I TO 8
COLREG ← 46D

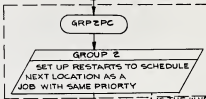
NEXTCOL
SH 55

BEGIN THE PROCESS OF INTEGRATING
THE W-MATRIX

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DESIGNED BY <i>J. Chubb</i> NOVEMBER 1958	ORBITAL INTEGRATION
FOR ANALYSIS BY <i>M. Robertson</i>	COLOSSUS II C
APPROVED BY <i>Robert M. ...</i>	FC-2300
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COME HERE FROM SHEET 32

(A) CONTINUE WITH INTEGRATION OF THE W-MATRIX



LOAD \bar{L}
 $XZ \leftarrow COLREG$

\bar{L} IS THE \bar{W} VECTOR POINTER FOR W-MATRIX OPERATIONS. IT TAKES ON THE VALUES 6, 7, ... 0 ($XZ = -48, -42, \dots, -6, 0$) FOR A 9x9 MATRIX, OR 5, 4, ... 0 ($XZ = -30, -24, \dots, -6, 0$) FOR A 6x6 MATRIX

$W_{i+1} \leftarrow Z^{n+1}$
 $(W \neq 548) XZ \leftarrow ZV$
 SHIFTED @ Z^0

STORE THE NEW VELOCITY VECTOR INTO ITS PROPER SPOT IN EITHER SUBMATRIX W_0, W_1 , OR W_2 OF W-MATRIX

LOAD ψ_{n+1}
 $MPACV \leftarrow YV$
 SHIFTED @ Z^0

ψ_{n+1} IS SHIFTED FROM Z^2 TO Z^0

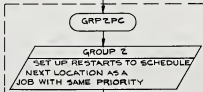
OVERFLOW
 YES
 NO

WHATEND
 SH 37

IF OVERFLOW OCCURS AS A RESULT OF SHIFTING LEFT THEN AT LEAST ONE COMPONENT OF ψ_{n+1} IS Z^2

$W_i \leftarrow \psi_{n+1}$
 $(W \neq XZ) V \leftarrow MPACV$
 @ Z^0

STORE THE NEW POSITION VECTOR INTO ITS PROPER SPOT IN EITHER SUBMATRIX W_0, W_1 , OR W_2 OF W-MATRIX



LOAD \bar{L}
 $XZ \leftarrow COLREG$

\bar{L} IS THE \bar{W} VECTOR POINTER FOR W-MATRIX OPERATIONS

$SZ \leftarrow 0$

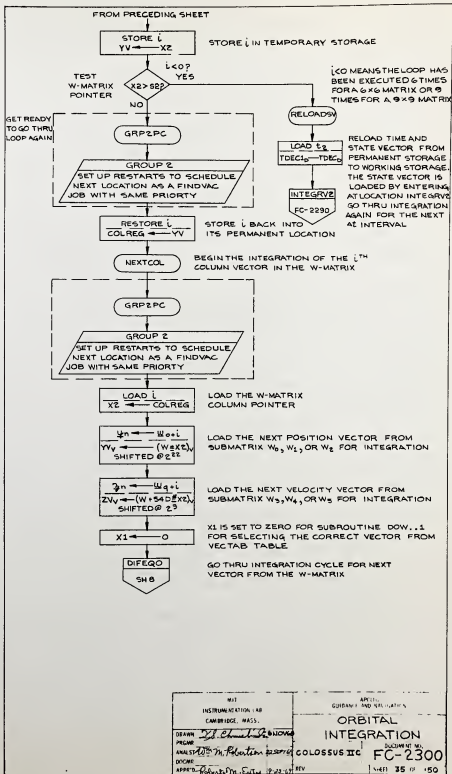
SET SZ TO ZERO FOR SUBSEQUENT USE IN TEST FOR $L=0$

$\bar{L} \leftarrow \bar{L} - 1$
 $XZ \leftarrow XZ + 6$

CHANGE POINTER TO POINT AT NEXT VECTOR $W_{\bar{L}-1}$

NEXT SHEET

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DRAWN <i>J. J. Chumbley</i> FROM <i>J. J. Chumbley</i> ANALYST <i>M. Robertson</i> DESIGN <i>J. J. Chumbley</i> APPROV <i>J. J. Chumbley</i>	DOCUMENT NO. COLOSSUS IIC FC-2300 SHEET 34 OF 50



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DRAWN <i>J. Chubb</i>		ORBITAL INTEGRATION	
PREPARED <i>J. Chubb</i>		COLLOSSUS IIC	
ANALYST <i>M. Robertson</i>		DOCUMENT NO. FC-2300	
CHECKED <i>Robert D. Suter</i>		REV	
APPROVED <i>Robert D. Suter</i>		14-01 35 OF 150	

CKMIDE IS ONLY ENTERED DURING INTEGRATION IF INTEGRATION WAS CALLED BY MIDTOAV ROUTINE. TDEC₀ CONTAINS TIME t₂ TO INTEGRATE TO

INTEGRATE TO CURRENT TIME PLUS 10 SECS.

CLEAR

MID1FLAG

INTEGRATE TO A SPECIFIED TIME t₂ IN TDEC₀

MIDE

LOADTIME
CURRENT TIME t₁ IN MPAC₀
FC-2100

OUTPUT
1. MPAC₀ = t_c, CURRENT TIME

TEST IF TDEC₀ IS WITHIN ±2 CSECS OF TDEC₀

t₂ - t₁ < 2 CSECS?

NO

IS t₂ AHEAD OF t_c CURRENT TIME BY AT LEAST ±12.5 SEC?

t₂ ≥ t_c + ±12.5?

NO

NOTIME

SIGNAL NOT ENOUGH TIME FOR INTEGRATION
FC-2250

TESTLOOP
SH 3

IT IS OK TO CONTINUE THE INTEGRATION

CONTINUE THE INTEGRATION

LOADTIME
PUT CURRENT TIME t_c IN MPAC₀
FC-2100

t₁ - t_c ≥ 5.6 SEC?

YES

T-TO-ADD ← TO-TO-ADD + TIMEDELTA

A-PCHK
SH.38

END INTEGRATION

TIME INC

LOADTIME
CURRENT TIME t₁ IN MPAC₀
FC-2100

OUTPUT
1. MPAC₀ = t_c, CURRENT TIME

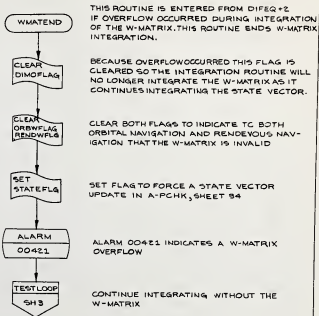
t₂ = t_c + Δt
TDEC₀ ← MPAC₀ + T-TO-ADD

TIME TO INTEGRATE TO (TIME OF IGNITION) IS SLIPPED BY Δt_{slip} 10 SECS

TESTLOOP
SH 3

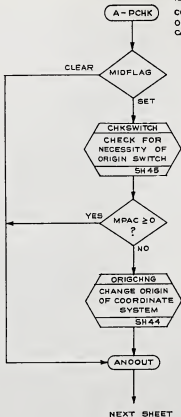
CONTINUE WITH INTEGRATION

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN <i>J. J. Chubb</i>		ORBITAL INTEGRATION	
FRGAB		DIVISION NO.	
ANALYST <i>M. Robertson</i>		COLOSSUS IIC	
SCHEM		FC-2300	
APPROV <i>W. J. ...</i>		REV	
		SHEET 36 OF 50	

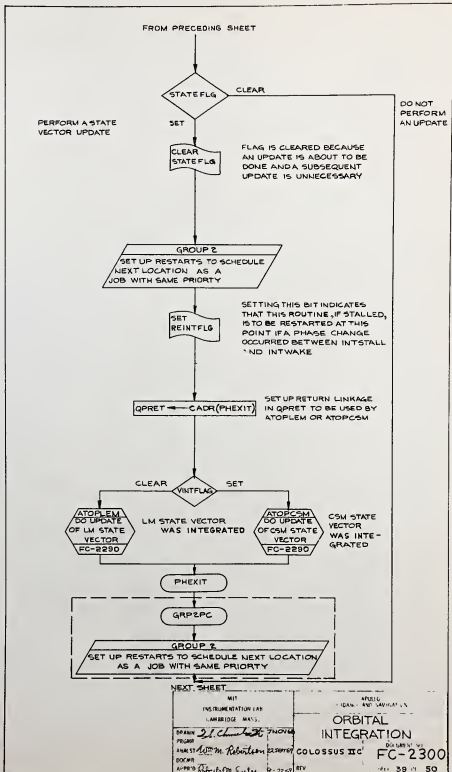


N18 INSTRUMENTATION LAB CAMBRIDGE, MASS		APPLIC GUIDANCE AND NAVIGATION ORBITAL INTEGRATION	
DRAWN <i>J. P. ...</i> CHECKED <i>J. P. ...</i> ANALYST <i>J. P. ...</i> DESIGNER <i>J. P. ...</i> APPROVED <i>J. P. ...</i>	PROJECT COLLOSSUS II	DRAWING NO. FC-2300	DATE 14 OCT 37 11 50

A-PCHK CHECKS TO SEE IF AN UPDATE IS DESIRED AND, IF SO, PERFORMS IT. COME HERE FROM POOCHK IF $|\Delta t| \leq 2$ CSEC OR IF $\Delta t < \Delta t_{max}$ AND INTEGRATION WAS CALLED BY POO



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
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PROGRAM: <i>[Signature]</i>	ANALYST: <i>[Signature]</i>	DOCUMENT NO. COLOSSUS IIC	FC-2300
DOCNO:	APPR'D: <i>[Signature]</i>	REV:	SHEET 38 OF 50



MIT
INSTRUMENTATION LAB
CAMBRIDGE MASS.

DRANK *J. J. Chubbuck* 7/10/64
PROGRAM
ANALYST *John M. Roberts* 12/22/67
BOOK#
APPROV *Robert S. ...* 12-22-67

APPROV. AND DATE
ORBITAL INTEGRATION
COLOSSUS II C
DUALS 11 1/2
FC-2300
REV 39 11 50

FROM PRECEDING SHEET

RECTOUT

THIS ROUTINE DOES A RECTIFICATION AND STORES THE OUTPUT IN THE PUSH LIST

SET PUSH LIST POINTER TO ZERO

RECTIFY
DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS
SH 43

INPUT	OUTPUT
1. $RCV_v = I_{CON}$	1. $XZ = PBODY$
2. $VCV_v = V_{CON}$	2. $RRECT_v = I_{CON} + \delta$
3. $\Delta T_{UV}_v = \delta$	3. $RRECT_v = Y_{CON} + \frac{1}{2}$
4. $TNUV_v = \frac{1}{2}$	4. $RCV_v = I_{CON} = NEW I_{CON}$
	5. $RCV_v = V_{CON} = NEW V_{CON}$
	6. $\Delta T_{UV}_v = \delta = (0, 0, 0)$
	7. $TNUV_v = \frac{1}{2} = (0, 0, 0)$
	8. $TC_0 = T = 0$
	9. $XKEP_0 = X = 0$

$PL0_v \leftarrow RRECT_v$ SHIFTED @ c^2
 $PL1_v \leftarrow RRECT_v$ SHIFTED @ c^2
 $PL2_v \leftarrow TRT_0$ @ $2^2/c^2$
 $PL3_v \leftarrow RRECT_v$ @ $2^2/c^2$
 $PL4_v \leftarrow RRECT_v$ @ c^2/c^2
 $PL5_v \leftarrow (MUEARTH \# X C)_0$

STORE INTEGRATION OUTPUT IN PUSH LIST. THIS INCLUDES I_0, Y_0, t_0, d_p

MOONFLAG

EARTH IS PRIMARY BODY

MOON IS PRIMARY BODY

INTEXIT

COME HERE DIRECTLY FROM POOCHK IF $t_2 > t_1 + 4\delta t$

SET PUSH LIST POINTER TO ZERO

TURN OFF OVERFLOW INDICATOR

CLEAR MIDVFLG

CLEAR AVEMIDSW

CLEAR PRECI FLG

ALLOW UPDATE OF DOWNLINK CSM STATE VECTOR. SEE SHEET 20, FC-2300

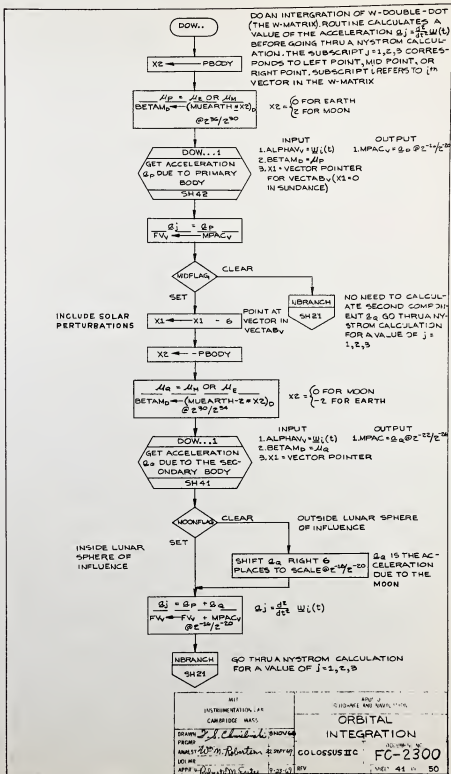
QPRET \leftarrow IRETURN

STORE RETURN ADDRESS INTO QPRET SO INTWAKE CAN RETURN TO CALLING ROUTINE BY USING THE RVQ INSTRUCTION

INTWAKE
FC-2290

RETURN TO CALLING ROUTINE VIA INTWAKE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	AFSC/D GUIDANCE AND NAVIGATION
DESIGN: <i>J. B. Chubbuck</i>	ORBITAL
PROGRAM: <i>J. B. Chubbuck</i>	INTEGRATION
ANALYSIS: <i>M. Robertson</i>	COLOSSUS IC
DATE: <i>10/23/60</i>	FC-2300
APPROVED: <i>Charles F. Felt</i>	REV: <i>40</i>



DOW..1

CALCULATE THE ACCELERATION COMPONENT \hat{a}_p OR \hat{a}_q FOR A GIVEN W_i

STORE W_i
 $PL_v \leftarrow \text{ALPHAV}_v$
 SHIFTED @ $2^{24}/2^{22}$

FORM $U = |UNIT|$
 $r = |I|$
 $(PL+6)_v \leftarrow \text{UNIT}(\text{VECTAB} \# X_i)$
 $\text{FL} \rightarrow 0 @ 2^{29}/2^{27}$
 $\text{FL} \rightarrow 0 @ 2^{29}/2^{27} (\text{VECTAB} \# X_i)_v$

X_i IS A POINTER USED TO SELECT EITHER $I(t)$ OR $I_{ac}(t)$ FROM A TABLE. IN SUNDANCE $X_i = 0$.

FORM $(U \cdot W_i) U$
 $MPAC_v \leftarrow [(PL+8)_v \text{ALPHAV}_v] (PL+8)_v$
 $@ 2^{24}/2^{20}$

PROJECT W_i ONTO I WHERE $U = W_i$ IS THE MAGNITUDE OF W_i IN THE DIRECTION OF I .

FORM $B = (U \cdot W_i) U - W_i$
 $PL_v \leftarrow 2/4_0$ $MPAC_v \leftarrow PL_v$
 $@ 2^{24}/2^{22}$

$3/4 = 3.0 @ 2^2$

STORE r NORMALIZED
 $(PL+6)_0 \leftarrow MPAC_0 \leftarrow PL_0 6_0$
 NORMALIZED @ $2^{29-m}/2^{27-m}$

THE NORMALIZING COUNT - m IS STORED IN $5E$

STORE r^3 NORMALIZED
 $(PL+6)_0 \leftarrow MPAC_0^3 \cdot (PL+6)_0$
 NORMALIZED @ $2^{29-m*3}/2^{27-m*3}$

THE NORMALIZING COUNT - n IS STORED IN PL_3+4 .

FORM $\frac{U}{PS} [B \cdot (U \cdot W_i) U - W_i]$
 $MPAC_v \leftarrow \text{BETAM}_0 \cdot PL_v$
 $@ 2^{-24+2m+n}/2^{-26-2m+n}$

THIS IS THE ACCELERATION COMPONENT \hat{a}_p OR \hat{a}_q . EQ 2.2.31, PAGE 5.2-23

FORM $-3m-n$
 $XE \leftarrow 5E + 3E + 2E + PL_3+4$

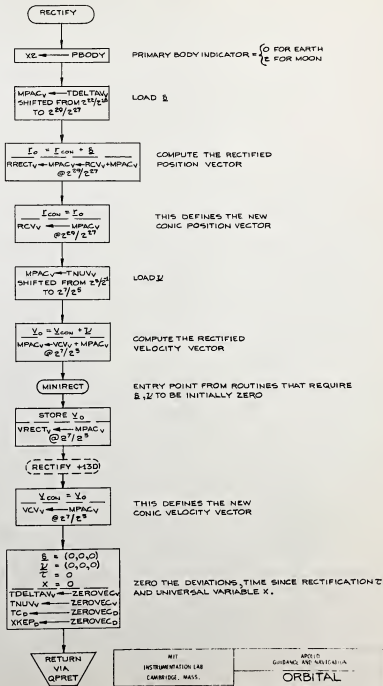
$-3m-n$ IS THE UNNORMALIZING COUNT

SHIFT $MPAC_v$ TO UNNORMALIZE AND SCALE @ $2^{-10}/2^{-20}$

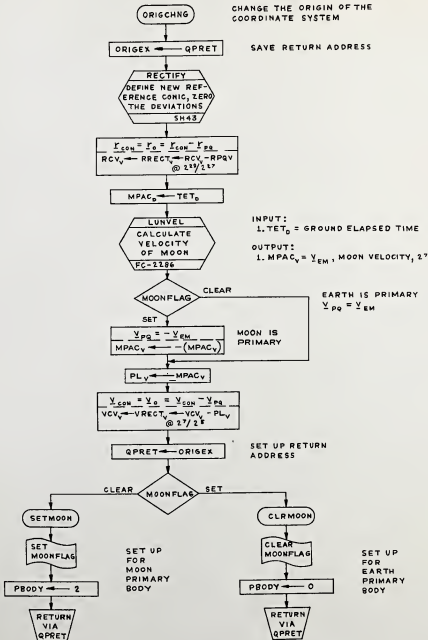
RETURN
 VIA
 QPRET

MIT ASTRONAUTICAL LAB CAMBRIDGE MASS PROJECT COLLABORATOR APPROVED APPROVED	AIR FORCE GUIDANCE AND NAVIGATIONAL ORBITAL INTEGRATION COLIN COLOSSUS IIC FC-2300 42 / 50
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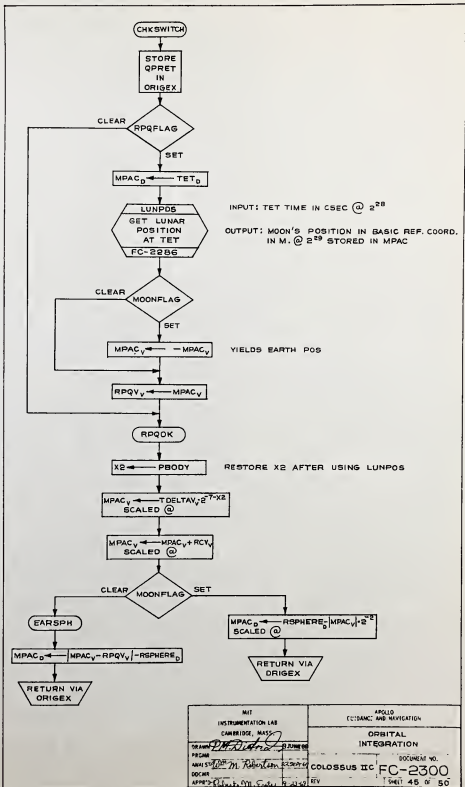
THE RECTIFY SUBROUTINE IS CALLED BY THE INTEGRATION ROUTINE AND OCCASIONALLY BY THE MEASUREMENT INCORPORATION ROUTINES TO DEFINE A NEW REFERENCE CONIC.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>L. J. Chubbuck</i>		ORBITAL INTEGRATION	
ANALYST <i>A. M. Robertson</i>		DOCUMENT NO FC-2300	
APPROVED <i>R. S. ...</i>		REV	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS. ORDER NO. <i>FC-2300</i> QUANTITY <i>100</i> DATE <i>10/15/64</i> REV. <i>10-22-64</i>	AIR FORCE GUIDANCE AND CONTROL ORBITAL INTEGRATION COLOSSUS IIC FC-2300 50
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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED COSMOS AND NAVIGATION
DRAWN: <i>[Signature]</i> PROGRAM: <i>[Signature]</i> CHECKED: <i>[Signature]</i> APPROVED: <i>[Signature]</i>	ORBITAL INTEGRATION DOCUMENT NO. COLOSSUS IIC FC-2300 SHEET 45 OF 50

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
SGNAGRF	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
KFPLERN	FC2310	KEPLER ROUTINE COMPUTES THE NEW CONIC STATE VECTOR	SH. 31
ATOPLEM	FC2240	DO UPDATE OF PERMANENT LM STATE VECTOR	SH. 33, 38
ATOPCSM	FC2250	DO UPDATE OF PERMANENT CSM STATE VECTOR	SH. 33, 38
INTEGRV2	FC2250	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	FC2250	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
DIMOFMAG (1, 3)	INTEGRATE THE W-MATRIX	DO NOT INTEGRATE THE W-MATRIX		SH. 37	SH. 9, 12, 32
D6OR9FLG (2, 3)	W-MATRIX IS 6X9	W-MATRIX IS 6X6			SH. 33
STATEFLG (3, 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 INTEGRV 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

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>B. G. ...</i>		ORBITAL INTEGRATION	
PERFORMER	ANALYST <i>W. V. ...</i>	COLOSSUS IIC	DOCUMENT NO.
DOCSR	APPROVED <i>...</i>	FC-2300	
REV			SHEET 46OF 50

FLAGS (CONTINUED)

NAME (BIT, FLAGWORD)	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
MOONFLAG (12, 0)	INSIDE LUNAR SPHERE OF INFLUENCE	OUTSIDE LUNAR SPHERE OF INFLUENCE	SH. 44	SH. 44	SH. 11, 13, 15, 19, 31, 40, 41, 44, 45 SH. 44
RPQFLAG (15, 8)	CALCULATE THE VECTOR RPQ	DO NOT CALCULATE THE VECTOR RPQ	SH. 32		
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		
MIDIFLAG (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	OSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
DT/2 _D	t	TIME INTERVAL FOR ONE INTEGRATION CYCLE	CSEC	CSEC	2 ²⁰
TDEC1 _D	t ₂	TIME TO INTEGRATE TO	CSEC	CSEC	2 ²⁸
RCV _V	E _{con}	CONIC POSITION VECTOR	M	M	2 ²⁹ /2 ²⁷
VCV _V	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	E _o	POSITION VECTOR AT RECTIFICATION	M	M	2 ²⁹ /2 ²⁷

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		NO. FILED ESTIMATE AND NUMBER ORBITAL INTEGRATION	
DESIGN <i>A. J. Smith</i>	DATE 2/20/68	ANALYST <i>W. M. ...</i>	PROJECT COLOSSUS IIC FC-2300
APPROVED <i>W. M. ...</i>	DATE 2-22-68	BY ...	47 50

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
VECT _V	\underline{v}_0	VELOCITY VECTOR AT RECTIFICATION	M/CSEC	M/CSEC	$2^7/2^5$
TDELTA _V	$\underline{\delta}$	POSITION DEVIATION VECTOR	M	M	$2^{22}/2^{18}$
TN _V	\underline{v}	VELOCITY DEVIATION VECTOR	M/CSEC	M/CSEC	$2^3/2^{-4}$
TC _D	t_{21}	TIME SINCE RECTIFICATION	CSEC	CSEC	2^{28}
NKEP _D	x	UNIVERSAL VARIABLE	M ^{1/2}	M ^{1/2}	$2^{17}/2^{16}$
V _V	$\underline{\delta}$	INTERMEDIATE VALUE OF $\underline{\delta}$	M	M	$2^{22}/2^{18}$
Z _V	\underline{v}	INTERMEDIATE VALUE OF \underline{v}	M/CSEC	M/CSEC	$2^3/2^{-4}$
DIFQCNT	J	SUBSCRIPT FOR LEFT, MID, AND RIGHT POINTS	INTEGER	INTEGER	
ALPHA _V	α_j	INTERMEDIATE VALUE OF $\underline{\delta}$	M	M	$2^{22}/2^{18}$
H _D	h	RUNNING TIME INCREMENT EQUALS 0, $\Delta 1/2$, Δt	CSEC	CSEC	2^{10}
E _V	\underline{f}_j	VALUE OF SECOND DERIVATIVE AT POINT J	M/(CSEC) ²	M/(CSEC) ²	$2^{-16}/2^{-20}$
BETA _V	$\underline{\beta}_j$	INTERMEDIATE VALUE OF r_0	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	$ \alpha_j $, MAGNITUDE OF α_j	M	M	$2^{29}/2^{27}$
BETAM _D	β_j	$ \beta_j $, MAGNITUDE OF β_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	2^{28}
TAU _D	t_D	DESIRED TRANSFER TIME	CSEC	CSEC	
PHV _V	$\underline{\phi}$	RUNNING SUM OF $k_1 + 2k_2$	M/(CSEC) ²	M/(CSEC) ²	$2^{-13}/2^{-17}$
PSIV _V	$\underline{\phi}$	RUNNING SUM OF $k_1 + k_2 + k_3$	M/(CSEC) ²	M/(CSEC) ²	$2^{-13}/2^{-17}$
PBODY	P	PRIMARY BODY INDICATOR	INTEGER	INTEGER	
XKEPNEW _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	$2^{19}, 2^0$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
PROGRAM <i>A. J. ...</i>		ORBITAL INTEGRATION	
ANALYST <i>W. J. ...</i>		COLOSSUS IIC	DOCUMENT NO. FC-2300
APPROVED <i>...</i>		REV	SHEET 46 OF 50

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 ϵ	1000 SEC	100,000 C/SEC	2^{20}
DT 2MIN _D	ϵ_t	MINIMUM VALUE OF ϵ ALLOWED	3 C/SEC	3 C/SEC	2^{20}
$3^{-4}D_D$			0.75	3	2^2
RECRATIO _D			0.01	.01	2^0
ZEROVEC _V		(0, 0, 0)	(0, 0, 0, 0, 0)		
RDE _D	r_{DE}	RADIUS OF RELEVANCE OF EARTH	80467200 M	SAME	2^{24}
RDM _D	r_{DM}	RADIUS OF RELEVANCE OF MOON	16093440 M	SAME	2^{27}
$3/5D_D$			3/5	.6	2^2
ZUNIT _V		(0, 0, 1)	(0, 0, 0, 0, 1, 0)	(0, 0, 0, 0, 0, 5)	2^1
$3^3 3^2D_D$			3.0	3.0	2^5
$15^1 16D_D$			15.0	15.0	2^4
$7.12D_D$			7/3	.5833...33	2^0
$2^{-3}D_D$			4/3	.666...67	2^0
$9^{-16}D_D$			9/4	9.0	2^4
$5/128D_D$			5/4	5.0	2^7
J4REZ/J3 _D	J_4E^rE J_3E	RATIO OF COEFFICIENTS OF FOURTH AND THIRD HARMONICS OF EARTH'S POTENTIAL FUNCTION	4901607.301	SAME	2^{26}
2J3RE/J2 _D	J_3E^rE J_2E	RATIO OF COEFFICIENTS OF THIRD AND SECOND HARMONICS OF EARTH'S POTENTIAL FUNCTION	13554.26363	SAME	2^{27}
J2REQSQ _D	$J_2E^rE^2 u_E^2$	SECOND HARMONIC, RADIUS AND MU OF EARTH	$1.75501138 \times 10^{21}$	SAME	2^{72}
J2REQSQ _D -2	$J_2M^rM^3 u_M^3$	SECOND HARMONIC, RADIUS AND MU OF MOON	$3.067493316 \times 10^{18}$	SAME	2^{60}
$5/8D_D$			5.0	5.0	2^3
$3J22R2MU_D$	$3.122M^rM^2 u_M^2$		$9.20179018 \times 10^{-16}$	SAME	2^{58}
QUARTER _D			1.0	0.25	2^0
HALFDP _D			2.0	0.5	2^0
THREE/8			3.0	0.375	2^0

NO. 1	APPROVED
INSTRUMENTATION LAB	INTEGRATION AND ANALYSIS
CAMPBELL MASS.	ORBITAL INTEGRATION
DRAWN <i>A. J. [Signature]</i>	COLOSSUS IIC
PROGRAM <i>A. J. [Signature]</i>	FC-2300
ANALYSIS <i>A. J. [Signature]</i>	49 50
DOCS. <i>A. J. [Signature]</i>	
APPROVED <i>A. J. [Signature]</i>	

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	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 ²⁸
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				

ISSUE INFORMATION LAB CAMBRIDGE MASS.	DATE: _____ BY: _____
DRAWN: <i>R. J. Smith</i> 23 REVISE	ORBITAL INTEGRATION
DESIGN: <i>M. P. Robinson</i> 23 REVISE	COLOSSUS II C
APP'D: <i>R. J. Smith</i> 23 REV	FC-2300
APP'D: <i>R. J. Smith</i> 23 REV	80 80

CONIC SUBROUTINES

ENCLOSED ARE REVISED SHEETS (SH. 12,
13, 21) TO UPDATE THE COLOSSUS IIA
FLOWCHART FC-2310, REV. 1, TO THE
COLOSSUS IIC FLOWCHART FC-2310,
REV. 2.

ART IDENTIFICATION OR SERIAL NO., DATE	APPRO SERIAL NO. OR DATE
SECRET	CONIC SUBROUTINES
SECRET	COLOSSUS IIC, FC-2310
SECRET	REV. 2
	FIGURE NO. FC-2310 1 SHEET OF

FLOW CHART CONVENTIONS FOR THE CONIC SUBROUTINES

1. $c_1 = \sqrt{PN} r_1 (t) \cot \gamma$
 NEPC1 = $\sqrt{P \cdot R1} \cdot COGA$
 SCALED AT $2^{17}/2^{16}$

PAGE 42,
REF. 3

In boxes divided by a broken line, the upper half represents the mathematical formulation of the statement and the lower half represents how the statement was coded in the computer. The arrow implies that the quantity computed on the right side of the arrow was stored into the location specified on

the left side, or mathematically the quantity on the left was set equal in the quantity on the right. Where possible, equations are referenced by equation, page and reference number.

2. All values are considered to be double-precision numbers (28 bits of precision plus sign) unless subscripted with an $_s$ for single-precision (14 bits plus sign) or subscripted with a $_v$ for a vector quantity (3 double-precision components). All flags are considered to be one-bit indicators unless shown otherwise.
3. Double-precision numbers are considered in he scaled fractions lying in the range between -1.0 and 1.0. The scaling factor included in the box is the value by which the number as stored internally must be multiplied to obtain its true value. It can also be interpreted as defining the binary point. Thus a scaling of 2^5 means that the binary point lies to the right of bit -5, where bit positions are labeled 0, -1, -2 ... going from left to right, starting with the sign bit. In cases where a pair of scaling factors are included, the first applies to the nominal situation and the second applies to the off-nominal situation. A scaling of 2^{28} indicates the double-precision number is an integer. Thus, all values of time are given as an integral number of centiseconds.
4. A push list is available for temporary storage of data and for storage of data common to several sub-routines. Locations within the push list are referred to relative to its initial location and are given as decimal numbers. Thus 6D refers to location 6 in the push list, counting from zero. The values can range from 0D to 42D. For a general location within the push list the name PL is used.
5. MPAC The name MPAC refers to the multipurpose accumulator used by the interpreter routine. It consists of seven consecutive locations within erasable memory and holds the results of interpretive arithmetic operations. It is functionally equivalent to the actual accumulator register within the AGC.



The unit operation, corresponding to the subscript unit, computes a vector of unit length parallel to the specified vector, and leaves the result in MPAC with a scaling of 2^5 . It also automatically stores the magnitude in double-precision in push list location 38D.



Vertical bars enclosing a quantity imply forming the absolute value of the quantity, which may be either a scalar or a vector.



Testing the overflow indicator automatically turns it off.

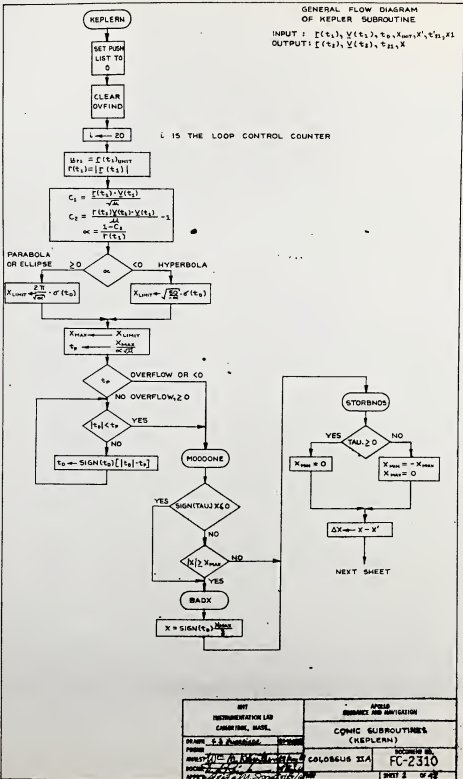
REFERENCES FOR CONIC SUBROUTINES

- Battin, R. H., Astronautical Guidance, McGraw-Hill Inc., New York, 1964.
- Hildebrand, F. B., Introduction to Numerical Analysis, McGraw-Hill Inc., New York, 1956.
- Guidance System Operations Plan Using Program COLOSSUS II, (GSOP), R-577, Section 3, Guidance Equations, March 1969.
- Marscher, W. F., A Unified Method of Generating Conic Sections, R-479, MIT/IL, February 1965.
- Robertson, W. M., Explicit Universal Series Solutions for the Universal Variable X, MIT/IL, SGA Memo 6-67, May 1967.
- Newman, C. M., Power Series Economization, MIT/IL, SGA Memo 11-67, August 1967.
- Krause, K., Generalized Slope Iterator, MIT/IL, SGA Memo 4-67, February 1967.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
		CONIC SUBROUTINES	
APPROVED BY <i>[Signature]</i>	DATE JULY 68	COLOSSUS II SGA	DOCUMENT NO. FC-2350
REVISION 1	DATE JULY 68	REVISION 1	SHEET # OF 48

GENERAL FLOW DIAGRAM
OF KEPLER SUBROUTINE

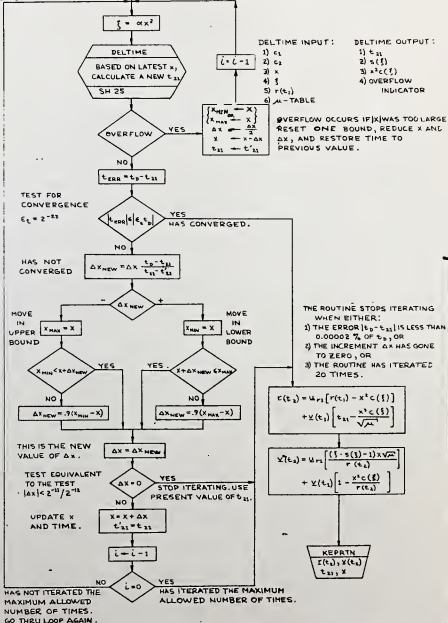
INPUT: $r(t_1), v(t_1), t_0, X_{\text{INIT}}, X', t_{21}, X_1$
OUTPUT: $r(t_2), v(t_2), t_{21}, X$



007 INSTRUMENTATION LAB CAMBRIDGE, MASS.	AFSSD RESEARCH AND INVESTIGATION
	COMIC SUBROUTINES (KEPLERN)
DRAWN: S. S. P... P... CHECKED: ... APPROVED: ...	COLOGUS IIIA FC-2310
APPROX: ...	SHEET 2 OF 2

FROM PRECEDING SHEET

GO THRU LOOP A MAXIMUM OF 20 TIMES. WITHIN MAIN LOOP c_1, c_2, α ARE CONSTANT.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
CONIC SUBROUTINES (KEPLER)		DOCUMENT NO. FC-2310	
DESIGNER: <i>F. Remond</i>	REVISION:	SHEET 3 OF 42	
ANALYST: <i>W. P. ...</i>	DATE: <i>...</i>		
ROOM: <i>...</i>	WORKED: <i>...</i>		
APPROVED: <i>...</i>	DATE: <i>...</i>		

KEPLERN

SET PUSH LIST
POINTER TO 0D

X1 = -4

X1 = -10D

SET UP
μ-TABLE
FOR EARTH

SET UP
μ-TABLE
FOR MOON

$$\begin{aligned} M_{V_1} &= \frac{E(t_1)_{UNIT}}{r(t_1)} \\ URECT_V &= UNIT(VRECT_V) \\ R1 &= 360 \\ &\text{SCALED AT } 2^{10}/2^{17} \end{aligned}$$

L = 20 INITIALIZE THE
ITERCTR → 20D ITERATION
COUNTER.

$$C_1 = \frac{E(t_1) \cdot X(t_1)}{\sqrt{\mu}}$$

KEPC1 = (VRECT_V - VRECT_{V0}) / ROOTMU
SCALED AT 2¹⁷/2¹⁴

$$C_2 = \frac{r(t_1) \cdot X(t_1) \cdot V(t_1) - 1}{\mu}$$

KEPC2 = MPAC - R1 (VRECT_V - VRECT_{V0}) / MU - D1/64
SCALED AT 2⁸

$$\alpha = \frac{1 - C_2}{r(t_1)}$$

ALPHA = MPAC - \frac{D1/64 - MPAC}{R1}
SCALED AT 2⁻¹²/2⁻¹⁰

TO NEXT SHEET

GIVEN THE INITIAL STATE VECTOR $E(t_1)$ AND $V(t_1)$,
AND THE DESIRED TRANSFER TIME t_2 , THIS ROUTINE
COMPUTES THE NEW STATE VECTOR $E(t_2)$ AND $V(t_2)$.

CALLED BY: KEPPREP

INPUT:

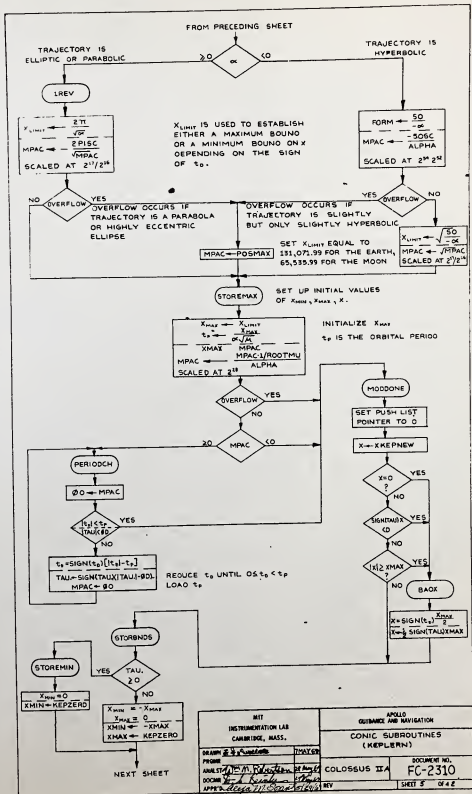
- 1) VRECT_V = $E(t_1)$, INITIAL POSITION VECTOR, IN METERS,
AT 2¹⁰/2¹⁷.
- 2) VRECT_V = $V(t_1)$, INITIAL VELOCITY VECTOR, IN METERS/
CSEC, AT 2⁷/2⁸.
- 3) TAU = t_2 , DESIRED TRANSFER TIME, IN CSECS, AT 2¹⁸.
- 4) XKEPNEW = X_{INIT}, THE FIRST GUESS OF X CORRESPONDING
TO TIME t_2 , IS THE OUTPUT OF KEPPREP, IN METERS^{1/2},
AT 2¹⁷/2¹⁴.
- 5) XPREV = X, THE VALUE OF X FROM A PREVIOUS COMPUTATION
CYCLE, IS USED ONLY TO CALCULATE AN INITIAL X_1 ,
IN METERS^{1/2}, AT 2¹⁷/2¹⁴.
- 6) TC = t_1 , THE PREVIOUS VALUE OF TRANSFER TIME
CORRESPONDING TO X_1 , IN CSECS, AT 2¹⁸.
- 7) X15 = INDEX REGISTER 1 CONTAINING A VALUE USED TO
SELECT THE PROPER μ-TABLE, IS -2 FOR EARTH,
IS -10D FOR MOON.

OUTPUT:

- 1) RCV_V = $E(t_2)$, TERMINAL POSITION VECTOR, IN METERS,
AT 2¹⁰/2¹⁷.
- 2) VCV_V = $V(t_2)$, TERMINAL VELOCITY VECTOR, IN METERS/
CSEC, AT 2⁷/2⁸.
- 3) TC = t_2 , TRANSFER TIME CORRESPONDING TO THE VALUE
OF X TO WHICH KEPLER ROUTINE CONVERGED, IN CSECS,
AT 2¹⁸.
- 4) XPREV = MPAC = X, THE VALUE OF X TO WHICH
KEPLER CONVERGED, IN METERS^{1/2}, AT
2¹⁷/2¹⁴.
- 5) PUSH LIST POINTER IS AT 0D.

NOTE: IF X_L IS CONSIDERED TO BE THE
LTH ITERATE OF X, THEN X^L AND X_{INIT}
CAN BE CONSIDERED TO BE X_{-1} AND
 X_0 RESPECTIVELY.

MIT ENGINEERING LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
PROJECT: <i>Orbit Transfer</i>		CONIC SUBROUTINES (KEPLERN)	
ANALYST: <i>D. M. ...</i>	DESIGNED BY: <i>D. M. ...</i>	DOCUMENT NO.	FC 2310
DOCK: <i>D. M. ...</i>	DATE: <i>11/19/64</i>	COLORADO STATE	SHEET # OF 48
APPROVED BY: <i>D. M. ...</i>	SCALE: <i>1/2</i>		



MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

PROGRAM ANALYST: *[Signature]*
DOCUMENTED BY: *[Signature]*
APPROVED BY: *[Signature]*

ANGLO GUIDANCE AND NAVIGATION
CONIC SUBROUTINES
(KEPLERN)

COLOSSUS IIA

DOCUMENT NO. FC-2310

SHEET 5 OF 42

FROM PRECEDING SHEET

DXCOMP

COMPUTE AN INITIAL VALUE OF Δx FOR
USE IN FIRST PASS THROUGH MAIN LOOP.

$$\epsilon = |\epsilon_c - \epsilon_D|$$

$$\epsilon_c = 2^{-21}$$

EPSILON = $|\text{BEEZ} \cdot \text{TAU}|$
SCALED AT 2^{22}

CALCULATE Δx

$$\Delta x = x - x'$$

DELX = $x - x_{\text{PREV}}$
SCALED AT $2^{11}/2^{16}$

TO NEXT SHEET

NOTE: x' AND ϵ_{31} ARE NON-ZERO
ONLY IF THE SUBROUTINE IS
BEING USED REPETITIVELY.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>F. Reardon</i>		CONIC SUBROUTINES (KEPLER)	
FROM	DATE	DOCUMENT NO.	
ANALYST <i>M. Keeler</i>	<i>11/2/68</i>	FC 2310	
DOCS <i>L. D. Cook</i>	<i>11/2/68</i>	COLONBUS II A	SHEET # OF 42
APPROV <i>J. A. Moran</i>	<i>11/2/68</i>	RV	

FROM PRECEDING SHEET

GO THRU LOOP
A MAXIMUM OF
20 TIMES.

THIS IS THE START OF THE MAIN LOOP.
WITHIN THIS LOOP C_1, C_2, M ARE CONSIDERED CONSTANT.

FORM x^2
 $\phi D \leftarrow x^2$
SCALED AT $2^{M-N}/2^{31-M}$

x^2 IS STORED IN A NORMALIZED FORM
IN AN ATTEMPT TO MAINTAIN MAXIMUM PRECISION.

$f \leftarrow m x^2$
 $x_1 \leftarrow MPAC - ALPHA \cdot \phi D$
SCALED AT 2^4

DELTIME
CALCULATE THE
TRANSFER TIME t_{21}
BASED ON A NEW
VALUE OF K .
SH 25

DELTIME INPUT:
1) KEPC1 = C_1
2) KEPC2 = C_2
3) $X = x$
4) $\phi D = x^2$
5) $x_1 = m_1$ NORMALIZING
FACTOR
6) MPAC = $x_1 \cdot f$
7) $R1 = r(t_1)$
8) μ - TABLE

DELTIME OUTPUT:
1) $T = MPAC + t_{21}$
2) $S(x_1) = S(f)$
3) $XSGC(I) = x^2 \cdot C(I)$
4) OVIND = OVERFLOW INDICATOR

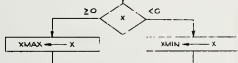
OVERFLOW

YES

OVERFLOW INDICATES
 x WAS TOO LARGE.

TIME OVFL

$t_{err} = t_0 - t_{21}$
 $DEL \leftarrow \tau_{21} \cdot MPAC$
SCALED AT 2^{28}



TEST FOR
CONVERGENCE.
 $\epsilon_1 = 2^{-12}$

YES
HAS
CONVERGED

KEPCDNV
SH 9

$\Delta X \leftarrow \frac{\Delta X}{2}$
 $DELX \leftarrow \frac{DELX}{2}$
REDUCE ΔX

HAS NOT
CONVERGED.

$\Delta x_{new} = \Delta x \frac{t_0 - t_{21}}{t_{21} - t_{22}}$
 $\phi D \leftarrow \frac{DELX \cdot DELT}{T - TC}$
SCALED AT $2^{17}/2^4$

RETURN VIA
KEPRTN

DELX

X ← X - ΔX REDUCE X
X ← X - DELX

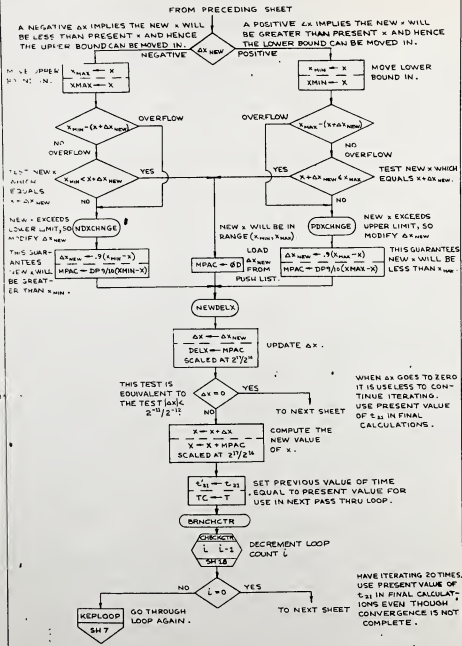
TO NEXT SHEET

$t_{21} \leftarrow t_{22}$
T ← TC RESTORE TIME TO
ITS PREVIOUS
VALUE

BRENCHTR
SH 8

GO THRU LOOP AGAIN
WITH REDUCED
VALUES OF $X, \Delta X$.
(IF NOT BOTH TIME)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
CONIC SUBROUTINES (KEPLERN)		DOCUMENT NO.	
DESIGN: <i>W. A. ...</i>	ANALYST: <i>W. A. ...</i>	FC-2310	
DOCNO: <i>...</i>	APPROV: <i>...</i>	SHEET 2 OF 42	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
CONIC SUBROUTINES (KEPLERN)		DOCUMENT NO.	
BRANCH	PROGRAM	ANALYST	DOCKET
9-11-64	CONIC	M. R. K. / J. D. / J. D.	FC 2310
APPROV	DATE	REV	SHEET # OF #
J. D. / J. D.	1-20-65	1	11 OF 48

FROM PRECEDING SHEET

KEPCONVG

$$\text{FORM } \psi_{r1} \left[\frac{r(t_{21}) - x^2 c(s)}{\phi D_v - \text{URECT}_v \left[\frac{R1 - XSGC(X1)}{2^{23}/2^{21}} \right]} \right]$$

$$\text{FORM } \chi(t_1) \left[\frac{1 - \frac{x^2 s(s)}{\sqrt{\mu}}}{\text{MPAC}_v - \text{VRECT}_v \left[\frac{T - X^3 - 1}{\text{ROOTMU} \cdot S(X)} \right]} \right]$$

MPAC_v ← VRECT_v [T - X³ - 1 / ROOTMU · S(X)]
SCALED AT 2²³ / 2²¹

$$\epsilon(t_2) = \psi_{r1} \left[\frac{r(t_{21}) - x^2 c(s)}{\phi D_v - \text{URECT}_v \left[\frac{R1 - XSGC(X1)}{2^{23}/2^{21}} \right]} \right] + \chi(t_1) \left[\frac{1 - \frac{x^2 s(s)}{\sqrt{\mu}}}{\text{MPAC}_v - \text{VRECT}_v \left[\frac{T - X^3 - 1}{\text{ROOTMU} \cdot S(X)} \right]} \right]$$

RCV_v ← MPAC_v - φD_v + MPAC_v
SCALED AT 2²³ / 2²¹

COMPUTE ε(t₂)

$$r(t_2) = \frac{|\epsilon(t_2)|}{\text{RCNORM} - |\text{MPAC}_v|}$$

RCNORM ← |MPAC_v|
SCALED AT 2²³ / 2²¹

r(t₂) IS STORED IN NORMALIZED FORM.

$$\text{FORM } \psi_{r1} \left[\frac{\left[\frac{s(s) - 1}{r(t_2)} \right] \sqrt{\mu}}{\phi D_v - \text{URECT}_v \left[\frac{(X1 \cdot S(X1) - D1/28 \cdot X \cdot \text{ROOTMU})}{\text{RCNORM}} \right]} \right]$$

SCALED AT 2²⁶ / 2²³

$$\text{FORM } \chi(t_1) \left[\frac{1 - \frac{x^2 c(s)}{r(t_2)}}{\text{MPAC}_v - \text{VRECT}_v \left[\frac{D1/256 - \frac{XSGC(X1)}{\text{RCNORM}}}{\text{RCNORM}} \right]} \right]$$

MPAC_v ← VRECT_v [D1/256 - XSGC(X1) / RCNORM]
SCALED AT 2²⁵ / 2²³

$$\chi(t_2) = \psi_{r1} \left[\frac{\left[\frac{s(s) - 1}{r(t_2)} \right] \sqrt{\mu}}{\phi D_v - \text{URECT}_v \left[\frac{(X1 \cdot S(X1) - D1/28 \cdot X \cdot \text{ROOTMU})}{\text{RCNORM}} \right]} \right] + \chi(t_1) \left[\frac{1 - \frac{x^2 c(s)}{r(t_2)}}{\text{MPAC}_v - \text{VRECT}_v \left[\frac{D1/256 - \frac{XSGC(X1)}{\text{RCNORM}}}{\text{RCNORM}} \right]} \right]$$

VCV_v ← φD_v + MPAC_v
SCALED AT 2²⁷ / 2²⁴

COMPUTE χ(t₂)

TC ← T

THE FINAL VALUES OF t₂₁ AND x ARE STORED IN THEIR OUTPUT LOCATIONS

XPREV ← MPAC ← X

KEPRTN
ε(t₂), χ(t₂),
t₂₁, x

THE RETURN ADDRESS IN KEPRTN IS SET UP BY THE PROGRAM CALLING KEPLER (I.E. KEPPREP) AND NOT BY KEPLER.

- KEPLER TERMINATES THE ITERATION WHEN EITHER:
- 1) THE INDEPENDENT VARIABLE t₂₁ HAS CONVERGED TO WITHIN 0.00002% OF THE DESIRED TIME t₀; OR
 - 2) THE CHANGE IN THE DEPENDENT VARIABLE x HAS GONE TO ZERO (I.E. LESS THAN 2⁻¹⁵/2²²); OR
 - 3) IT HAS ITERATED THE MAXIMUM (28) NUMBER OF TIMES.

AT RETURN TIME THERE IS NO INDICATION OF WHICH CRITERION STOPPED THE ITERATION.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. R. Rouse</i>		CONIC SUBROUTINES (KEPLER)	
PROGRAM ANALYST <i>W. B. Rouse</i>	DATE <i>12-1-68</i>	COLLOSSUS II	DOCUMENT NO. FC 2310
DOCNO <i>FC 2310</i>	APPROVED <i>J. R. Rouse</i>		SHEET 9 OF 42

GENERAL FLOW DIAGRAM OF
LAMBERT SUBROUTINE

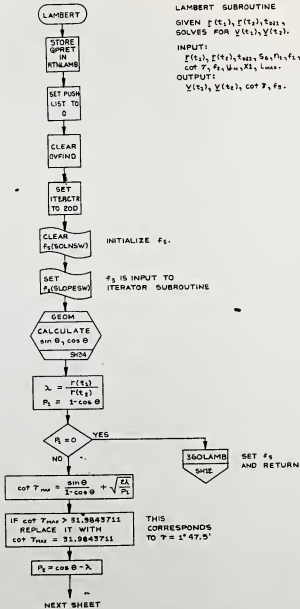
GIVEN $f(t_1)$, $f(t_2)$, t_{022} , S_0 , P_1 , f_1
SOLVES FOR $\psi(t_1)$, $\psi(t_2)$.

INPUT:

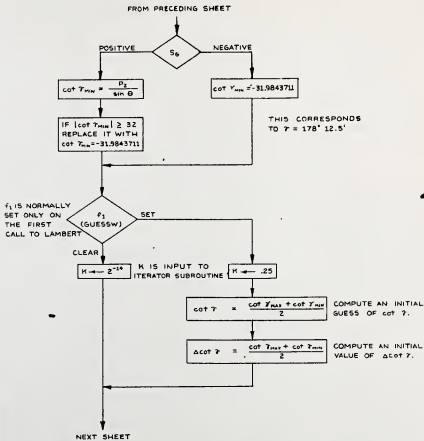
$f(t_1)$, $f(t_2)$, t_{022} , S_0 , P_1 , f_1 ,
 $\cot \tau$, f_2 , U_{01} , X_1 , L_{max} .

OUTPUT:

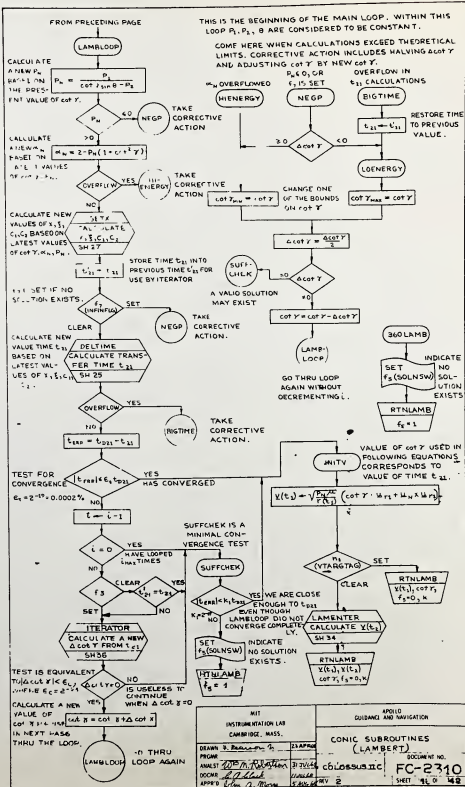
$\psi(t_1)$, $\psi(t_2)$, $\cot \tau$, f_2 .



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED DYNAMICS AND NAVIGATION	
		CONIC SUBROUTINES (LAMBERT)	
DESIGNED BY <i>J. J. ...</i>	DRAWN BY <i>J. J. ...</i>	COLOSSUS III	DOCUMENT NO. FC-2310
PROGRAM	ANALYST <i>M. J. ...</i>		
BOOK	APPROVED BY <i>J. J. ...</i>		SHEET 10 OF 40



MIT THE INDEPENDENT LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
		CONIC SUBROUTINES (LAMBERT)	
DESIGN	DATE	REVISED	DATE
PROJECT	NO. 1	NO. 1	NO. 1
APPROVED BY: <i>[Signature]</i>		APPROVED BY: <i>[Signature]</i>	
COLOSSUS II		DOCUMENT NO. FC-2310	
SHEET 11		OF 48	



LAMBERT

THIS SUBROUTINE CALCULATES THE INITIAL VELOCITY REQUIRED TO TRANSFER A POINT-MASS ALONG A CONIC TRAJECTORY FROM AN INITIAL POSITION $\Sigma(t_1)$ TO A TERMINAL POSITION $\Sigma(t_2)$ IN A PRESCRIBED TIME INTERVAL t_{D21} . THE RESULTING TRAJECTORY MAY BE A SECTION OF A CIRCLE, ELLIPSE, PARABOLA OR HYPERBOLA WITH RESPECT TO EITHER THE EARTH OR THE MOON. THE RESTRICTIONS ARE:

- 1) RECTILINEAR TRAJECTORIES CAN NOT BE COMPUTED.
- 2) ACCURACY DEGRADATION OCCURS AS $\cos \theta$ APPROACHES 1.0.
- 3) THE ANGLE γ BETWEEN ANY POSITION VECTOR AND ITS VELOCITY VECTOR MUST BE IN THE RANGE ($1^\circ 47.5'$, $178^\circ 32.5'$).
- 4) A NEGATIVE TRANSFER TIME IS AMBIGUOUS AND WILL RESULT IN NO SOLUTION.

CALLED BY: INITVEL

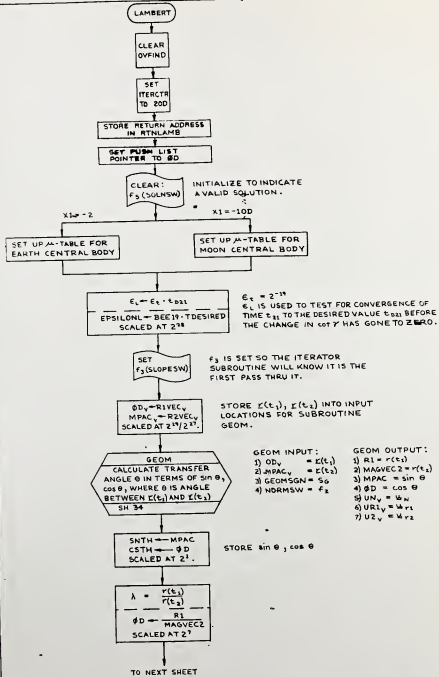
INPUT:

- 1) RIVEC_v = $\Sigma(t_1)$, INITIAL POSITION VECTOR, IN METERS, AT $2^{11}/2^{13}$.
- 2) RZVEC_v = $\Sigma(t_2)$, TERMINAL POSITION VECTOR, IN METERS, AT $2^{13}/2^{11}$.
- 3) TDESIRE = t_{D21} , DESIRED TRANSFER TIME, IN CSEC, AT 2^{18} .
- 4) GEOMSGN = S_{θ} , A FLAG, IS POSITIVE IF THE DESIRED TRANSFER ANGLE θ IS $\leq 180^\circ$, IS NEGATIVE IF $\theta > 180^\circ$.
- 5) VTARGTAG_v = n_1 , A FLAG, IS CLEAR IF THE TERMINAL VELOCITY VECTOR $\Sigma(t_2)$ IS TO BE CALCULATED, IS SET IF $\Sigma(t_2)$ IS NOT TO BE CALCULATED.
- 6) GUESSW = f_1 , A FLAG, IS CLEAR IF AN INITIAL GUESS OF $\cot \gamma$ IS INCLUDED AS INPUT, IS SET IF AN INITIAL GUESS IS NOT INPUT BUT MUST BE CALCULATED BY THE LAMBERT ROUTINE.
- 7) COGA = $\cot \gamma$, AN INITIAL GUESS OF VALUE IF f_1 IS CLEAR, IS IGNORED IF f_1 IS SET, AT 2^5 .
- 8) NORMSW = f_2 , A FLAG, IS CLEAR IF u_n IS TO BE COMPUTED BY THE GEOM SUBROUTINE CALLED BY LAMBERT, IS SET IF u_n IS INCLUDED AS INPUT TO LAMBERT.
- 9) UN_v = u_n , A UNIT VECTOR NORMAL TO THE DESIRED ORBIT PLANE IN THE DIRECTION OF THE RESULTING ANGULAR MOMENTUM VECTOR, IS IGNORED IF f_2 IS CLEAR, AT 2^7 .
- 10) X1 = INDEX REGISTER 1 CONTAINING VALUE USED TO SELECT PROPER μ -TABLE, IS -2 IF EARTH IS CENTRAL BODY, IS -10 IF MOON IS CENTRAL BODY.

OUTPUT:

- 1) VVEC_v = $\Sigma(t_1)$, INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7/2^5$.
- 2) VTARGET_v = $\Sigma(t_2)$, TERMINAL VELOCITY VECTOR, IS COMPUTED ONLY IF n_1 IS CLEAR, IN METERS/CSEC, AT $2^7/2^5$.
- 3) MPAC_v = VVEC_v IF n_1 IS SET, IS VTARGET_v IF n_1 IS CLEAR.
- 4) COGA = $\cot \gamma$, COTANGENT OF FLIGHT PATH ANGLE MEASURED FROM THE VERTICAL, CORRESPONDS TO LAST CALCULATED VALUE OF TIME t_{D21} , AT 2^5 .
- 5) SOLNSW = f_2 , A FLAG, IS CLEAR IF LAMBERT WAS ABLE TO CALCULATE A VALID SOLUTION, IS SET IF NO SOLUTION WAS POSSIBLE DUE TO A TRANSFER ANGLE TOO CLOSE TO 0° OR 360° , OR A TIME t_{D21} TOO SMALL.
- 6) PUSH LIST POINTER IS LEFT AT θD .

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY: <i>J. R. ...</i>		CONIC SUBROUTINES (LAMBERT)	
FROM: <i>...</i>		DOCUMENT NO. FC2310	
ANALYST: <i>...</i>		COLOSSUS: <i>...</i>	
CHECKED: <i>...</i>		REV: <i>...</i>	
APPROVED: <i>...</i>		SHEET 13 OF 42	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>F. R. ...</i>		CONIC SUBROUTINES (LAMBERT)	
PROGRAM: <i>...</i>		DOCUMENT NO.	
ANALYST: <i>...</i>		FC 2310	
DOCS: <i>...</i>		SHEET 14 OF 48	
APPROV: <i>...</i>		REV	

FROM PRECEDING SHEET

$$P_1 = 1 - \cos \theta$$

$$1 - \text{CSTH} = D1/4 = \text{CSTH}$$

SCALED AT 2⁶.

$P_1 = \emptyset$

THIS TEST IS EQUIVALENT TO $P_1 < 2^{-44}$. THIS CORRESPONDS TO A TRANSFERRED ANGLE θ WITHIN 35 ARC SECS $1.5''$ OR $1.5'$. FURTHER CALCULATIONS ARE POSSIBLE. SET P_2 AND RETURN.

360LAMB
54.21

$$\text{FORM } \sqrt{\frac{2\lambda}{1 - \cos \theta}}$$

$$2D \leftarrow \frac{\theta D}{\sqrt{1 - \text{CSTH}}}$$

SCALED AT 2⁶.

$$\text{COT } \gamma_{\text{MAX}} = \frac{\sin \theta}{1 - \cos \theta} + \sqrt{\frac{2\lambda}{1 - \cos \theta}}$$

$$\text{COGAMAX} \leftarrow \frac{\text{SINTH}}{1 - \text{CSTH}} + 2D$$

SCALED AT 2⁶.

THIS IS THE MAXIMUM THEORETICAL VALUE THAT COT γ CAN ACHIEVE BASED ON θ, λ, D .

OVERFLOW

OVERFLOW IMPLIES $|\gamma| < 1^\circ 47.5'$ AND HENCE COT γ_{MAX} EXCEEDS UPPER LIMIT.

IF NEGATIVE, COT γ_{MAX} DOES NOT EXCEED UPPER LIMIT.

$\text{COT } \gamma_{\text{MAX}} < 0$

$\text{COT } \gamma_{\text{MAX}} > 0$

$\text{COT } \gamma_{\text{MAX}} > 31.9843711$

$$\text{COT } \gamma_{\text{MAX}} = 31.9843711$$

$$\text{COGAMAX} = \text{COGULIM}$$

SCALED AT 2⁶.

SET COT γ_{MAX} EQUAL TO UPPER LIMIT. THIS IS THE LARGEST VALUE POSSIBLE FOR COT γ THAT WILL NOT PRODUCE OVERFLOW IN θ CALCULATIONS.

MAXCOGA

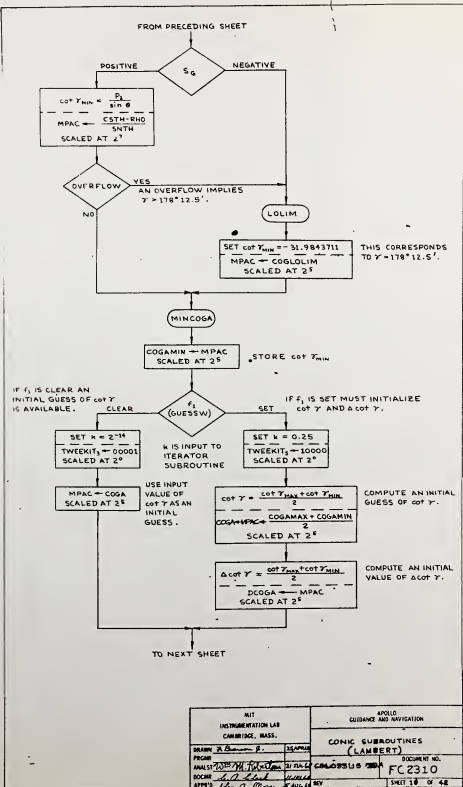
$$P_2 = \cos \theta - 2$$

$$\text{CSTH} - \text{RHO} = \text{CSTH} - \theta D$$

SCALED AT 2⁷.

TO NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>P. Moore</i>		CONIC SUBROUTINES (LAMBERT)	
PROB <i>APOLLO</i>		DOCUMENT NO.	
ANALYST <i>John M. Peterson</i>		FC 2310	
ROOM <i>APOLLO</i>		SHEET 18 OF 48	
APPROVED <i>J. Moore</i>		REV	



FROM PRECEDING SHEET

LAMBLOOP

THIS IS THE BEGINNING OF THE MAIN LOOP.
WITHIN THIS LOOP θ , P_1 , P_2 ARE CONSIDERED
TO BE CONSTANT.

$$P_N = \frac{P_1}{\cos^2 \gamma \sin \theta - P_2} - \frac{1 - \text{CSTH}}{\text{MPAC} - \text{MPAC} \cdot \text{SNTH} - (\text{CSTH} - \text{RND})}$$

SCALED AT 2^4

CALCULATE A NEW VALUE OF P_N
BASED ON THE PRESENT VALUE
OF $\cot \gamma$.

P_N

≤ 0

> 0

NECF
SH 21

HAVE EXCEEDED THEORETICAL
LIMITS. TAKE CORRECTIVE
ACTION.

$P \leftarrow \text{MPAC}$
SCALED AT 2^4

STORE P_N

$$\alpha_N = 2 - P_N (1 + \cot^2 \gamma)$$

$$\text{RIA} \leftarrow \text{MPAC} - \text{DI}/32 - P(\text{DI}/1024 + \text{COGA}^2)$$

SCALED AT 2^4

CALCULATE A NEW VALUE OF α_N
BASED ON LATEST VALUES OF
 $\cot \gamma$, P_N .

OVERFLOW

YES

NO

HIENERGY
SH 21

OVERFLOW OCCURS IF
 $|M_N| \geq 64$. HAVE EXCEEDED
THEORETICAL LIMITS. TAKE
CORRECTIVE ACTION.

GETX

CALCULATE NEW VALUES
OF X_1, \ddagger, C_1, C_2 BASED ON LATEST
VALUES OF $\cot \gamma, \alpha_N, P_N$
SH 26

GETX INPUT:

- 1) SNTH = sin θ
- 2) CSTH = cos θ
- 3) COGA = cot γ
- 4) R1 = $r(t)$
- 5) RIA = α_N
- 6) MPAC = P_N

GETX OUTPUT:

- 1) X = X
- 2) XI = \ddagger
- 3) KEPC1 = C_1
- 4) KEPC2 = C_2
- 5) $\Phi D = x^2$
- 6) INFINFLG = f

$t_{21} \leftarrow t_{21}$
 $\text{TPREV} \leftarrow T$
SCALED AT 2^{28}

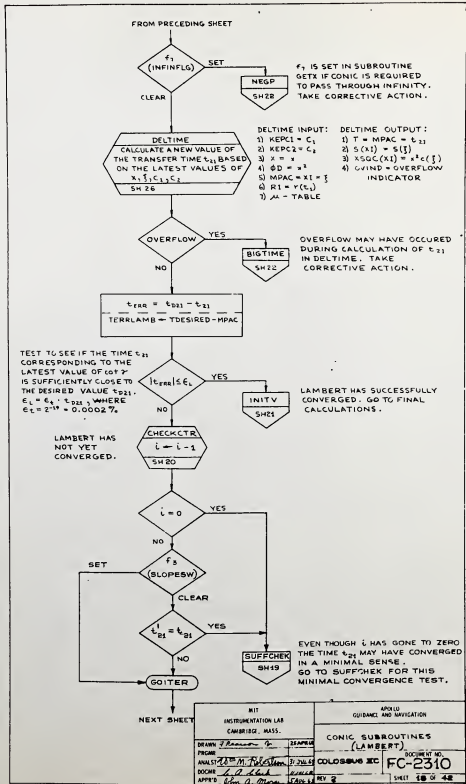
SAVE t_{21} WHICH NOW BECOMES THE PREVIOUS
VALUE OF TIME. THE ITERATOR ROUTINE
REQUIRES TWO SUCCESSIVE VALUES OF
TIME TO LINEARLY INTERPOLATE A NEW
VALUE OF $\cot \gamma$.

$\text{MPAC} \leftarrow X1$

LOAD \ddagger IN PREPARATION
FOR DELTIME.

TO NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DEVELOP <i>F. Roush</i>		CONIC SUBROUTINES (LAMBERT)	
PROGRAM	DATE	DOCUMENT NO.	
ANALYST <i>J. M. Robertson</i>	3/20/66	FC-2310	
DOCNO <i>J. P. Galt</i>	11/20/66	SHEET 17 OF 48	
APPROV <i>John A. Mura</i>	1/26/67	REV	



FROM PRECEDING SHEET

ITERATOR
LINEARLY INTERPOLATE A
VALUE OF $\Delta \cot \gamma$ THAT WILL
PRODUCE A BETTER
ESTIMATE $\cot \gamma + \Delta \cot \gamma$.
SH 36

ITERATOR INPUT:

- 1) ORDERSW = f_4
- 2) SLOPESW = f_5
- 3) T = t_{21}
- 4) TPREV = t_{21}
- 5) TERLAMB = t_{ERR}
- 6) DCOGA = $\Delta \cot \gamma$
- 7) COGA = $\cot \gamma$
- 8) TWEEKIT = K
- 9) COGAMAX = $\cot \gamma_{MAX}$
- 10) COGAMIN = $\cot \gamma_{MIN}$

ITERATOR OUTPUT:

- 1) DCOGA = $\Delta \cot \gamma$
- 2) SLOPESW = f_5
- 3) COGAMAX = $\cot \gamma_{MAX}$
- 4) COGAMIN = $\cot \gamma_{MIN}$

THIS TEST IS
EQUIVALENT TO
 $|\Delta \cot \gamma| < \epsilon_L$,
WHERE $\epsilon_L = 2^{-33}$

$\Delta \cot \gamma = 0$

YES
STOP ITERATING.

WHEN $\Delta \cot \gamma$ GOES TO ZERO IT IS USE-
LESS TO CONTINUE ITERATING, HOWEVER
EVEN THOUGH THE ITERATION IS STOPPED
PREMATURELY THE TIME t_{21} MAY HAVE
CONVERGED IN A MINIMAL SENSE. IF SO
GO TO VELOCITY CALCULATIONS.

NO
CONTINUE
ITERATING.

ACULATE A BETTER
ESTIMATE OF $\cot \gamma$.
THIS VALUE WILL
CORRESPOND TO THE
VALUE OF t_{21} THAT
IS CALCULATED ON
THE NEXT PASS.

$\cot \gamma = \cot \gamma + \Delta \cot \gamma$
COGA = COGA + MPAC
SCALED AT 2^8

SO THROUGH
THE LOOP AGAIN.

LAMBLOOP
SH 17

SUFFERER

$|t_{ERR}| < K_1 \cdot t_{21} + 2$

K_1 IS THE MINIMAL ACCEPT-
ANCE PERCENTAGE OF
 t_{21} TO WHICH t_{ERR} MUST
CONVERGE. IT IS CURRENTLY
EQUAL TO 2^{-2} .

NO
FINAL ERROR
IS TOO LARGE.

GO TO THE
VELOCITY
CALCULATIONS
ON THE NEXT SHEET.

INDICATES
NO SOLUTION
EXISTS.

SET:
 f_4 (SOLNSW)

RETURN VIA
RTHLAMB

CHECKCTR

$i \leftarrow i - 1$
MPAC = ITERCTR * FIXLOC -
(ITERCTR * FIXLOC) - 1

RETURN VIA
DANZIG

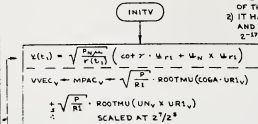
THIS SUBROUTINE IS CODED
IN BASIC LANGUAGE.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO DISTANCE AND SAMPLING	
CONK SUBROUTINES (LAMBERT)		DOCUMENT NO.	
DESIGNED BY <i>[Signature]</i>	DATE <i>[Date]</i>	COL-53418-1	FC2310
APPROVED BY <i>[Signature]</i>	DATE <i>[Date]</i>		
APPROVED BY <i>[Signature]</i>	DATE <i>[Date]</i>		
SHEET 10 OF 48		SHEET 10 OF 48	

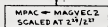
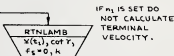
LAMBERT TERMINATES ITERATING AND COMES HERE FOR THE FINAL CALCULATIONS

- IF EITHER:
- 1) THE ERROR $|t_{D21} - t_{21}|$ FOR INTERMEDIATE VALUES OF t_0 AND $\cot \gamma$ IS LESS THAN 0.0002 % OF THE DESIRED TIME t_{D21} , OR
 - 2) IT HAS GONE THROUGH THE LOOP \sqrt{h} AND THE ERROR $|t_{D21} - t_{21}|$ IS LESS THAN 2^{-17} OF THE DESIRED TIME t_{D21} .

THE VALUE OF $\cot \gamma$ USED IN THE FOLLOWING CALCULATIONS CORRESPONDS TO THE LAST CALCULATED VALUE OF TIME t_{21} .

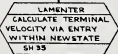


CALCULATE INITIAL VELOCITY VECTOR.



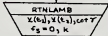
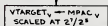
LOAD $r(t_1)$ FOR ENTRY INTO NEWSTATE AT LAMENTER.

LAMENTER IS ACTUALLY AN ENTRY POINT WITHIN SUB-ROUTINE NEWSTATE.



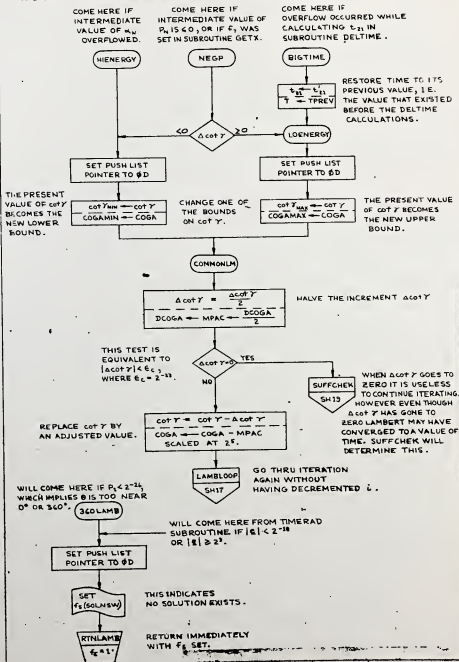
- LAMENTER INPUT: LAMENTER OUTPUT:
- 1) VVEC_v = $V(t_1)$
 - 2) MPAC = $r(t_1)$
 - 3) UR1_v = U_{r1}
 - 4) X = x
 - 5) XI = ξ
 - 6) S(X) = $s(\xi)$
 - 7) XSGC(X) = $x^2 c(\xi)$
 - 8) μ - TABLE
 - 9) MPAC_v = $V(t_2)$

STORE TERMINAL VELOCITY VECTOR $V(t_2)$.

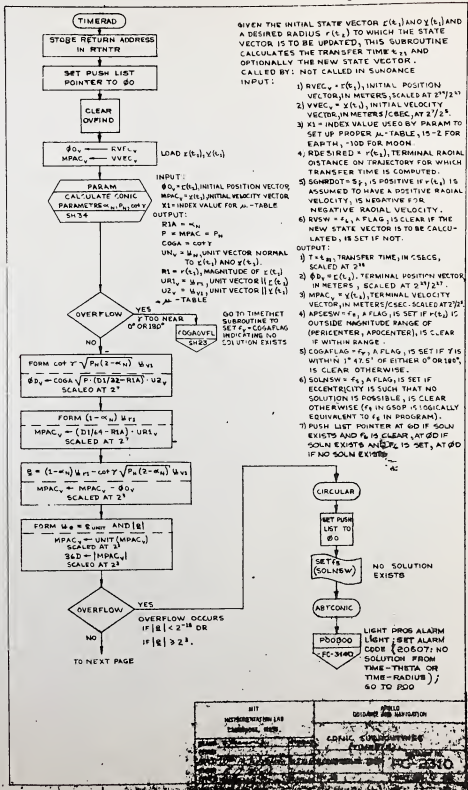


MILITARY INSTRUMENTATION LAW		ARLGO GUIDANCE AND NAVIGATION	
CALCULATIONS, BASE.		CONIC SUBROUTINES (LAMBERT)	
DESIGN <i>J. Camp</i>	DATE <i>10/17/64</i>	PROGRAM NO. <i>FC 310</i>	REVISION NO.
APPROV <i>J. P. ...</i>	DATE <i>10/17/64</i>	SHEET 25 OF 48	

PROGRAM COMES TO ONE OF THESE ENTRIES WHENEVER THE CALCULATIONS EXCEED THE THEORETICAL BOUNDS. CORRECTIVE ACTION IS TAKEN BY HALVING THE INCREMENT $\Delta \cot \gamma$ AND THEN ADJUSTING THE VALUE OF $\cot \gamma$ WITH THE NEW $\Delta \cot \gamma$.



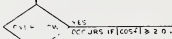
MIT METEOROLOGICAL LAB CAMBRIDGE, MASS.		APOLLO ORBITANCE AND NAVIGATION	
		LONIC SUBROUTINES (LAMBERT)	
PROJECT		DOCUMENT NO.	
ANALYST		FC 2310	
ROOM		SHEET 28 OF 48	
APPROVED			



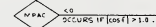
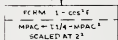
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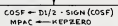
STORE U_0



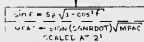
IF OVERFLOW OCCURS THE MAGNITUDE OF $\cos \theta$ WILL BE INCORRECT BUT THE SIGN WILL BE CORRECT.



RADR2



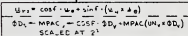
FOR THIS SITUATION SET $\cos \theta = 1.0$ WITH CORRECT SIGN; $\sin \theta = 0.0$.



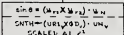
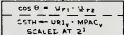
THIS INDICATES $\cos \theta$ WAS COMPUTED > 1.0 , IMPLYING $r(t_2)$ IS OUTSIDE RANGE OF (PERICENTER, APOCENTER).

SET $f_2(\text{APSEW})$

TERMINVEC



THE METHOD OF COMPUTATION AUTOMATICALLY FORCES $\cos \theta$ INTO THE RANGE $(-0.999 \dots, +0.999 \dots)$.



MPAC ← P LOAD P_n



INPUT: $\text{SNTH} = \sin \theta$
 $\text{CSTH} = \cos \theta$
 $\text{COGA} = \cos \gamma$
 $R1 = r(t_1)$
 $P1A = P_n$
 $MPAC = P_n$

OUTPUT: $X = X$
 $Y = Y$
 $KEP1 = C_1$
 $KEP2 = C_2$
 $\Phi D = X^2$
 $\text{INFINFL} = f_2$

CLEAR $f_2(\text{SOLSW})$ INDICATES SOLUTION IS VALID

GO TO TIMETHET SUBROUTINE FOR CALCULATION OF TRANSFER TIME t_{23} AND THEN RETURN TO CALLING ROUTINE DIRECTLY FROM TIMETHET.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
PROGRAM ANALYST ROOM APPROV	<i>James S. ...</i> <i>M. ...</i> <i>...</i> <i>...</i>	CONIC SUBROUTINES - (TIMERAD)	DOCUMENT NO. FC 2340 SHEET 26 OF 48

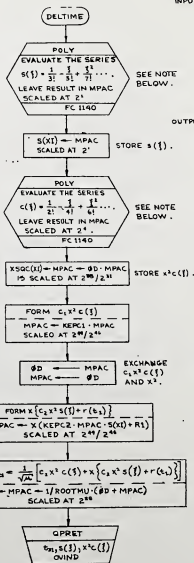
GIVEN A VALUE OF THE UNIVERSAL VARIABLE x , AND THE VALUES c_1, c_2 , AND ξ , THIS SUBROUTINE CALCULATES THE CORRESPONDING TRANSFER TIME t_{21} .

CALLED BY :

INPUT: KEPLERN, LAMBERT, TIMETHET.

- 1) KEPC1 = c_1 AT $2^{17}/2^{18}$.
- 2) XPC2 = c_2 AT 2^4 .
- 3) X = x , UNIVERSAL VARIABLE, AT $2^{17}/2^{18}$.
- 4) $\theta_0 = x^2$, NORMALIZED AT $2^{14}/2^{12} \cdot n$.
- 5) X1 = INDEX REGISTER CONTAINING THE NORMALIZING VALUE = n .
- 6) MPAC = ξ , AT 2^4 .
- 7) R1 = $r(t_1)$, THE MAGNITUDE OF $r(t_1)$, AT $2^{24}/2^{21}$.
- 8) μ - TABLE APPROPRIATE FOR EITHER EARTH OR MOON.
- 9) THE PUSH LIST POINTER IS AT ZD.

- OUTPUT:
- 1) T = MPAC = t_{21} , TRANSFER TIME, IN CSECS, AT 2^{24} .
 - 2) SX(X) = $s(x)$, AT 2^7 .
 - 3) XSC(X) = $x^2 c(x)$, AT $2^{17}/2^{21}$.
 - 4) OVFIND = THE OVERFLOW INDICATOR, IT MAY BE TURNED ON AS A RESULT OF t_{21} CALCULATION, IMPLYING THE VALUE OF X AT INPUT WAS TOO LARGE.
 - 5) PUSH LIST POINTER IS LEFT AT θ_0 .



NOTE:

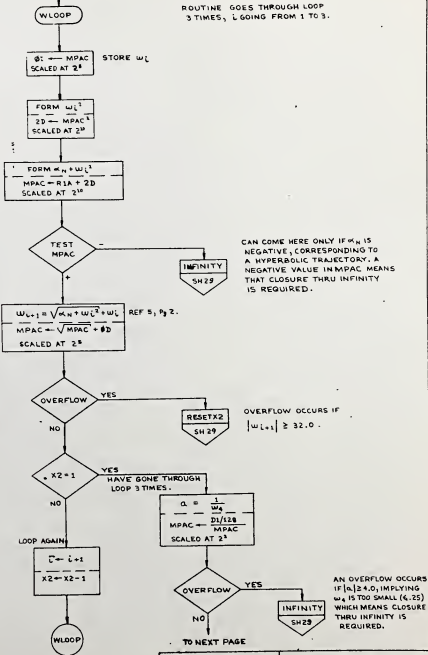
THE INFINITE SERIES $s(x)$ AND $c(x)$ ARE APPROXIMATED BY POLYNOMIALS OF DEGREE 9. THE COEFFICIENTS USED ARE THE RESULT OF A CHEBYSHEV POLYNOMIAL APPROXIMATION TO EACH SERIES. SEE REF. 6 AND REF. 2, PAGES 391-5. THE COEFFICIENTS USED ARE AS FOLLOWS.

$s(x)$	$c(x)$
0.083333374 x 2^1	0.031250001 x 2^4
-0.246666684 x 2^{-5}	-0.166666719 x 2^{-8}
0.406349155 x 2^{-11}	0.355555413 x 2^{-8}
-0.361198675 x 2^{-17}	-0.406347410 x 2^{-14}
0.210153242 x 2^{-23}	0.288962094 x 2^{-10}
-0.086221951 x 2^{-29}	-0.140117894 x 2^{-16}
0.026268912 x 2^{-35}	0.047247387 x 2^{-22}
-0.006163314 x 2^{-41}	-0.013081923 x 2^{-28}
0.001177344 x 2^{-47}	0.002806393 x 2^{-34}
-0.000190558 x 2^{-53}	-0.000529414 x 2^{-40}

MIT METROLOGICAL LAB CHEMISTRY, MASS.		APPLS GUIDANCE AND INDICATION	
FORM NO. <u>7-71-6</u>		CONIC SUBROUTINES (DELTIME)	
PROJECT <u>Project on Radiation</u>	DATE <u>7-21-64</u>	OPERATOR'S NAME	PROJECT NO.
DOCSN <u>7-71-6</u>	REV <u>1</u>		FC 2310
APPROV <u>[Signature]</u>	BY		SHEET 25 OF 42

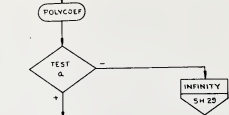
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ROUTINE GOES THROUGH LOOP
3 TIMES, GOING FROM 1 TO 3.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
PROJECT EQUATION 3		CONIC SUBROUTINES (RETX)	
ANALYST M. J. Robinson	DATE 31 JUL 68	CONTRACT NO. DAAG-50-67-001	DOCUMENT NO. FC 2310
APPROV A. P. Black	REV 1	SHEET 29 OF 48	

FROM PRECEDING PAGE

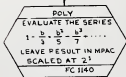


A NEGATIVE α MEANS CLOSURE THRU INFINITY IS REQUIRED.

$\phi D = MPAC$
SCALED AT 2^6 STORE α

$b = N \alpha^2$
 $MPAC \leftarrow R1A \cdot MPAC$
SCALED AT 2^6

b IS INPUT TO POLY



THE INFINITE SERIES IS APPROXIMATED BY A POLYNOMIAL OF DEGREE 6. THE COEFFICIENTS USED ARE THE RESULT OF A CHEBYSHEV POLYNOMIAL APPROXIMATION TO THE GIVEN INFINITE SERIES. SEE REF. 6 AND REF. 2, PAGES 391-395. THE COEFFICIENTS USED IN THE SUBROUTINE ARE:

1.000 000 000 0.111 006 504
-0.333 333 540 -0.094 518 194
0.200 000 784 0.081 388 408
-0.142 802 172

$x_N = 2^6 \alpha (1 - \frac{b}{3} + \frac{b^2}{5} - \dots)$
 $\phi D \leftarrow \phi D \cdot MPAC$
SCALED AT 2^6

$x_N = \frac{x}{\sqrt{r(t_1)}}$ IS THE NORMALIZED VALUE OF X.
THE MULTIPLICATION BY 2^6 IS ACCOMPLISHED BY SHIFTING.



TRUE 360 X



$x_N = \frac{2Y}{\sqrt{r(t_1)}} - x_N$
 $\phi D \leftarrow MPAC - \frac{2P15C}{\sqrt{R1A}} - \phi D$
SCALED AT 2^6

IF F_w WAS SET THE RECIPROCAL CALCULATION ACTUALLY COMPUTED AN x_N CORRESPONDING TO AN ANGLE OF $360^\circ - \theta$. THIS CALCULATES THE x_N CORRESPONDING TO θ .

TO NEXT PAGE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGNED BY: <i>W. R. ...</i>		CONIC SUBROUTINES (62X)	
PROGRAM ANALYST: <i>W. R. ...</i>		DOCUMENT NO. FC2310	
ROOM: <i>...</i>		SHEET 29 OF 30	
APPROVED BY: <i>...</i>			

FROM PRECEDING PAGE

$$\xi = X_N \text{ OR } N$$

$$X1 = \text{MPAC}^2 - R1A$$

SCALED AT 2^4

$$X = \sqrt{r(\xi_1)} X_N$$

$$X = \text{MPAC} - \sqrt{R1} \cdot \theta D$$

SCALED AT $2^{11}/2^{14}$

$$\theta D = \text{MPAC}^2$$

SCALED AT $2^{11} \cdot 2^{11} / 2^{11} \cdot 2^{11}$

STORE X^2 NORMALIZED, WITH
-N1 IN $X1$.

$$C_1 = \sqrt{P_{WR}(\xi_1)} \cdot \text{COPF}$$

$$\text{KEPC1} = \sqrt{D \cdot R1} \cdot \text{COGA}$$

SCALED AT $2^{17}/2^{14}$

$$C_2 = 1 - \alpha_N$$

$$\text{KEPC2} = D1/64 - R1A$$

SCALED AT 2^6

CLEAR
 $F_2(\text{INFLG})$

INDICATES SOLUTION
IS VALID.

QPRET
 X_1, C_1, C_2
 $X^2, F_2 = 0$

INFINITY

COME HERE IF NO SOLUTION EXISTS
BECAUSE CLOSURE THROUGH INFINITY
IS REQUIRED.

SET PUSH LIST
PTR TO θD

CLEAR
OVIND

CLEAR THE
OVERFLOW INDICATOR

SET
 $F_2(\text{INFLG})$

THIS INDICATES CLOSURE
THROUGH INFINITY REQUIRED

QPRET
 $F_2 = 1$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
CONIC SUBROUTINES (GETX)		DOCUMENT NO.	
DESIGN BY <i>W. M. Peterson</i>	DATE <i>10/27/68</i>	COLLOSSUS JOB	FC2310
ANALYSIS BY <i>W. M. Peterson</i>	DATE <i>10/27/68</i>	REV.	SHEET <i>02</i> OF <i>48</i>
BOOK BY <i>W. M. Peterson</i>	DATE <i>10/27/68</i>		
APP'D BY <i>W. M. Peterson</i>	DATE <i>10/27/68</i>		

360CHECK

RESET X2

COME HERE IF w_1 OVERFLOWED.
CALCULATE α USING RECIPROCAL FORMULA.

X2 ← 3

SET $i = 1$ SET PUSH LIST
POINTER TO 00 w_1 ET
 $f_w(360SW)$

$$\frac{1}{w_1} = \frac{\sin \theta}{\sqrt{D_n (1 + \cos \theta - \sin \theta \cot \gamma)}}$$

$$2i \leftarrow \text{MPAC} \leftarrow \frac{\text{SNTH}}{\sqrt{D_n (31/32 + \text{C5TH} \cdot \text{SNTH} \cdot \text{COGA})}}$$

SCALED AT 2^{-1}

REF 5, Pg 3.

$$\text{FORM } \left(\frac{1}{w_1} \right)^2$$

$$34D \leftarrow \text{MPAC}^2$$

SCALED AT 2^{-2}

MPAC ← 1/16

SET $v_1 = 1$, SCALED AT 2^4

1/WLOOP

ROUTINE GOES THROUGH LOOP
3 TIMES, i GOING FROM 1 TO 3.2D ← MPAC, SCALED AT 2^4
4D ← MPAC², SCALED AT 2^8 STORE v_1, v_1^3

$$\text{FORM } \alpha_n \left(\frac{1}{w_1} \right)^2 + v_1^2$$

$$\text{MPAC} \leftarrow \text{RIA} \cdot 34D + 4D$$

SCALED AT 2^8

TEST
MPACINFINITY
SH 2D

$$v_{i+1} = \sqrt{\alpha_n \left(\frac{1}{w_1} \right)^2 + v_i^2} + v_1$$

$$\text{MPAC} \leftarrow \sqrt{\text{MPAC} + 2D}$$

SCALED AT 2^4

X2 ← 1

LOOP AGAIN

YES
HAVE GONE THROUGH
LOOP 3 TIMES

$$\alpha = \left(\frac{1}{w_1} \right) / v_4$$

$$\text{MPAC} \leftarrow \frac{3D}{\text{MPAC}}$$

SCALED AT 2^1

GO BACK AND
EVALUATE γ_n .POLYCOEF
SH 2B $i \leftarrow i + 1$
 $X2 \leftarrow X2 - 1$

1/WLOOP

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
PROGRAM ANALYST: <i>J. P. ...</i>		CONIC SUBROUTINES (GETX)	
DOCNO: <i>...</i>		DOCUMENT NO. FC 2310	
APPROV: <i>John A. ...</i>		SHEET 06 OF 08	

A VARIABLE v_L IS DEFINED RECURSIVELY IN REF. 5 AS

$$v_1 = 1$$

$$v_L = \sqrt{\frac{\alpha}{w_L^2} + v_{L-1}^2} + v_{L-1} \quad \text{FOR } L = 2, 3, \dots$$

THE RECIPROCAL $\frac{1}{w_4}$ IS DEFINED AS

$$\frac{1}{w_4} = \left(\frac{1}{w_1}\right) / v_4$$

THE SUBROUTINE EVALUATES INSTEAD THE VARIABLE $\frac{1}{w_L}$ AND VARIABLE v_L RECURSIVELY THROUGH v_4 AS:

$$\frac{1}{w_1} = \frac{\sin \theta}{\frac{1}{2} + \cos \theta - \sin \theta \cot \gamma} \left(\frac{1}{\sqrt{P}}\right), \quad \text{WHERE } \frac{1}{\sqrt{P}} = \sqrt{\frac{r}{P}}$$

$$v_1 = 1$$

$$v_L = \sqrt{\frac{\alpha_N}{w_L^2} + v_{L-1}^2} + v_{L-1} \quad \text{FOR } L = 2, 3, 4$$

THE RELATIONS BETWEEN $\frac{1}{w_1}$ AND $\frac{1}{w_L}$, AND v_1 AND v_L ARE AS FOLLOWS:

$$\frac{1}{w_1} = \frac{1}{\sqrt{P}} \frac{1}{w_L} \quad \text{AND HENCE } \frac{\alpha_N}{w_L^2} = \frac{\alpha}{w_1^2}$$

$$v_1 = v_L$$

$$v_2 = \sqrt{\frac{\alpha_N}{w_2^2} + v_1^2} + v_1 = \sqrt{\frac{\alpha}{w_1^2} + v_1^2} + v_1 = v_2$$

$$v_3 = \sqrt{\frac{\alpha_N}{w_3^2} + v_2^2} + v_2 = \sqrt{\frac{\alpha}{w_1^2} + v_2^2} + v_2 = v_3$$

$$v_4 = \sqrt{\frac{\alpha_N}{w_4^2} + v_3^2} + v_3 = \sqrt{\frac{\alpha}{w_1^2} + v_3^2} + v_3 = v_4$$

SUBSTITUTING THESE VALUES OF $\frac{1}{w_1}$ AND v_4 BACK INTO THE EQUATION FOR $\frac{1}{w_4}$ GIVES

$$\frac{1}{w_4} = \left(\frac{1}{w_1}\right) / v_4 = \left(\frac{\sqrt{P}}{w_1}\right) / v_4 = \frac{\sqrt{P}}{w_1 v_4}$$

SUBSTITUTING THIS INTO THE EQUATION FOR X GIVES

$$x = \frac{2^4 \sqrt{P}}{w_1 v_4} \left[1 - \frac{1}{3} \alpha \left(\frac{r}{w_1^2 v_4^2}\right) + \frac{1}{5} \alpha^2 \left(\frac{r}{w_1^2 v_4^2}\right)^2 - \dots \right]$$

LETTING $a = \frac{2^4 \sqrt{P}}{w_1 v_4}$ AND $b = \alpha_N \alpha^2 = \frac{\alpha_N}{w_1^2 v_4^2}$; AND RECALLING THAT $\alpha_N = \alpha r$, GIVES

$$x_N = \frac{x}{\sqrt{P}} = 2^4 a \left[1 - \frac{1}{3} b + \frac{1}{5} b^2 - \frac{1}{7} b^3 + \dots \right]$$

THIS IS EXACTLY THE SAME FORM FOR EVALUATING x_N AS IN THE PREVIOUS CASE; USING THE ABOVE VALUES OF a AND b .

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DEVELOPER: <i>F. R. ...</i>		CONIC SUBROUTINES (GETX)	
PROGRAM:	2.201.6	DOCUMENT NO.	FC 2310
ANALYST: <i>M. ...</i>		COLDSTART IS:	
DOOR: <i>L. ...</i>			
APPROVED: <i>...</i>	DATE: <i>...</i>		SHEET 28 OF 42

THIS SUBROUTINE COMPUTES THE CONIC PARAMETERS $\mu_n, P_n, \cot \gamma$ FOR A GIVEN TIME t_n .

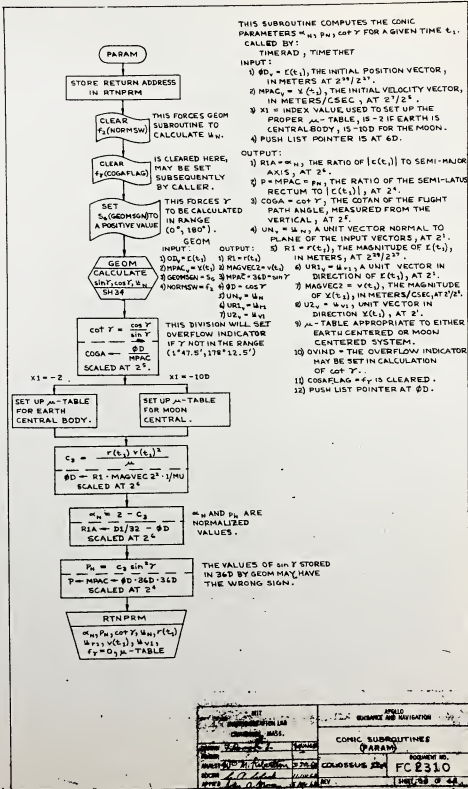
CALLED BY:
TIMERAD, TIMETHET

INPUT:

- 1) $\phi_D = [c(t_n)]$, THE INITIAL POSITION VECTOR, IN METERS AT $2^{24}/2^8$.
- 2) $MPAC_n = v(t_n)$, THE INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7/2^8$.
- 3) $XI =$ INDEX VALUE, USED TO SET UP THE PROPER μ_n -TABLE, IS -2 IF EARTH IS CENTRAL BODY, IS -10 FOR THE MOON.
- 4) PUSH LIST POINTER IS AT 6D.

OUTPUT:

- 1) $RIA = \mu_n$, THE RATIO OF $|c(t_n)|$ TO SEMI-MAJOR AXIS, AT 2^8 .
- 2) $P = MPAC_n$, THE RATIO OF THE SEMI-LATUS RECTUM TO $|c(t_n)|$, AT 2^8 .
- 3) $COGA = \cot \gamma$, THE COTAN OF THE FLIGHT PATH ANGLE, MEASURED FROM THE VERTICAL, AT 2^8 .
- 4) $UN_n = u_n$, A UNIT VECTOR NORMAL TO PLANE OF THE INPUT VECTORS, AT 2^8 .
- 5) $R1 = r(t_n)$, THE MAGNITUDE OF $r(t_n)$, IN METERS, AT $2^{24}/2^{27}$.
- 6) $UR1_n = u_{r1}$, A UNIT VECTOR IN DIRECTION OF $r(t_n)$, AT 2^8 .
- 7) $MAGVEC2 = v(t_n)$, THE MAGNITUDE OF $v(t_n)$, IN METERS/CSEC, AT $2^7/2^8$.
- 8) $U2_n = u_{v1}$, UNIT VECTOR IN DIRECTION $v(t_n)$, AT 2^8 .
- 9) μ_n -TABLE APPROPRIATE TO EITHER EARTH-CENTERED OR MOON-CENTERED SYSTEM.
- 10) $OVIIND =$ THE OVERFLOW INDICATOR MAY BE SET IN CALCULATION OF $\cot \gamma$.
- 11) $COGAFLAG = \cot \gamma$ IS CLEARED.
- 12) PUSH LIST POINTER AT ϕ_D .



TITLE CONIC SUBROUTINE (PARAM) PROJECT NO. FC 2310	FIELD BUSINESS AND NAVIGATION CONIC SUBROUTINES (PARAM) PROJECT NO. FC 2310 SHEET 28 OF 48
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GIVEN TWO VECTORS \vec{a}_1 AND \vec{a}_2 , THIS SUBROUTINE COMPUTES THE SINE AND COSINE OF THE ANGLE ϕ BETWEEN THEM, AND OPTIONALLY A UNIT VECTOR \vec{u}_N NORMAL TO THE PLANE DEFINED BY THE VECTORS.

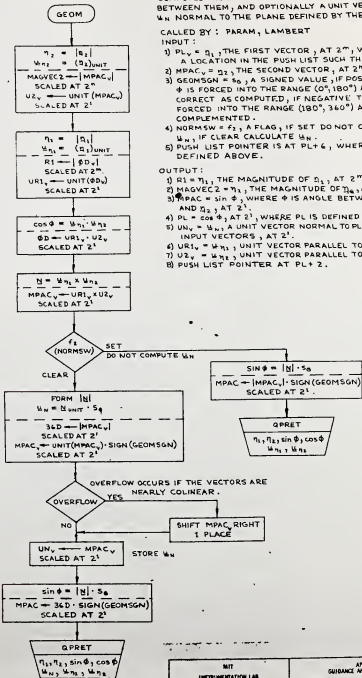
CALL BY: PARAM, LAMBERT

INPUT:

- 1) $PLV = \vec{a}_1$, THE FIRST VECTOR, AT 2^m, WHERE PL IS A LOCATION IN THE PUSH LIST SUCH THAT 0 & PL & 300.
- 2) $MPACV = \vec{a}_2$, THE SECOND VECTOR, AT 2^m.
- 3) $GEOMSGN = \phi_0$, A SIGNED VALUE, IF POSITIVE THEN ϕ IS FORCED INTO THE RANGE (0°, 180°) AND \vec{u}_N IS CORRECT AS COMPUTED, IF NEGATIVE THEN ϕ IS FORCED INTO THE RANGE (180°, 360°) AND \vec{u}_N IS COMPLEMENTED.
- 4) $NORMSW = f_2$, A FLAG, IF SET DO NOT CALCULATE \vec{u}_N , IF CLEAR CALCULATE \vec{u}_N .
- 5) PUSH LIST POINTER IS AT $PL+6$, WHERE PL IS DEFINED ABOVE.

OUTPUT:

- 1) $R1 = \eta_1$, THE MAGNITUDE OF \vec{a}_1 , AT 2^m.
- 2) $MAGVEC2 = \eta_2$, THE MAGNITUDE OF \vec{a}_2 , AT 2^m.
- 3) $MPAC = \sin \phi$, WHERE ϕ IS ANGLE BETWEEN \vec{a}_1 AND \vec{a}_2 , AT 2^m.
- 4) $PL = \cos \phi$, AT 2^m, WHERE PL IS DEFINED ABOVE.
- 5) $UNV = \vec{u}_N$, A UNIT VECTOR NORMAL TO PLANE OF INPUT VECTORS, AT 2^m.
- 6) $UR1V = \vec{u}_{r1}$, UNIT VECTOR PARALLEL TO \vec{a}_1 , AT 2^m.
- 7) $U2V = \vec{u}_{r2}$, UNIT VECTOR PARALLEL TO \vec{a}_2 , AT 2^m.
- 8) PUSH LIST POINTER AT $PL+2$.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
CONIC SUBROUTINES		DOCUMENT NO.	
CONIC SUBROUTINES		FC 2310	
PREPARED BY: M. J. PETERSON CHECKED BY: J. J. GARDNER APPROVED BY: J. J. GARDNER	DATE: 11/22/64 SCALE: 1:1 REV:	SHEET 306 OF 48	

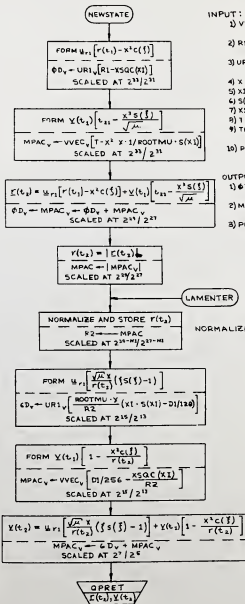
THIS SUBROUTINE CALCULATES THE NEW STATE VECTORS $\epsilon(t_2)$ AND $\gamma(t_2)$. IT IS CALLED BY: TIMBETHET LAMBERT (AT LOCATION LAMENTER)

INPUT:

- 1) $VVEC_v = \gamma(t_1)$, THE INITIAL VELOCITY VECTOR, IN METERS/CSEC, SCALED AT $2^7/2^5$.
 - 2) $R1 = r(t_1)$, THE MAGNITUDE OF INITIAL POSITION VECTOR, IN METERS, SCALED AT $2^{10}/2^{27}$.
 - 3) $UR1_v = \hat{u}_{r1}$, A UNIT VECTOR IN DIRECTION OF INITIAL POSITION VECTOR $\epsilon(t_1)$, SCALED AT 2^5 .
 - 4) $X = x$, THE UNIVERSAL VARIABLE, SCALED AT $2^{11}/2^8$.
 - 5) $X1 = f = \mu/x^2$, SCALED AT 2^9 .
 - 6) $S(X1) = S(\hat{s})$, SCALED AT 2^7 .
 - 7) $XSQC(X1) = X^2 \cdot C(\hat{s})$, SCALED AT $2^{23}/2^{23}$.
 - 8) $1 = t_{21}$, THE TRANSFER TIME, SCALED AT 2^{18} .
 - 9) THE μ -TABLE APPROPRIATE FOR EITHER THE EARTH OR MOON.
- 10) PUSH LIST POINTER IS AT THE GENERAL VALUE PL IF ENTRY AT NEWSTATE, AT PL+6 IF ENTRY AT LAMENTER, WHERE 0 < PL < 80.

OUTPUT:

- 1) $\Phi D_v = \gamma(t_2)$, THE TERMINAL POSITION VECTOR, IN METERS, SCALED AT $2^{10}/2^{27}$.
- 2) $MPAC_v = \gamma(t_2)$, THE TERMINAL VELOCITY VECTOR, IN METERS/CSEC, SCALED AT $2^7/2^5$.
- 3) PUSH LIST POINTER AT PL+6 NORMALLY; AT PL IF ROUTINE WAS ENTERED BY LAMBERT AT LOCATION LAMENTER, WHERE PL IS THE ENTRY VALUE.



LAMENTER

THIS IS THE ENTRY POINT FROM THE LAMBERT ROUTINE, IN WHICH CASE $\epsilon(t_2)$ IS NOT CALCULATED IN THIS ROUTINE.

NORMALIZING VALUE IS $-N1$, STORED IN $X1$.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		POLLOID GUIDANCE AND NAVIGATION	
DRAWN BY <i>Raymond A.</i>		CONIC SUBROUTINES (NEWSTATE)	
PROGRAM	DATE	DOCUMENT NO.	
APPROVED BY <i>R. A. ...</i>	<i>...</i>	COLOSSUS II	FC2310
APPROVED BY <i>R. A. ...</i>	<i>...</i>	SHEET	35 OF 48

THE ITERATOR SUBROUTINE GENERATES BY LINEAR INTERPOLATION AN INCREMENT Δx IN THE INDEPENDENT VARIABLE x , THUS PROVIDING A NEW ESTIMATE OF x TO PRODUCE A VALUE OF THE DEPENDENT VALUE y CLOSER TO THE DESIRED VALUE y_{final} .

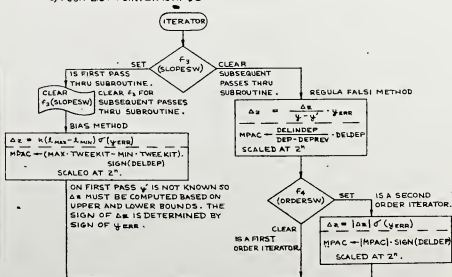
CALLED BY: LAMBERT, P10 AND P11.

INPUT:

- 1) ORDERSW = f_2 , A FLAG, IF CLEAR SUBROUTINE ACTS AS A FIRST ORDER ITERATOR, IF SET ACTS AS SECOND ORDER ITERATOR.
- 2) SLOPESW = f_3 , A FLAG, IF SET IS FIRST PASS THRU AND MUST USE BIAS METHOD TO CALCULATE Δx , IF CLEAR IS SUBSEQUENT PASS AND CAN USE THE REGULA FALSI METHOD TO CALCULATE Δx .
- 3) DEP = y , PRESENT VALUE OF DEPENDENT VARIABLE, AT 2".
- 4) DEPREV = y' , PREVIOUS VALUE OF y , AT 2".
- 5) DELDEP = $y_{final} - y$, ERROR IN y , EQUAL TO $y_{final} - y$, AT 2".
- 6) DELINDEP = Δx , INCREMENT IN INDEPENDENT VARIABLE THAT PRODUCED THE PREVIOUS INCREMENT $y - y'$, AT 2".
- 7) INDEP = x , PRESENT VALUE OF INDEPENDENT VARIABLE, AT 2".
- 8) TWEKIT = k , A FRACTION BETWEEN 0 AND 1, DETERMINES MAGNITUDE OF Δx ON FIRST PASS THROUGH SUBROUTINE, AT 2".
- 9) MAX = I_{MAX} , PREESTABLISHED UPPER BOUND ON x , AT 2".
- 10) MIN = I_{MIN} , PREESTABLISHED LOWER BOUND ON x , AT 2".
- 11) PUSH LIST POINTER MUST BE AT ΦD .

OUTPUT:

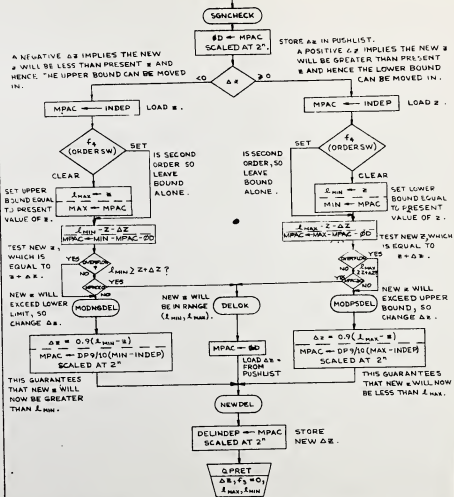
- 1) DELINDEP = $MPAC \cdot \Delta x$, A NEW INCREMENT IN x SUCH THAT THE NEW VALUE OF x , EQUAL TO $x + \Delta x$, WILL PRODUCE AN ERROR y_{ERR} OF SMALLER MAGNITUDE, AT 2".
- 2) SLOPESW = f_3 , A FLAG, IS CLEARED BY SUBROUTINE ON THE FIRST PASS FOR SUBSEQUENT PASSES.
- 3) MAX = I_{MAX} , IF f_4 IS CLEAR A NEW UPPER BOUND MAY BE ESTABLISHED BY THE SUBROUTINE, AT 2".
- 4) MIN = I_{MIN} , IF f_4 IS CLEAR A NEW LOWER BOUND MAY BE ESTABLISHED BY THE SUBROUTINE, AT 2".
- 5) PUSH LIST POINTER IS AT ΦD .



TO NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFOLIO OUTLINE AND NAVIGATION	
DRAWN <i>J. H. ...</i>		CONIC SUBROUTINES (ITERATOR)	
PROJ. <i>...</i>	SCALE <i>...</i>	CONTRACT NO. <i>...</i>	FORM NO. <i>...</i>
DOC. <i>...</i>	DATE <i>...</i>	CONTRACT NO. FC 2310	SHEET 36 OF 48
APPRO. <i>...</i>	DATE <i>...</i>		

FROM PRECEDING SHEET

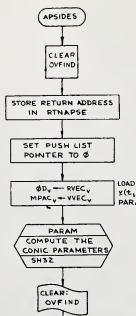


THE ITERATOR SUBROUTINE IS DESIGNED TO BE CALLED ONCE ON EACH PASS THROUGH A LOOP THAT IS ATTEMPTING TO CONVERGE ON A SOLUTION TO AN EQUATION OF THE FORM $y = y(z)$, WHERE A VALUE OF THE DEPENDENT VARIABLE y (CALLED y_{FINAL}) IS GIVEN AND THE PROGRAM IS SOLVING FOR THE CORRESPONDING VALUE OF THE INDEPENDENT VARIABLE z . EACH CALL TO THE ITERATOR GENERATES AN INCREMENT Δz WHICH IS A LINEAR APPROXIMATION ANSWER TO THE QUESTION: IF A CHANGE IN z EQUAL TO $\Delta z = z_i - z_{i-1}$ PRODUCED A CHANGE IN y EQUAL TO $y_i - y_{i-1}$, THEN WHAT CHANGE IN z WILL NOW PRODUCE A CHANGE IN y EQUAL TO $y_{FINAL} - y_i$? THIS NEW CHANGE IN z IS CALLED Δz_i AND THE VALUES y_i, y_{i-1} ARE THE PRESENT AND PREVIOUS VALUES OF y , RESPECTIVELY. THE RELATIONSHIP CAN BE EXPRESSED AS:

$$\frac{\Delta z_i - z_i}{y_i - y_{i-1}} = \frac{\Delta z_i}{y_{FINAL} - y_i} \quad \text{OR AS} \quad \Delta z_i = \frac{\Delta z_{i-1}}{y_i - y_{i-1}} \cdot (y_{FINAL} - y_i)$$

HENCE ADDING Δz_i TO z_i SHOULD NULL OUT THE ERROR BETWEEN y_{FINAL} AND y_i , IMPLYING THAT $z_{i+1} = z_i + \Delta z_i$ IS THE SOLUTION TO THE EQUATION. A NECESSARY CONDITION FOR CONVERGENCE IS THAT y MUST BE MONOTONICALLY INCREASING (OR DECREASING) THROUGHOUT THE RANGE (z_{MIN}, z_{MAX}) OF THE INDEPENDENT VARIABLE. REFER TO REFERENCE 7.

REV	APOLLO
DESCRIPTION LAB.	CHANGE AND NAVIGATION
COMMENTS	
SONIC SUBROUTINE (ITERATOR)	
FORMER: <i>J. D. ...</i>	FORMER NO.
PREP: <i>J. D. ...</i>	APPROVED BY: <i>J. D. ...</i>
DATE: <i>10/1/68</i>	FC 2310
APP: <i>J. D. ...</i>	SHEET 27 OF 42



THIS ROUTINE CALCULATES THE RADIUS OF PERICENTER,
RADIUS OF APOCENTER AND ECCENTRICITY OF A
GIVEN CONIC.

CALLED BY: PERIAPD
INPUT:

- 1) $r_{VEC} = r(t_1)$, THE INITIAL POSITION VECTOR, IN METERS, AT $2^{19} / 2^{17}$.
- 2) $v_{VEC} = v(t_1)$, THE INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7 / 2^5$.
- 3) $X1 =$ INDEX VALUE USED TO SET UP THE PROPER μ -TABLE; IS -2 IF EARTH IS CENTRAL BODY; IS -10D IF MOON IS CENTRAL BODY.

OUTPUT:

- 1) $\phi D = r_p$, THE RADIUS OF PERICENTER, IN METERS, AT $2^{11} / 2^{17}$.
- 2) $MPAC = r_a$, THE RADIUS OF APOCENTER, IN METERS AT $2^{11} / 2^{17}$.
- 3) $ECC = e$, THE ECCENTRICITY OF CONIC TRAJECTORY, AT 2^9 .
- 4) PUSH LIST POINTER AT ϕD .

PARAM INPUT:

- 1) $\phi D_v = r(t_1)$
- 2) $MPAC_v = v(t_1)$
- 3) $X1 = -2$ FOR EARTH,
-10D FOR MOON

PARAM OUTPUT:

- 1) $RIA = \alpha_n$
- 2) $P = MPAC = p_n$
- 3) $COGA = \cot \gamma$
- 4) $R1 = r(t_1)$
- 5) μ -TABLE

p_n AND α_n ARE
NORMALIZED VALUES.

OVERFLOW OCCURS IF TRAJECTORY IS
HIGHLY ELLIPTIC, PARABOLIC, OR
SLIGHTLY HYPERBOLIC.

A NEGATIVE VALUE IMPLIES TRAJECTORY
IS HYPERBOLIC.

SET RADIUS OF APOCENTER EQUAL TO r_{MAX} , THE
LARGEST VALUE POSSIBLE;
WHERE $r_{MAX} = \begin{cases} 2^{11} - 2 & \text{FOR THE EARTH.} \\ 2^{11} - 5 & \text{FOR THE MOON.} \end{cases}$

NO INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED MECHANICS AND NAVIGATION	
DESIGNED BY: <i>[Signature]</i>		CONIC SUBROUTINES (APSIDES)	
PHASE: <i>[Signature]</i>	DATE: <i>[Signature]</i>	COLONEL: <i>[Signature]</i>	ACQUISITION NO. FC 8310
ANALYST: <i>[Signature]</i>	DATE: <i>[Signature]</i>	APPROVED BY: <i>[Signature]</i>	SHEET 28 OF 48

GENERAL INFORMATION FOR CONICS

SUBROUTINES CALLED ON OTHER CHARTS

NAME	DESCRIPTION	CALLED BY
PMY	EVALUATE A POLYNOMIAL OF SPECIFIED DEGREE	DELTIME, GETX
TPMODE	SET MODE TO TRIPLE SPECION	DELTIME

FLAGS USED

NAME	MEANING		WHERE SET	WHERE CLEARED	WHERE TESTED
	SET	CLEAR			
COENSW (1)	INITIAL GUESS OF eot ? NOT AVAILABLE	INITIAL GUESS OF eot - IS AVAILABLE	INITVEL	INITVEL	LAMBHT
NOHMSW (1)	θ_N IS INPUT TO LAMBERT	θ_N IS COMPUTED BY LAMBERT	INITVEL	PARAM, INITVEL	GEOM, 540.1, 540.7
CALLPFSW (1)	INITIAL CALL TO ITERATOR	SUBSEQUENT CALL TO ITERATOR	LAMBERT, P10	ITERATOR	ITERATOR
ORDERSW (1)	SECOND ORDER ITERATION	FIRST ORDER ITERATION	(NO WHERE)	P10	ITERATOR (1)
SOLNSW (1)	NO SOLN POSSIBLE	SOLN VALID	LAMBERT (2)	LAMBERT, TIMERAD	(NO WHERE)
RVSW (1)	DO NOT COMPUTE NEW STATE VECTOR	COMPUTE NEW STATE VECTOR	P29, P34, CS/A (2)	CDHMVR	TIMETHET
INFINFLG (1)	CONIC PASSES THRU INFINITY	CONIC SOLN EXISTS	GETX	GETX	LAMBERT, TIMETHET
APSW (1)	POSITION VECTOR OUTSIDE RANGE (PERICENTER, APOCENTER)	POSITION VECTOR WITHIN RANGE (PERICENTER, APOCENTER)	TIMERAD	TIMERAD	(NO WHERE)
TRNSW (1)	TRANSFER ANGLE NEAR 360°	TRANSFER ANGLE NOT NEAR 360°	GETX	GETX	GETX
COGAFLAG (1)	NO SOLN EXISTS, TOO CLOSE TO RECTILINEAR	SOLN EXISTS	TIMETHET	TIMETHET, PARAM	(NO WHERE)
VTARGETAG (1)	$\gamma(t_2)$ NOT CALCULATED	$\gamma(t_2)$ IS CALCULATED	INITVEL	INITVEL	LAMBERT, INITVEL (2)
GEOM-ON (1)	IS MINUS IF TRANSFER ANGLE $> 180^\circ$	IS PLUS IF TRANSFER ANGLE $\leq 180^\circ$	INITVEL	INITVEL, PARAM	LAMBERT, GEOM (3)
SGNRDOT (1)	IS MINUS IF RADIAL VELOCITY NEGATIVE	IS PLUS IF RADIAL VELOCITY POSITIVE	(NO WHERE)	(NO WHERE)	TIMERAD

VARIABLES USED (BOTH PUSH LIST AND ERA-SABLE)

NAME	MEANING	SCALING	LOCATION
ALPHA	RECIPROCAL OF SEMI-MAJOR AXIS	$2^{-22}/2^{-20}$	8D
MDN	LOWER BOUND ON x	2^0	8D
COGAMIN	LOWER BOUND ON eot	2^5	8D
XMAX	MAXIMUM VALUE OF x	$2^{17}/2^{16}$	10D
XMIN	MINIMUM VALUE OF x	$2^{17}/2^{16}$	12D
DELINDEP	Δx	2^0	12D
DCOGA	Δeot	2^5	12D
MAX	UPPER BOUND ON x	2^0	14 D
COGAMAX	UPPER BOUND ON eot	2^5	14D
1/MU	$1/\mu$	$2^{-34}/2^{-28}$	14D
ROOTMU	$\sqrt{\mu}$	$2^{38}/2^{15}$	16D

MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.APOLLO
GUIDANCE AND NAVIGATION

CONIC SUBROUTINES

DRAWN *J. Brown* 2/24/68
 PROGRAM ANALYSIS *J. Brown, P. J. Brown* 2/24/68
 ROOM *2-2-68*
 APPROVED *J. Brown* 2/24/68

CDLOGS/SAIS
 207A

DOCUMENT NO.
 FC-2310

SHEET 39 OF 42

VARIABLES USED (BOTH PUSH LIST AND ERASABLE) (CONT.)

NAME	MEANING	SCALING	LOCATION
RTNTR ₀	RETURN ADDRESS FROM TIMERAD		E5, 1710
RTNADR ₀	RETURN ADDRESS FROM APSIDES		E5, 1710
\hat{r}_2	UNIT VECTOR	2^1	E5, 1714
MAGVEC 2	VECTOR MAGNITUDE, METERS/CSEC	$2^7/2^5$	E5, 1717
R2	NORMALIZED VECTOR MAGNITUDE, METERS/CSEC	$2^{29-m}/2^{27-m}$	E5, 1717
U1 ₁	UNIT VECTOR	2^1	E5, 1721
SIN ϕ	$\sin(\phi)$	2^1	E5, 1727
COS ϕ	$\cos(\phi)$	2^1	E5, 1741
1-COS ϕ	$1 - \cos(\phi)$	2^2	E5, 1733
COS $\theta - \lambda$	$\cos(\theta) - \lambda$	2^7	E5, 1745
P	$P_N = \rho^2 r_1$	2^4	E5, 1747
R1A	$\rho_N = r_1/10$	2^6	E5, 1741
VVFC _v	VELOCITY VECTOR, METERS/CSEC	$2^7/2^3$	E5, 1744
ECC	ECCENTRICITY	2^3	E5, 1751
RTNPRM ₀	RETURN ADDRESS FROM PARAM		E5, 1753
SCNRD0T ₀	$\#_2$, SIGN OF RADIAL VELOCITY	2^0	E5, 1754
RDSIRE	RADIAL DISTANCE, METERS	$2^{29}/2^{27}$	E5, 1755
DELDEP	γ ERR	2^{01}	E5, 1757
TERRLAMB	CONVERGENCE CRITERION, CSEC	2^{28}	E5, 1757
DEPREV	PREVIOUS VALUE OF γ	2^{03}	E5, 1761
TPREV	PREVIOUS TIME, CSEC	2^{28}	E5, 1761
EPSILON1	CONVERGENCE CRITERION, CSEC	2^{28}	E5, 1763
COGA	$\cot \gamma$	2^3	E5, 1765
INDEP	λ	2^0	E5, 1765

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		CONIC SUBROUTINES	
DESIGN			
PROGRAM			
ANALYST	<i>John A. Pollock</i>	COLLOSSUS 300A	DOCUMENT NO. FC-2310
DOCS	<i>John A. Pollock</i>	FILED	
APPROV	<i>John A. Pollock</i>	IS-801-1071	SHEET 48 OF 48

CONSTANTS USED

NAME	PHYSICAL MEANING	SCALING	COMPUTER VALUE
D1 1	1.0	2^2	1.0 B-2
D1 2	1.0	2^3	1.0 B-3
D1 10	1.0	2^4	1.0 B-4
D1 32	2.0	2^6	1.0 B-5
D1 64	1.0	2^6	1.0 B-6
D1 128	1.0	2^7	1.0 B-7
D1 256	1.0	2^8	1.0 B-8
D1 1024	1.0	2^{10}	1.0 B-10
DPI 4	1.0	2^2	1.0 B-2
REE19	$c_t = 2^{-19}$	2^0	000000100 _B
BEE22	$c_t = 2^{-22}$	2^0	000000100 _B
ONEBIT	2^{-28}	2^0	1.0 B-28
2PASC	2 π	2^6	6.28318530 B-6
-30SC	-50.0	2^{12}	-50.0 B-12
DP9.10	0.9	2^0	0.9 B0
COGUPM	$\cos \gamma_{\max} = 31.9843711$	2^5	0.999511597 B0
COGL0M	$\cos \gamma_{\min} = -31.9843711$	2^5	-0.999511597 B0
MUTABLE +2	$1/\mu$	2^{-34}	0.25087606 $\times 10^{-10}$ B34
MUTABLE +4	$\sqrt{\mu_E}$	2^{16}	1.4650405×10^5 B-18
MUTABLE +6	$1/\sqrt{\mu_E}$	2^{-17}	0.50087529 $\times 10^{-5}$ B17
MUTABLE +10D	$1/\mu_M$	2^{-28}	0.203966 $\times 10^{-8}$ B28
MUTABLE +12D	$\sqrt{\mu_M}$	2^{15}	2.21422176 $\times 10^4$ B-15
MUTABLE +14D	$1/\sqrt{\mu_M}$	2^{-14}	0.45162595 $\times 10^{-4}$ B14
BEE17	$k_1 = 2^{-17}$	2^0	000000400 _B

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Hanson</i>		CONIC SUBROUTINES	
PROGRAM	ANALYST <i>J. Hanson</i>	DOCUMENT NO.	FC - 2310
DOCS	APPROVED <i>J. Hanson</i>	SHEET 92 OF 94	

DAP INTERFACE AND SERVICE ROUTINES

THE ENCLOSED SHEETS UPDATE THE COLOSSUS II
FLOWCHART FC-2370, REV. 0, TO THE COLOSSUS IIA
FLOWCHART FC-2370, REV. 1.

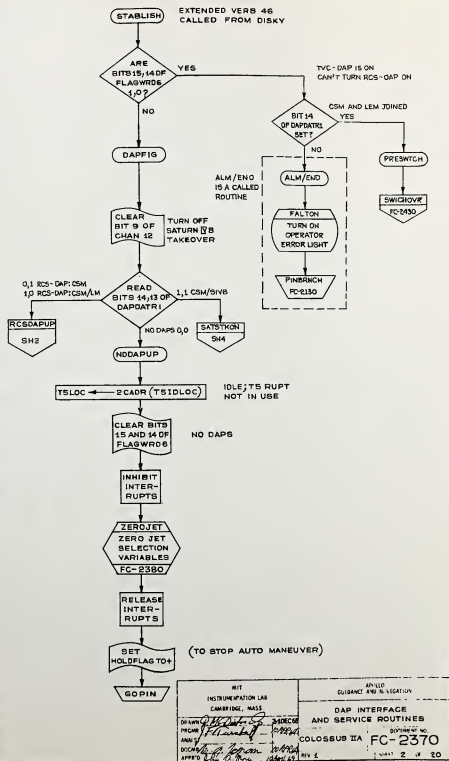
IN ADDITION, THE SHEETS HAVE BEEN RENUMBERED
TO INCLUDE A TITLE SHEET.

EFFECTIVE SHEETS FOR COLOSSUS IIA FC-2370,
REV. 1 ARE:

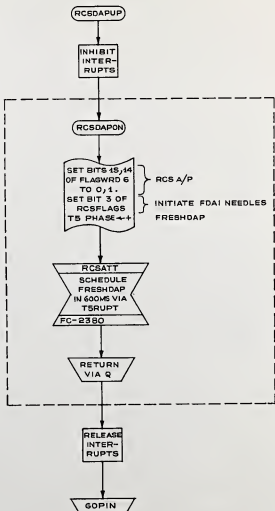
SH. 1	REV. 1
SH. 2-4	REV. 0
SH. 5	REV. 1
SH. 6-7	REV. 0
SH. 8	REV. 1
SH. 9-20	REV. 0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		DAP INTERFACE AND SERVICE ROUTINE	
DRAWN <i>J. A. Hill</i>	<i>1/6/68</i>	COLLOSSUS II-A	DOCUMENT NO. FG-2370
PROGRAM <i>J. A. Hill</i>	<i>2/1/68</i>		
ANALYST			
DOXAR <i>J. A. Hill</i>	<i>2/1/68</i>		
APPROV. <i>J. A. Hill</i>	<i>2/1/68</i>	REV. 1	SHEET 1 OF 20

EXTENDED VERB 46: RCS DAP TURN-ON



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS DEVEL'D BY: <i>[Signature]</i> PRGMR: <i>[Signature]</i> ANAL: <i>[Signature]</i> DOCUM: <i>[Signature]</i> APP'D: <i>[Signature]</i>	APPLIED GUIDANCE AND NAVIGATION DAP INTERFACE AND SERVICE ROUTINES COLLOSSUS IIA FC-2370 REV 1 2 OF 20
--	---



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J.M. [unclear]</i>		DAP INTERFACE AND SERVICE ROUTINES	
FROM <i>R.L. [unclear]</i>		DOCUMENT NO.	
ANALY <i>[unclear]</i>		COLOSSUS IIA FC-2370	
CHECKED <i>[unclear]</i>		REV 1	
APPROVED <i>[unclear]</i>		REV 3 14 20	

SATSTKON

INHIBIT
INTER-
RUPTS

REDSAT
SCHEDULE
SATURN -
DAP TURN-
ON IN 10MS
FC-2540

DONE VIA
TSRUPT

SET
BITS 14,15 OF
FLAGWRD 6

ENABLE SATURN
CONTROL OF DAP

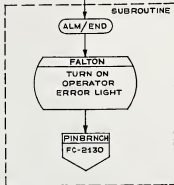
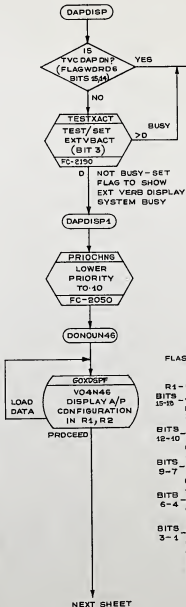
ZEROJET
ZERO JET
SELECTION
VARIABLES
FC-2380

RELEASE
INTER-
RUPTS

GOPIN

MIT		APPLIC	
INTELLIGENCE LAB		GUIDANCE AND NAVIGATION	
CAMER-DEF. MASS.		DAP INTERFACE AND SERVICE ROUTINES	
DESIGN <i>[Signature]</i>	DESIGNED <i>[Signature]</i>	COLOSSUS IIA	
PROGRAM <i>[Signature]</i>	PROGRAM <i>[Signature]</i>	FC-2370	
ANALYSIS <i>[Signature]</i>	ANALYSIS <i>[Signature]</i>	REV 3	
APPROVED <i>[Signature]</i>	APPROVED <i>[Signature]</i>	REV 4	

VERB 4B LOAD AUTO PILOT DATA



FLASHING VD4 N46 - REQUEST RESPDNSE
AUTO PILOT CONFIGURATION (OCTAL CODE)

R1 - DAPDATR1	R2 - DAPDATR2
BITS 15-10 - VEHICLE CONFIGURATION	BITS 15-10 - QUAD AC ROLL
0 - C/M	1 - CSM/LM
1 - CSM	3 - CSM/SUBV
0 - CSM/LM (ASCENT)	0 - FAIL QUAD AC (I.E. USE BD)
1 - USE QUAD AC	1 - USE QUAD AC
BITS 9-7 - XTRANS CODE QUAD AC	BITS 9-7 - QUAD A
0 - FAIL QUAD AC X-TRANSLATION	0 - FAIL QUAD A
1 - USE QUAD AC	1 - USE QUAD A
BITS 9-7 - XTRANS CODE QUAD BD	BITS 9-7 - QUAD B
0 - FAIL QUAD BD X-TRANSLATION	0 - FAIL QUAD B
1 - USE QUAD BD	1 - USE QUAD B
BITS 6-4 - DEADBAND	BITS 6-4 - QUAD C
0 - ± 0.5 DEG	0 - FAIL QUAD C
1 - ± 5 DEG	1 - USE QUAD C
BITS 3-1 - MANEUVER RATE	BITS 3-1 - QUAD D
0 - 0.05 DEG/SEC	0 - FAIL QUAD D
1 - 0.2 DEG/SEC	1 - USE QUAD D
2 - 0.5 DEG/SEC	
3 - 2 DEG/SEC	

MI1
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DESIGN: *[Signature]*
PROGRAM: *[Signature]*
ANALYSIS: *[Signature]*
DOCUMENTATION: *[Signature]*
APPROVED: *[Signature]*

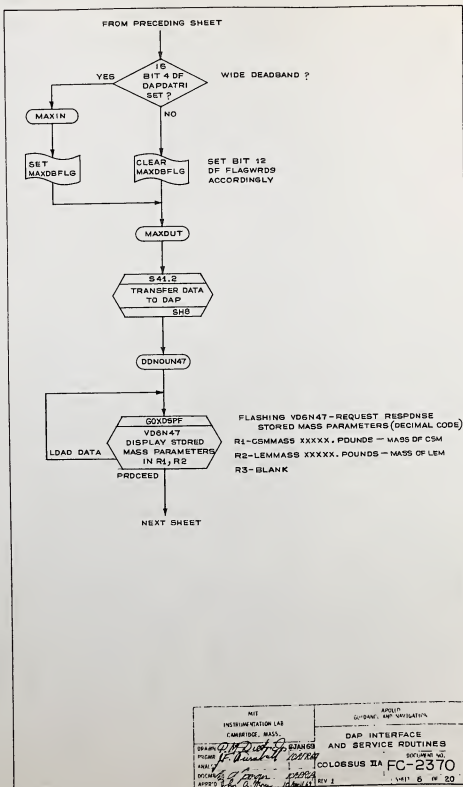
MI100
G-12, 14, AND 15, 17, 19

DAP INTERFACE
AND SERVICE ROUTINES

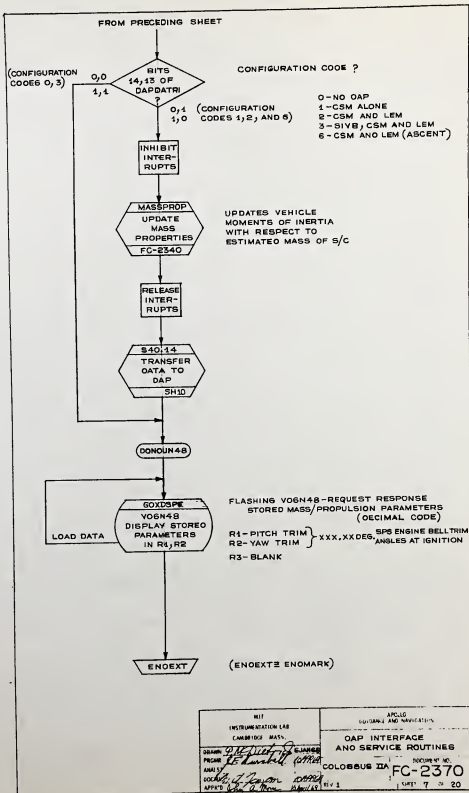
COLOSSUS IIA FC-2370

REV 1

FC-2370



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ADULT DESIGN, EMP. VERIFICATION
DESIGN: <i>D. J. ...</i> REVISIONS	DAP INTERFACE AND SERVICE ROUTINES
DRAWN: <i>W. ...</i> DATE: <i>10/18/61</i>	DOCUMENT NO. COLOGUSUS II
DOCUMENT: <i>...</i> APPROVED: <i>...</i>	SERIALS NO. FC-2370
REV 1	MAR 6 1962



541.2, 540.14 AND 540.15-DECODE DAP DATA NOUNS

541.2
 RATEINDEX ← 2 (BITS
 2, 1 OF DAPDATRI)

VALUES AFTER DOUBLING:
 0 → 0.05°/SEC
 2 → 0.2°/SEC
 4 → 0.5°/SEC
 6 → 2.0°/SEC

INHIBIT
 INTER-
 RUPTS

AN INTERRUPT OCCURRING WHILE A BIT IS BEING SET
 COULD ALTER THE FLAGWORD, AND THIS ALTERATION
 WOULD BE LOST SO MUST NOT ALLOW INTERRUPT

ARE
 BITS 14,13
 OF DAPDATRI
 = 1,0?

IS LEM ATTACHED?
 YES

TOGETHER

CLEAR BIT 2
 OF FLAGWRD

SET BIT 2
 OF FLAGWRD

RELEASE
 INTER-
 RUPTS

IS
 BIT 4
 OF DAPDATRI
 CLEARED?

YES, NARROW DEADBAND

NO, WIDE
 DEADBAND

ADB ← 5.0°

ADB ← 0.5°

ACX

1,0

0,1

BDX

XTRANS ← -1

AC
 B'D
 0,0
 1,1
 XTRANS ← +0

XTRANS ← +1

+1 → USE BD QUAD FOR X TRANSLATIONS
 -1 → USE AC QUAD FOR X TRANSLATIONS
 0 → USE BOTH QUADS FOR X TRANSLATIONS

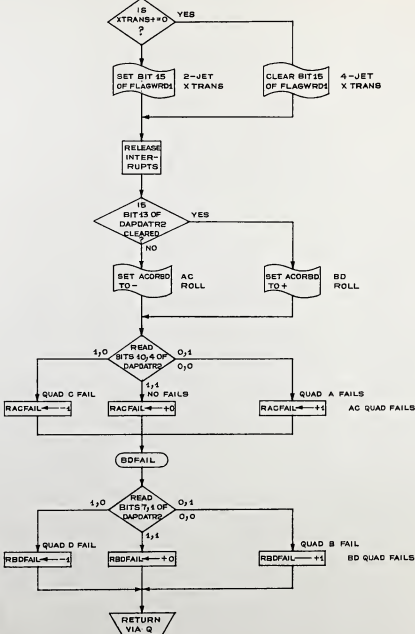
INHIBIT
 INTER-
 RUPTS

NEXT SHEET

MIT
 INSTRUMENTATION LAB
 CAMBRIDGE, MASS
 DESIGNER: *[Signature]*
 DRAWN: *[Signature]*
 ANALYST: *[Signature]*
 APPROVED: *[Signature]*
 DATE: 12/10/61

APPROVED
 GLENDEN AND WARRINGTON
 DAP INTERFACE
 AND SERVICE ROUTINES
 COLOSSUS IIA
 FC-2370
 SHEET 8 OF 20

FROM PRECEDING SHEET



NET INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFPOD CHARTER AND NAVIGATION	
DRAWN: <i>[Signature]</i> CHECKED: <i>[Signature]</i> DESIGNED: <i>[Signature]</i> APPROVED: <i>[Signature]</i>		DAP INTERFACE AND SERVICE ROUTINES	
ANALYST: <i>[Signature]</i> DATE: <i>[Date]</i> REV 1		DOCUMENT NO. COLOSSUS IIA FC-2370 SHEET 3 OF 20	

S40.14

J/M ← IXX (.662034)
J/M1 ← IAVG (.662034)
J/M2 ← IAVG (.662034)
KMJ ← .00418 / IXX
KMJ1 ← .00418 / IAVG
KMJ2 ← .00418 / IAVG

S/C INERTIA TO TORQUE RATIO-X AXIS
S/C INERTIA TO TORQUE RATIO-Y AXIS
S/C INERTIA TO TORQUE RATIO-Z AXIS
S/C TORQUE TO INERTIA RATIO-X AXIS
S/C TORQUE TO INERTIA RATIO-Y AXIS
S/C TORQUE TO INERTIA RATIO-Z AXIS

RETURN
VIA Q

MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

4P01U
SUBROUTINE AND SIMULATION

DAP INTERFACE
AND SERVICE ROUTINES

DRAWN *[Signature]*
DESIGNED *[Signature]*
ANALYST
APPROVED *[Signature]*

COLOSSUS IIA FC-2370

REV 10 0 20

EXTENDED VERB 59 - ENABLE AUTOMATIC MANEUVERS

ENATMA

EXTENDED VERB 59 - RESET STIKFLAG
(ENABLE AUTOMATIC MANEUVERS)

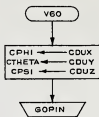
CLEAR
STIKFLAG

RESET FLAG SO THAT R61 MAY PERFORM
AUTOMATIC TRACKING MANEUVERS
AFTER INTERRUPT BY RHC ACTIVITY
(STIKFLAG = FLAGWRD 1 BIT 14)

GOPIN

BIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		DAP INTERFACE AND SERVICE ROUTINES	
PROGRAM <i>[Signature]</i>		REV 1	
FAMILY <i>[Signature]</i>		COLOSSUS IIA	
CHECKED <i>[Signature]</i>		FC-2370	
APPROVED <i>[Signature]</i>		SHEET 11 OF 20	

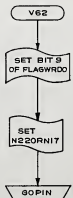
EXTENDED VERBS 60-63 DAP ERROR DISPLAY CONFIGURATION



EXTENDED VERB 60 - SET ERROR NEEDLE
REFERENCE ANGLES TO CURRENT CDU READINGS



EXTENDED VERB 61 - CLEAR NEEDLE FLG
FOR DISPLAY OF A/P FOLLOWING ERROR
(DISPLAY MODE 1)



EXTENDED VERB 62 - SET NEEDLE FLG
FOR DISPLAY OF TOTAL ATTITUDE ERROR
(DISPLAY MODE 2)

SET BIT 6 OF
FLAGWRDD (DISPLAY MODE 2)

MAIL INSTRUMENTATION LAB CAMBRIDGE, MASS.	REC'D COMBANG AND REFLAT-105
DESIGNED BY <i>D. J. ...</i>	DAP INTERFACE AND SERVICE ROUTINES
DRAWN BY <i>J. ...</i>	COLOSSUS IIA FC-2370
ANALYSED BY <i>J. ...</i>	REV 5
APPROVED BY <i>J. ...</i>	DATE: 12 17 70

V63

EXTENDED VERB 63 - CLEAR NEEDLE FLG
FOR DISPLAY OF TOTAL ALTITUDE ERROR
(DISPLAY MODE 3)

SET
BIT 9 OF
FLAGWRDD

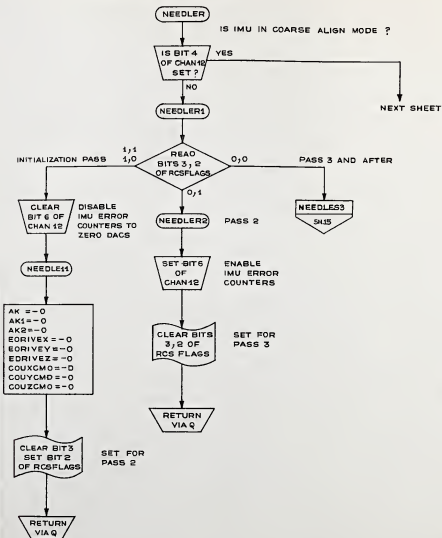
CLEAR
NBBORNIT

CLEAR BIT 6
OF FLAGWRD 9
(DISPLAY MODE 3)

GO PIN

MII INSTRUMENTATION LAB CAMBRIDGE, MASS.	AFGLD GUIDANCE AND NAVIGATION
DRAWN <i>[Signature]</i> CHECKED <i>[Signature]</i> ANALYST <i>[Signature]</i> ROOM <i>[Signature]</i> APPROV <i>[Signature]</i>	DAP INTERFACE AND SERVICE ROUTINES DOCUMENT NO. COLOSSUS IIA FC-2370 REV 1 SHEET 13 OF 20

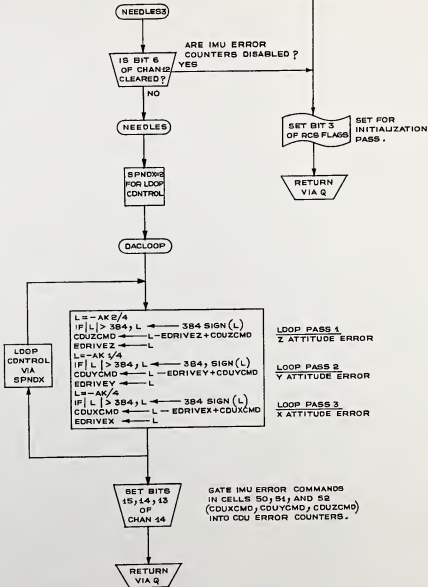
FDA! NEEDLE DRIVE ROUTINE



FBI INVESTIGATION LAB CHESTER, MASS.	ANALY ELEMENT AND MATERIALS DAP INTERFACE AND SERVICE ROUTINES NO. REC. NO. COLUSSUS IIA FC-2370 DIV 5 104 14 20
--	---

MARKED BY: *[Signature]*
 CHECKED BY: *[Signature]*
 DATE: *[Date]*
 APPROVED BY: *[Signature]*

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIC GUIDANCE AND NAVIGATION
DRAWN: <i>[Signature]</i> PROGRAM: <i>[Signature]</i> ANALYSIS: <i>[Signature]</i> CHECKED BY: <i>[Signature]</i> APPROVED BY: <i>[Signature]</i>	DASP INTERFACE AND SERVICE ROUTINES DOCUMENT NO. FC-2370 REVISION 15 OF 20

RCS - DAP SUBROUTINES

STICKCHK

DMANNDX ← COMPL.(BITS 2-1 OF A)
 YMANNDX ← COMPL.(BITS 4-3 OF A)
 RMANNDX ← COMPL.(BITS 6-5 OF A)

RETURN
 VIA Q

DECODE STICK COMMANDS

(A CONTAINS CONTENTS OF CHAN 31, OR CHAN 32)

PITCH } 0 → NO ROTATION
 YAW } 1 → + ROTATION
 ROLL } 2 → - ROTATION
 (3 → NO ROTATION)

SETMAXDB

SET MAXIMUM DEADBAND

ADB ← 5.0°

WIDE DEADBAND

SET BIT 4
 OF DAPDATR1

RETURN
 VIA Q

SETMINDB

SET MINIMUM DEADBAND

THETADX ← COU1
 THETADY ← COU2
 THETAZ ← COU3

ZERO ATTITUDE ERRORS TO
 SAVE PROPELLANT ON SWITCHOVER
 TO NARROW DEADBAND

ADB ← 0.5°

NARROW DEADBAND

CLEAR BIT 4
 OF DAPDATR1

RETURN
 VIA Q

DATE	APPROVED	BY	REV.
DESIGNED BY	DESIGNED BY	DESIGNED BY	DESIGNED BY
DRAWN BY	DRAWN BY	DRAWN BY	DRAWN BY
CHECKED BY	CHECKED BY	CHECKED BY	CHECKED BY
APPROVED BY	APPROVED BY	APPROVED BY	APPROVED BY

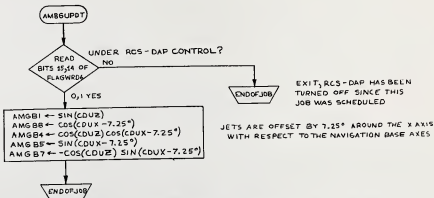
INSTRUMENTATION LAB
 CAMBRIDGE, MASS

DAP INTERFACE
 AND SERVICE ROUTINES

COLOSSUS IIA FC-2370

REV. 16

MATRIX UPDATE SUBROUTINE



EXIT, RCS-DAP HAS BEEN
TURNED OFF SINCE THIS
JOB WAS SCHEDULED

JETS ARE OFFSET BY 7.25° AROUND THE X AXIS
WITH RESPECT TO THE NAVIGATION BASE AXES

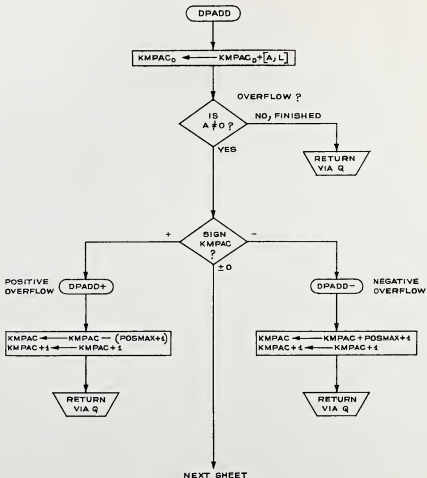
TRANSFORMATION MATRIX: GIMBAL ANGLE DIFFERENCES
TO BODY ANGLE DIFFERENCES

$$\begin{pmatrix} 1 & \sin(\text{CDUX}) & 0 \\ 0 & \cos(\text{CDUX}) \cos(\text{CDUX}-7.25) & \sin(\text{CDUX}-7.25) \\ 0 & -\cos(\text{CDUX}) \sin(\text{CDUX}-7.25) & \cos(\text{CDUX}-7.25) \end{pmatrix}$$

$$MGB = \begin{pmatrix} 1 & \sin \psi & 0 \\ 0 & \cos \psi \cos \phi & \sin \phi \\ 0 & -\cos \psi \sin \phi & \cos \phi \end{pmatrix}$$

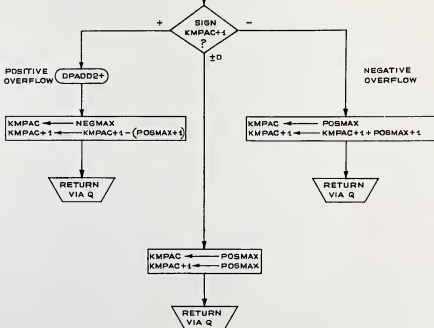
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	DEPT. OF PHYSICS AND ASTRONOMY HARVARD UNIVERSITY CAMBRIDGE, MASS.
DESIGN: <i>[Signature]</i> PROGRAM: <i>[Signature]</i> AREA: <i>[Signature]</i> DOCUMENT: <i>[Signature]</i> APPROVED: <i>[Signature]</i>	DAP INTERFACE AND SERVICE ROUTINES COLOSSUS IIA FC-2370 REV 1

MYSUBB ARITHMETIC SUBROUTINES



MIT INSTRUMENTATION LAB LAMAR EDE. MASS.	APPLIED CALCULUS AND NAVIGATION DAP INTERFACE AND SERVICE ROUTINES
DRAWN <i>DM</i> FROM <i>15 Dec 60</i> ANALY <i>12/19/60</i> DESIGNED <i>12/19/60</i> APPROVED <i>12/19/60</i>	PROJECT NO. FC-2370 REV 1 148 10 20

FROM PRECEDING SHEET



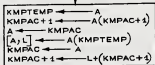
THE REAL VALUE OF THE ANGLE STORED IN KMPAC LIES ALWAYS BETWEEN $\pm 360^\circ$. THE STORAGE CAPACITY OF KMPAC, HOWEVER, IS BETWEEN $\pm 180^\circ$. IF POSITIVE OVERFLOW, THE REAL VALUE LIES BETWEEN $+180^\circ$ AND $+360^\circ$, WHILE THE STORED VALUE IS 180° SMALLER. HOWEVER, BY SUBTRACTING 180° ($POSMAX+1$) FROM THIS STORED VALUE, IT BECOMES EQUIVALENT TO THE REAL VALUE (AS $9-360^\circ = -9$) AND 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° ($= -180^\circ$) AND THE CLOSEST APPROXIMATION IS DOUBLE PRECISION POSMAX.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED ELECTRICAL AND MECHANICAL	
DRAWN <i>P. M. Dwyer</i>		DESIGNED <i>W. R. ...</i>	
CHECKED <i>W. R. ...</i>		DATE <i>...</i>	
APPROVED <i>John Wilson</i>		REV 1	
COLLOSSUS IIA		FC-2370	
		MAY 19 3 20	

SMALLMP

DOUBLE PRECISION PRODUCT
OF $KMPAC_0$ AND A_j ;
RESULTS IN $KMPAC_0$.

CALCULATION : $A(X+Y)$



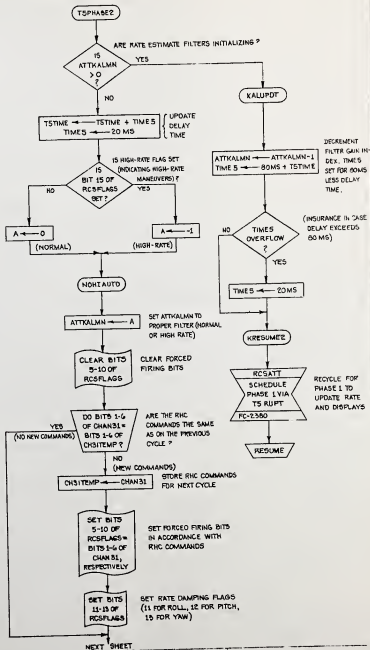
$A \cdot Y$ (S.P., LOW ORDER HALF LOST)

$A \cdot X$ (D.P.,
HIGH HALF } $AX + AY$
LOW HALF }

RETURN
VIA Q

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APR 65 GUIDANCE AND NAVIGATION DAP INTERFACE AND SERVICE ROUTINES
DESIGNED BY <i>D. H. ...</i> PROGRAM <i>COLOSSUS II</i> ANALY <i>D. H. ...</i> CHECKED <i>J. P. ...</i> APPROVED <i>J. P. ...</i>	DOCUMENT NO. COLOSSUS II FC-2370 REV 2

RCS-DAP PHASE 2



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN A.C. WILLIAMS 15 JUN 68
 CHECKED *[Signature]* 16 JUN 68
 ANALYST *[Signature]*
 DESIGNED *[Signature]* 15 JUN 68
 APPROVED *[Signature]* 16 JUN 68

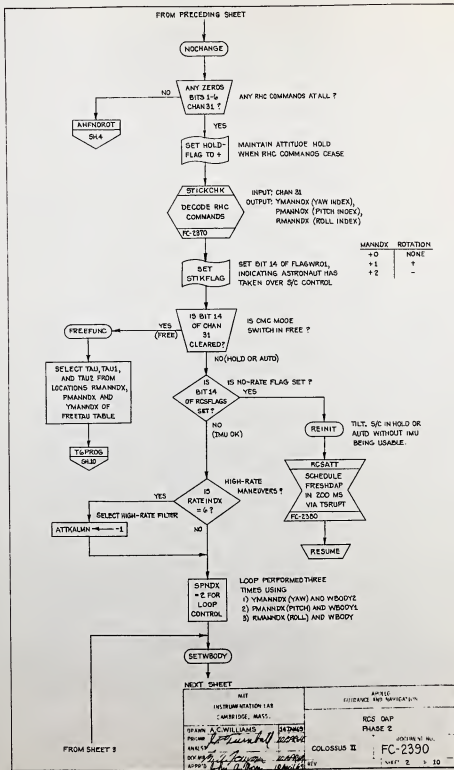
ARLDD
C. BRANCE AND NAVIGATIONAL

RCS DAP
PHASE 2

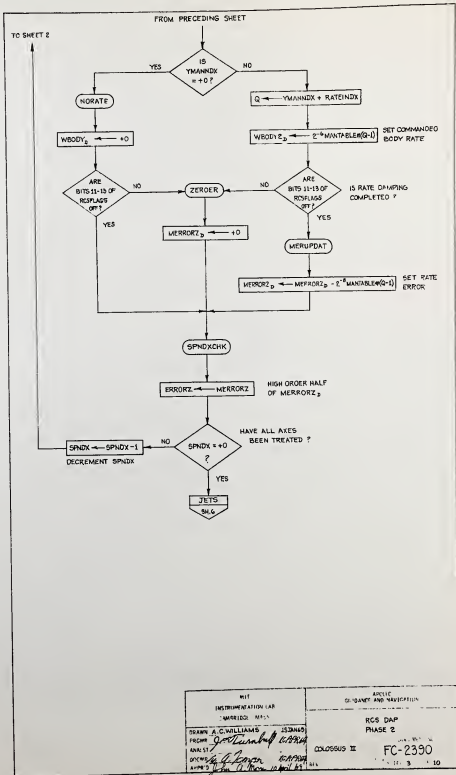
FC-2390

COLLOSSUS II

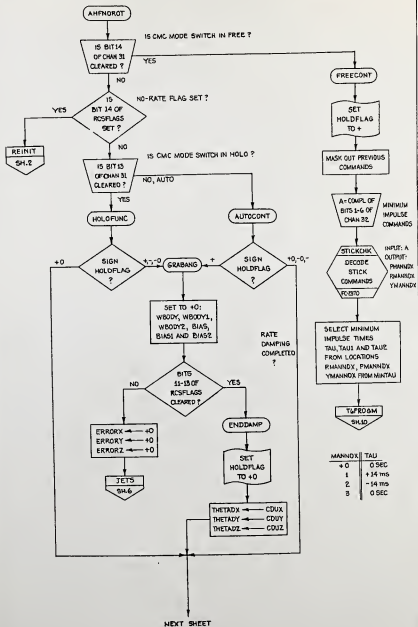
REV 10



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED ELECTRICAL AND MECHANICAL	
DESIGNED BY SPAWN A. WILLIAMS		RCS OAP PHASE 2	
PROJECT PROJECT <i>Colossus II</i>		JOHN W. HILL	
ANALYST BY <i>John A. Hill</i>		FC-2390	
APPROVED BY <i>John A. Hill</i>		COLLOSSUS II	
REV		SHEET 2 OF 30	



MIT INSTRUMENTATION LAB		ARCIC G. QUANEY AND NADEAU	
PROJECT: M-1		RCS DAP PHASE 2	
DRAWN: A. C. WILLIAMS	DESIGNED: [Signature]	COLLOSSUS II	
FROM: [Signature]	DATE: [Signature]	FC-2390	
ANALYST: [Signature]	APP'D: [Signature]	APR 10 1963	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARJLO GUIDANCE AND NAVIGATION	
SPAN: A. C. WILLIAMS PROGRAM: <i>Jet control</i> ANALYST: <i>J. J. ...</i> DESIGNER: <i>J. J. ...</i> APPROVER: <i>J. J. ...</i>		RCS DAP PHASE 2 COLLOSSUS II FC-2390 SHEET 4 of 10	

FROM PRECEDING SHEET

ATTHOLD

$ERRORX \leftarrow (CDUX - THETAIX) + AMGB1(CDUY - THETAY)$
 $ERRORY \leftarrow AMGB4(CDUY - THETAY) + AMGB5(CDUZ - THETAIZ)$
 $ERRORZ \leftarrow AMGB7(CDUY - THETAY) + AMGB6(CDUZ - THETAIZ)$

ROLL ERROR } RESOLVED INTO
 PITCH ERROR } VEHICLE CO-ORDINATES
 YAW ERROR } VIA KMATFIX

IS
HOLDFLAG
= - ?

AUTOMATIC MANEUVERS ?

NO

YES

$ERRORX \leftarrow ERRORX + BIAS$
 $ERRORY \leftarrow ERRORY + BIAS1$
 $ERRORZ \leftarrow ERRORZ + BIAS2$

ADD IN BIASES
 (BIASES COMPUTED IN
 KALCMANU)

NEXT SHEET

MIL INSTRUMENTATION LAB CAPITOL HILL	NAVIC OCSAN BPT 34307 04
DRAWN A.C. WILLIAMS PROGRAM <i>Thurcraft</i> ANALYSIS <i>Thurcraft</i> INFORMED <i>Thurcraft</i> APPROVED <i>Thurcraft</i>	RCS OAP PHASE 2 COROLUS II FC-2390 S 10

FROM PRECEDING PAGE

JETS

TS TEMP ← ADB + .044°

DEADBAND + FLAT REGION

SPNDY = 2
FOR
LOOP
CONTROL

INDEXED VARIABLES IN JLOOP

PASS 1	PASS 2	PASS 3
ADOT _{2 dp}	ADOT _{1 dp}	ADOT _{dp}
WBODY _{2 dp}	WBODY _{1 dp}	WBODY _{dp}
ERROR _Z	ERROR _Y	ERROR _X
TAU _Z	TAU ₁	TAU
J/M _Z	J/M ₁	J/M

JLOOP IS EXECUTED ONCE FOR EACH AXIS

JLOOP

S/C ANGULAR RATE (ESTIMATE)

EDOT_{dp} ← ADOT_{2 dp}

IS
HOLD FLAG
= 0?

INCLUDE AUTOMATIC MANEUVER RATES

EDOT_{dp} ← EDOT_{dp} - WBODY_{2 dp}

INHOLD

AERR ← ERROR_Z S/C ATTITUDE ERROR

SINCE THE PHASE PLANE IS SYMMETRIC ABOUT THE ORIGIN, THE RATE IS TAKEN AS POSITIVE AND THE SIGNS OF EDOT_T, TSEMP AND AERR ADJUSTED ACCORDINGLY. THE SUFFIX "VEL" IN THE MNEMONIC DESIGNATES THE ADJUSTED VALUES.

SIGN
EDOT?

NEGVEL

POSVEL

EDOTVEL ← -EDOT
ADBVEL ← -TSEMP
AERRVEL ← -AERR

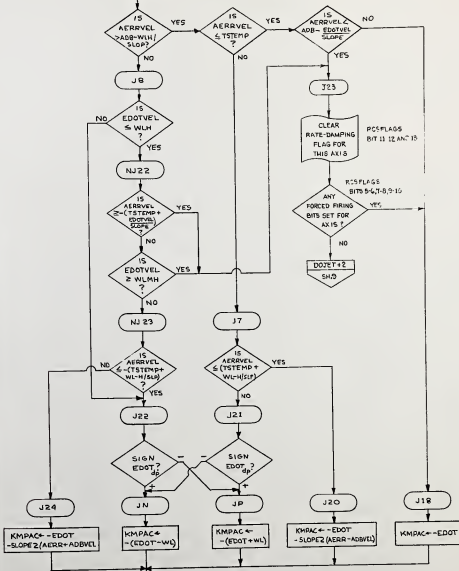
EDOTVEL ← EDOT
ADBVEL ← TSEMP
AERRVEL ← AERR

TO NEXT PAGE

BIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO DISTANCE AND NAVIGATION	
DESIGNER: <i>W. J. ...</i> DRAWN: <i>W. J. ...</i> CHECKED: <i>W. J. ...</i> APPROVED: <i>W. J. ...</i>		RCS DAP PHASE 2 CALLOSSUB II	
DATE: <i>11/11/67</i> APPROVED: <i>W. J. ...</i>		DOCUMENT NO. FC 2390	SHEET 6 OF 10

FROM PRECEDING PAGE

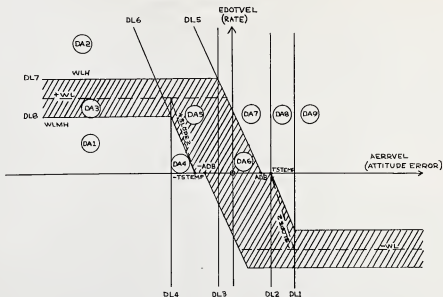
SEE NEXT SHEET FOR
EXPLANATION OF THIS LOGIC



TO SHEET 7

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGNED BY <i>J. R. ...</i> 8-22-67		RCS DAP PHASE 2	
PROGRAMMED BY <i>J. R. ...</i> 8-10-67		DOCUMENT NO. FC 2390	
DESIGNED BY <i>J. G. ...</i> 8-22-67		COLOSSUS II	
APPROVED BY <i>J. G. ...</i> 8-22-67		REV	
USED ON		SHEET 7 OF 10	

PHASE PLANE LOGIC



DECISION LOGIC

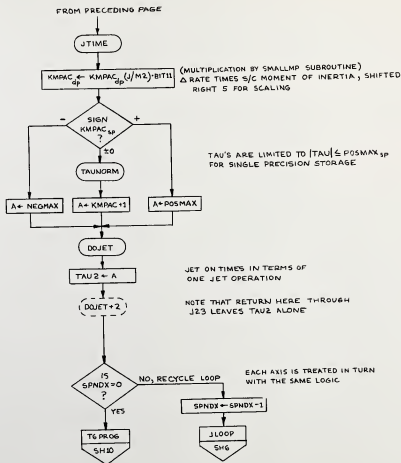
DECISION LINE (DL) ON GRAPH	1	2	3	4	5	6	7	8
DECISION POINT IN LOGIC	J7	J6+1	J6	NJ23	J6+2	NJ22	J8	NJ22+1
OUTCOME	{ LOGICAL "YES" { LOGICAL "NO"	LEFT RIGHT	LEFT RIGHT	RIGHT LEFT	LEFT RIGHT	LEFT RIGHT	BELOW ABOVE	ABOVE BELOW

LOGICAL PATHS

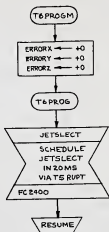
DECISION AREA (DA)	LOGICAL PATHS	RESPONSE
DA1	J6 - J8 - NJ22 - NJ22 + 1 - NJ23 - J22 →	DRIVE RATE TO +WL
DA2	J6 - J8 - J22 →	DRIVE RATE TO +WL
DA3	J6 - J8 - NJ22 - NJ22 + 1 - J23 →	NO ACTION*
DA4	J6 - J8 - NJ22 - NJ22 + 1 - NJ23 - J24 →	DRIVE RATE TO +SLOPE 2
DA5	J6 - J8 - NJ22 - J23 →	NO ACTION*
DA6	J6 - J6+1 - J6+2 - J23 →	NO ACTION*
DA7	J6 - J6+1 - J6+2 - J18 →	DRIVE RATE TO ZERO
DA8	J6 - J6+1 - J7 - J20 →	DRIVE RATE TO -SLOPE 2
DA9	J6 - J6+1 - J7 - J21 →	DRIVE RATE TO -WL

* IF THERE ARE ANY RMC COMMANDS,
THEN THE RATE IS DRIVEN TO ZERO
BEFORE EXECUTION OF THE COMMANDS.

	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP PHASE 2
DESIGNED BY <i>J. J. Moore</i>	8-20-65	DOCUMENT NO. FC2390
FORWARDED BY <i>J. J. Moore</i>	8-25-65	
CHECKED BY <i>J. J. Moore</i>	10-6-65	COLONELIAUS I
APPROVED BY <i>J. J. Moore</i>	10-11-65	
USED ON		SHEET 8 OF 30



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		RCS DAP PHASE 2
DESIGNED BY	<i>J. H. ...</i>	DOCUMENT NO.
PROGRAMMED BY	<i>J. N. ...</i>	FC2390
DOCUMENTED BY	<i>J. A. ...</i>	COLOSSUS II
USED ON	<i>J. H. ...</i>	SHEET 9 OF 10



ZERO ATTITUDE ERROR IF IN
FREE MODE, OR IF MANUAL COMMANDS
ARE BEING RECOGNIZED

BIT		APPLIED	
METROINFORMATION LAB		GUIDANCE AND NAVIGATION	
CAMBRIDGE, MASS.		RCS DAP	
		PHASE-2	
SEARCHED <i>E. Hancock</i>	INDEXED <i>10/24</i>	COLOSSUS II	DOCUMENT NO.
FORWARDED <i>E. Hancock</i>	FILED <i>11-11-57</i>		FC2390
SOLICIT <i>J. Hancock</i>	DATE <i>10-23-57</i>	REV	SHEET 30 OF 10
APPROVED <i>J. Hancock</i>	DATE <i>10-23-57</i>		

CALLED BY T5RUPRT FROM SP50N ALLOW
 AT LEAST .42 SEC FOR SPS THRUST
 BUILDUP, INPUTS SET BY SP50N
 TVCFHASE = 1
 TVCEXPHS = 0
 FLAGWRD 6 BITS 1st, 14 = 10

TVC DAPON

BANKRUPT ← L
 QRUPT ← Q

SAVE RETURN
 VALUES FOR
 RESUME

WRCLEAN

OMEGAYC THRU
 OMEGAYC + 51 ← 0

RESET 52 TEMPORARY
 DAP VARIABLES:

OMEGAYC₀ = OMEGAYC₀
 OMEGAYC₀ = 34E+4ZB0
 PTHP1 = PTHP1
 YTMP1 - YTMP6
 ROLLFIR - ROLL #1 ORC
 TEMRES - STRKFI
 DELFB1 - DELFB2
 PDELOFF - PDELOFF

TVCINIT1
 SCHEDULE IN
 LCS VIA
 T5RUPRT

ENDMRC

RESUME

TVCINIT1

BANKRUPT ← L
 QRUPT ← Q

MASSPROP
 UPDATE TVC
 MASS
 PARAMETERS
 TVCARS 511E

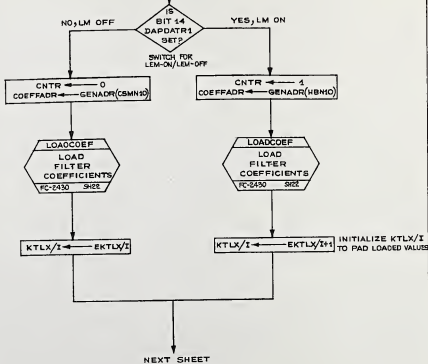
MASS DECREMENT FOR 1ST 10 SECS =
 1000 * SPS FUEL FLOW RATE IN
 KG/CSEC. TENMDOT IN KG @ 210
 EXPECTED VEHICLE MASS AFTER FIRST
 10 SECS OF BURN, KG @ 214

$TENMDOT = 1000 \cdot EMDOT$
 $MASSTMP = CMVMSS - TENMDOT$

NEXT SHEET

DRAWN PROG ANALY DOCNO APPR	<i>J. J. ...</i> <i>P. J. ...</i> <i>J. A. ...</i>	TVC START-UP AND EXECUTIVE ROUTINES COLOSSUS II A FC-2430
---	--	--

FRM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS. DRAWN: <i>P. H. ...</i> DESIGNED: <i>P. H. ...</i> ANALYST: <i>P. H. ...</i> CHECKED: <i>P. H. ...</i> APPROVED: <i>P. H. ...</i>	APOLLO GUIDANCE AND NAVIGATION TVC START-UP AND EXECUTIVE ROUTINES DOCUMENT NO. COLOSSUS IIA FC-2430 REV. SHEET 2 OF 22
---	---

FROM PRECEDING SHEET



INPUTS: IXK (FROM MASSPROP ROUTINE)
 KTLX/I (ABOVE)
 IAVG/TLX (FROM MASSPROP ROUTINE)
 OUTPUT: 1/CONACC = 1/ACC IN DEG²/REV @ 2"
 VARK = DAP FILTER GAIN FACTOR
 DEG/DEG @ 1/2(BASCREV)



KPRIMED₀ ← 0000₈
 TSTVCDT ← 5777₈ - KPRIMED₀0000

KPRIMED₀ ← 0000₈
 TSTVCDT ← 5777₈ - KPRIMED₀0000

TSTVCDT IS THE ΔTIME FOR TVC DAP ITERATION. IN T'S FORM
 FIXED MEMORY
 2 CS LEM-OFF; 4 CS LEM-ON



FLAGWRDS BITS
 RESET ← SWTOVER HAS
 NOT OCCURRED YET

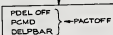
KPRIMED₀ ← KPRIMED₀ - EKPRIME
 REPPFRAC ← EREPPFRAC
 CNTR ← 0000₈
 STRKTIME ← -1
 VCNTR ← 19D
 V87VCNTR ← 19D

KPRIMED₀ ← KPRIMED₀ + EKPRIME
 REPPFRAC ← EREPPFRAC + 1
 CNTR ← 0000₈
 STRKTIME ← -1
 VCNTR ← 19D
 V87VCNTR ← 19D

STURNS GAIN PARAMETER
 GAIN FOR TMC 007
 TIME OF ONE-SHOT TVC CORRECTION
 INHIBIT STROKE TEST
 UPDATE COUNTER



STORE INITIAL PITCH TRIM VALUE



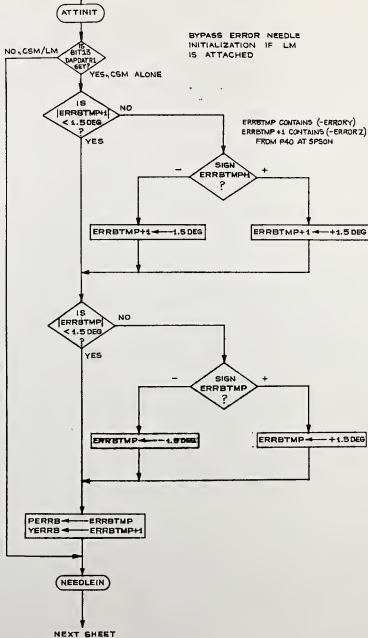
STORE INITIAL YAW TRIM VALUE



NEXT SHEET

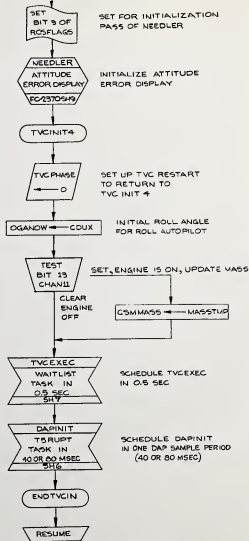
MIT INSTRUMENTATION AND CAMBRIDGE MASS.	REVISED 10 JAN 67
DRAWN <i>J. J. Chisholm</i> CHECKED <i>J. J. Chisholm</i> ANALYST <i>J. J. Chisholm</i> APPROV <i>J. J. Chisholm</i> 9 April 67	TVC START-UP AND EXECUTIVE ROUTINES FC-2430 3 22

FROM PRECEDING SHEET

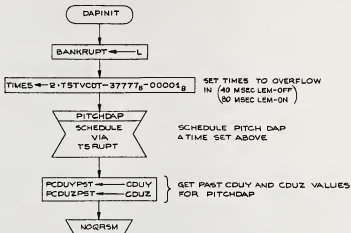


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC START-UP AND EXECUTIVE ROUTINES	
PROGRAM	APOLLO	DOCUMENT NO.	FC-2430
ANALYST <i>[Signature]</i>	4449	COLOSSUSIA	
DOCNR		SHEET 4 OF 22	
APPROV <i>[Signature]</i>	7801 43	REV	

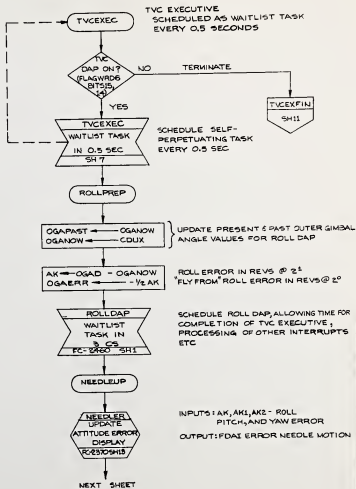
FROM PRECEDING SHEET



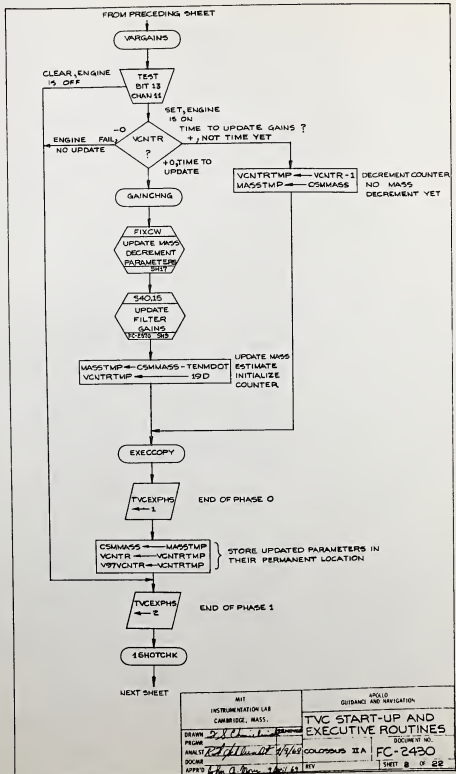
TITLE INSTRUMENTATION AND COMMANDS DRAWN BY CHECKED BY APPROVED BY DATE	TITLE TVC START-UP AND EXECUTIVE ROUTINES FC-2430 PAGE 5 22
DRAWN BY <i>J. A. Pinn</i>	APPROVED BY <i>J. A. Pinn</i>
DATE 9 April 63	INSTRUMENTATION AND COMMANDS FC-2430



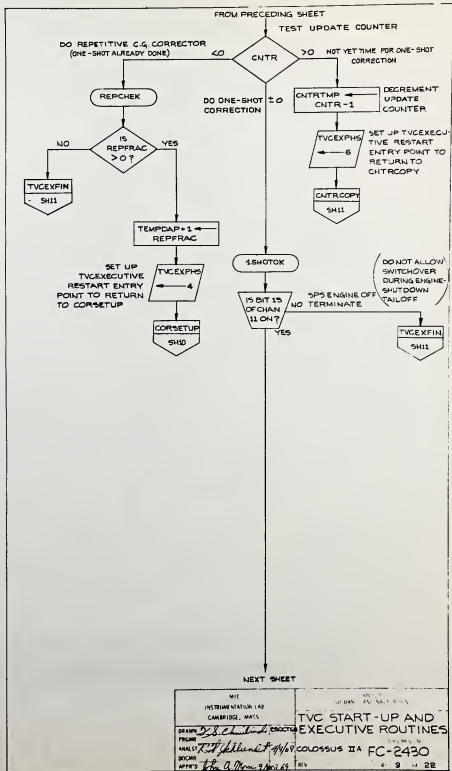
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARCELD GUIDANCE AND NAVIGATION	
DRAWN <i>J.P. ...</i>		TVC START-UP AND EXECUTIVE ROUTINES	
FROM <i>J.P. ...</i>		DOCUMENT NO.	
ANALY <i>J.P. ...</i>		COLOSSUS IIA FC-2430	
CHECK		REV	
APPR <i>John D. ...</i>		SHEET 6 OF 22	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		TVC START-UP AND EXECUTIVE ROUTINES	
DESIGN <i>J. J. Chumbley</i>		COLLOSSUS IIA FC-2430	
FROM <i>J. J. Chumbley</i>		REV	
APPROV <i>J. J. Chumbley</i> 9 April 62		REV	
		104 7 29 62	

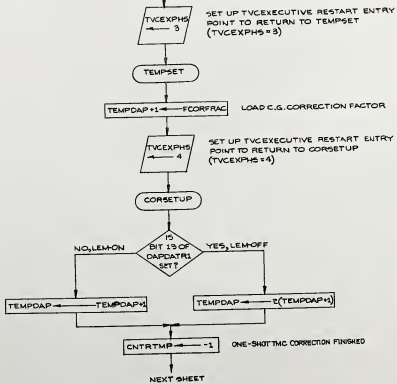


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. J. ...</i>		TVC START-UP AND EXECUTIVE ROUTINES	
PREPARED <i>R. J. ...</i>		DOCUMENT NO. FC-2430	
ANALYST <i>R. J. ...</i>		SHEET 8 OF 22	
DOOR <i>John A. ...</i>		REV	
APPROVED <i>John A. ...</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS	MIT RESEARCH AND DEVELOPMENT
DRAWN BY <i>B.S. Chubbuck</i> PROGRAM <i>R.T. Johnson</i> ANALYST <i>R.T. Johnson</i> CHECKER <i>J.A. Moore</i> APPROVED <i>J.A. Moore</i>	TVC START-UP AND EXECUTIVE ROUTINES COLLOSSUS II A FC-2430 REV 9 6 9 69

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Chubbuck</i>		TVC START-UP AND EXECUTIVE ROUTINES	
PCBMS	ANALYS <i>J. Chubbuck</i>	COLLOSSUS II A	DOCUMENT NO.
DOCHR	APPROV <i>J. Chubbuck</i>	FC-2430	
APPROV <i>J. Chubbuck</i>	REV		SHEET 10 OF 22

FROM PRECEDING SHEET

CG.CORR

$PACTMP_D \leftarrow PDEOFF + \frac{1}{4} [TEMPCAP (DELTPAR - PDEOFF)]$

PITCH TRIM-TRACKER CORRECTION

$YACTMP_S \leftarrow YDEOFF + \frac{1}{4} [TEMPCAP (DELTPAR - YDEOFF)]$

YAW TRIM-TRACKER CORRECTION

CORCOPY

TVCEXPHS
← 5

SET UP TVCEXECUTIVE RESTART ENTRY POINT TO RETURN TO CORCOPY = 1 (TVCEXPHS = 5)

CORCOPY + 1

$PACTOFF_S \leftarrow PACTMP_S$
 $PDEOFF_D \leftarrow PACTMP_D$

STORE NEW VALUES FOR PITCH TRIM-TRACKER CORRECTION

$YACTOFF_S \leftarrow YACTMP_S$
 $YDEOFF_D \leftarrow YACTMP_D$

STORE NEW VALUES FOR YAW TRIM-TRACKER CORRECTION

TVCEXPHS
← 6

SET UP TVCEXECUTIVE RESTART ENTRY POINT TO RETURN TO CNTRCOPY (TVCEXPHS = 6)

CNTRCOPY

$CNTR \leftarrow CNTR.TMP$

UPDATE TMC LOOP COUNTER

TVCEXFIN

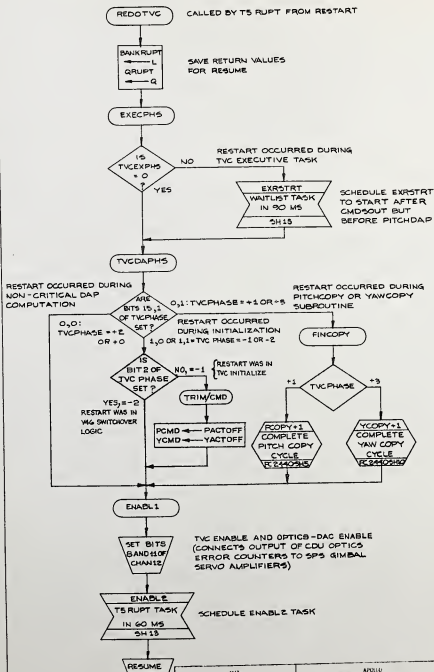
TVCEXPHS
← 0

TASKOVER

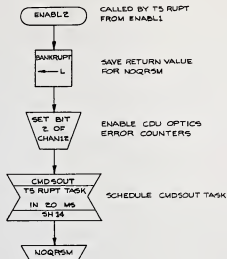
END OF TVCEXECUTIVE

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		TVC START-UP AND EXECUTIVE ROUTINES	
DRAWN <i>28 Chmel</i>		REVISION	
CHECKED <i>Est. Johnson</i> 4/4/69		COLOSSUS II A	
APPROVED <i>John A. Rose</i> April 69		FC-2430	
		11 22	

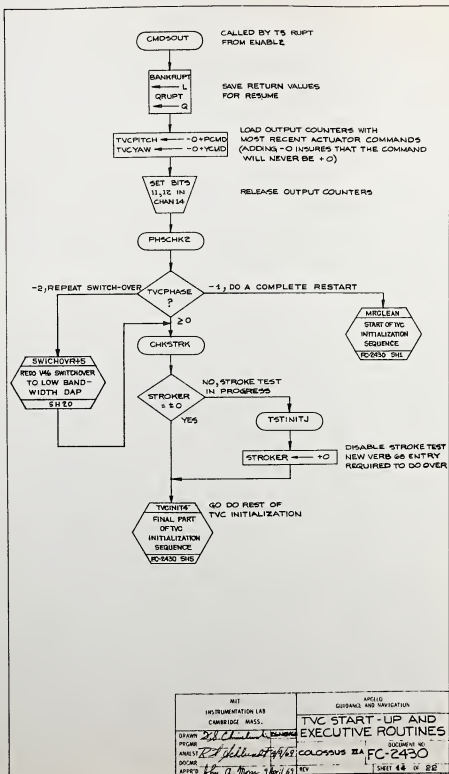
TVC RESTART PACKAGE



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	ARCELL GUIDANCE AND NAVIGATION TVC START-UP AND EXECUTIVE ROUTINES
DRAWN <i>J.P. Chubbuck</i>	CHECKED <i>J.P. Chubbuck</i>
PROGRAM <i>J.P. Chubbuck</i>	DOCUMENT NO. COLOSSUS IIA FC-2430
ANALYST <i>J.P. Chubbuck</i>	SHEET 12 OF 20
DATE <i>John A. Ross 1-14-67</i>	REV



MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		TVC START - UP AND EXECUTIVE ROUTINES	
DESIGNER <i>B. Chrestman</i>	PROGRAMMER <i>B. Chrestman</i>	COLLOSSUS IIA	FC-2430
ANALYST <i>B. Chrestman</i>	DATE <i>7/14/69</i>		
DOCNO	APPROVED <i>John A. Brown 7/14/69</i>		13 22



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC START-UP AND EXECUTIVE ROUTINES	
PROGRAM <i>[Signature]</i>		DOCUMENT NO	
DATE <i>[Signature]</i>		FC-2430	
APPROV <i>[Signature]</i>		SHEET 44 OF 85	

EXRSTRT

GO TO LOCATION WHOSE
ADDRESS IS CONTAINED
IN LOCATION TVCEXPHS
OF TVCEXADR TABLE

TVCEXPHS VALUE	ENTRY POINT	RC2490 SHEET NO.
1	EXECOCOPY+1	8
2	1SHOTCRK	8
3	TEMPSET	10
4	CORSETUP	10
5	CORCOPCY+1	11
6	ENTRCOPY	11

MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

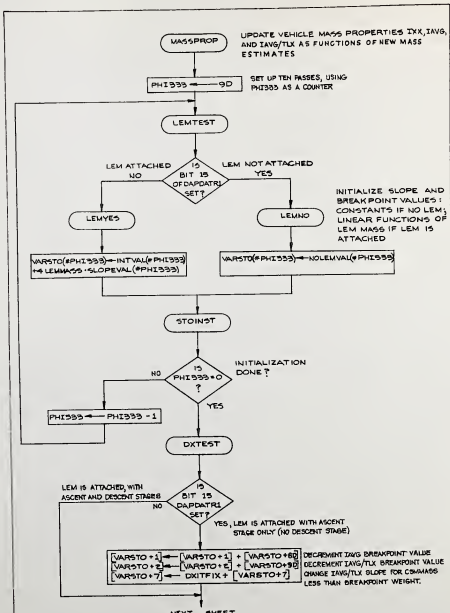
APPLIC
ADDRESS: MIT INSTR. LAB

TVC START-UP AND
EXECUTIVE ROUTINES

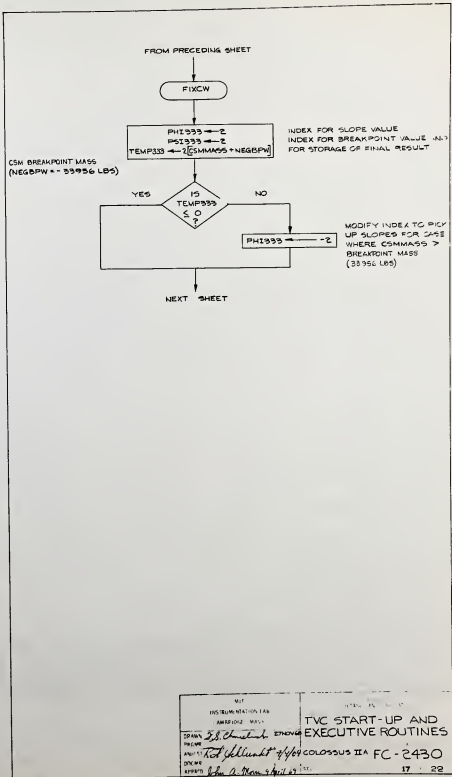
DRIVER *J. C. Chubb*
PROGRAM
ANALYST *Paul Chubb*
DOCOR
APPR'D *J. C. Chubb* April 69

COLOSSUS II A FC-2430

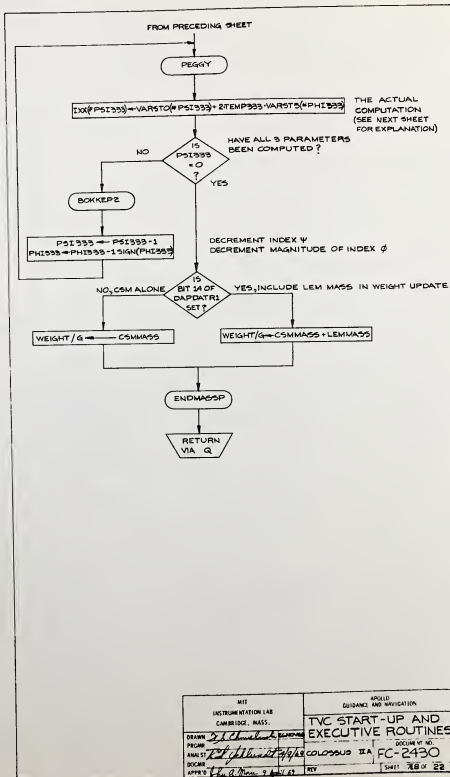
SHEET 15 OF 22



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Chouinard</i>		TVC START-UP AND EXECUTIVE ROUTINES	
PROGRAM <i>J. Chouinard</i>		DOCUMENT NO.	
ANALYST <i>Paul J. ...</i>		FC-2430	
DOCSR		SHEET 18 OF 28	
APPROVED <i>John A. ...</i>		REV	



MIT INSTRUMENTATION LAB AMERSON WAY		TVC START-UP AND EXECUTIVE ROUTINES	
DESIGN	<i>S.B. Chivukula</i>	ENGINEER	
PROGRAM			
ANALYST	<i>Robert J. Hillenbrand</i>	4/16/69	COLLOSSUS IIA FC - 2430
DOC NO			
APPROVED	<i>John A. Nease</i>	4/17/69	17 - 22



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. Chouhanchou</i>		TVC START-UP AND EXECUTIVE ROUTINES	
PROGRAM <i>FC-2430</i>		DOCUMENT NO.	
ANALYST <i>J. Chouhanchou</i>		COLLOSSUS IIA FC-2430	
CHECKED <i>J. Chouhanchou</i>		REV	
APPROVED <i>J. Chouhanchou</i> 9 April 69		SHEET 18 OF 22	

MASSPROP COMPUTATION:

STEP 1: COMPUTE COEFFICIENTS ON BASIS OF LEM MASS (M_{LEM})

LEMTEST

NO LEM	LEM ON
V ₀ = 25445 (KGM ²)	V ₀ = 26850 (KGM ²) + 1.96907 (M ²) · M _{LEM} (KG)
V ₁ = 87400 (KGM ²)	V ₁ = 127510 (KGM ²) + 27 5774 (M ²) · M _{LEM} (KG)
V ₂ = .80725 (SEC ²)	V ₂ = .84059 (SEC ²) + 2.3548 · 10 ⁻⁸ (SEC ² /KG) · M _{LEM} (KG)
V ₃ = 1.22277 · 10 ⁻⁸ (SEC ² /KG)	V ₃ = 153964 · 10 ⁻¹⁰ (SEC ² /KG) + 2.1777 · 10 ⁻⁹ (SEC ² /KG ²) · M _{LEM} (KG)
V ₄ = 1.6096 (M ²)	V ₄ = -742925 (M ²) + 1.044 · 10 ⁻⁹ (M ² /KG) · M _{LEM} (KG)
V ₅ = 1.54 (M ²)	V ₅ = 1.5598 (M ²) + 0
V ₆ = 7.77177 (M ²)	V ₆ = 9.68 (M ²) + 2.21088 · 10 ⁻⁹ (M ² /KG) · M _{LEM} (KG)
V ₇ = 3.46455 · 10 ⁻⁸ (SEC ² /KG)	V ₇ = .647625 · 10 ⁻⁸ (SEC ² /KG) + 1.5166 · 10 ⁻⁹ (SEC ² /KG ²) · M _{LEM} (KG)
V ₈ COMPUTED, BUT NOT MEANINGFUL AND NOT USED	V ₈ = -27226 (KGM ²) - 1.284 (M ²) · M _{LEM} (KG)
	V ₉ = -.206476 (SEC ²) + 2 · 10 ⁻⁸ (SEC ² /KG) · M _{LEM} (KG)

STEP 2: IF LEM ASCENT STAGE ONLY ATTACHED, MODIFY V₁, V₂ AND V₇:

DXTEST

$$V_1 = V_1 (KGM^2) + V_8 (KGM^2)$$

$$V_2 = V_2 (SEC^2) + V_9 (SEC^2)$$

$$V_7 = V_7 (SEC^2/KG) - 1.88275 \cdot 10^{-8} (SEC^2/KG)$$

STEP 3: COMPUTE IXX (KGM²), IAVG (KGM²), AND IAVG/TLX (SEC²):

PEGGY

CSM WEIGHT ≤ 33956 LBS (15402.17 KG)	CSM WEIGHT > 33956 LBS (15402.17 KG)
IXX = V ₀ (KGM ²) + V ₅ (M ²) (M _{CSM} - 15402.17) (KG)	IXX = V ₀ (KGM ²) + V ₅ (M ²) (M _{CSM} - 15402.17) (KG)
IAVG = V ₁ (KGM ²) + V ₆ (M ²) (M _{CSM} - 15402.17) (KG)	IAVG = V ₁ (KGM ²) + V ₆ (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 ₇ (SEC ² /KG) (M _{CSM} - 15402.17) (KG)

IN THE ABOVE EQUATIONS

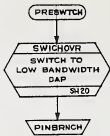
IXX = MOMENT OF INERTIA ABOUT VEHICLE X AXIS
 IAVG = AVERAGE MOMENT OF INERTIA ABOUT Y AND Z AXIS
 IAVG/TLX = IAVG / (VEHICLE GAIN)
 M_{CSM} = CSM MASS
 M_{LEM} = LEM MASS

IN KG M² @ 200
 IN KG M² @ 250
 IN SEC² @ 25
 IN KG @ 256
 IN KG @ 256

NOTE: VEHICLE MASS IS KEYED IN IN POUNDS, BUT INTERNALLY, MASS IS STORED IN KG.

MIT INSTRUMENTATION LAB CAMBRIDGE MASS		DATE JAN 27 1968
DRAWN <i>[Signature]</i>		TYC START-UP AND EXECUTIVE ROUTINES COLUSSUS IIA FC-2430
PEGM		
ANALYST <i>[Signature]</i>		
DOCM		
APPROV <i>[Signature]</i>		19 82

CSM/LM V46 SWITCHOVER FROM HIGH-BANDWIDTH FILTER
TO LOW-BANDWIDTH FILTER.



RELINT; AND TERMINATE VERB 46



SAVE CURRENT PHASE NUMBER FOR RESTART

SET UP TO RESTART SWICHOVR AT
THE NEXT LOCATION

RESTART ENTRY POINT

ZERO TEMPORARIES FOR PITCH AND
YAW FILTERS.

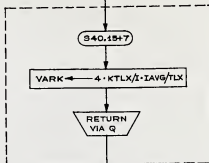
INDICATE SWITCHOVER
HAS OCCURRED

SET GAIN TO LOW-BANDWIDTH
PAD LOADED VALUE

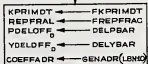
NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC START-UP AND EXECUTIVE ROUTINES	
DESIGNER <i>[Signature]</i>	ENGINEER <i>[Signature]</i>	DOCUMENT NO.	
ANALYST <i>[Signature]</i>	DATE <i>[Signature]</i>	COLOSSUS IIA	FC-2430
DOCTOR		APPROVED <i>[Signature]</i>	SHEET 20 OF 22

FROM PRECEDING SHEET



VARIABLE GAIN



STEERING GAIN
TMC LOOP GAIN
TRIM ESTIMATES ARE SET TO DEFILTER VALUES

INPUT TO LOADCOEF ROUTINE TO
SELECT LOW BANDWIDTH COEFFICIENTS



LOAD N10 - N10+14 FOR
LOW BANDWIDTH DAP

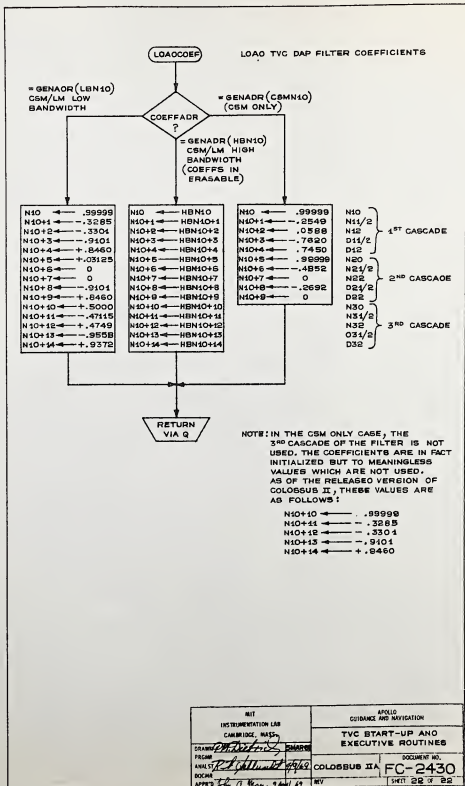


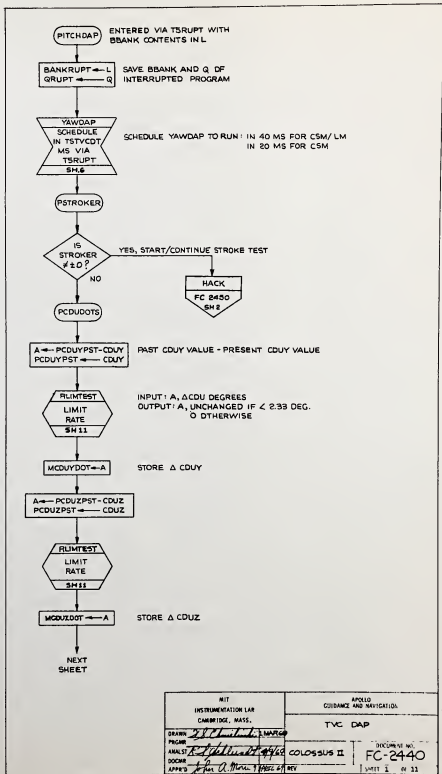
RESTORE PHASE NUMBER



RETURN TO CALLER

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED CUTTING AND NAVIGATION
DRAWN <i>[Signature]</i> P/COMP <i>[Signature]</i> APPROV <i>[Signature]</i>	TVC START-UP AND EXECUTIVE ROUTINES DOCUMENT NO. FC-2430 SHEET 21 OF 22





FROM
PRECEDING
SHEET

PINTEGRL

$$\begin{aligned} \omega_y &= +\cos \phi \cdot \cos \psi \cdot \dot{\theta} + \sin \phi \cdot \dot{\psi} \\ \theta_e &= \theta_e z^{-1} + \omega_{yc} - \omega_y \\ \text{OMEGAYB}_D &\leftarrow -4(\text{COSCDUX} - \text{COSCDUZ} - \text{MCDUYDOT}) - 2(\text{SINDUX} - \text{MCDUZDOT}) \\ \text{ERRBTMP}_D &\leftarrow \text{PERRB} + \text{OMEGAYC} - \text{OMEGAYS} \end{aligned}$$

MEASURED RATE
ATTITUDE ERROR = \int RATE ERROR
(ω_{yc} = COMMANDED RATE)

PERORLIM

ERRORLIM
LIMIT
ATTITUDE
ERROR
SH11

TO AVOID OVERFLOW, ATTITUDE ERROR
IS LIMITED TO $\pm 45^\circ$

PFORWARD

$$\begin{aligned} \text{TMP1}_D &\leftarrow \text{PTMP1}_D \\ \text{TMP3}_D &\leftarrow \text{PTMP3}_D \\ \text{TMP5}_D &\leftarrow \text{PTMP5}_D \end{aligned}$$

SET UP STORAGE LOCATIONS FOR FORWARD FILTER

FWDFLTR

DAP1 \leftarrow 0
DAP2 \leftarrow 0
DAP3 \leftarrow 0
CMOTMP \leftarrow 0
DELBRTMP \leftarrow 0

1DAPCAS

1ST CASCADE

$$\text{DAP1}_D \leftarrow \text{NID} \cdot \text{ERRBTMP}_D + \text{TMP1}_D$$

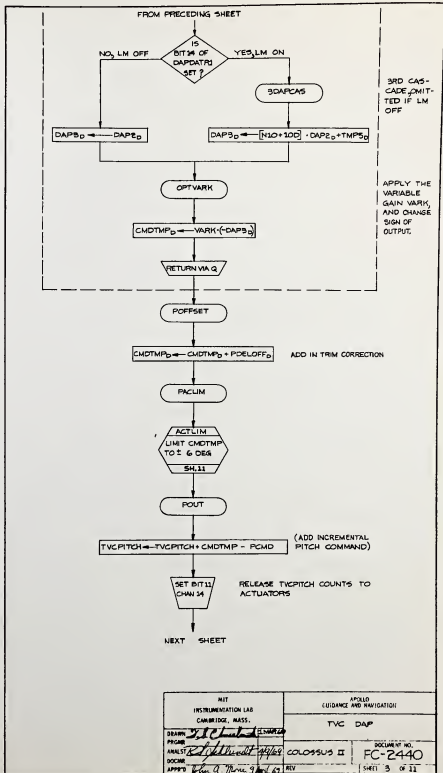
2DAPCAS

2ND CASCADE

$$\text{DAP2}_D \leftarrow \text{NID} + 5 \cdot \text{DAP1}_D + \text{TMP3}_D$$

NEXT
SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGN <i>W. P. ...</i>		TVC DAP	
PERSONAL <i>...</i>		DOCUMENT NO.	
ANALYST <i>...</i>		FC-2440	
CHECKED <i>...</i>		SHEET 2 OF 11	
APPROVED <i>...</i>		REV	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		TVC DAP	
DESNR	<i>2-1-68</i>	COSMOS II	DOCUMENT NO.
PRGMR	<i>R. J. ...</i>		FC-2440
ANLST	<i>R. J. ...</i>		
DOCHR			
APPRD	<i>John A. ...</i>	REV	SHEET 3 OF 11

FROM PRECEDING SHEET

PPRECOMP

TMP2_D ← PTMP2_D
 TMP4_D ← PTMP4_D
 TMP6_D ← PTMP6_D

} SET UP FILTER STORAGE FOR PRECOMPUTATION

PRECOMP

FILTER COMPUTATION FOR THE NEXT PASS

TMP1_D ← 2[(20+3)·ERRBTMP_D - (20+3)·DAP1_D] + TMP2_D
 TMP2_D ← [(10+2)·ERRBTMP_D - (10+2)·DAP1_D]

1ST CASCADE

2CASFLTR

2ND CASCADE

TMP3_D ← 2[(20+6)·DAP1_D - (10+6)·DAP2_D] + TMP4_D
 TMP4_D ← [(20+7)·DAP1_D - (10+9)·DAP2_D]

YES, LM OFF
 NO, LM ON

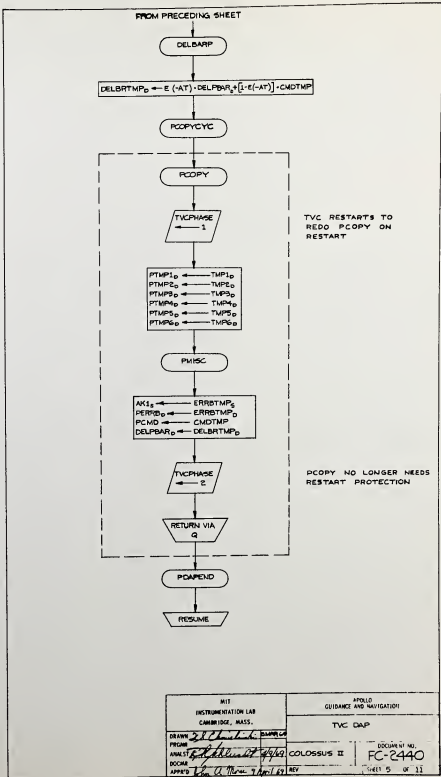
3RD CASCADE (OMITTED IF LM IS OFF)

TMP5_D ← 2[(10+10)·DAP2_D - (10+10)·DAP3_D] + TMP6_D
 TMP6_D ← [(10+12)·DAP2_D - (10+14)·DAP3_D]

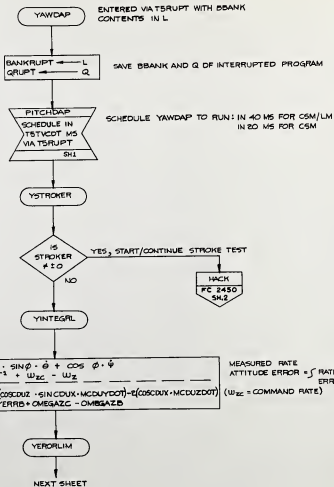
RETURN VIA Q

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		TVC DAP	
PEPME <i>[Signature]</i>		DOCUMENT NO.	
ANALYST <i>[Signature]</i>		COLOSSUS II	
DOCTR		FC-2440	
APPROV <i>[Signature]</i>		SHEET 4 OF 11	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		TVC GAP	
DRAWN <i>J. J. ...</i>	ENGINEER <i>J. J. ...</i>	DOCUMENT NO. COLOSSUS II	FC-2440
DESIGNER <i>J. J. ...</i>	ANALYST <i>J. J. ...</i>	REV	SHEET 5 OF 11
APPROVED <i>J. J. ...</i>		DATE <i>7 April 68</i>	



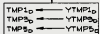
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN: <i>J. J. Chubb</i>		TVC DAP	
FROM: <i>J. J. Chubb</i>	ANALYST: <i>J. J. Chubb</i>	DOCUMENT NO. COLOSSUS II	FC-2440
DOCK:	APPROV: <i>J. A. M...</i>	REV:	SHEET 6 OF 11

FROM PRECEDING SHEET



TO AVOID OVERFLOW, ATTITUDE ERROR IS LIMITED TO $\pm 45^\circ$

Y FORWARD



SET UP STORAGE LOCATIONS FOR FORWARD FILTER

FWD FLTR



1DAPCAS

1ST CASCADE

$$DAP1_D = N10 \cdot ERRTMP_D + TMP1_D$$

2DAPCAS

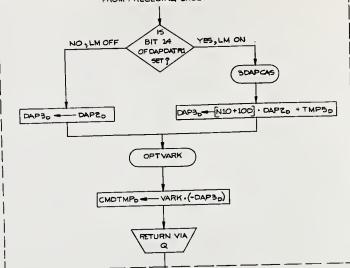
2ND CASCADE

$$DAP2_D = \{N10 \cdot S\} \cdot DAP1_D + TMP2_D$$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. L. Chubb</i>		TVC DAP	
PROGRAM	COLOSSUS II	DOCUMENT NO. FC-2440	
ANALYST <i>R. L. ...</i>	REV	SHEET 7 OF 11	
DOCNO			
APPROV <i>John A. ...</i>			

FROM PRECEDING SHEET



3RD CASCADE OMITTED IF LM OFF

APPLY THE VARIABLE GAIN VARK, AND CHANGE SIGN OF OUTPUT.



ADD IN TRIM CORRECTION



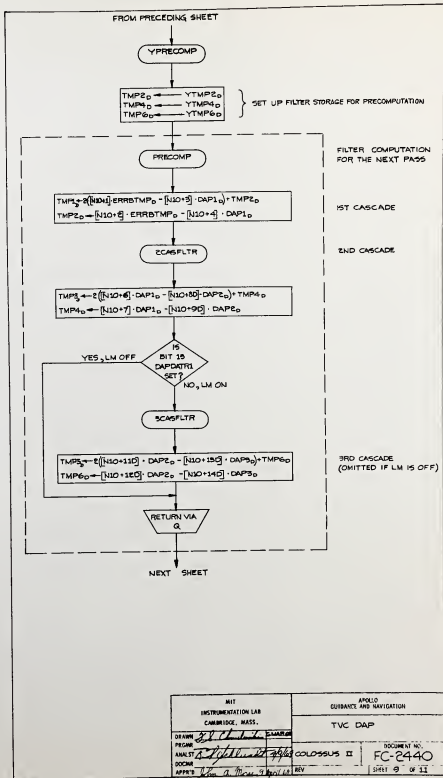
(ADD INCREMENTAL YAW COMMAND)



RELEASE TVC YAW COUNTS TO ACTUATOR

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		TVC DAP	
DESIGNER <i>S. J. Chilton</i>	DRAWN <i>S. J. Chilton</i>	COLOSSUS II	DOCUMENT NO. FC-2440
ANALYST <i>R. J. Chilton</i>	DATE <i>1/19/69</i>		SHEET 8 OF 11
DOCKED	APPROVED <i>Wm. A. Brown</i>	REV	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.
DRAWN: <i>[Signature]</i> CHECKED: <i>[Signature]</i> ANALYST: <i>[Signature]</i> DOCNO: <i>[Signature]</i> APPR: <i>[Signature]</i>

APOLLO GUIDANCE AND NAVIGATION
TVC DAP
DOCUMENT NO. FC-2440
SHEET 9 OF 11

FROM PRECEDING SHEET

DELBARY

$DELBRTMP_0 \leftarrow E(AT) \cdot DELBARY_0 + [1 - E(AT)] \cdot CMDTMP$

YCOPYCYC

YCOPY

TVCPHASE
← 3

TVCRESTARTS TO REDO
YCOPY ON RESTART

YTMP1₀ ← TMP1₀
YTMP2₀ ← TMP2₀
YTMP3₀ ← TMP3₀
YTMP4₀ ← TMP4₀
YTMP5₀ ← TMP5₀
YTMP6₀ ← TMP6₀

YMISC

AXE₀ ← ERRBRTMP₀
YERRB₀ ← ERRDRTMP₀
YCMD ← CMDTMP
DELYBAR₀ ← DELBRTMP₀

YCOPY NO LONGER NEEDS
RESTART PROTECTION

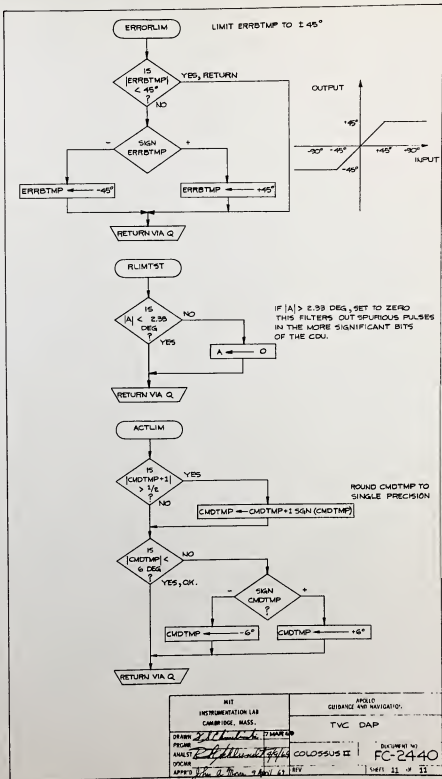
TVCPHASE
← 0

RETURN VIA
Q

YDAPEND

RESUME

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		TVC DAP	
DRAWN <i>J. J. [unclear]</i>	DESIGNED <i>[unclear]</i>	DOCUMENT NO.	
ANALYST <i>[unclear]</i>	FC-2440	COLOSSUS II	FC-2440
DOCTR		REV	SHEET 10 OF 11
APPROD <i>[unclear]</i>	9 April 61		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION: TVC DAP	
DRAWN	2/12/67	COLLOSSUS II	DOCUMENT NO
PRECISE			FC-2440
ANALYST	R. J. ...		5471 11 of 11
DISCAR			
APPROV	J. ... 9 April 67	RTV	

R35 - LUNAR LANDMARK SELECTION
ENTERED VIA A V79E CALL BY ASTRONAUT

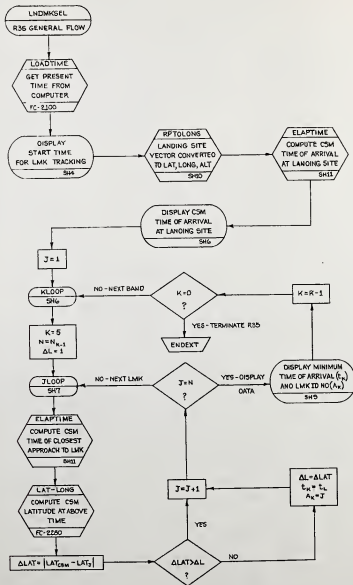
MAJOR SUBROUTINES

- RPTOLDG - CONVERTS RADIUS VECTOR IN PLANETARY
COORDINATES TO LAT, LONG AND ALT.
ELAPTIME - COMPUTES TIME TO POINT OF CLOSEST
ARRIVAL OF LANDING SITE OR LANDMARK.

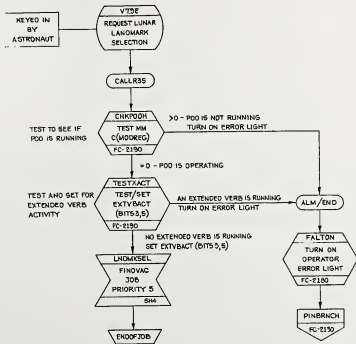
SPECIAL CONVENTIONS

- 1) SCALING INDICATED AS $2^3/2^7$ MEANS 2^3 IS THE SCALING
WHEN IN EARTH SPHERE OF INFLUENCE AND 2^7 IS FOR
MOON SPHERE OF INFLUENCE.
- 2) "VARIABLE" IN THE SCALING FIELD OF THE SUMMARY SHEETS
INDICATES THAT THE ERASABLE LOCATION IS USED AS A
TEMPORARY REGISTER HAVING MANY SCALINGS.
- 3) THE SYMBOL # INDICATES INDIRECT ADDRESSING,
I.E. ABL# #X1 MEANS ABL# IS INDIRECTLY ADDRESSED
BY X1.

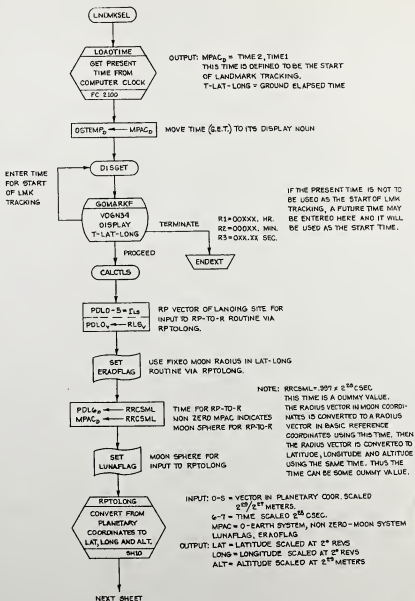
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. Williams		R35 - LUNAR LANDMARK SELECTION	
PROGRAM J.E. Crocker	210444	DOCUMENT #	
ANALYST		COLOSSUS 237	FC-2505
DOOR # P. Goodell	210444	Sheet 1 of 18	
APPROV. <i>[Signature]</i>	DATE		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APRIS GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		R36 - LUNAR LANDMARK SELECTION	
PROGRAM F.E. COOPER	100076	DOCUMENT NO.	
ANALYST	1300218	COLOSSUS 237	FC-2595
ROOM	2307E	REV	SHEET 2 OF 18
APPROVED <i>John A. Stone</i>			



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APR10 GUIDANCE AND NAVIGATION	
DRAWN A.G. WILLIAMS		R35 - LUNAR LANDMARK SELECTION	
PROGR. F.C. DICKINSON	000210	COL08008 037	DOCUMENT NO.
ANALYST R. G. GARDNER	000210	FC-2595	
DOCOR. R. G. GARDNER	000210		
APPROV. J. G. GARDNER	000210		
	REV		54113 12 18



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		RPLD GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		R35 - LUNAR LANDMARK SELECTION	
PROGRAM F.E. COCKER	DATE 28 OCT 78	DOCUMENT NO. FC-2595	
ANALYST	REVISION 130714	COLLOSSUS 237	SHEET 4 OF 18
APPROVED John A. Brown	DATE 14 OCT 78	REV	

FROM PREVIOUS SHEET

$L_{SLONG}_0 \leftarrow LONG_0$
 $TDEC1_0 \leftarrow OSPTM1_0$

SAVE LANDING SITE LONGITUDE
MOVE T-LAT-LONG FOR INPUT TO CSMPREC

CSMPREC
 EXTRAPOLATE
 CSM STATE
 VECTOR TO TDEC1
 FC-2290

INPUT: TDEC1 = TIME SCALED 2^{20} CSEC
 OUTPUT: RATT1 = POSITION VECTOR SCALED $2^{29}/2^{27}$ METERS
 VATT1 = VELOCITY VECTOR SCALED $2^7/2^5$ METERS/CSEC
 TAT = TIME SCALED 2^{20} CSEC

$Z = PDL14-19$
 $POSVECT_0 \leftarrow RATT1_0$
 $ALPHAV_0 \leftarrow RATT3_0$

STORE POSITION VECTOR FOR INPUT TO ELAPTIME
STORE POSITION VECTOR FOR INPUT TO LAT-LONG

$Y = PDL20-25$
 $VELVECT_0 \leftarrow VATT_0$

STORE VELOCITY VECTOR FOR INPUT TO ELAPTIME

$T = PDL32-33$
 $VECTIME_0 \leftarrow TAT_0$
 $MPAC_0 \leftarrow TAT_0$

STORE TIME FOR INPUT TO ELAPTIME
TIME IN MPAC FOR INPUT TO LAT-LONG

LAT-LONG
 CONVERT FROM
 RADIAL VECTOR
 TO LAT, LONG, ALT.
 FC-2280

INPUT: ALPHAV = POSITION VECTOR IN BASIC REF. SCALED $2^{29}/2^{27}$ METERS
 MPAC = TIME SCALED 2^{20} CSEC
 ERADFLAG, LUNARFLAG
 OUTPUT: LAT = LATITUDE SCALED 2^7 REVS
 LONG = LONGITUDE SCALED 2^7 REVS
 ALT = ALTITUDE SCALED 2^{23} METERS

$LONGSAVE_0 \leftarrow LONG_0$
 $X1_0 \leftarrow ADDRESS\ OF\ LSLONG_0$

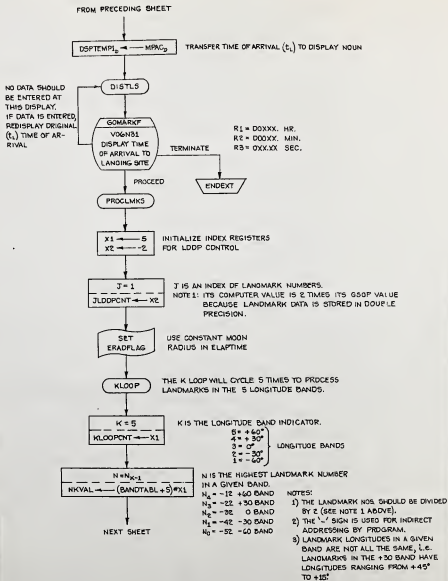
SAVE CSM LONGITUDE (LONG) FOR INPUT TO ELAPTIME
GET LANDING SITE LONGITUDE (LONG₂) ADDRESS FOR INPUT TO ELAPTIME

ELAPTIME
 DETERMINE
 TIME OF CLOSEST
 APPROACH TO THE
 LANDING SITE
 SHLL

INPUT: POSVECT(C) = CSM POSITION VECTOR SCALED $2^{29}/2^{27}$ METERS
 VELVECT(V) = CSM VELOCITY VECTOR SCALED $2^7/2^5$ METERS/CSEC
 VECTIME(T) = TIME SCALED 2^{20} CSEC
 LONGSAVE (LONG) = CSM LONGITUDE SCALED 2^7 REVS
 $X1(LONG_2)$ = LANDING SITE LONGITUDE ADDRESS
 OUTPUT: MPAC(T₁) = TIME OF CLOSEST APPROACH TO LANDMARK SCALED 2^{20} CSEC

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		RSS - LUNAR LANDMARK SELECTION	
DRAWN A.C. Williams	CHECKED J.R. Conner	DOCUMENT NO. COLOSSUS 23T	FC-2595
ANALYST R.P. Smith	APPROVED John A. Puse	SHEET 5	OF 18



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P35-LUNAR LANDMARK SELECTION	
DRAWN A. C. WILLIAMS	DATE 11/20/68	COLLOSSUS 237	DOCUMENT NO. FC-2595
PROGRAM J. E. S. ...	2/20/69		
DESIGN P. ...	2/20/69	REV	SHEET 6 OF 18
APPROVED A. ...	2/20/69		

FROM PRECEDING SHEET

$\Delta L_1 = 1$
DELTA₁ ← DPROSMAX₁

INITIALIZE LATITUDE TEST VALUE
DPROSMAX = DEC .399999996

JLOOPP

THIS LOOP CYCLED 5 TIMES TO DETERMINE WHICH LANDMARK IN THE N_{K-1} BAND IS CLOSEST TO THE CSM GROUND TRACK.

X1 ← ADDRESS OF (LNGTAB-2)

LONGTAB IS THE BEGINNING ADDRESS OF THE LONGITUDE TABLE

X1 ← X1 - JLOOPCNT

DETERMINE THE ADDRESS OF LONG_J - THE LONGITUDE OF THE JTH LANDMARK.

ELAPTIME
DETERMINE TIME OF CLOSEST APPROACH TO THIS LANDMARK
SH11

INPUT: POSVECT(x) = CSM POSITION VECTOR SCALED 2²⁹/2²⁷ METERS
VELVECT(y) = CSM POSITION VECTOR SCALED 2²⁹/2²⁷ METERS/C-SEC
VECTIME(z) = TIME SCALED 2²⁹ C-SEC
LONGSAB(LONG) = CSM LONGITUDE SCALED 2²⁷ REVS
X1(LONG_J) = LANDMARK LONGITUDE ADDRESS
OUTPUT: MPAC(t_J) = TIME OF CLOSEST APPROACH TO LANDMARK SCALED 2²⁹ C-SEC

XPRHOLD_J ← MPAC_J

SAVE TIME FOR POSSIBLE USE IF THIS LANDMARK IS CLOSEST TO THE CSM GROUND TRACK FOR THIS BAND.

SET LUNAFLAG

USE MOON SPHERE IN LAT-LONG

LAT-LONG
CONVERT RADIOUS VECTOR TO LAT, LONG, ALT.
RC-2250

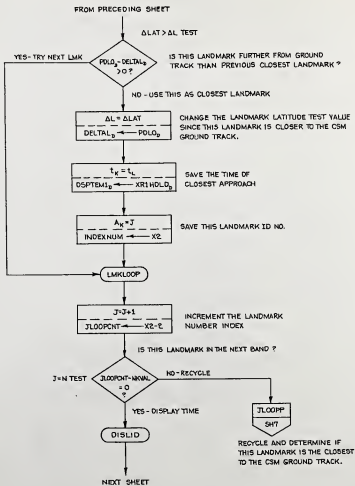
INPUT: ALPHAV = CSM POSITION VECTOR SCALED 2²⁹ METERS
MPAC = TIME SCALED 2²⁹ C-SEC
ERADFLAG, LUNAFLAG
OUTPUT: LAT = LATITUDE SCALED 2²⁷ REVS
LONG = LONGITUDE SCALED 2²⁷ REVS
ALT = ALTITUDE SCALED 2²⁹ METERS

ALAT = |LAT - LAT_J|
PCLO_J ← ABS [LAT - (LATTAB-2) * JLOOPCNT]

COMPUTE THE DIFFERENCE BETWEEN THE CSM AND LANDMARK LATITUDES AT THE TIME OF CLOSEST APPROACH.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		RDS - LUNAR LANDMARK SELECTION	
PROGRAM I. S. Coaker	1962-74	DOCUMENT NO.	
ANALYST J. P. Scudell	23-0114	COLOSSUS 237	FC-2595
APPROVED John A. Moran	24-0004	SCALE 7 0 18	

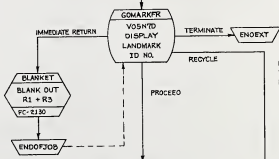


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		R35-LUNAR LANDMARK SELECTION	
DRAWN A.C. WILLIAMS	15OCT68	COLOSSUS 257	DOCUMENT NO. FC-2595
PROGRAM J.E. COOPER	23OCT68		SHEET 6 OF 18
ANALYST J.P. COOPER	23OCT68		
APPROVED John A. Moore	23OCT68		

FROM PRECEDING SHEET

LANDMARK ← $-(INDEXNUM/2) + 1$

DETERMINE LANDMARK ID NO.
 NOTE: SINCE THE FIRST STORED LANDMARK HAS ID NO. 2,
 1 IS ADDED (LANDING SITE HAS ID NO. 1).
 R1 = BLANK
 R2 = D00XX - LANDMARK ID NO
 R3 = BLANK



DISPLAY OF LANDMARK ID CLOSEST
 TO CSM GROUND TRACK IN BAND
 N_{k-1} .

DISSTL

GOMARKFR
 V06N54
 DISPLAY t_k
 FOR THIS
 LANDMARK

R1 = D0XXX. HK.
 R2 = 000XX. VLN.
 R3 = 000XX. SEC.

DISPLAY OF TIME TO LANDMARK
 CLOSEST TO CSM GROUND TRACK
 IN BAND N_{k-1} .

RECYCLE

TERMINATE

ENDEXT

NEXTBAND

$K = K - 1$
 $KLOOPCNT ← KLOOPCNT - 1$

INCREMENT BAND INDEX

WAS THIS THE LAST BAND ?

KLOOPCNT = D ?

NO

YES

KLOOP
 SWG

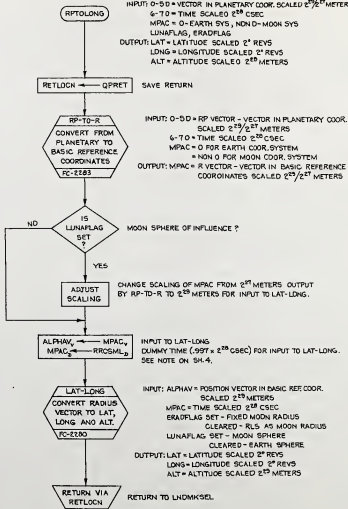
END OF R35

ENDEXT

RECYCLE TO DETERMINE
 LANDMARK CLOSEST TO
 CSM GROUND TRACK IN
 THE NEXT BAND.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PSS-LUNAR LANDMARK SELECTION	
PROGRAM T.C. CONNER	DESIGNED BY SGO/TAB	DOCUMENT NO.	
ANALYST	28027A	COLDSSUS 237	FC-2595
INCHG. [Signature]	PS/KTP	SHEET 9 OF 18	
APPROV. [Signature]	APPROV. [Signature]		

THIS SUBROUTINE CONVERTS A RADIUS VECTOR IN PLANETARY COORDINATES TO LAT, LONG AND ALT.
 INPUT: 0-5D = VECTOR IN PLANETARY COOR. SCALED $2^{25}/2^{21}$ METERS
 6-7D = TIME SCALED 2^{28} CSEC
 MPAC = 0 - EARTH SYS, NON 0 - MOON SYS
 LUNAFLAG, ERADFLAG
 OUTPUT: LAT = LATITUDE SCALED 2^8 REVS
 LONG = LONGITUDE SCALED 2^8 REVS
 ALT = ALTITUDE SCALED 2^{25} METERS



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C.WILLIAMS		R55 - LUNAR LANDMARK SELECTION	
PROW J.E. Ince	2507/AS	COLOSSUS 2 DT	DOCUMENT NO.
ANALY P. P. Smith	2507/AS	FC-2595	SHEET 30 OF 38
APPR'D John A. Brown	2507/AS		

THIS SUBROUTINE CALCULATES THE TIME OF CLOSEST APPROACH BETWEEN THE CSM AND THE JTH LANDMARK.

INPUT: POSVECT (r) = CSM POSITION VECTOR SCALED $2^{29}/c^{21}$ METERS
 VELVECT (v) = CSM VELOCITY VECTOR SCALED $2^{29}/c^{21}$ METERS/CSEC
 VECTIME (t) = TIME FOR POSITION AND VELOCITY SCALED 2^{28} CSEC
 LONGSAVE (LONGS) = CSM LONGITUDE SCALED 2^8 REVS
 X1 (LONGS_J) = LANDMARK LONGITUDE ADDRESS
 OUTPUT: MPAC (r_c) = TIME OF CLOSEST APPROACH TO LANDMARK SCALED 2^{28} CSEC

ELAPTIME

KETLOC ← QPRET SAVE RETURN

XR1HOLD ← X1 SAVE LANDMARK LONGITUDE (LONG_J) ADDRESS

POLO_v ← HIUNITZ_v THIS IS \hat{h}_2 - THE UNIT VECTOR ALONG THE POLAR AXIS OF THE MOON IN PLANETARY COORDINATES. } INPUT TO RP-TO-R
 POLLO_g ← VECTIME_g TIME FOR CSM VELOCITY AND POSITION COMPUTATION }
 MPAC_g ← OPPOSMA_g NON-ZERO IN MPAC

RP-TO-R CONVERT FROM PLANETARY TO BASIC REFERENCE COORDINATES FC-2283
 INPUT: 0-60 = RP VECTOR - VECTOR IN PLANETARY COORDINATES SCALED $2^{29}/c^{21}$ METERS.
 G-TO = TIME SCALED 2^{28} CSEC
 MPAC = 0 - EARTH COOR.
 NON 0 - MOON COOR.
 OUTPUT: MPAC = R VECTOR - VECTOR IN BASIC REFERENCE COORDINATES SCALED $2^{29}/c^{21}$ METERS.

$\hat{u}_2 = \text{MPAC}$ UNIT VECTOR ALONG THE POLAR AXIS OF THE MOON IN BASIC REFERENCE COORDINATES.
 UZ_v ← MPAC_v

$\hat{u}_r = \text{UNIT}(r)$ UNIT VECTOR OF CSM POSITION IN BASIC REFERENCE COORDINATES.
 URR_v ← UNIT(POSVECT_v)

$\hat{u}_w = \text{UNIT}(\hat{u}_r \times \hat{u}_2)$ \hat{u}_w, \hat{u}_r and \hat{u}_2 DEFINE AN ORTHOGONAL COORDINATE SYSTEM USED TO DETERMINE θ . } SEE NOTE
 UW_v ← UNIT(UNIT(POSVECT_v) × UZ_v)

$\hat{h}_w = \text{UNIT}(\hat{h}_w \times \hat{h}_2)$
 UNW_v ← UNIT(UNIT(UNIT(POSVECT_v) × UZ_v) × UW_v)

$\hat{v} = \text{UNIT}(v \times \hat{v})$ UNIT VECTOR OF THE PLANE OF ORBIT
 POLA_v ← UNIT(POSVECT_v × VELVECT_v)

NOTE: EQU. 6.1 PG. 5.6-48 R-577
 COLOSSUS SECT. 5 REV. 2

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGNER: A.C. WILLIAMS	SECTION: 3002	R35 - LUNAR LANDMARK SELECTION	
PROGRAM: T.E. Coaker	LOCATION: 3002	COLOSSUS 227	DOCUMENT NO. FC-2595
ANALYST: J.P. Scobie	REVISION: 34		SHEET 11 OF 18
DOCS: J.P. Scobie			
APPROVED: John A. Pines			

FROM PRECEDING SHEET

THIS BEGINS GSOP FIG. G.9-2, PG. 5.4-49
(SEE 5th. FOR REFERENCE)

$$\Delta \text{LONG} = .397 (\text{LONG}_1 - \text{LONG}_2)$$

$$\text{POL}30_2 \leftarrow \text{RRC SML} (\text{LONG} - \text{SAVE}_2 - 0 \cdot \text{KR1 HOLD}_2)$$

COMPUTE LONGITUDE DIFFERENCE BETWEEN THE
CSM AND THE 3rd LANDMARK.
.397 IS A FACTOR USED TO ACCOUNT FOR THE
RELATIVE RATES OF THE CSM AND LANDMARK.

$$u_2 = \text{UNIT} \left[(u_w \sin(\Delta \text{LONG}) + u_v \cos(\Delta \text{LONG})) \times V \right]$$

$$\text{ALPHA} u_2 \leftarrow \text{UNIT} \left[(u_{w1} \sin(\text{POL}30_2) + u_{v1} \cos(\text{POL}30_2)) \times \text{POL}24_v \right]$$

THIS IS THE POSITION VECTOR OF THE
CSM AT THE POINT OF CLOSEST APPROACH
TO THE 3rd LANDMARK.

$$\cos \theta = (u_2 \cdot u_1)$$

$$\text{CSTH} \leftarrow \text{ALPHA} u_2 \cdot \text{URR}_v$$

θ IS THE CENTRAL ANGLE BETWEEN u_1 AND THE
POINT OF CLOSEST APPROACH.
INPUT TO TIMETHET.

$$\sin \theta = \sin [\arccos (\cos \theta)]$$

$$\text{SNTH} \leftarrow \sin (\text{ACOS} (\text{ALPHA} u_2 \cdot \text{URR}_v))$$

INPUT TO TIMETHET

$$\text{NO} \quad \text{YES}$$

$$\text{TEST} \leftarrow (\text{URR}_v \cdot \text{ALPHA} u_2) - \text{POL}24_v$$

$$\text{TEST} < 0$$

TEST OF $(u_2 \cdot u_1) \cdot u < 0$
THIS TEST DETERMINES IF THE
CSM HAS PAST THE 3rd LANDMARK.

$$\sin \theta = -\sin \theta$$

$$\text{SNTH} \leftarrow -\text{SNTH}$$

IF THE CSM IS BEYOND THE LANDMARK,
 $\theta = 360 - \theta$. THUS $\sin \theta = \sin (360 - \theta) = -\sin \theta$.

$$r(t_2) = r$$

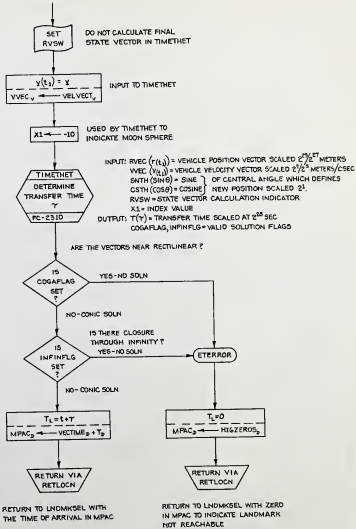
$$\text{RVECT}_v \leftarrow \text{POSVECT}_v$$

INPUT TO TIMETHET

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		FDS - LUNAR LANDMARK SELECTION	
DRAMAN	A.C. WILLIAMS	21 OCT 69	
PROJECT	T.R. Conner	21 OCT 69	
ANALYST	J.P. Gault		
BOOK			
APP'D	John A. Brown	24 OCT 69	
		DOCUMENT NO. COLOSSUS 237	FC-2595
		SHEET 22 OF 18	

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS	PROJ 165	R50 - LUNAR LANDMARK SELECTION	
PROGRAM J.R. CRACKER	23074	DOCUMENT NO.	
ANALYSIS J.P. CRACKER	23074	COLOSSUS 23T	FC-2595
BOOKED A.P.P. 1/11/68	23074	SHEET 15 OF 18	

SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
CHKPOOR	2190	TESTS TO SEE IF POO IS RUNNING	SH3
TESTXACT	2190	TESTS FOR EXTENDED VERB ACTIVITY	SH3
FALTON	2180	TURN ON OPERATOR ERROR LIGHT	SH3
LOADTIME	2100	GET PRESENT TIME FROM COMPUTER CLOCK	SH4
CSMPREC	2290	EXTRAPOLATE CSM STATE VECTOR TO TDECI	SH5
LAT-LONG	2280	CONVERT FROM RADIUS VECTOR TO LAT, LONG, ALT	SH5,7,10
RP-TO-R	2283	CONVERT FROM PLANETARY TO BASIC REFERENCE COORDINATES	SH10,11
TIMETHET	2310	DETERMINE TRANSFER TIME	SH13
BLANKET	2130	BLANK OUT R1 AND R3	SH9

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
ERADFLAG FLAGWORD1 BIT13	EARTH: COMPUTE FISHER ELLIPSOID RADIUS MOON: USE FIXED RADIUS	EARTH: USE FIXED RADIUS MOON: USE RLS FOR LUNAR RADIUS	SH4, 6		
LUNAFLEG FLAGWORD3 BIT12	LAT-LONG IS FOR MOON	LAT-LONG IS FOR EARTH	SH4, 7		SH10
RVM FLAGWORD7 BIT9	DO NOT COMPUTE FINAL STATE VECTOR IN TIMETHET	COMPUTE FINAL STATE VECTOR IN TIMETHET	SH13		
COGAFLEG FLAGWORD8 BIT4	NO CONIC SOLUTION, TOO CLOSE TO RECTILINEAR	CONIC SOLUTION EXISTS			SH13
INFINFLG FLAGWORD8 BIT7	NO CONIC SOLUTION, CLOSURE THROUGH INFINITY REQUIRED	CONIC SOLUTION EXISTS			SH13

DISPLAYS

VERB- NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N34	FLASHING	R1 = 00XXX. HR. R2 = 000XX. MIN. TIME OF EVENT R3 = 0XX.XX SEC.	SH4, 9
V06N31	FLASHING	R1 = 00EXX. HR. R2 = 000EX. MIN. TIME OF ARRIVAL TO LANDING SITE R3 = 0XX.XX SEC.	SH6
V05N70	FLASHING	R1 = BLANK R2 = 000XX - LANDMARK ID NUMBER R3 = BLANK	SH9

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		R35	
		LUNAR LANDMARK SELECTION	
DRAWN <i>G. J. Smith</i>	APPROVED <i>DOCTER</i>	DOCUMENT NO.	
FIGURE <i>1-6</i>	DATE <i>1/20/68</i>	COLLOSSUS 237	FC-2595
ANALYST <i>Patricia Hill</i>	DATE <i>1/20/68</i>		SHEET 14 OF 18
DOCUMENT <i>Patricia Hill</i>	DATE <i>1/20/68</i>		
APPROVED <i>John A. Thomas</i>	DATE <i>1/20/68</i>		

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
DSPTMP		REGISTER USED TO DISPLAY TIME	HR., MIN., SEC.	CSEC	2 ²⁴
RLS	E_{LS}	LANDING SITE RADIUS VECTOR	NAUT. MI.	METERS	2 ²⁴ /2 ²⁷
LDNG		LONGITUDE OUTPUT OF LAT-LONG SUBROUTINE	DEGS.	REVS	2 ⁶
LSELONG		LANDING SITE LONGITUDE	DEGS.	REVS	2 ⁶
RATT1		STATE VECTOR POSITION COMPONENT		METERS	2 ²⁴ /2 ²⁷
VATT1		STATE VECTOR VELOCITY COMPONENT		METERS/ CSEC	2 ⁷ /2 ⁵
TAT		TIME FOR ABOVE STATE VECTOR		CSEC	2 ²⁴
POSVECT	E	CSM POSITION AT TIME T		METERS	2 ²⁴ /2 ²⁷
VELVECT	V	CSM VELOCITY AT TIME T		METERS/ CSEC	2 ⁷ /2 ⁵
VECTIME	T	TIME FOR ABOVE POSITION AND VELOCITY		CSEC	2 ²⁴
LONGSAVE	LDNG	CSM LONGITUDE	DEGS.	REVS	2 ⁶
JLOOPCNT	J	INDEX FOR LANDMARK ID NOS.		(INTEGER)	2 ¹⁴
KLOOPCNT	K	INDEX FOR BAND NOS.		(INTEGER)	2 ¹⁴
NRVAL	N	HIGHEST LANDMARK ID NO. IN A GIVEN BAND		(INTEGER)	2 ¹⁴
DELTA	ΔL	MINIMUM LATITUDE DEVIATION TEST VALUE	DEGS.	REVS	2 ⁶
LAT		LATITUDE OUTPUT OF LAT-LONG SUBROUTINE	DEGS.	REVS	2 ⁶
XRHOLD		TEMPORARY STORAGE REGISTER		(INTEGER)	VARIABLE
INDEXNUM	A_K	TEMPORARY STORAGE OF LANDMARK ID NO.		(INTEGER)	2 ¹⁴
LANDMARK		DISPLAY NOON FOR LANDMARK ID NO.		(INTEGER)	2 ¹⁴
RETLOCN		RETURN ADDRESS REGISTER		(INTEGER)	2 ¹⁴
ALPHAV		POSITION VECTOR INPUT TO LAT-LONG		METERS	2 ²⁴
UZZ	U_Z	UNIT VECTOR OF MOON POLAR COORDINATE			2 ¹
URR	U_R	UNIT VECTOR OF CSM POSITION			2 ¹
UW	U_W	{ USED WITH U_Z TO DEFINE AN ORTHOGONAL COORDINATE SYSTEM			2 ¹
UNN	U_N				2 ¹
CSTH		COS θ } θ IS THE CENTRAL ANGLE BETWEEN SIN θ } E AND POINT OF CLOSEST APPROACH			2
SSTR					2
RVEC	$E(t_1)$	CSM POSITION VECTOR } INPUT TO CSM VELOCITY VECTOR } TIMETHET		METERS	2 ²⁴ /2 ²⁷
VVEC	$V(t_1)$			METERS/ CSEC	2 ⁷ /2 ⁵
T	T	TRANSFER TIME FROM TIMOTHET	SEC	CSEC	2 ²⁴

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		R35	
PROGRAM <i>[Signature]</i>	1-10-70	LUNAR LANDMARK SELECTION	
ANALYST <i>[Signature]</i>	1-10-70	COLOSSUS 237	FORM NO. FC-2595
DOCKMAN <i>[Signature]</i>	1-10-70		SHEET 15 OF 18

PROGRAM CONSTANTS

AGC TAG	GSCF SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
RRCMML		FACTOR USED TO ACCOUNT FOR ROTATION OF MOON	.997	37716 33106	2 ⁰
SANDTABL		BEGINNING OF TABLE CONTAINING BAND LIMITS		(INTEGER)	2 ¹⁴
DPFDSMAX		DOUBLE PRECISION REGISTER CONTAINING MAXIMUM VALUE	-.999999996	37777 37777	2 ⁰
LONGTAB		BEGINNING ADDRESS FOR LONGITUDES OF STORED LANDMARKS	} SEE BELOW	(INTEGER)	2 ¹⁴
LATJAB		BEGINNING ADDRESS FOR LATITUDES OF STORED LANDMARKS		(INTEGER)	2 ¹⁴
HIUNITE		UNIT VECTOR IN Z DIRECTION	(0,0,1)	(00000 00000, 00000 00000, 20000 00000)	(2 ¹ , 2 ¹ , 2 ¹)
HI66EROS		BEGINNING ADDRESS FOR 6 REGISTERS IN HIGH CORE CONTAINING ZERO		(INTEGER)	2 ¹⁴

LUNAR LANDMARK TABLE

AGC TAG	LANDMARK NUMBER (OCTAL) AND COORDINATE TYPE		ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
LATTAB	LATITUDE	LMK ID NO 2	3 ⁰ 29' SOUTH	-.015231481 REVS	2 ⁰
LATTAB+2	LATITUDE	LMK ID NO 3	0 ⁰ 47' NORTH	.002175926 REVS	2 ⁰
+4	↓	↓	0 ⁰ 51' N	.002381111	↓
+6	↓	↓	5 0 ⁰ 40' S	-.001851852	↓
+8			6 1 ⁰ 00' N	.002777776	
+10			7 1 ⁰ 03' S	-.002916667	
+12			10 1 ⁰ 56' S	-.005462963	
+14			11 2 ⁰ 24' N	.006666667	
+18			12 0 ⁰ 49' N	.016935185	
+18			13 0 ⁰ 54' N	.002500000	
+20			14 1 ⁰ 14' N	.003425926	
+22			15 1 ⁰ 42' S	-.004722222	
+24			16 0 ⁰ 32' S	-.001461481	
+28			17 1 ⁰ 07' N	.003101852	
+28			20 1 ⁰ 15' N	.003472222	
+30			4 ⁰ 30' S	-.012500000	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. J. Smith</i> 14 OCT 68		R 35	
PROGRAM <i>J. R. Smith</i> 25 OCT 68		LUNAR LANDMARK SELECTION	
ANALYST		COLOSSUS 287	DOCUMENT NO. FC-2595
DOCUMENT <i>(Signature)</i> 25 OCT 68		APPROVED <i>(Signature)</i> 25 OCT 68	SHEET 16 OF 18

LUNAR LANDMARK TABLE (CONTINUED)

AGC TAG	LANDMARK NUMBER (OCTAL) AND COORDINATE TYPE	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
LATTAB+32	LATITUDE LMK ID NO 22	0°08' NORTH	000277777 REVS	2 ⁰
+34	23	4°05' N	011342592	↓
↓ +36	↓ 24	↓ 1°26' N	↓ 003981481	↓
+38	25	2°53' S	-009009259	
+40	26	1°10' N	.003240741	
+42	27	2°03' S	-.005694444	
+44	30	0°49' N	.002268518	
+46	31	2°49' S	-.007824074	
+48	32	1°57' N	.005416667	
LONGTAB	LONGITUDE	2 58°01' EAST	.16157407	
↓ +2	↓ 3	↓ 57°37'	↓ .160046296	
+4	4	51°35'	.143287037	
+6	5	41°46'	.116018518	
+8	6	38°28'	.106851852	
+10	7	37°41'	.104675928	
+12	10	34°02'	.094537037	
+14	11	33°55'	.094212963	
+16	12	33°03'	.091805555	
+18	13	30°05'	.083564615	
+20	14	23°42'	.065833333	
+22	15	18°20'	.050925928	
+24	18	15°21'	.042638888	
+26	17	16°17'	.023009259	
+28	20	3°45'	.010416667	
+30	21	0°01'	.000046296	
+32	22	1°20' WEST	-.003703704	
+34	23	7°27' ↓	-.020694444	
+36	24	8°32'	-.023703704	
+38	25	16°31'	-.051435185	
+40	26	24°30'	-.088055556	
+42	27	30°38'	-.085092593	
+44	30	37°18'	-.100833333	
+46	31	36°42'	-.101944444	
+48	32	42°16'	-.117407407	
ALTTAB	ALTITUDE	2 -6857 FEET*	-2029 METERS*	2 ²⁹
↓ +2	↓ 3	↓ -6857	↓ -2029	↓
+4	4	-6673	-1790	↓

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGNED BY <i>J. P. ...</i> DATE <i>10/21/64</i>		R 35	
DRAWN BY <i>J. P. ...</i> DATE <i>11/10/64</i>		LUNAR LANDMARK SELECTION	
ANALYST <i>J. P. ...</i> DATE <i>11/10/64</i>		DOCUMENT NO.	
CHECKED BY <i>J. P. ...</i> DATE <i>11/10/64</i>		COLOSSUS 237	FC-2595
APPROVED BY <i>J. P. ...</i> DATE <i>11/10/64</i>		SHEET 17 OF 19	

LUNAR LANDMARK TABLE (CONTINUED)

AGC TAG	LANDMARK NUMBER (OCTAL) AND COORDINATE TYPE		ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
ALTAB 6	ALTITUDE	LMK ID NO 5	-3576 FEET*	-1090 METERS*	2 ²¹
+8	↓	↓	8 -3084	↓	↓
+10			7 -952		
+12			10 -951		
+14			11 -9082		
+16			12 -2920		
+18			13 -4889		
+20			14 -10600		
+22			15 16770		
+24			16 22670		
+26			17 16760		
+28			20 9876		
+30			21 12830		
+32			22 -3070		
+34			23 7743		
+36			24 8235		
+38			25 689		
+40			28 3150		
+42			27 4298		
+44			30 6026		
+46			31 -8609		
+48			32 8022		

*MEASURED ABOVE MEAN LUNAR RADIUS

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
REVISOR <i>G. J. Smith</i>		R35 LUNAR LANDMARK SELECTION	
DESIGNER <i>G. J. Smith</i>	DATE 10/21/64	ANALYST <i>F. J. Smith</i>	DOCUMENT NO. FC-2595
DOCSM <i>F. J. Smith</i>	7/19/64	APPROV <i>J. A. Moore</i>	COLOSSUS 237
		REV	SHEET 18 OF 18

PE3 - CISLUNAR MIDCOURSE NAVIGATION
CALLED FROM DSKY

MAJOR SUBROUTINES

POINTAX - COMPUTES THE CSM TO LANDMARK/HORIZON POINTING VECTOR
HORIZ - COMPUTES HORIZON LOCATION VECTOR

SPECIAL CONVENTIONS

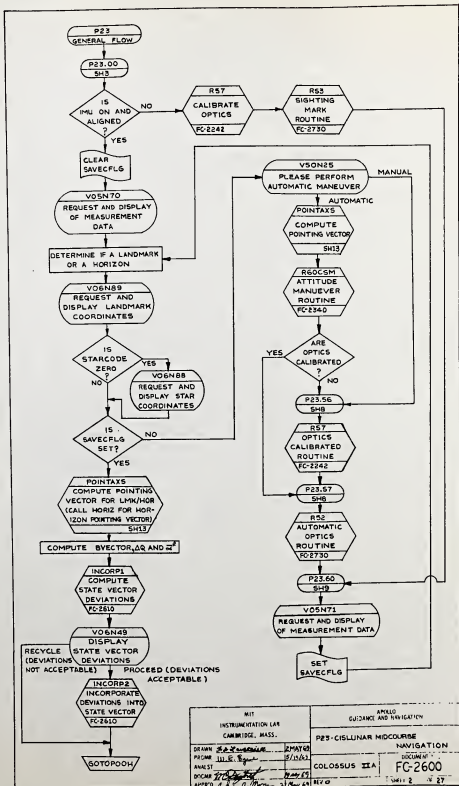
- 1) SCALING INDICATED AS $2^3/2^Y$ MEANS 2^3 IS THE SCALING IN EARTH SPHERE OF INFLUENCE AND 2^Y IS THE SCALING IN MOON SPHERE OF INFLUENCE
- 2) *VARIABLE* IN THE SCALING FIELD OF THE SUMMARY SHEETS INDICATES THAT THE ERASABLE LOCATION IS EITHER A MATRIX WHOSE COMPONENTS HAVE DIFFERENT SCALING OR A 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. NY0, 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 "NY0".

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARLOND GUIDANCE AND NAVIGATION	
BRAIN A. C. WILLIAMS		PE3 - CISLUNAR MIDCOURSE NAVIGATION	
PROJ: W.E. Byrd	TH0605	COLLOSSUS II A	DOCUMENT NO. FC-2600
INSTR: <i>[Signature]</i>	5/1/61	REV D	UNIT 1 OF 2
BOOK: <i>[Signature]</i>	5/2/61		
APP: <i>[Signature]</i>	5/2/61		



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO
GUIDANCE AND NAVIGATION

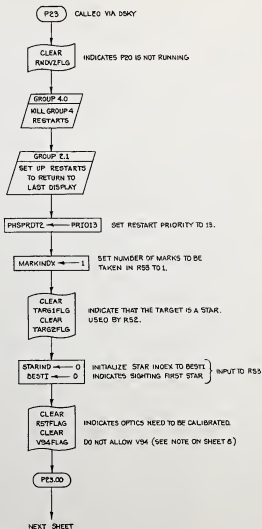
DRN: *W. S. ...* 2/24/68
PICAR: *W. S. ...* 8/15/62
ANALYST: *W. S. ...* 11/21/65
DOCAR: *W. S. ...* 11/21/65
APPRO: *W. S. ...* 2/24/68

P23-CISLUNAR MIDCOURSE NAVIGATION

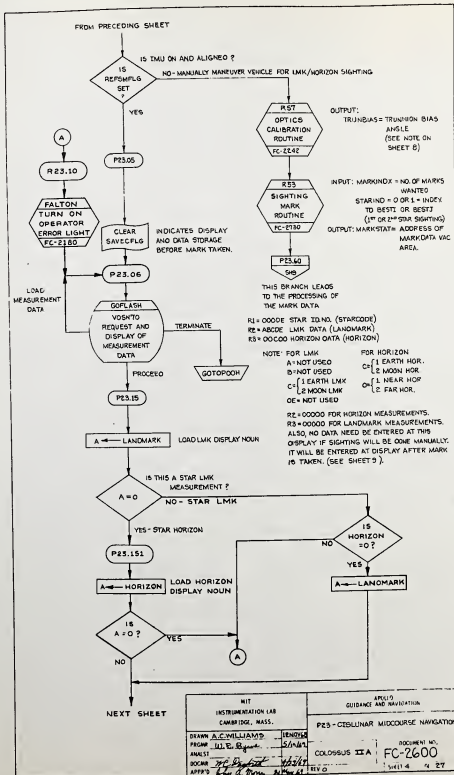
COLOSSUS IIIA

FC-2600

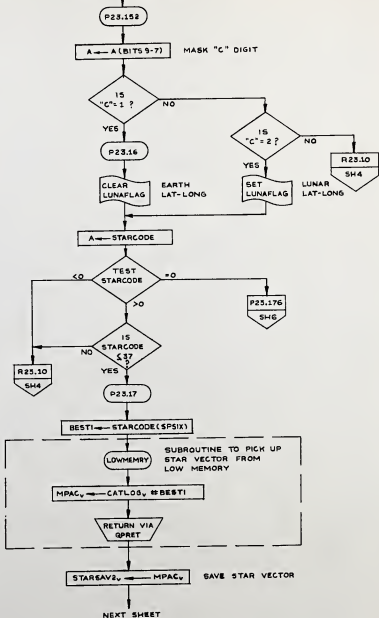
1 2 27



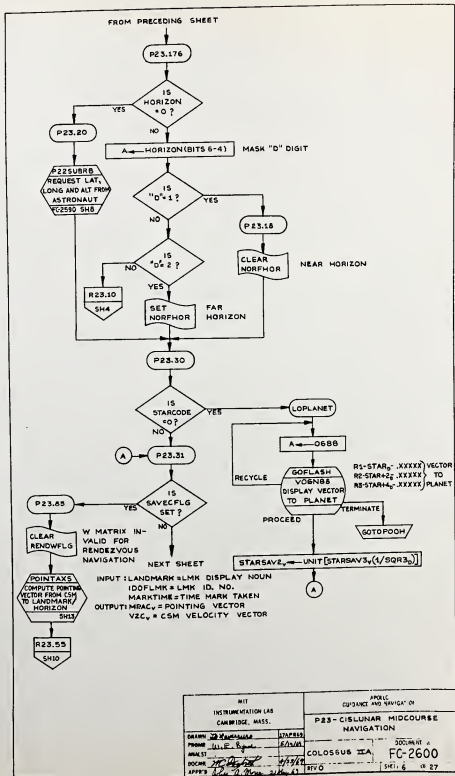
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN: A.C. WILLIAMS		P23 - CIRCULAR MIDCOURSE NAVIGATION	
PROGRAM: J.L.E. 8/1964	REVISED: 5/11/67	DRAWING NO.	
APPROVED: J.C. D. 8/1964	REVISED: 4/1967	COLOSSUS II A	
APPROVED: J.C. D. 8/1964		REV 0	
		FC-2600	
		SHEET 5 OF 27	

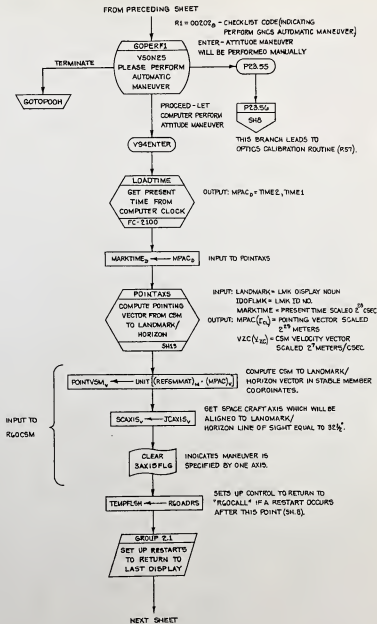


FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P23-CISLUNAR MIDCOURSE NAVIGATION	
DRAWN <i>W.A. Gammale</i>	DESIGNED <i>S/S/62</i>	DOCUMENT NO.	
PROG. <i>111.16.6</i>		COLOSSUS IIA	FC-2600
ANALYST <i>W.S. Gammale</i>	TESTER <i>W.S. Gammale</i>	REV 0	SHEET 5 OF 27
APPROV. <i>John H. ...</i>			





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRWING	A. D. WILLIAMS	15K28A	PE3 - CIRCULAR MIDCOURSE NAVIGATION
DESIGN	J. D. B.	5/15/68	
ANALYST			DOCUMENT NO.
DOCK			COLOSSUS IIA
APP'G			FC-2600
		REV D	SHEET 14 OF 17

FROM PRECEDING SHEET

R60CALL

R60CSM

ATTITUDE
MANEUVER
ROUTINE
FC-2340

INPUT: POINTVSM = DIRECTION OF ALIGNMENT
SCAX IS = SPACECRAFT BODY VECTOR TO BE ALIGNED
SANSPLS = SET - 3 AXIS MANEUVER
CLEAR = 1 AXIS MANEUVER
OUTPUT: SCAX IS WILL BE ALIGNED TO POINTVSM

GROUP2

SET UP RESTARTS
TO SCHEDULE NEXT
LOCATION AS A FINOVAC
JOB WITH SAME PRIORITY

HAVE OPTICS BEEN CALIBRATED ?

YES

IS
R5TFLAG
SET ?

NO

P23.54

R5T

OPTICS
CALIBRATION
ROUTINE
FC-2242

OUTPUT: TRUNBIAS = TRUNNION BIAS ANGLE
I.E. ANGLE DETERMINED WHEN SHAFT
AND LMK LINE OF SIGHTS ARE SUPER-
IMPOSED (NOT NECESSARILY ZERO
BECAUSE OF UNEVEN HEATING BY SUN)

P23.57

SET

V54FLAG
GET
R5TFLAG

ALLOW V54 TO BE ENTERED WHILE IN R52 (R55).
NOTE: IF THE ASTRONAUT WISHES TO RECYCLE AND REMANUEVER THE VEHICLE,
HE WILL ENTER V54 BEFORE ACCEPTING THE MARK (VIA R55) AND THE
PROGRAM RETURNS TO "V45CENTER" (SHT).
INDICATES THAT OPTICS HAVE BEEN CALIBRATED.

R52

AUTOMATIC
OPTICS
ROUTINE
FC-2730

INPUT: STARSVEZ = STAR VECTOR
OPTICS DRIVEN AUTOMATICALLY TO SIGHT
ON GIVEN STAR.
OUTPUT: MARKSTAT = ADDRESS OF MARK DATA TAKEN IN R55.
NOTE: R52 WILL CONTINUE TO POINT SXT LOS AT THE GIVEN
STAR UNTIL THE OPTICS SWITCH IS PLACED IN MANUAL
(FROM AUTOMATIC) WHICH AUTOMATICALLY CALLS
R53 TO TAKE MARKS.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARC10 GUIDANCE AND NAVIGATION	
DESIGN: J.C. WILLIAMS	INFORM: J.C. WILLIAMS	P23 - CISLUNAR MIDCOURSE NAVIGATION	
PROGRAM: J.C.S. B. Jones	3/25/64	DOCUMENT NO.	
ANALYST:		COLOSSUS II A	FC-2600
DOCNO: FC-2600	6/25/67		
APPROV: John A. Ryan	2/2/68	HYO	SHEET 6 OF 27

FROM PRECEDING SHEET

CLEAR
V54FLAG
CLEAR
R57FLAG

DO NOT ALLOW V54 TO BE ENTERED
AFTER THIS POINT.
INDICATES THAT THE OPTICS SHOULD BE
RECALIBRATED IF ANOTHER MARK IS TO BE TAKEN

P23.60

INHIBIT
INTER-
RUPTS

MARKDATA ← MARKSTAT (BITS 10 TO 1)

GET ADDRESS OF MARK
DATA TAKEN BY R55

MARKSTAT LOCATIONS
0,1 = TIME
2,4,6 = IMU ANGLES
5 = TRUNNION ANGLE
3 = SHAFT ANGLE

MARKTIME₂ ← O₂ # MARKDATA

GET TIME OF MARK

TRUNION ← S # MARKDATA

GET TRUNNION ANGLE

RELEASE
INTER-
RUPTS

MARKDOWN₁ ← MARKDATA
MARKDOWN₂ ← MARKDATA # 6

LOAD
MEASUREMENT
DATA

GOPFLASH
VORNTS
REQUEST AND
DISPLAY OF
MEASUREMENT DATA

TERMINATE

R1=000DE STAR ID
R2=ABCE LMK ID
R3=00CDD HDR ID

SEE NOTE ON SHEET 4
FOR COOES.

GOTOPOOH

PROCEED

P23.65

SET
SAVECFLO

INDICATES THAT MARK HAS BEEN TAKEN AND IT SHOULD
BE INCORPORATED INTO STATE VECTOR AFTER ABOVE
MEASUREMENT DATA IS PROCESSED.

P23.15

SHA

THIS BRANCH LEADS TO
PROCESSING OF ABOVE
MEASUREMENT DATA.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS	15/NOV/66	P23 - CSLINAR MIDCOURSE NAVIGATION	
PROB'D W. B. RYAN	5/12/66	DOCUMENT NO.	
ANALYST		COLOSSUS II A	FC-2600
BOOKED	6/23/67		
APPROVED	7/1/67	REV D	SHEET 5 OF 27

RES50

$$\begin{aligned} \vec{U}_{CS} &= \text{UNIT}(\vec{r}_{CS}) \\ \text{POLD}_0 &\leftarrow \text{UNIT}(\text{MPAC})_V \end{aligned}$$

COMPUTE UNIT POINTING VECTOR FROM CSM
TO LANDMARK/HORIZON.
GSOP EQU. 2.6.2

$$\begin{aligned} \text{POL30} &\leftarrow r_{CS}^2 \\ \text{POL32} &\leftarrow |r_{CS}| \\ \text{POL30}_V &\leftarrow \text{POL3A}_V \end{aligned}$$

SAVE r_{CS}^2 FOR USE IN COMPUTING THE VARIANCE, σ_{θ}^2 .
NOTE: r_{CS}^2 (AND $|r_{CS}|$ IN POL32) ARE FORMED BY
THE ABOVE UNIT INSTRUCTION.

$$\begin{aligned} \vec{V}_C^* &= \text{UNIT}(\vec{U}_{CS} + \vec{V}_C^*/c) \\ \text{UCLSTAR}_V &\leftarrow \text{UNIT}(\text{POLD}_0 + (\text{VEC}_0)(\text{ONE}/c)) \end{aligned}$$

CORRECT POINTING VECTOR FOR ABERRATION.
GSOP EQU. 2.6.4

$$\begin{aligned} \vec{U}_S^* &= \text{UNIT}(\vec{U}_S + (\vec{V}_S^* - \vec{V}_{E13})/c) \\ \text{USSTAR}_V &\leftarrow \text{UNIT}(\vec{U}_S + [(\text{VEC}_0 - \text{VESS}_0)(\text{ONE}/c)]) \end{aligned}$$

CORRECT STAR VECTOR FOR ABERRATION.
GSOP EQU. 2.6.3
 \vec{V}_{E13} = VELOCITY OF SUN RELATIVE TO THE EARTH

$$\begin{aligned} \text{COSQ} &= \vec{U}_S^* \cdot \vec{U}_{CLSTAR}^* \\ \text{POLD}_0 &\leftarrow \text{USSTAR}_V \cdot \text{UCLSTAR}_V \end{aligned}$$

COMPUTE COSINE OF ESTIMATED ANGLE BETWEEN
STAR AND POINTING VECTOR.
GSOP EQU. 2.6.21

$$\vec{b}_0 = \text{UNIT}(\vec{U}_S^* - \text{COSQ} \cdot \vec{U}_{CLSTAR}^*)$$

COMPUTE GEOMETRY OF
MEASUREMENT VECTOR (b_0, b_1, b_2)
GSOP EQU. 2.6.21

$$\begin{aligned} b_1 &= 0 \\ b_2 &= 0 \\ (\text{BVECTOR} + \vec{b}_0)_V &\leftarrow \text{ZEROVECS}_V \\ (\text{BVECTOR} + \vec{b}_2)_V &\leftarrow \text{ZEROVECS}_V \end{aligned}$$

$$\begin{aligned} \text{POL2} &= -\cos^{-1}(\text{COSQ}) \\ \text{POL2}_0 &\leftarrow -\text{ARCOS}(\text{POLD}_0) \end{aligned}$$

SAVE STAR TO POINTING VECTOR ANGLE

$$\begin{aligned} \text{MPAC}_0 &\leftarrow \text{ZEROVECS}_0 \\ \text{MPAC} &\leftarrow \text{TRUNION} - \text{VARSUBL} \\ \text{POLA}_0 &\leftarrow \text{MPAC}_0 \end{aligned}$$

CLEAR MPAC.
CONVERT TRUNION ANGLE FROM 1'S TO 2'S COMPLEMENT.
(BY SPECIAL SUBTRACT INSTRUCTION)
STORE TRUNION ANGLE FOR LATER USE.

NOTE: VARSUBL IS DEFINED TO BE 3 WORDS,
THE FIRST WORD OF WHICH IS ZERO.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO EVIDENCE AND NAVIGATION	
DRAWN A.C. POLLETT/MSD		PES-CELESTIAL MIDCOURSE NAVIGATION	
FROM 10.85.8	DATE 5/10/65	DOCUMENT NO.	
ANALYST	COLOSSUS IIA	FC-2600	
DOCMT 700-22-200	4/23/67	SHEET 10 OF 27	
APPR'D J. L. ...	REV 0		

FROM PRECEDING SHEET

$$MPAC = \left[(A - TRUNJN_{MAX}) - \cos^{-1}(\cos Q) + 19.77 \right] (r_{GL})$$

$$MPAC_D \leftarrow \left[(POLA_D - TRUNJN/A_S) + POLB_D + TRUNIS \cdot POL3E_D \right] (PI/4.0)_D$$

COMPUTE MEASUREMENT DEVIATION
GSOP EQU. 2.6.21

IS MOON SPHERE OF INFLUENCE?
MOON FLG SET?

NO

YES

ADJUST SCALING
MPAC SCALED 2^{27} METERS FROM 2^{28} METERS IF IN MOON SPHERE OF INFLUENCE.

RES.51

$\Delta Q = MPAC$
DELTAQ $\leftarrow MPAC_D$
DEVIATION BETWEEN MEASURED ANGLE AND ESTIMATED ANGLE.

$$\sigma^2 = r_{GL}^2 \cdot VAR_{TRUN} + VAR_{POL}$$

$$VARIANCE_T \leftarrow \left[(POL3D_D - TRUNVAR_D)_T + VARSUB_T \right]$$

VARIANCE OF MEASUREMENT ERRORS.
GSOP EQU. 2.6.22

CLEAR DIMENFLG
INDICATES W-MATRIX IS OK FOR INCORPORATION

INCRP1
COMPUTE STATE VECTOR DEVIATIONS
 $\Delta X = (\Delta \delta, \Delta V)$
FC-2410

INPUT: VARIANCE (σ^2) = MEASUREMENT OF ERROR
VARIANCE SCALED 2^{28} METERS²
DELTAQ (ΔQ) = MEASUREMENT DEVIATION SCALED 2^{28} METERS
BYVECTOR = MEASUREMENT GEOMETRY VECTOR
DIMENFLG = DIMENSION OF W-MATRIX
OUTPUT: DELTAX = STATE VECTOR DEVIATIONS

GRUPE2

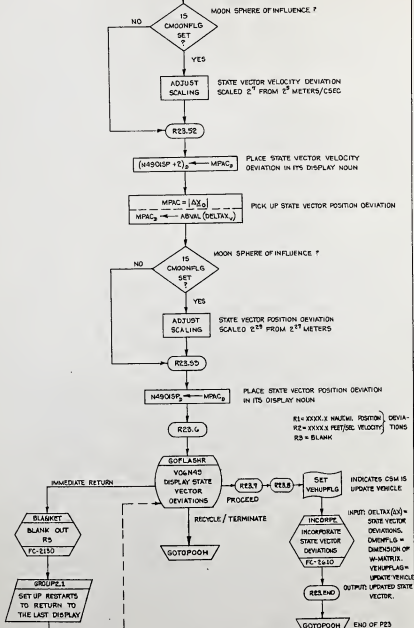
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINDVAC JOB WITH SAME PRIORITY

$MPAC = |\Delta X_T|$
 $MPAC_D \leftarrow ADVAL(DELTAQ + G)_D$
PICK UP STATE VECTOR VELOCITY DEVIATION

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DESIGNER A.C. WILLIAMS	ISSUED 5/19/68	PDS - CESLINAR MIDCOURSE NAVIGATION	
PROGRAMMER L.J. Szymanski	APPROVED J.L. Szymanski	COLLOSSUS IIA	DOCUMENT NO. FC-2600
ANALYST		REV 0	DATE 11 19 68

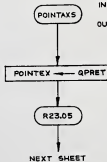
FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P23-CISLUNAR MIDCOURSE NAVIGATION	
PROGRAM IN FC-2600	5/1/62	DOCUMENT NO.	
ANALYST		COLOSSUS II A	FC-2600
DOCSR			SHEET II OF 12
APPROVED		BY	

SUBROUTINE WHICH COMPUTES THE CSM TO
LANDMARK/HORIZON POINTING VECTOR

INPUT : LANDMARK = LMK DISPLAY NOUN
MARKTIME = TIME MARK TAKEN
OUTPUT: PDLO = MPAC(L_{CC}) = POINTING VECTOR
 SCALED 2²⁹ METERS
VZC(V_{ZC}) = CSM VELOCITY VECTOR
 SCALE 2⁷ METERS/CSEC



SAVE RETURN

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO COURSE AND NAVIGATION:	
		P23 Cislunar Midcourse NAVIGATION	
DESIGN OF <i>W. H. ...</i>	IMAYM	DOCUMENT NO.	
PROGRAM <i>UL-10-0</i>	5162	COLOSSUS IIA	FC-2600
ANALYST <i>J. ...</i>		SHEET 15 OF 27	
DOCSN <i>...</i>		REV 0	
APPROV <i>...</i>	8/15/65		

FROM PRECEDING SHEET

IS THE W-MATRIX INITIALIZED FOR MIDCOURSE NAVIGATION ?

YES

NO

PDL0 ← WMIDPOS0

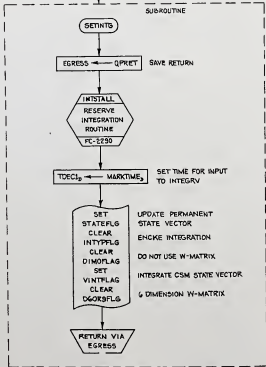
PLACE PAD LOADED W-MATRIX POSITION (w_{mr}) AND VELOCITY (w_{mv}) INITIALIZATION ELEMENTS IN THE PUSHLIST FOR INPUT TO INITIALW.

INITIALW
INITIAL W
MATRIX FOR
MIDCOURSE
NAVIGATION
FC-2550

INPUT: PDL(WMIDPOS) = W-MATRIX POSITION INITIALIZATION VALUE
PDL(WMIDVEL) = W-MATRIX VELOCITY INITIALIZATION VALUE
OUTPUT: INITIALIZED W-MATRIX

$$\begin{bmatrix} W_0 & W_1 \\ W_2 & W_3 \end{bmatrix} = \begin{bmatrix} w_{mr} & 0 & 0 & 0 \\ 0 & w_{mv} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

RE3.1



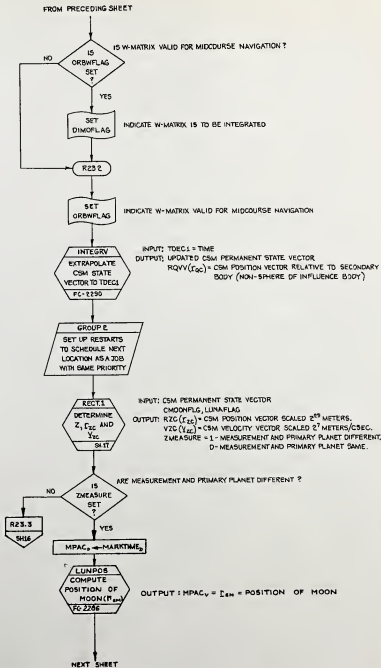
SAVE RETURN

SET TIME FOR INPUT TO INTEGRV

UPDATE PERMANENT STATE VECTOR
ENCKE INTEGRATION
DO NOT USE W-MATRIX
INTEGRATE CSM STATE VECTOR
& DIMENSION W-MATRIX

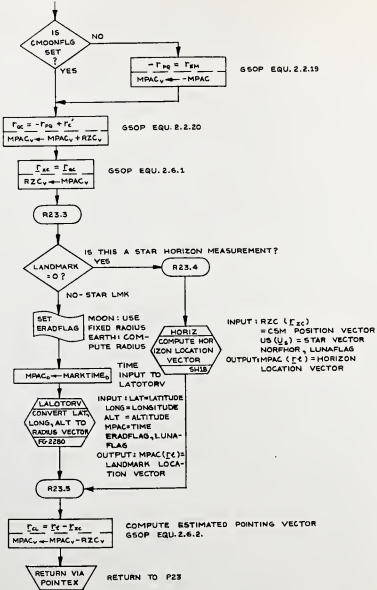
NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		P23 - CISLUNAR MIDCOURSE NAVIGATION	
PROGRAM W. E. B. GUNN	CS/ONS	DOCUMENT NO.	
ANALYST	S. A. G. S.	FC-2600	
DOCM	4/3/67	COLOSSUS II A	
APPROV	4/24/67	WELL 14 OF 27	



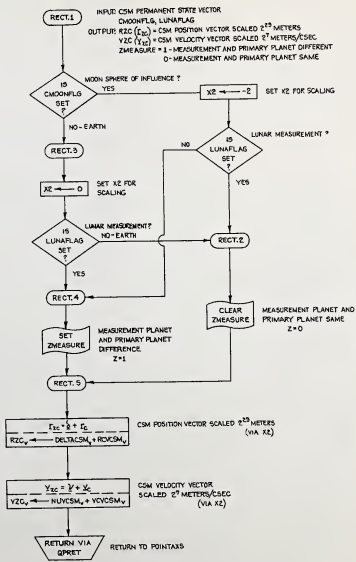
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAMAN A. C. WILLIAMS	REVISIONS 5/1/69	PFS-C/LUNAR MIDCOURSE NAVIGATION	
PROGRAM J. E. D.	ANALYST M. S. G.	DOCUMENT NO. COLDOSUS IA	FC-2600
APPROVED L. R. B.	REV D	DATE MAY 15 1969	TIME 10 27

FROM PRECEDING SHEET



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P23 CISELUNAR MIDCOURSE NAVIGATION	
DRAWN <i>J.P. Gorman</i>	DESIGNED <i>J.M. Hayes</i>	DOCUMENT #1	
PROF. <i>M.E. Gorman</i>	SCALE <i>5/10/60</i>	COLOSSUS IIA	FC-2600
ANALYST <i>J.P. Gorman</i>	DATE <i>5/10/60</i>	RVC	SHEET 16 OF 27
DOCTR. <i>J.P. Gorman</i>	APPROV. <i>J.P. Gorman</i>		

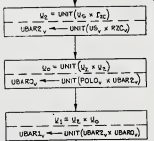
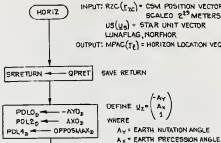
SUBROUTINE TO COMPUTE Z , r_{zc} AND v_{zc}



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PES-CISLUNAR MIDCOURSE NAVIGATION	
FROM W.A.C. BROWN	DATE 5/2/63	DOCUMENT NO. FC-2600	
REVISION 2	DATE 10/2/67	SHEET 22 OF 27	
APPROVED J.P. ...	REV 0		

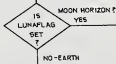
SUBROUTINE WHICH COMPUTES HORIZON LOCATION VECTOR

INPUT: RZC (r_{zc}) = CSM POSITION VECTOR RELATIVE TO MEASUREMENT PLANET
 SCALED 2^{13} METERS.
 US (u_s) = STAR UNIT VECTOR
 LUNAFLAG, HORIZHOR
 OUTPUT: MPAC (r_p) = HORIZON LOCATION VECTOR SCALED 2^{19} METERS.

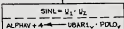


GSOE EQU 2.6.6
 DEFINE ORTHOGONAL
 COORDINATE SYSTEM
 WITH:
 u_0 ALONG SEMI MAJOR
 AXIS OF HORIZON ELLIPSE.
 u_2 ALONG SEMI MINOR
 AXIS OF HORIZON ELLIPSE.
 u_1 PERPENDICULAR TO
 HORIZON ELLIPSE.

NOTE:
 THE HORIZON ELLIPSE IS THE
 INTERSECTION OF THE PLANE
 DEFINED BY THE STAR UNIT
 VECTOR, u_0 , AND THE CSM
 POSITION VECTOR, r_{zc} , WITH
 THE HORIZON OF THE EARTH
 (MOON).



L IS THE INCLINATION
 ANGLE OF THE HORIZON
 ELLIPSE WITH RESPECT
 TO THE EQUATORIAL
 PLANE OF THE EARTH.



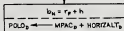
GSOE EQU 2.4.5



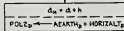
GSOE EQU 2.6.20
 SET SEMI MINOR
 AND SEMI MAJOR
 AXES OF HORIZON
 ELLIPSE TO MOON
 RADIUS.



INPUT: ALPHA + 4 (SINL)
 + SINE OF LATITUDE
 SCALED 2^1
 OUTPUT: MPAC = ERADM
 = RADIUS OF EARTH
 SCALED 2^{19} METERS



DETERMINE SEMI MINOR AXIS
 OF HORIZON ELLIPSE
 GSOE EQU 2.4.9



DETERMINE SEMI MAJOR AXIS
 OF HORIZON ELLIPSE
 GSOE EQU 2.6.10

HORIZOR

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PES-CIS-LINAR MIDCOURSE NAVIGATION	
PREPARED W.A.L.E. BRYANT		COLLOSSUS IIIA	
ANALYST		FC-2600	
DOORMAN		SHEET 10 OF 24	
APPROVED		REV 0	

FROM PRECEDING SHEET

$$\begin{matrix} \overline{E}_u = M \overline{E}_{10} \\ \text{PDL4}_D \leftarrow (\text{UBARD}_u)(\text{RZC}_v) \end{matrix}$$

TRANSFORM POINTING VECTOR TO THE HORIZON COORDINATE SYSTEM. GSOP EQU. 2.6.12

$$\begin{matrix} \overline{U}_{2M} = M \overline{U}_2 \\ \text{PDL10}_D \leftarrow (\text{UBARD}_u)(\overline{U}_2) \end{matrix}$$

TRANSFORM STAR VECTOR TO THE HORIZON COORDINATE SYSTEM. GSOP EQU. 2.6.12

NOTE:
$$M = \begin{pmatrix} 0 & 1 \\ U_1^T & U_2^T \end{pmatrix}$$

$$\begin{matrix} \text{PDL34}_D \leftarrow \text{PDL2}_D \\ \text{MPAC}_D \leftarrow \text{FDL4}_D \end{matrix}$$

PICK UP δ_u
PICK UP X_u

$$\begin{matrix} \text{DIVIDE} \\ \text{MPAC}_D = \frac{\text{MPAC}_D}{\text{PDL34}_D} \\ \text{SUZZ} \end{matrix}$$

FORM $\frac{X_u}{\delta_u}$

$$\text{PDL30}_D \leftarrow \text{MPAC}_D \cdot \text{MPAC}_D$$

FORM $\frac{X_u^2}{\delta_u^2}$

$$\begin{matrix} \text{PDL34}_D \leftarrow \text{PDL2}_D \\ \text{MPAC}_D \leftarrow \text{PDL6}_D \end{matrix}$$

PICK UP b_u
PICK UP Y_u

$$\begin{matrix} \text{DIVIDE} \\ \text{MPAC}_D = \frac{\text{MPAC}_D}{\text{PDL34}_D} \\ \text{SUZZ} \end{matrix}$$

FORM $\frac{Y_u}{b_u}$

$$\begin{matrix} A = \frac{X_u^2}{\delta_u^2} + \frac{Y_u^2}{b_u^2} \\ \text{PDL16}_D \leftarrow \text{PDL30}_D + \text{MPAC} \cdot \text{MPAC} \end{matrix}$$

GSOP EQU. 2.6.17

$$\begin{matrix} \text{PDL15} = \sqrt{A-1} \\ \text{PDL18}_D \leftarrow \text{SQRT}(\text{PDL16}_D - 1.0810) \end{matrix}$$

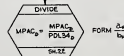
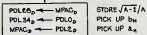
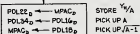
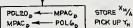
$$\begin{matrix} \text{PDL34}_D \leftarrow \text{PDL16}_D \\ \text{MPAC}_D \leftarrow \text{FDL4}_D \end{matrix}$$

PICK UP X_u
PICK UP A

NEXT SHEET

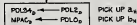
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PES - COLLINAR MIDCOURSE NAVIGATION	
FORM M.F. 8	5/1/62	DOCUMENT NO.	
APPROV. <i>[Signature]</i>	2/2/62	COLOSSUS III A	FC-2600
APPROV. <i>[Signature]</i>	2/2/62	REVO	SHEET 13 OF 17

FROM PRECEDING SHEET



$$A = \frac{a_D}{b_D} \cdot \sqrt{A-1}/A - Y_D$$

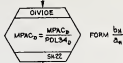
PDL24_D ← MPAC_D · POLE2_D · PDL6_D



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		PES - CIRCULAR MIDCOURSE NAVIGATION	
FROM W.E. Boyette	2/12/63	DOCUMENT NO.	
ANALYST		COLOSSUS II A	FC-2600
DOOR	12/9/62	REV 0	SHEET 20 of 27
APPROV	John D. ...		

FROM PRECEDING SHEET



$A/A = b_H/\Delta_n \cdot \sqrt{A-1}/A \cdot X_H$
$PDL26_D \leftarrow MPAC_D \cdot PDL20_D \cdot PDLA_D$

$t_{01} = X_H/A + A/A$	} GSOP EQU. 2.6.15
$PDL28_D \leftarrow PDL20_D + PDL24_D$	

$t_{02} = Y_H/A - A/A$
$PDL30_D \leftarrow PDL22_D - PDL26_D$

$t_{11} = X_H/A - A/A$	} GSOP EQU. 2.6.16
$PDL36_D \leftarrow PDL30_D - PDL24_D$	

$t_{12} = Y_H/A - A/A$
$PDL18_D \leftarrow PDL22_D + PDL24_D$

$t_{13} = 0$
$PDL20_D \leftarrow ZEROVECS_D$

$t_{03} = 0$
$PDL32_D \leftarrow ZEROVECS_D$

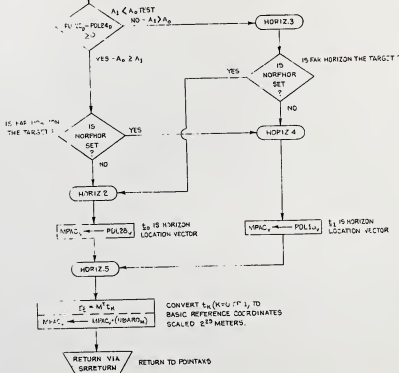
$A_0 = U_{2H} \cdot UNIT(t_{01} - t_{02})$	} GSOP EQU. 2.6.18
$PDL22_D \leftarrow PDL10_D \cdot UNIT(PDL20_D - PDLA_D)$	

$A_1 = U_{2H} \cdot UNIT(t_{11} - t_{12})$
$PDL24_D \leftarrow PDL10_D \cdot UNIT(PDL36_D - PDLA_D)$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN <u>A. C. WILLIAMS</u> KTH/ML	RES-CIS/LINAR W/COURSE NAVIGATION
PFRM <u>W.L.C. B.</u> 5/11/68	DOCUMENT NO.
ANALST <u>[Signature]</u>	COLOSSUS IIA <u>FC-2600</u>
DOCM <u>[Signature]</u> 10/28/72	SHEET 22 OF 27
APPR <u>[Signature]</u> 10/28/72	REV 0

FROM PRECEDING SHEET



DIVIDE

$POL2_{00} \leftarrow \text{NORM}(MPAC_{00})/C$ NORMALIZING COUNT IN X1
 $MPAC_{00} \leftarrow \text{NORM}(POL2_{00})$ NORMALIZING COUNT IN S1

$MPAC_{00} \leftarrow POL2_{00}/MPAC_0$ FORM $\frac{MPAC}{POL2_{00}}$

$X1 \leftarrow X1 - S1$ X1 CONTAINS SCALE ADJUSTING FACTOR

RETURN VIA GPRET RETURN TO HORIZ

INSTRUMENTATION LAB CAMPBELL J. WATTS LEAH A. C. WILLIAMS W.E. B. JONES J. D. GIBSON J. H. ROSE	223-CISLUNAR MIDCOURSE NAVIGATION COLLOSSUS II A FC-2600 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
P2SUBRB	2550	REQUEST LAT, LONG AND ALT FROM ASTRONAUT	SH 6
LOADTIME	2100	GET PRESENT TIME FROM COMPUTER CLOCK	SH 7
R80CSM	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
RNDVFLG 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 8 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	DMU ON AND ALIGNED	DMU 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 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 8	SH 6	SH 22
RENDWFLG FLAGWORD 5 BIT 1	W - MATRIX VALID FOR RENDEZVOUS NAVIGA- TION	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	

BIT INSTRUMENTATION LAB CAMBERLINE, MASS.		ORIGID GUIDANCE AND NAVIGATION	
FORM 8-64		P23 - Cislunar MIDCOURSE NAVIGATION	
DATE	APPROVED	COLOSSUS IIA	DOCUMENT NO. FC-2600
NOV 17 1964	5/141		
APPROVED	NOV 17 1964		
APPROVED		REV 0	SHEET 23 OF 27

1
 FLAGS (CONTINUED)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
U000N1FLG FLAGWORD 8 BIT 12	PERMANENT CSM STATE VECTOR IN LUNAR SPHERE	PERMANENT CSM STATE VECTOR IN EARTH SPHERE			SH 11, 12, 17
U000N1FLG FLAGWORD 3 BIT 9	DIMENSION OF W-MATRIX IS 8 FOR INCORPORATION	DIMENSION OF W-MATRIX IS 6 FOR INCORPORATION		SH 11	
V000P1FLG FLAGWORD 1 BIT 8	CSM STATE VECTOR IS BEING UPDATED	LEM STATE VECTOR IS BEING UPDATED	SH 12		
W000R1FLG FLAGWORD 3 BIT 6	W-MATRIX VALID FOR MIDCOURSE NAVIGATION	W-MATRIX INVALID FOR MIDCOURSE NAVIGATION	SH 15		SH 14, 15
X000S1FLG FLAGWORD 3 BIT 5	PERMANENT STATE VECTOR TO BE UPDATED	PERMANENT STATE VECTOR NOT TO BE UPDATED	SH 14		
Y000T1FLG FLAGWORD 3 BIT 4	CONIC INTEGRATION	ENCKE INTEGRATION		SH 14	
Z000O1FLG FLAGWORD 3 BIT 1	W-MATRIX IS TO BE USED	W-MATRIX NOT TO BE USED	SH 15	SH 14	
A000I1FLG FLAGWORD 3 BIT 3	CSM STATE VECTOR TO BE INTEGRATED	LEM STATE VECTOR TO BE INTEGRATED	SH 14		
D000R1FLG FLAGWORD 3 BIT 2	DIMENSION OF W-MATRIX IS 9 FOR INTEGRATION	DIMENSION OF W-MATRIX IS 6 FOR INTEGRATION		SH 14	
ZMEASURE FLAGWORD 0 BIT 10	MEASUREMENT PLANET AND PRIMARY PLANET DIFFERENT	MEASUREMENT PLANET AND PRIMARY PLANET SAME	SH 17	SH 17	SH 15
ERADFLAG FLAGWORD 1 BIT 13	EARTH: COMPUTE FISCHER ELLIPSOID RADIUS MOON: USE FIXED RADIUS	EARTH: USE FIXED RADIUS MOON: USE RLS FOR RADIUS	SH 18		

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 _D ² - .XXXXX R3 = STAR _D ⁴ - .XXXXX	VECTOR TO PLANET SH 6
V50N25	FLASHING	R1 = 00200	PLEASE PERFORM AUTOMATIC MANEUVER SH 7
V05N71	FLASHING	R1 = 000DE - STAR ID NO R2 = ABCDE - LMK DATA R3 = 000CD0 - HORIZON DATA	REQUEST MEASUREMENT DATA AFTER MARK IS TAKEN SH 9
V06N49	FLASHING	R1 = XXXX X NAUT. MI. POSITION DEVIATION R2 = XXXX X FEET/SEC VELOCITY DEVIATION R3 = BLANK	SH 12

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION P23-CISLUNAR MIDCOURSE NAVIGATION	
DESIGN BY: <i>R. J. ...</i>	DATE 5/1/61	DRAWING NO. FC-24600	
PREPARED BY: <i>R. J. ...</i>	DATE 5/1/61	REVISED BY: <i>R. J. ...</i>	
APPROVED BY: <i>R. J. ...</i>	DATE 5/1/61	SHEET 24 OF 27	

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNIT	AGC UNIT	AGC SCALING
PISPRDT2		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
STARS AV2 (ALSO TAGGED US)		TEMPORARY STORAGE OF STAR 1 UNIT VECTOR			(2 ¹ , 2 ¹ , 2 ¹)
IDOFLMK		LANDMARK ID NUMBER		(INTEGER)	2 ¹⁴
MARKTIME		TIME OF MARK	SEC	CSEC	2 ²⁸
REFSMAT		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)
R80ADRS		DESIRED ADDRESS OF 'R80 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	$\underline{U}^* \underline{CL}$	CSM TO LANDMARK/HORIZON UNIT VECTOR CORRECTED FOR ABERRATION			(2 ¹ , 2 ¹ , 2 ¹)
VZC	$\underline{V}^* \underline{C}$	CSM VELOCITY VECTOR	FEET/SEC	METERS/CSEC	(2 ⁷ , 2 ⁷ , 2 ⁷)
USSTAR	$\underline{U}^* \underline{S}$	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	(b_0, b_1, b_2)	GEOMETRY OF MEASUREMENT MATRIX			VARIABLE
TRUNBIAS		CALIBRATION ANGLE FOR SEXTANT	DEG	REV	2 ³
DELTAQ	α	MEASURED AND ESTIMATED DEVIATION	NAUT. MI.	METERS	2 ²⁹ /2 ²⁷
VARIANCE	α^2	VARIANCE OF MEASUREMENT ERRORS		METERS ²	2 ⁴⁰
DELTAQ	α_0	STATE VECTOR POSITION DEVIATIONS	NAUT. MI.	METERS	2 ²⁹ /2 ²⁷
DELTAQ+6	α_1	STATE VECTOR VELOCITY DEVIATIONS	FEET/SEC	METERS/CSEC	2 ⁷ /2 ⁵
N49DISP		DISPLAY NOUN FOR DELTAQ	NAUT. MI.	METERS	2 ²⁹
N49DISP+6		DISPLAY NOUN FOR DELTAQ+6	FEET/SEC	METERS/CSEC	2 ⁷
POINTEX		RETURN ADDRESS FROM POINTAX		(INTEGER)	2 ¹⁴

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		FIELD GUIDANCE AND NAVIGATION	
DRAWN <i>A. J. ...</i> 24 DEC 68		P23 - Cislunar MIDCOURSE NAVIGATION	
PROJ: <i>U.W.S. 86</i>	DATE: <i>5/10/73</i>	DOCUMENT NO.	
ANALYST: <i>J. ...</i>	APPROVED: <i>J. ...</i>	COLOSSUS IIA	FC-2600
DOCNO: <i>...</i>	APPROVED: <i>...</i>	REV D	SHEET 25 OF 27

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNIT	AGC UNIT	AGC SCALING
ALT		ALTITUDE	NAUT. MI	METERS	2^{20}
LAT		LATITUDE	DEG	REV	2^0
LONG		LONGITUDE	DEG	REV	2^0
LANDALT		ALTITUDE DISPLAY NOUN	NAUT. MI.	METERS	2^{20}
LANDLONG		LONGITUDE DISPLAY NOUN	DEG	REV	2^0
EGRESS		SUBROUTINE RETURN ADDRESS		(INTEGER)	2^{14}
TDEC1		TIME FOR INTEGRATION	SEC	CSEC	2^{28}
RZC	$\underline{r} z c$	CSM POSITION VECTOR RELATIVE TO MEASUREMENT PLANET		METERS	2^{20}
RQVV	$\underline{r} q v v$	CSM POSITION VECTOR RELATIVE TO SECONDARY PLANET		METERS	2^{20}
RL	$\underline{r} l$	LANDMARK/HORIZON LOCATION VECTOR		METERS	2^{20}
RCLL	$\underline{r} c l l$	CSM TO LANDMARK/HORIZON VECTOR		METERS	2^{20}
DELTA CSM	$\underline{\delta}$	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{v}	CSM CONIC VELOCITY DEVIATION		METERS/ CSEC	$2^1/2^5$
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

THE INSTRUMENTATION - AL		DATE OF REVISION	
APPROVE NO. 5		P23 - Cislunar MIDCOURSE NAVIGATION	
DRAN <i>G. J. ...</i>	SECRET	COLLOSSUS IIA	FC-2600
FROM <i>W. R. ...</i>	SECRET		
ANALYST <i>...</i>			
ISSUED <i>...</i>			
APPROVED <i>...</i>			26 27

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
PH013		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 ^{1/2} 90° 32 ^{1/2}	{ 269649905 0 .421698725	{ 2 ¹ 2 ¹ 2 ¹
ONE/C		RECIPROCAL OF SPEED OF LIGHT	1/9.835712 x 10 ⁻⁹ FT/SEC	.333564049 x 10 ⁻⁶ CSEC/METERS	2 ⁻²¹
ZEROVECS		BEGINNING ADDRESS OF 8 REGISTERS OF 0	0	0	2 ¹⁴
VARSUBL		LANDMARK/HORIZON ERROR VARIANCE		3.4299040 x 10 ⁶	2 ⁴⁰
TRUN19		TRUNNION HAS ANGLE	19.77 DEG	.065 REV	2 ⁰
PI/4.0		CONVERSION FACTOR REVS TO RADANS	2π $\frac{RAD}{REV}$.1592 $\frac{RAD}{REV}$	2 ³
TRUNVAR		TRUNNION ERROR VARIANCE		2.5 x 10 ⁻⁸	2 ⁻¹⁹
SDWID		DECIMAL 2		(INTEGER)	2 ¹⁴
LATTAB		BEGINNING ADDRESSES OF STORED LANDMARK		(INTEGER)	2 ¹⁴
LONGTAB		LATITUDE, LONGITUDE, AND ALTITUDE TABLES			
ALTTAB					
DPPOSMAX		DOUBLE PRECISION REGISTER CONTAINING MAXIMUM VALUE	.999999996	37777 37777	2 ⁰
PADMOON	r _m	RADIUS OF MOON		1739090 METERS	2 ²⁹
AEARTH	a	A - AXIS OF EARTH		6378168 METERS	2 ²⁹

PAD LOADS

AGC TAG	GSOP TAG	MEANING
WMIDPOS	w _{mr}	W - MATRIX POSITION INITIALIZATION VALUE
WMIDVEL	w _{vr}	W - MATRIX VELOCITY INITIALIZATION VALUE
VES0	v _{ES}	VELOCITY OF SUN RELATIVE TO EARTH
-AY0	A _y	EARTH NUTATION ANGLE
AX0	A _x	EARTH PRECESSION ANGLE
HORIZALT	h	EARTH HORIZON ALTITUDE

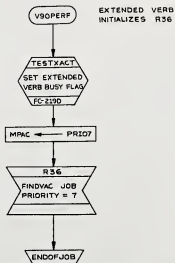
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APCLO ORBITAL AND NAVIGATION	
DESIGN <i>A. J. ...</i>		P23-CISLUNAR MIDCOURSE NAVIGATION	
PROGRAM <i>W. E. ...</i>		COLLOSSUS IIA	
ANALYST <i>M. ...</i>		REV 0	
BOOKING <i>M. ...</i>		FC-2600	
APPROVED <i>J. A. ...</i>		SHEET 27 OF 27	

R36: OUT-OF-PLANE RENDEZVOUS ROUTINE

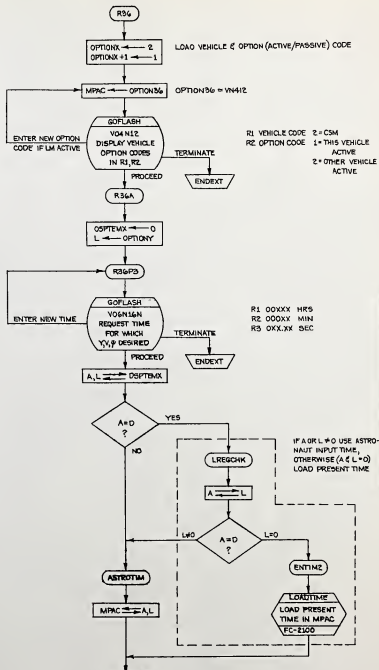
FC-2631

V90PERF, R36

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFOLIO GUIDANCE AND NAVIGATION	
DRAWN: A. C. WILLIAMS		R36	
PKCMB: J. C. Craden		RENDEZVOUS OUT-OF-PLANE DISPLAY	
ANALYST: J. C. Craden		DOCUMENT NO.	
DOOR: J. C. Craden		COLOSSUS II-A FC-2631	
APPROV: John A. Moore		REV. 1 SHEET 1 OF 7	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
		R36	
RENDEZVOUS OUT-OF-PLANE DISPLAY			
DESIGN <i>J.E. Craven</i>	ETCHER	DOCUMENT NO.	
PROGRAM <i>J.E. Craven</i>	FILE NO.	FC-2631	
ANALYST			
DOOR <i>J.E. Craven</i>	REV 1	SHEET 2 OF 7	
APPROV <i>J.E. Craven</i>			

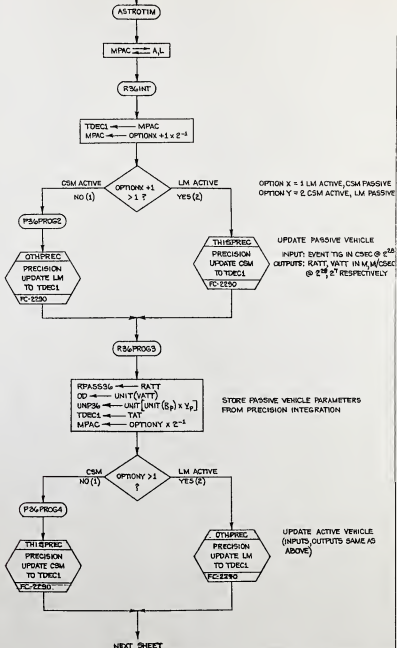


R1 VEHICLE CODE 2 = CSM
R2 OPTION CODE 1 = THIS VEHICLE
ACTIVE
2 = OTHER VEHICLE
ACTIVE

R1 00XXX HRS
R2 000XX MIN
R3 0XX.XX SEC

MIT		APOLLO	
INSTRUMENTATION LAB		GUIDANCE AND NAVIGATION	
CAMBRIDGE, MASS.		R36	
DESIGN	A.C. WILLIAMS	RENDEZVOUS OUT-OF-PLANE DISPLAY	
PROGRAM	2760		
ANALYST			
ROOM		COLOSSUS II - A	DOCUMENT NO.
APPROVED		REV 3	FC-2631
			SHEET 3 OF 7

FROM PRECEDING SHEET



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRWEN A. WILLIAMS	ELAPAS	R36 RENDEZVOUS OUT-OF-PLANE DISPLAY	
PROG# 48	24604	DOCUMENT NO.	
ANALYST		COLOSSUS II-A	FC-2631
DOC#			
APPRD		REV	SHEET 4 OF 7

FROM PRECEDING SHEET

R56-PROGS

$OOD \leftarrow VATT_V$
 $OOD \leftarrow RATT_V$
 $06D \leftarrow RATT_V$
 $1ED \leftarrow RATT_V$
 $3OD \leftarrow TAT_V$
 $MPAC \leftarrow RATT_V$

$LOS_V = \Gamma_P - \Gamma_A$
 $1ED \leftarrow RPASS36 - MPAC$

LINE OF SIGHT VECTOR

$Y = U \cdot \Gamma_A$
 $RANGE \leftarrow (UNP36 \cdot MPAC) \times 2^{-1}$

ACTIVE VEHICLE DISTANCE FROM PLANE OF PASSIVE VEHICLE (ALONG PASSIVE Y-AXIS)

$\dot{Y} = U \cdot \dot{\Gamma}_A$
 $RRATE \leftarrow UNP36 \cdot OOD$

OUT-OF-PLANE COMPONENT OF ACTIVE VEHICLE VELOCITY

$MPAC \leftarrow UNIT(\Gamma_A)$
 $06D \leftarrow UNIT(\Gamma_A)$

$U_A = U_{PA} \wedge Y_A$
 $WIPAC \leftarrow MPAC \times OOD$

ACTIVE VEHICLE MOMENTUM (PLANE) VECTOR

$U_{HP} = (U_{PA} \times Y_A) \times U_{PA}$
 $MPAC \leftarrow UNIT(MPAC \times 180)$

ACTIVE VEHICLE UNIT FORWARD HORIZONTAL

R56B

$OOD \leftarrow MPAC$
 $MPAC \leftarrow 1ED$

$U_{LV} = U_{PA} \times (U_{LV} \cdot \Gamma_A)$
 $MPAC \leftarrow OOD \times (1ED \cdot 180)$

UNIT VERTICAL $\times \cos^{-1}(U_{LV} \cdot \Gamma_A)$
= VERTICAL COMPONENT OF UNIT LOS

$UNIT(U_{HL}) = U_{LV} - U_{PA} \times (U_{LV} \cdot \Gamma_A)$
 $1ED \leftarrow UNIT(1ED - MPAC)$

UNIT HORIZONTAL COMPONENT OF LOS
= UNIT LOS - UNIT VERTICAL COMPONENT LOS

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C. WILLIAMS		R56	
PROGRAM J. A. Leach		RENDEZVOUS OUT-OF-PLANE DISPLAY	
SHEET		COLOSSUS II-A	DOCUMENT NO.
DOC#		FC-2631	
APPROV		REV 1	SHEET 5 OF 7

FROM PRECEDING SHEET

$$\psi = \cos^{-1} \left(\frac{U_{AP} \cdot U_{A'}}{MPAC} \right)$$

$$RTHETA \leftarrow \text{ARCCOS}(\text{OD} \cdot \text{MPAC})$$

PDI

$$\text{MPAC} \leftarrow \frac{(U_{AP} \times U_{A'}) \cdot \sin \psi}{\text{OD} \times \text{MPAC} \cdot \cos \psi}$$

UNIT HORIZONTAL OF ACTIVE VEHICLE CROSSED INTO LOS PROJECTION ON HORIZONTAL; RESULT COMPARED WITH VERTICAL FOR SENSE (PARALLEL UP MEANS PASSIVE VEHICLE IS LEFT OF ACTIVE VEHICLE PLANE/ FORWARD HORIZONTAL.)

SGNMPAC
+ ?

$$\psi = 360^\circ - \psi$$

$$RTHETA \leftarrow \text{DPPSMAX} - RTHETA$$

IF ψ , SUBTRACT FROM 360° TO GIVE POS ANGLE.

R3GTACZ

MPAC \leftarrow BOD RETRIEVE EVENT TIME

SGNAGREE
FORCE SIGN
AGREEMENT TP
FC-2100

OUTPUT IN MPAC, MPAC + 1

DSPTDAX \leftarrow MPAC₀

GOFDASH
VOGNASH
DISPLAY Y, ψ , ϕ

R1 XXX.XX Y IN NAUTICAL MILES TO NEAREST.01 NM

RE YXXX.X Y DOT IN FPS TO NEAREST .1 FPS

R3 XXX.XX PDI, ANGLE BETWEEN LOS VECTOR PROJECTED ON HORIZONTAL PLANE AND UNIT HORIZONTAL ACTIVE

RECYCLE FOR
NEW EVENT TIME

R3GPD
SH1

TERMINATE

PROCEED

ENDEX

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
RESEARCHER A. G. WILLIAMS		RSC RENDEZVOUS OUT-OF-PLANE DISPLAY	
PROJECT J. C. LAMB		DOCUMENT NO.	
ANALYST		COLOSSUS II-A	
DOCUMENT		FC-2631	
APPROVED		REVISION	
		SHEET 6 OF 7	

SUBROUTINES

LOADTIME	LOADS PRESENT TIME INTO MPAC	SH 5
THISPREC	ENKE UPDATE OF CSM	SH 4
OTHPREC	ENKE UPDATE OF LM	SH 4
SGNAGREE	FORCE SIGN AGREEMENT (TRIPLE PRECISION)	SH 6
TESTRACT	SETS EXTENDED VERB BUSY FLAG	SH 2

DISPLAYS

WHERE

VO4N1Z	DISPLAY VEHICLE CODE (1=LM, 2=CSM) IN R1 AND OPTION CODE (1=THIS VEHICLE ACTIVE, 2=PASSIVE) IN R2	SH1
VO6N16N	REQUEST TIME FOR WHICH Y, \dot{Y} , \ddot{Y} DESIRED	SH1
VO6N50N	DISPLAY Y, \dot{Y} , \ddot{Y}	SH4

ERASABLES

UNITS

SCALING

OPTIONX	VEHICLE OPTION CODE (LM=1, CSM=2)		2^1
OPTIONX +1	(EQUALS OPTIONX) VEHICLE CODE (1=CSM ACTIVE, 2=LM ACTIVE)		2^1
DSPTENX	DISPLAY BUFFER AREA (SAME AS OPTIONX)		
TDEC1	TIME STORAGE LOS	CSEC	2^{28}
RPM556	STORAGE FOR PASSIVE VEHICLE POSITION VECTOR	METERS	2^{28}
UNP36	UNIT VECTOR OF PASSIVE VEHICLE MOMENTUM/PLANE		
RANGE	Y, ACTIVE VEHICLE DISTANCE FROM PASSIVE VEHICLE PLANE	METERS	
RRATE	\dot{Y} , ACTIVE VEHICLE VELOCITY COMPONENT NORMAL TO PASSIVE PLANE	M/CSEC	
RTHETA	ψ , ANGLE BETWEEN ACTIVE VEHICLE UNIT FORWARD HORIZONTAL & LOS PROJECTED INTO HORIZONTAL PLANE		

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <u>A.C. WILLIAMS</u>		RD6	
PROJEN <u>J.C. Linder</u>	DATE <u>2.7.68</u>	RENDEZVOUS OUT-OF-PLANE DISPLAY	
ENHET		COLOSSUS II - A	DOCUMENT NO. <u>FC-2631</u>
DOCK <u>John A. Rem</u>	DATE <u>1.16.68</u>	REV 1	SHEET 7 OF 7

MAJOR SUBROUTINES

VTI100 SETS UP INTERMEDIATE VARIABLES FOR GAMDV10 ITERATOR, LIMITS X(1) CHANGE, TESTS RESULTS

GAMDV10 SUBROUTINE WHICH PRODUCES MINIMUM SOLUTIONS FROM ITERATION ON X(1)

PREC100 PRODUCES PRECISION TRAJECTORY CLOSE TO FINAL RADUS AND FLIGHT PATH ANGLE PRODUCED BY CONIC SECTION

RTEVN COMPUTES AND DISPLAYS LANDING SITE

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.

ENCLOSED IS A REPLACEMENT SHEET (SH. 17) TO UPDATE THE COLOSSUS II FLOW CHART FC-2642, REV. 0, TO THE COLOSSUS IIC FLOW CHART FC-2642, REV. 1

MIT THE INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFIELD GUIDANCE AND NAVIGATION	
DRAWN <i>G. J. Smith</i>		P 37	
CHECKED <i>J. P. Smith</i>		RETURN TO EARTH	
PROJECT <i>FC-2642</i>	DESIGNED <i>J. P. Smith</i>	COLOSSUS IIC	DOCUMENT NO.
ANALYST <i>J. P. Smith</i>	APPROVED <i>J. P. Smith</i>		FC-2642
APPROVED <i>J. P. Smith</i>	DATE <i>10/11/54</i>	REV.	SHEET 3 OF 5

P37

P37 IS KEYED IN BY ASTRONAUT OR RECYCLED BY DSKY V32 ENTER AT MOST DISPLAYS.

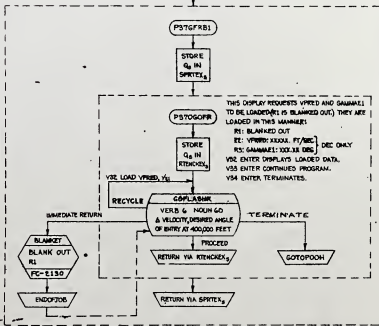
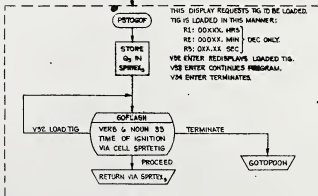
GROUP 4.0
KILL GROUP
& RESTARTS

P37 IS NOT RESTARTABLE

ECSTEER ← OCT. 04000

1 @ 2¹ FOR P40: VALUE USED IN CROSS-PRODUCT STEERING FOR LAMBERT MANEUVER.

YPRD = 0.1 X = 0
GAMMA1 ← ZEROVECS
YPRD ← ZEROVECS



IMMEDIATE RETURN PUTS CONTROL BACK TO PSTGFR1, WHICH CALLS BLANKET. THE END OF JOB RETURNING CONTROL TO GOFLASHR IN PSTGOFPR.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AMSLD GUIDANCE AND SEPARATION	
DESIGNER J. C. VAN LIND	DESIGNED BY J. C. VAN LIND	PST - RETURN TO EARTH (MAIN PROGRAM)	
ANALYST A. J. ...	ANALYZED BY A. J. ...	DOCUMENT NO. COLOSSUS II	FC-2642
DOOR	SHEET 3 OF 53	
APPROVED J. B. ...	DATE 9/24/61		

FROM PRECEDING SHEET

VTEWD ← VTEWD
 RTEGAMED ← MAMAX1
 CDM*1 ← IRTEB1
 MAMAX ← ARTE

VTEWD = VELOCITY VECTOR IN METERS/SEC @ 2°
 GAMMA1 = ANGLE OF ENTRY OF WELLS, IN RADS @ 2°
 POSITIVE ABOVE HORIZON
 IRTEB1 = DEC 8.0 @ 2°4. THIS VALUE IS COMPLEMENTED
 AND LOADED INTO X1 TO OBTAIN THE PROPER ALPHA-VALUE
 VALUES IN CONIC ROUTINES
 CARTE = 6.986643 x 10¹⁶ MAJOR AXIS UPPER BOUND ON
 RETURN TRAJECTORIES
 IRTEB1 = 2 @ 2°18 IN METERS @ 2°20

INVC100
 CALCULATE R(T)/V,
 (Y(T)), T1, P(T), UN,
 VV,
 UM, R(T), CPA
 SHIS

INVC100 CALLS COMPREC, WHICH CALCULATES POSITION AND VELOCITY
 VECTORS AT TIG. IF TIG PUTS THE CRAFT IN THE MOON'S SPHERE OF
 INFLUENCE, IT CALLS AN ALARM, THE ALARM GIVES THE ASTRONAUT
 THE OPTION OF TERMINATING OR RECYCLING, BY WHICH A NEW TIG
 MAY BE ENTERED. IF NO ALARM OCCURS, THE POSITION AND VELOCITY
 VECTORS AT TIG ARE EXAMINED TO DETERMINE WHETHER THEY ARE
 SO NEARLY COLLINEAR AS TO MAKE IT IMPOSSIBLE TO DETERMINE THE
 PLANE OF THE TRANSFER IF THEY ARE WITHIN 1.5 DEGREES, THE PLANE
 OF THE TRANSFER IS ARBITRARILY DEFINED SUCH THAT THE INCLINA-
 TION OF THE ORBIT AFTER THE MANEUVER WILL BE EQUAL TO THE
 ANGLE WHICH THE POSITION VECTOR AT TIG MAKES WITH THE
 EQUATORIAL. (UN, V = ((0,0,1) x R(T)) / |...|)

CLEAR SLOWFLG

Z 0
 RTEDVD < 0
 YES
 NO

INPUT: DSM STATE VECTOR
 SPTTIG = TIG = TIME OF IGNITION.
 OUTPUT: R(T)/V = POSITION VECTOR AT TIG IN METERS @ 2°/2°
 V(T)/V = VELOCITY VECTOR AT TIG IN METERS/SEC @ 2°/2°
 T1 = TIG
 UP(T) = UNIT R(T)/V @ 2°
 UN(V) = UNIT HORIZONTAL VECTOR @ 2°
 CPA = COSINE OF INITIAL FLIGHT PATH ANGLE @ 2°

RTEDVD ← |RTEDVD|

R(T) < KIRTE
 YES
 NO

POLY IS A POLYNOMIAL EVALUATOR: MA = C₀ + C₁P(t₂) + C₂P(t₂)² + C₃P(t₂)³
 INPUT: MPAC R(T) = R(T)/V @ 2°
 C₀ = DEC. 181000.454.0 @ 2°18
 C₁ = DEC. 1.50785145 @ 2°
 C₂ = DEC. -6.44923087 x 10⁻²⁰ @ 2-27
 C₃ = DEC. 9.7169389916 x 10⁻¹⁸ @ 2-34
 OUTPUT: MAMAX2 = MAJOR AXIS UPPER BOUND LIMIT ON RETURN
 TRAJECTORIES OF POSITIVE RADIAL COMPONENT
 IN METERS @ 2°20

SET SLOWFLG

POLY
 MAMAX2 = COT
 C1 - R(T) + C2 - R(T)²
 + C3 - R(T)³
 FC-2100

SIGN (MAM2) IS EQUIVALENT TO C₃ IN G50P5, COLOSSUS R-577.
 T₂ = COUNTLINE FOR CONIC PHASE, UNLA CD; FOR PRECISION, UNLA CD.
 R_{CON} = RADIUS OF CONIC TRAJECTORY (TEMPORARY ESTIMATE).

T₂ = 0
 R_{CON} = 6495000 @ 2°18
 UNLA = MORTHEBIS
 RCON = KIRTE

MORTHE = DEC. -3.0
 KIRTE = DEC. 6495000.0 @ 2°18

IS KEYED-IN FLIGHT PATH ANGLE = 0?
 YES
 NO

IS RTGAMED = 0?
 YES
 NO

$$X(t_2) = \cos(90^\circ - Y(t_2))$$

$$Y(t_2) = \cos^{-1} \text{RTE BC} - \text{RTEGAM2} @ 2^\circ$$

RTEGAMED = HETES-IN ENTRY ANGLE
 RTEBDE = 1/2 @ 90°

RTG340
 DOES TIG PUT DSM CLOSE TO EARTH?
 YES
 NO
 IS K(T) < KIRTE?
 YES
 NO

RTE350

RADIUS SMALL
 $X(t_2) = K_4$
 $Y(t_2) = KIRTE$
 $K_4 = 5^{\circ}23.5'$
 $KIRTE = DEC. -06.105$

RADIUS LARGE
 $X(t_2) = K_4$
 $Y(t_2) = KIRTE$
 $K_4 = 5^{\circ}50'$
 $KIRTE = DEC. -13.453$

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO ORBITANCE AND NAVIGATION	
DRAWN BY: A. C. WELLS/LATES		P37 - RETURN TO EARTH (MAIN PROGRAM)	
FROM: [Signature]		DOCUMENT NO.	
CHECKED BY: [Signature]		COLOSSUS II	
APPROVED BY: [Signature]		FC-2642	
		SHEET 4 @ 33	

FROM PRECEDING SHEET

RTE360

ENTRANCE FROM RTE360

VET500
 COMPUTE
 $VE(T_1), DV,$
 $X(T_1), POSN, \beta$
 SHIT

VET500

CALLS: GAMDVLO
 KTLILM
 DVCALC

INPUT:

- 1) $R(T_1)$ = MAGNITUDE OF INITIAL POSITION VECTOR IN METERS @ 2^{28}
- 2) $RCON$ = MAGNITUDE OF FINAL POSITION VECTOR IN METERS @ 2^{28}
- 3) $V(T_1)$ = INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
- 4) $MPRVDV$ = Δ VELOCITY DESIRED IN METERS/CSEC @ 2^7
- 5) URD_0 = UNIT INITIAL POSITION VECTOR @ 2^1
- 6) UR_0 = UNIT HORIZONTAL VECTOR @ 2^1
- 7) $X(T_1)$ = COS OF FINAL FLIGHT PATH ANGLE @ 2^1
- 8) $CPHA$ = COS OF INITIAL FLIGHT PATH ANGLE @ 2^1
- 9) $MAMAXI$ } TEMPORARY { LOWER } BOUND ON GAMDV ITERATOR
- 10) $MAMAXE$ } TEMPORARY { UPPER } BOUND ON GAMDV ITERATOR
- 11) $NNIA$ = CONIC ITERATION COUNTER. ($NNIA < 0$ IMPLIES THIS IS CONIC PHASE.)

OUTPUT:

- 1) $VE(T_1)$ = POST-IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^7
- 2) DV = INITIAL DELTA V IN METERS/CSEC @ 2^7
- 3) $X(T_1)$ = COTAN OF INITIAL FPA (POST-IMPULSE) @ 2^8
- 4) $POSN$ = SEMI-LATUS RECTUM IN METERS @ 2^{28}
- 5) $BETA$ = $(1 + X(T_1)^2)^{1/2}$
- 6) $MPAC = 0$, NORMAL EXIT
 $MPAC \neq 0$, ALARM CODE OCT 605 - EXCESSIVE ITERATIONS IN GAMDVLO.
- 7) ABORT EXIT TO POOD00 : OCT 610

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO ORBITAL AND NAVIGATION	
DESIGNER: A.C. WILLIAMS		P37 - RETURN TO EARTH (MAIN PROGRAM)	
PROB: <i>P37</i>	CRS: <i>0</i>	COLOSSUS <i>33</i>	DOCUMENT NO. FC-2642
REPLY: <i>2/1/68</i>	DATE: <i>2/1/68</i>		
BOOK: <i>2/1/68</i>	TIME: <i>7:45 PM</i>		
APPROV: <i>2/1/68</i>	TIME: <i>7:45 PM</i>		SHEET 5 OF 23

FROM PRECEDING SHEET



PUT PST VARIABLES INTO LOCATIONS EXPECTED BY TMRAD10, THE CONIC SUBROUTINE CALLED BY TMRAD100.



INPUT: RVEC₀ INITIAL POSITION VECTOR IN METERS @ t₁
 VVEC₀ INITIAL VELOCITY VECTOR IN METERS/SEC @ t₁
 RCON = REFERENCE RAD. FOR WHICH TRANSFER TIME IS TO BE COMPUTED IN METERS @ t₂
 OUTPUT: R(T₂) FINAL POSITION VECTOR IN METERS @ t₂
 V(T₂) FINAL VELOCITY VECTOR IN METERS/SEC @ t₂
 T₂ TRANSFER TIME TO FINAL RAD IN CSEC @ t₂



T₂ = FINAL TIME



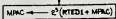
TAKE ASTRONAUT'S ENTRY ANGLE ?

COMPUTE FPA DESIRED (CENTER OF CORRIDOR)

USE ASTRONAUT'S ENTRY ANGLE



INPUT: $k = |v(t_2)|/V_0$
 $D_1 = 0$
 $D_2 = -4.8716771 \times 10^{-6} @ t_2^2$
 $D_3 = 4.8418476 \times 10^{-6} @ t_2^4$
 $D_4 = -1.4317675 \times 10^{-6} @ t_2^{-10}$
 OUTPUT: MPMC ← D1 + D2X + D3X² + D4X³ = GSOP X(t₂)



RTED1 = PAD LOAD EQUIVALENT TO D1 ON PAGE 5.4-65 OF COLLOSSUS GSOPS, RSTT



NEXT SHEET

INT ENGINEERING LAB COMPUTIVE. BSES.		ANELL CORRIDOR AND SIMULATION	
DATE: A.C. 1964-1965		PST - RETURN TO EARTH (MAIN PROGRAM)	
PROJECT: <i>FC-2642</i>	DESIGNER: <i>[Signature]</i>	COLLUSION: <i>[Signature]</i>	DESIGNING NO. FC-2642
BOOK: <i>[Signature]</i>	DATE: <i>[Signature]</i>	NO.	1 OF 63

FROM PRECEDING SHEET

FLOOD \leftarrow MPAC - $X(T_1)$
ALPHAM \leftarrow UNIT $\left(\frac{R(T_1)}{X(T_1)} \right)$

$X(t_2)_{ERR} @ Z'$



GETERAD:
INPUT: ALPHAM + 4 + Z COMPONENT OF $\frac{R(T_1)}{|R(T_1)|}$
OUTPUT: ERADM, WHERE $b^2 = 2BXSC = .0179450685 @ Z'$
 $\left(1 - \frac{3\lambda}{a^2}\right) = EE = 6.6995116 \times 10^{-3} @ Z'$
ERADM = $F_1 = MPAC \times$ EARTH-RADIUS FOR $R(T_1)$
IN METERS $@ Z'$

FLOOD \leftarrow ERADM + ESRTE

RCOM' ESRTE = DEC 12.19620 $@ Z'$ = ENTRY ALTITUDE ABOVE FISCHER ELLIPSOID (EQUIVALENT TO 400,000 FT)



EPCSRTE = $E_2 = DEC .100 @ Z'$
HAS THIS CONIC PORTION CONVERGED TO A SUITABLE RADIUS ?

RTE374



EPCSRTE = $E_3 = DEC .001 @ Z'$
WAS THE LAST CHANGE IN THE OBTANGENT OF THE FINAL FLIGHT PATH ANGLE WITHIN AN ACCEPTABLE LIMIT ?

RTE375

NNIA \leftarrow NNIA + IRTE375 INCREMENT COUNTER

PSTE



IS $n_0 < 1.0$?
NO - EXCESSIVE ITERATIONS

RTE380

MPAC \leftarrow OCT006

MORT382 = DEC .5 $@ Z'$
ALARM DISPLAY
OCCAL CODE 605
SH45 EXCESSIVE ITERATIONS



BOT380 P37
FC-2816 SH3
TERMINATE RECYCLE



RTE385
 $Dx(t_2) = X(t_2)_{ERR}$
MPAC \leftarrow FLOOD

$$Dx(t_2) = X(t_2)_{ERR} \left[\frac{X(t_2)_{ERR} - Y(t_2)}{X(t_2)_{ERR} - AL_0(t_2)_{ERR}} \right]$$

MPAC \leftarrow FLOOD
$$\frac{Y(t_2) - X(t_2)}{NORMAL (FLOOD - DRCA)} @ Z'$$

SLOPE ITERATION

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED GUIDANCE AND NAVIGATION	
DESIGNED BY: A.C. WILLIAMS		P37 - RETURN TO EARTH (MAIN PROGRAM)	
PROJECT: P37	DATE: 1/2/62	COLORADO III	INCIDENT NO. FC-2642
ANALYST: J.L. ...	DATE: 1/2/62		SHEET 7 OF 83
REVISION: 1	DATE: 1/2/62	REV	

FROM PRECEDING SHEET

RTE350

PL16D → DX(t₂)
 RCON ← RCONL
 PL16D ← MPAC
 RCON ← FLOED

IS
 THERE
 OVERFLOW?
 YES
 NO

FLOED MAY = DRCON (X(t₂)_{over} - X(t₂)<sub>over})
 IN THAT CASE X(t₂), X(t₂)_{over} AND X(t₂)_{over} ARE
 NOT UPDATED</sub>

RTE360
 SHE

X(t₂)_{over} → X(t₂)<sub>over
 X(t₂) → X(t₂)
 X(t₂) → DX(t₂) + X(t₂)
 DRCON ← FLOED
 RPRE₂ ← X(t₂)
 X(t₂) → PL16D + X(t₂)</sub>

SAVE LATEST FIGURES

RTE360
 SHE

BIT INSTRUMENTATION LAB CAMDEN, N.J.		SHIELD GUIDANCE AND NAVIGATION P17 - RETURN TO EARTH (MAIN PROGRAM)	
DRAWN A.C. WILLIAMS CHECKED DATE 1/2/64	ANALYST J. J. O'NEILL CHECKED DATE 1/2/64	COLUSSUS II	DOCUMENT NO. FC-2642
APP'D J. J. O'NEILL DATE 1/2/64	REV	SHEET 8 OF 33	



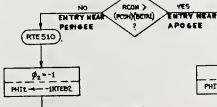
INPUT: $V(T2)w, R(T2)w, VE(T2)w, V(T2)w,$
 $UR1w, UR2w, SPRETIG, T2.$

OUTPUT: DISPLAY
LATITUDE } AT 400,000 FT.
LONGITUDE }
DELTA TIME TO 400,000 FT
VPRED: MAGNITUDE OF VELOCITY AT 400,000 FT
GAMMAEL: FLIGHT PATH ANGLE AT 400,000 FT
DELTA VC: IMPULSIVE DELTA V
* ASTRONAUT MAY APPROVE OF THESE CALCULATIONS AND
PROCEED, OR DISAPPROVE AND EITHER TERMINATE
OR RECYCLE.

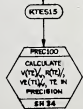
RCON = RADIUS OF CONIC TRAJECTORY.
PCON IS CALCULATED IN DVALC.

$PCON = \frac{a_2}{1 - e_2^2} =$ SEMI LATUS RECTUM

$BETA1 = 1 + e_2(TE)^2$ CALCULATED IN VET100



(THIS OCCURS ONLY FOR NEARLY CIRCULAR ORBITS.)



PREC100: PRECISION INTEGRATION SUBROUTINE
CALLS: RTECON, RTECON, (RCON), TIMEAD, VET100, INTSALL
COMPUTES A NUMERICALLY INTEGRATED TRAJECTORY, USING
CONSTRAINTS DERIVED FROM THE CONIC INTEGRATION:

INPUT:

- 1) RCON = R_{CON} = FINAL RAD OF CONIC TRAJECTORY IN METERS @ 2^{23}
- 2) $R(T2)w = R(T2)$ = PRE-RETURN POS. VECTOR IN METERS @ 2^{28}
- 3) $V(T2)w = V(T2)$ = PRE-RETURN VELOCITY VECTOR IN M/SEC @ 2^{27}
- 4) $TE = t_2$ = TIME OF PRE-RETURN STATE VECTOR IN CSEC @ 2^{28}
- 5) $TTE = t_{22}$ = TRANSFER TIME TO $T2$, THE FINAL POSITION TIME IN CSEC @ 2^{28}
- 6) $R(T2)$ = MAGNITUDE OF $R(T2)w$ IN METERS @ 2^{23}
- 7) $V(T2)$ = COSIN OF FINAL FLIGHT PATH ANGLE @ 2^{27}
- 8) $R(T2)$ = COSIN OF FINAL FLIGHT PATH ANGLE @ 2^{27}
- 9) $R(T2)w$ = DELTA VELOCITY VECTOR IN METERS/CSEC @ 2^{27}
- 10) MAXAXE = MAX = MAXOR AXIS LIMIT ON LOWER BOUND OF GAUSS FERRITER IN METERS @ 2^{28}
- 11) MAXAXE = MAX = MAXOR AXIS LIMIT ON UPPER BOUND OF GAUSS FERRITER IN METERS @ 2^{28}
- 12) $UR1w = UR1$ = UNIT PRE-RETURN POSITION VECTOR @ 2^{27}
- 13) $UR2w = UR2$ = UNIT HORIZONTAL VECTOR @ 2^{27}
- 14) BETA1 = $B_1 = 1 + e_2(TE)^2$ @ 2^{27}
- 15) PH1E = $A_1 = 1 + e_2(TE)^2$ @ 2^{27}
+1 = APOGEE -1 = PERIGEE

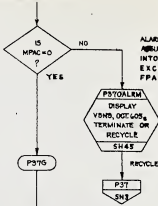
OUTPUT:

- 1) $V(T2)w = V_2(R_2)$ = POST IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2^{27}
- 2) $R(T2)w = R(T2)$ = FINAL POSITION VECTOR IN METERS @ 2^{28}
- 3) $V(T2)w = V_2(R_2)$ = FINAL VELOCITY VECTOR IN METERS/CSEC @ 2^{27}
- 4) $TE = t_2$ = FINAL TIME IN CSEC @ 2^{28}
- 5) MPAC = 0 FOR NORMAL EXIT
MPAC = OCTALS OR OCTOBS FOR ALARM EXIT.

NEXT SHEET

BIT INTEGRATION LAB CAMBRIDGE, MASS.		APPROVAL AND SIGNATURE	
DESIGNER: J. C. WILSON DRAWN: J. C. WILSON CHECKED: J. C. WILSON APPROVED: J. C. WILSON DATE: 7/24/61		P57 - RETURN TO EARTH (MAIN PROGRAM) COL. OSSUS II FC-2642 SHEET 9 OF 9	

FROM PRECEDING SHEET



ALARM EXITS FROM PREC100, AND GAMVSD, ABRURROUTINE, LOAD 605 OR 613 OCT INTO MPAC: EXCESSIVE ITERATIONS OR FINAL FPA NOT REACHED.

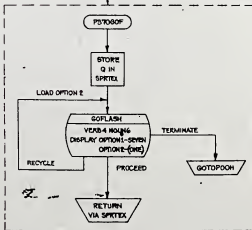
P37OALRM CALLS GOFSLASH, WITH A VERB 5 NOUN 9, AND DISPLAYS OCTAL 605 OR 613 ALARM CODE. V34 ENTER TERMINATES PROGRAM V35 ENTER CONTINUES THE FLASH V32 ENTER RECYCLES P37.



RTEVN CALLS RTEORBP: CALLS TMRAD100, AUGDEVGL AND LAT-LONG SUBROUTINES.

INPUTS:
 $VTE(t_2) = V(t_2)$; $SPKTEIG = MEYED-IN TIG$; $TE =$ TEMPORARY TIME OF $t_2(t_2)$; $R(TE) = r(t_2)$; $UN = U_2$; $V(t_1) = V_1(t_1)$.
 $VECT(V_2) = V_2(t_2)$; $UN(V_2) = U_2(t_2)$

DISPLAY:
 1) LAT (SPL) LATITUDE AND LONGITUDE OF SPLASHDOWN
 LNS (SPL)
 2) TSTOT4 = $TE - SPKTEIG$, OR $t_2 - T_{26}$ = TRANSFER TIME TO 400,000 FT.
 3) VPRED = $|VTE(t_2)|$, VELOCITY MAGNITUDE AT 400,000 FT.
 4) GAMMAE1 = FLIGHT PATH ANGLE.
 5) DELTAV = CHANGE IN VELOCITY MAGNITUDE.

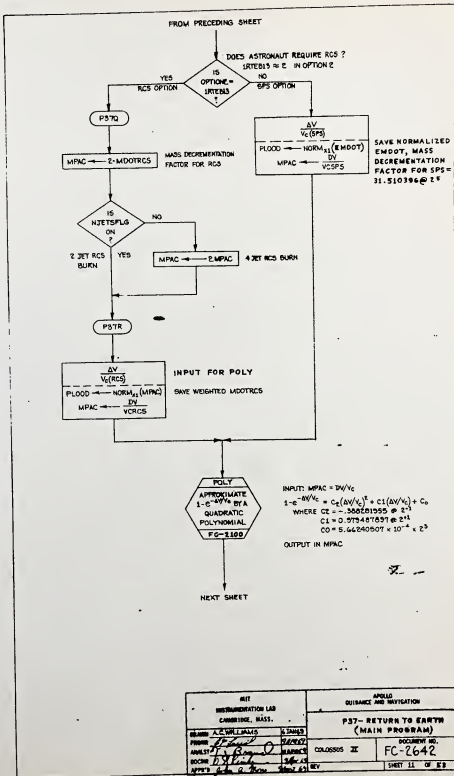


DISPLAY OPTION CODE, AND SPS OPTION
 OPTION1 = SEVEN = R25-SPS OPTION
 OPTION2 = ONE = SPS OPTION (ASSUMED)

FOR SPS - PROCEED (OR LOAD RE WITH OCT 1)
 FOR RCS - LOAD OPTION 2 WITH OCT 0002.

SET PUNCH LIST TO 0
 NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED DYNAMICS AND MECHANICS	
SEARCHED <i>[initials]</i>		PROJECT NO. <i>[initials]</i>	
INDEXED <i>[initials]</i>		PROGRAM NO. FC-2642	
SERIALIZED <i>[initials]</i>		COLOSSUS II	SHEET 10 OF 13
APPROVED <i>[initials]</i>		REV	



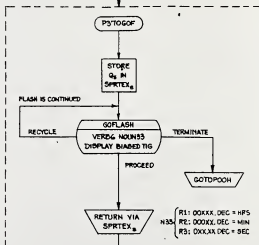
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO DISURBANCE AND INVESTIGATION	
DESIGNER: A.C. SULLIVAN		P37- RETURN TO EARTH (MAIN PROGRAM)	
PROBING: <i>[Signature]</i>	DATE: 2/26/62	DOCUMENT NO.	
ANALYST: <i>[Signature]</i>	REVISION:	COLOSSUS II	FC-2642
DOCTR: <i>[Signature]</i>	DATE: 3/6/62	REV	SHEET 11 OF 83
APPROVED: <i>[Signature]</i>	DATE: 3/6/62		

FROM PRECEDING SHEET

$$T_{10} = T_1 - C_V \Delta T_0$$

TIG → T₁ - WEIGHT / (C_v * CSUBST * MPRAC * (PLOGG))

BIASED TIG



THIS DISPLAYS BIASED TIG, COMPUTED FROM KEYS IN TIG, AND THRUST PARAMETTPS OF THRUST OPTION KEYS IN. ASTRONAUT SHOULD RECORD DATA AND KEY IN PROCEED. THERE IS NO SSPD OPT'N FOR LOADING DATA.

R1: 00XX, DEC = HPS
R2: 00XX, DEC = MIN
R3: 0XX,XX, DEC = SEC

CLEAR MARK COUNTERS (INITIALIZE FOR NEW USE OF RADAR)
NUMBER OF VNF MARKS INCORPORATED.
NUMBER OF RENDEZVOUS MARKS TAKEN.

WMCNT₀ ← ZERO₀
TRKMKCNT₀ ← ZERO₀

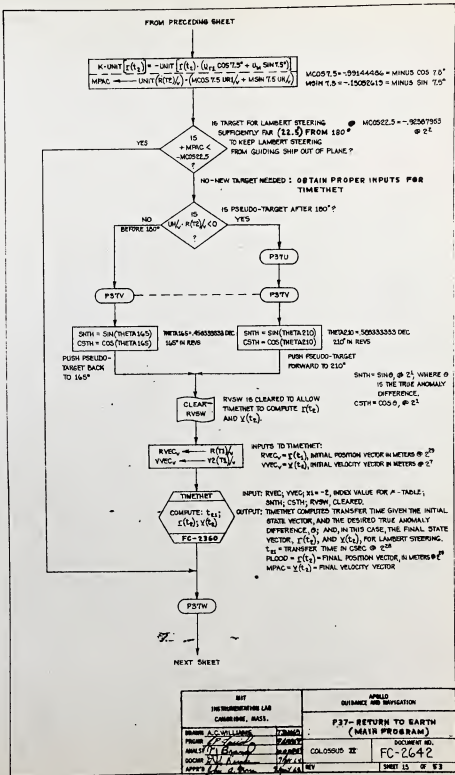


RTENCK1: SETS INTYPLG, MAKING THE INTEGRATION ROUTINE, INTEGRVS, DO CONIC INTEGRATION CLEARS MOONFLAG, INDICATING EARTH SPHERE OF INFLUENCE. LOADS THE INPUT INTO THE VARIABLES EXPECTED BY INTEGRVS, AND LOADS THE OUTPUT INTO VARIABLES EXPECTED BY PST.

INPUT: R(T₁), V_e(T₁), T₁, T₂
OUTPUT: R(T₂), V(T₂), T₂
R(T₂) ← RATT = POSITION VECTOR IN METERS @ 2¹⁷
V(T₂) ← VATT = VELOCITY VECTOR IN M/SEC @ 2⁷
T₂ ← TAT = TIME IN CSEC @ 2¹⁰
X1 ← CONIC X1 FOR PROPER μ-TABLE VALUES.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED DISTANCE AND NAVIGATION	
		P37 - RETURN TO EARTH (MAIN PROGRAM)	
BRANCH: A.C. WILLIAMS	6/24/62	COLOSSUS II	DOCUMENT NO. FC-2642
ANALYST: J. J. Gagnand	7/26/62		SHEET 12 OF 23
BOOK NO. 74-100	7/26/62		
APPROV: J. J. Gagnand	8/6/62		



MIT THE INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED GUIDANCE AND NAVIGATION
P37 - RETURN TO EARTH (MAIN PROGRAM)	
DESIGNER: A.C. WILLIAMS PROGRAMMER: P. J. BARNETT ANALYST: P. J. BARNETT CHECKER: P. J. BARNETT APPROVED: P. J. BARNETT	DOCUMENT NO. COLOSSUS XX FC-2642 SHEET 15 OF 53

FROM PRECEDING SHEET

CLEAR
XDELVPL&
CLEAR
NORMSW
SET
FINALFLG

INPUT TO NO, 04L

XDELVPL&: LAMBERT (AIMPOINT) COMPUTATION
NORMSW: LAMBERT MUST COMPUTE
ITS OWN NORM.

THIS FLAG ALLOWS PROPER COMPUTATION OF MGA
AND TERMINATION OF VN1645 BY V33 ENTER.

$t_e = t_{10} + t_{11}$
RTARG ← FLOOD
TPASS4 ← T + T1
DELVSN ← $v_2(t) \sqrt{v_1 - v_2(t)}$

$f(t_e)$

t_e
INPUT FOR VN1645

VN1645
COMPUTE Q_{ms}
DISPLAY
MEX CTR, TMS Q_{ms}
FC-E720

KEYBOARD ENTRIES :

V33 ENTER } TERMINATE
V34 ENTER } P37
V32 ENTER TRANSFERS
TO PSTW.

INPUT: DELVSN

FLAG: FINALFLG SET

OUTPUT: MGA-MIDDLE GIMBAL ANGLE

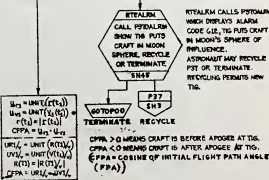
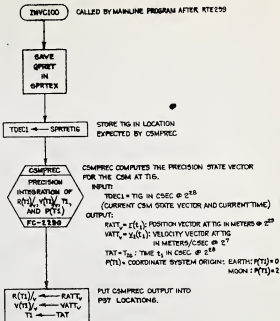
DISPLAY:

VERB 16
NOUN 45
R1: MARKS: NOT MEANINGFUL.
R2: TPE: TIME TO TG (MIN/SEC)
XXXXX MIN/SEC
R3: MIDDLE GIMBAL ANGLE
XXXX.XX DEG.
IF REFSMAT FLAG IS CLEAR,
R3 = -0000.
IF REFSMAT FLAG IS SET,
R3 WILL BE COMPUTED.

PSTW

V32 RECYCLES VN1645, ASKING
FOR TERMINATE OR PROCEED
RESPONSE.

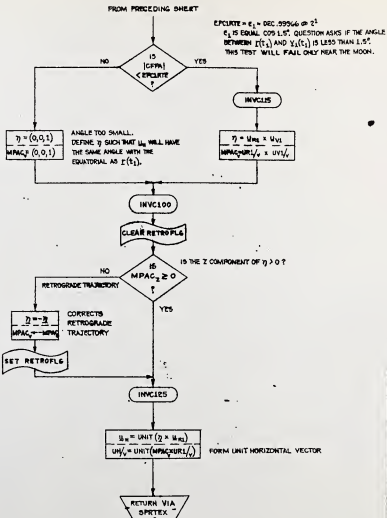
JNET INTELLIGENCE LAB CAMBRIDGE, MASS.		AFIELD OUTRAGE AND INVESTIGATION	
BENNY A. C. WILLIAMS		P37 - RETURN TO EARTH (MAIN PROGRAM)	
PROJID	FC-2642	DOCUMENT NO.	FC-2642
ANALYST	J. R. ...	COLOSSUS II	FC-2642
BOOK	J. R. ...	REV	SHEET 14 OF 23
APPR	J. R. ...	REV	



$U_{r1} = UNIT(r(t_1))$
 $U_{v1} = UNIT(v(t_1))$
 $r(t_1) = |r(t_1)|$
 $CPFA = U_{r1} \cdot U_{v1}$
 $U_{R1} = UNIT(R(t_1))$
 $U_{V1} = UNIT(V(t_1))$
 $R(t_1) = |R(t_1)|$
 $CPFA = U_{R1} \cdot U_{V1}$

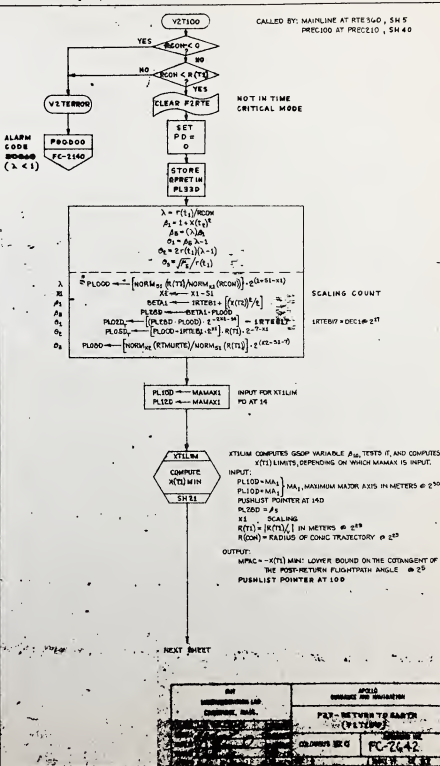
NEXT SHEET

INT REGENERATION LAB COLUMBIA, MISS.		SPEED QUANTITY AND DIMENSION	
P37 - RETURN TO EARTH (INVC100)		DOCUMENT NO. FC-2642	
PERFORMED BY DATE	CHECKED BY DATE	COLLOSIUS 3C	SHEET IS OF 53



BUT INFORMATION LAB CARLSB. MASS.	APOLLO ORBITER AND NAVIGATION P-7 - RETURN TO EARTH (INVC100)
NAME: A.C. WILKINS PHONE: [REDACTED] AGENCY: [REDACTED] ROOM: [REDACTED] APP'D: [REDACTED]	DOCUMENT NO. FC-2642 SHEET 14 OF 89

CALLED BY: MAINLINE AT RTE360, SH 5
PREC100 AT PREC210, SH 40



FROM PRECEDING SHEET

VZT100

SAMDY10

COMPUTE $VZ(T1)_V$
BY $X(T1)$, $PCOIN$
SHT13

GAMDY10 CALLS DVCALC BY ITERATION, IT CALCULATES
 $VZ(T1)_V = Y_L(t_1)$, $DV = \Delta V$, $X(T1) = X(t_1)$ AND
 $PCOIN = PCOIN$.

INPUT:

PUSHLIST:

002 $\theta_1 = \theta_0 \lambda - 1$

050 $\theta_2 = 2 r(t_1) \lambda - 1$

080 $\theta_3 = \sqrt{\theta_1} / r(t_1)$

100 $X(t_1)_{MIN} =$ LOWER BOUND ON INDEPENDENT
VAR $X(t_1)$

120 $\Delta X(t_1)_{MAX} =$ MAXIMUM $\Delta X(T1)$

140 $X(T1)_{MAX} =$ UPPER BOUND ON INCL. VAR $X(t_1)$

160 $\Delta X(t_1) =$ CHANGE IN $X(t_1)$

OTHER:

$V(T1)_V = Y(t_1) =$ INITIAL, PRE-IGNITION VELOCITY VECTOR
IN METERS/CSEC @ 2^7

$RTEDVD = \Delta V_0 =$ KEYED-IN Δ VELOCITY DESIRED
IN METERS/CSEC @ 2^7

$U(R1)_V = U_{R1} =$ UNIT POSITION VECTOR AT T_{10}

$U(H)_V = U_H =$ UNIT HORIZONTAL VECTOR UNIT($\theta = RT1$) $_V$

$X(T1) =$ COTANGENT OF INITIAL FLIGHT PATH ANGLE
FROM THE VERTICAL.

PERTE = FLAG ON MEANS TIME CRITICAL MODE.

FLAG OFF MEANS NOT IN TIME CRITICAL MODE.

OUTPUT:

$VZ(T1)_V = Y_L(t_1) =$ POST-IMPULSE VELOCITY VECTOR
IN METERS/CSEC @ 2^7

$DV = \Delta V =$ CHANGE IN VELOCITY

$X(T1) =$ COT. OF INITIAL POST-RETURN FLIGHT PATH
ANGLE FROM VERTICAL.

$PCOIN = PCOIN =$ SEMI-LATUS RECTUM IN METERS @ $2^{10}/2^{24}$

MPC ← RTEDVD

IS THIS FUEL CRITICAL MODE T

YES

IS RTEDVD=0 ?

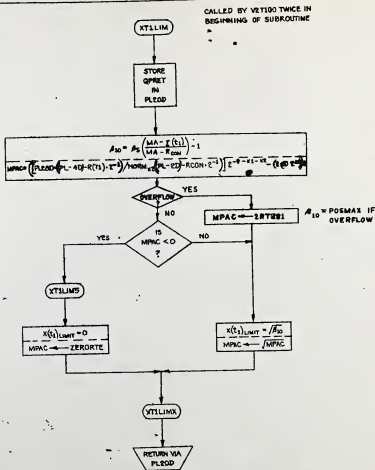
NO

VZTIX

RETURN VIA
330

NEXT SHEET

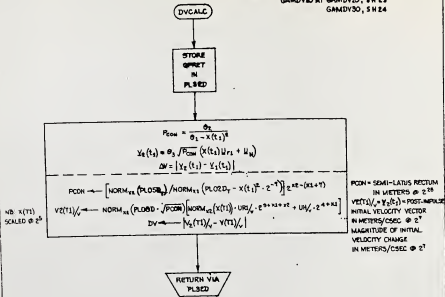
MIT METROLOGICAL LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
PROJECT: RETURN TO EARTH (VZT100)		DOCUMENT NO.	
DESIGNER: A.C. WILLIAMS	DATE: 10/15/68	COLOSSUS	FC-2642
ANALYST: J. J. Gagnier	DATE: 10/15/68	II	
DOCTOR: J. J. Gagnier	DATE: 10/15/68	REV	SHEET 15 OF 83



XTILIM IS USED TWICE: ONCE USING MAMAX1 AND ONCE USING MAMAX2.
WHEN MAMAX1 IS USED, XTILIM DETERMINES WHETHER THE PRESENT TRAJECTORY IS CLOSE TO PARABOLIC. IF IT IS, THE POST-IMPULSE FLIGHT PATH ANGLE IS NOT PERMITTED TO HAVE A NEGATIVE RADIAL COMPONENT.
WHEN MAMAX2 IS USED, XTILIM DETERMINES WHETHER $R(t1)$, THE ABSOLUTE VALUE OF THE POSITION VECTOR, IS GREATER THAN MAMAX2. IN THAT CASE, THE MAXIMUM RADIUS IS TAKEN TO BE $R(t1)$ ITSELF. THE POST-IMPULSE FPA IS THEREFORE NOT PERMITTED TO HAVE A POSITIVE RADIAL COMPONENT.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AIRFIELD GUIDANCE AND SIMULATION	
		POST - RETURN TO EARTH (XTILIM)	
DESIGNER J.C. WILLIAMS	DATE 8/20/62	DOCUMENT NO.	FC-2642
PROGRAM	7/26/62	COLLOSSUS III	
ANALYST	8/1/62	REV	SHEET 11 OF 15
DOCTOR	8/1/62		
APPROVED	9/10/62		

CALLED BY: VETLOG AT VETROS, 5H20
 GAMDVIO AT GAMDVIO, 5H13
 GAMDV30, 5H24



NO. X(T1)
 SCALED @ 2⁵

PCOM = SEMI-LATUS RECTUM
 IN METERS @ 2²⁸
 VZ(T1) = VZ(T1) = POST-IMPULSE
 INITIAL VELOCITY VECTOR
 IN METERS/CSEC @ 2⁷
 MAGNITUDE OF INITIAL
 VELOCITY CHANGE
 IN METERS/CSEC @ 2⁷

PCOM SATISFIES THE EQUATION:
$$R_{COM} = \frac{2r(t_1) \left(\frac{r(t_1)}{R_{COM}} - 1 \right)}{\left(\frac{r(t_1)}{R_{COM}} \right)^2 (1 + (X(t_1))^2) - (1 + (X(t_1))^2)}$$
 WHERE

$O_1 = 2r(t_1) \left(\frac{r(t_1)}{R_{COM}} - 1 \right)$ AND $O_2 = \left(\frac{r(t_1)}{R_{COM}} \right)^2 (1 + (X(t_1))^2) - 1$, WHERE $r(t_1)$ = RADIOS.

AT T_1 ; R_{COM} = FINAL RADIOS AND $X(t_1)$ = COTANGENT OF THE FINAL FLIGHT PATH ANGLE.
 $X(t_1)$ IS THE INDEPENDENT VARIABLE, EQUALING COTANGENT OF THE INITIAL FLIGHT PATH ANGLE.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFSP6 ENGINEERING AND SIMULATION	
DESIGNED BY: J.C. WELLS (148)		PROJECT - RETURN TO EARTH (VETCALC)	
PROVEN BY: [Signature]	DATE: 1/2/62	DOCUMENT NO. FC-2642	SHEET 22 OF 23
ANALYZED BY: [Signature]	DATE: 1/2/62		
BOOKED BY: [Signature]	DATE: 1/2/62	REV	

CALLED BY: VET100 AT: VET150
 VET165
 VET175

GAMDR0

STORE
 QPSET
 IN
 PL16D

DVCALC
 CALCULATE
 VET(1), V₂,
 PDDM
 SINE

DVCALC:
 INPUT:
 PUSHLIST:
 $QED = Q_1 = (1 + X(t_1)^2)^{1/2} - 1$ WHERE $\lambda = r(t_1)/R_{COM}$
 $QSD = Q_2 = 2 \cdot r(t_1) \cdot (\lambda - 1)$
 $QED = Q_3 = \sqrt{R_1} / r(t_1)$
 OTHER:
 $V(t_1) = V_1(t_1)$ = PRE-IMPULSE VELOCITY VECTOR
 IN METERS/CSEC @ z^1
 $U(t_1) = U_1(t_1) = \text{UNIT}(r(t_1)) @ z^1$
 $U(t_1) = U_2 = \text{UNIT HORIZONTAL VECTOR} @ z^1$
 $X(t_1) = \text{COTANGENT OF THE POST IMPULSE FLIGHT PATH ANGLE} @ z^2$
 OUTPUT:
 $V(t_1) = V_2(t_1)$ = POST-IMPULSE VELOCITY VECTOR
 IN METERS/CSEC @ z^1
 $DV = DV = |V_2(t_1) - V_1(t_1)|$ IN METERS/CSEC @ z^2
 $PDDM = P_{DDM} = \text{SEMI-LATUS RECTUM IN METERS} @ z^2$

DOES
 OVERFLOW
 PL14D-PL15D
 CAUSE
 OVERFLOW ?

DOES $X(t_1)_{MAX} - X(t_1)_{MIN}$ CAUSE OVERFLOW ?

IS
 PL14D-PL15D <
 EPCORTE ?

IS $X(t_1)_{MAX}$ WITHIN ϵ_1 OF $X(t_1)_{MIN}$?
 $\epsilon_{PCORTE} = \epsilon_1 = 1/2^{25}$

EXIT: BOUNDS OF
 R (R₁) CLOSE
 TOGETHER

IS
 PL14D-PL15D <
 PL15D ?

IS THE DIFFERENCE BETWEEN THE BOUNDS
 ON $X(t_1)$ LESS THAN THE MAXIMUM
 ALLOWABLE CHANGE IN $X(t_1)$?
 IF SO, LIMIT $\Delta X(t_1)$.

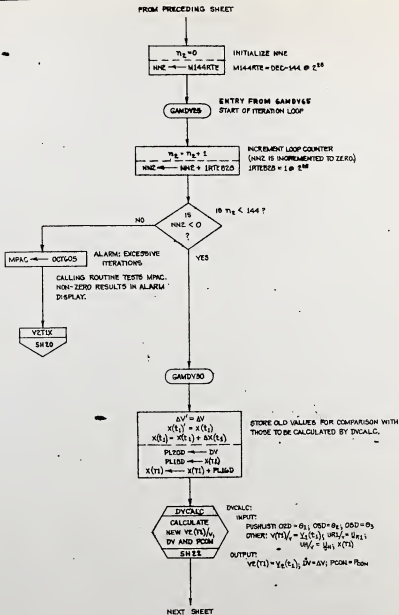
GAMDR15

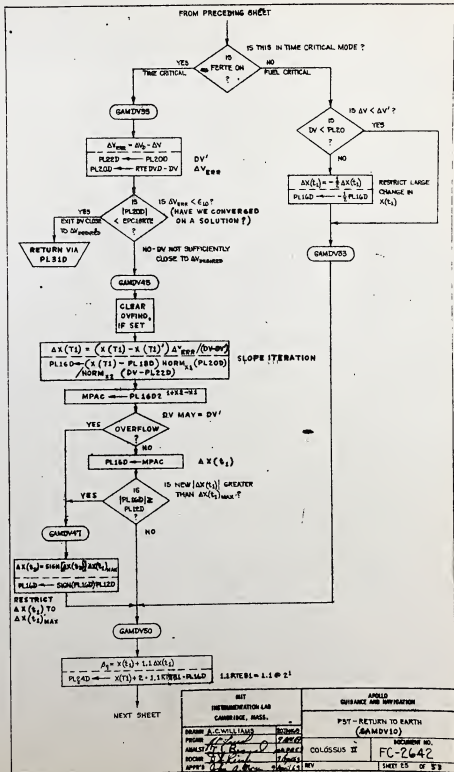
$\Delta X(t_1) = \frac{1}{2} (X(t_1)_{MAX} - X(t_1)_{MIN}) \text{SIGN}(X(t_1))$
 $PL15D \leftarrow \frac{1}{2} \text{SIGN}(PL14D)(PL14D - PL15D)$
 LIMIT $\Delta X(t_1)$

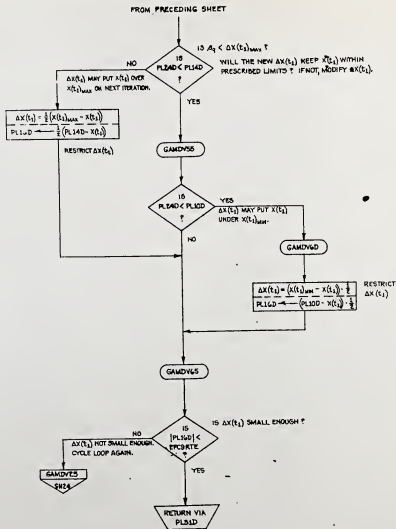
GAMDR10

NEXT SHEET

507 RECOMMENDED L&S EXHIBIT NUMBER		5078 RETURN TO EARTH (GAMDR10)	
NAME: J. C. ... TITLE: ... DATE: ... APPROVED: ...	STATUS: ... CHECKED: ... APPROVED: ...	COLLOQUIUM 33	INCHUTE NO. FC-2642
		REV	SHEET 23 OF 23







MIT INFORMATION LAB CAMBRIDGE, MASS.		Apollo GUIDANCE AND NAVIGATION	
SEARCH A.C. [] FILED [] INDEX [] APPROV. []		P37 - RETURN TO EARTH (GAMDV10)	
FORM 37-1 10/65		COLONEL'S III	DOCUMENT NO. FC-2642
DATE []		REV []	SHEET 26 OF 33

TIME RADIIUS CALLING SUBROUTINE

INPUT:

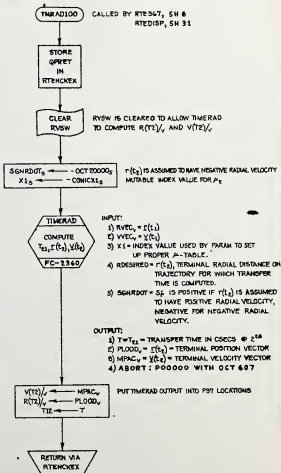
RVEC INITIAL POSITION VECTOR
 VVEC INITIAL VELOCITY VECTOR
 RDESIRD FINAL RADIIUS FOR WHICH TRANSFER
 TIME IS TO BE COMPUTED

VECT @ 2^{10} METRS
 VECT @ 2^7 METRS/CSEC
 OP @ 2^{10} METERS

OUTPUT:

$R(t_2)/v$ FINAL POSITION VECTOR
 $V(t_2)/v$ FINAL VELOCITY VECTOR
 TIE TRANSFER TIME TO FINAL RADIIUS
 ABORT EXIT FOR NO SOLUTION:
 P00000, WITH OCT #07

VECT @ 2^{10} METERS
 VECT @ 2^7 METRS/CSEC
 OP @ 2^{10} CSEC



MIT RESEARCH LABORATORY CAMBRIDGE, MASS.		ARCAS GUIDANCE AND NAVIGATION	
MEMO A.C. WILLIAMS		P87-RETURN TO EARTH (THRAD100)	
FROM: <i>W. Williams</i>	DATE: <i>10/10/64</i>	COLOSSUS II	DOCUMENT NO.
APPROVED: <i>W. Williams</i>	DATE: <i>10/10/64</i>		FC-2642
APPROVED: <i>W. Williams</i>	DATE: <i>10/10/64</i>	REV	SHEET 01 OF 03

CALLED BY: PSTE
PST6

RTEVN

STORE
QPRET
IN
VNSTORE

RTEDISP
CALCULATE:
LATITUDE, LONGITUDE,
FINAL STATE VECTOR
& TRANSIT TIME
SH31

RTEDISP CALLS: TRIRAD00, AUGKUGSL AND LAT-LOH5.
 INPUT: $V(2) = V(1) \hat{i}$ FINAL VELOCITY VECTOR IN METERS/SEC @ 2⁷
 $R(2) = R(1) \hat{i}$ FINAL POSITION VECTOR IN METERS @ 2⁷
 $V(1) = V_0 \hat{i}$ POST-IMPULSE INITIAL VELOCITY VECTOR
 IN METERS/SEC @ 2⁷
 $V(1) = V_0 \hat{i}$ PRE-IMPULSE INITIAL VELOCITY VECTOR
 IN METERS/SEC @ 2⁷
 $UR(1) = U_{H1} \hat{i}$ UNIT INITIAL POSITION VECTOR @ 2⁷
 $UH(1) = U_{H1} \hat{i}$ UNIT HORIZONTAL VECTOR AT TIG
 SPRINTG = KEYED-IN TIG IN CSEC @ 2¹⁰
 TE = FINAL TIME IN CSEC @ 2¹⁰
 OUTPUT: LATNSPL = LATITUDE AT TE IN REVS @ 2⁸
 LONGSPL = LONGITUDE AT TE IN REVS @ 2⁸
 VPRED = MAGNITUDE OF VELOCITY AT 400,000 FT
 IN METERS/SEC @ 2⁷
 GAMMAEL = FLIGHT PATH ANGLE @ 400,000 FT
 IN REVS AND ABOVE HORIZON @ 2⁸
 T300R4 = TRANSIT TIME TO 400,000 FT. IN CSEC @ 2¹⁰
 DELVAVC = INITIAL VELOCITY CHANGE VECTOR IN LOCAL
 VERTICAL COORDINATES IN METERS/SEC @ 2⁷

PSTGOPR

SAVE
Q IN
RTNCKEX

GOPASHR
VERB & HOUR G1
LATITUDE = LAT(SPL)
LONGITUDE = LONG(SPL)

DISPLAY
R1: LATITUDE DEC.000.XX DEG
R2: LONGITUDE DEC.000.XX DEG
R3: BLANKED OUT

RECYCLE

TERMINATE

PROCEED

RETURN VIA
RTNCKEX

DISPLAY:
LATITUDE = LAT(SPL)
LONGITUDE = LONG(SPL)

GOTDPOOH

PST
SH3

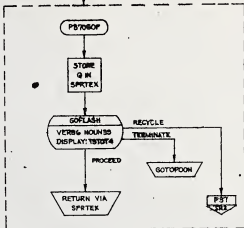
BLANKET
OUT
R3
FC-2130

ENDOFJOB

NEXT SHEET

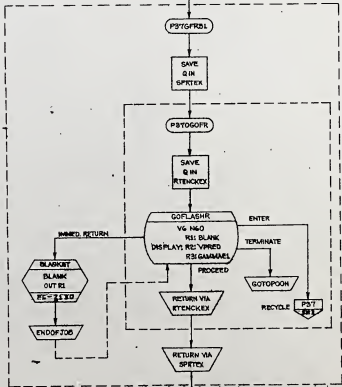
807 INTERCOMMUNICATION LAB CAMBRIDGE, MASS.		AIRTEL ORIGINATOR AND IDENTIFICATION PST-RETURN TO EARTH	
PRIME: A.C. WILKINSON PROGRAM: <i>[Signature]</i> ANALYST: <i>[Signature]</i> SPECIALIST: <i>[Signature]</i> APPROVED: <i>[Signature]</i>	17 AUG 75 11:42 AM 4121 REV	COL. OBUSUS XX FC-2642	DOCUMENT NO. SHEET 22 OF 25

FROM PRECEDING SHEET



DISPLAY%STOT4
TRANSFER TIME
TO 400,000 FT.
R1: HR%1
O00.XX
R2: MIN
O00.XX
R3: SEC
OXX.XX

DEL-
MAL



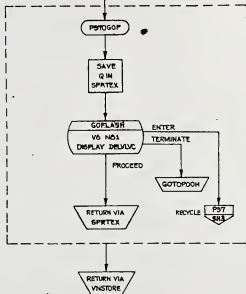
NOTE: PBYGFRDL
INTERLOCKS WITH
PBYGOFR IN THIS
MANNER:
IMMEDIATE RETURN
FROM GOFLAGHR IN
PBYGOFR TO
BLANKET, WHICH IS
CONTAINED IN
PBYGFRDL. ENDOF-
JOB RETURNS DIS-
PLAY FOR
ASTRONAUT RES-
PONSE.

R1: BLANK
R2: V%RD DEC XXXXX
IN FT/SEC -
VELOCITY MAG-
NITUDE AT
400,000 FT.
R3: GAMMAE1
DEC XXX.XX IN
DEGREES-FLIGHT
PATH ANGLE AT
400,000 FT.

NEED BLANKET

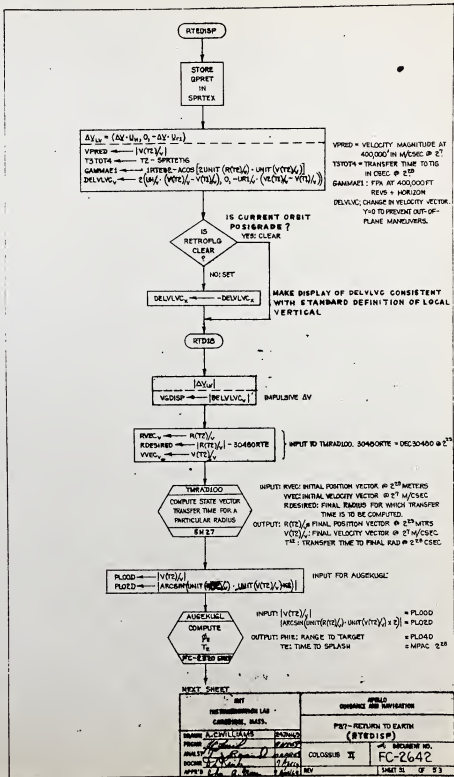
BRT BRT OPERATOR LOG COMMAND, DATA		APOLLO ORBITANCE AND NAVIGATION	
FROM: <u>WILLIAMS</u>		P31 - RETURN TO EARTH (RTN)	
DATE: <u>11/13/68</u>		COLOSSUS III	
SIGNATURE: <u>[Signature]</u>		INCIDENT NO. FC-2642	
APPR: <u>[Signature]</u>		SHEET 13 OF 53	

FROM PRECEDING SHEET



DELTA V (LV) =
DELVLC = DEC XXXX X
FT/SEC EACH COM-
PONENT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DESIGNED BY: A.C. WILLIAMS		PST - RETURN TO EARTH (RETURN)	
PREPARED BY: [Signature]	CHECKED BY: [Signature]	COLLOSSUS II	DOCUMENT NO. FC-2642
ANALYST: [Signature]	APPROVED BY: [Signature]	REV	SHEET NO. OF 83



FROM PRECEDING SHEET

$$T_{LS} = t_z + t_{rz} + t_e$$

$$\text{FLOED} \rightarrow \text{MPAC} + T_{rz} + T_e$$

TIME TO SPLASH-DOWN

NO

CHANGE IN RANGE ?

YES

$\text{LOAD}_s \rightarrow \text{PSTRANGE}_s$

USE P37 RANGE FOR DISPLAY

RTDZ

$$S_{\beta z} \rightarrow \sin(\beta_z)$$

$$C_{\beta z} \rightarrow \cos(\beta_z)$$

$$\text{LNG(SPL)} \rightarrow \sin(\text{LOAD})$$

$$\text{LAT(SPL)} \rightarrow \cos(\text{LOAD})$$

$$U_x = \text{UNIT} \left[\left(r(t_z) + Y(t_z) \right) \times r(t_z) \right]$$

$$U_y = U_x C_{\beta z} + U_z S_{\beta z}$$

$$\text{LOAD}_s \rightarrow \text{UNIT} \left[\text{UNIT}(R(TZ)) \times \text{UNIT}(V(TZ)) \times \text{UNIT}(R(TZ)) \times \text{LNG(SPL)} \right]$$

$$\text{ALPHA} \rightarrow \text{LOAD}_s + \text{LAT(SPL)} \times \text{UNIT}(R(TZ))$$

$$\text{MPAC} \rightarrow \text{FLOED}$$

$$T_{LS} = t_z + t_{rz} + t_e$$

$$S_{\beta z} = \sin(\beta_z)$$

$$C_{\beta z} = \cos(\beta_z)$$

$$U_x = \text{UNIT} \left[\left(r(t_z) + Y(t_z) \right) \times r(t_z) \right]$$

$$U_y = U_x C_{\beta z} + U_z S_{\beta z}$$

$$\text{FLOED} \rightarrow \text{MPAC} + T_{rz} + T_e$$

$$\text{LNG(SPL)} \rightarrow \sin(\text{LOAD})$$

$$\text{LAT(SPL)} \rightarrow \cos(\text{LOAD})$$

$$\text{LOAD}_s \rightarrow \text{UNIT} \left[\text{UNIT}(R(TZ)) \times \text{UNIT}(V(TZ)) \times \text{UNIT}(R(TZ)) \times \text{LNG(SPL)} \right]$$

$$\text{ALPHA} \rightarrow \text{LOAD}_s + \text{LAT(SPL)} \times \text{UNIT}(R(TZ))$$

$$\text{MPAC} \rightarrow T_e + T_{rz} + T_e$$

CLEAR ERADFLAG

LAT-LONG USES FIXED RADIUS

CLEAR LUNAFLAG

LAT-LONG COMPUTES FOR EARTH

NEXT SHEET

BIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVAL CONFORMANCE AND INFORMATION	
DRAWN BY <u>A.C. WILLIAMS</u>	DATE <u>12/22/61</u>	P37 - RETURN TO EARTH TO (RTDISP)	
PROJECT <u>Colossus II</u>	APPROVED BY <u>[Signature]</u>	COLLOSSUS II -	DESIGN NO. <u>FC-2642</u>
DOC NO. <u>FC-2642</u>	DATE <u>1/10/62</u>	REV	SHEET NO. OF 88
APPROVED BY <u>[Signature]</u>	DATE <u>3/21/61</u>		

FROM PRECEDING SHEET



INPUT: MPAC=TIME CSEC @ 2²⁷
 ERADFLAG=0 MEANS FIXED EARTH RAD
 LUNAFLAG=0 MEANS FOR EARTH
 ALPHA= POSITION VECTOR IN METERS @ 2²⁹
 OUTPUT: LAT = LATITUDE IN REVS @ 2²
 LONG = LONGITUDE IN REVS @ 2²



7. -

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED ORBITANCE AND NAVIGATION	
DESIGNER: A.C. WILLIAMS		PROJECT: P87 - RETURN TO EARTH (RTEDISP)	
FIGURE: <i>10</i>	DATE: <i>7/20/68</i>	COLOR COPY: <input type="checkbox"/>	DOCUMENT NO.: <i>FC-2642</i>
ANALYST: <i>J. J. Berman</i>	DATE: <i>7/20/68</i>		SHEET 55 OF 58
DOOR: <i>J. J. Berman</i>	DATE: <i>7/20/68</i>	REV: <i>1</i>	
APPROVED: <i>J. J. Berman</i>	DATE: <i>9 April 69</i>		

PREC100 CALLED BY MAINLINE FLOW AT RTES15

STORE
QPRET
IN
SPWTEK₀

$n_1 = 10$
 $R_0 = RCON$
 $f_1 = 1$
NN1A ← 10RTE
RD ← RCON

IN THIS PROGRAM, NN1A
POSITIVE IS EQUIVALENT
TO f_1 SET. f_1 SET MEANS
THIS IS THE PRECISION
PHASE.
 $RCON$ COMPUTED BY CONIC
PHASE IS NOW HELD
CONSTANT.

PREC120

ITERATION ENTRY
FOR NEW $VZ (T_1)_{1/2}$

$\Delta t_{1/2} = ROSMAX$
 $N_2 = 0$
DTE1PR ← ZRTEB1
NNZ ← MTRTE

NNZ IS INCREMENTED TOWARD 0.

RTENCK3
CALL INSTALL
CLEAR INTYPLG
CLEAR MOONFLAG
CALL INTEGRVS
COMPUTE R(TE)_{1/2}
V(TE)_{1/2}, T2, N1
SH43

RTENCK3 THIS ROUTINE TAKES THE VECTORS $V(T_1)_{1/2}$, PRODUCED
BY VETD3, AND $R(T_1)_{1/2}$ AND PRECISION INTEGRATES TO TE.
RTENCK3 ENTERS THE INTEGRATION ROUTINE WITH
INTYPLG AND MOONFLAG CLEARED, FIRST CALLING
INSTALL TO ENSURE THAT THE INTEGRATION ROUTINE
IS NOT BEING USED, IT LOADS P37 VARIABLES INTO
INPUT LOCATIONS USED BY THE INTEGRATION ROUTINE
AND LOADS THE OUTPUT OF THE INTEGRATION ROUTINE
INTO LOCATIONS USED BY P37.

INPUT: 1. $R(T_1)_{1/2}$ = INITIAL POSITION VECTOR IN METERS @ 2²⁵
2. $V(T_1)_{1/2}$ = POST IMPULSE VELOCITY VECTOR
IN METERS/SEC @ 2²⁵
3. T1 = INITIAL TIME IN CSEC @ 2²⁵
4. TE = FINAL TIME IN CSEC @ 2²⁵
OUTPUT: 1. $R(T_2)_{1/2}$ = FINAL POSITION VECTOR IN METERS @ 2²⁵
2. $V(T_2)_{1/2}$ = FINAL VELOCITY VECTOR IN METERS/SEC @ 2²⁵
MTRAC = $V(T_2)_{1/2}$
3. T2 = FINAL TIME IN CSEC @ 2²⁵
4. X1 = CONICELL = μ - TABLE INDEX FOR EARTH.
5. PLODD = $R(T_2)_{1/2}$

PREC125

SUB-ITERATION LOOP
ENTRY (FOR "TIME - GAMMA" ITERATION
ROUTINE)

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		FIELD GUIDANCE AND INFORMATION	
DRAWN A.C. WILLIAMS PLOTTED [Signature] ANALYST [Signature] CHECKED [Signature] APPROV [Signature]	REVISION APPROV [Signature] DATE [Signature]	P37 - RETURN TO EARTH (PREC100)	DOCUMENT NO. FC-2642
COLLOQUIUM II		SHEET 24 OF 25	

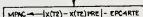
FROM PRECEDING SHEET



PARAM: COMPUTES CONIC PARAMETERS FOR THE OPTI DETERMINED BY $R(\tau_2)_{\text{opt}}$, $V(\tau_2)_{\text{opt}}$ AT τ_2 . IT CALLS SUBRM
INPUT: 1. PLOD = $R(\tau_2)_{\text{opt}}$
2. MPAC = $V(\tau_2)_{\text{opt}}$
3. X1 = -CONICKS = -Z FOR EARTH
OUTPUT: 1. RIA = α_{opt} , RATIO OF $|R(\tau_2)_{\text{opt}}|$ TO SEMI-MAJOR AXIS @ z^2
2. P = P_{opt} , RATIO OF SEMI-LATUS RECTUM TO $|R(\tau_2)_{\text{opt}}|$ @ z^2
3. COGA = $\cot \gamma$, THE COTAN OF THE FLIGHT PATH ANGLE, MEASURED FROM THE VERTICAL @ z^2
4. R1 = MAGNITUDE OF $R(\tau_2)_{\text{opt}}$ IN METERS @ z^2



OUTPUTS OF PARAM ARE PUT INTO P37 LOCATIONS.



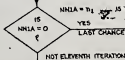
CALCULATION OF COGA MAY CAUSE OVERFLOW.



DOES $x(\tau_2)_{\text{PRE}}$ COME WITHIN .0005° OF $x(\tau_2)$? (FIGURE .0005° FOUND ON PAGE S.9-9 OF R-871, SECTION 5 OF COLOSSUS G50P) $x(\tau_2)$ IS TAKEN AS FIXED AFTER THE CONIC SECTION OF P37. THE RADIUS CAN VARY IN THE SEARCH FOR A PRECISION ORBIT AND TRANSFER TIME THAT ACHIEVE $x(\tau_2)$.



THE CODING FROM HERE TO THE LOOP BRANCH AFTER PREC134 MAY BE CONSIDERED A "TIME-GAMMA" SUBROUTINE.



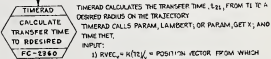
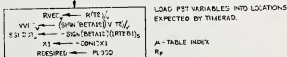
ELEVENTH ITERATION

TO SHEET 36

NEXT SHEET

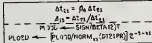
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
BRANCH A.C. WILLIAMS		P37 - RETURN TO EARTH (PREC100)	
PROJECT	ANALYST	DOCUMENT NO.	DOCUMENT NO.
FC-2640	A.C. Williams	COLOSSUS II	FC-2642
APPROVED	DATE	SHEET 55 OF 63	
A.C. Williams	2/24/61		

FROM PRECEDING SHEET



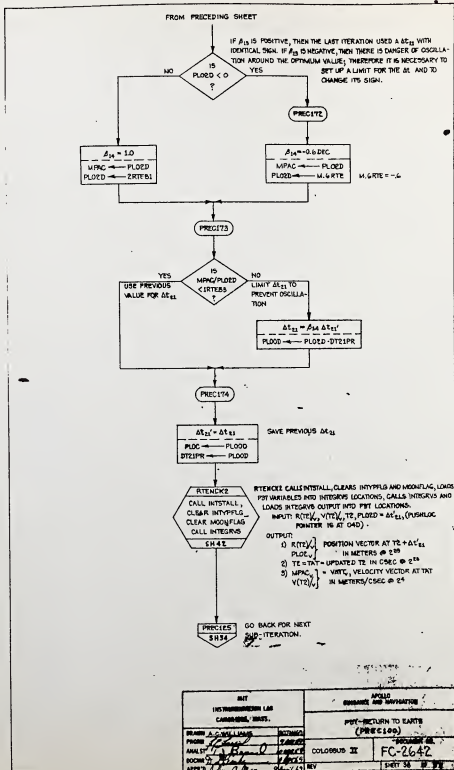
- 1) RVEC = $R_{PI} / |R_{PI}|$ = POSITION VECTOR FROM WHICH TRANSFER TIME TO THE RADIUS DESIRED WILL BE CALCULATED. IN METERS @ 2²⁹
 - 2) VVEC = $V_{PI} / |V_{PI}|$ = VELOCITY VECTOR CORRESPONDING TO $R_{PI} / |R_{PI}|$ IN METERS/CSEC @ 2⁷
 - 3) X1 = -CONGX1, FOR PROPER μ -TABLE REFERENCE.
 - 4) RDESIRED = RADIUS OF POINT ON THE TRAJECTORY IN METERS @ 2²⁹
 - 5) SIGNRDT = -0.2E0000, IMPLIES THAT RDESIRED HAS A NEGATIVE RADIAL VELOCITY.
- RVSW IS SET SO THAT THE NEW STATE VECTOR WILL NOT BE CALCULATED.

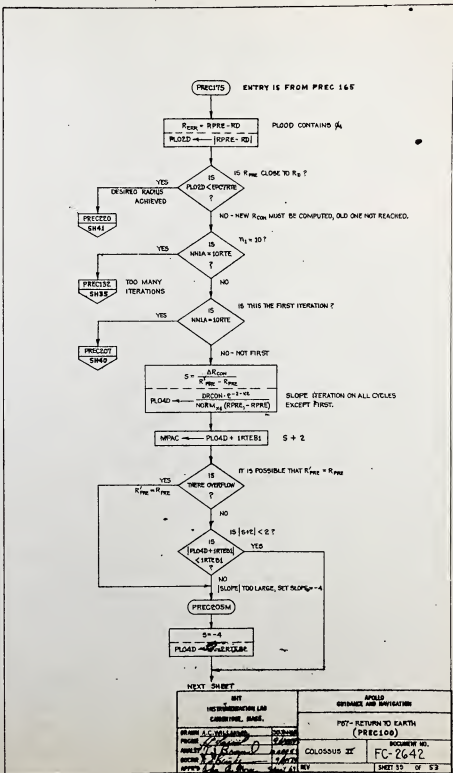
OUTPUT:
 T = TRANSFER TIME IN CSEC @ 2²⁸
 ABORT EXIT: P00000: OCT #07



NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J.C. WILLIAMS		P37- RETURN TO EARTH (PRECIOUS)	
FROM	ANALYST	COLLUSION II	DOCUMENT NO. FC-2642
DOC#	APPR'D		
		REV	SHEET 37 OF 53

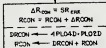
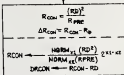




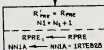
FROM PRECEDING SHEET

PRECED06

PRECED07

ENTRY FROM
PREC 175

PRECED10

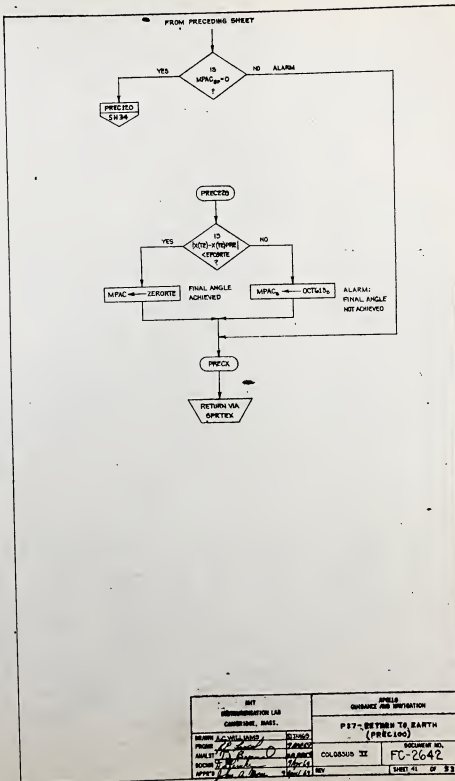
STORE LAST RPRE FOR COMPARISON
DECREMENT COUNTER T_1 

VET100 CALLS GAMEV10
X(TLIM)
DVCALC

INPUT: 1) $R(1)$ = MAGNITUDE OF INITIAL POSITION VECTOR
IN METERS @ 2^{10}
2) $PCON$ = MAGNITUDE OF FINAL POSITION VECTOR
IN METERS @ 2^{10}
3) $VET(1)$ = INITIAL VELOCITY VECTOR IN METERS/SEC @ 2^7
4) $RTEDVD$ = Δ VELOCITY DESIRED IN METERS/SEC @ 2^7
5) $URV(1)$ = UNIT INITIAL POSITION VECTOR @ 2^1
6) $CH(1)$ = UNIT HORIZONTAL VECTOR @ 2^1
7) $X(2)$ = COTANGENT OF FINAL FLIGHT PATH ANGLE @ 2^1
8) $X(1)$ = COTANGENT OF INITIAL FLIGHT PATH ANGLE @ 2^1
9) $CFPA$ = COSINE OF INITIAL FLIGHT PATH ANGLE @ 2^1
10) $MAV(1)$ [LOWER] BOUND ON $MAV(1)$
11) $MAV(2)$ [UPPER] BOUND ON $MAV(1)$
12) $PHIZ$ = PERCENTAGE INDICATOR: -1 = PERCENTAGE
-1 = APOGEE
13) $NN1A$ = PRECISION ITERATION COUNTER
($MAV > 0$ IMPLIES THIS IS FREEDMAN PHASE)
OUTPUT: 1) $VET(1)$ = FINAL VELOCITY VECTOR
IN METERS/SEC @ 2^7
2) DV = INITIAL DELTA IN METERS/SEC @ 2^7
3) $X(1)$ = COTAN OF INITIAL FPA (POST-IMPULSE) @ 2^1
4) $PCON$ = DELTA-LATUS RECTUM IN METERS @ 2^{10}
5) $BETAL = 1 + X(1)^2 @ 2^1$
6) $MPAC = 0$ NORMAL EXIT MODE
 $MPAC \neq 0$ ALARMA CODE OCTOBS
EXCESSIVE ITERATIONS IN GAMEV10.

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO SUBSPACE AND NAVIGATION	
	P37 - RETURN TO EARTH (PRECED08)	
MANAGER A.C. WILLIAMS PROGRAMER [Signature] ANALYST [Signature] DOCUMENTER [Signature] APPROVED [Signature]	COLLOSSUS II REV	DOCUMENT NO. FC-2642 SHEET 40 OF 89



INT REGENERATION LAB CHESTER, MASS.		SPELLS GUIDANCE AND DEFINITION	
NAME: A.C. WILLIAMS		P17 - RETURN TO EARTH (PREC100)	
PROGRAM: <i>[Signature]</i>		DOCUMENT NO.	
ANALYST: <i>[Signature]</i>		COLLABOR: III FC-2642	
BOOKS: <i>[Signature]</i>		REV	
APPROV: <i>[Signature]</i>		SHEET 41 OF 53	

RTENCK1 CALLED BY PRIT

STORE
SPRET
IN
RTENCKEX

INSTALL
STALL THIS JOB
IF INTEGRATION
IS BEING USED
FC-2290

$I(t_1)$
MPAC \leftarrow RTENCKEX

SET
INTYPFLG DO CONIC INTEGRATION TO DEFINE
PSEUDO TARGET FOR LAMBERT STEERING.

RTENCK30
SH49

RTENCK2 CALLED BY PREC174

STORE
Q IN
RTENCKEX

INSTALL
STALL THIS PROGRAM
IF INTEGRATION
IS BEING USED
FC-2290

CLEAR
INTYPFLG DO PRECISION INTEGRATION.

RQL \leftarrow RTENCKEX
VQV \leftarrow VTCEN
TET \leftarrow TE
MPAC \leftarrow TE + PLOC

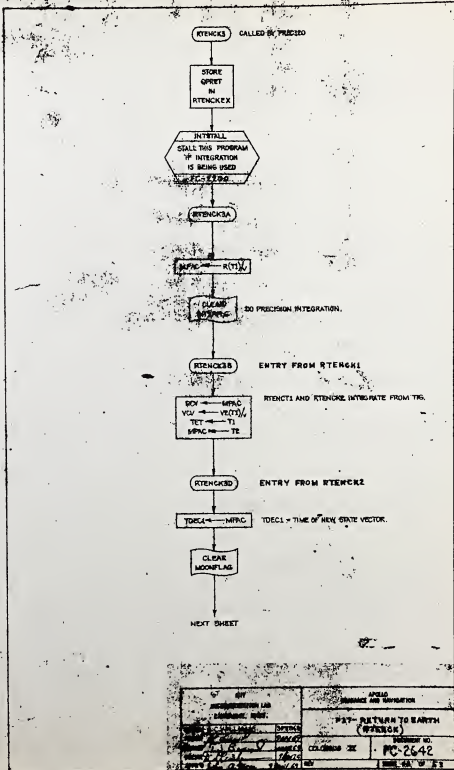
PUT PSI VARIABLES INTO LOCATIONS EXPECTED
BY INTEGRIS

MPAC = Ψ - LATEST QUANTITY IN PUSHLIST
(ADVANCES TE BY Δt_{21})

RAATHER THAN CORRELATE A NEW FINAL STATE VECTOR
FROM RTENCKEX, AND VTCEN, TIME IS SAVED BY EXTRAPOLATING
THE NEW FINAL STATE VECTOR FROM THE OLD,
USING ONLY A SMALL CHANGE IN TE, I.E. STATE VECTOR
AT TE + Δt_{21} IS EXTRAPOLATED FROM STATE VECTOR
AT TE.

RTENCK30
SH49

APPROVED BY _____ DATE _____	PREPARED BY _____ DATE _____
CHECKED BY _____ DATE _____	DOCUMENT NO. FC-2642
DRAWN BY _____ DATE _____	SHEET NO. OF 83
REVISIONS NO. 1 BY _____ DATE _____	



DIV RESEARCH LAB WASHINGTON, D.C.	AFSPD AIRSPACE AND NAVIGATION
PROJECT NO. 100-100-100-100	PAY - RETURN TO EARTH (RTENCKE)
DATE 10/1/68	DOCUMENT NO. PC-2642
BY J. B. ...	CHECKED BY J. B. ...
APPROVED BY J. B. ...	DATE 10/1/68

FROM PRECEDING SHEET



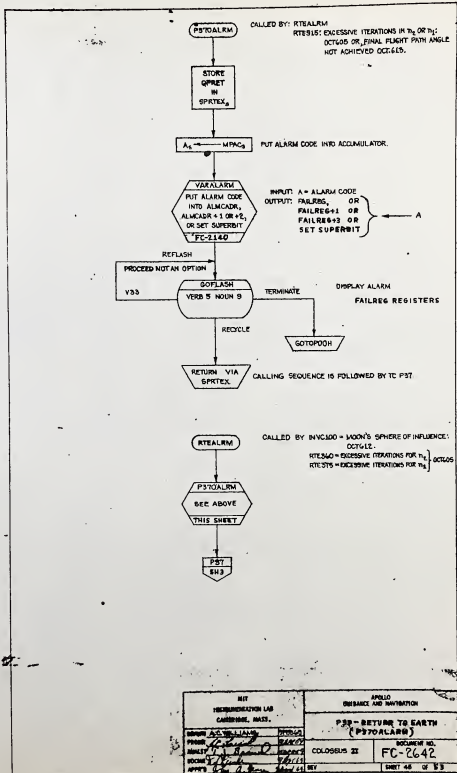
INTEGRYS
 INPUT:
 RCH: POSITION VECTOR AT TET @ 2¹⁵
 VCH: VELOCITY VECTOR AT TET @ 2¹⁷
 TET: TIME TO BE INTEGRATED FROM
 TDEC1: TIME OF NEW STATE VECTOR @ 2¹⁸
 OUTPUT:
 RATT: POSITION VECTOR AT TDEC1
 IN METERS @ 2¹⁵
 VATT: VELOCITY VECTOR AT TDEC1
 IN METERS/SEC @ 2¹⁷
 TAT: TDEC1 IN DEC @ 2¹⁸



-CONICK1 = A TABLE INDEX VALUE



MIT INFORMATION LAB CAMBRIDGE, MASS.		APPLIC GUIDANCE AND NAVIGATION	
DRAWN: A.C. MILLER CHECKED:		P37-RETURN TO EARTH (RTENCK)	
FROM: <i>Handwritten</i> ANALYST: <i>Handwritten</i> ROOM: <i>Handwritten</i> APPROV: <i>Handwritten</i>		DOCUMENT NO. COLOSSUS 82 FC-2642	
		SHEET 44 OF 82	



ERASABLE LOCATIONS USED

AGC TAG	OSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
AI PHA ₁	$r(t_2)$	INPUT TO GETERAD (UNIT $[R(T_2)]_V$)			
BEFA _{1D}	β_1	$1 + x(t_2)^2$			2^1
BEFA _{2D}	ϕ_4	SIGN INDICATOR FOR TIMERAD			
CFPA _{1D}	C_{FPA}	COSINE OF PRE-RETURN FPA			2^1
COGA _{1D}	$(t_2)_{PRE}$	OUTPUT OF PARAM COT OF PRECISION ORBIT AT T2			2^5
CSTH _{1D}		INPUT TO TIMETHET- COS OF 165° OR 210°			2^2
CONICX _{1S}		CONIC μ - TABLE INDEX			
DEL.VSD _{1D}	$V_2(t_1)$	$V_2(t_1) - V_1(t_1)$ INPUT TO N2645	FT/SEC	M/CSEC	2^7
DRCO _{ND}	ΔR_{CON}	RCON SLOPE ITERATOR	METERS	METERS	2^{20}
DT21PR _{1D}	Δt_{21}	PREVIOUS Δt_{21}	SECONDS	CSEC	2^{26}
DV _{1D}	ΔV	TEMP ABSOLUTE VALUE OF Δ VELOCITY AT TIG	FT/SECOND	M/CSEC	2^7
ECSTEER _{1S}		STEERING CONSTANT FOR LAMBERT STERRING	EQUALS 1 @	2^1	$.5 @ 2^2$
ERADM _{1D}		RADIUS OF FISCHER ELLIPSOID FOR T2	METERS	METERS	2^{28}
GAMMAE _{1D}		DISPLAY LOCATION FOR NOUN 60-FINAL FPA	DEGREES	REVS	2^0
MAMA _{1D}	MA_1	MAJOR AXIS CLOSE TO PARABOLIC TRAJECTORY USED TO COMPUTE LOWER BOUND ON $x(T1)$, COT OF POST IMPULSE FPA	METERS	METERS	2^{10}
MAMA _{2D}	MA_2	MAXIMUM MAJOR AXIS USED FOR COMPUTING UPPER BOUND ON $x(T1)$	METERS	METERS	2^{10}
NN1 _{1D}	n_1	COUNTER #1 FOR ITERATION			
SIGN(NN1A)	f_1	POSITIVE = PRECISION PHASE NEGATIVE = CONIC PHASE			
NN2 _{1D}	n_2	COUNTER #2 FOR ITERATION			
P/RPRE _{1D}	P/R_{PRE}	RATIO OF SEMI-LATUS RECTUM TO $[R(T_2)]_V$			2^4
PCON _{1D}	P_{CON}	TEMPORARY SEMI-LATUS RECTUM	METERS	METERS	2^{29}
PHIE _{1D}	ϕ_E	RANGE FROM 400,000 FT ENTRY ALTITUDE TO SPLASHDOWN	NAUTICAL MILES	METERS	2^{29}
PHI2 _{1D}	ϕ_2	PERIGEE-APOGEE INDICATOR -1 = APOGEE -1 = PERIGEE			
*EMDOT	\dot{M}	MASS DECREMENTATION FACTOR FOR CSM	LB/SEC	KG/CSEC	2^3

 MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

 APOLLO
GUIDANCE AND NAVIGATION

P 37

RETURN TO EARTH

 DRAWN *G. J. ...* CHECKED *...*
 ANALYST *...* COLLOSSUS II
 DOCUMENT NO. *...*
 APPROVED *...* REV

 DOCUMENT NO.
FC-2642
SHEET 46 OF 53

ERASABLE LOCATIONS USED (CONTINUED)

PSTRANGE		RANGE FROM 300 K FT TO SPLASH IF $\neq 0$. IF = 0, USE AUGKUGL COMPUTATION.	NAUTICAL MILES	REVS	2^0
PT1 _D	$P(t_1)$	PRIMARY BODY AT TIG 1 - MOON 0 - EARTH			
R'APRE _D	αR_1 PRE	RATIO OF $[R(t_2)/V]$ 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^{20}
RCV _V		RADIUS VECTOR INPUT TO INTEGRVS	METERS	METERS	2^{24}
RD _D	R_D	FINAL RADIUS DESIRED	METERS	METERS	2^{29}
RDESIRED _D	R_F	TEMPORARY FINAL RADIUS	METERS	METERS	2^{29}
RPHE _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
RTEGAM2 _D	$r(t_2)_D$	FINAL FPA DESIRED	DEGREES	REVS	2^0
RTENCKEX _S		RETURN ADDRESS STORAGE			
RVEC _V		INPUT TO CONIC SUBROUTINES (RADIUS VECTOR)	METERS	METERS	2^{29}
RT1 _D	$r(t_1)$	RAH'S MAGNITUDE AT TIG	METERS	METERS	2^{28}
RT1 _V	$r(t_1)$	RADIUS VECTOR AT TIG	METERS	METERS	2^{29}
RT2 _V	$r(t_2)$	RADIUS VECTOR AT T_2	METERS	METERS	2^{29}
SGNRDOT _S		INPUT TO TMRAD POSITIVE FOR POSITIVE RADICAL VELOCITY NEGATIVE FOR NEGATIVE RADICAL VELOCITY			
SNTH _D		INPUT TO TIME/TIG SINCE OF 165° OF 210°			2^1
SPRTETIG _D	T_{IG}	TIME OF IGNITION	SECONDS	CSEC	2^{28}
SPHTEX _S		RETURN ADDRESS STORAGE			
TAT _D		TIME OF OUTPUT VECTORS OF CONIC SUBROUTINES	SECONDS	CSEC	2^{28}

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P37 RETURN TO EARTH	
DRAWN <i>G. J. Sengell</i>	LINEAR		
FROM <i>W. J. ...</i>	STANDARD		
ANALYST <i>W. J. ...</i>	INDEXED	COLOSSUS II	DOCUMENT NO.
DOCKED <i>W. J. ...</i>	LISTED		FC-2642
APPROV <i>W. J. ...</i>	REV		SHEET 47 OF 53

SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
DOUY	2100	DOUBLE PRECISION POLYNOMIAL EVALUATOR	SH, 4, 6, 11
GETERAD	2280	COMPUTE EARTH RADIUS	SH, 7
TIME THET	2360	COMPUTE TIME AND, IF JWSW IS CLEAR, STATE VECTOR TO A PARTICULAR ANGLE, THETA.	SH, 13
AN1645	2720	COMPUTE AND DISPLAY MIDDLE GIMBAL ANGLE	SH, 14
CSMPREC	2200	EXTRAPOLATE PRECISION STATE VECTOR TO TIME (IN THIS CASE, TIG)	SH, 15
TIMERAD	2360	COMPUTE TIME TO A PARTICULAR RADIUS	SH, 27, 37
UGENUGI	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, 45
INTSTALL	2200	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 FAILREC REGISTER, OR SET SUPERBIT	SH, 45

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
RASW	DO NOT COMPUTE FINAL STATE VECTOR IN TIME-THETA, TIMERAD	COMPUTE FINAL STATE VECTOR IN TIME-THETA, TIMERAD	SH, 37	SH, 13, 27	
DELFLG	EXTERNAL DELTA VG COMPUTATION	LAMBERT (AIM POINT) VG COMPUTATIONS		SH, 14	
NORMSW	UNIT NORMAL INPUT TO LAMBERT	LAMBERT COMPUTES ITS OWN UNIT NORMAL		SH, 14	
FINALFLG	LAST PASS THROUGH RENDEZVOUS PROGRAM COMPUTATIONS	INTERM PASS THROUGH RENDEZVOUS PROGRAM COMPUTATIONS	SH, 14		
F2RTE	IN TIME CRITICAL MODE	IN FUEL CRITICAL MODE	SH, 20	SH, 17	SH, 25
ERADFLAG	COMPUTE USING FISCHER ELLIPSOID	COMPUTE USING FIXED RADIUS		SH, 32	
LUNAF LG	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

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i> 12 NOV 68		P37 RETURN TO EARTH	
PROGRAM <i>[Signature]</i> 12 NOV 68		DOCUMENT NO.	
ANALYST <i>[Signature]</i> 12 NOV 68		COLOSSUS II	
DOCSR <i>[Signature]</i> 12 NOV 68		FC-2642	
APPROV <i>[Signature]</i> 12 NOV 68		SHEET 48 OF 53	

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TDEC _{1D}		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
TPASS _{4D}		TIME INPUT TO S46.9	SECONDS	CSEC	2 ²⁸
TRKMKCNT _S		TRACKING MARK COUNT			
T _{1D}	t ₁	INITIAL VECTOR TIME (TIG)	SECONDS	CSEC	2 ²⁸
T _{12D}	t ₁₂	TRANSFER TIME TO FINAL RADIUS	SECONDS	CSEC	2 ²⁸
T _{2D}	t ₂	TIME OF RE-ENTRY	SECONDS	CSEC	2 ²⁸
UH _V	\underline{u}_H	UNIT HORIZONTAL VECTOR			
UR _{1V}	\underline{u}_{R1}	UNIT RADIUS VECTOR AT t ₁			
UV _{1V}	\underline{u}_{V1}	UNIT VELOCITY VECTOR AT t ₁			
V(T ₁) _V	$\underline{v}_1(t_1)$	VELOCITY VECTOR AT t ₁ (PRE-IMPULSE)	FT/SEC	M/CSEC	2 ⁷
V(T ₁) _V	$\underline{v}_2(t_1)$	VELOCITY VECTOR AT t ₁ (POST-IMPULSE)	FT/SEC	M/CSEC	2 ⁷
V(T ₂) _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(T ₁) _V)	FT/SEC	M/CSEC	2 ⁷
WEIGHT/G _D		MASS OF VEHICLE	POUNDS	KG	2 ¹⁶
X(T ₁) _D	x(t ₁)	COTAN (INITIAL POST-IMPULSE FPA)			2 ⁵
X(T ₂) _D	x(t ₂)	COTAN (FINAL FPA)			2 ⁰
X(T ₂)PRE _D	x(t ₂)PRE	COTAN OF FINAL FPA OF PRECISION TRAJECTORY			2 ⁰

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P37 RETURN TO EARTH	
DRAWN <i>A. J. Smith</i>	CHECKED <i>A. J. Smith</i>	COLLOSSUS II	DOCUMENT NO. FC-2642
ANALYST <i>A. J. Smith</i>	APPROVED <i>A. J. Smith</i>	DATE 1/23/68	SHEET 29 OF 53

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N33	GOFFLASH	R1 00XXX HRS R2 000XX MIN DEC ONLY TIG R3 0XX.XX SEC	SH. 3
V06N60	GOFFLASHR	R1 BLANKED OUT R2 VPRED XXXXX FT/SEC DEC ONLY R3 GAMMAE1 (FLIGHT PATH ANGLE) FINAL FPA DESIRE	SH. 3
V04N06	GOFFLASH	R1 OPTION CODE R2 ASSUMED OPTION OCTAL RCS-SPS OPTION R3 NOT USED	SH. 10
V06N33	GOFFLASH	R1 00XXX HRS R2 000XX MIN DEC ONLY: BIASED TIG R3 0XX.XX SEC	SH. 12
V06N61	GOFFLASHR	R1 XXX.XX R2 XXX.XX R3 BLANKED OUT LATITUDE } DEGREES LONGITUDE }	SH. 28
V06N39	GOFFLASH	R1 00XXX HRS R2 000XX MIN DECIMAL TRANSFER TIME R3 0XX.XX SEC	SH. 29
V06N60	GOFFLASHR	R1 BLANKED OUT R2 VPRED XXXXX FT/SEC DEC ONLY PREDICTED V R3 GAMMAE1 XXX.XX DEGREES DEC ONLY PREDICTED FINAL FPA	SH. 29
V06N81	GOFFLASH	R1 XXXX.X FT/SEC R2 XXXX.X FT/SEC Δ V VECTOR R3 XXXX.X FT/SEC	SH. 30
V06N09	GOFFLASH	R1 OCTAL ALARM CODE FROM MPAC, 00XXX, NONE R2 REGISTER R3	SH. 45

PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
RTED _{1D}	D ₁	X ⁰ COEFFICIENT IN COMPLETION OF x(t ₀)	.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	MA1	MAXIMUM MAJOR AXIS FOR R(T1)/V WITH NEGATIVE RADIAL COMPONENT	8. x 10 ⁸ METERS	8 x 10 ⁸ METERS	2 ³⁰
EPC1RTE _D	E ₁	VALUE USED TO TEST WHETHER RADII AND VELOCITY VECTORS ARE NEARLY COLLINEAR	COS(1.5 ⁰)	.99966	2 ¹

MIT INSTRUMENTATION ENG CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>D. J. Smith</i>		P37 RETURN TO EARTH	
FIGURE	921007	COLOSSUS II	DOCUMENT NO.
ANALYST	<i>D. J. Smith</i>		FC-2642
ROOM	7B-115	REV	SHEET NO. OF 53
APPROVED	<i>D. J. Smith</i>		

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	OSOP 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 $.058^\circ$)	.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 $.00058^\circ$)	.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 $.114^\circ$)	.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
ERTE _D	E_3	REENTRY ALTITUDE ABOVE FISCHER ELLIPSOID	121920 M	121420 M	2^{29}
K1RTE _D	K_1	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 $ R(T)/V < K_1$ (EQUIVALENT TO $-3^\circ 28.5'$)	-.06105	-.06105	2^0

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>A. J. ...</i> 12 NOV 62		P 37 RETURN TO EARTH	
PROGRAM <i>A. J. ...</i> 2 MAR 63	ANALYST <i>A. J. ...</i> 2 MAR 63	COLOSSUS II	DOCUMENT NO. FC-2642
DOCNO <i>A. J. ...</i> 2 MAR 63	APPROVED <i>A. J. ...</i> 2 MAR 63	REV	SHEET #1 OF 53

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
K4HYE ₁	K ₄	INITIAL ESTIMATE OF COTANGENT OF REENTRY ANGLE USED WHEN $ R(T2)/V > K_1$ (EQUIVALENT TO $-5^{\circ}58'$)	-.10453	-.10453	2 ⁰
MCOS7.5 _D	-COS 7.5 ⁰	USED IN DETERMINING GSOP QUANTITY K	-.09144486	-.09144488	2 ⁰
MCOS22.5 _D	-COS 22.5 ⁰	CRITERION USED TO DETERMINE WHETHER TARGET FOR LAMBERT STEERING IS TOO CLOSE TO 180 ⁰	-.82387853	-.82387853	2 ²
MDOTH _D	\dot{m} (SPS)	MASS DECREMENTATION FACTOR FOR SPS BURN	63.8 LB/SEC	.000391032 KG/CSEC	2 ³
MIXTRCS _D	\dot{m} (RCS)	MASS DECREMENTATION FACTOR FOR RCS BURN	.16375 KG/SEC	.0016375 KG/CSEC	2 ³
MISIN7.5 _D	-SIN 7.5 ⁰	USED IN DETERMINING GSOP QUANTITY K	-.13052819	-.13052819	2 ⁰
RTMURTE _D	$\sqrt{g_E}$	SQUARE ROOT OF EARTH GRAVITATIONAL CONSTANT	19965050.1 M ^{3/2} /SEC	199650.501 M ^{3/2} /CSEC	2 ¹⁸
THETA165 _D	165 ⁰	165 ⁰ = POSITION OF NEW TARGET FOR LAMBERT STEERING	165 ⁰	.458333333 REVS	2 ⁰
THETA210 _D	210 ⁰	210 ⁰ = POSITION OF ALTERNATE NEW TARGET FOR LAMBERT STEERING	210 ⁰	.58333333 REVS	2 ⁰
VCRCSD _D	V _C (RCS)	THRUST VELOCITY OF RCS JETS	2708.64 METERS/SEC	27.0664 METERS/CSEC	2 ⁵
VCSPSD _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
3048ORTE _D	30480	INPUT TO TIMERAD = R(T2)/V - 30480	30480 METERS	30480 METERS	2 ²⁸
THE FOLLOWING ARE INPUTS TO THE POLY SUBROUTINE. CALLED TO COMPUTE MAMAX2, XR2 ² , AND $-\Delta v/v_e$, IN THE ORDER THEY APPEAR. (ALL VALUES DF. NO AGC TAGS - POLY USES INDEXED ADDRESSING.)					
C ₀		} COEFFICIENTS USED TO COMPUTE MA ₂	1.81000434 x 10 ⁸ M	1.81000434 M	2 ³¹
C ₁			1.50785145	1.50785145	2 ²
C ₂			-6.49983057 x 10 ⁻⁹ M ⁻¹	-6.49993057 x 10 ⁻⁹ M ⁻¹	2 ⁻²⁷
C ₃			8.76938926 x 10 ⁻¹⁸ M ⁻²	8.76938926 x 10 ⁻¹⁸ M ⁻²	2 ⁻⁵⁶

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY <i>[Signature]</i>		P 37 RETURN TO EARTH	
PROGRAM <i>[Signature]</i>		DOCUMENT NO.	
ANALYST <i>[Signature]</i>		COLOSSUS II	
DOCOR <i>[Signature]</i>		FC-2642	
APPROVED BY <i>[Signature]</i>		SHEET 26 OF 59	

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(T ₂)'	-4.8760771 x 10 ⁻⁴ S/M	0		
	D ₂			-4.8760771 x 10 ⁻² CSEC/M	2 ⁻⁴	
	D ₃			4.5419478 x 10 ⁻⁸ S ² /M ²	4.5419478 x 10 ⁻⁴ CSEC ² /M ²	2 ¹¹
	D ₄			-1.4317675 x 10 ⁻¹² S ³ /M ³	-1.4317675 x 10 ⁻⁶ CSEC ³ /M ³	2 ⁻¹⁸
	C ₀	} COEFFICIENTS USED TO COMPUTE (1-c-Δv/v _c)		5.68240507 x 10 ⁻⁴	2 ³	
	C ₁			0.079487897	2 ¹	
	C ₂			-388281955	2 ⁻¹	

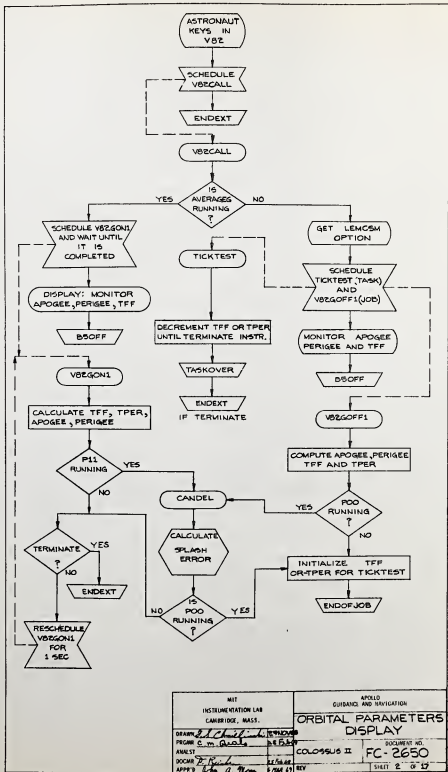
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		SPSOLD GUIDANCE AND NAVIGATION	
		P 37	
		RETURN TO EARTH	
DESIGN <i>[Signature]</i>	DATE <i>7/2/60</i>	COLLOSSUS II	DOCUMENT NO.
ANALYST <i>[Signature]</i>	DATE <i>7/2/60</i>		FC-2642
DESIGNER <i>[Signature]</i>	DATE <i>7/2/60</i>		SHEET 59 OF 53
APPROVER <i>[Signature]</i>	DATE <i>7/2/60</i>		

ORBITAL PARAMETERS DISPLAY

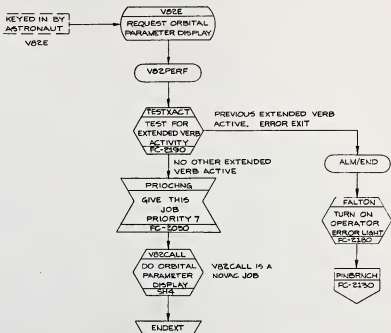
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

V82PERF:	ENTRY FROM VERB FAN	SH. 3
V82CALL:	DISPLAY AND CALLING ROUTINE	SH. 4
TICKTEST:	TFF COUNTDOWN MECHANISM	SH. 10
SR30.1:	SUBROUTINE FOR CALCULATING TFF AND TPER	SH. 12

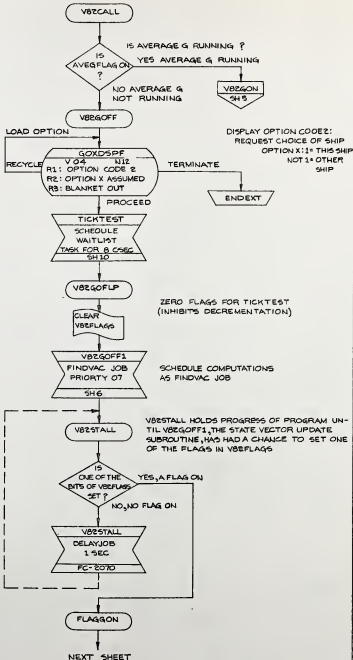
INSTRUMENT ON LINE	ORBITAL PARAMETERS DISPLAY
CRAFT NO. 40157	COLLOSSUS II
<i>John S. Chappell</i> NAME OF OPERATOR DATE 28 FEB 68	PC-2650
NAME OF <i>J. R. ...</i> OPERATOR DATE 28 FEB 68	1 17



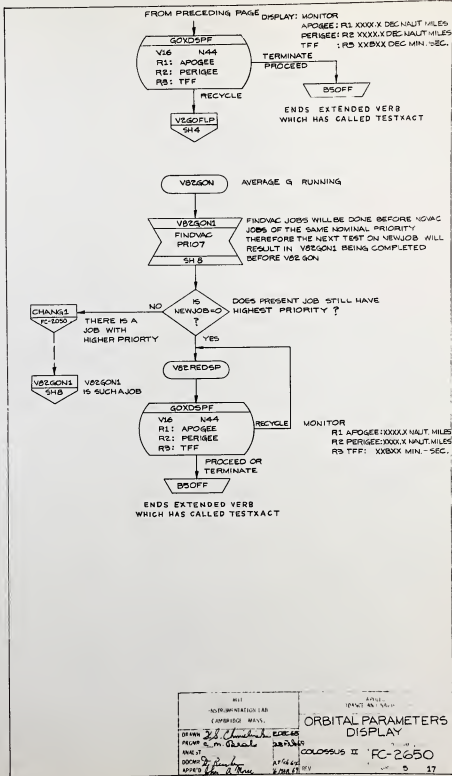
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>E. M. Quate</i>		ORBITAL PARAMETERS DISPLAY	
FROM <i>E. M. Quate</i>		DOCUMENT NO.	
ANALYST		COLOSSUS II	
DOCNO <i>2-10-68</i>		FC-2650	
APPRO <i>E. M. Quate</i>		SHEET 2 OF 17	



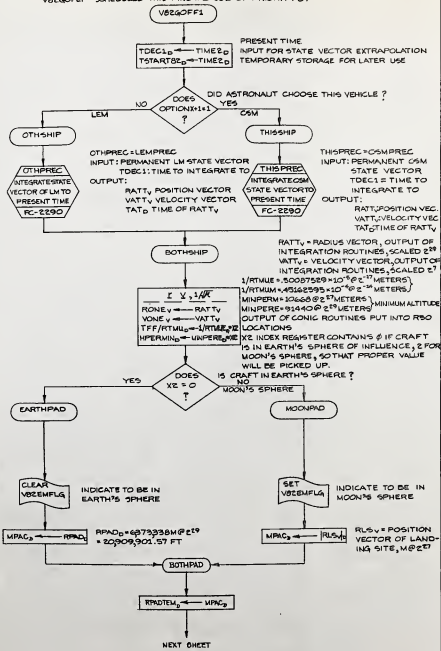
MIT INSTRUMENTATION LAB CAMBRIDGE MASS.		REVISIONS DATE AND VALUE	
DRAWN <i>ET. Chubbuck</i> EDG:CS		ORBITAL PARAMETERS DISPLAY	
PROGRAM BY <i>Geale</i> 08/16/57		COLOSSUS II FC-2650	
ANALYST			
DESIGN BY <i>Geale</i> H/8/57			
APPROVED BY <i>Don A. Brown</i> L/22/57		REV	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
		ORBITAL PARAMETERS DISPLAY	
DRAWN BY <i>J. Chouinard</i>	DATE <i>10/20/64</i>	PROJECT <i>COLLOSSUS II</i>	DOCUMENT NO. <i>FC-2650</i>
DESIGNED BY <i>J. Chouinard</i>	DATE <i>10/20/64</i>	APPROVED BY <i>J. Chouinard</i>	SHEET 4 OF 17



V82G0FLP SCHEDULED THIS FINDVAC JOB OF PRIORITY 07



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIC GUIDANCE AND NAVIGATION
ORBITAL PARAMETERS DISPLAY	
DRAWN: <i>J. S. Chubbuck</i> PROGRAM: <i>E. M. Quinn</i> ANALYST: <i>J. S. Chubbuck</i> APPROVED: <i>J. S. Chubbuck</i>	COLUSSUS II DOCUMENT NO: FC-2650 REV: <i>2/24/61</i>
SHEET 6 OF 17	

SR90.1

INPUT: POVE_v = PRESENT POSITION VECTOR:

METERS @ 2²⁹

VOVE_v = PRESENT VELOCITY VECTOR:

M/CSEC @ 2⁷

VBLEMFLG = FLAG ON = MOON'S SPHERE

FLAG OFF = EARTH'S SPHERE

RPADTEM_D = RADIUS OF PAD: METERS @ 2²⁸

OUTPUT: HAPOXD_D = APOGEE ALTITUDE ABOVE

PAD: METERS @ 2²⁹

HPERXD_D = PERIGEE ALTITUDE ABOVE PAD

RADIUS: METERS @ 2²⁹

TFF_D = TIME OF FREE FALL: SEC @ 2²⁸

-TPER_D = TIME TO PERIGEE: CSEC @ 2²⁸

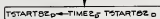
FROM PRECEDING SHEET



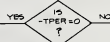
IS POO RUNNING?



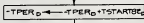
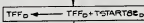
ENTRANCE FROM SPLRET1 WITH POO RUNNING



TIME ELAPSED SINCE TSTARTEDD



-TPER IS SET TO ZERO WHEN PERICENTER IS ABOVE MINIMUM, F50. TFF WILL BE DISPLAYED AS 59859 AND -TPER WILL BE DECREMENTED. NOTE, TFF WILL ALSO BE DISPLAYED AS 59859 WHEN APOCENTER IS BELOW MINIMUM PERICENTER, BUT IT WILL THEN START DECREMENTING, GIVING MEANINGLESS VALUES.



FLAG SET FOR TICKTEST, AND TO RELEASE MONITOR DISPLAY FROM STALL



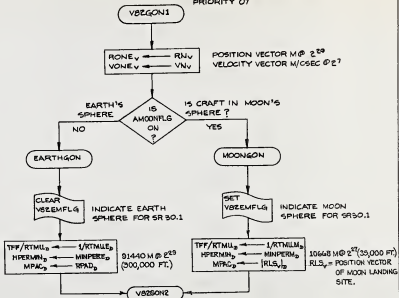
DATE: 2/1/68
 DRAWN: J. Chisholm
 CHECKED: M. G. G. / J. G. G.
 TITLE: ORBITAL PARAMETERS DISPLAY
 PART: 28FA449
 FILE: 28FA449
 SHEET: 7 OF 17

ORBITAL PARAMETERS DISPLAY

COLOSSUS II FC-2650

7 17

VBECON1 SCHEDULED THIS FINDVAC JOB OF PRIORITY 07



RPADEM ← MPAC_D

NEXT SHEET

SR30.1

INPUT:

RONE_v = POSITION VECTOR IN METERS @ E²⁹

VONE_v = VELOCITY VECTOR IN METERS/CSEC @ E²⁷

RPADEM = PAD RADIUS IN METERS @ E²⁹

VBEEMFLG ON = MOON, OFF = EARTH

OUTPUT:

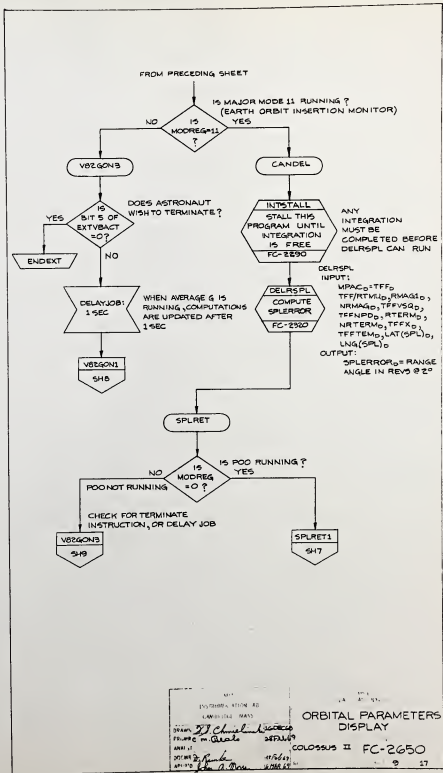
HPERC_D = PERIGEE HEIGHT ABOVE PAD RADIUS @ E²⁹

HAPOC_D = APOGEE HEIGHT ABOVE PAD RADIUS @ E²⁹

TFF_D = TIME OF FREEFALL } CSEC @ E²⁸

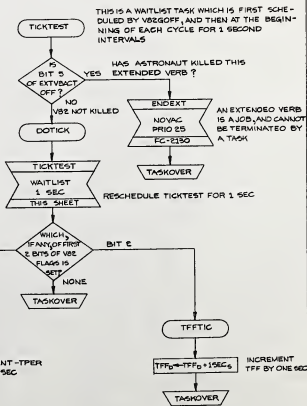
-TPERC_D = TIME TO PERIGEE }

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		ORBITAL PARAMETERS DISPLAY	
DRAWN <i>J. J. Chalk</i>	DESIGNED <i>J. J. Chalk</i>	DOCUMENT NO. COLOSSUS II FC-2650	
FROM <i>E. M. G. G. G.</i>	DATE <i>10/25/64</i>		
ANALYST <i>J. J. Chalk</i>			
DOCS <i>J. J. Chalk</i>			
APPROVED <i>J. J. Chalk</i>	DATE <i>10/25/64</i>	SHEET 8 OF 17	

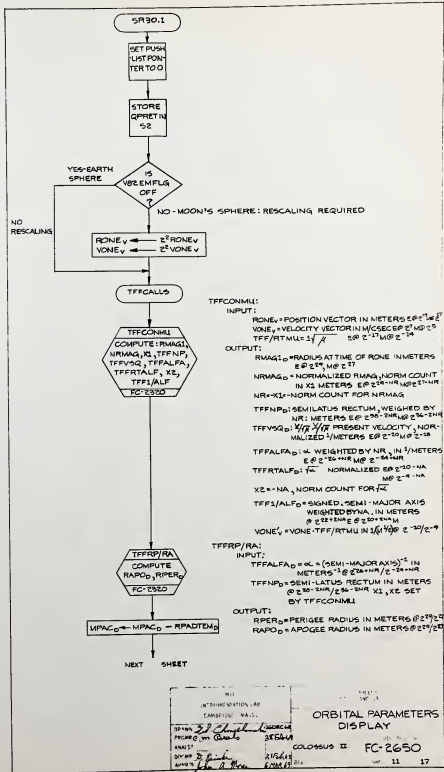


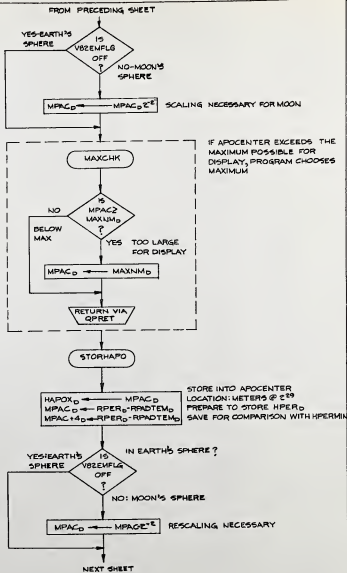
157200A, SECTION 40
LAWRENCE, MASS
FORM 37 *Chas. L. ...*
FR-40C in *Circle* 2871469
ANNEX
207-101 *John A. ...* 11/6/57
APPROVE *John A. ...* 11/6/57

ORBITAL PARAMETERS
DISPLAY
COLOSSUS II FC-2650

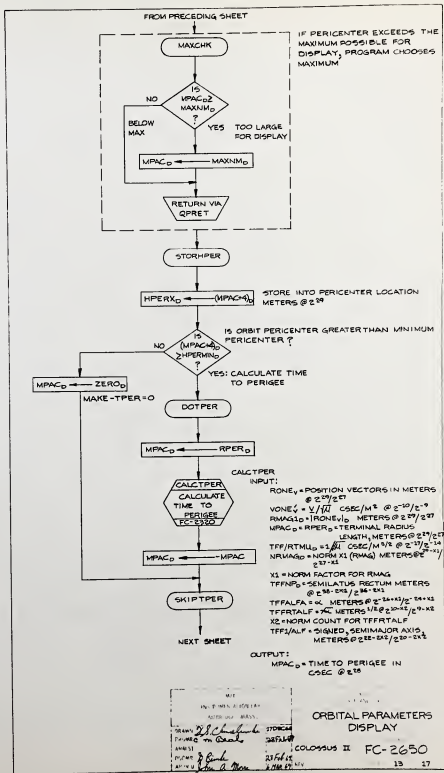


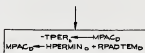
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>J. J. ...</i>		ORBITAL PARAMETERS DISPLAY	
DESIGN <i>G. M. ...</i>		DOCUMENT NO.	
ANALYST <i>J. J. ...</i>		COLOSSUS II	
DOCNO <i>J. J. ...</i>		FC-2650	
APPROV'D <i>J. J. ...</i>		REV	
		SHEET 20 OF 17	





MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		ORBITAL PARAMETERS DISPLAY	
DRAWN <i>[Signature]</i>	DESIGNED <i>[Signature]</i>	COLLAPSED II	DOCUMENT NO. FC-2650
ANALYST <i>[Signature]</i>	APPROVED <i>[Signature]</i>		SHEET 12 OF 17





CALCTFF

INPUT

$RONE_v, VONE_v, RMAG1_0, MPAC + RPADTEM + HPERMIN,$
 $TFF/RTM1_0, RTMAG_0, X1, TFFNP_0, TFFALFA_0,$
 $TFFRTALF_0, X2, TFF1/ALF$

OUTPUT

$MPAC_0 = TFF \cdot \text{TIME OF FREE-FALL, IN CSEC @ } 250$

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	
		ORBITAL PARAMETERS DISPLAY	
DRAWN <i>J. J. ...</i>	DESIGNED <i>J. J. ...</i>	DOCUMENT NO.	
PERFORMED <i>C. M. ...</i>	TESTED <i>J. J. ...</i>	FC-2650	
DOCKED <i>J. J. ...</i>	APPROVED <i>J. J. ...</i>	COLUSSUS II	SHEET 14 OF 17

DISPLAYS

VERB NOI N	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXE/TESTED
	FALTON	TURN ON OPERATOR ERROR LIGHT: PREVIOUS EXTENDED VERB ACTIVE.	SH. 3
04-12	GOXDSPF	R1 OPTION CODE 2 R2 OPTION 1 ASSUMED R3 BLANKED OUT	SH. 3
16-44	GOXDSPF	R1 APOGEE: XXXX. X D NAUT MILES R2 PERIGEE XXXX. X D NAUT MILES R3 TFF: XXBXN D MIN, SEC	SH. 5

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
AVERAGEFLAG	AVERAGEG NOT RUNNING	AVERAGEG NOT RUNNING			SH. 4
BIT 5 OF EXTVACT	DO NOT TERMINATE EXTENDED VERB	TERMINATE EXTENDED VERB			SH.
AMOOONFLG	IN MOON'S SPHERE	IN EARTH'S SPHERE			SH. 8
EMFLG	IN MOON'S SPHERE	IN EARTH'S SPHERE	SH. 6, 8	SH. 6, 8	SH. 11, 12
FLAGS	EITHER SET: START DISPLAY	NEITHER SET: HOLD DISPLAY	SH.	SH. 4	SH. 4
BIT 1 OF FLAGS	TICKPER OPERATING	TICKPER NOT OPERATING	SH. 7		
BIT 2 OF FLAG	TICKTFF OPERATING	TICKTFF NOT OPERATING	SH. 7		

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. 14
CALCTPER	2320	CALCULATES TIME OF FREE FALL TO PERICENTER	SH. 13
DELAYJOB	2070	DELAYS A JOB FOR A PARTICULAR TIME PERIOD	SH.
DELRSPL	2320	CALCULATES ERROR IN SPLASHDOWN BETWEEN CALCULATED AND PREDICTED	SH. 9
ENDEXT	2130	ENDS AN EXTENDED VERB	SH. 10
FALTON	2130	TURNS ON OPERATOR ERROR LIGHT	SH. 3
OTHPREC	2300	UPDATE LEM VECTOR TO A PARTICULAR TIME	SH. 6
PRIOCHNG	2050	CHANGE CALLING JOB'S PRIORITY	SH. 3
TESTXACT	2150	TEST FOR EXTENDED VERB ACTIVITY	SH. 3
TFFCONMU	2320	COMPUTES VARIOUS PARAMETERS USED IN THE TFF ROUTINES, AND ESTABLISHES THEM IN THE PCH LIST AREA	SH. 11
TFFRP/RA	2320	CALCULATES PERIGEE AND APOGEE RADII FOR A GIVEN CONIC	SH. 11
THSPREC	2300	UPDATE CSM STATE VECTOR TO A PARTICULAR TIME	SH. 6
INTSTALL	2300	STALL CALLING PROGRAM UNTIL INTEGRATION IS NOT IN USE, THEN INHIBIT ANY OTHER PROGRAM FROM USING INTEGRATION UNTIL INTWAKE IS CALLED.	SH. 9

ORBITAL PARAMETERS
DISPLAY

COLOSSUS II FC-2650

15 17

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
RV _V	r	RADIUS VECTOR AS GIVEN BY AVERAGE	FEET	METERS	2 ²⁹
RONE _V	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
RPER _D	r _p	MAGNITUDE OF PERICENTER	FEET	METERS	2 ²⁷ /2 ²⁹
TF _D	t _H	TIME OF FREE FALL TO A CERTAIN ALTITUDE	SECONDS	CSEC	2 ²⁸
TF/RTMU _D	1/√a	INVERSE OF SQUARE ROOT OF MU	SEC/FEET ^{3/2}	CSEC/M ^{3/2}	2 ¹⁴ /2 ¹⁷
TFALFA _D	a	INVERSE OF THE SEMIMAJOR AXIS OF A CONIC	1/FEET	1/METERS	2 ^{-28-X1} / 2 ^{-24-X1}
TFNP _D	p	SEMILATUS RECTUM, NORMALIZED	FEET	METERS	2 ^{28+X1} / 2 ^{36+X1}
TFRTALF _D	√a	SQUARE ROOT OF ALPHA	1/FEET ^{1/2}	1/M ^{1/2}	2 ^{-10-X1} / 2 ^{-9-X1}
TFV _{QD}	(v') ²	VELOCITY/√a	1/FEET ^{1/2}	1/M ^{1/2}	2 ⁻²⁰ /2 ⁻¹⁸
TF1/ALF _D		SIGNED, SEMI-MAJOR AXIS, WEIGHTED BY X2	FEET	METERS	2 ^{22-2X2} / 2 ^{20-2X2}
TIME2 _D		TIMING REGISTERS	SECONDS	CSEC	2 ²⁸
TSTART2 _D		STORAGE FOR TIME2 INPUT	SECONDS	CSEC	2 ²⁸
TDEC1 _D		TIME TO BE INTEGRATED TO	SECONDS	CSEC	2 ²⁸

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		ORBITAL PARAMETERS DISPLAY	
DESIGN <i>[Signature]</i>	REVISION <i>[Signature]</i>	COLOSSUS II	DOCUMENT NO.
ANALYST	DATE		FC-2650
DOCTR <i>[Signature]</i>	REV		SHEET 16 OF 17

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 AVERAGED	FEET/SEC	M/CSEC	2 ⁷
VONE _V		VELOCITY VECTOR	FEET/SEC	M/CSEC	2 ⁷
VONE _V		VONE/ $\sqrt{\mu}$	FEET ^{-1/2}	M ^{-1/2}	2 ^{-10/2-0}

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 _p MIN	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 M	2 ²⁹
1/RTMUE	1/ $\sqrt{u_e}$	INVERSE OF THE SQUARE ROOT OF MU FOR EARTH	.0008427916 x 10 ⁻⁵	50087529 x 10 ⁻⁵	2 ⁻¹⁷
1 RTMU	1/ $\sqrt{u_M}$	INVERSE OF THE SQUARE ROOT OF MU FOR MOON	.007599228 x 10 ⁻⁴ SEC/FT ^{3/2}	.45162595 x 10 ⁻⁴ CSEC/M ^{3/2}	2 ⁻¹⁴

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ORBITAL PARAMETERS DISPLAY	
TRAIN <i>S. C. ...</i>	PROGRAM <i>...</i>	COLLOSSUS II	DOCUMENT NO
ANN ST	DOCS <i>...</i>	FC-2650	REV
APPRO <i>...</i>	DATE <i>...</i>	REV	REV

REV 17 OF 17

P-76 TARGET DELTA VELOCITY

MAJOR SUBROUTINES & EXTERNAL ENTRY POINTS:
COMPMAT (SH2), P76SUB1 (SH3)

MIT
SUBSTITUTION LAB
CAMBRIDGE, MASS

FORM NO. 100-100

P-76

TARGET DELTA V

5/3 1965
1/6 1965
1/6 1965
1/6 1965

STANDARD

COLOMBUS

1/6 1965

1/6 1965

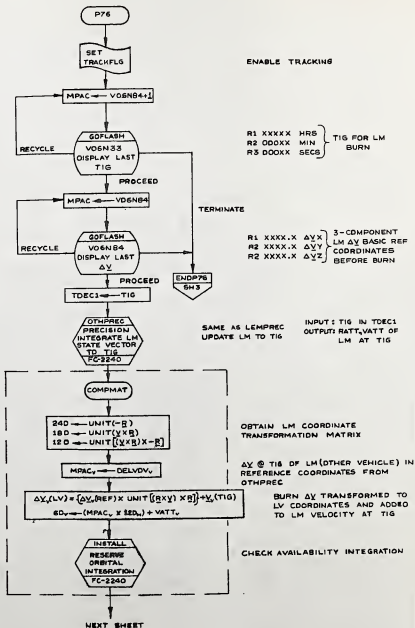
COLOMBUS IIC

REV 1

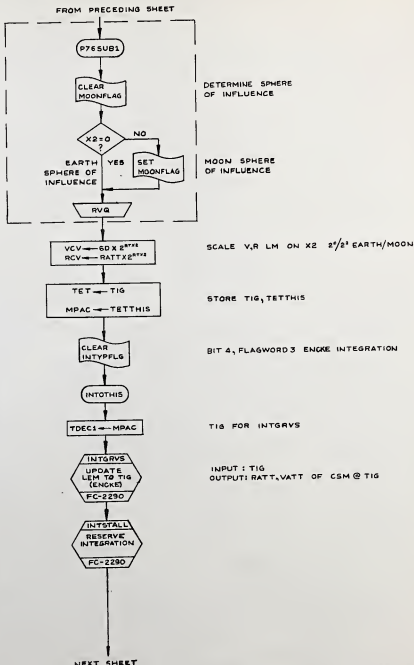
FORM NO. 100-100

FC-2670

PAGE 1 OF 6

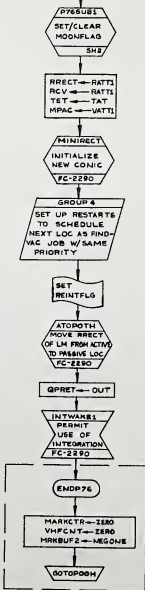


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P-76 TARGET DELTA V	
DRAWN BY <i>J. B. ...</i>	DATE <i>7/1/68</i>	COLOSSUS IIC	DOCUMENT N.:
FROM <i>J. B. ...</i>	BY <i>J. B. ...</i>		FC-2670
DOC# <i>FC-2670</i>	REV <i>1</i>	REV 4	SHEET 2 OF 6



767 IDENTIFICATION TAG		AFFILE COSMOS AND VATT	
COSMOS, MARS		P76	
DRARY V. O. Zanderke	SHADON	TARGET DELTA V	
PCWAS J. G. Jensen	SCAPE KIT	00-00-00-00	
ANNSI	2. 2. 2. 2.	COLOSSUS IIC	FC-2670
APR 2 John A. Brown	REV 1	1-561	3 6

FROM PRECEDING SHEET



SAVE CSM POSITION, VELOCITY, TIME
INTEGRATED TO

BIT 7, FLAG 10
INTEGRATION ROUTINE TO BE RESTARTED
(SAME AS ATOPLEM)

RELINQUISH INTEGRATION ROUTINE

CLEAR COUNTERS

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
		P76 TARGET DELTA V	
DRWNR: <i>W.B. Woodcock</i>	DESIGNER:	ANALYST: <i>John J. Blalock</i>	DOCUMEN. N°: <i>FC-2670</i>
PREPDR: <i>J.E. Sacks</i>	ISSUANCE:	APPROV: <i>John J. Blalock</i>	
SCALE:		DATE: <i>2 May 68</i>	
APPR: <i>John J. Blalock</i>	REV: 1	SHEET: 4 OF 6	

SUBROUTINES CALLED

SUBROUTINE NAME	DESCRIPTION
OTHIPREC	(SAME AS LEMPREC) PRECISION INTEGRATION OF LM
INTSTALL	RESERVES ORBITAL INTEGRATION
INTGRVS	ENKE UPDATE OF LM TO TIG
MINIRECT	INITIALIZE NEW CONIC
ATOPOTH	MOVES LM STATE VECTOR TO PASSIVE STORAGE LOC
INTWAKE1	RELEASES INTEGRATION ROUTINES

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
TRACKFLAG	ENABLE MARKTAKING	INHIBIT MARKTAKING	SH, 1		
MOONFLAG	MOON SPHERE OF INFLUENCE	EARTH SPHERE OF INFLUENCE	SH, 2	SH, 2	
INTYFLAG	ENKE INTEGRATION	CONIC INTEGRATION		SH, 2	
REINTFLAG	RESTART INTEGRATION	DO NOT RESTART INTEGRATION	SH, 3		

VARIABLE ERASABLE LOCATIONS USED

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TDEC1		STORAGE LOC FOR INTEGRATION TIME		CSEC	2^8
TIG		STORAGE LOC FOR IGNITION TIME		CSEC	2^{20}
DELVOV		ΔV OTHER VEHICLE (LM)		M/CSEC	2^7
VCV		TEMPORARY CONIC VELOCITY		M/CSEC	2^7
RCV		TEMPORARY CONIC POSITION		M	2^{20}
TET		TEMPORARY TIME OF STATE VECTOR		CSEC	2^{28}
TETTHS		TEMPORARY TIME OF CSM STATE VECTOR		CSEC	2^{28}
RRRECT		TEMPORARY POSITION AT RECT TIME		M	2^{20}
MARKCTR		MARK COUNTER (USED BY R32)			2^0
VIFCNT		VIF MARK COUNTER			2^0
MRKBUF2		TEMP MARK COUNTER FOR R21			2^0
NEGONE		NEGATIVE 1			2^{14}

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PROJECT GUIDANCE AND NAVIGATION P76	
DESIGN 3.6	DATE 12/15/68	TARGET DELTA V	
ANALYST J. S. ...	APPROVED J. S. ...	COLLOSSUS IIC	FC-2670
		REV 1	SHEET 5 OF 6

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N84		DISPLAY LAST ΔY	SH. 1
V06N83		DISPLAY LAST TIG	SH. 1

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
		P76 TARGET DELTA V	
DRAWN <i>J. E. Gardner</i>	1 APR 68	DOCUMENT NO.	
FIGURE <i>J. E. Gardner</i>	2 APR 68	FC-2670	
ANALYST		COLOSSUS IIC	
DOOR		REV 1	SHEET 6 OF 6
APPROVED <i>J. E. Gardner</i>	<i>J. E. Gardner</i>		

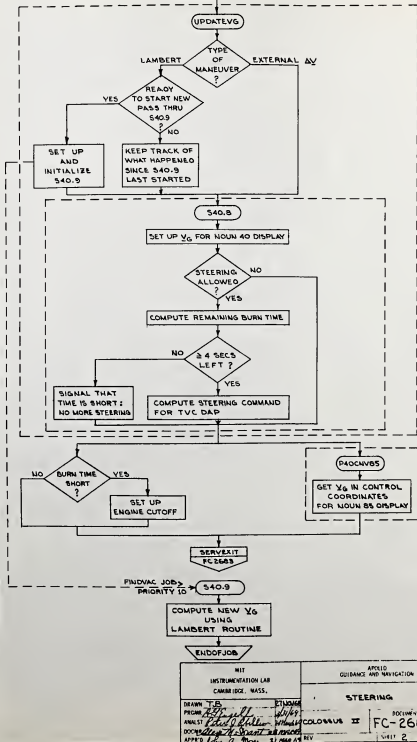
STEERING

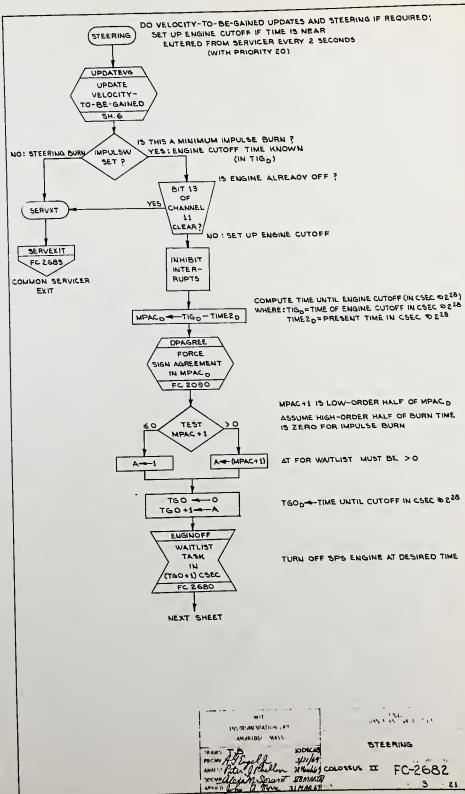
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS		
STEERING:	CAUSES VELOCITY-TO-BE-GAINED UPDATE AND STEERING COMPUTATIONS	SH 5
CALCN85:	PREPARES NOUN 85 (VELOCITY-TO-BE-GAINED) FOR DISPLAY	SH 5
P40CNV85:	CONVERTS VELOCITY-TO-BE-GAINED TO CONTROL COORDINATES	SH 5
UPDATEVG:	SETS UP VELOCITY-TO-BE-GAINED AND CROSS-PRODUCT STEERING COMPUTATIONS	SH 6
S40.8:	COMPUTES REMAINING BURN TIME AND, IF NECESSARY, STEERING COMMANDS	SH 9
S40.9:	UPDATES VELOCITY-TO-BE-GAINED, USING LAMBERT ROUTINE	SH 14
REDO40.9:	POSSIBLE RESTART ENTRY TO S40.9	SH 17

REF	DATE AND TIME
INSTRUMENTATION, AR	
FAMROUSE, MAVS.	
DRAWN <i>G. J. [unclear]</i>	STEERING
DESIGNED <i>G. J. [unclear]</i>	COLLOSSUS II
ANALYZED <i>G. J. [unclear]</i>	FC-2682
CHECKED <i>G. J. [unclear]</i>	REV. 1
APPROVED <i>G. J. [unclear]</i>	21

STEERING
GENERAL FLOW

BOTH PART OF FINOVAC JOB, PRIORITY 20

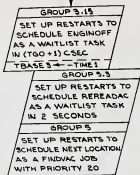
CALC/NBS
GENERAL FLOW



1000000
 FC-2682
 3 21

STEERING
 FC-2682

FROM PRECEDING
SHEET



NOTE: 2 TIMES FOR THIS AND OTHER
GROUP 3 WAITLIST TASK RESTARTS
ARE MEASURED FROM THE LAST
TIME REREADAC WAS SCHEDULED

CLEAR
IMPULSW

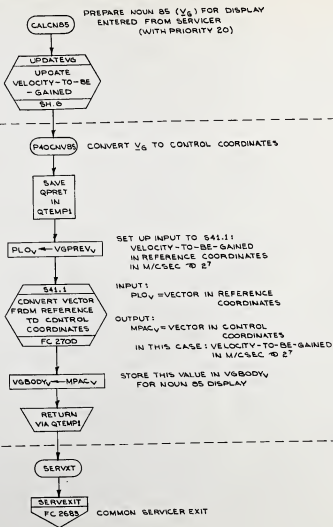
CUTOFF-TIME NO LONGER NEEDED-
ENGINOFF ALREADY SET UP

SERVKT

SERVEXIT
FC 2682

COMMON SERVICES EXIT

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AIRFOIL GUIDANCE AND NAVIGATION	
DRAWN T.S.		STEERING	
FROM <i>FC-2682</i>	DESIGN <i>1/16/68</i>	COLLOGRAM II	DOCUMENT NO.
ANALYST <i>W. J. ...</i>	DATE <i>1/16/68</i>		FC-2682
DOCKED <i>...</i>	REV <i>...</i>		SHEET 4 OF 21
APPROVED <i>...</i>			

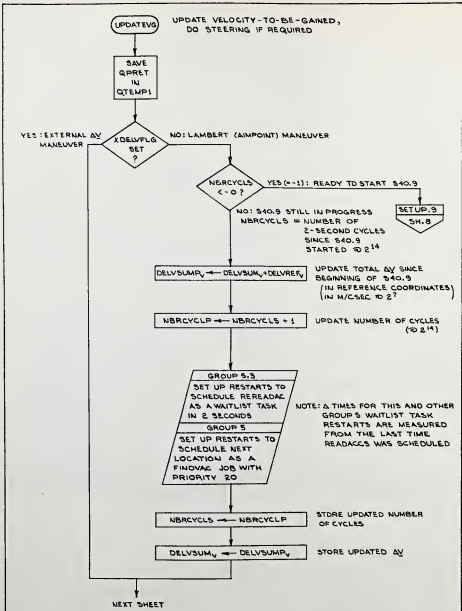


NEXT INSTRUMENTATION LOG	
AMERIDOLE W.A.S.	
DIAGN. T. 20	20/164
PREPARE	20/164
ANALYST	20/164
APPROVED BY	20/164
APPROVED DATE	20/164

STEERING

COLUMBUS II FC-2682

5 21



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN: <i>[Signature]</i>		STEERING	
ANALYST: <i>[Signature]</i>		DOCUMENT NO. COLONY II	
APPROVED: <i>[Signature]</i>		FC-2682	
DATE: 1 MAR 68		SHEET 6 OF 21	

FROM
PRECEDING SHEET

CALL 40.8

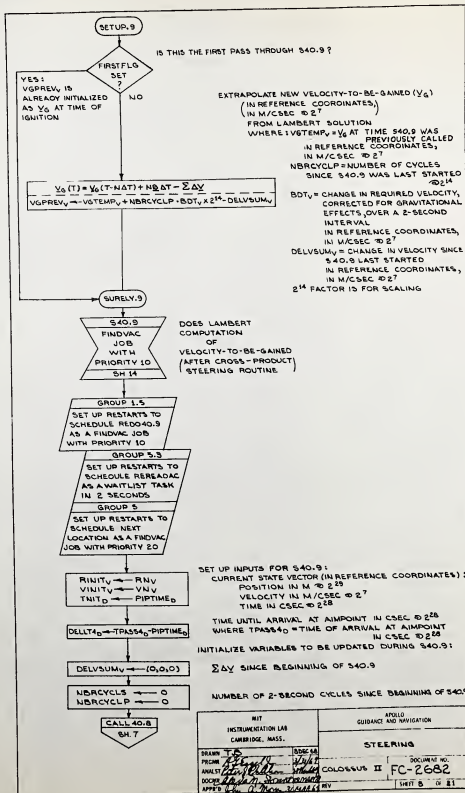


INPUTS: $V_G\text{PREV}_V$ = LAST VALUE OF VELOCITY-TO-BE-GAINED
IN REFERENCE COORDINATES,
IN M/CSEC $\times 10^2$
 ΔBDT_V = CHANGE IN REQUIRED VELOCITY, CORRECTED
FOR GRAVITATIONAL EFFECTS, OVER
2 SECONDS
IN REFERENCE COORDINATES,
IN M/CSEC $\times 10^2$
 $\Delta V\text{REF}_V$ = SENSED VELOCITY CHANGE
IN REFERENCE COORDINATES,
IN M/CSEC $\times 10^2$
IDLEFAIL - INDICATES WHETHER ENGINE FAIL
INHIBITED
STEERSW - INDICATES WHETHER STEERING IS
TO BE DONE
 $P\text{I}\text{TIME}_D$ = TIME OF LAST ΔV MEASUREMENT,
IN CSEC $\times 10^{2.5}$
 $C\text{STEER}$ = CROSS PRODUCT STEERING CONSTANT $\times 10^2$
 $K\text{PRIMEDT}_D$ = STEER LAW GAIN $\times \text{TVC DAP CYCLE TIME}$
(FROM TVC DAP) IN REVS $\times 10^{-4}$

OUTPUTS: $V_G\text{PREV}_V = V_GV$ = NEW VELOCITY-TO-BE-GAINED
IN REFERENCE COORDINATES,
IN M/CSEC $\times 10^2$
 $V_G\text{DISP}_D$ = MAGNITUDE OF V_G FOR DISPLAY
IN M/CSEC $\times 10^2$
 $T\&O_D$ = BURN TIME REMAINING IN CSEC $\times 10^{2.5}$
 ΩMAGAC_V = ROTATIONAL STEERING COMMAND
(FOR TVC DAP) IN NAV. BASE COORDINATES
IN REVS $\times 10^{-1}$

RETURN VIA
QTEMP1

REF	INSTRUMENTATION LAB CAMBRIDGE MASS.	ENGINEERING	FC-2682
DRAWN BY	T.B.	PROGRAM	COLOSSUS II
ANALYST	<i>[Signature]</i>	OFFICE	FC-2682
APPROVED	<i>[Signature]</i>	DATE	7 21



EXTRAPOLATE VELOCITY-TO-BE-GAINED,
COMPUTE REMAINING BURN TIME,
STEERING COMMAND IF APPROPRIATE

540.8

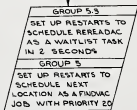
SAVE
QPRET
IN
QTEMP

$$\begin{aligned} V_G(T+\Delta T) &= V_G(T) + \frac{\Delta T}{\Delta T} \Delta V \\ V_G &= V_GPREV_V + BDT_V - DELVREF_V \end{aligned}$$

UPDATE VELOCITY-TO-BE-GAINED FOR NEW CYCLE
IN M/CSEC @ 2² IN REFERENCE COORDINATES
WHERE: V_GPREV_V = LAST VALUE OF V_G
IN M/CSEC @ 2²
BDT_V = CHANGE IN REQUIRED VELOCITY,
CORRECTED FOR GRAVITATIONAL
EFFECTS, OVER A 2-SECOND
INTERVAL
DELVREF_V = SENSED CHANGE IN VELOCITY
IN REFERENCE COORDINATES

$$V_GDISP_0 \leftarrow |V_G|$$

STORE MAGNITUDE FOR NOUN 40 DISPLAY



$$V_GPREV_V \leftarrow V_G$$

SAVE NEW VALUE OF V_G
(WILL USE NEXT TIME THROUGH 540.8
UNLESS REPLACED BY NEW EXTRAPOLATED
LAMBERT VALUE FROM 540.9)

YES
STEERSW
SET?

NO [THIS PATH ALWAYS TAKEN DURING P41]

RETURN
VIA
QTEMP

$$\begin{aligned} \Delta V - \Delta V_p \\ MPAC_0 \leftarrow |\Delta VREF_V|_0 - DVTHRESH * 2 \end{aligned}$$

$\Delta V = |\Delta VREF_V| = 2\text{-SECOND VELOCITY CHANGE IN M/CSEC @ } 2^2$
 $\Delta V_p = DVTHRESH = \text{MINIMUM ACCEPTABLE 2-SECOND } \Delta \text{ VELOCITY}$
 $\geq \text{EFFECT OF 15\% FULL SPB THRUST}$
IN M/CSEC @ 2²
2² FACTOR IS FOR SCALING

MPAC₀ < 0?

NO: ENABLE CENTER-OF-GRAVITY TRACKING

LOTHRUST
SH.15

IS LM ATTACHED TO C.M.?

NO
A ← 0

YES
A ← 1

STORE APPROPRIATE STEADY STATE
GAIN CONSTANT USED IN THRUST
MISALIGNMENT LOOP OF TVC DAP—
(PAD-LOADED) VALUE DEPENDS
ON WHETHER OR NOT LM IS
ATTACHED:
0.0375 @ 2²
OR
0.250 @ 2³
RESPECTIVELY

NOTE: IF LM IS ATTACHED
TO CSM, THE VALUE
STORED IS IMPROPER
AFTER SWITCHOVER,
SHOULD BE TAKEN
FROM FREPFRAC

$$REPFRAF \leftarrow EREPFRAC * A$$

NEXT SHEET

540.8

SYSTEMS DIVISION - 40
AMERICA WASH.

DESIGNER: J.B.
CHECKED: [Signature]
DATE: 11/16/69
PROJECT: COLOSSUS II
FC-2682

APPROVED: [Signature]
DATE: 11/16/69

REVISIONS:
1. [Signature] 11/16/69

STEERING

FC-2682

FROM PRECEDING SHEET

TGOCALC

$$\text{UNIT}(\Delta V_G) \cdot Y_G$$

$$PLO_D \leftarrow \text{UNIT}(\Delta V_G) \cdot Y_G - \Delta V_{REF_Y}$$

$$|\Delta V_G| = \sqrt{(\Delta X - \Delta Y)^2}$$

$$PL360 \leftarrow |\Delta V_G| - \Delta V_{REF_Y}$$

IS ΔV_G IN SAME DIRECTION AS Y_G ?

$PLO_D \geq 0$?

YES

NO

INCRSVG

ALARM

TURN ON ALARM LIGHT, SET ALARM CODE

FC 2140

INPUT: ALARM CODE 1407 (INCREASING Y_G)

RETURN VIA QTEMP

COMPUTE TIME TO GO UNTIL ENGINE CUTOFF, IN CSEC @ 2^{28}

WHERE:

$$TGO_0 \leftarrow (1 - 1/2 \frac{\text{UNIT}(\Delta V_G) \cdot Y_G}{V_E}) \frac{\text{UNIT}(\Delta V_G) \cdot Y_G}{TGO_0} \Delta T - \Delta T_{\text{TAIL-OFF}}$$

$$TGO_0 \leftarrow \left[\left(2^{14} + \frac{PLO_D}{2V_{EXHUST_0}} \right) \frac{PLO_D}{PL360} - (\text{FOURDT}_0) \times 2^{10} \right] - [\text{ETDECAY} \times 2^{14}]$$

$2V_{EXHUST} = 2V_E$, WHERE V_E = ENGINE EXHAUST VELOCITY = 31,510.936 M/CSEC @ 2^7

$\text{FOURDT}_0 = 200$ CSEC @ 2^{14}

ETDECAY = ENGINE TAIL-OFF TIME IN CSEC @ 2^{14} (PAD LOADED)

$2^1 = 1$ @ 2^1

2^{10} AND 2^{14} FACTORS ARE FOR SCALING

$$TIG_D \leftarrow P\text{I}T\text{I}M\text{E}_D + TGO_0$$

STORE ENGINE CUTOFF TIME (IN CSEC @ 2^{28}) = TIME-TO-GO FROM LAST MEASUREMENT TIME

$TGO_0 < 4$ SEC?

YES

NO: STILL TIME FOR STEERING

540.61

SH. 12

NEXT SHEET

DETERMINE COMPONENT OF V_G IN THE DIRECTION ΔV_G IN M/CSEC @ 2^8

WHERE: $V_{G_Y} = Y_G$ IN REFERENCE COORDINATES IN M/CSEC @ 2^7

ΔV_{REF_Y} = SENSED ΔV OVER 2 SECONDS IN REFERENCE COORDINATES IN M/CSEC @ 2^7

ΔV_{REF_Y} = CHANGE IN REQUIRED VELOCITY, CORRECTED FOR GRAVITATIONAL EFFECTS, OVER 2 SECONDS IN REFERENCE COORDINATES IN M/CSEC @ 2^7

UNIT OPERATION CREATES UNIT VECTOR @ 2^8

MAGNITUDE OF ΔV_G (IN M/CSEC @ 2^7) SAVED (BY UNIT OPERATION)

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FROM: <i>[Signature]</i>		COLONYBUS II	
ANALYST: <i>[Signature]</i>		DOCUMENT NO. FC-2682	
CHECKED BY: <i>[Signature]</i>		SHEET 10 OF 21	
APPROVED BY: <i>[Signature]</i>			

FROM PRECEDING SHEET

XPRODUCT

$$\text{MPAC}_V \leftarrow \text{REFSMAT}_u \cdot \left[\text{UNIT}(V_{0y}) \times \text{UNIT}(C_B \Delta T - \Delta V) \right]$$

◆ 5MNB ◆
 CONVERT VECTOR FROM STABLE MEMBER TO NAV. BASE COORDINATES
 FC 227D

INPUT: MPAC_V = VECTOR IN S.M. COORDINATES
 OUTPUT: MPAC_V = VECTOR IN N.B. COORDINATES, IN THIS CASE, ROTATIONAL STEERING DIRECTION

OMEGACL

$$\text{OMEGAC}_V \leftarrow \text{KPRIMEOT}_D \times \text{MPAC}_V$$

COMPUTE STEERING COMMAND FOR TVC OAP IN NAVIGATIONAL BASE COORDINATES IN REVS @ 2¹ WHERE KPRIMEOT_D = STEER LAW GAIN (REVS/CSEC) x ΔT (C/SEC) OF DAP CYCLE @ 2⁻⁴ (SET BY TVC OAP)

RETURN VIA QTEMP

CREATE UNIT VECTOR IN DIRECTION OF DESIRED ROTATIONAL STEERING IN S.M. COORDINATES @ 2³ WHERE:
 REFSMAT_u = TRANSFORMATION MATRIX FOR CONVERSION BETWEEN REFERENCE AND STABLE MEMBER COORDINATE SYSTEMS @ 2³
 V_{0y} = VELOCITY TO BE GAINED IN REFERENCE COORDS IN M/CSEC @ 2³
 CSTEER = CROSS PRODUCT STEER₁₁ CONSTANT @ 2³
 ΔV_{0y} = CHANGE IN REQUIRED VELOCITY, CORRECTED FOR GR/MOTIONAL EFFECTS OVER 2 SECS IN REFERENCE COORDS IN M/CSEC @ 2³
 DELVREF = ISSUED ΔV IN REFERENCE COORDS IN M/CSEC @ 2³
 2³ FACTOR 8 FOR SCALING

INSTRUMENTATION AND CAMBRIDGE MASS.		STEERING	
DRAWN <i>T.S.</i>	BY <i>S. J. ...</i>	FC 2682	REV. 11 21
CHKD <i>...</i>	BY <i>...</i>	COLOSSUS II	
APP'D <i>...</i>	DATE <i>...</i>		

540.81

ENTERED FROM 540.8 WHEN LESS THAN 4 SECONDS OF BURN REMAINING

SET
IMPULSW

HAVE ENGINE CUTOFF TIME
MINIMUM IMPULSE BURN FROM NOW ON

RATEZERO

DMEGACV ← (0,0,0)

ZERO STEERING COMMAND

CNTR ← POSMAX

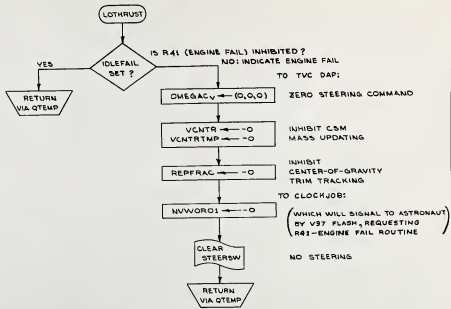
INHIBIT SWITCHOVER, CENTER OF GRAVITY OFFSET CORRECTION
(ORDINARILY PERFORMED BY TVC DAP)
BY SETTING CNTR > 0

CLEAR
STEERSW

NO MORE STEERING

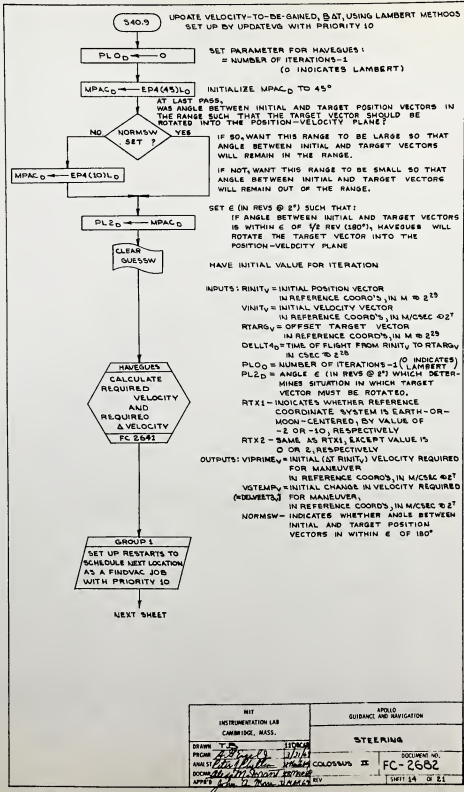
RETURN VIA
QTEMP

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
		STEERING	
DRAWN: <i>[Signature]</i>	PHONE: <i>[Signature]</i>	DOCUMENT NO.	
FROM: <i>[Signature]</i>	DATE: <i>[Signature]</i>	FC-2682	
ANALYST: <i>[Signature]</i>	COLLUSION II	Sheet 12 of 21	
DOOR: <i>[Signature]</i>			
APPROV: <i>[Signature]</i>			



DESIGNED BY: T.D.
 DRAWN BY: [Signature]
 CHECKED BY: [Signature]
 APPROVED BY: [Signature]

STEERING
 FC-2682
 15 21



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN BY <i>[Signature]</i>		STEERING	
PROGRAM <i>[Signature]</i>	DATE <i>11/1/63</i>	DOCUMENT NO.	FC-2682
ANALYST <i>[Signature]</i>	APPROVED <i>[Signature]</i>	SHEET 1A OF 21	

FROM PRECEDING SHEET

ENCLAMB

FIRST PASS THROUGH 540.9?

YES
FIRSTFLG SET?
NO

COMPUTE Δt - CHANGE IN REQUIRED VELOCITY CORRECTED FOR GRAVITATIONAL EFFECTS, OVER 2 SECONDS IN REFERENCE COORDS. IN M/CSEC @ 2¹⁷

WHERE: V_{PRIMEV} = NEW REQUIRED VELOCITY @ 2¹⁷ (SEE PAR 21E)
 V_{RPREV} = REQUIRED VELOCITY AT LAST PASS IN REFERENCE COORDS IN M/CSEC @ 2¹⁷

T_{NIT0} = TIME CORRESPONDING TO PRESENT COMPUTATION IN CSEC @ 2¹⁸

$T_{NITPREV}$ = TIME CORRESPONDING TO COMPUTATIONS OF LAST PASS IN CSEC @ 2¹⁸

$200CSH1$ Δt = 200 CSEC @ 2¹⁷
 $GOT/2V$ = 1/2 THE CHANGE IN VELOCITY DUE TO GRAVITATIONAL ACCELERATION OVER $\Delta t = 2$ SEC

IN REFERENCE COORDS IN M/CSEC @ 2¹⁷
2¹⁷ FACTOR IS FOR SCALING

$$\Delta t = \frac{V_{PRIMEV} - V_{RPREV}}{GOT/2V} - \Delta t$$
$$GOT/2V = 2 \left[(T_{NIT0} - T_{NITPREV}) \times 2^{17} + 200CSH1 \right] - GOT/2V$$

FIRSTIME

IN MOON'S SPHERE OF INFLUENCE?

YES
RTX2 > 0?
NO: IN EARTH'S SPHERE OF INFLUENCE

CORRECT VELOCITY-TO-BE-GAINED FOR EFFECTS (SO FAR) OF EARTH OBLATENESS

WHERE: V_{GTEMP} = V_0 AT TIME 540.9 WAS CALLED, IN REF. COORDS. IN M/CSEC @ 2¹⁷

$EARTHMU_0 = -\mu_E = -3.986032 \times 10^{24}$

R_N = POSITION VECTOR IN REFERENCE COORDS IN M @ 2¹⁸

$G_{OBL}/2V$ = CORRECTION TERM FOR GRAVITATIONAL ANOMALY DUE TO EARTH OBLATENESS @ 2¹⁷

(SEE CALCGRAM P. 2685)

$PIPTIME_0$ = TIME OF LAST DVY MEASUREMENT IN CSEC @ 2²⁰

$NOMTIG_0$ = NOMINAL TIME OF IGNITION, IN CSEC @ 2²⁰

$$V_0 \rightarrow V_0 + G_{OBL}/2V \left[\frac{EARTHMU_0}{|R_N|^3} (PIPTIME_0 - NOMTIG_0) \right]$$
$$V_{GTEMP} \rightarrow V_{GTEMP} + \frac{EARTHMU_0}{|R_N|^3} G_{OBL}/2V (PIPTIME_0 - NOMTIG_0)$$

MOONCASE

GROUP 1

SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINOAC JOB WITH PRIORITY 10

NEXT SHEET

STEERING

COLOSSUS II FC-2682

FROM PRECEDING
SHEET

COPY 40.9

SAVE VALUE FOR NEXT PASS:

TNITPREV₀ ← TNIT₀

TIME CORRESPONDING TO COMPUTATIONS,
IN CSEC @ 225

VRPREV_v ← VPRIME_v

REQUIRED VELOCITY AT THIS TIME
IN REFERENCE COORDS, IN M/CSEC @ 27

CLEAR
FIRSTFLG

FIRST PASS THROUGH 540.9 FINISHED

ENDS40.9-2

(MAY BE ENTERED FROM PED040.9 SK.17)

NBRCYCL5 ← -1

INDICATE READY TO BEGIN NEXT
PASS THROUGH 540.9

ENDS40.9

GROUP 1.0
KILL GROUP 1
RESTARTS

ENDOFJOB

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ANALYST			
DOCAE			
APPROV			SHEET 16 OF 21

REDO40.9

POSSIBLE RESTART ENTRY TO S40.9
(IF RESTART OCCURS BETWEEN INITIALIZATION AND
RETURN FROM HAVEGUES)

DELVSUM_v ← (0,0,0)

RE-INITIALIZE $\Sigma \Delta y$

NBRCYCL5 ← +0

AND NUMBER OF CYCLES
(SINCE S40.9 BEGUN)

NBRCYCLP ← +0

VGTEMP_v ← VGPREV_v

USE LAST VALUE OF VELOCITY-TO-BE-GAINED
(IN REFERENCE COORDINATES, IN M/CSEC @ 2°)

ENDS40.9 = Z

SET UP NEW PASS THROUGH S40.9

SH. 16

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		40-10 CUSTOMER'S SPECIFICATION
DRAWN BY <i>J. B. [Signature]</i>		STEERING
PROGRAM BY <i>J. B. [Signature]</i>	DESIGNED BY <i>[Signature]</i>	FIGURE NO. FC-2682
ANALYST <i>[Signature]</i>	TESTING BY <i>[Signature]</i>	REV. 17 - 21
SYNOPSIS <i>[Signature]</i>	APPROVED BY <i>[Signature]</i>	

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. 10
DPAGREE	2090	FORCES SIGN AGREEMENT IN DOUBLE PRECISION MPAC	SH. 3
ENGINOFF	2680	TURNS OFF SPS ENGINE	SH. 3
HAVEGUES	2641	CALCULATES VELOCITY AND A VELOCITY REQUIRED FOR A MANEUVER	SH. 14
SERVEXIT	2683	COMMON EXIT FROM SERVICER ROUTINES	SH. 4, 5
S41.1	2700	CONVERTS VECTOR FROM REFERENCE TO CONTROL COORDINATE SYSTEM	SH. 5
SMNB	2270	CONVERTS VECTOR FROM STABLE MEMBER TO NAVIGATION BASE COORDINATE SYSTEM	SH. 11

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DAPDATR1 BIT 14	LM ATTACHED TO CM	LM NOT ATTACHED TO CM			SH. 9
FIRSTFLG FLAGWRD2 BIT 7	FIRST PASS THROUGH S40.9	LATER THAN FIRST PASS THROUGH S40.9		SH. 16	SH. 9 SH. 13
GUESS FLAGWRD1 BIT 2	NO STARTING VALUE FOR ITERATION	HAVE STARTING VALUE FOR ITERATION		SH. 14	
IDLEFAIL FLAGWRD1 BIT 6	R41 (ENGINE FAIL) INHIBITED	R41 (ENGINE FAIL) ENABLED			SH. 13
IMPULSW FLAGWRD2 BIT 9	MINIMUM IMPULSE BURN - CUTOFF TIME KNOWN	CUTOFF TIME NOT DETERMINED	SH. 13	SH. 4	SH. 4
NORMSW FLAGWRD7 BIT 10	ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS IS SUCH THAT TARGET VECTOR NEED NOT BE ROTATED INTO POSITION VELOCITY PLANE	ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS IS SUCH THAT TARGET VECTOR MUST BE ROTATED INTO POSITION VELOCITY PLANE			SH. 14
STEERSW FLAGWRD2 BIT 11	STEERING TO BE DONE	STEERING OMITTED		SH. 12, 13	SH. 9
XDELVFLG FLAGWRD2 BIT 8	EXTERNAL ΔV MANEUVER	LAMBERT (AIMPOINT) MANEUVER			SH. 6

DISPLAYS

VERB- NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
	ALARM	ALARM LIGHT ON; R1, R2, R3 NOT AFFECTED	SH. 10

RIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>W. S. ...</i>		STEERING	
PROGRAM <i>APOLLO</i>	ANALYST <i>...</i>	COLLOSSUS II	DOCUMENT NO. FC-2682
APPROVED <i>...</i>		SHEET 18 OF 21	

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
RHT _V	B AT	CHANGE IN REQUIRED VELOCITY, CORRECTED FOR GRAVITATIONAL EFFECTS, OVER $\Delta t = 2$ SECONDS	M/SEC	M/CSEC	2 ⁷
CNTR		USED HERE AS INDICATOR TO TVC DAP OF WHETHER SWITCHOVER, CENTER OF GRAVITY OFFSET CORRECTION SHOULD BE DONE			
CSTEER	C	CROSS - PRODUCT STEERING CONSTANT			2 ²
DELLT _D		TIME OF FLIGHT TO AIMPOINT	SEC	CSEC	2 ²⁸
DELVREF _V	ΔV	SENSED VELOCITY CHANGE IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷
DELSUM _V	$\Sigma \Delta V$	TOTAL SENSED VELOCITY CHANGE SINCE LAST TIME S40.9 STARTED, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷
DELVSUMP _V		TEMPORARY UPDATED VERSION OF DELVSUM _V (ABOVE)	M/SEC	M/CSEC	2 ⁷
KPRIMED _T	K' ΔT	STEER LAW GAIN \times TVC DAP CYCLE TIME	DEGREES	REVS	2 ⁻⁴
NBRCYCLP		TEMPORARY UPDATED VERSION OF NBRCYCLS (BELOW)			2 ¹⁴
NBRCYCLS	N	NUMBER OF 2-SECOND CYCLES SINCE S40.9 LAST STARTED			2 ¹⁴
N\WORD1		INDICATES WHETHER ANY DISPLAY IS TO BE DONE BY CLOCKJOB AND, IF SO, WHICH ONE.			
OMEGAC _V	ω CNB AT	ROTATIONAL STEERING COMMAND (TO TVC DAP) IN NAVIGATOR BASE COORDINATES	DEGREES	REVS	2 ⁻¹
PIPTIME _D	T	TIME OF LATEST ACCELEROMETER READING	SEC	CSEC	2 ²⁸
REFSMAT _M	[REFSMAT]	TRANSFORMATION MATRIX FOR CONVERSION BETWEEN STABLE MEMBER AND REFERENCE COORDINATE SYSTEM			2 ¹
REPPFRAC		STEADY STATE GAIN CONSTANT USED IN THRUST MISALIGNMENT LOOP OF TVC DAP - VALUE AND SCALING DEPENDS ON WHETHER LM IS ATTACHED TO CM (SEE S11.9)			2 ² OR 2 ³
RUNIT _V	R	INITIAL POSITION VECTOR IN REFERENCE COORDINATES	M	M	2 ²⁹
RN _V	R	POSITION VECTOR IN REFERENCE COORDINATES	M	M	2 ²⁹
TGO _D	T _{GO}	TIME UNTIL ENGINE CUTOFF	SEC	CSEC	2 ²⁸
TIG _D	T _{IG}	TIME OF ENGINE IGNITION OR CUTOFF, WHICHEVER IS CURRENTLY RELEVANT	SEC	CSEC	2 ²⁸
TIME _D		PRESENT TIME	SEC	CSEC	2 ²⁸

INSTRUMENTATION LOG		STEERING	
DESIGN	DATE	BY	NO.
PREP	10/16/68	J. J. Sullivan	21
CHKD		J. J. Sullivan	
REV		J. J. Sullivan	
APP'D		J. J. Sullivan	
COLOSSUS II		FC-2682	
		REV. 15 21	

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
SDT ₂	$1/3(G\Delta T)$	1/2 THE CHANGE IN VELOCITY DUE TO GRAVITATIONAL ACCELERATION OVER AT (2 SECONDS), IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷
GOBL ₂ V	$-\frac{R^2}{\mu E} \underline{Q}_B(T)$	CORRECTION TERM FOR GRAVITATIONAL ANOMALY DUE TO EARTH OBLATENESS - SATISFIES THE EQUATION: $\underline{Q}(AT R) = \frac{\mu E}{R^2} \text{UNIT}(R) + \underline{Q}_B$			2 ¹
TINT _D	T	INITIAL TIME - CORRESPONDING TO RINIT _V , VINIT _V	SEC	CSEC	2 ²⁸
TPASS _{1D}		TIME OF ARRIVAL AT AIMPOINT	SEC	CSEC	2 ²⁸
VCNTR		VARIABLE - GAIN UPDATE COUNTER USED BY TVC DAP			
VCNTRTMP		TEMPORARY STORAGE FOR VCNTR(ABOVE)			
VG _V	$\underline{V}_G(T+\Delta T)$	VELOCITY-TO-BE-GAINED, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷
VGBOVD _V	\underline{V}_G	VELOCITY-TO-BE-GAINED, IN CONTROL COORDINATES (FOR NOUN 88 DISPLAY)	M/SEC	M/CSEC	2 ⁷
VGDISP _D	$ \underline{V}_G $	MAGNITUDE OF VELOCITY-TO-BE-GAINED, FOR NOUN 40 DISPLAY	M/SEC	M/CSEC	2 ⁷
VGTEMP _V	\underline{V}_G	UPDATED VELOCITY-TO-BE-GAINED, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷
DELVEET ₃ V	$\underline{V}_G(T)$	VELOCITY-TO-BE-GAINED AT PREVIOUS PASS THROUGH S40, S, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷
VINIT _V	\underline{V}	INITIAL VELOCITY VECTOR IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷
VN _V	$\underline{V}(T)$	VELOCITY VECTOR 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
EP4(10) _D	10°	POSSIBLE VALUE FOR MINIMUM ANGLE BETWEEN INITIAL AND FINAL POSITION VECTORS SUFFICIENT TO DEFINE PLANE OF FLIGHT	10 DEGREES	.027777777 REV	2 ⁰
EP4(45) _D	45°	POSSIBLE VALUE FOR MINIMUM ANGLE BETWEEN INITIAL AND FINAL POSITION VECTORS SUFFICIENT TO DEFINE PLANE OF FLIGHT	45 DEGREES	.125 REV	2 ⁰
2VEKHUST _D	2 x V _E	2 x ENGINE EXHAUST VELOCITY	8302, 0792 M/SEC	83, 020782 M/CSEC	2 ⁷

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STEERING	
DRAWN BY <u>W. J. ...</u> PROGRAM <u>...</u> ANALYST <u>...</u> DOCUMENT <u>...</u> APPROVED BY <u>...</u>	COLLOSSUS II FC-2682 REV. 10 24

PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
DVTHRESH	ΔV_p	MINIMUM ACCEPTABLE 2-SECOND VELOCITY CHANGE = 15% OF FULL SFS THRUST FOR 2 SECONDS	.65654715 M/SEC	.0065654715 M/CSEC	2^{-2}	00656
EREPPFRAC		STEADY STATE GAIN CONSTANT USED IN THRUST MISALIGNMENT LOOP OF TVC DAP - FOR LM NOT ATTACHED TO CM	0.25	0.25	2^{-9}	01000
EREPPFRAC-1		STEADY STATE GAIN CONSTANT USED IN THRUST MISALIGNMENT LOOP OF TVC DAP - FOR LM ATTACHED TO CM (BEFORE SWITCH-OVER - SEE SH. 9)	0.0375	0.0375	2^{-2}	00232
ETDECAV	$\Delta T_{tail-off}$	ENGINE TAIL-OFF TIME	.59 SEC	59 CSEC	2^{-14}	00073

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PART 10 6.17.70 AND "APP. V. 2"	
DESIGN <i>J. H. Fournelle</i>		STEERING	
PERFORM <i>J. H. Fournelle</i>	REVISIONS <i>2/1/68</i>	20. REV. 1	
ANALYS <i>J. H. Fournelle</i>	APPROVED <i>J. H. Fournelle</i>	COLOSSUS II FC-2682	
DOC. NO. <i>FC-2682</i>	DATE <i>2/1/68</i>	REV. 21 21	

SERVICER

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS		
PREREAD:	INITIALIZES SERVICER	SH. 3
PREREADI:	ZERO PIPAS	SH. 3
NORMLIZE:	DOES INITIAL STATE VECTOR UPDATE	SH. 5
HEADACCS:	READS ACCELEROMETERS, SETS UP SERVICER, RESCHEDULES ITSELF EVERY 2 SECONDS UNTIL STOPPED	SH. 6
PIPASR:	READS PIPA COUNTERS	SH. 9
REREADAC:	POSSIBLE RESTART ENTRY TO HEADACCS - IN CASE ACCELEROMETERS MUST BE REREAD	SH. 10
QUICKREAD:	TAKES QUICK ACCELEROMETER READINGS FOR DOWNLINK TELEMETRY	SH. 12
SERVICER:	CHECKS & VELOCITY VALUES READ IN, DOES PERMANENT STATE VECTOR UPDATE USING SENSED & VELOCITY	SH. 13
CALCRVG:	COMPUTES NEW STATE VECTOR	SH. 16
CALCGRAV:	CALCULATES GRAVITATIONAL ACCELERATION AT SPECIFIED POSITION	SH. 17
AVGEND:	FINAL EXIT FROM SERVICER. PERFORMS TRANSITION TO COASTING FLIGHT ROUTINES	SH. 19
SERVEXIT:	COMMON END OF SERVICER ROUTINES	SH. 21

INSTRUMENTATION LAB CAMBRIDGE, MASS.		SERVICER	
DESIGNED BY: <i>[Signature]</i> DRAWN BY: <i>[Signature]</i> CHECKED BY: <i>[Signature]</i> APPROVED BY: <i>[Signature]</i>	DATE: 12/11/68 SCALE: 1:1 SHEET NO.: 1 OF 2	COLLOSSUS II FC-2683 1 26	

PREREAD INITIALIZATION OF SERVICER
ENTERED FROM P40, P41, 561.1 (P61, P62), P47
POWERED ENTRY (POWERED FLIGHT MONITOR)
FLIGHT

LASTBIAS
NOVAC JOB WITH PRIORITY 21
FC 2230
DOES LAST GYRO COMPENSATION IN FREE-FALL (DRIFT) MODE;
BEGINNING PIPA-READING MODE
(SETS 1/PIPADT = Δ TIME BETWEEN PIPA READINGS)
(USED BY 1/PIPA — SEE SHEET 13)

REDO5.31

PREREAD1 ALSO CALLED BY P11 (EARTH ORBIT INSERTION MONITOR)

SAVE Q
IN RUPTRG1

PIPASR
READ AND CLEAR PIPAS
SH 9

INITIALIZES PIPAS FOR LATER READINGS

PIPAGE ← 1

INDICATE PIPA READING FINISHED

SET AVEGFLAG
CLEAR DRIFTFLG
SET VSTFLAG

CONTINUE RUNNING SERVICER
DON'T DO GYRO COMPENSATION
NOT IN DRIFT PORTION OF FLIGHT
SERVICER IS RUNNING

DVTOTAL ← 0
D

INITIALIZE SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE BEGINNING OF MANEUVER

RETURN VIA RUPTRG1

NEXT SHEET

SERVICER		SERVICER	
MISSION INFORMATION LAB CANNON/DT MAIL	PHYSICS AND NAVIGATION	SERVICER	
TEAM: T-13	SHOWING	FOR INSTR. NO.	
FROM: <i>H. H. ...</i>	1778-44	COLLOSSUS II FC-2683	
ANALYST: <i>...</i>	1778-44	REV. 3 of 26	
DATE: <i>...</i>	21-08-64		
APPROVED BY: <i>...</i>	21-08-64		

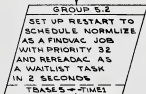
FROM
PRECEDING SHEET



DOES INITIAL STATE VECTOR UPDATE



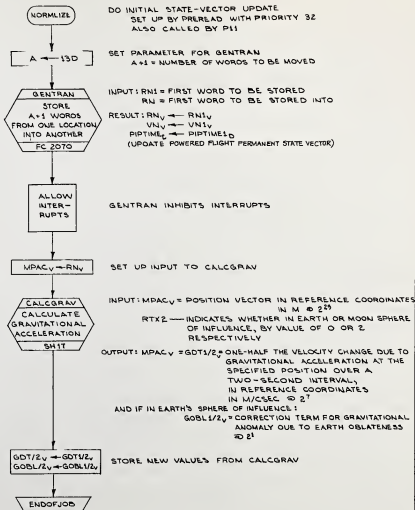
TAKES ACCELEROMETER READINGS



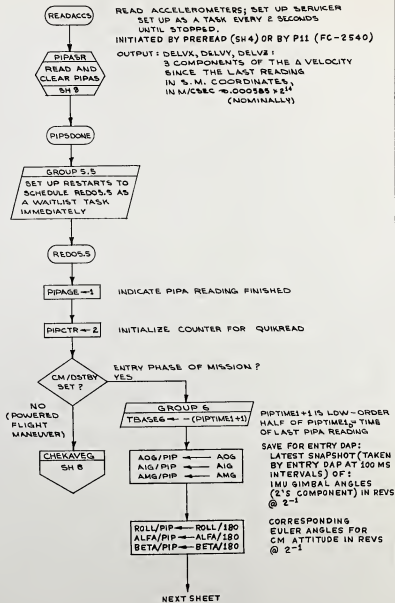
NOTE: LASTBIAS IS NOT RESTART PROTECTED.



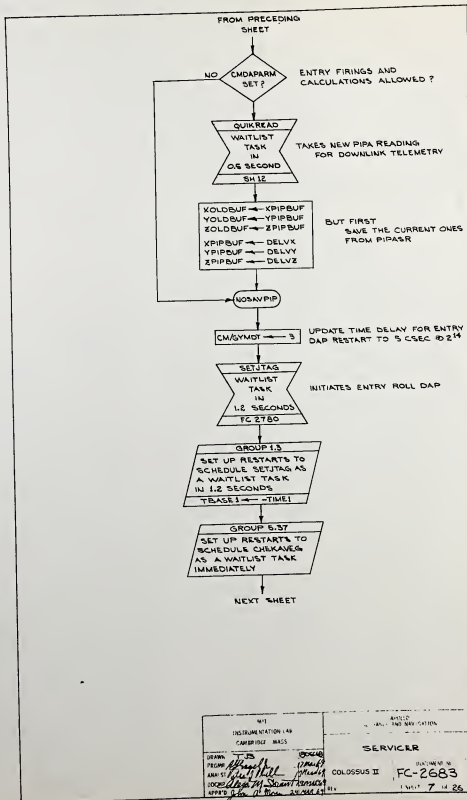
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
SERVICER		SERVICER	
DESIGN: J.B.	64-0004	DOCUMENT NO.	
PROGRAM: <i>FC-2683</i>	<i>FC-2683</i>	COLOSSAUS II	
ANALYST: <i>J.H.</i>	<i>J.H.</i>	FC-2683	
DOCUMENTED BY: <i>John A. Searl</i>	<i>11/10/68</i>	REV	
APPROVED BY: <i>John A. Searl</i>	<i>11/10/68</i>	SHEET 4 OF 26	



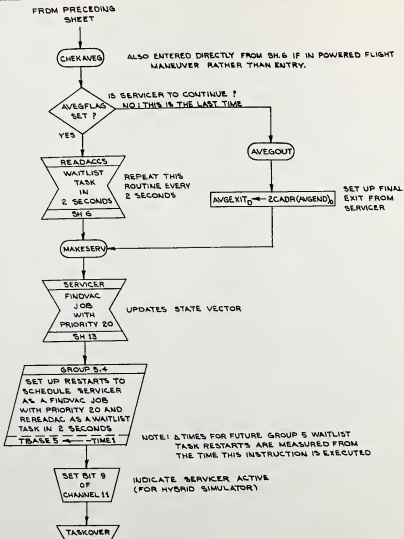
UNIT INSTRUMENTATION LAB LABORATORY MASS.	8-110 NAV AND S&A DIVISION SERVICER
DRAWN T.D. CHECKED <i>[Signature]</i> DATE 11/11/61 APPROVED <i>[Signature]</i>	COLLOSSUS II FC-2683 5 x 26



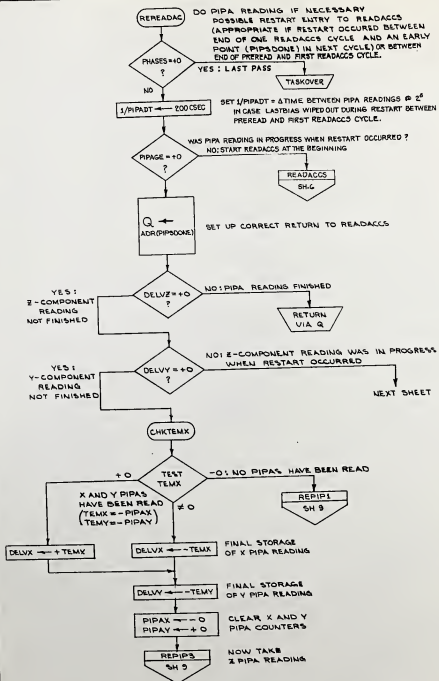
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION SERVICER	
DRAWN <i>[Signature]</i>	DATE 10/20/68	DOCUMENT NO. FC-2683	SHEET 6 OF 26
PROGRAM <i>[Signature]</i>	ANALYST <i>[Signature]</i>	APPROVED <i>[Signature]</i>	



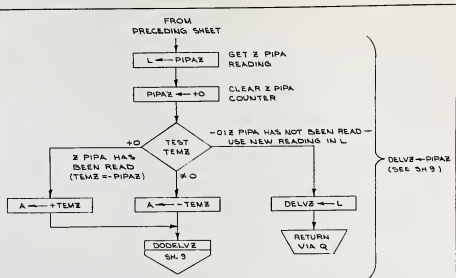
INSTRUMENTATION LAB CHARLOTTE, N.C.		ASSIGNED TO: [] DATE: []	
DRAWN BY: [] CHECKED BY: [] APPROVED BY: []		SERVICER: [] COLLOSSUS II FC-2683 1 MAY 7 11 26	



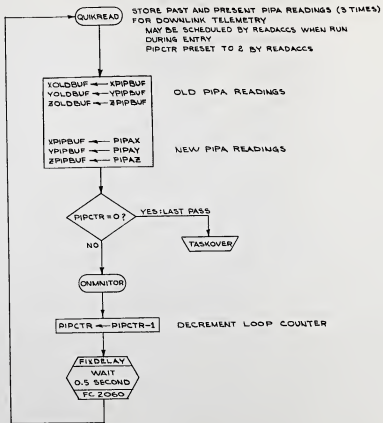
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
SERVICER		DOCUMENT NO.	
DESIGN: <i>[Signature]</i>	MONITOR: <i>[Signature]</i>	FC-2683	
PREPARED: <i>[Signature]</i>	DATE: 12/16/69	COLOSSUS II	
ANALYST: <i>[Signature]</i>	DATE: 12/16/69	SHEET 8 OF 26	
DOCKED: <i>[Signature]</i>	DATE: 12/16/69		
APPROVED: <i>[Signature]</i>	DATE: 12/16/69		



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>T.S.</i>		SERVICER	
PROGRAM <i>226-113</i>		DOCUMENT NO.	
ANALYST <i>W.H. Hall</i>		FC-2683	
DOCUMENT NO. <i>226-113</i>		T-SHEET NO. <i>026</i>	
APPROV. <i>John G. ...</i>			



SIT INSTRUMENTATION LAB CAMBRIDGE, MASS		RITTED JULIAN L. FORD NAVIGATION	
DRAWN TJS		SERVICER	
PROJECT 100-100	DATE 12/1/68	ANALYST J. L. FORD	COLONY II
APPROVED BY J. L. FORD	DATE 12/1/68	REV	FC-2683
			SHEET 11 OF 26



HIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AIRFIELD GUIDANCE AND NAVIGATION	
SEARCH <i>T.S.</i> PROGRAM <i>PIP</i> ANALYST <i>John M. Grant</i> SPECIALIST <i>John M. Grant</i> APPROVED <i>John M. Grant</i>		SERVICER COLLOSSUS II DOCUMENT NO: FC-2683 SHEET 12 OF 24	

FROM
PRECEDING SHEET

OUTTOTUP

$OUTTOTAL_D = DVTOTAL_D + KPIPI * IDELV_V$

UPDATE DVTOTAL_D = SUM OF THE MAGNITUDES OF
Z-SECOND VELOCITY CHANGES SINCE
BEGINNING OF THE MANEUVER
IN M/CSEC @ 2⁷
WHERE KPIPI = .000585 * 2⁷
SCALING FACTOR FOR DELV_V

AVERAGED

GROUP 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 FINDING
JOB WITH PRIORITY 20

CALC RVG
UPDATE
STATE
VECTOR
SH 16

INPUT: DELV_V = Z-SECOND VELOCITY CHANGE IN S.M. COORDINATES
IN M/CSEC @ .000585 * 2¹⁴
RN_V = OLD POSITION VECTOR IN REFERENCE COORDINATES
IN M @ 2²⁰
VN_V = OLD VELOCITY VECTOR IN REFERENCE COORDINATES
IN M/CSEC @ 2⁷
GOTR/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 @ 2⁷
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 @ 2⁷
RN1_V = UPDATED POSITION VECTOR IN REFERENCE
COORDINATES IN M @ 2²⁰
VN1_V = UPDATED VELOCITY VECTOR IN REFERENCE
COORDINATES IN M/CSEC @ 2⁷
GOT1/2_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
@ 2⁷
AND IF IN EARTH'S SPHERE OF INFLUENCE:
GOBL1/2_V = GRAVITATIONAL ANOMALY DUE TO
EARTH OBLATENESS @ 2¹

GROUP 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 FINDING JOB
WITH PRIORITY 20

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIED GUIDANCE AND NAVIGATION
DRAWN BY <i>[Signature]</i> FROM <i>[Signature]</i> ANALYST <i>[Signature]</i> CHECKED BY <i>[Signature]</i> APPROVED BY <i>[Signature]</i>	SERVICER DOCUMENT NO. FC-2683 SHEET 14 OF 26

FROM
PRECEDING SHEET

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 ← RN_{1v}
VN_v ← VN_{1v}
PIPTIME_D ← PIPTIME_{1D}
GOT/2_v ← GOT/2_v
GOL/2_v ← GOL/2_v
(UPDATE POWERED FLIGHT PERMANENT STATE VECTOR
- IN REFERENCE COORDINATES)

ALLOW
INTERRUPTS

GENTRAN INHIBITS INTERRUPTS

GROUPS 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 FINDAC JOB
WITH PRIORITY 20

LOCATION SPECIFIED
IN AVGEXIT_D

AVGEXIT_D SET BY PROGRAM USING SERVICES:
STEERING (FC 2682) SET BY P40 (SP6 THRUST)
CALC N B5 (FC 2682) SET BY P40, P41 (THRUST)
CM/POS E (FC 2775) SET BY P62 (ENTRY)
CALC N B3 (FC 2700) SET BY P47 (THRUST MONITOR)
VHHDOT (FC 2640) SET BY P11 (EACH ORBIT INSERTION MONITOR)
AVGEND (SM 13) SET BY READACCS IN FINAL PASS
SERVEXT (SM 21) COMMON END OF THIS ROUTINE

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		SERVICER	
DRAWN BY <i>[Signature]</i>	DESIGNED BY <i>[Signature]</i>	SERVICER	
PROGRAM <i>[Signature]</i>	APPROVED BY <i>[Signature]</i>	SERVICER	
DATE <i>[Signature]</i>	APPROVED BY <i>[Signature]</i>	SERVICER	

COLOSSUS II
FC-2683
15 26

CALC RVG UPDATE STATE VECTOR

$\Delta Y_{REF} = \Delta Y_{SH} [REFSMAT]$
 $DELVR_{REF} \leftarrow KPIPI \times DELV_v \times REFSMAT_{21} \times 2^1$

CONVERT ΔY SAVED INTO REFERENCE COORDINATES IN M/CSEC $\times 2^7$
WHERE: $DELV_v = \Delta Y$ IN S.M. COORDINATES IN M/CSEC $\times 0.00085 \times 2^{14}$
 $KPIPI = .000585 \times 2^7$ (FOR SCALING $DELV_v$)
 $REFSMAT_{21}$ = TRANSFORMATION MATRIX FOR CONVERSION BETWEEN S.M. AND REFERENCE COORDS $\times 2^1$
 2^1 FACTOR IS FOR SCALING

$PLQ_v \leftarrow 1/2 DELVR_{REF}$

SAVE INTERMEDIATE RESULTS: $1/2 \Delta Y$ (IN REFERENCE COORDS, IN M/CSEC $\times 2^7$)

$PLG_v \leftarrow GDT/2_v + 1/2 DELVR_{REF}$

$1/2 G(T) \Delta T + 1/2 \Delta Y$ (IN REFERENCE COORDS IN M/CSEC $\times 2^7$)

COMPUTE NEW POSITION VECTOR IN REFERENCE COORDS, IN M $\times 2^{25}$

WHERE: R_{N_v} = OLD POSITION VECTOR IN REFERENCE COORDINATES IN M $\times 2^{25}$

V_{N_v} = OLD VELOCITY VECTOR IN REFERENCE COORDINATES IN M/CSEC $\times 2^7$

$GDT/2_v$ = $1/2$ THE VELOCITY CHANGE DUE TO GRAVITATIONAL ACCELERATION AT R_{N_v} OVER A 2-SECOND INTERVAL IN REFERENCE COORDINATES IN M/CSEC $\times 2^7$
 $2.5LC(22)_v = 200$ CSEC $\times 2^{22}$

$B(T-\Delta T) = B(T) + \Delta T [V(T) + G(T) \Delta T/2 + \Delta Y/2]$
 $MPAC_v \leftarrow R_{N_v} + 2.5LC(22)_v [V_{N_v} + GDT/2_v + \frac{1}{2} DELVR_{REF}]$

SAVE QPRET IN PL 31

$R_{N1}_v \leftarrow MPAC_v$

SAVE NEW POSITION VECTOR

INPUT: $MPAC_v$ = POSITION VECTOR IN REFERENCE COORDINATES IN M $\times 2^{25}$

RTX_2 - INDICATES WHETHER IN EARTH OR MOON SPHERE OF INFLUENCE, BY VALUE OF 0 OR 2, RESPECTIVELY

CALC GRV
CALCULATE GRAVITATIONAL ACCELERATION
SH IT

OUTPUT: $MPAC_v = GDT/2_v = 1/2$ THE CHANGE IN VELOCITY DUE TO GRAVITATIONAL ACCELERATION AT THE SPECIFIED POSITION OVER A 2-SECOND INTERVAL IN REFERENCE COORDINATES IN M/CSEC $\times 2^7$

AND IF IN EARTH'S SPHERE OF INFLUENCE:
 $G(0BL)/2_v$ = GRAVITATIONAL ANOMALY DUE TO EARTH OBLATENESS $\times 2^1$

COMPUTE NEW VELOCITY VECTOR IN REFERENCE COORDS, IN M/CSEC $\times 2^7$

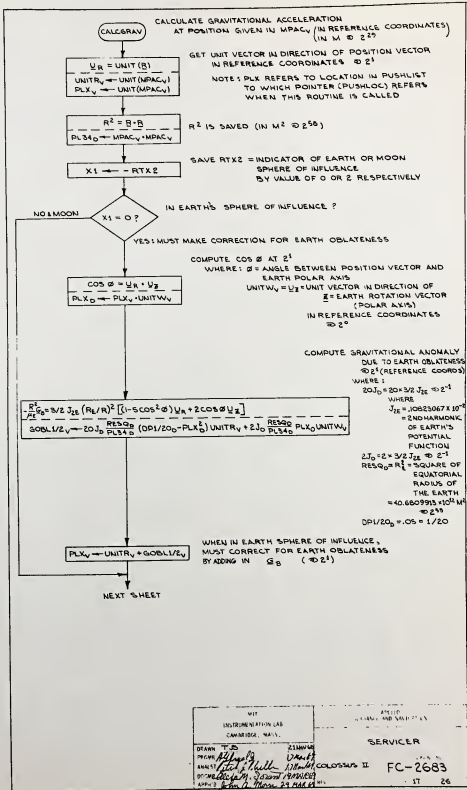
WHERE: V_{N_v} = OLD VELOCITY VECTOR IN REFERENCE COORDINATES IN M/CSEC $\times 2^7$

$V(T+\Delta T) = V(T) + \frac{(G(T+\Delta T) + G(T)) \Delta T + \Delta Y}{2}$
 $V_{N1}_v \leftarrow V_{N_v} + MPAC_v + PLG_v + PLQ_v$

PLG_v } INTERMEDIATE RESULTS SAVED ABOVE
 PLQ_v }

RETURN VIA PL 31

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
	SERVICE	
DRAWN BY <i>AS</i> PERFORMED BY <i>AS</i> ANALYSIS BY <i>AS</i> DOCUMENTED BY <i>AS</i> APPROVED BY <i>AS</i>	(SHOW US) COLLOSSUS II	DOCUMENT NO. FC-2683 SHEET 16 OF 26



FROM
PRECEDING SHEET

(TIGMOON)

TEST
X1

-Z:MOON

O: EARTH

$$\begin{aligned} 1/2 G \Delta T &= 1/2 \left(\frac{-GM}{R^2} U_n \right) \Delta T \\ MPAC_V &= \frac{-MUOT(\hat{D})}{PL34 D} \times PLX_V \times Z^{21} \end{aligned}$$

$$\begin{aligned} 1/2 G \Delta T &= 1/2 \left(\frac{-GM}{R^2} U_n + \hat{S}_D \right) \Delta T \\ MPAC_V &= \frac{-MUOT(\hat{D})}{PL34 D} \times PLX_V \times Z^{21} \end{aligned}$$

COMPUTE 1/2 G ΔT
= 1/2 THE ΔVELOCITY DUE TO
GRAVITATIONAL ACCELERATION
(AT SPECIFIED POSITION)
OVER 2 SECONDS
IN REFERENCE COORDINATES
IN M/CSEC @ Z²¹

WHERE:

$$\begin{aligned} -MUOT(\hat{D}) &= -M U_n \Delta T \\ &= -(4902778 \times 10^3 \frac{M^2}{SEC^2}) \times (2000 CEC) \\ &\quad @ Z^{24} \end{aligned}$$

$$\begin{aligned} -MUOT(\hat{D}) &= -M \hat{S}_D \Delta T \\ &= -(398603225 \frac{M^3}{SEC^2}) \times (2000 CEC) \\ &\quad @ Z^{24} \end{aligned}$$

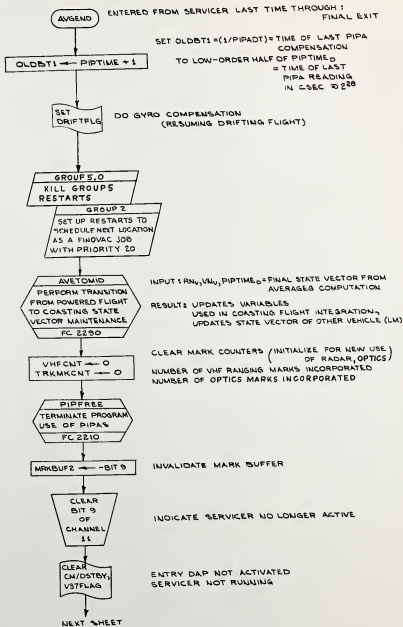
Z²¹ FACTOR IS FOR SCALING

GOT 1/2 V → MPAC_V

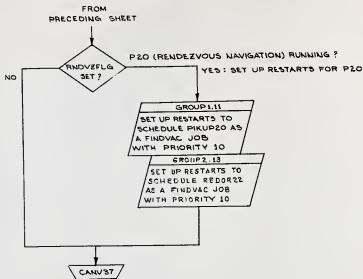
STORE NEW VALUE FOR 1/2 G ΔT

RETURN
VIA QPRET

W-1 INSTRUMENTATION LAB CAMPBELL, MASS.	SPECIAL COPYABLE AND REPRODUCIBLE
DRAWN: T. D. CHECKED: [Signature] APPROVED: [Signature] DATE: 10/16/54	SERVICER FC-2683 REV. 10-1-56



MIT INSTRUMENTATION LAB CAMBRIDGE MASS		SERVICER	
DRYAN T.B.	FINOVAC	FC-2683	
PERNO <i>[Signature]</i>	12/11/64	12-11-64	
ANST <i>[Signature]</i>	12/11/64	12-11-64	
SOCR <i>[Signature]</i>	12/11/64	12-11-64	
UPRD <i>[Signature]</i>	12/11/64	12-11-64	



N-1 INSTRUMENTATION LAB CAMBRIDGE MASS	ADDED GUIDANCE AND NAVIGATION
DRAWN BY <i>[Signature]</i> CHECKED BY <i>[Signature]</i> DESIGNED BY <i>[Signature]</i> APPROVED BY <i>[Signature]</i>	SERVICER COLONNUS II DOCUMENT NO. FC-2683 SHEET 20 OF 26

SERVEXIT

COMMON END OF SERVER ROUTINES

GROUP 5.3

SET UP RESTARTS TO
SCHEDULE REREADAC
AS A WAITLIST TASK
IN 2 SECONDS

ENDOFJOB

MIT
ASTRONOMICAL LAB
CAMBRIDGE, MASS.

SEARCHED *js* INDEXED *js*
SERIALIZED *js* FILED *js*
APR 21 1976
FBI - BOSTON

SEARCHED *js* INDEXED *js*
SERIALIZED *js* FILED *js*
APR 21 1976
FBI - BOSTON

SEARCHED *js* INDEXED *js*
SERIALIZED *js* FILED *js*
APR 21 1976
FBI - BOSTON

APR 21 1976

SERVICER

COLONIA II FC-2683

APR 21 1976

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.13
VECTOMIO	2290	PERFORMS TRANSITION FROM POWERED FLIGHT TO COASTING FLIGHT MAINTENANCE OF STATE VECTOR. UPDATES STATE VECTOR OF OTHER VEHICLE (LM)	SH.19
CALCN83	2700	UPDATES TOTAL ΔV FOR NOUN 83 DISPLAY AND INERTIAL V. RATE OF CHANGE OF V. ALTITUDE ABOVE PAD FOR NOUN 82 DISPLAY	SH.15
CALCN85	2682	UPDATES VELOCITY-TO-BE-GAINED FOR NOUN 85 DISPLAY	SH.15
CM POSE	2775	RETURN POINT TO RE-ENTRY CONTROL	SH.15
GENTRAN	2070	TRANSFERS A STRING OF DATA WORDS FROM ONE LOCATION TO ANOTHER	SH.5 SH.15
LASTBIAS	2230	DOES LAST GYRO COMPENSATION IN FREE FALL (DRIFTING) MODE	SH.3
PIPFREE	2210	TERMINATES PROGRAM USE OF PIPAS	SH.19
SETTAG	2780	INITIATES ENTRY ROLL DAP	SH.7
STEERING	2682	UPDATES VELOCITY-TO-BE-GAINED, COMPUTES STEERING RATE COMMANDS FOR TVC DAP	SH.15
VHHDOT	2540	UPDATES AND DISPLAYS INERTIAL V. RATE OF CHANGE OF V. ALTITUDE ABOVE PAD (NOUN 82)	SH.15
I PIPA	2230	DOES PIPA COMPENSATION CORRECTS SENSED ΔV VALUES FOR SCALE-FACTOR, BIAS ERRORS	SH.13

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
CM DAPARM FLAGWRD6 BIT2	ENTRY FIRINGS AND CALCULATIONS ALLOWED	ENTRY FIRINGS AND CALCULATIONS INHIBITED			SH.7
CM D8THY FLAGWRD6 BIT2	ENTRY DAP ACTIVATED	ENTRY DAP NOT ACTIVATED		SH.19	SH.6
DRIFTFLG FLAGWRD2 BIT5	DRIFTING FLIGHT GYRO COMPENSATION DONE	NOT DRIFTING NO GYRO COMPENSATION DONE	SH.19	SH.3	
RNDVZFLG FLAGWRD0 BIT7	P20 RUNNING	P20 NOT RUNNING			SH.20
V37FLAG FLAGWRD7 BIT6	SERVICER RUNNING	SERVICER NOT RUNNING	SH.3	SH.19	

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. 10	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		SERVICER	
PROGRAM <i>[Signature]</i>	ANALYST <i>[Signature]</i>	DOCUMENT NO. COLLOSSUS II	DOCUMENT NO. FC-2683
DOCUMENT NO. <i>[Signature]</i>	APPROVED <i>[Signature]</i>		SHEET 22 OF 26

DISPLAYS

VERB - NOI N	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
	ALARM	ALARM LIGHT ON, R1, R2, R3 NOT AFFECTED	SH 13

EHASABLE LOCATIONS USED

AGC TAG	OSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
AIG		SNAPSHOT OF INNER IMU GIMBAL ANGLE (2'S COMPLEMENT)	DEGREES	REVS	2 ⁻¹
AIG/PIF		VALUE OF AIG (ABOVE) AT TIME OF LAST PIPA READING (USED BY ENTRY DAP)	DEGREES	REVS	2 ⁻¹
ALFA'PIF		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/PIF		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'PIF		VALUE OF AOG (ABOVE) AT TIME OF LAST PIPA READING (USED BY ENTRY DAP)	DEGREES	REVS	2 ⁻¹
AVGENIT _D		2CADR OF LOCATION WHICH BEGINS ROUTINE TO RUN AFTER SERVICER			
BETA/PIF		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	ΔV_{REF}	SENSED VELOCITY CHANGE IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷
DELV _V (DELV _D _X) (DELV _D _Y) (DELV _D _Z)	ΔV	SENSED VELOCITY CHANGE IN STABLE MEMBER COORDINATES	M/SEC	M/CSEC	.000585 x 2 ¹⁴
DELV _D _X	ΔV_X	X - COMPONENT OF SENSED VELOCITY CHANGE IN S. M. COORDINATES	M/SEC	M/CSEC	.000585 x 2 ¹⁴
DELV _D _Y	ΔV_Y	Y - COMPONENT OF SENSED VELOCITY CHANGE IN S. M. COORDINATES	M/SEC	M/CSEC	.000585 x 2 ¹⁴
DELV _D _Z	ΔV_Z	Z - COMPONENT OF SENSED VELOCITY CHANGE IN S. M. COORDINATES	M/SEC	M/CSEC	.000585 x 2 ¹⁴
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 G(T)ΔT	1/2 THE CHANGE IN VELOCITY DUE TO GRAVITATIONAL ACCELERATION OVER A 2-SECOND INTERVAL, IN REFERENCE COORDINATES	M/SEC	M/CSEC	2 ⁷

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPROVAL AND SIGNATURE SERVICER
DRAWN: <i>G. A. ...</i> FROM: <i>...</i> ANALY: <i>...</i> CHECKED: <i>...</i> APPRO'D: <i>...</i>	DOCUMENT NO. FC-2683 SHEET 23 OF 26

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSDP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
GDT1 2 _V	$1/2 \frac{G}{T} \Delta T \Delta t$	TEMPORARY STORAGE FOR UPDATED VERSION OF GDT/2 _V (ABOVE)	M/SEC	M/CSEC	2 ⁷
GOBL 2 _V	$-\frac{R^2}{\mu_E} \dot{G}_B(T)$	CORRECTION TERM (IN REFERENCE COORDINATES) FOR GRAVITATIONAL ANOMALY DUE TO EARTH OBLATENESS - SATISFIES THE EQUATION $\dot{G}_B(ATR)^2 \frac{2\mu_E}{R^2} \text{UNIT}(R) + \dot{G}_B$			2 ¹
GOBL1 1/2 _V	$-\frac{R^2}{\mu_E} \dot{G}_B(T \cdot \Delta T)$	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 TME BETWEEN PIPA READINGS OR TME OF LAST PIPA COMPENSATION	SEC	CSEC	2 ⁸ OR 2 ¹⁴
PHASE 5		INDICATES WHETHER CERTAIN ROUTINES ARE TO BE RESTARTED AND, IF SO, AT WHAT POINT			
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 S, M, COORDINATES) SINCE LAST READING	M/SEC	M/CSEC	.000585 $\times 2^{14}$ (NOMINALLY)
PIPAY		COUNTER ACCUMULATING Y-COMPONENT VELOCITY CHANGE (IN S, M, COORDINATES) SINCE LAST READING	M/SEC	M/CSEC	.000585 $\times 2^{14}$ (NOMINALLY)
PIPAZ		COUNTER ACCUMULATING Z-COMPONENT VELOCITY CHANGE (IN S, M, COORDINATES) SINCE LAST READING	M/SEC	M/CSEC	.000585 $\times 2^{14}$ (NOMINALLY)
PIPTIME _D		TIME OF LAST PIPA READING	SEC	CSEC	2 ²⁸
PIPTIME _I _D		TEMPORARY UPDATED VERSION OF PIPTIME _D (ABOVE)	SEC	CSEC	2 ²⁸
REFSMMAT _M	[REFSMMAT]	TRANSFORMATION MATRIX FOR CONVERSION BETWEEN S, M, AND REFERENCE COORDINATE SYSTEMS			2 ¹
RN _V	B(T)	POSITION VECTOR IN REFERENCE COORDINATES	M	M	2 ²⁰
RN1 _V	B(T+ Δ T)	TEMPORARY UPDATED VERSION OF RN _V (ABOVE)	M	M	2 ²⁰
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 $\times 2^{14}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO SUBSPACE AND NAVIGATION	
		SERVICER	
DRAWN <i>C. J. ...</i>	DESIGNED <i>...</i>	DOCUMENT NO.	
PROGRAM <i>...</i>	DATE <i>...</i>	FC-2683	
ANALYST <i>...</i>	PROJECT <i>...</i>	SHEET 24 OF 26	
DOCUMENT NO. <i>...</i>	REV <i>...</i>		
APPROVED <i>...</i> 24 MAR 64			

ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
TEMY		TEMPORARY STORAGE FOR PIPA READING (PIPAY ABOVE)	M/SEC	M/CSEC	$\times 10^{14}$ $\times 2^{14}$
TEMZ		TEMPORARY STORAGE FOR PIPA READING (PIPAZ ABOVE)	M/SEC	M/CSEC	$\times 2^{14}$ $\times 2^{14}$
TIME2 _V = (TIME2) (TIME1)		PRESENT TIME	SEC	CSEC	2^{28}
TRKMKCNT		NUMBER OF OPTICS MARKS INCORPORATED			
UNITR _V	\underline{U}_R	UNIT VECTOR IN DIRECTION OF POSITION VECTOR (IN REFERENCE COORDINATES)			2^3
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	000585×2^{14}
XPIPBUF		NEW PIPAX (SEE ABOVE) READING FOR DOWNLINK TELEMETRY	M/SEC	M/CSEC	000585×2^{14}
YOLDBUF		OLD PIPAY (SEE ABOVE) READING FOR DOWNLINK TELEMETRY	M/SEC	M/CSEC	000585×2^{14}
YPIPBUF		NEW PIPAY (SEE ABOVE) READING FOR DOWNLINK TELEMETRY	M/SEC	M/CSEC	000585×2^{14}
ZOLDBUF		OLD PIPAZ (SEE ABOVE) READING FOR DOWNLINK TELEMETRY	M/SEC	M/CSEC	000585×2^{14}
ZPIPBUF		NEW PIPAZ (SEE ABOVE) READING FOR DOWNLINK TELEMETRY	M/SEC	M/CSEC	000585×2^{14}

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
KPIPI		SCALING FACTOR FOR CONVERTING ΔV SENSED TO USUAL SCALING	0.000585×2^7	0.000585×2^7	2^0
-MAXDELV		-(MAXIMUM ΔV COMPONENT) (HARDWARE CAN SENSE - 2)	-6398 PULSES	-6398 PULSES	2^{14}
-MUDT(E) _D	$\mu_{0.01}$	-(EARTH GRAVITATIONAL CONSTANT) \times (2 SECONDS)	$-79730645 \times 10^{10} \text{ M}^3/\text{SEC}$	$-79730645 \times 10^{13} \text{ M}^3/\text{CSEC}$	2^{44}

MIL INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFSEE OPERATIONAL AND NAVIGATION	
DRAWN: <i>[Signature]</i> 25 OCT 64		SERVICER	
PROGRAM: <i>[Signature]</i> D. M. S. 4		COLOSSUS II	
ANALYSIS: <i>[Signature]</i> D. M. S. 4		1	
DOCUMENT: <i>[Signature]</i> D. M. S. 4		DOCLINK NO. FC-2683	
APPROVED: <i>[Signature]</i> D. M. S. 4		MAY 25 1965	

PROGRAM CONSTANTS (CONTINUED)

AGC TAG	CSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
-MUTOM _D	$\mu^M M^{2E}$	(MOON GRAVITATIONAL CONSTANT) x (2 SECONDS)	$- .9805556 \times 10^{13}$ M ³ /SEC	$- .9805556 \times 10^{13}$ M ³ /CSEC	2 ⁴⁴
RESQ _D	R _E ²	SQUARE OF EQUATORIAL RADIUS OF THE EARTH	$40.6809913 \times 10^{12}$ M ²	$40.6809913 \times 10^{12}$ M ²	2 ⁵⁹
2J _D	$2 \times (3/2 J_2 E)^1$	2 x 3/2 x THE 2ND HARMONIC OF EARTH'S POTENTIAL FUNCTION	3.2469201×10^{-3}	3.2469201×10^{-3}	2 ⁻¹
20J _D	$20 \times (3/2 J_2 E)^1$	20 x 3/2 x THE 2ND HARMONIC OF EARTH'S POTENTIAL FUNCTION	3.2469201×10^{-2}	3.2469201×10^{-2}	2 ⁻¹

AGC TAG	CSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING	OCTAL VALUE
UNITW _V	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	$\begin{pmatrix} 77777 \\ 76203 \\ 00000 \\ 25740 \\ 37777 \\ 37777 \end{pmatrix}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED GUIDANCE AND NAVIGATION	
DRAWN <i>[Signature]</i>		SERVICER	
PROJECT <i>[Signature]</i>	APPROVED <i>[Signature]</i>	DOCUMENT NO. COLOSSUS II	FC-2683
DATE <i>[Signature]</i>	APPROVED <i>[Signature]</i>	SHEET 24 OF 26	

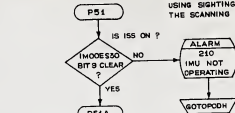
P51, P53

P51 (-P53)	IMU DETERMINATION PROGRAM	SH. 2
PLANET	OBTAIN STAR VECTOR IN REFERENCE COORDS	SH. 7
CHKSDATA (-R54)	CHECK VALIDITY OF A PAIR OF STAR SIGHTINGS	SH. 8

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROV GUIDANCE AND ASSISTANCE	
DRAWN		P51, P52 IMU ORIENTATION DETERMINATION	
PROJECT	DATE	COLOSSUS	FC-2710
ANALYST		IIA	
DOCNO	APPROV	REV 1	

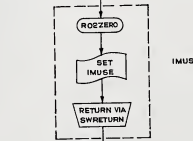
DRAWN: *[Signature]* DATE: 6/19/64
 PROJECT: *Colossus*
 ANALYST: *C. S. MULLY*
 DOCNO: *FC-2710*
 APPROV: *[Signature]* DATE: 6/19/64

DETERMINE THE INERTIAL ORIENTATION OF THE IMU USING SIGHTINGS ON TWO CELESTIAL BODIES USING THE SCANNING TELESCOPE OR THE SEXTANT.



IMU MUST BE TURNED ON BEFORE THIS PROGRAM CAN OPERATE.

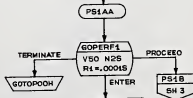
IMUSE IN USE



PLEASE PERFORM CELESTIAL BODY ACQUISITION

R1 - 00015
R2 - BLANK
R3 - BLANK

SKIP COARSE ALIGN



ZERO THE DESIRED GIMBAL ANGLES



DISPLAY NEW CDU ANGLES

R1 - 00000
R2 - 00000
R3 - 00000



PASTE UP V41 - LEAVE REMAINDER OF DISPLAY V41N22

R1 - THETA0 = 06 YAW
R2 - THETA0+1 = 16 PITCH
R3 - THETA0+2 = 16 ROLL



COARSE ALIGN ISS

INPUT : THETA0, +1, +2
OUTPUT : CDU CMD, CDU CMD, CDU CMD, (COMMAND REGISTER)
CH 14 (15, 14, 15) TURN ON NO ATT LIGHT, CLEAR
REFSMFLG

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	PROJECT GIMBALS AND ACQUISITION PS4, PS3 IMU ORIENTATION DETERMINATION
DESIGNED BY <i>[Signature]</i>	COLOSSUS II-A FC-2710
PROGRAM BY <i>[Signature]</i>	DATE 2 11
ANALYST <i>[Signature]</i>	
DOCKED BY <i>[Signature]</i>	
APPROVED BY <i>[Signature]</i>	

FROM PRECEDING SHEET

IMUSTALL
GO TO SLEEP
UNTIL FINISHED
FC-2210

CURTAINS
ALARM 217 BAD
RETURN FROM STALL

TERMINATE COARSE ALIGN MODE IN ISS
RESUME ATTITUDE HOLD OF VEHICLE
IMUFINE ALIGN MODE SWITCH
TURN OFF NO ATT LIGHT

IMUFINE20
RETURN TO FINE
ALIGN MOOE
FC-2210

IMUSTALL
WAIT FOR
COMPLETION
FC-2210

CURTAINS
ALARM 217 BAD
RETURN FROM STALL

GROUP 4
RESTART JOB
AT NEXT
INSTRUCTION
PRIORITY 13

PS1AA
SH 2

PS1B

GROUP 4-1
RESTART JOB
AT LAST
DIS PLAY

CLEAR
STARIND

FIRST SIGHTING

SET1/POT

V/PIPAOT TIME1

TIME OF GCOMP INITIALIZATION

RETURN VIA
DANZIG

NEXT SHEET

PS1, P55
20 AUG 68 IMU ORIENTATION DETERMINATION
7401
COLOSSUS II-A FC-2710
DRAWN: *[Signature]*
BY: *[Signature]*
CHECKED: *[Signature]*
DATE: 7/26/68
1 3 11

FROM PRECEDING SHEET

GCOMP ← 0

ZERO COMPENSATING TORQUES

SET
DPIFTFLG

ENABLE GYRO COMPENSATION

CLEAR
TARG2FLG

SET TARGET FLAG TO STAR FOR USE BY THE
SIGHTING MARK ROUTINE (R53)

MARKINDX ← BITS1

SET MARK INDEX TO 1 FOR USE BY THE
SIGHTING MARK ROUTINE (R53)

PS1C

GROUP 4

RESTART JOB
AT NEXT
INSTRUCTION
PRIORITY IS

CHECK MODREG TO SEE IF REGULAR OR
BACKUP PROGRAM IS OPERATING

CHECKMM

CHECK
MOOREG

FC-2030

BACKUP-P53

(PS1)

PS1C-1

R53

SIGHTING MARK
ROUTINE

FC-2730

R56
SIGHTING MARKS
FOR BACKUP
ROUTINE-P53
FC-2730

INPUT: STARIND = STAR INDX

OUTPUT: BESTI_(STARIND) = STARCODE XG

INPUT: TARG2FLG - TARGET FLAG = STAR
STARIND - INDEX TO BESTI OR BESTJ
MARKINDX - NO. OF MARKS WANTED
MARKSTAT - INDEX WHERE MARK DATA
IS STORED BESTI (INDEXED BY STARIND)
- STAR NO. SIGHTED
TSIGHT_D - TIME OF MARK

DRAWN <i>[Signature]</i> CHECKED <i>[Signature]</i> INKST DOCNO <i>[Signature]</i> APPR <i>[Signature]</i>	TITLE INFLUENCE VARIATION LAB CAMBRIDGE, MASS. PROJECT AND REPORT NO. PS1, P53 IMU ORIENTATION DETERMINATION COLLOSSUS II-A FC-2710 REV. 4 OF 11
--	--

FROM PRECEDING SHEET

PS1C.2

SXTSM
COMPUTE AN
LOS VECTOR
FC-273D

INPUT: CAOR (MARKSTAT) = ADDRESS OF VAC AREA
STARIND = 1ST OR SECOND STAR
OUTPUT: MPAC = LOS VECTOR

OO_v ← MPAC_v

PUT LOS VECTOR IN PUSH LIST

IS
STARIND
SET ?

YES - SECOND SIGHTING

STARS_{AV2} ← OO_v

LOS VECTOR FOR SECOND SIGHTING

NO - FIRST SIGHTING

PS1D

STARS_{AV1} ← OO_v
MPAC₀ ← TSIGHT₀

LOS VECTOR FOR FIRST SIGHTING
(TIME OF SIGHTING)

PLANET
PROVIDE
REFERENCE
DIRECTION
VECTOR
SH 7

PROVIDE THE REFERENCE DIRECTION FOR THE
SIGHTED CELESTIAL BODY
INPUT: TIME IN MPAC (TSIGHT₀), AOTCODE
OUTPUT: MPAC_v = STORED DIRECTION OF SIGHTED BODY

PLANVEC_v ← MPAC_v

REFERENCE DIRECTION VECTOR OF FIRST BODY

PS1E

GROUP 4
RESTART JOB
AT NEXT
INSTRUCTION
PRIORITY 13

MKRELEAS
RELEASE THE
MARK SYSTEM
FC-2240

RELEASE THE MARK SYSTEM TO MAKE IT AVAILABLE

SECOND SIGHTING

IS
STARIND
SET ?

NO - FIRST SIGHTING

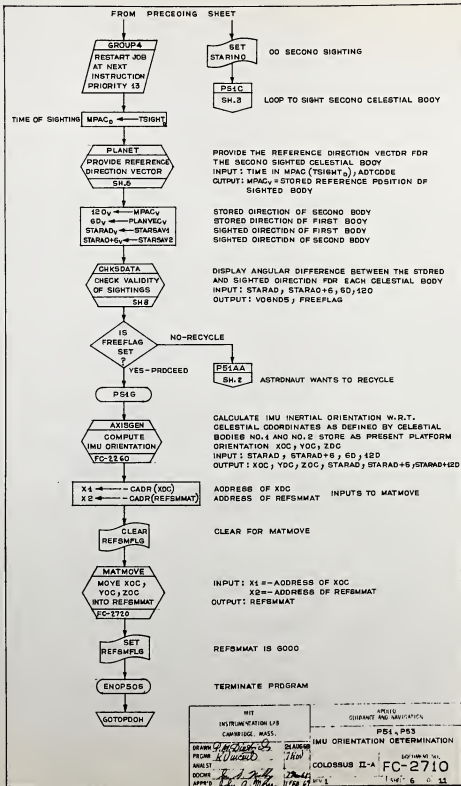
GROUP 4
RESTART JOB
AT NEXT
INSTRUCTION
PRIORITY 13

PS1F

NEXT SHEET

NEXT SHEET

MI
 "CORRECTIONAL" "C"
 APPLICABLE MARKS
 PS1, PS3
 IMU ORIENTATION DETERMINATION
 AUG 68 20 AUG 68
 COLLOSSUS II- FC-2710
 5 11



PLANET

TSIGHT₀ ← MPAC₀
QMIN ← QPRET

LOCSAM
COMPUTE
POSITION OF EARTH,
SUN AND MOON
FC-2720

VEARTH_v ← VSUN_v

INTERCHANGE VECTORS TO GET INTO RIGHT ORDER FOR INDEXING

NOSAM

BEST1 (STARIND) ← STARCODE X6
(BITS 8-1)

STAR CODE

FIRST DISPLAY IS GARBAGE THEN
LOAD
POSITION VECTOR AT PRESENT
TIME IN REFERENCE COORDINATES
VO6N88
R1-STAR-X COMPONENT
R2-STAR-Y COMPONENT
R3-STAR-Z COMPONENT

IS IT A PLANET?

YES-PLANET

GOFLASH
VO6N88

ENTER

NO-STAR CODE NOT DO

PROCEED

NOTPLAN TARGET NOT A PLANET

POSITION VECTOR OF
PLANET
 $MPAC_v \leftarrow UNIT \left[\frac{1}{\sqrt{3}} R_3, \frac{1}{\sqrt{3}} R_2, \frac{1}{\sqrt{3}} R_1 \right]$

NO-STAR
BEST1 (STARIND)
 ≥ 228
 $228 = 38 X 6$
 $38 = 46 8$
X1 ← BEST1 (STARIND)
MPAC_v ← CATALG (X1)

YES-SUN, EARTH OR MOON

CALSAM1

X1 ← BEST1 (STARIND)
MPAC_v ← STARAD-228 (X1)

POSITION VECTOR OF APPROPRIATE
BODY
STARAD_v-228 = VSUN = (X1=0)
STARAD_v-228 = VEARTH = (X1=6)
STARAD_v-228 = VMOON = (X1=12)

CORPLAN

MPAC_v ← UNIT [MPAC + VEL/C]

AOD ABERRATION CORRECTION (VELIC) TO POSITION VECTOR

RETURN VIA
QMIN

*

STAR INSTEAD OF STARAD DUE TO CONFLICT WITH
AUTO OPTICS IN COLOSSUS GSOP IV IS WRONG

INPUT: STARIND = 1 OR 2 FOR 1ST AND 2ND CELESTIAL
BODY TSIGHT = TIME OF SIGHTING
OUTPUT: MPAC_v = REFERENCE DIRECTION VECTOR

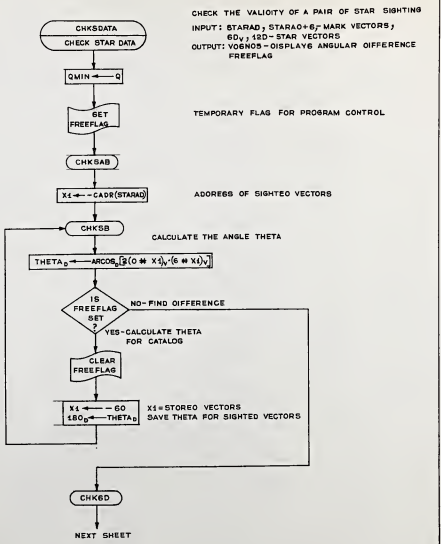
TIME OF SIGHTING
SAVE RETURN

INPUT: TSIGHT

OUTPUT: VEARTH_v, VSUN_v, VMOON_v

PS4.P53

8 SEP 68 1MU ORIENTATION DETERMINATION
FC-2710
1 7 11



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APPLIC: E-10DAM3 AND NAVIGATION PS1, PS3
DRAWN: <i>[Signature]</i>	IMU ORIENTATION DETERMINATION
PROGRAM: <i>[Signature]</i>	DOCUMENT NO.
ANALYST: <i>[Signature]</i>	COLOSSUS II-A FC-2710
DCOMP: <i>[Signature]</i>	SHEET 8 OF 12
APPROV: <i>[Signature]</i>	

FROM PRECEDING SHEET

$MPAC_D \leftarrow |THETA_D - 180_D|$

DIFFERENCE BETWEEN STORED AND OBSERVED THETAS

SNAGREE
FORGE SIGN
AGREEMENT IN
MPAC,
FC-2400

MAKE SECOND WORD SAME SIGN AS FIRST
(THIRD WORD IS ZERO)

$NORMTEM1 \leftarrow MPAC_D$

SET
FREEFLAG

CLEANDSP
CLEAN OUT
OLD DISPLAY

GOFLASH
VDGNOS
 $R1 = NORMTEM1$

ENTER

DIFFERENCE BETWEEN ACTUAL AND INDICATED
ANGLES BETWEEN CELESTIAL BODY VECTOR NO.1
AND CELESTIAL BODY VECTOR NO.2
 $R1 =$ SIGHTING ANGLE DIFFERENCE

PROCEED

CLEAR
FREEFLAG

ANGLE EXCEEDS ACCEPTABLE
TOLERANCE

CHKSDA

RETURN VIA
QMIN

INT	STEP 10
INSTRUMENTATION LAB	PS4, PS3
CAMBRIDGE MASS	IMU ORIENTATION DETERMINATION
APPROVED: <i>[Signature]</i>	DATE: <i>[Date]</i>
APPROVED: <i>[Signature]</i>	DATE: <i>[Date]</i>
APPROVED: <i>[Signature]</i>	DATE: <i>[Date]</i>
FC-2710	FC-2710
1	9 11

SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
IMUCOARS	FC-2210	COARSE ALIGN THE GIMBALS	SH. 2
IMUSTALL	FC-2210	WAIT FOR COMPLETION	SH. 3
IMUFINE20	FC-2210	RETURN TO FINE ALIGN MODE	SH. 3
RS3	FC-2730	SIGHTING MARK ROUTINE	SH. 4
RS6	FC-2730	SIGHTING MARKS FOR BACKUP ROUTINE	SH. 4
SXTSM	FC-2730	COMPUTE AN LOS VECTOR	SH. 5
MKRELEAS	FC-2240	RELEASE THE MARK SYSTEM	SH. 5
AXISGEN	FC-2260	COMPUTE IMU ORIENTATION	SH. 6
MATMOVE	FC-2720	MOVE XDC, YDC INTO REFSMMAT	SH. 6
LOCSAM	FC-2720	COMPUTE POSITION OF EARTH, SUN AND MOON	SH. 7
SGNAGREE	FC-2100		

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
DRIFTFLG	ENABLE GYRO COMPENSATION	TRUPT DOES NO GYRO COMPENSATION	SH. 3		
IMUSE	IMU IN USE	IMU NOT IN USE	SH. 2		
STARIND	2ND SIGHTING	FIRST SIGHTING	SH. 6	SH. 4	SH. 5
TARG2FLG	SIGHTING LANDMARK	SIGHTING STAR		SH. 4	
REFSMFLG	REFSMAT GOOD	REFSMAT NO GOOD	SH. 6	SH. 6	
FREFFLAG	TEMP FLAG	TEMP FLAG	SH. 8, 9	SH. 8, 9	SH. 6 & 8

DISPLAYS

VERB-NOUN	TYPE OF DISPLAYS	DESCRIPTION OF EACH REGISTER	WHERE CALLED
V06N22	OBSERVE	ALARM - 210 - IMU NOT OPERATING DISPLAY NEW CDU ANGLES R1 - 00000 R2 - 00000 R3 - 00000	SH. 2 SH. 2
V41N22	OBSERVE	PASTE UP V41 R1 - THETAD R2 - THETAD+1 R3 - THETAD+2	SH. 2
V06N88	FLASHING	CURTAINS - 217 - BAD RETURN FROM STALL LOAD POSITION VECTOR R1 - STAR X COMPONENT R2 - STAR Y COMPONENT R3 - STAR Z COMPONENT	SH. 3 SH. 7
V06N05	FLASHING	R1 - SIGHTING ANGLE DIFFERENCE R2 - BLANK R3 - BLANK	SH. 9

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	MODEL G2-PART 1 AC VOLTAGE 115
DRAWN <i>R. A. Moore</i> CHECKED <i>R. A. Moore</i> ANALYST DONE BY <i>G. S. NALL</i> APPROVED <i>John G. Moore</i>	P51-P53 IMU ORIENTATION DETERMINATION COLLOSSUS II-A FC-2710 REV 1

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
THEIAD		GIMBAL ANGLES			
PLANVEC		REFERENCE VECTOR			
STARAD		SIGHTED DIRECTION OF FIRST BODY			
STARAD*6		SIGHTED DIRECTION OF SECOND BODY			
1 PIPADT		TIME OF GCOMP INITIALIZATION			
STARSAV1		MARK VECTOR NO 1			
STARSAV2		MARK VECTOR NO 2			
GCOMP		COMPENSATION PULSES FOR FREEFALL DRIFT			
TSIGHT		TIME OF SIGHTING			
VEARTH		UNIT POSITIONAL VECTOR OF EARTH			
VSUN		UNIT POSITIONAL VECTOR OF SUN			
BESTI					
BESTJ					
VEL/C		ABERRATION CORRECTION			
STAR		SAME AS STARAD			
NORMTEM1		SIGHTED ANGLE DIFFERENCE			

INFORMATION BY
 NAME OF VEHICLE
 PHILPESJ
 IMU ORIENTATION DETERMINATION
 BY: A.C. WILLIAMS 31669
 DATE: 1/16/69
 AND: G. B. NALLY 37604
 COLUSSO II-A FC-271C
 APPROVED: John A. Shaw 11/28/69 1 11 11

R52, R53, R56

R52	AUTO OPTICS POSITIONING ROUTINE	SH. 2
ADVORB	SET UP ADVANCED ORBIT TRACKING	SH. 5
SH52.1	TARGET DETERMINATION	SH. 6
ROTA	ROTATE VECTOR	SH. 10
R53	SIGHTING MARK ROUTINE	SH. 11
CHNSCODE	CHECK STARCODE	SH. 12
SXTSM	COMPUTE LOS VECTOR IN SM COORDINATES	SH. 13
R56	ALTERNATE SIGHTING MARK ROUTINE	SH. 14

ENCLOSED IS A REPLACEMENT SHEET (SH. 6) TO UPDATE THE COLOSSUS IIA FLOW-
CHART FC-2730, REV. 1, TO THE COLOSSUS IIC FLOWCHART FC-2730, REV. 2.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		PUBLIC LOADING AND MARKING UNIT R52, R53, R56	
DRAWN	EDMUND	DATE: 1/14/61	
PCB		COLOSSUS IIC	
AMAS		FC-2730	
DOC#	G. S. NALLEY	REV. 2	
APP#	1/14/61	1 of 15	

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 RENDEVOUS
 TRACKING OPERATION

R52
 AUTOOPTICS POSITIONING ROUTINE

DO THE TRACKING ATTITUDE ROUTINE (R61) EVERY 1/6 SEC.
 DURING RENDEVOUS TRACKING OPERATIONS
 INPUT: PRESET BYCALLER-TARG1FLG, TARG2FLG, RENOVZ FLG,
 TRACKFLG, MARKINDX, STARCODE
 THROUGH DSKY - LAT-LONG, ALT OF LANDMARK,
 STARCODE
 OUTPUT: DRIVE SHAFT AND TRUNNION CDUS

SAVGR52 ← QPRET

CLEAR
 ADVTRK

NOT ADVANCED GROUND TRACK

R52VRB

DESOPPT ← CDUT
 DESOPTS ← COUS
 OPTIND ← 0

CLEAR
 R52FLAG

V51 NOT INITIATED

R52A

SET
 TRUNFLAG

DRIVING OF TRUNNION ALLOWED

IS
 TARG1FLG
 SET?

IS THE LM TARGET FLAG SET?

YES - LM

R52HA
 SH4

CLEAR
 TERMIFLG

DO NOT TERMINATE R52

R52C

IS
 SWSAMPLE
 > 0

IS OPTICS MODE IN AGC?

NO - MANUAL

YES - AGC

R52M
 SH3

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		ARCHIVE SAFE AND SOUND
DRAWN <i>[Signature]</i>		R52, R53, R56
PREPARED <i>[Signature]</i>	ANALYST <i>[Signature]</i>	01 (REV) NO.
DOCNO <i>[Signature]</i>	APPROVED <i>[Signature]</i>	COLOSSUS IIC FC-2730
		MAY 2 1966

FROM PRECEDING SHEET

R52D

SR52.1
DETERMINE
TARGET
SH6

INPUT : TARG1FLG, TARG2FLG
OUTPUT: SAC - SHAFT ANGLE DESIRED
PAC - TRUNNION ANGLE DESIRED

ERROR > 50°

ERROR > 90°

GOOD - < 50°

SET
TRUNFLAG

DRIVING OF
TRUNNION
ALLOWED

R52JA

R52J

CLEAR
TRUNFLAG

DRIVING OF TRUNNION
NOT ALLOWED

ALARM
AUTO OPTICS RE-
QUEST TRUN ANGLE
> 50 DEG
407

R52L

IS THIS A LM?

IS TARG1FLG
SET?

YES

NO

PRIOR ALARM
TARGET OUT OF VIEW
TRUN ANGLE > 90 DEG
404

ENDOFJOB
IMMEDIATE RETURN

TERM52
SH5
TERMINATE

PROCEED/ENTER

IS THIS A LM?

IS TARG1FLG
SET?

YES

NO

IS V51 INITIATED?

YES

IS R53FLAG
SET?

YES

NO

GOODSPR
VOGN92

NOTE: THIS DISPLAY WILL NOT
APPEAR IF R53 HAS ALREADY
BEEN CALLED BY SWITCHING
OPTICS MODE SWITCH TO
MANUAL.

DISPLAY DESIRED OPTICS ANGLES
R1-SAC- DESIRED SHAFT
ANGLE IN DEG
R2-PAC- DESIRED TRUNNION
ANGLE IN DEG

R52E

IS THE OSS IN CMC MODE?

IS SW5SAMPLE
SET?

NO

YES

IS TRUNNION DRIVE
FLAG SET?

NO - JUST SHAFT

YES

DESOPT - PAC

DRIVE TRUNNION
COUS

NEXT SHEET

NEXT SHEET

NEXT SHEET

R52M

IS R53FLAG
SET?

YES

NO - R53 IS NOT OPERATING

INHINT

R53JOB
FINDVAC
SH3

RELINT

R53JOB

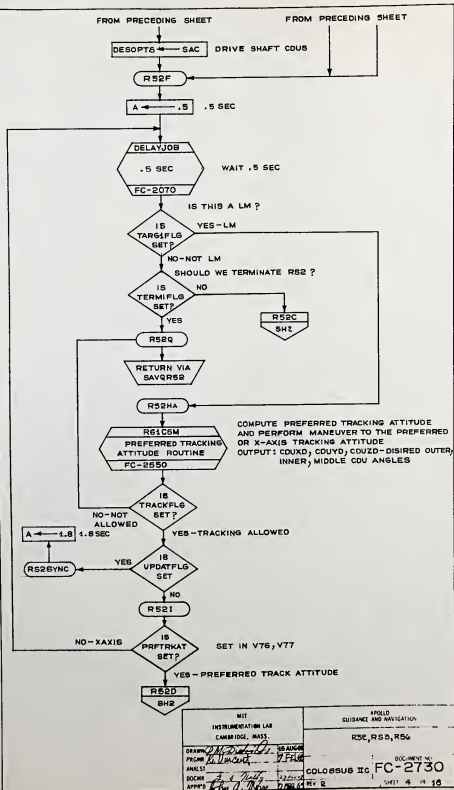
R53
SIGHTING MARK
ROUTINE
SH11

ENDOFJOB

R52, R53, R56

Handwritten notes and signatures at the bottom of the page.

COLLOSSUS IC FC-2730



MIT
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CAMBRIDGE, MASS.

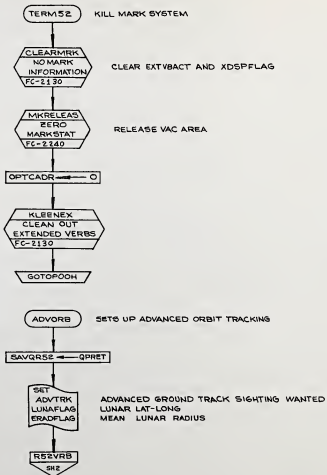
DRAWN: *[Signature]* 15 AUG 64
 PROGRAM: *[Signature]* 17 FEB 64
 ANALYST: *[Signature]*
 CHECKED: *[Signature]*
 APPROVED: *[Signature]* 17 FEB 64

APOLLO
GUIDANCE AND NAVIGATION

R52, R53, R54

DOCUMENT NO.
COLOSSUS IIC FC-2730

SHEET 4 OF 10



DPABN	7/11/78	153000
PRGNO	7/11/78	260
ANNST		
EPFNO	7/11/78	
LNPRB	7/11/78	2

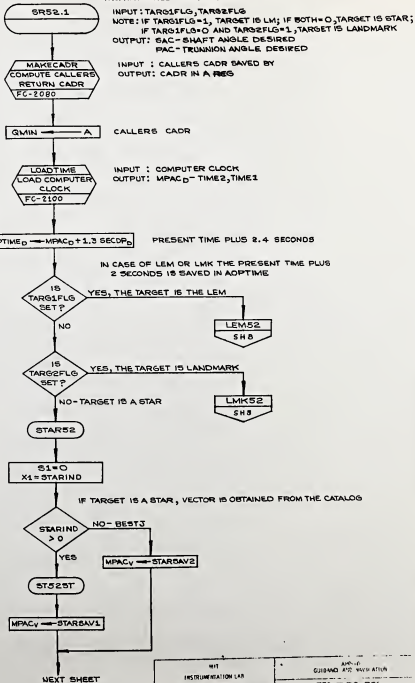
INSTRUMENTATION LAB
ADDRESS: WASH DC

COLOSSUS II FC-2730

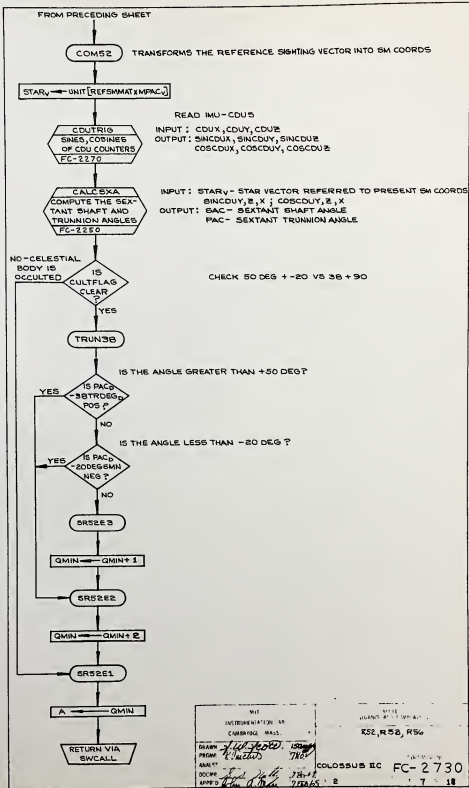
R52, R53, R56

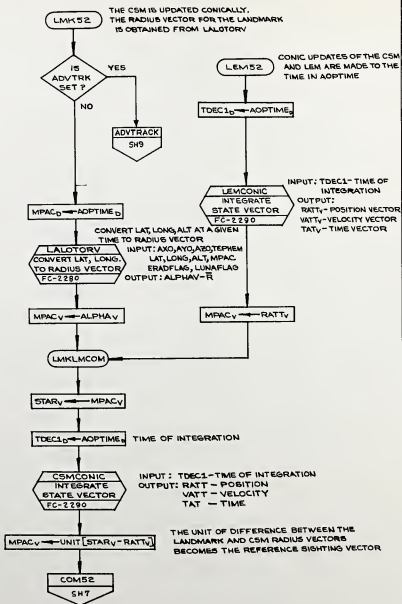
5 18

TARG1 AND TARG2 FLAGS ARE LOOKED AT TO DETERMINE IF TARGET IS LEM, STAR OR LANDMARK. A REFERENCE SIGHTING VECTOR IS OBTAINED AND TRANSFORMED INTO STABLE MEMBER COORDINATES. FINALLY A TRUNNION ANGLE TEST IS MADE.



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPROVED AND AUTHORIZED R52, R33, R56	
DRAWN 7/14/52 7995	7/14/52 7995	COLLOSSUS IIC FC-2730	
PROG 7/14/52	7/14/52	REV E	
CHKD	7/14/52	SHEET 6 OF 10	
APPR 7/14/52	7/14/52		





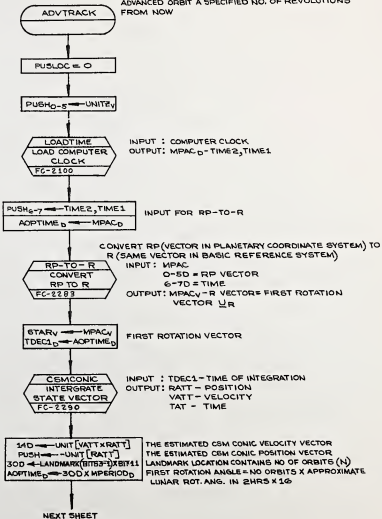
MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DESIGN: *J. J. ...*
PROGRAM: *...*
ANALYST: *...*
DOCK: *...*
APPRO: *...*

RP11
GUIDANCE AND TOLERANCE
R52, R53, R56

COLOSSUS IIC FC-2730
REV B

CALLED BY SR52.1
 USED TO COMPUTE AN OPTICS LOS VECTOR TO A POINT ON
 THE GROUND
 TRACK 60 DEGREES FORWARD OF THE LOCAL VERTICAL OF AN
 ADVANCED ORBIT A SPECIFIED NO. OF REVOLUTIONS
 FROM NOW



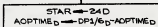
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		REV. NO. R52, R53, R56
DESIGN <i>J. J. ...</i>	PROGRAM <i>Advanced</i>	ANALYSIS <i>J. J. ...</i>
SCHEMATIC <i>J. J. ...</i>	APPROVED <i>J. J. ...</i>	7 FEB 64
COLOSSUS IIC		FC-2730

FROM PRECEDING SHEET

ROTATE THE LOCAL VERTICAL VECTOR ABOUT THE POLAR AXIS OF THE MOON TO ACCOUNT FOR LUNAR ROTATION
 INPUT : PUSH_{O-5} = -UNIT (RAIT)



STAR_V = FIRST ROTATION VECTOR \underline{U}_R
 AOPTIME = ANGLE THROUGH WHICH MOON ROTATES IN ONE NOMINAL LUNAR - ORBITAL PERIOD X NO OF ORBITS - (A = A_{MN})
 OUTPUT : PUSH_{O-5}



2ND ROTATION VECTOR
 2ND ROTATION ANGLE = 60° - A

ROTATE VECTOR ABOUT THE NORMAL TO THE CSM ORBITAL PLANE TO ATTAIN DESIRED 60° ANGLE



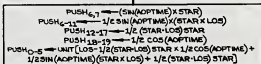
INPUT : STAR = LOS VECTOR
 AOPTIME = 60° - FIRST ROTATION ANGLE - (A = $\frac{\pi}{3} - A$)
 OUTPUT : PUSH_{O-5}



DESIRED LINE OF SIGHT VECTOR \underline{U}_{LOS}



INPUT : AOPTIME = ROTATION ANGLE - (A)
 STAR = ROTATION VECTOR - (\underline{U}_R)
 PUSH_{O-5} = LOS VECTOR - (\underline{U}_{LOS})
 OUTPUT : PUSH_{O-5} = FINAL DESIRED LINE OF SIGHT VECTOR (\underline{U}_{LOS})



ROTATE THE VECTOR \underline{U}_{LOS} ABOUT \underline{U}_R THROUGH THE ANGLE A BY
 $\underline{U}_{LOS} = (1 - \cos A)(\underline{U}_R \times \underline{U}_{LOS}) \underline{U}_R + \underline{U}_{LOS} \cos A + \underline{U}_R \times \underline{U}_{LOS} \sin A$



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		RPL GUIDANCE AND NAVIGATION RS2, RS3, RS6	
DRAWN <i>[Signature]</i>	ANALYST <i>[Signature]</i>	COLOSSUS IIC 17-11 1964	DOCUMENT NO. FC-2730 REV. 10

R53
SIGHTING MARK ROUTINE

PURPOSE IS TO PERFORM A SATISFACTORY NUMBER OF OPTICAL
SIGHTING MARKS FOR THE REQUESTING PROGRAM(OR ROUTINE)
INPUT : TARG2FLG - TARGET FLAG- STAR OR LANDMARK
MARKINDX - NO. OF MARKS WANTED
STARIND - INDEX TO BEST1 OR BESTJ
OUTPUT: R53FLAG
TERIFLG

R53EXIT → QPRET SAVE RETURN

SET
R53FLAG

SET SIGHTING MARK FLAG INDICATES THAT A VSI REQUEST TO
PLEASE MARK HAS BEEN INITIATED

R53A

A ← MARKINDX(BITS-1)

NO OF MARKS

SXTMARK
RESERVE VAC
AREA AND SCHEDULE
MKVBS1 JOB
FC-2240

INPUT : BIT 3-1 OF A: NO OF MARKS REQUESTED
OUTPUT: MARKSTAT = MARK VALUE AND VAC AREA ADDRESS
QPRET = VAC AREA POINTER VALUE
VAC AREA WORD 1 = 0

OPTSTALL
WAIT FOR MARK
TO FINISH
FC-1150

CURTAINS
ALARM
00217
FC-2240

RELEASE VAC AREA

MARKSTAT ← MARKSTAT - 1

IS
QPRET
(MARKSTAT)
> 0

HAVE ANY MARKS BEEN DONE?
QPRET, (MARKSTAT) = NUMBER OF MARKS ACTUALLY PERFORMED
(MKVBS1)

R53B

IS CALLING PROGRAM P22 OR P23?

CHECKMM
CHECK
MODREG
FC-1150

YES - BYPASS DISPLAY

NO - DISPLAY

NEXT SHEET

R53C1

A ← 40

CLEANDSP
BLANK
DISPLAY
REGISTERS
FC-1150

NEXT SHEET

WHI
DISTRIBUTION STATEMENT - 144
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11 FEB 68
81265
32000
7 FEB 68

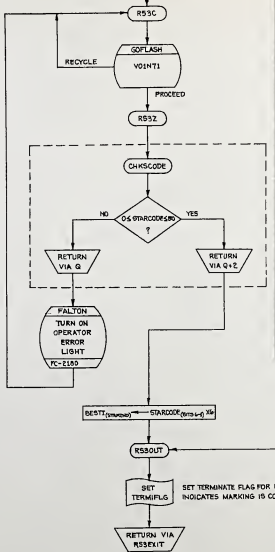
R52, R53, R54

COLOSSUS 300

FC-2730

11 11 18

FROM PRECEDING SHEET

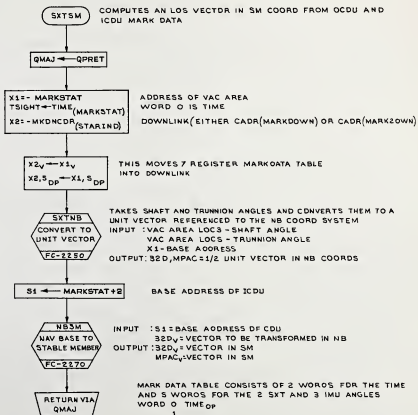


REQUEST RESPONSE AND DISPLAY
OF CELESTIAL BODY CODE
VOINT1
R1 - 000XX - CELESTIAL BODY CODE
R2 - BLANK
R3 - BLANK
CELESTIAL BODY CODE
00 - PLANET
01-45 - STAR FROM CELESTIAL
BODY CODE LIST

46 - SUN
47 - EARTH
50 - MOON

OBTAIN STAR VECTOR
FROM STORED EPHEMERIS.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APPLIED SPACE AND NAVIGATION	
DRAWN A.C. WILLIAMS		R52, R53, R54	
PROGRAM X. W. HARRIS	DESIGNED J. E. BIRD	REV. 12 1965	
ANALYST G. S. WALKER	DATE 2-7-68	COLOSSUS 2C	
APPROVED John H. ...	REV. 2	FC-2730	



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 APPROVED
 [Signature]
 27 Nov 11
 75619

R52, R53, R56

COLOSSUS IC

FC-2730

**R56
ALTERNATE SIGHTING MARK ROUTINE**

PERFORM SIGHTING MARKS FOR THE BACKUP ALIGNMENT PROGRAMS
 INPUT: STARIND - STAR INDEX = 0 OR 1
 OUTPUT: BESTZ (STARIND) * STAR CODE * 6

STORE
 QPRET
 IN
 RBDEXT

ENTER
 NEW ANGLES

GOFLASH
 VOGN94

R1: CDUS - SHAFT - SAC - OPTICS SHAFT ANGLE IN DEG. TO NEAREST .01 DEG.
 R2: COUT - TRUNNION - PAC - OPTICS TRUNNION ANGLE IN DEG. TO NEAREST .001 DEG.
 R3: BLANK
 PROCEED - ANGLES O.K.

R56A

SKYMRK+2
 RESERVE
 VAC AREA
 FC-2340

CLEANDSP
 CLEAR DISPLAY

PROCEED

R56A1
 GOMARKZ
 VS3

REQUEST PLEASE PERFORM ALTERNATE LOG SIGHTING MARK
 V53M
 R1 - BLANK
 R2 - BLANK
 R3 - BLANK

ENTER

SAC_{DP} ← MRKBUP1+3_{DP}
 PAC_{DP} ← MRKBUP1+3_{DP}

INHINT

USING MARKSTAT AS AN INDEX
 STORE THE FOLLOWING IN
 VAC AREA
 VAC+0 ← TIME_{DP}
 VAC+2 ← CDUY
 VAC+3 ← SAC
 VAC+4 ← CDUZ
 VAC+5 ← PAC
 VAC+6 ← CDUX

STORE COU ANGLES (ACTUAL) AND MANUALLY INSERTED
 OPTICAL ANGLES OF NDUN 92

RELINT

CLEARMRK
 ENABLE
 EXTENDED VERBS
 FC-2130

CLEAR EXTVBACT
 NO SPECIAL MARK INFORMATION

RECYCLE

GOOPERF3
 V50N25

REQUEST PLEASE PERFORM TERMINATION OF THIS ROUTINE
 V50N25
 R1 = 00016
 R2 = BLANK
 R3 = BLANK

PROCEED

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		SPOLE GUIDANCE AND NAVIGATION R56, R53, R56	
DRAWN: G. J. [Signature] PREPARED: [Signature] AMAS ST: DISCOM: [Signature] APPROVED: [Signature]	14-00000 1200 12-20-64 12-20-64	COLOSSUS IIC	DESIGN RE. NO. FC-2730 SHEET 14 OF 18

FROM PRECEDING SHEET



MPS INSTRUMENTATION LAB CAMBRIDGE, MASS	
DRAWN A.C. WILLIAMS	SPERLO
FROM <i>H. Vincent</i>	7/6/69
REVISED	
DATE	
APPROVED <i>G.S. VALLY 2/7/69</i>	
<i>for 1/2/69 755661</i>	

REVISIONS R52, R55, R56
COLOSSUS II C
FC-2730
REV. 2
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
CALCSA	FC-2250	COMPUTE THE SEXTANT SHAFT AND TRUNNION ANGLES	SH. 7
LALOTRV	FC-2280	CONVERT LAT, LONG TO RADIUS VECTOR	SH. 8
LEMCONIC	FC-2290	INTEGRATE STATE VECTOR	SH. 8
CSMCONIC	FC-2290	INTEGRATE STATE VECTOR	SH. 8, 9
LOADTIME	FC-2100	LOAD COMPUTER CLOCK	SH. 9
RP-TO-R	FC-2283	CONVERT RP TO R	SH. 9
SXTMARK	FC-2240	RESERVE VAC AREA AND SCHEDULE MKVB51 JOB	SH. 11, 14
OPTSTALL	FC-2210	WAIT FOR MARK TO FINISH	SH. 11
CHECKMM	FC-2030	CHECK MODREG	SH. 11
SXTNB	FC-2250	CONVERT TO UNIT VECTOR	SH. 13
NBSM	FC-2270	NAV BASE TO STABLE MEMBER	SH. 13

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION R52, R53, R56	
DRAWN <i>[Signature]</i>	BY <i>[Signature]</i>	COLOSSUS II G	DOCUMENT NO. FC-2730
PROG. E. THORNTON	TESTED <i>[Signature]</i>		SHEET 16 OF 15
ANALYST	DATE 2-2-69	APP'D <i>[Signature]</i>	REV D

FLAGS					
NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
ADVTRK	ADVANCE GROUND TRACK WANTED	NOT A DVANCED 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
TERMINFLG	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
V01N71	FLASHING	PROLARM - TARGET OUT OF VIEW - 404	SH. 3
		ALARM - AUTO OPTICS REQUEST TRUN ANGLE - 407	SH. 3
		CURTAINS - ALARM 217	SH. 11
V53	PLEASE PERFORM	RESPONSE AND DISPLAY OF CELESTIAL BODY CODE	SH. 12
		R1 - CELESTIAL BODY CODE	
		R2 - BLANK	
		R3 - BLANK	
V06N94	FLASHING	PLEASE PERFORM ALTERNATE LOS SIGHTING MARK	SH. 14
		R1 - BLANK	
		R2 - BLANK	
		R3 - BLANK	
V50N25	PLEASE PERFORM	R1 - CDUS - SNAFT	SH. 14
		R2 - CDUT - TRUNNION	
		R3 - BLANK	
		PLEASE PERFORM TERMINATION OF THIS ROUTINE	SH. 14
		R1 - 00016	
		R2 - BLANK	
		R3 - BLANK	

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION R52, R53, R56	
DRAWN <i>J. H. Chandler</i>	DESIGNED <i>J. H. Chandler</i>	CHECKED <i>J. H. Chandler</i>	APPROVED <i>J. H. Chandler</i>
ANALYST <i>J. H. Chandler</i>	DATE 12-7-68	PROJECT COLOSSUS IIC	FC-2730
APPROVED <i>J. H. Chandler</i>	DATE 12-7-68	REV. 2	17 18

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
CDUT		OPTICS TRUNNION ANGLE	DEGREES	REVS	2 ⁻⁵
COUS		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
ALPHA _V		RADIUS VECTOR	M	M	2 ²⁹
LANDMARK		NO OF REVOLUTIONS			
AOPTIME		TEMPORARY			
STAR _V		TEMPORARY			
STARIND		STAR INDICATOR			
TDECI _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
36TRDEG		50° TO 65° ANGLE CHECK	60 DEGS	.16866667 REV	2 ⁻²
20DEGSMN		85° TO 90° ANGLE CHECK	-36 DEGS	-.1098 REV	2 ⁻²
MPERIOD		LINEAR ANGULAR ROTATION IN 2 HOURS	1.071432 DEGS	.0029762 REV	2 ⁻⁴
DPI/6		1/6 REVOLUTION = 80°	60 DEGS	.16866666 REV	2 ⁰

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		AFOLD GUIDANCE AND NAVIGATION R5Z, R5D, R5G	
DRAWN: <i>[Signature]</i>	STAMP: <i>[Stamp]</i>	COLUSSUS ID: <i>[Stamp]</i>	BOOK NO: <i>[Stamp]</i>
FROM: <i>[Stamp]</i>	ANALYST: <i>[Stamp]</i>	ROOM: <i>[Stamp]</i>	DATE: 18 3 18
APPROV: <i>[Signature]</i>	DATE: 2-7-67	REV: 2	

160'S - ENTRY PROGRAMS

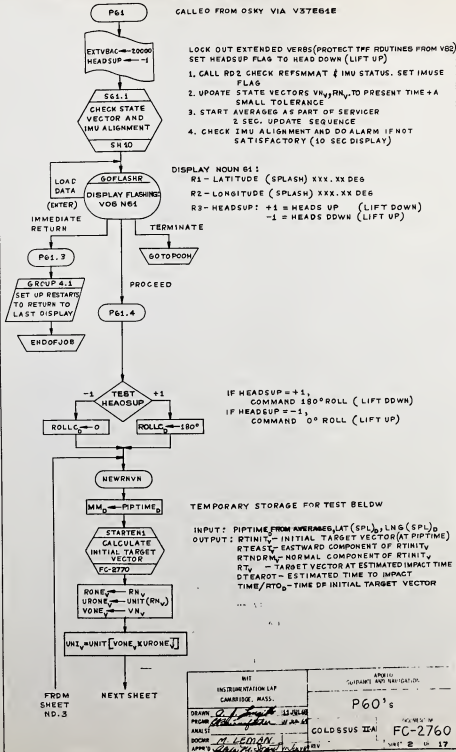
1701	MANUEVER TO CM SM SEPARATION ATTITUDE	SH. 2
1702	CM SM SEPARATION AND PRE-ENTRY MANUEVER	SH. 4
WAKEUP02	SCHEDULE 1703	SH. 5
03	ENTRY INITIALIZATION	SH. 6
1704	POST .05G ENTRY MODE	SH. 6
1705	CP CONTROL ENTRY MODE	SH. 7
1706	BALLISTIC ENTRY MODE	SH. 8
1707	FINAL ENTRY MODE	SH. 8
1707.1	FINAL ENTRY DISPLAY (N67)	SH. 9
1707.2	CALCULATION FOR N67 DISPLAY	SH. 9
S61.1	CHECK FOR PROPER IMU ALIGNMENT AND ENSURE THAT AVERAGE IS STARTED	SH. 10
S61.1C	START AVERAGE	SH. 11
S61.1A	CHECK ENTRY IMU ALIGNMENT	SH. 11
S61.2	CALCULATION FOR N60, N68 DISPLAYS	SH. 12
1881TARG	RANGE ESTIMATOR	SH. 16
P62.3	COMPUTE DESIRED ENTRY ATTITUDE	SH. 17

160'S

P.M. Dick
M. L. E. MAN
 11/22/69

COLOSSUS II A FC-227C0

P61: MANEUVER TO CM/SM SEPARATION ATTITUDE



WIT INSTRUMENTATION LAP CAMBRIDGE, MASS.	APPROV SUPPLIES AND REVISIONS P60's GOLDSSUS IZAI FC-2760 WIT 2 IN 17
DRAWN <i>D. J. Smith</i> 11-26-68 PLOTTED <i>John</i> 11-26-68 ANALYST DOCUMENT <i>M. LEONAN</i> APPROV <i>John</i>	FC-2760

TO SHEET NO. 2 FROM PRECEDING SHEET

DUMPP61

YES $MM_0 < PIPTIME_0$?

IF PIPTIME HAS BEEN UPDATED, IT MEANS THAT AVERAGE HAS RUN 50 ABOVE CALCULATIONS ARE INVALID AND MUST BE REDONE USING NEW STATE VECTOR

S61.2
DATA FOR
NOUNG 60, 63
SH 42

INPUT: $RONE_{V_1}$, $VONE_{V_1}$, $URONE_{V_1}$, UN_{V_1} , $UNITW_{V_1}$, $EMEA_{LT}$
OUTPUT: $GMAX$ = MAXIMUM PREDICTED DECELERATION DURING ENTRY (IN g's)
 $VPRED$ = PREDICTED INERTIAL VELOCITY AT 400,000 FT
 $GAMMAET$ = PREDICTED FLIGHT PATH ANGLE (γ) AT 400,000 FT
 $RTGO_0$ = RANGE FROM EMS ALTITUDE TO SPLASH
 VIO = PREDICTED INERTIAL VELOCITY AT EMS ALTITUDE
 TTE = TIME TO GO FROM PRESENT POSITION TO EMS ALTITUDE
(EMS ALTITUDE = ALTITUDE AT .05g G. VALUE = 284,643 FT ORBITAL ENTRY = 297,431 FT LUNAR ENTRY)
R1: XXX.XXG ($GMAX$)
R2: XXXXX.FT/SEC (VIO)
R3: XXX.XX DEG ($GAMMAET$)

P61.1
CLEARMRK
ENABLE
EXTENDED VERB6
(EXTVBAC ← 0)
FC=2130

GOFLASH
DISPLAY FLASHING
VOG N60
RECYCLE
PROCEED

(N60 (N63 ARE UNMOLESTED UNTIL P64)
TERMINATE
GOTOPOOH

P61.2
LOADTIME
LOAD CURRENT
TIME INTO MPAC₀
FC=2100

CORRECT TTE FOR TIME USED SINCE CALCULATION. (MM_0 = TIME OF AVERAGE WHEN $RONE_0$ AND $VONE_0$ WERE SAVED. BOTH TTE & TTE1 ARE NEGATIVE)

$TTE_0 = TTE1 + (MPAC_0 - MM_0)$
GOFLASH
DISPLAY FLASHING
VOG N63
RECYCLE
PROCEED

NOTE: V3RE "MAY BE USED TO UPDATE TTE ON DEMAND.

R1: XXXX.X NM (RTGO)
R2: XXXXX.FT/SEC (VIO)
R3: XX-XX MIN, SEC (TTE)

NEWMODEX
DISPLAY
MAJOR MODE 62
FC=2030

CHANGE MAJOR MODE TO P62, AND FALL INTO P62

SET UP DOWN-
LINK FOR
ENTRY DOWN-
LIST

DNLSTCOD ← 1

NEXT SHEET

WIT
WATERGATE LAR
CAMBRIDGE, MASS.
DRAWN BY: *[Signature]* 11 JUL 68
PROJECT: *[Signature]*
CHECKED BY: *[Signature]*
APPROVED BY: *[Signature]*

APPROVED AND SIGNED
P60's

COLOSSUS IIIA FC-2760

3 17

FROM PRECEDING SHEET

FLOW IN FROM P61 OR BY DSKY REQUEST

P62

CM/SM SEPARATION AND PRE-ENTRY MANEUVER

[IF ENTERED VIA DSKY, START AVERAGE ALSO]

S61.1
ENTER STATE
VELOCITY AND
IMPA. TEXT
SH 10

POSEXIT ← CADR (P62.3)

SET CM/POSE EXIT ADDRESS TO CALCULATE DESIRED .05g
GIMBAL ANGLES, BUT WITHOUT DISPLAY VIA ENTRYV.

CM/DAPIC
START ENTRY
DAP IN
IDLE MODE
PC2700

START CALCULATIONS OF BODY RATES
FOR ENTRY OAP
DISABLE ENTRY DISPLAY: ENTRYDSP FLAG CLEARED

P62.2

PUT CM/POSE IN SERVICER 2 SEC. UPDATE SEQUENCE
FOR CALCULATION OF BODY ATTITUDE
FOLLOWING AVERAGE ROUTINE. REMAINS ACTIVE UNTIL
END OF ENTRY.

AVERAGEEXIT + 2CADR (CM/POSE)

ENTER
GOPERFIR
DISPLAY FLASHING
VSON25
CHECKLIST 41

IMMEDIATE RETURN

P61.3

GROUP 4.1
RESTART
AT LAST
DISPLAY

R1 = 00041 (CM-SM
SEPARATION
R2 }
R3 } BLANK REQUEST)

TERMINATE
SO TO POOH

PROCEED
CM/DAPON
SWITCHOVER
TO ENTRY
DAP
PC 2790

DISABLE RCS DAP
SET NODOFLAG TO INHIBIT FURTHER V37'S
ENABLE ENTRY DAP
DO ATTITUDE HOLD, BEGINNING AFTER FIRST CM/POSE UPDATE

P62.1

(BEYOND THIS POINT, "TERMINATE" WILL NOT TERMINATE
THE ENTRY SEQUENCE. TO UNCONDITIONALLY CANCEL
THE P60'S, V37E OOE MUST BE USED)

LOAD DATA

GOFLASH
DISPLAY
FLASHING
VOGNB1

R1 - LATITUDE OF SPLASHPPOINT XXX.XX DEG
R2 - LONGITUDE OF SPLASHPPOINT XXX.XX DEG
R3 - HEADSUP: +1 = UP, -1 = DOWN ± 0000X
(UP = LIFT DOWN, AND VICE VERSA)

TERMINATE

ENTER
PROCEED
GROUP 4
SET UP RESTARTS
TO SCHEDULE NEXT
LOCATION AS A JOB WITH
OLD PRIORITY

TEST
HEADSUP

-1
ROLL ← 0°

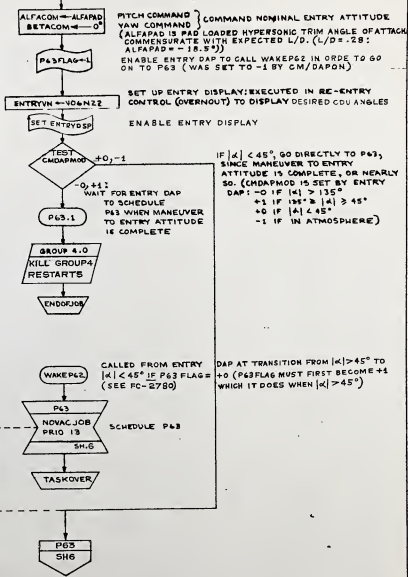
+1
ROLL ← 180°

COMMAND APPROPRIATE ENTRY DAP ROLL
ANGLE FOR CONFIGURATION REQUESTED
IF HEADSUP = +1, ROLL = 180° (LIFT DOWN)
IF HEADSUP = -1, ROLL = 0° (LIFT UP)

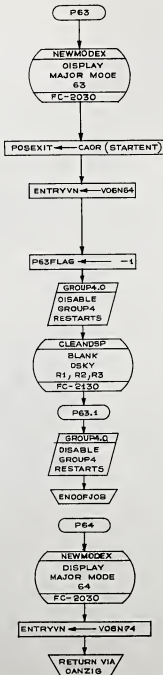
NEXT
SHEET

INT INSTRUMENTATION LAB CONNECTIONS, SIGNALS		APPLS ORIGIN AND DIVISION	
		P60's	
NAME	DATE	COLOSSUS IIA	RECORD NO.
NO. 1	12/14/60		FC-2760
NO. 2			
NO. 3			
NO. 4			
NO. 5			
NO. 6			
NO. 7			
NO. 8			
NO. 9			
NO. 10			

FROM PRECEDING PAGE



INT INTEGRATION LAB CAMBRIDGE, MASS.		AFIELD SURVIVAL AND NAVIGATION	
		P60's	
DESIGNER <i>C. J. ...</i>	PLANNED BY <i>...</i>	COLLOSSUS ID#	DOCUMENT NO. FC-2760
ANALYST <i>M. ...</i>	DATE <i>...</i>		
ISSUED ON	REVISED		SHEET 5 OF 7



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
CAOR (SCALEPOP) FOR SUBSEQUENT PASSES)
(STARTENT OMTS OISPLAY)

SET UP ENTRY OISPLAY EXECUTED IN RE-ENTRY
CONTROL (OVERNOUT) TO OISPLAY NOUN 64 EACH
2 SEC :

R1 - XXX.XX G DRAG ACCELERATION
R2 - XXXXX FPS VELOCITY
R3 - XXXXX NM OISTANCE 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 GROUP4 - OISPLAY IS RESTARTED
IN RE-ENTRY CONTROL (GROUPS)

REMOVE VOEN22, IF PRESENT. P63 OISPLAY
BEGINS ON SECOND PASS THRU ENTRY STEERING

DISABLE GROUP4 - OISPLAY IS RESTARTED
IN RE-ENTRY CONTROL (GROUPS)

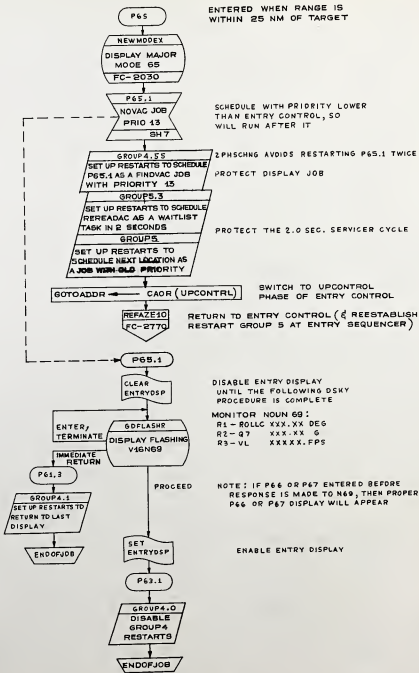
CALLED FROM RE-ENTRY CONTROL WHEN
.05 G IS INITIALLY EXCEEDD

MAJOR MODE DISPLAY P64

SET UP ENTRY DISPLAY EXECUTED IN RE-ENTRY
CONTROL (OVERNOUT) TO OISPLAY NOUN 74 EACH
2 SEC :

R1 - XXX.XX DEG ROLL COMMAND (ROLLC)
R2 - XXXXX FPS VELOCITY (VMAGI)
R3 - XXXXX G DRAG (O)
(NOUN 68 OISPLAY MAY STILL BE CALLED UP)

MIT		AND US	
INSTRUMENTATION LAB		GUIDANCE AND NAVIGATION	
CAMBRIDGE, MASS		P60'S	
DRAWN <i>[Signature]</i> MAY 60 CHECKED <i>[Signature]</i> JUNE 60 ANALYST SOLWR <i>[Signature]</i> APPROV <i>[Signature]</i>	COLUSSUB A FC-2760 MAY 16 1960	SOLUTION NO.	2760

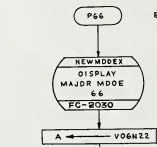


9. 11/11/68
 M. LEHMAN
 7 47

P60's

COLOSSUS II-A FC-2760

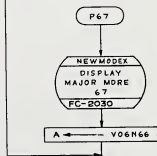
7 47



ENTERED WHEN DRAG < QT

SET UP ENTRY DISPLAY TO DISPLAY DESIRED GIMBAL ANGLES (NOUN 22)

R1-XXX.XX DEG
R2-XXX.XX DEG
R3-XXX.XX DEG



CALLED FROM RE-ENTRY CONTROL WHEN FINAL PHASE TRAJECTORY IS ENTERED (WHEN DRAG LEVEL EXCEEDS D.2 g)

SET UP ENTRY DISPLAY EXECUTED IN RE-ENTRY CONTROL (OVERNDUT) TO DISPLAY NOUN 66:

R1-XXX.XX DEG ROLL COMMAND (ROLL C)
R2-XXXX.X NM CRDSE-RANGE ERROR
R3-XXXX.X NM DOWN-RANGE ERROR



ENABLE ENTRY DISPLAYS IN CASE CAME FROM P67. (N69 IF STILL ACTIVE, WILL BE REPLACED BY CURRENT DISPLAY NOUN)

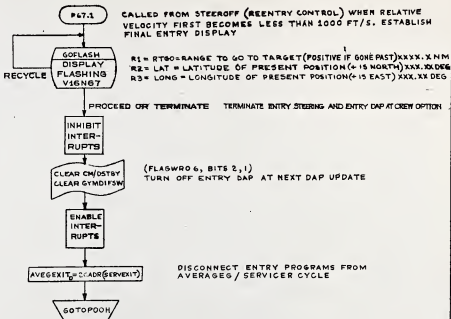


DISABLE GRP4 IN CASE COME FROM HUNTEST (SIDETRACKED ITERATION) OR FROM P65 (FLASHING DISPLAY)

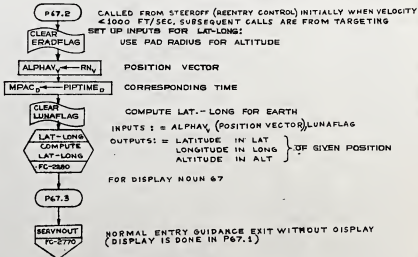


RETURN TO CALLER IN INTERPRETIVE

TITLE INSTRUMENTATION-143 1-ANALYSIS, CLASS	P60's COLLOSSUS IIA FC-2760
DRAWN <i>D. J. Smith</i> FROM <i>W. Smith</i> CHECKED <i>M. LEMAN</i> APPROVED <i>W. Smith</i>	10 SEP 68 B 17



CALCULATION FOR FINAL DISPLAY, N67



MIT MEMORANDUM FOR OPERATIONS, BASE.		APOLLO GUIDANCE AND NAVIGATION	
DATE: 17 4 1968		P60's	
FROM: [Signature]		COLLOSSUS II-A	
SUBJECT: LUNAR		FC-2770	
[Signature]		NOV 9 1967	



ASSURE THAT AVERAGE6 IS OPERATING AND CHECK THAT IMU IS ALIGNED PROPERLY FOR ENTRY

SETS IMUSE FLAG TO PREVENT ZEROING IMU CDUS BY A RESTART POSSIBLE PROG ALARM, WITH ALARM CODE 00210 (IMU NOT ON) OR 00220 (IMU NOT ORIENTATION NOT KNOWN IE, NO REF5MMAT)

FLAG SET OR RESET IN SERVERIC

IF AVERAGE6 ON, SKIP START-UP SEQUENCE

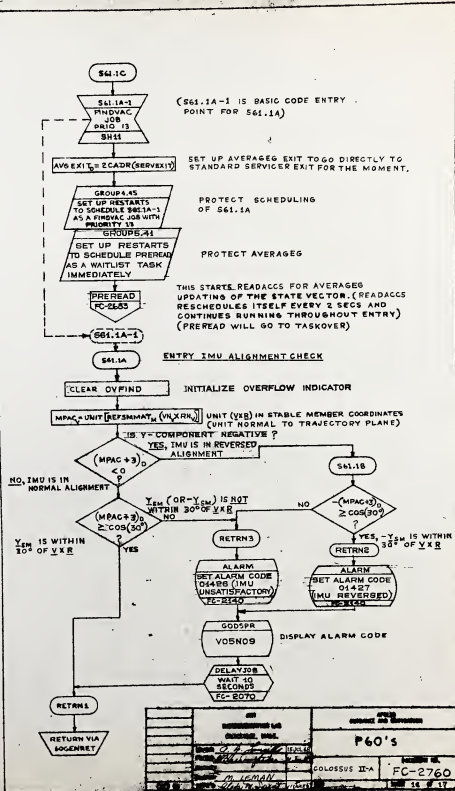
PRECISION INTEGRATION OF STATE VECTOR

OUTPUTS:
 RN1, VN1 : STATE VECTOR IN FUTURE BY AMOUNT OF TOLERANCE
 PIPTIME1 : TIME OF RN1, VN1
 MPAC_{dp} : Δ TIME, CURRENT TIME TO PIPTIME1

(SAVE FOR RESTART PROTECTION RELATIVE TO TBASE6)

SCHEDULE S61.1C TO BEGIN AT THE START OF AVERAGE6 TO ESTABLISH PREREAD

UNIT INSTRUMENTATION LAB CAMBRIDGE MASS.	PROJECT NO. 100 P60's COLOSSUS II-A FC-2760 10 10 67
DESIGN <i>A. J. Long</i> PROGRAM <i>Richard Fisher</i> ANALYST OPERATOR <i>M. LERMAN</i> APPROVED <i>Alvin S. ...</i>	10-10-67 FC-2760



(S61.1A-1 IS BASIC CODE ENTRY POINT FOR S61.1A)

SET UP AVERAGE EXIT TO GO DIRECTLY TO STANDARD SERVICER EXIT FOR THE MOMENT.

PROTECT SCHEDULING OF S61.1A

PROTECT AVERAGES

THIS STARTS READACCS FOR AVERAGES UPDATING OF THE STATE VECTOR. (READACCS RESCHEDULES ITSELF EVERY 2 SECS AND CONTINUES RUNNING THROUGHOUT ENTRY) (PREREAD WILL GO TO TASKOVER)

ENTRY IMU ALIGNMENT CHECK

INITIALIZE OVERFLOW INDICATOR

UNIT (YXR) IN STABLE MEMBER COORDINATES (UNIT NORMAL TO TRAJECTORY PLANE)

IS Y - COMPONENT NEGATIVE ?
YES, IMU IS IN REVERSED ALIGNMENT

NO, IMU IS IN NORMAL ALIGNMENT

Y_{EM} (OR -Y_{EM}) IS NOT WITHIN 30° OF Y X R

-(MPAC+3) ≥ COS(30°)

Y_{EM} IS WITHIN 10⁴ OF Y X R

YES, -Y_{EM} IS WITHIN 30° OF Y X R

RETRN3

RETRNE

ALARM
SET ALARM CODE
05498 (IMU UNSATISFACTORY)
FC-2070

ALARM
SET ALARM CODE
01427
(IMU REVERSED)
FC-2070

GODSPR
VOSNOS
DISPLAY ALARM CODE

DELAYJOB

WAIT 40 SECONDS

FC-2070

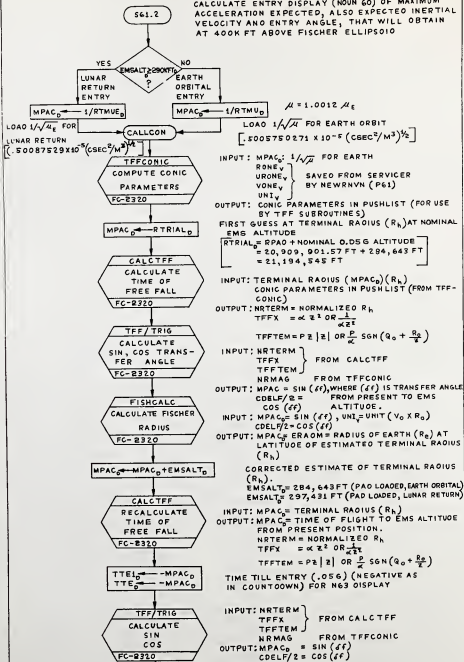
RETRNL

RETURN VIA SOGNET

OPERATOR'S NAME [Blank]		OPERATOR'S GRADE [Blank]	
OPERATOR'S SIGNATURE [Blank]		OPERATOR'S SIGNATURE [Blank]	
OPERATOR'S NAME M. LEMAN		OPERATOR'S GRADE COLLOSSUS II-A	
OPERATOR'S SIGNATURE [Blank]		OPERATOR'S SIGNATURE [Blank]	
OPERATOR'S NAME [Blank]		OPERATOR'S GRADE P60's	
OPERATOR'S SIGNATURE [Blank]		OPERATOR'S SIGNATURE [Blank]	
OPERATOR'S NAME [Blank]		OPERATOR'S GRADE FC-2760	
OPERATOR'S SIGNATURE [Blank]		OPERATOR'S SIGNATURE [Blank]	

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



$\mu = 1.0012 \mu_E$

LOAD $1/\sqrt{\mu_E}$ FOR LUNAR RETURN
[.50087529X10⁻⁵(CGEC²/M)^{3/2}]

LOAD $1/\sqrt{\mu}$ FOR EARTH ORBIT
[.8005750271 X 10⁻⁵ (CGEC²/M)^{3/2}]

INPUT: MPAC₀: $1/\sqrt{\mu}$ FOR EARTH
RONE_v
URONE_v
VONE_v
UN_v
} SAVED FROM SERVICER BY NEWRVN (P61)

OUTPUT: CONIC PARAMETERS IN PUSHLIST (FOR USE BY TFF SUBROUTINES)

FIRST GUESS AT TERMINAL RADIUS (R_h) AT NOMINAL EMS ALTITUDE
[RTrial₀ = RPA0 + NOMINAL 0.05 G ALTITUDE
= 20,909,901.57 FT + 294,643 FT
= 21,194,545 FT]

INPUT: TERMINAL RADIUS (MPAC₀)(R_h)
CONIC PARAMETERS IN PUSHLIST (FROM TFFCONIC)

OUTPUT: NRTERM = NORMALIZED R_h
TFFX = αZ^2 OR $\frac{1}{\alpha Z^2}$
TFFTEM = $PZ |Z|$ OR $\frac{P}{\alpha} \text{SGN}(Q_0 + \frac{Q_0}{Z})$

INPUT: NRTERM
TFFX
TFFTEM
NRMAG } FROM CALCTFF

OUTPUT: MPAC = SIN(θ), WHERE (θ) IS TRANSFER ANGLE
CDELFF/2 = FROM PRESENT TO EMS ALTITUDE.

INPUT: MPAC₀ = SIN(θ), UN_v = UNIT (V₀ X R₀)
CDELFF/2 = COS(θ)

OUTPUT: MPAC₀ ERAOM = RADIUS OF EARTH (R_e) AT LATITUDE OF ESTIMATED TERMINAL RADIUS (R_h)
CORRECTED ESTIMATE OF TERMINAL RADIUS (R_h).
EMSA LT₀ = 284,643 FT (PAD LOADED, EARTH ORBITAL)
EMSA LT₀ = 297,431 FT (PAD LOADED, LUNAR RETURN)

INPUT: MPAC₀ = TERMINAL RADIUS (R_h)
OUTPUT: MPAC₀ = TIME OF FLIGHT TO EMS ALTITUDE FROM PRESENT POSITION.
NRTERM = NORMALIZED R_h
TFFX = αZ^2 OR $\frac{1}{\alpha Z^2}$
TFFTEM = $PZ |Z|$ OR $\frac{P}{\alpha} \text{SGN}(Q_0 + \frac{Q_0}{Z})$

TIME TILL ENTRY (.05G) (NEGATIVE AS IN COUNTDOWN) FOR N63 DISPLAY

INPUT: NRTERM
TFFX
TFFTEM
NRMAG } FROM CALCTFF

OUTPUT: MPAC₀ = SIN(θ)
CDELFF/2 = COS(θ)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DATE: 23 SEP 68

PROJECT: P60's

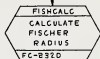
DESIGNER: M. LEMAN

ANALYST: COLLOSSUS II-A

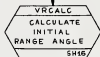
FC-2760

REV: 12

FROM
PRECEEDING SHEET



INPUT: $\sin(\delta_f)$, $\cos(\delta_f)$, UNI_V
OUTPUT: URH_V , UNIT RADIUS VECTOR AT .05g POINT
ERADM, FISCHER RADIUS AS LATITUDE OF
ESTIMATED .05g POINT



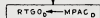
INPUT: URH_V
 RT_V UNIT VECTOR AT IMPACT POINT
OUTPUT: $MPAC_D$ RANGE ANGLE IN REVOLUTIONS



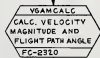
INPUT: $MPAC_D$ RANGE ANGLE
 $RTINIT_V$, $RTEAST_V$, $RTNORM_V$
OUTPUT: RT_V
 $MPAC_D$ RANGE ANGLE, UPDATED



OUTPUT: $MPAC_D$ RANGE ANGLE



RANGE ANGLE FROM EMS ALTITUDE TO SPLASH
FOR N63 DISPLAY



INPUT: NRTERM (FROM CALCTFF)
CONIC PARAMETERS IN PUSHLIST FROM
TFCONIC
OUTPUT: $VELO_D$ TERMINAL VELOCITY (V_t)
 $MPAC_D$ FLIGHT PATH ANGLE (δ_e) (RELATIVE
TO HORIZONTAL)

$$V_{EMS} = V_h + \frac{-1,510,000}{V_h \cdot \delta_e}$$
$$VIC_D \leftarrow PLO_D + \frac{VEMSGON_D}{PLO_D \cdot MPAC_D}$$

PREDICTED INERTIAL VELOCITY AT EMS
ALTITUDE FOR N63 DISPLAY (COMPENSATED
TO ACCOUNT FOR ATMOSPHERIC DRAG)

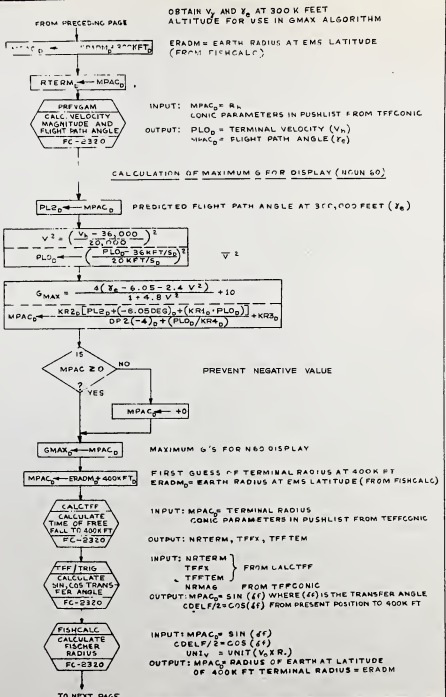
NEXT SHEET

TRAIN *O. J. Smith* 23 SEP 68
PERIOD *23 SEP 68*
APPROVED *Billie West* 23 SEP 68

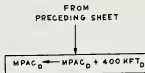
P60's

COLOSSUS II-A FC-2760

13 17



INT INSTRUMENTATION LAB CAMBRIDGE, MASS.		SPREAD SCHEDULE AND NOTIFICATION	
APPROV BY DATE		P60's	
APPROV BY DATE		COLOSSUS IIA	DOCUMENT NO. FC-2760
USED ON	APPROV BY DATE	PAGE 14 OF 17	



CORRECTED ESTIMATE OF
RADIUS AT 400KFT



SAVE RANGE ANGLE FROM EMS
ATTITUDE (HIGH ORER HALF)
FOR DOWNLINK



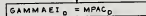
INPUT: $MPAC_0$ = TERMINAL RADIUS CONIC
PARAMETERS IN PUSHLIST
FROM TFFCONIC
OUTPUT: $MPAC_0$ = FLIGHT PATH ANGLE AT
400KFT (θ_0)
 $POLO_0$ = VELOCITY 400KFT (V_h)



GAMMAEI IS NEGATIVE FOR ENTRY



FROM PACKED WORD FOR DOWNLINK:
PUT RTGO (HI-WORD) INTO LO-WORD OF
GAMMAEI



FLIGHT PATH ANGLE AT 400KFT FOR
N60.
DOWN-LINK QUANTITY:
HIGH-WORD = θ_0
LOW-WORD = RANGE TO GO



CONIC VELOCITY AT 400KFT
FOR NOUN 60 DISPLAY



NOTE: EFFECT OF RTGO IN LO-WORD OF
GAMMAEI ON OSKY IS NEGLIGIBLE
($\approx .005^\circ \text{ DEG}$)

REF: 07/19/68
ANALYST: M. LEMAR
APPROVED: [Signature]

DATE: 7/19/68

P60's

COLOSSUS IIA FC-2760

15 17

DISPTARG

RANGE ESTIMATOR

SAVE QPRET
IN
60GENRET $C(MPAC_0)$ = RANGE ANGLE ESTIMATEDTEARCT = $K T_{01} \theta + t_{ff}$
DTEARCT₀ ← $K T_{01} MPAC_0 T_{TEI_0}$ $K T_{01} = 1100$ $T_{TE} = -t_{ff} = -(\text{TIME OF FREE FALL})$ ERRORT2
LOGATE PREDICTED
IMPACT POINT
FC-2250INPUT: DTEARCT₀ (ESTIMATED FLIGHT TIME)
DTINIT_v, RTEAT_v, RTNORM_v, TIME/RT₀
OUTPUT: RT_v, PREDICTED TARGET VECTORVRCALC
CALCULATE
RANGE ANGLE
SM16INPUT: URH_v, RT_v
OUTPUT: MPAC₀, RANGE ANGLE IN
REVOLUTIONSRETURN VIA
60GENRET

VRCALC

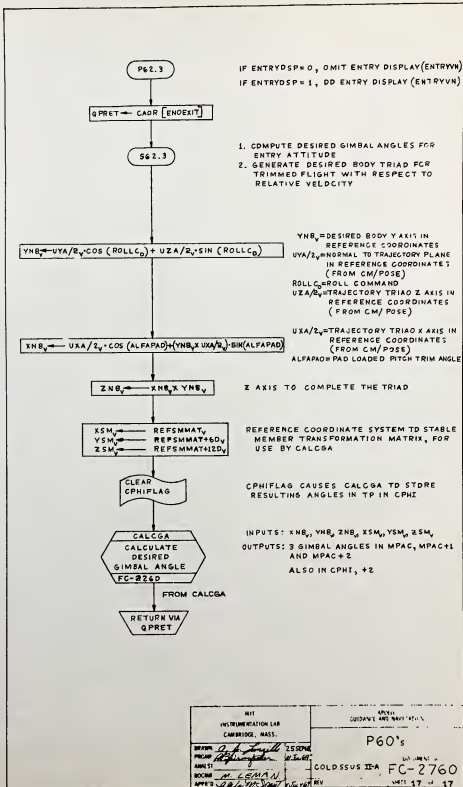
 $\theta = \cos^{-1} \left[\frac{UR_H \cdot RT}{|UR_H \cdot RT|} \right]$
 $MPAC_0 = \text{ARCCOS} \left[\frac{UR_H \cdot RT_V}{|UR_H \cdot RT_V|} \right]$ INPUT: URH (UNIT RADIUS AT .05g POINT)
RT (UNIT TARGET VECTOR)
OUTPUT: MPAC₀, RANGE ANGLE IN
REVOLUTIONSRETURN VIA
QPRET

DATE	10/10/68
TIME	10:00
UNIT	INSTRUMENTATION LAB
OPERATOR	CAMBRIDGE MASS
PROJECT	Q ₂ & J ₂ Small
ANALYST	W. J. Sasse
DIAGRAM	M. L. L. L.
APPROVED	W. J. Sasse

P60's

COLOSSUS II-A FC-2760

16 17



INDEX - SECTION 17.0

ACCOMP	FC-2300 ORB INTEGRATION	ENTRY	9		
ACROLL	FC-2400 RCS DAP JET SELECT	ENTRY	5		
ACTIVE	FC-2626 P32, P72 - CSI	CALLED	16		
ACTIVE	FC-2627 P33, P73 - CDH	CALLED	2		
ACTLIM	FC-2440 TVC DAP	ENTRY	16		
ADVANCE	FC-2626 P32, P72 - CSI	ENTRY	9		
ADVANCE	FC-2627 P33, P73 - CDH	CALLED	2		
ADVDRB	FC-2730 R52, R53, R56	ENTRY	5		
ADVDRB	FC-2590 P22 ORBITAL NAV	CALLED	7		
ADVTRK	FC-2730 R52, R53, R56	S-5		C-2	T-R
AGAIN	FC-2680 THRUST PROGRAMS	ENTRY	38		
AGAIN	FC-2620 P30, P31	CALLED	7		
AHFNDROT	FC-2390 RCS DAP PHASE 2	ENTRY	4		
ALARM	FC-2020 FRESH START	CALLED	20,32		
ALARM	FC-2140 ALARM AND ABORT	ENTRY	3		
ALARM	FC-2200 T4RUPT	CALLED	6,15,16,29,32,33,41,42		
ALARM	FC-2627 P33, P73 - CDH	CALLED	3		
ALARM	FC-2682 STEERING	CALLED	10		
ALARM	FC-2683 SERVICER	CALLED	13		
ALARM	FC-2760 ENTRY PROGRAMS	CALLED	11		
ALARM2	FC-2140 ALARM AND ABORT	ENTRY	3		
ALARUMS	FC-2545 TPI SEARCH PROG	ENTRY	13		
ALFLT	FC-2530 PRELAUNCH INIT	ENTRY	16		
ALFLT1	FC-2530 PRELAUNCH INIT	ENTRY	16		
ALLOOP	FC-2530 PRELAUNCH INIT	ENTRY	15		
ALM/END	FC-2450 STROKE TEST PKG	CALLED	1		
ALMXITA	FC-2626 P32, P72 - CSI	ENTRY	22		
ALM-END	FC-2605 NAV EXTENDED VERBS	CALLED	2,6		
ALWAYS	FC-2530 PRELAUNCH INIT	ENTRY	20		

AMRGUPDT FC-2370 DAP INTER-SERV ROUT	ENTRY 17		
AMRGUPDT FC-2380 RCS DAP INIT	CALLED 4,8		
AMRGUPDT FC-2460 ROLL AUTOPILOT	CALLED 8		
AM00NFLG FC-2290 INTEG INITIAL	S-20	C-20	T-17,18
AM00NFLG FC-2540 EARTH ORBIT INSERT			T-18
AM00NFLG FC-2650 ORB PARAM DISPLAY			T-8,11
APSESW FC-2310 CONIC SUBROUTINES	S-24	C-24	
APSIDES FC-2310 CONIC SUBROUTINES	ENTRY 38		
ASTNFLAG FC-2680 THRUST PROGRAMS			T-20
ASTNFLAG FC-2681 CLOKTASK- CLOKJOB	S-6	C-13	T-6
ATERJOB FC-2540 EARTH ORBIT INSERT	ENTRY 10		
ATOPCSM FC-2290 INTEG INITIAL	ENTRY 5		
ATOPCSM FC-2300 ORB INTEGRATION	CALLED 33,38		
ATOPLEM FC-2290 INTEG INITIAL	ENTRY 5		
ATOPLEM FC-2300 ORB INTEGRATION	CALLED 33,38		
ATOPOTH FC-2670 TARGET DELTA V PROG	CALLED 4		
ATTCHFLG FC-2370 DAP INTER-SERV ROUT	S-8	C-8	
AUGKUGL FC-2320 TFFCONICS	ENTRY 15		
AUGKUGL FC-2642 RETURN TO EARTH	CALLED 31		
AVAFLAG FC-2644 P38-P78; P39-P79	CALLED 3,9		
AVEGFLAG FC-2650 ORB PARAM DISPLAY			T-3,4
AVEGFLAG FC-2683 SERVICER	S-3		T-7
AVEGFLAG FC-2760 ENTRY PROGRAMS			T-10
AVEMIDSW FC-2290 INTEG INITIAL	S-16		
AVETOMID FC-2290 INTEG INITIAL	ENTRY 16		
AVETOMID FC-2683 SERVICER	CALLED 19		
AVFLAG FC-2545 TPI SEARCH PROG	S-4	C-4	T-3,4,8
AVFLAG FC-2620 P30, P31	S-8		
AVFLAG FC-2626 P32, P72 - CSI	S-2	C-2	

AVFLAG	FC-2627 P33, P73 - CDH	S-1	C-1	
AVFLAG	FC-2630 TPI TARGETTING	S-2	C-2	
AVFLAG	FC-2640 TPM TARGETTING	S-1	C-1	
AVFLAG	FC-2644 P3R-P7R; P39-P79	S-3	C-3	T-17
AVFLAG	FC-2680 THRUST PROGRAMS	S-33,36		
AVFLAGA	FC-2545 TPI SEARCH PRDG	CALLED 3		
AVFLAGA	FC-2627 P33, P73 - CDH	CALLED 1		
AVFLAGA	FC-2630 TPI TARGETTING	CALLED 2		
AVFLAGA	FC-2640 TPM TARGETTING	CALLED 1		
AVFLAGP	FC-2545 TPI SEARCH PRDG	CALLED 3		
AVFLAGP	FC-2626 P32, P72 - CSI	ENTRY 2		
AVFLAGP	FC-2627 P33, P73 - CDH	CALLED 1		
AVFLAGP	FC-2630 TPI TARGETTING	CALLED 2		
AVFLAGP	FC-2640 TPM TARGETTING	CALLED 1		
AVFLAGP	FC-2644 P3R-P7R; P39-P79	CALLED 3,9		
AVGEND	FC-2683 SERVICER	ENTRY 19		
AVWMIDSW	FC-2300 ORB INTEGRATION		C-40	
AXISGEN	FC-2710 P51, P53 IMU ORIENT	CALLED 6		
AXISGEN	FC-2720 IMU REALIGN PROG	CALLED 20		
AZMTHCG1	FC-2530 PRELAUNCH INIT	ENTRY 34		
A-PCHK	FC-2290 INTEG INITIAL	CALLED 21		
A-PCHK	FC-2300 ORB INTEGRATION	ENTRY 38		
BADEND	FC-2550 P20 RENDEZVOUS NAV	CALLED 34		
RAILOUT	FC-2140 ALARM AND ABORT	ENTRY 3		
RAILOUT	FC-2060 WAITLIST	CALLED 13		
RAILOUT	FC-2240 SXTMARK	CALLED 1		
RAILOUT	FC-2242 OPTICS CAL ROUTINE	CALLED 2		
BANKCALL	FC-2080 INT BNK COMMUN	ENTRY 1		
BANKJUMP	FC-2080 INT BNK COMMUN	ENTRY 2		

HDF27	FC-2400 RCS DAP JET SELECT	ENTRY	11		
RDROLL	FC-2400 RCS DAP JET SELECT	ENTRY	7		
RIGTIME	FC-2310 CONIC SUBROUTINES	ENTRY	21		
BLANKET	FC-2190 PINBALL	CALLED	5		
BLANKET	FC-2242 OPTICS CAL ROUTINE	CALLED	3,4		
BLANKET	FC-2360 -S-BAND ANTENNA	CALLED	5		
BLANKET	FC-2590 P22 ORBITAL NAV	CALLED	3,6,16		
BLANKET	FC-2595 LUNAR LAND SELECT	CALLED	9		
BLANKET	FC-2600 CISELUNAR MID NAV	CALLED	12		
BLANKET	FC-2626 P32, P72 - CSI	CALLED	2		
BLANKET	FC-2720 IMU REALIGN PROG	CALLED	18		
HVECTORS	FC-2550 P20 RENDEZVOUS NAV	ENTRY	39		
HVECTORS	FC-2590 P22 ORBITAL NAV	CALLED	15		
CA+ECE	FC-2200 T4RUPT	CALLED	43		
CALCGA	FC-2720 IMU REALIGN PROG	CALLED	9		
CALCGA	FC-2760 ENTRY PROGRAMS	CALLED	17		
CALCGRAV	FC-2680 THRUST PROGRAMS	CALLED	36		
CALCGRAV	FC-2683 SERVICER	ENTRY	17		
CALCGTA	FC-2540 EARTH ORBIT INSERT	CALLED	13		
CALCGTA	FC-2720 IMU REALIGN PROG	CALLED	26		
CALCMAN2	FC-2350 MANEUV CALC & STEER	S-9		C-10	T-10
CALCMAN3	FC-2350 MANEUV CALC & STEER	S-9			
CALCNR3	FC-2700 P47 THRUST MONITOR	ENTRY	6		
CALCNR3	FC-2683 SERVICER	CALLED	15		
CALCRV6	FC-2683 SERVICER	ENTRY	16		
CALCSGA	FC-2730 R52, R53, R53	CALLED	7		
CALCSMSC	FC-2720 IMU REALIGN PROG	ENTRY	25		
CALCTFF	FC-2650 DRB PARAM DISPLAY	CALLED	20		
CALCTFF	FC-2760 ENTRY PROGRAMS	CALLED	12,14		

CALCTPER	FC-2320	TFFCONICS	ENTRY	5
CALCTPER	FC-2650	ORB PARAM DISPLAY	CALLED	19
CAL53A	FC-2720	IMU REALIGN PROG	ENTRY	22
CCSHOLE	FC-2140	ALARM AND ABORT	ENTRY	3
CDHMVR	FC-2626	P32, P72 - CSI	CALLED	16
CDHMVR	FC-2627	P33, P73 - CDH	ENTRY	5
CDUINC	FC-2100	SINGLE PREC SURROUTS	ENTRY	10
CDRVE	FC-2200	T4RUPT	ENTRY	4
CDULOGIC	FC-2100	SINGLE PREC SUBROUTS	ENTRY	3
CDULOGIC	FC-2350	MANEUV CALC & STEER	CALLED	22
CDUTGCSM	FC-2340	ATTITUDE MANEUVER	CALLED	5
CDUTODCM	FC-2350	MANEUIV CALC & STEER	ENTRY	22
CDUTODCM	FC-2340	ATTITUDE MANEUVER	CALLED	5
CDUTRIG	FC-2325	RENDEZ PAR DISPLAY	CALLED	4
CDUTRIG	FC-2540	EARTH ORBIT INSERT	CALLED	13
CDUTRIG	FC-2550	P20 RENDEZVOUS NAV	CALLED	13,14
CDUTRIG	FC-2700	P47 THRUST MONITOR	CALLED	8
CDUTRIG	FC-2720	IMU REALIGN PROG	CALLED	9,13
CDUTRIG	FC-2730	R52, R53, R53	CALLED	7
CHAZFOGC	FC-2530	PRELAUNCH INIT	ENTRY	33
CHECKCTR	FC-2310	CONIC SUBROUTINES	ENTRY	19
CHECKG	FC-2530	PRELAUNCH INIT	ENTRY	39
CHECKMM	FC-2030	PHASE TABLE MAINT	ENTRY	3
CHECKMM	FC-2240	SXTMARK	CALLED	2,8
CHECKMM	FC-2605	NAV EXTENDED VERBS	CALLED	6
CHECKMM	FC-2730	R52, R53, R53	CALLED	11
CHKCOMED	FC-2530	PRELAUNCH INIT	ENTRY	13
CHKPOOH	FC-2190	PINBALL	CALLED	2
CHKPOOH	FC-2330	CREW DEF MANEUVER	CALLED	2

CHKPOOH FC-2360 -S-RAND ANTENNA	CALLLED 2		
CHKPOOH FC-2361 V89 (R63)	CALLLED 2		
CHKPOOH FC-2595 LUNAR LAND SELECT	CALLLED 3		
CHKSCODE FC-2720 IMU REALIGN PRDG	CALLLED 18		
CHKSCODE FC-2730 R52, R53, R56	ENTRY 12		
CHKSDATA FC-2710 P51, P53 IMU ORIENT	ENTRY 8		
CHKSDATA FC-2720 IMU REALIGN PRDG	CALLLED 20		
CKMID? FC-2300 ORR INTEGRATION	ENTRY 36		
CKOPTVP FC-2530 PRELAUNCH INIT	ENTRY 26		
CLEANDSP FC-2760 ENTRY PROGRAMS	CALLLED 6		
CLEARMRK FC-2020 FRESH START	CALLLED 24,36		
CLEARMRK FC-2240 SXTMARK	CALLLED 8		
CLEARMRK FC-2730 R52, R53, R53	CALLLED 5,14		
CLEARMRK FC-2760 ENTRY PROGRAMS	CALLLED 3		
CLOCKJOB FC-2681 CLOKTASK- CLOCKJOB	ENTRY 4		
CLOKTASK FC-2626 P32, P72 - CSI	CALLLED 23		
CLOKTASK FC-2680 THRUST PROGRAMS	CALLLED 12		
CLOKTASK FC-2681 CLOKTASK- CLOCKJOB	ENTRY 3		
CMDAPARM FC-2683 SERVICER			T-7
CMDSDUT FC-2430 TVC ROUTINES	ENTRY 14		
CMOONFLG FC-2290 INTEG INITIAL	S-5,18	C-5,18	T-5
CMOONFLG FC-2550 P20 RENDEZVOUS NAV			T-35
CMOONFLG FC-2590 P22 ORBITAL NAV			T-4,19,20,22 23,24,25,30
CMOONFLG FC-2600 CISLUNAR MID NAV			T-11,12,17
CMOONFLG FC-2630 TPI TARGETTING			T-14
CM/DAPIC FC-2760 ENTRY PROGRAMS	CALLLED 4		
CM/DAPON FC-2760 ENTRY PROGRAMS	CALLLED 4		
CM/DSTRY FC-2683 SERVICER		C-19	T-6

CM/DSTRY FC-2760 ENTRY PROGRAMS		C-9
CM/POSE FC-2683 SERVICER	CALLED 15	
CNTNUP30 FC-2620 P30, P31	ENTRY 6	
CNTRCHK FC-2120 AGC SELFCECK	ENTRY 7	
COAALIGN FC-2530 PRELAUNCH INIT	ENTRY 36	
COGAFLAG FC-2310 CONIC SUBROUTINES	S-22	C-22,33
COGAFLAG FC-2595 LUNAR LAND SELECT		
COMPAT FC-2670 TARGET DELTA V PROG	ENTRY 2	
COMPTGO FC-2620 P30, P31	CALLED 5,10	
COMPTGO FC-2626 P32, P72 - CSI	ENTRY 22	
COMPVER FC-2530 PRELAUNCH INIT	ENTRY 26	
CPHIFLAG FC-2760 ENTRY PROGRAMS		C-17
CREWMANU FC-2330 CREW DEF MANEUVER	ENTRY 2	
CRS61.1 FC-2550 P20 RENDEZVOUS NAV	ENTRY 11	
CSI/A FC-2626 P32, P72 - CSI	ENTRY 11	
CSMCONIC FC-2190 PINBALL	CALLED 3,4	
CSMCONIC FC-2290 INTEG INITIAL	ENTRY 7	
CSMCONIC FC-2360 -S-BAND ANTENNA	CALLED 3	
CSMCONIC FC-2361 V89 (R63)	CALLED 4	
CSMCONIC FC-2545 TPI SEARCH PROG	CALLED 4,5	
CSMCONIC FC-2590 P22 ORBITAL NAV	CALLED 3	
CSMCONIC FC-2720 IMU REALIGN PROG	CALLED 11	
CSMCONIC FC-2730 R52, R53, R53	CALLED 8,9	
CSPREC FC-2290 INTEG INITIAL	ENTRY 6	
CSPREC FC-2325 RENDEZ PAR DISPLAY	CALLED 7	
CSPREC FC-2590 P22 ORBITAL NAV	CALLED 19	
CSPREC FC-2595 LUNAR LAND SELECT	CALLED 5	
CSPREC FC-2642 RETURN TO EARTH	CALLED 15	
CSPREC FC-2644 P38-P78; P39-P79	CALLED 12	

T-13

CMSPREFC	FC-2720 IMU REALIGN PROG	CALLED 8,10		
CMSSTURE	FC-2545 IPI SEARCH PROG	CALLED 4		
CULTFLAG	FC-2720 IMU REALIGN PROG	S-17	C-17	T-14,15
CULTFLAG	FC-2730 R52, R53, R56			T-7
CURTAINS	FC-2140 ALARM AND ABORT	ENTRY 3		
C33TEST	FC-2200 T4RIIPT	ENTRY 38		
DAPRIT1	FC-2370 DAP INTER-SERV ROUT	S-4	C-3	T-2,5,17
DAPRIT1	FC-2430 TVC ROUTINES			T-7
DAPRIT1	FC-2450 STROKE TEST PKG			T-1
DAPRIT1	FC-2540 EARTH ORBIT INSERT	S-19		T-10
DAPRIT1	FC-2680 THRUST PROGRAMS	S-22	C-21	T-27,44
DAPRIT2	FC-2370 DAP INTER-SERV ROUT	S-3,4		T-2,5,17
DAPRIT2	FC-2430 TVC ROUTINES			T-7
DAPRIT2	FC-2450 STROKE TEST PKG			T-1
DAPRIT2	FC-2540 EARTH ORBIT INSERT	S-19		T-10
DAPRIT2	FC-2680 THRUST PROGRAMS		C-21,22	T-27,44
DAPRAT1	FC-2680 THRUST PROGRAMS	S-25	C-7	
DAPRAT1	FC-2682 STEERING			T-9
DAPDISP	FC-2370 DAP INTER-SERV ROUT	ENTRY 5		
DAPINTT	FC-2430 TVC ROUTINES	ENTRY 6		
DCMTICDH	FC-2340 ATTITUDE MANEUVER	CALLED 7		
DCMTICDH	FC-2350 MANEUVR CALC & STEER	ENTRY 20		
DELAYJOB	FC-2020 FRESH START	CALLED 31		
DELAYJOB	FC-2070 SERVICE ROUTINES	ENTRY 8		
DELAYJOB	FC-2190 PINBALL	CALLED 5		
DELAYJOB	FC-2325 RENDEZ PAR DISPLAY	CALLED 3		
DELAYJOB	FC-2360 -S-RAND ANTENNA	CALLED 5		
DELAYJOB	FC-2550 P20 RENDEZVOUS NAV	CALLED 31		
DELAYJOB	FC-2626 P32, P72 - CSI	CALLED 6		

DELAYJOB FC-2650 ORB PAR DISPLAY	CALLED 12		
DELAYJOB FC-2760 ENTRY PROGRAMS	CALLED 11		
DELCOMP FC-2340 ATTITUDE MANEUVER	CALLED 6,7		
DELCOMP FC-2350 MANEUV CALC & STEER	ENTRY 16		
DELR SPL FC-2320 TFFCONICS	ENTRY 13		
DELR SPL FC-2650 ORB PARAM DISPLAY	CALLED 13		
DELTIME FC-2310 CONIC SUBROUTINES	ENTRY 25		
DIFE0+0 FC-2300 ORB INTEGRATION	ENTRY 27		
DIFE0+1 FC-2300 ORB INTEGRATION	ENTRY 27		
DIFE0+2 FC-2300 ORB INTEGRATION	ENTRY 32		
DIMOFLAG FC-2290 INTEG INITIAL	S-4,16	C-3,6,7,8,19	
DIMOFLAG FC-2300 ORB INTEGRATION		C-37	T-9,12,32
DIMOFLAG FC-2550 P20 RENDEZVOUS NAV	S-4,21	C-7	
DIMOFLAG FC-2580 P21 GRD TRACK DET		C-3,4	
DIMOFLAG FC-2590 P22 ORBITAL NAV	S-10,18	C-11,18	
DIMOFLAG FC-2600 CISELUNAR MID NAV	S-15	C-14	
DISDLVLC FC-2626 P32, P72 - CS1	ENTRY 8		
DISPLA YE FC-2630 TPI TARGETTING	ENTRY 15		
DISPMGA FC-2620 P30, P31	ENTRY 5		
DIVIDE FC-2600 CISELUNAR MID NAV	ENTRY 22		
DLY2-1 FC-2060 WAITLIST	ENTRY 10		
DMENFLG FC-2590 P22 ORBITAL NAV	S-15	C-12,26	T-13,18
DMENFLG FC-2600 CISELUNAR MID NAV		C-11	
DMENFLG FC-2610 MEASUREMENT INCOR			T-3,5,8,9,
DNTMFAST FC-2200 T4RUPT	ENTRY 42		
DOFSTART FC-2020 FRESH START	ENTRY 3		
DOW.. FC-2300 ORB INTEGRATION	ENTRY 41		
DOW..1 FC-2300 ORB INTEGRATION	ENTRY 42		
DOWNT2 FC-2070 SERVICE ROUTINES	ENTRY 3		

DOWNFLAG FC-2070 SERVICE ROUTINES	ENTRY 4	
DOWNFLAG FC-2140 ALARM AND ABORT	CALLED 6,12	
DPADD FC-2370 DAP INTER-SERV ROUT	ENTRY 18	
DPAGREF FC-2682 STEERING	CALLED 3	
DRIFTFLG FC-2200 T4RUPT		C-31,32
DRIFTFLG FC-2683 SERVICER	S-19	C-3
DRIFTFLG FC-2710 P51, P53 IMU ORIENT	S-3	
DRIFTFLG FC-2720 IMU REALIGN PROG	S-4,23	
DSKYFLAG FC-2150 KEYRUPT AND UPRUPT	S-4	
DSKYFLAG FC-2200 T4RUPT		T-4
DSPOUTSR FC-2200 T4RUPT	ENTRY 47	
DSPTAR+1 FC-2070 SERVICE ROUTINES	S-13	C-13
DYNDISP FC-2681 CLOKTASK- CLOCKJOB	ENTRY 4	
D6OR9FLG FC-2290 INTEG INITIAL		C-3,16
D6OR9FLG FC-2300 ORB INTEGRATION		T-33
D6OR9FLG FC-2550 P20 RENDEZVOUS NAV		C-7
D6OR9FLG FC-2590 P22 ORBITAL NAV	S-10,18	C-11,18
D6OR9FLG FC-2600 C1SLUNAR MID NAV		C-14
EARROT2 FC-2760 ENTRY PROGRAMS	CALLED 16	
EARTH# FC-2530 PRELAUNCH INIT	ENTRY 38	
EARTH#+3 FC-2530 PRELAUNCH INIT	ENTRY 38	
EARTH#+3 FC-2540 EARTH ORBIT INSERT	CALLED 5	
EARTH# FC-2530 PRELAUNCH INIT	ENTRY 37	
ECSTEER FC-2626 P32, P72 - CSI	S-2	
ENABL2 FC-2430 TVC ROUTINES	ENTRY 13	
ENATMA FC-2370 DAP INTER-SERV ROUT	ENTRY 11	
ENDEXT FC-2650 ORB PARAM DISPLAY	CALLED 14	
ENDMARK FC-2242 OPTICS CAL ROUTINE	CALLED 5	
ENDTNON FC-2200 T4RUPT	ENTRY 35	

ENGINEOFF FC-2630 TPI TARGETTING	ENTRY	24	
ENGINEOFF FC-2682 STEERING	CALLED	3	
ENGNONFLG FC-2680 THRUST PROGRAMS	S-20		C-27
ENG2FLAG FC-2680 THRUST PROGRAMS	S-5		C-4 T-40
ENTRYDSP FC-2760 ENTRY PROGRAMS	S-5,7,8		C-7
ERADFLAG FC-2320 TFFCONICS			C-14
ERADFLAG FC-2540 EARTH ORBIT INSERT			C-7
ERADFLAG FC-2580 P21 GRD TRACK DET			C-5
ERADFLAG FC-2590 P22 ORBITAL NAV	S-4		
ERADFLAG FC-2595 LUNAR LAND SELECT	S-4,6		
ERADFLAG FC-2600 CISELUNAR MID NAV	S-16		
ERADFLAG FC-2642 RETURN TO EARTH			C-32
ERADFLAG FC-2720 IMU REALIGN PROG	S-7		
ERADFLAG FC-2760 ENTRY PROGRAMS			C-9
ERASCALC FC-2530 PRELAUNCH INIT	ENTRY	42	
ERRORLIM FC-2440 TVC DAP	ENTRY	11,15	
ERTHRVSE FC-2530 PRELAUNCH INIT	ENTRY	41	
ESTIMS FC-2530 PRELAUNCH INIT	ENTRY	11	
ETPIFLAG FC-2630 TPI TARGETTING	S-3		C-3 T-3,4,7
EXDAPDFF FC-2530 PRELAUNCH INIT	ENTRY	31	
EXRSTRT FC-2430 TVC ROUTINES	ENTRY	15	
EXTVRACT FC-2070 SERVICE ROUTINES			C-12
EXTVRACT FC-2242 OPTICS CAL ROUTINE	S-2		T-2
EXTVRACT FC-2325 RENDEZ PAR DISPLAY	S-5		T-3,5
EXTVRACT FC-2650 ORB PARAM DISPLAY			T-12,14
FALTON FC-2020 FRESH START	CALLED	33	
FALTON FC-2190 PINBALL	CALLED	2	
FALTON FC-2325 RENDEZ PAR DISPLAY	CALLED	2	
FALTON FC-2330 CREW DEF MANEUVER	CALLED	2	

FALTON	FC-2360 -S-RAND ANTENNA	CALLED 2	
FALTON	FC-2361 VR9 (R63)	CALLED 2	
FALTON	FC-2550 P20 RENDEZVOUS NAV	CALLED 17	
FALTON	FC-2595 LUNAR LAND SELECT	CALLED 3	
FALTON	FC-2600 CISELUNAR MID NAV	CALLED 4	
FALTON	FC-2605 NAV EXTENDED VERRS	CALLED 2,6	
FALTON	FC-2650 ORB PARAM DISPLAY	CALLED 2	
FA7AR5	FC-2290 INTEG INITIAL	CALLED 18	
FRR3	FC-2300 ORB INTEGRATION	ENTRY 28	
FINALFLG	FC-2626 P32, P72 - CSI	S-7	T-3,6
FINALFLG	FC-2627 P33, P73 - CDH		T-4
FINALFLG	FC-2630 TPI TARGETTING		T-16
FINALFLG	FC-2642 RETURN TO EARTH	S-14	
FINALFLG	FC-2644 P3R-P7R: P39-P79	S-7,9	T-5,6,7,9
FINETIME	FC-2530 PRELAUNCH INIT	ENTRY 40	
FIRSTFLG	FC-2680 THRUST PROGRAMS	S-32	
FIRSTFLG	FC-2682 STEERING		C-16 T-8,15
FISHCALC	FC-2320 TFFCONICS	ENTRY 12	
FISHCALC	FC-2760 ENTRY PROGRAMS	CALLED 12,13, 14	
FIXDELAY	FC-2060 WAITLIST	ENTRY 10	
FRAOFLAG	FC-2730 R52, R53, R56	S-5	
FREFFLAG	FC-2710 P51, P53 IMU ORIENT	S-8,9	C-8,9 T-6,8
FRESHDAP	FC-2380 RCS DAP INIT	ENTRY 6	
FXFX	FC-2120 AGC SELF CHECK	ENTRY 10	
FWDFLTR	FC-2440 TVC DAP	ENTRY 4	
F2RTE	FC-2642 RETURN TO EARTH	S-20	C-17
GAMCOMP	FC-2300 ORB INTEGRATION	ENTRY 23	
GAMDV10	FC-2642 RETURN TO EARTH	ENTRY 23	
GENTRAN	FC-2020 FRESH START	CALLED 28	

GENTRAN	FC-2070 SERVICE ROUTINES	ENTRY 11
GENTRAN	FC-2240 SXTMARK	CALLED 5
GENTRAN	FC-2550 P20 RENDEZVOUS NAV	CALLED 18,20
GENTRAN	FC-2683 SERVICER	CALLED 5,15
GENTRAN	FC-2700 P47 THRUST MONITOR	CALLED 7
GEOM	FC-2310 CONIC SUBROUTINES	ENTRY 34
GETERAD	FC-2320 TFFCONICS	CALLED 12
GETERAD	FC-2600 CISELUNAR MID NAV	CALLED 18
GETERAD	FC-2642 RETURN TO EARTH	CALLED 7
GET+MGA	FC-2620 P30, P31	CALLED 5,9
GET+MGA	FC-2626 P32, P72 - CSI	CALLED 6
GETUM	FC-2550 P20 RENDEZVOUS NAV	ENTRY 38
GETUM	FC-2590 P22 ORBITAL NAV	CALLED 12
GETX	FC-2310 CONIC SUBROUTINES	ENTRY 26
GLOCKMON	FC-2200 T4RUPT	ENTRY 43
GOESTIMS	FC-2530 PRELAUNCH INIT	ENTRY 5
GOINT	FC-2630 TPI TARGETTING	ENTRY 14
GOODEND	FC-2550 P20 RENDEZVOUS NAV	CALLED 34
GOPROG	FC-2020 FRESH START	ENTRY 13
GOPROG2	FC-2020 FRESH START	ENTRY 20
GOTOPOOH	FC-2020 FRESH START	ENTRY 24
GTSCPSS1	FC-2530 PRELAUNCH INIT	ENTRY 2
GUESSW	FC-2310 CONIC SUBROUTINES	
GUESSW	FC-2682 STEERING	C-14
GYMDIFSW	FC-2760 ENTRY PROGRAMS	C-9
HACK	FC-2440 TVC DAP	CALLED 1,6
HACK	FC-2450 STROKE TEST PKG	ENTRY 2
HACKWLST	FC-2450 STROKE TEST PKG	ENTRY 2
HAVEGUES	FC-2682 STEERING	CALLED 14

T-11,16

HIENERGY FC-2310 CONIC SUBROUTINES	ENTRY	21		
HORIZ FC-2600 CISLUNAR MID NAV	ENTRY	18		
IRNKCALL FC-2080 INT BNK COMMUN	ENTRY	4		
IDLEFAIL FC-2681 CLOKTASK- CLOCKJOB	S-10		C-10	
IDLEFAIL FC-2682 STEERING				T-13
IGNFLAG FC-2680 THRUST PROGRAMS	S-20			
IGNFLAG FC-2681 CLOKTASK- CLOCKJOB	S-13			T-6
IGNITION FC-2630 TPI TARGETTING	ENTRY	20		
IGNITION FC-2681 CLOKTASK-CLOCKJOB	CALLED	6		
IMPULSW FC-2680 THRUST PROGRAMS	S-17		C-19,21	T-21
IMPULSW FC-2682 STEERING	S-13		C-4	T-4
IMURAD FC-2200 T4RUPT	CALLED	35		
IMUCAGE FC-2200 T4RUPT	ENTRY	31		
IMUCOARS FC-2710 P51, P53 IMU ORIENT	CALLED	2		
IMUCOARS FC-2720 IMU REALIGN PROG	CALLED	23		
IMUFINE2 FC-2710 P51, P53 IMU ORIENT	CALLED	3		
IMUFIN20 FC-2720 IMU REALIGN PROG	CALLED	23		
IMUMON FC-2200 T4RUPT	ENTRY	25		
IMUOP FC-2200 T4RUPT	ENTRY	32		
IMUPULSE FC-2720 IMU REALIGN PROG	CALLED	26		
IMUSE FC-2550 P20 RENDEZVOUS NAV			C-8	
IMUSE FC-2710 P51, P53 IMU ORIENT	S-2			
IMUSEFLA FC-2200 T4RUPT			C-32	T-34,35
IMUSTALL FC-2710 P51, P53 IMU ORIENT	CALLED	3		
IMUSTALL FC-2720 IMU REALIGN PROG	CALLED	23,26		
IMUSTLLG FC-2530 PRELAUNCH INIT	ENTRY	36		
INCORFLG FC-2550 P20 RENDEZVOUS NAV	S-22,24		C-28	T-24,27,28
INCORFLG FC-2590 P22 ORBITAL NAV	S-14		C-17	T-17
INCORP1 FC-2550 P20 RENDEZVOUS NAV	CALLED	26		

INCORP1	FC-2590	P22 ORBITAL NAV	CALLED	15		
INCORP1	FC-2600	CISLUNAR MID NAV	CALLED	11		
INCORP1	FC-2610	MEASUREMENT INCOR	ENTRY	3		
INCORP2	FC-2550	P20 RENDEZVOUS NAV	CALLED	27		
INCORP2	FC-2590	P22 ORBITAL NAV	CALLED	16		
INCORP2	FC-2600	CISLUNAR MID NAV	CALLED	12		
INCORP2	FC-2610	MEASUREMENT INCOR	ENTRY	9		
INCRCDUS	FC-2100	SINGLE PREC SUBROUTS	ENTRY	9		
INFINFLG	FC-2310	CONIC SUBROUTINES	S-29		C-29	T-12,18,22
INFINFLG	FC-2595	LUNAR LAND SELECT				T-13
INFINITY	FC-2310	CONIC SUBROUTINES	ENTRY	29		
INITIALW	FC-2550	P20 RENDEZVOUS NAV	ENTRY	36		
INITSUR	FC-2020	FRESH START	ENTRY	25		
INITV	FC-2310	CONIC SUBROUTINES	ENTRY	20		
INITVEL	FC-2545	TPI SEARCH PROG	CALLED	8		
INITVEL	FC-2630	TPI TARGETTING	CALLED	12		
INITVEL	FC-2680	THRUST PROGRAMS	CALLED	39		
INSTALL	FC-2580	P21 GRD TRACK DET	CALLED	3		
INSTALL	FC-2610	MEASUREMENT INCORP	CALLED	7		
INTEGREV	FC-2580	P21 GRD TRACK DET	CALLED	4		
INTEGRV	FC-2290	INTEG INITIAL	ENTRY	8		
INTEGRV	FC-2550	P20 RENDEZVOUS NAV	CALLED	4,5,21,22		
INTEGRV	FC-2580	P21 GRD TRACK DET	CALLED	4		
INTEGRV	FC-2590	P22 ORBITAL NAV	CALLED	12		
INTEGRV	FC-2600	CISLUNAR MID NAV	CALLED	15		
INTEGRVS	FC-2290	INTEG INITIAL	ENTRY	8		
INTEGRVS	FC-2325	RENDEZ PAR DISPLAY	CALLED	9		
INTEGRVS	FC-2630	TPI TARGETTING	CALLED	15		
INTEGRVS	FC-2642	RETURN TO EARTH	CALLED	44		

INTEGRV2 FC-2290 INTEG INITIAL	ENTRY R		
INTEGRV2 FC-2300 ORR INTEGRATION	CALLED 35		
INTFLAG FC-2290 INTEG INITIAL	S-11	C-13	T-10
INTGRATE FC-2300 ORR INTEGRATION	ENTRY R		
INTGRVS FC-2670 TARGET DELTA V PROG	CALLED 3		
INTINT FC-2626 P32, P72 - CSI	CALLED 3,15,16		
INTINT FC-2627 P33, P73 - CDH	CALLED 2		
INTINT FC-2630 TPI TARGETTING	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-2020 FRESH START	CALLED 35		
INTSTALL FC-2290 INTEG INITIAL	ENTRY 10		
INTSTALL FC-2325 RENDEZ PAR DISPLAY	CALLED 8,9,10		
INTSTALL FC-2550 P20 RENDEZVOUS NAV	CALLED 7,9		
INTSTALL FC-2590 P22 ORBITAL NAV	CALLED 10,18		
INTSTALL FC-2600 CISELUNAR MID NAV	CALLED 14		
INTSTALL FC-2605 NAV EXTENDED VERBS	CALLED 3		
INTSTALL FC-2642 RETURN TO EARTH	CALLED 42,43		
INTSTALL FC-2650 ORB PARAM DISPLAY	CALLED 13		
INTSTALL FC-2670 TARGET DELTA V PROG	CALLED 2,3		
INTWAKE FC-2290 INTEG INITIAL	ENTRY 12		
INTWAKE FC-2300 ORR INTEGRATION	CALLED 40		
INTWAKE FC-2320 TFFCONICS	CALLED 14		
INTWAKE FC-2605 NAV EXTENDED VERBS	CALLED 4		
INTWAKE FC-2610 MEASUREMENT INCORP	CALLED 12		
INTWAKE0 FC-2290 INTEG INITIAL	ENTRY 12		
INTWAKE0 FC-2320 TFFCONICS	CALLED 14		
INTWAKEU FC-2290 INTEG INITIAL	ENTRY 14		

INTWAKE1 FC-2670 TARGET DELTA V PRG	CALLED 4		
INTYPH1A FC-2670 TARGET DELTA V PRG		C-2	
INTYPH1G FC-2290 INTEG INITIAL	S-7	C-3,6,20	T-8
INTYPFLG FC-2325 RENDEZ PAR DISPLAY	S-8,9	C-8,9	
INTYPFLG FC-2550 P20 RENDEVOUS NAV		C-7	
INTYPFLG FC-2580 P21 GRD TRACK DET		C-4	
INTYPFLG FC-2590 P22 ORBITAL NAV		C-10,18	
INTYPFLG FC-2600 CISELUNAR MID NAV		C-14	
INTYPFLG FC-2630 TPI TARGETTING	S-14	C-14	
INTYPFLG FC-2642 RETURN TO EARTH	S-42	C-42,43	
ISWCALL FC-2080 INT BNK COMMUN	ENTRY 4		
ISWRETRN FC-2080 INT BNK COMMUN	ENTRY 4		
ITERATOR FC-2310 CONIC SUBROUTINES	ENTRY 36		
ITSWICH FC-2545 TPI SEARCH PRG	S-10	C-7	T-10
ITSWICH FC-2627 P33, P73 - CDH	S-4		
ITSWICH FC-2630 TPI TARGETTING	S-3	C-3,4	T-4,7
ITURNOM FC-2200 T4RUPT	ENTRY 29		
JETSLFCT FC-2380 RCS DAP INIT	CALLED 2		
JETSLECT FC-2390 RCS DAP PHASE 2	CALLED 10		
JETSLECT FC-2400 RCS DAP JET SELECT	ENTRY 1		
JETSLFCT FC-2460 ROLL AUTOPILOT	CALLED 2		
JORSLEEP FC-2290 INTEG INITIAL	CALLED 10		
JORWAKE FC-2290 INTEG INITIAL	CALLED 13		
JORWAKE FC-2670 TARGET DELTA V PRG	CALLED 10		
JSWITCH FC-2300 ORB INTEGRATION	S-33	C-8	T-8,27
KALCMAN3 FC-2340 ATTITUDE MANEUVER	CALLED 4		
KEPLERN FC-2310 CONIC SUBROUTINES	ENTRY 4		
KEPLERN FC-2300 ORB INTEGRATION	CALLED 31		
KEPPREP FC-2300 ORB INTEGRATION	ENTRY 29		

KEPPREP	FC-2290 INTEG INITIAL	CALLED	9		
KEYCOM	FC-2150 KEYRUPT AND UPRUPT	ENTRY	4		
KEYCOM	FC-2240 SXTMARK	CALLED	4		
KEYRUPT1	FC-2150 KEYRUPT AND UPRUPT	ENTRY	3		
KFLAG	FC-2545 TPI SEARCH PRG	S-4,5		C-4,5	T-5,6,7,10,11
KLEENEX	FC-2240 SXTMARK	CALLED	8		
KLEENEX	FC-2550 P20 RENDEZVOUS NAV	CALLED	18		
KLEENEX	FC-2730 R52, R53, R53	CALLED	5		
KNOWNFLG	FC-2590 P22 ORBITAL NAV	S-6		C-6	T-7,13
LALOTORV	FC-2320 TFFCONICS	CALLED	14		
LALOTORV	FC-2540 EARTH ORBIT INSERT	CALLED			
LALOTORV	FC-2590 P22 ORBITAL NAV	CALLED	23		
LALOTORV	FC-2600 CISELUNAR MID NAV	CALLED	16		
LALOTORV	FC-2720 IMU REALIGN PRG	CALLED	8		
LALOTORV	FC-2730 R52, R53, R53	CALLED	8		
LAMBERT	FC-2310 CONIC SUBROUTINES	ENTRY	14		
LAMENTER	FC-2310 CONIC SUBROUTINES	ENTRY	35		
LASTHIAS	FC-2683 SERVICER	CALLED	3		
LATAZCHK	FC-2530 PRELAUNCH INIT	ENTRY	47		
LAT-LONG	FC-2580 P21 GRD TRACK DET	CALLED	5		
LAT-LONG	FC-2590 P22 ORBITAL NAV	CALLED	7,20		
LAT-LONG	FC-2595 LUNAR LAND SELECT	CALLED	5,7,10		
LAT-LONG	FC-2642 RETURN TO EARTH	CALLED	33		
LAT-LONG	FC-2720 IMU REALIGN PRG	CALLED	7		
LAT-LONG	FC-2760 ENTRY PROGRAMS	CALLED	9		
LEMCONIC	FC-2190 PINBALL	CALLED	4		
LEMCONIC	FC-2361 V89 (R63)	CALLED	4		
LEMCONIC	FC-2545 TPI SEARCH PRG	CALLED	3,8		
LEMCONIC	FC-2730 R52, R53, R53	CALLED	8		

LEMPREC	FC-2290	INTEG INITIAL	ENTRY 6		
LEMPRHC	FC-2325	RENDEZ PAR DISPLAY	CALLED 7,10		
LEMSTIRH	FC-2545	TPI SEARCH PRNG	CALLED 3		
LFTFLGNM	FC-2530	PRELAUNCH INIT	ENTRY 33		
LINUS	FC-2340	ATTITUDE MANEUVER	CALLED 8		
LINVEL	FC-2300	ORB INTEGRATION	CALLED 44		
LISTINGD	FC-2550	P20 RENDEZVOUS NAV	ENTRY 1		
LISTINGD	FC-2580	P21 GRD TRACK DET	ENTRY 1		
LISTINGD	FC-2605	NAV EXTENDED VERRS	ENTRY 1		
LISTINGD	FC-2760	ENTRY PROGRAMS	ENTRY 1		
LITTLSHR	FC-2530	PRELAUNCH INIT	ENTRY 46		
LLASRD	FC-2720	IMU REALIGN PRNG	CALLED 7		
LLASRDA	FC-2720	IMU REALIGN PRNG	CALLED 8		
LMOONFLG	FC-2290	INTEG INITIAL	S-5	C-5	T-5
LMOONFLG	FC-2550	P20 RENDEZVOUS NAV			T-35
LMPREC	FC-2644	P38-P78; P39-P79	CALLED 12		
LOADCDEF	FC-2430	TVC ROUTINES	ENTRY 22		
LOADTIME	FC-2100	SINGLE PREC SUBROUTS	ENTRY 2		
LOADTIME	FC-2190	PINBALL	CALLED 3		
LOADTIME	FC-2290	INTEG INITIAL	CALLED 3,19		
LOADTIME	FC-2300	ORB INTEGRATION	CALLED 36		
LOADTIME	FC-2360	-S-BAND ANTENNA	CALLED 3		
LOADTIME	FC-2361	V89 (R63)	CALLED 3		
LOADTIME	FC-2550	P20 RENDEZVOUS NAV	CALLED 3,11,19,20		
LOADTIME	FC-2580	P21 GRD TRACK DET	CALLED 5		
LOADTIME	FC-2590	P22 ORBITAL NAV	CALLED 3,7		
LOADTIME	FC-2595	LUNAR LAND SELECT	CALLED 4		
LOADTIME	FC-2600	CISLUNAR MID NAV	CALLED 7		
LOADTIME	FC-2631	R36 (V90)	CALLED 3		

LOADTIME FC-2640 TPM TARGETTING	CALLED 1	
LOADTIME FC-2650 ORB PARAM DISPLAY	CALLED 6	
LOADTIME FC-2720 IMU REALIGN PROG	CALLED 5,18	
LOADTIME FC-2730 R52, R53, R53	CALLED 6,9	
LOADTIME FC-2760 ENTRY PROGRAMS	CALLED 3	
LOCSAM FC-2710 P51, P53 IMU ORIENT	CALLED 7	
LOCSAM FC-2720 IMU REALIGN PROG	ENTRY 11	
LOADSAMP FC-2150 KEYRUPT AND UPRUPT	CALLED 3,5	
LOMAT FC-2630 TPI TARGETTING	ENTRY 14,15	
LOMAT FC-2620 P30, P31	CALLED 3	
LONGCALL FC-2060 WAITLIST	ENTRY 21	
LOWMEMRY FC-2600 CISLUNAR MID NAV	ENTRY 5	
LSPOS FC-2300 ORB INTEGRATION	CALLED 11	
LSPOS FC-2720 IMU REALIGN PROG	CALLED 11	
LUMPOS FC-2300 ORB INTEGRATION	CALLED 45	
LUNAFLAG FC-2580 P21 GRD TRACK DET	S-4	C-4
LUNAFLAG FC-2590 P22 ORBITAL NAV	S-4,20,22,24	C-4,20,22,24
LUNAFLAG FC-2595 LUNAR LAND SELECT	S-4,7	T-10
LUNAFLAG FC-2600 CISLUNAR MID NAV	S-5	C-5 T-17,18
LUNAFLAG FC-2642 RETURN TO EARTH		C-32
LUNAFLAG FC-2730 R52, R53, R56	S-5	
LUNAFLAG FC-2760 ENTRY PROGRAMS		C-9
LUNAFLG FC-2720 IMU REALIGN PROG	S-7	
LUNPOS FC-2190 PINBALL	CALLED 3	
LUNPOS FC-2360 -S-BAND ANTENNA	CALLED 3	
LUNPOS FC-2600 CISLUNAR MID NAV	CALLED 15	
MAJNRTNE FC-2644 P38-P78; P39-P79	ENTRY 6	
MAKECADR FC-2080 INT BNK COMMUN	ENTRY 2	
MAKECADR FC-2340 ATTITUDE MANEUVER	CALLED 2	

MAKECADR FC-2550 P20 RENDEZVOUS NAV	CALLED 10		
MAKECADR FC-2670 TARGET DELTA V PROG	CALLED 10		
MAKECADR FC-2720 IMU REALIGN PROG	CALLED 13		
MAKECADR FC-2730 R52, R53, R53	CALLED 6		
MARKCONT FC-2240 SXTMARK	ENTRY 5		
MARKDIF FC-2240 SXTMARK	ENTRY 9		
MARKDISP FC-2240 SXTMARK	CALLED 5		
MARKDISP FC-2242 OPTICS CAL ROUTINE	ENTRY 4		
MARKINDX FC-2720 IMU REALIGN PROG	S-18		
MARKIT FC-2240 SXTMARK	ENTRY 9		
MARKRUPT FC-2240 SXTMARK	ENTRY 4		
MARK2 FC-2240 SXTMARK	ENTRY 6		
MASSPROP FC-2430 TVC ROUTINES	ENTRY 16		
MASSPROP FC-2020 FRESH START	CALLED 31		
MASSPROP FC-2370 DAP INTER-SERV ROUT	CALLED 7		
MASSPROP FC-2680 THRUST PROGRAMS	CALLED 25		
MATMOVE FC-2720 IMU REALIGN PROG	ENTRY 27		
MATMOVE FC-2710 P51, P53 IMU ORIENT	CALLED 6		
MATRXJOB FC-2540 EARTH ORBIT INSERT	ENTRY 7		
MAXCHK FC-2620 P30, P31	CALLED 4,8		
MAXDRFLG FC-2370 DAP INTER-SERV ROUT	S-6	C-6	
MIDAVFLG FC-2290 INTEG INITIAL	S-20		
MIDAVFLG FC-2300 ORB INTEGRATION		C-40	T-32
MIDFLAG FC-2300 ORB INTEGRATION	S-3	C-3	T-6,10,38,41
MIDGIM FC-2620 P30, P31	CALLED 8		
MIDGIM FC-2680 THRUST PROGRAMS	CALLED 34,36		
MIDTOAV1 FC-2290 INTEG INITIAL	ENTRY 19		
MIDTOAV1 FC-2680 THRUST PROGRAMS	CALLED 12		
MIDTOAV2 FC-2290 INTEG INITIAL	ENTRY 19		

MIDTNAV2 FC-2700 P47 THRUST MONITOR	CALLED 3		
MIDTNAV2 FC-2760 ENTRY PROGRAMS	CALLED 10		
MIDIFLAG FC-2290 INTEG INITIAL	S-19	C-19	
MIDIFLAG FC-2300 ORB INTEGRATION			T-36
MINIRECT FC-2300 ORB INTEGRATION	ENTRY 43		
MINIRECT FC-2290 INTEG INITIAL	CALLED 17		
MINIRECT FC-2670 TARGET DELTA V PRNG	CALLED 4		
MKREJECT FC-2240 SXTMARK	ENTRY 7		
MKRFLFAS FC-2240 SXTMARK	ENTRY 3		
MKRELFAS FC-2590 P22 ORBITAL NAV	CALLED 9		
MKRELFAS FC-2710 P51, P53 IMU ORIENT	CALLED 5		
MKRELFAS FC-2720 IMU REALIGN PRNG	CALLED 19		
MKRELEAS FC-2730 R52, R53, R53	CALLED 5		
MKRLEFS FC-2550 P20 RENDEZVOUS NAV	CALLED 7		
MKVR51 FC-2240 SXTMARK	ENTRY 8		
MMDSPLAY FC-2020 FRESH START	CALLED 21		
MMONTHIS FC-2325 RENDEZ PAR DISPLAY			T-8,9
MMONTHIS FC-2610 MEASUREMENT INCORP			T-10
MOVEACSM FC-2610 MEASUREMENT INCORP	CALLED 11		
MOVEALEM FC-2610 MEASUREMENT INCORP	CALLED 11		
MOVEPCSM FC-2610 MEASUREMENT INCORP	CALLED 10		
MOVEPLEM FC-2610 MEASUREMENT INCORP	CALLED 10		
MMONFLAG FC-2290 INTEG INITIAL	S-5,14,21	C-5,14	T-5,8
MMONFLAG FC-2300 ORB INTEGRATION	S-44	C-44	T-11,13,15,19 31,40,41,44 45
MMONFLAG FC-2325 RENDEZ PAR DISPLAY	S-8,9	C-8,9	
MMONFLAG FC-2580 P21 GRD TRACK DET	S-4	C-3	
MMONFLAG FC-2630 TPI TARGETTING	S-14	C-14	

MOONFLAG FC-2642 RETURN TO EARTH		C-43	
MOONFLAG FC-2670 TARGET DELTA V PROG	S-2	C-2	
MR KLFAN FC-2020 FRESH START	ENTRY 7		
MR KLFAN FC-2140 ALARM AND ABORT	CALLED 6,13		
MXM3 FC-2350 MANUV CALC & STEER	ENTRY 25		
MXM3 FC-2340 ATTITUDE MANEUVER	CALLED 6,7		
NRDUNLY FC-2060 WAITLIST	CALLED 20		
NRSM FC-2550 P20 RENDEZVOUS NAV	CALLED 38		
NRSM FC-2730 R52, R53, R53	CALLED 13		
*NRSM FC-2325 RENDEZ PAR DISPLAY	CALLED 5		
NEEDFLG FC-2380 RCS DAP INIT			T-5
NEEDLER FC-2380 RCS DAP INIT	CALLED 5		
NEEDLER FC-2430 TVC ROUTINES	CALLED 5,7		
NEEDLER FC-2460 ROLL AUTOPILOT	CALLED 5		
NEEDLER FC-2540 EARTH ORBIT INSERT	CALLED 4,16,17,20,21		
NEEDLES3 FC-2370 DAP INTER-SERV ROUT	ENTRY 15		
NEEDFLG FC-2680 DAP INTER SERV ROUT	S-12,13	C-12	
NEGP FC-2310 CONIC SUBROUTINES	ENTRY 21		
NEWIFLG FC-2290 INTFG INITIAL	S-8		
NEWIFLG FC-2300 ORB INTEGRATION		C-6	T-6
NEWMODEA FC-2030 PHASE TABLE MAINT	ENTRY 2		
NEWMODEA FC-2020 FRESH START	CALLED 42		
NEWMODEX FC-2030 PHASE TABLE MAINT	ENTRY 2		
NEWMODEX FC-2540 EARTH ORBIT INSFR	CALLED 4		
NEWMODEX FC-2760 ENTRY PROGRAMS	CALLED 3,6,7,8		
NEWPHASE FC-2030 PHASE TABLE MAINT	ENTRY 4		
NEWSTATE FC-2310 CONIC SUBROUTINES	ENTRY 35		
NEXTCOL FC-2300 ORB INTEGRATION	ENTRY 35		
NJETSFLG FC-2680 THRUST PROGRAMS			T-5,17

NJETSFLG	FC-2642 RETURN TO EARTH			T-11
NNOACY	FC-2400 RCS DAP JET SELECT	ENTRY	8	
NNOATTOFF	FC-2200 T4RUPT	CALLED	34,35	
NNOBDZ	FC-2400 RCS DAP JET SELECT	ENTRY	6	
NNOODFLAG	FC-2290 INTEG INITIAL	S-3		C-4
NNOODFLAG	FC-2140 ALARM AND ABORT			C-6
NNOODPO1	FC-2540 EARTH ORBIT INSERT	S-4		
NNOERANK	FC-2120 AGC SELF-CHECK	ENTRY	6	
NNOFHOR	FC-2600 CISELUNAR MID NAV	S-6		C-6 T-22
NNOFMLIZE	FC-2683 SERVICER	ENTRY	5	
NNOFMLIZE	FC-2540 EARTH ORBIT INSERT	CALLED	9	
NNOORMSW	FC-2310 CONIC SUBROUTINES			C-33 T-34
NNOORMSW	FC-2620 P30, P31			C-7
NNOORMSW	FC-2642 RETURN TO EARTH			C-14
NNOORMSW	FC-2680 THRUST PROGRAMS			T-38
NNOORMSW	FC-2682 STEERING			T-14
NNOORMINIT	FC-2100 SINGLE PREC SURROUTS	ENTRY	15	
NNOORMUNX1	FC-2100 SINGLE PREC SURROUTS	ENTRY	15	
NNOO2Y	FC-2400 RCS DAP JET SELECT	ENTRY	10	
N22ORNI7	FC-2370 DAP INTER-SERV ROUT	S-12		C-13
N22ORNI7	FC-2380 RCS DAP INIT			T-5
OPTMODES	FC-2070 SERVICE ROUTINES	S-13		
OPTMON	FC-2200 T4RUPT	ENTRY	11	
OPTNSW	FC-2644 P38-P78; P39-P79	S-4		C-4 T-5
OPTSTALL	FC-2730 R52, R53, R53	CALLED	11	
OPTTEST	FC-2200 T4RUPT	ENTRY	6	
ORRWFLAG	FC-2290 INTEG INITIAL			C-14 T-4,16
ORRWFLAG	FC-2300 ORB INTEGRATION			C-37
ORRWFLAG	FC-2550 P20 RENDEZVOUS NAV			C-22

ORRWFLAG FC-2590 P22 ORBITAL NAV		C-39	T-11,18
ORRWFLAG FC-2600 CISELUNAR MID NAV	S-15		T-14,15
ORRWFLAG FC-2605 NAV EXTENDED VERRS		C-5,7	
ORDERSM FC-2310 CONIC SUBROUTINES			T-36,37
ORIGCHNG FC-2300 ORB INTEGRATION	ENTRY	44	
OTHPREC FC-2631 R36 (V90)	CALLED	4	
OTHPREC FC-2650 ORB PARAM DISPLAY	CALLED	7	
OVERFFIX FC-2530 PRELAUNCH INIT	ENTRY	36	
PARAM FC-2310 CONIC SUBROUTINES	ENTRY	33	
PARAM FC-2642 RETURN TO EARTH	CALLED	35	
PASSIVF FC-2626 P32, P72 - CSI	CALLED	3	
PASSIVE FC-2627 P33, P73 - CDH	CALLED	2	
PCOPY FC-2430 TVC ROUTINES	CALLED	12	
PCOPY FC-2440 TVC DAP	ENTRY	8	
PDSPFLAG FC-2340 ATTITUDE MANEUVER	S-8		T-4,R
PDSPFLAG FC-2550 P20 RENDEZVOUS NAV	S-10	C-10	T-34
PERIAPD FC-2545 TPI SEARCH PRDG	CALLED	9	
PERIAPD FC-2626 P32, P72 - CSI	CALLED	13	
PERIAPD1 FC-2620 P30, P31	CALLED	4,R	
PERIAPD1 FC-2626 P32, P72 - CSI	CALLED	16	
PERIAPD1 FC-2630 TPI TARGETTING	CALLED	5	
PERIAPD1 FC-2644 P38-P78; P39-P79	CALLED	7	
PFAILOK FC-2200 T4RUPT	CALLED	37	
PFRATFLG FC-2680 THRUST PROGRAMS	S-6		
PFRATFLG FC-2720 IMU REALIGN PRDG		C-4,20	
PHASCHNG FC-2030 PHASE TABLE MAINT	ENTRY	5	
PICAPAR FC-2720 IMU REALIGN PRDG	ENTRY	13	
PINBRNCH FC-2370 DAP INTER-SERV ROUT	CALLED	2,5	
PINBRNCH FC-2605 NAV EXTENDED VERRS	CALLED	2,6,7	

PIPACHK	FC-2530 PRELAUNCH INIT	ENTRY	6	
PIPASR	FC-2683 SERVICER	ENTRY	9	
PIPATASK	FC-2530 PRELAUNCH INIT	ENTRY	7	
PIPFAIL	FC-2200 T4RUPT	ENTRY	41	
PIPFREE	FC-2683 SERVICER	CALLED	19	
PIPJARR	FC-2530 PRELAUNCH INIT	ENTRY	8	
PITCHDAP	FC-2440 TVC DAP	ENTRY	2	
PITCHDAP	FC-2430 TVC ROUTINES	CALLED	6	
PITCHTIM	FC-2400 RCS DAP JET SELECT	ENTRY	11	
PLANET	FC-2710 P51, P53 IMU ORIENT	ENTRY	7	
PLANET	FC-2720 IMU REALIGN PROG	CALLED	18,19	
POINTAXS	FC-2600 CISELUNAR MID NAV	ENTRY	13	
POLY	FC-2310 CONIC SUBROUTINES	CALLED	25,28	
POLY	FC-2642 RETURN TO EARTH	CALLED	4,6,11	
POODOO	FC-2140 ALARM AND ABORT	ENTRY	3	
POODOO	FC-2060 WAITLIST	CALLED	9	
POODOO	FC-2300 ORB INTEGRATION	CALLED	22	
POOKLEAN	FC-2020 FRESH START	ENTRY	7	
POSN17C	FC-2530 PRELAUNCH INIT	ENTRY	36	
POSTRURN	FC-2630 TPI TARGETTING	ENTRY	29	
POSTJUMP	FC-2080 INT BNK COMMUN	ENTRY	2	
POST41	FC-2630 TPI TARGETTING	ENTRY	30	
POST41	FC-2681 CLOKTASK-CLOCKJOB	CALLED	5	
POWRSERS	FC-2540 EARTH ORBIT INSERT	CALLED	11	
PRECIFLG	FC-2290 INTEG INITIAL	S-4,6,8		C-4
PRECIFLG	FC-2300 ORB INTEGRATION			C-40
PRECOMP	FC-2440 TVC DAP	ENTRY	7	
PREC/TT	FC-2644 P38-P78; P39-P79	ENTRY	11	
PRECSET	FC-2626 P32, P72 - CSI	CALLED	9	

PRECSET	FC-2630 TPI TARGETTING	CALLED	4		
PRFCSFT	FC-2640 TPM TARGETTING	CALLED	1		
PRECSFT	FC-2644 P3R-P7R: P39-P79	CALLED	10,11		
PREC100	FC-2642 RETURN TO EARTH	ENTRY	34		
PREREAD	FC-2680 THRUST PROGRAMS	CALLED	15		
PREREAD	FC-2683 SERVICFR	ENTRY	3,4,11,15		
PREREAD	FC-2700 P47 THRUST MONITOR	CALLED	4		
PREREAD	FC-2760 ENTRY PROGRAMS	CALLED	11		
PREREAD1	FC-2683 SERVICER	ENTRY	3		
PREREAD1	FC-2540 EARTH ORBIT INSERT	CALLED	4		
PRESWTCH	FC-2430 TVC ROUTINF5	ENTRY	20		
PREVGAM	FC-2320 TFFCONICS	ENTRY	11		
PREVGAM	FC-2760 ENTRY PROGRAMS	CALLED	14,15		
PRE40.6	FC-2680 THRUST PROGRAMS	ENTRY	44		
PRE40.6	FC-2681 CLOKTASK-CLOCKJDR	CALLED	13		
PRFTRKAT	FC-2190 EXTENDED VERRS	S-3		C-3	T-5
PRFTRKAT	FC-2361 VR9 (R63)	S-3		C-3	T-5
PRFTRKAT	FC-2550 P20 RENDEZVOUS NAV	S-3			
PRIOCHNG	FC-2340 ATTITUDE MANEUVER	CALLED	R		
PRIOCHNG	FC-2370 DAP INTER-SERV ROUT	CALLED	5		
PRIOCHNG	FC-2550 P20 RENDEZVOUS NAV	CALLED	6,19,31		
PRIOCHNG	FC-2650 ORR PARAM DISPLAY	CALLED	2		
PRIOCHNG	FC-2700 P47 THRUST MONITOR	CALLED	5		
PRIOALARM	FC-2140 ALARM AND ABORT	ENTRY	3		
PROCKEY	FC-2200 T4RUPT	CALLED	5		
PROG 21	FC-2580 P21 GRD TRACK DET	ENTRY	2		
PROG20	FC-2550 P20 RENDEZVOUS NAV	ENTRY	3		
PROG22	FC-2590 P22 ORBITAL NAV	ENTRY	2		
PROG52	FC-2720 IMU REALIGN PROG	ENTRY	1		

PROUT	FC-2530 PRELAUNCH INIT	ENTRY	37
PROUT	FC-2540 EARTH ORBIT INSERT	CALLED	5
PTHPREC	FC-2670 TARGET DELTA V PROG	CALLED	2
PTOACSM	FC-2290 INTEG INITIAL	ENTRY	5
PTOALEM	FC-2290 INTEG INITIAL	ENTRY	5
PULSEIMU	FC-2100 SINGLE PREC SUBROUTS	ENTRY	12
P11	FC-2540 EARTH ORBIT INSERT	ENTRY	3
P17	FC-2545 TPI SEARCH PROG	ENTRY	3
P17.1	FC-2545 TPI SEARCH PROG	ENTRY	3
P17.2	FC-2545 TPI SEARCH PROG	ENTRY	5
P17.3	FC-2545 TPI SEARCH PROG	ENTRY	12
P20FLGON	FC-2545 TPI SEARCH PROG	CALLED	3
P20FLGON	FC-2627 P33, P73 - CDH	CALLED	1
P20FLGON	FC-2630 TPI TARGETTING	CALLED	2
P20FLGON	FC-2640 TPM TARGETTING	CALLED	6
P20FLGON	FC-2644 P38-P78; P39-P79	CALLED	3,9
P21FLAG	FC-2580 P21 GRD TRACK DET	S-4	
P22MKFLG	FC-2590 P22 ORBITAL NAV	S-9	C-4
P22SURRB	FC-2600 CISELUNAR MID NAV	CALLED	6
P23	FC-2600 CISELUNAR MID NAV	ENTRY	3
P3XORP7X	FC-2626 P32, P72 - CSI	ENTRY	23
P30	FC-2620 P30, P31	ENTRY	2
P30/P31	FC-2620 P30, P31	ENTRY	2
P31	FC-2620 P30, P31	ENTRY	7
P32	FC-2626 P32, P72 - CSI	ENTRY	2
P33	FC-2627 P33, P73 - CDH	ENTRY	1
P34	FC-2630 TPI TARGETTING	ENTRY	2
P35	FC-2640 TPM TARGETTING	ENTRY	1
P37	FC-2642 RETURN TO EARTH	ENTRY	3

T-3

P38	FC-2644 P38-P78; P39-P79	ENTRY	3	
P39	FC-2644 P38-P78; P39-P79	ENTRY	9	
P39/74SW	FC-2644 P38-P78; P39-P79	S-9		T-6,8
P40CNV85	FC-2680 THRUST PROGRAMS	CALLED	11	
P40CNV85	FC-2681 CLOKTASK-CLOCKJOB	CALLED	4	
P40CSM	FC-2630 TPI TARGETTING	ENTRY	4	
P40RCS	FC-2630 TPI TARGETTING	ENTRY	29	
P40RCS	FC-2681 CLOKTASK-CLOCKJOB	CALLED	7	
P41CSM	FC-2630 TPI TARGETTING	ENTRY	5	
P47BODY	FC-2700 P47 THRUST MONITOR	ENTRY	5	
P47CSM	FC-2700 P47 THRUST MONITOR	ENTRY	3	
P51	FC-2710 P51, P53 IMU ORIENT	ENTRY	2	
P52LS	FC-2720 IMU REALIGN PROG	ENTRY	7	
P72	FC-2626 P32, P72 - CSI	ENTRY	2	
P73	FC-2627 P33, P73 - CDH	ENTRY	1	
P74	FC-2630 TPI TARGETTING	ENTRY	2	
P75	FC-2640 TPM TARGETTING	ENTRY	1	
P76SUR1	FC-2670 TARGET DELTA V PROG	ENTRY	3	
P77	FC-2545 TPI SEARCH PROG	ENTRY	3	
P78	FC-2644 P38-P78; P39-P79	ENTRY	3	
P79	FC-2644 P38-P78; P39-P79	ENTRY	9	
QUICTRIG	FC-2681 CLOKTASK-CLOCKJOB	CALLED	4	
QUIKDSP	FC-2200 T4RUPT	ENTRY	46	
QUIKREAD	FC-2683 SERVICER	ENTRY	12	
QUITFLAG	FC-2290 INTEG INITIAL			C-3 T-3
QUITFLAG	FC-2300 ORB INTEGRATION			T-3
RADSTALL	FC-2550 P20 RENDEZVOUS NAV	CALLED	32	
RANGERD	FC-2550 P20 RENDEZVOUS NAV	ENTRY	32	
RATELIM	FC-2460 ROLL AUTOPILOT	ENTRY	4	

RCSATT	FC-2370 DAP INTER-SERV ROUT	CALLED 3		
RCSATT	FC-2380 RCS DAP INIT	ENTRY 2		
RCSATT	FC-2390 RCS DAP PHASE 2	CALLED 1,2		
RCSATT	FC-2400 RCS DAP JET SHEET	CALLED 16		
RCSADAPON	FC-2370 DAP INTER-SERV ROUT	ENTRY 3		
RCSADAPON	FC-2020 FRESH START	CALLED 31		
RCSADAPON	FC-2380 RCS DAP INIT	CALLED 2		
RCSADAPON	FC-2460 ROLL AUTDPILOT	CALLFD 2		
RCSADAPON	FC-2680 THRUST PRDGRAMS	CALLED 25		
RCSADAPON	FC-2681 CLDKTASK-CLCKJOB	CALLED 9,13		
RCSADAPIP	FC-2370 DAP INTER-SERV ROUT	ENTRY 3		
RCSFLAGS	FC-2350 MANEUV CALC & STEER	S-10	C-26	
RCSFLAGS	FC-2370 DAP INTER-SERV ROUT	S-3,15,14	C-14	T-14
RCSFLAGS	FC-2380 RCS DAP INIT	S-2,3,8,5	C-8,5	T-3,5
RCSFLAGS	FC-2390 RCS DAP PHASE 2	S-1	C-1,7	T-1,2,3,4,7
RCSFLAGS	FC-2400 RCS DAP JET SELECT	S-17	C-16	T-17
RCSFLAGS	FC-2430 TVC ROUTINES	S-5		
RCSFLAGS	FC-2540 EARTH ORBIT INSERT	S-4,17,20		
RCSUP	FC-2380 RCS DAP INIT	ENTRY 2		
RDCDUS	FC-2720 IMU REALIGN PRNG	ENTRY 27		
READACCS	FC-2683 SERVICER	ENTRY 6		
READCDUK	FC-2350 MANEUV CALC & STEER	ENTRY 24		
READCDUK	FC-2340 ATTITUDE MANEUVER	CALLED 5		
READPIPS	FC-2100 SINGLE PREC SUBRDUTS	ENTRY 4		
RECT.1	FC-2600 CISLUNAR MID NAV	ENTRY 17		
RECTIFY	FC-2300 ORB INTEGRATION	ENTRY 43		
RECTIFY	FC-2290 INTEG INITIAL	CALLED 8,9		
RECTIFY	FC-2610 MEASUREMENT INCORP	CALLED 11		
RECTIFY+	FC-2290 INTEG INITIAL	CALLED 14		

RECTINIT	FC-2300 ORB INTEGRATION	ENTRY	40	
RECTOUT	FC-2290 INTEG INITIAL	CALLED	9	
REDD	FC-2530 PRELAUNCH INIT	ENTRY	31	
REDDRCS	FC-2380 RCS DAP INIT	ENTRY	2	
REDDSAT	FC-2540 EARTH ORBIT INSERT	ENTRY	20	
REDDSAT	FC-2370 DAP INTER-SERV ROUT	CALLFD	4	
REDDTVC	FC-2430 TVC ROUTINES	ENTRY	12	
REEFLG	FC-2720 IMU REALIGN PROG			T-20
REFAZE10	FC-2760 ENTRY PROGRAMS	CALLED	7	
REFSMFLG	FC-2200 T4RUPT			C-32,33
REFSMFLG	FC-2540 EARTH ORBIT INSERT	S-8		
REFSMFLG	FC-2550 P20 RENDEZVOUS NAV			T-6,31
REFSMFLG	FC-2600 CISLUNAR MID NAV			T-4
REFSMFLG	FC-2620 P30, P31			T-5,9
REFSMFLG	FC-2626 P32, P72 - CSI			T-6
REFSMFLG	FC-2710 P51, P53 IMU ORIENT	S-6		C-6
REFSMFLG	FC-2720 IMU REALIGN PROG	S-4,5		C-3
REINTFLA	FC-2670 TARGET DELTA V PROG	S-3		
REINTFLG	FC-2140 ALARM AND ABORT			C-6
REINTFLG	FC-2290 INTEG INITIAL			C-13
REINTFLG	FC-2300 ORB INTEGRATION	S-33,38		
REINTFLG	FC-2610 MEASUREMENT INCOR	S-7		
RELDSP	FC-2020 FRESH START	CALLFD	32,37,42	
RENDWFLG	FC-2290 INTEG INITIAL			C-14
RENDWFLG	FC-2300 ORB INTEGRATION			C-37
RENDWFLG	FC-2550 P20 RENDEZVOUS NAV	S-23		T-4,21,23
RENDWFLG	FC-2590 P22 ORBITAL NAV			C-3,11
RENDWFLG	FC-2600 CISLUNAR MID NAV			C-6
RENDWFLG	FC-2605 NAV EXTENDED VERBS			C-5,7

REPLACER FC-2400 RCS DAP JET SELECT	ENTRY	19		
REPLACFY FC-2400 RCS DAP JET SELECT	ENTRY	19		
REPL1 FC-2540 EARTH ORBIT INSERT	ENTRY	6		
RERFADAC FC-2683 SERVICER	ENTRY	10		
RESETX2 FC-2310 CONIC SUBROUTINES	ENTRY	30		
RESTARTS FC-2020 FRESH START	ENTRY	43		
RETROFLG FC-2642 RETURN TO EARTH	S-16		C-16	T-31
RLIMTEST FC-2440 TVC DAP	ENTRY	15		
RNDREFDR FC-2200 T4RUPT	CALLED	31,32		
RNDVZFLG FC-2200 T4RUPT			C-33	
RNDV7FLG FC-2550 P20 RENDEZVOUS NAV	S-3		C-8	T-8,17
RNDVZFLG FC-2590 P22 ORBITAL NAV			C-3	
RNDVZFLG FC-2600 CISLUNAR MID NAV			C-3	
RNDVZFLG FC-2683 SERVICER				T-20
ROLLDAP FC-2460 ROLL AUTOPILOT	ENTRY	1		
ROLLTIME FC-2400 RCS DAP JET SELECT	ENTRY	9		
RRODAP FC-2430 TVC ROUTINES	CALLED	7		
ROTA FC-2730 R52, R53, R56	ENTRY	10		
ROTATE FC-2626 P32, P72 - CSI	ENTRY	9		
ROUTINER FC-2070 SERVICE ROUTINES	ENTRY	12		
RPOFLAG FC-2290 INTEG INITIAL	S-8			
RPOFLAG FC-2300 ORB INTEGRATION	S-22			T-44
RP-T0-R FC-2290 INTEG INITIAL	CALLED	21		
RP-T0-R FC-2300 ORB INTEGRATION	CALLED	20		
RP-T0-R FC-2590 P22 ORBITAL NAV	CALLED	7,14		
RP-T0-R FC-2595 LUNAR LAND SELECT	CALLED	10,11		
RP-T0-R FC-2720 IMU REALIGN PROG	CALLED	7		
RP-T0-R FC-2730 R52, R53, R53	CALLED	9		
RTEVN FC-2642 RETURN TO EARTH	ENTRY	28		

RVCON	FC-2290 INTEG INITIAL	ENTRY 9	
RVSU	FC-2310 CONIC SUBROUTINES		T-22
RVSU	FC-2545 TPI SEARCH PROG	S-6	
RVSU	FC-2595 LUNAR LAND SELECT	S-13	
RVSU	FC-2626 P32, P72 - CSI	S-13,14	
RVSU	FC-2627 P33, P73 - CDH		C-8
RVSU	FC-2630 TPI TARGETTING	S-4	
RVSU	FC-2642 RETURN TO EARTH	S-37	C-13,27
R-TD-RP	FC-2300 DRB INTEGRATION	CALLED 15	
R-TD-RP	FC-2590 P22 ORBITAL NAV	CALLED 13,21	
R02B0TH	FC-2190 PINBALL	CALLED 2,3	
R02B0TH	FC-2360 -S-RAND ANTENNA	CALLED 3	
R02B0TH	FC-2361 VR9 (R63)	CALLED 2	
R02B0TH	FC-2550 P20 RENDEZVOUS NAV	CALLED 3	
R02B0TH	FC-2590 P22 ORBITAL NAV	CALLED 3	
R02B0TH	FC-2680 THRUST PROGRAMS	CALLED 6	
R02B0TH	FC-2700 P47 THRUST MONITOR	CALLED 3	
R02B0TH	FC-2720 IMU REALIGN PROG	CALLED 1	
R02B0TH	FC-2760 ENTRY PROGRAMS	CALLED 10	
R21MARK	FC-2550 P20 RENDEZVOUS NAV	S-18	C-18
R21MARK	FC-2780 ENT DIG AUTOPILOT		T-7
R22	FC-2550 P20 RENDEZVOUS NAV	ENTRY 19	
R23CSM	FC-2550 P20 RENDEZVOUS NAV	ENTRY 18	
R23FLG	FC-2550 P20 RENDEZVOUS NAV	S-17	C-17 T-17,18,25
R23.55	FC-2600 CISLUNAR MID NAV	ENTRY 10	
R31FLAG	FC-2325 RENDEZ PAR DISPLAY	S-2	C-2 T-3,4
R36	FC-2631 R36 (V90)	ENTRY 3	
R51	FC-2720 IMU REALIGN PROG	ENTRY 18	
R52	FC-2730 R52, R53, R56	ENTRY 2	

R52	FC-2550 P20 RENDEZVOUS NAV	CALLED 7		
R52	FC-2590 P22 ORBITAL NAV	CALLED 4		
R52	FC-2600 Cislunar MID NAV	CALLED 8		
R52	FC-2720 IMU REALIGN PRNG	CALLED 19		
R53	FC-2730 R52, R53, R56	ENTRY 11		
R53	FC-2600 Cislunar MID NAV	CALLED 4		
R53	FC-2710 P51, P53 IMU ORIENT	CALLED 4		
R53FLAG	FC-2730 R52, R53, R56	S-11		T-3
R55	FC-2720 IMU REALIGN PRNG	ENTRY 26		
R56	FC-2730 R52, R53, R56	ENTRY 14		
R56	FC-2710 P51, P53 IMU ORIENT	CALLED 4		
R56	FC-2720 IMU REALIGN PRNG	CALLFD 19		
R57	FC-2242 OPTICS CAL ROUTINE	ENTRY 1		
R57	FC-2600 Cislunar MID NAV	CALLED 4,8		
R57FLAG	FC-2600 Cislunar MID NAV	S-8	C-3,9	T-8
R60CSM	FC-2340 ATTITUDE MANEUVER	ENTRY 2		
R60CSM	FC-2190 PINBALL	CALLED 3		
R60CSM	FC-2330 CREW DEF MANEUVER	CALLED 3		
R60CSM	FC-2361 V89 (R63)	CALLED 3		
R60CSM	FC-2550 P20 RENDEZVOUS NAV	CALLED 10		
R60CSM	FC-2600 Cislunar MID NAV	CALLED 8		
R60CSM	FC-2680 THRUST PROGRAMS	CALLED 8		
R61CSM	FC-2550 P20 RENDEZVOUS NAV	ENTRY 10		
R61CSM	FC-2730 R52, R53, R53	CALLED 4		
R62DISP	FC-2330 CREW DEF MANEUVER	ENTRY 3		
R63	FC-2190 EXTENDED VERRS	ENTRY 4		
R63	FC-2361 V89 (R63)	ENTRY 4		
R63	FC-2550 P20 RENDEZVOUS NAV	CALLED 11		
SATSTICK	FC-2540 EARTH ORBIT INSERT	ENTRY 21		

SATSTKIN FC-2370 DAP INTER-SERV ROUT	ENTRY 4		
SATSTKIN FC-2540 EARTH ORBIT INSERT	ENTRY 19		
SAVEFLG FC-2600 CISLUNAR MID NAV	S-9	C-4	T-6
SRANDANT FC-2360 -S-RAND ANTENNA	ENTRY 3		
SCNDSIL FC-2626 P32, P72 - CSI	ENTRY 21		
SELFCMU FC-2630 TPI TARGETTING	ENTRY 17		
SELFCMU FC-2626 P32, P72 - CSI	CALLED 2		
SELFCMU FC-2627 P33, P73 - CDH	CALLED 1		
SFLFCMU FC-2640 TPM TARGETTING	CALLED 1		
SELECTMU FC-2644 P38-P78; P39-P79	CALLED 4,9		
SELFCHK FC-2080 INT RNK COMMUN	ENTRY 3		
SELFCHK FC-2120 AGC SELFCHCK	ENTRY 2		
SERVEXIT FC-2683 SERVICER	ENTRY 21		
SERVFXIT FC-2682 STEERING	CALLED 4,5		
SERVEXIT FC-2700 P47 THRUST MONITOR	CALLED 7		
SERVICER FC-2683 SERVICER	ENTRY 13		
SERVNDUT FC-2760 ENTRY PROGRAMS	CALLED 7		
SETCDARS FC-2200 T4RUPT	CALLED 43		
SETGWLST FC-2530 PRELAUNCH INIT	ENTRY 14		
SETINTG FC-2600 CISLUNAR MID NAV	ENTRY 14		
SETISSW FC-2200 T4RUPT	ENTRY 30		
SETJTAG FC-2683 SERVICER	CALLED 7		
SETMAXDR FC-2370 DAP INTER-SERV ROUT	ENTRY 16		
SETMAXDR FC-2630 TPI TARGETTING	ENTRY 25		
SETMAXDR FC-2020 FRESH START	CALLED 25		
SETMINDR FC-2370 DAP INTER-SERV ROUT	ENTRY 16		
SETMINDR FC-2630 TPI TARGETTING	ENTRY 7		
SETMINDR FC-2020 FRESH START	CALLED 25		
SETRE FC-2590 P22 ORBITAL NAV	CALLED 24		

SETTS	FC-2380 RCS DAP INIT	ENTRY	2		
SETVIARS	FC-2020 FRESH START	CALLED	19		
SET1/PDT	FC-2720 IMU REALIGN PROG	CALLED	23		
SGNAGREE	FC-2100 SINGLE PREC SUBROUTS	ENTRY	5		
SGNAGREE	FC-2300 ORB INTEGRATION	CALLED	4		
SGNAGREE	FC-2631 R36 (V90)	CALLED	6		
SGNAGREE	FC-2710 P51, P53 IMU ORIENT	CALLED	9		
SHOW	FC-2530 PRELAUNCH INIT	ENTRY	25		
SIGNMPAC	FC-2100 SINGLE PREC SUBROUTS	ENTRY	14		
SIGNMPAC	FC-2300 ORB INTEGRATION	CALLED	5		
SIGNMPAC	FC-2320 TFFCONICS	CALLED	9		
SIGNMPAC	FC-2350 MANEUV CALC & STEER	CALLED	7,16,17,18,19,20		
SKIPVHF	FC-2550 P20 RENDEZVOUS NAV			C-32	T-34
SLAPI	FC-2020 FRESH START	ENTRY	2		
SLOPES W	FC-2310 CONIC SUBROUTINES	S-10,14		C-36	T-12,18,36
SLOWFLG	FC-2642 RETURN TO EARTH	S-4		C-4	T-20
SMALLMP	FC-2370 DAP INTER-SERV ROUT	ENTRY	20		
SMCDURES	FC-2550 P20 RENDEZVOUS NAV	CALLED	13		
SMNR	FC-2190 PINBALL	CALLED	4		
SMNR	FC-2360 -S-RAND ANTENNA	CALLED	4		
SMNR	FC-2550 P20 RENDEZVOUS NAV	CALLED	14		
SMNR	FC-2682 STEERING	CALLED	11		
SMNR	FC-2700 P47 THRUST MONITOR	CALLED	8		
SOLNSW	FC-2310 CONIC SUBROUTINES	S-12,19,21,23		C-10,14,24	
SOMEERRR	FC-2530 PRELAUNCH INIT	ENTRY	37		
SOMERR2	FC-2530 PRELAUNCH INIT	ENTRY	37		
SOPTION	FC-2120 AGC SELF-CHECK	ENTRY	13		
SPCOS	FC-2110 SINGLE PREC SUBROUTS	ENTRY	2		
SPSPIN	FC-2110 SINGLE PREC SUBROUTS	ENTRY	2		

SPSOFF	FC-2630 TPI TARGETTING	ENTRY	27		
SPSOFF	FC-2020 FRFSH START	CALLED	30		
SPSOFF	FC-2681 CLOKTASK-CLOCKJOB	CALLED	9,12		
SR30.1	FC-2650 ORB PARAM DISPLAY	ENTRY	15		
SR52.1	FC-2730 R52, R53, R56	ENTRY	6		
STARLISH	FC-2370 DAP INTER-SERV ROUT	ENTRY	?		
STARIND	FC-2710 P51, P53 IMU ORIENT	S-6		C-4	T-5
STARIND	FC-2720 IMU REALIGN PROG	S-1R			T-19,20
SOURCEFLG	FC-2550 P20 RENDEZVOUS NAV	S-33		C-20	T-24,26,27 29,30
STARTFMJ	FC-2760 ENTRY PROGRAMS	CALLED	2		
STARTSR?	FC-2020 FRESH START	ENTRY	8		
STARTSIR	FC-2020 FRESH START	ENTRY	8		
STARTSW	FC-2020 FRESH START	ENTRY	2		
STATEFLG	FC-2140 ALARM AND ABORT			C-6	
STATEFLG	FC-2290 INTEG INITIAL	S-3		C-3	
STATEFLG	FC-2300 ORB INTEGRATION	S-37		C-3,3R	T-3R
STATEFLG	FC-2550 P20 RENDEZVOUS NAV	S-7			
STATEFLG	FC-2590 P22 ORBITAL NAV	S-10,18			
STATEFLG	FC-2600 CISELUNAR MID NAV	S-14			
STATINT	FC-2290 INTEG INITIAL	ENTRY	3		
STATINT1	FC-2290 INTEG INITIAL	ENTRY	3		
STEERING	FC-2683 SERVICER	CALLED	15		
STEERSW	FC-2680 THRUST PROGRAMS	S-23			
STEERSW	FC-2691 CLOKTASK- CLOCKJOB	S-10			
STEERSW	FC-2682 STEERING			C-12,13	T-9
STICKCHK	FC-2370 DAP INTER-SERV ROUT	ENTRY	16		
STICKCHK	FC-2540 EARTH ORBIT INSERT	CALLED	21		
STIKFLAG	FC-2370 DAP INTER-SERV ROUT			C-11	

STIKFLAG FC-2390 RCS DAP PHASE 2	S-2		
STOPRATE FC-2350 MANEUVR CALC & STEER	ENTRY 26		
STOPRATF FC-2020 FRESH START	CALLED 21,25		
STOPRATE FC-2550 P20 RENDEZVOUS NAV	CALLED 9		
STRKTST1 FC-2450 STROKE TEST PKG	ENTRY 1		
STROKON FC-2450 STROKE TEST PKG	ENTRY 1		
STRULLSW FC-2680 THRUST PROGRAMS	S-21	C-21	T-23
STSHOSUM FC-2120 AGC SELFCHK	ENTRY 7		
SIIPDACL FC-2080 INT BNK COMMUN	ENTRY 3		
SIIPDACL FC-2120 AGC SELFCHK	CALLED 9		
SIIPERSW FC-2080 INT BNK COMMUN	ENTRY 2		
SURFFLAG FC-2290 INTEG INITIAL			T-4,5,18
SURFFLAG FC-2325 RENDEZ PAR DISPLAY			T-R,9,10
SVDWN1 FC-2290 INTEG INITIAL	CALLED 5		
SVDWN1 FC-2610 MEASUREMENT INCRP	CALLED 11		
SVDWN2 FC-2290 INTEG INITIAL	CALLED 5		
SVDWN2 FC-2610 MEASUREMENT INCRP	CALLFD 11		
SWCALL FC-2080 INT BNK COMMUN	ENTRY 1		
SWICHQVR FC-2430 TVC ROUTINES	ENTRY 20		
SWICHQVR FC-2370 DAP INTER-SERV ROUT	CALLED 7		
SWRETURN FC-2080 INT BNK COMMUN	ENTRY 1		
SWTOVR FC-2430 TVC ROUTINES	S-20	C-3	
SXTMARK FC-2730 R52, R53, R53	CALLED 11,14		
SXTNR FC-2325 RENDEZ PAR DISPLAY	CALLED 6		
SXTNR FC-2550 P20 RENDEZVOUS NAV	CALLED 38		
SXTNR FC-2730 R52, R53, R53	CALLD 13		
SXTSM FC-2730 R52, R53, R56	ENTRY 13		
SXTSM FC-2710 P51, P53 IMU ORIENT	CALLED 5		
SXTSM FC-2720 IMU REALIGN PROG	CALLED 19		

SYSTEMST	FC-2530 PRELAUNCH INIT	ENTRY	31		
S11.1	FC-2540 FARTH ORBIT INSERT	ENTRY	18		
S11.1	FC-2700 P47 THRUST MONITOR	CALLED	6		
S17.1	FC-2545 TPI SEARCH PRDG	ENTRY	3		
S17.2	FC-2545 TPI SEARCH PRDG	ENTRY	6		
S22.1	FC-2590 P22 ORBITAL NAV	FNTRY	9		
S30.1	FC-2620 P30, P31	ENTRY	2		
S31.1	FC-2620 P30, P31	ENTRY	7		
S32.1F1	FC-2626 P32, P72 - CSI			C-11,21	T-12
S32.1F2	FC-2626 P32, P72 - CSI	S-11,21		C-18	T-18
S32.1F3A	FC-2626 P32, P72 - CSI	S-18,19		C-11,21	T-12,18,21
S32/33.X	FC-2626 P32, P72 - CSI	ENTRY	8		
S32/33.1	FC-2626 P32, P72 - CSI	ENTRY	5		
S32/33.1	FC-2627 P33, P73 - CDH	CALLED	4		
S32.1F3B	FC-2626 P32, P72 - CSI	S-11,19		C-18,21	T-12,18,21
S33/34.1	FC-2630 TPI TARGETTING	ENTRY	6		
S33/34.1	FC-2627 P33, P73 - CDH	CALLED	3		
S33-34.1	FC-2630 TPI TARGETTING	ENTRY	6		
S34/35.1	FC-2630 TPI TARGETTING	ENTRY	6		
S34/35.1	FC-2640 TPM TARGETTING	CALLED	1		
S34/35.1	FC-2644 P38-P78; P39-P79	CALLED	11		
S34/35.2	FC-2630 TPI TARGETTING	ENTRY	11		
S34/35.2	FC-2640 TPM TARGETTING	CALLED	2		
S34/35.3	FC-2630 TPI TARGETTING	ENTRY	13		
S34/35.4	FC-2630 TPI TARGETTING	ENTRY	16		
S34/35.5	FC-2630 TPI TARGETTING	ENTRY	16		
S34/35.5	FC-2640 TPM TARGETTING	CALLED	2		
S3435.25	FC-2630 TPI TARGETTING	ENTRY	11		
S3435.25	FC-2644 P38-P78; P39-P79	CALLED	6,10		

S40.1	FC-2680 THRUST PROGRAMS	ENTRY	32	
S40.13	FC-2630 TPI TARGETTING	ENTRY	17	
S40.13	FC-2681 CLOKTASK-CLOCKJOB	CALLED	14	
S40.14	FC-2370 DAP INTER-SERV ROUT	ENTRY	10	
S40.14	FC-2380 RCS DAP INIT	CALLED	6	
S40.14	FC-2460 ROLL AUTOPILOT	CALLED	6	
S40.15	FC-2430 TVC ROUTINES	CALLED	3,8	
S40.2,3	FC-2680 THRUST PROGRAMS	ENTRY	40	
S40.6	FC-2680 THRUST PROGRAMS	ENTRY	44	
S41.1	FC-2700 P47 THRUST MONITOR	ENTRY	8	
S41.1	FC-2682 STEERING	CALLED	5	
S41.2	FC-2370 DAP INTER-SERV ROUT	ENTRY	8	
S41.2	FC-2380 RCS DAP INIT	CALLED	6	
S41.2	FC-2460 ROLL AUTOPILOT	CALLED	6	
S50	FC-2720 IMU REALIGN PRG	ENTRY	11	
S52.2	FC-2720 IMU REALIGN PRG	ENTRY	9	
S52.3	FC-2720 IMU REALIGN PRG	ENTRY	10	
TAR EREF	FC-2530 PRELAUNCH INIT	ENTRY	45	
TARGDRVE	FC-2530 PRELAUNCH INIT	ENTRY	43	
TARG1FLG	FC-2340 ATTITUDE MANEUVER			T-8
TARG1FLG	FC-2550 P20 RENDEZVOUS NAV	S-6		
TARG1FLG	FC-2590 P22 ORBITAL NAV			C-7
TARG1FLG	FC-2600 CISELUNAR MID NAV			C-3
TARG1FLG	FC-2720 IMU REALIGN PRG	S-18		
TARG1FLG	FC-2730 R52, R53, R56			T-3,4,6
TARG2FLG	FC-2590 P22 ORBITAL NAV	S-7		
TARG2FLG	FC-2600 CISELUNAR MID NAV			C-3
TARG2FLG	FC-2710 P51, P53 IMU ORIENT			C-4
TARG2FLG	FC-2720 IMU REALIGN PRG	S-18		

TARG2FLG FC-2730 R52, R53, R56			T-6
TASKOVER FC-2060 WAITLIST	ENTRY 18		
TERMINFL FC-2730 R52, R53, R56		C-2,12	T-4
TESTLOOP FC-2300 ORR INTEGRATION	ENTRY 3		
TESTLOOP FC-2290 INTEG INITIAL	CALLED 8		
TESTXACT FC-2190 PINBALL	CALLED 2		
TESTXACT FC-2325 RENDEZ PAR DISPLAY	CALLED 2		
TESTXACT FC-2330 CREW DEF MANEUVER	CALLED 2		
TESTXACT FC-2360 -S-RAND ANTENNA	CALLED 2		
TESTXACT FC-2361 V89 (R63)	CALLED 2		
TESTXACT FC-2370 DAP INTER-SERV ROUT	CALLED 5		
TESTXACT FC-2595 LUNAR LAND SELECT	CALLED 3		
TESTXACT FC-2605 NAV EXTENDED VERRS	CALLED 2		
TESTXACT FC-2631 R36 (V90)	CALLED 2		
TESTXACT FC-2650 ORR PARAM DISPLAY	CALLED 2		
TFFCONIC FC-2320 TFFCONICS	ENTRY 3		
TFFCONIC FC-2760 ENTRY PROGRAMS	CALLED 12		
TFFCONMU FC-2320 TFFCONICS	ENTRY 3		
TFFCONMU FC-2650 ORR PARAM DISPLAY	CALLED 16		
TFFRP/RA FC-2320 TFFCONICS	ENTRY 4		
TFFRP/RA FC-2650 ORR PARAM DISPLAY	CALLED 16		
TFF/TRIG FC-2320 TFFCONICS	ENTRY 11		
TFF/TRIG FC-2760 ENTRY PROGRAMS	CALLED 12,14		
TFFSW FC-2320 TFFCONICS	S-5	C-5	T-5
THISPREC FC-2620 P30, P31	CALLED 3		
THISPREC FC-2631 R36 (V90)	CALLED 4		
THISPREC FC-2650 ORR PARAM DISPLAY	CALLED 7		
THISPREC FC-2680 THRUST PROGRAMS	CALLED 38		
TICKTEST FC-2650 ORR PARAM DISPLAY	ENTRY 14		

TIGAVEG	FC-2630 TPI TARGETTING	ENTRY	15	
TIGRLNK	FC-2630 TPI TARGETTING	ENTRY	14	
TIGNOW	FC-2630 TPI TARGETTING	ENTRY	30	
TIGON	FC-2700 P47 THRUST MONITOR	ENTRY	4	
TIG-0	FC-2630 TPI TARGETTING	ENTRY	20	
TIG-5	FC-2630 TPI TARGETTING	ENTRY	16	
TIMERAD	FC-2310 CONIC SUBROUTINES	ENTRY	23	
TIMFRAD	FC-2642 RETURN TO EARTH	CALLED	27,37	
TIMERFLG	FC-2620 P30, P31	S-6,10		C-6,10 .
TIMESTEP	FC-2300 ORB INTEGRATION	ENTRY	6	
TIMETHET	FC-2310 CONIC SUBROUTINES	ENTRY	22	
TIMETHFT	FC-2545 TPI SEARCH PROG	CALLED	7	
TIMETHET	FC-2595 LUNAR LAND SELECT	CALLED	13	
TIMETHET	FC-2626 P32, P72 - CSI	CALLED	13,14	
TIMETHET	FC-2627 P33, P73 - CDH	CALLED	5	
TIMETHET	FC-2630 TPI TARGETTING	CALLED	5	
TIMETHFT	FC-2642 RETURN TO EARTH	CALLED	13	
TIMETHET	FC-2644 P38-P78; P39-P79	CALLED	11	
TIMFLAG	FC-2681 CLOKTASK- CLOCKJOB			T-3
TIMRFLAG	FC-2680 THRUST PROGRAMS	S-R		C-28,31
TLIM	FC-2200 T4RUPT	ENTRY	28	
TNONTEST	FC-2200 T4RUPT	ENTRY	33	
TORQUE	FC-2530 PRELAUNCH INIT	ENTRY	25	
TPAGREE	FC-2680 THRUST PROGRAMS	CALLED	19	
TRACKFLG	FC-2200 T4RUPT			C-32,33
TRACKFLG	FC-2340 ATTITUDE MANEUVER			T-R
TRACKFLG	FC-2545 TPI SEARCH PROG	S-3		
TRACKFLG	FC-2550 P20 RENDEZVOUS NAV	S-3		C-8 T-6,8,17,31
TRACKFLG	FC-2620 P30, P31	S-2,7		

TRACKFLG FC-2626 P32, P72 - CSI	S-2		
TRACKFLG FC-2627 P33, P73 - CDH	S-1		
TRACKFLG FC-2630 TPI TARGETTING		S-2	
TRACKFLG FC-2640 TPM TARGETTING	S-1		
TRACKFLG FC-2644 P38-P78; P39-P79	S-3		
TRACKFLG FC-2670 TARGET DFLTA V PROG	S-1		
TRACKFLG FC-2720 IMU REALIGN PROG		C-1	
TRACKFLG FC-2730 R52, R53, R56			T-4
TRANSANG FC-2545 TPI SEARCH PROG	ENTRY 14		
TRANSP1 FC-2100 SINGLE PREC SURROUTS	ENTRY 13		
TRANSP2 FC-2100 SINGLE PREC SURROUTS	ENTRY 13		
TRFAIL0F FC-2070 SFRVICE ROUTINES	ENTRY 13		
TRFAIL0F FC-2550 P20 RENDEZVOUS NAV	CALLED 33		
TRFAIL0F FC-2605 NAV EXTENDED VERRS	CALLED 7		
TRFAIL0N FC-2070 SFRVICE ROUTINES	ENTRY 13		
TRFAIL0N FC-2550 P20 RENDEZVOUS NAV	CALLED 32		
TRINFLAG FC-2730 R52, R53, R56	S-2,3	C-3	T-3
TTG70 FC-2630 TPI TARGETTING	ENTRY 31		
TVCDAPI0N FC-2430 TVC ROUTINES	ENTRY 1		
TVCDAPI0N FC-2680 THRUST PROGRAMS	CALLED 22		
TVCEXEC FC-2430 TVC ROUTINES	ENTRY 7		
TVCINIT FC-2430 TVC ROUTINES	ENTRY 1		
TVC7AP FC-2630 TPI TARGETTING	ENTRY 28		
TVC7AP FC-2070 FRESH START	CALLED 31		
TVC2AP-1 FC-2681 CLOK1ASK-CLOCKJOB	CALLED 5,7		
TWIDDLE FC-2060 WAITLIST	ENTRY 9		
T3RUPT FC-2060 WAITLIST	ENTRY 16		
T4RUPT FC-2200 T4RUPT	ENTRY 3		
T5IDLOC FC-2020 FRESH START	ENTRY 17		

T5IDL0C	FC-2380 RCS DAP INIT	ENTRY	2	
T5PHASE	FC-2460 ROLL AUTOPILOT	CALLED	2	
T5PHASE2	FC-2390 RCS DAP PHASE 2	ENTRY	1	
T5PHASF2	FC-2380 RCS DAP INIT	CALLED	2	
T6PR0GM	FC-2390	ENTRY	10	
T6SETUP	FC-2400 RCS DAP JET SELECT	ENTRY	15	
T6START	FC-2400 RCS DAP JET SELECT	ENTRY	17	
T6START	FC-2380 RCS DAP INIT	CALLED	7	
T6START	FC-2460 ROLL AUTOPILOT	CALLED	7	
UPACTOFF	FC-2020 FRESH START	CALLED	36	
UPACTOFF	FC-2550 P20 RENDEZVOUS NAV	CALLED	12	
UPDATFLG	FC-2545 TPI SEARCH PROG	S-3,4,12,13	C-3,5	
UPDATFLG	FC-2550 P20 RENDEZVOUS NAV	S-3	C-8	T-31,34
UPDATFLG	FC-2620 P30, P31	S-2,7	C-2,7	
UPDATFLG	FC-2626 P32, P72 - CSI	S-2,3	C-7	
UPDATFLG	FC-2627 P33, P73 - CDH	S-4		
UPDATFLG	FC-2630 TPI TARGETTING	S-2,16		
UPDATFLG	FC-2640 TPM TARGETTING	S-1		
UPDATFLG	FC-2644 P38-P78; P39-P79	S-3,6,7	C-7,9	
UPDATFLG	FC-2720 IMU REALIGN PROG		C-1	
UPDATFLG	FC-2730 R52, R53, R56			T-4
UPENT2	FC-2070 SERVICE ROUTINES	ENTRY	2	
UPFLAG	FC-2070 SERVICE ROUTINES	ENTRY	4	
UPLOCKFL	FC-2150 KEYRUPT AND UPRUPT	S-7	C-8	T-8
UPRUPT	FC-2150 KEYRUPT AND UPRUPT	ENTRY	5	
UPSVFLAG	FC-2290 INTEG INITIAL		C-15	T-14
UPTMFAST	FC-2200 T4RUPT	ENTRY	42	
USEPI0S	FC-2290 INTEG INITIAL	ENTRY	21	
USPRCADR	FC-2080 INT BNK COMMUN	ENTRY	5	

VIS TO 2 FC-2100 SINGLE PREC SUBROUTS	ENTRY	6		
VAC5STOR FC-2020 FRESH START	ENTRY	27		
VAC5STOR FC-2140 ALARM AND ABORT	CALLED	3,5		
VALMIS FC-2530 PRELAUNCH INIT	ENTRY	24		
VARALARM FC-2140 ALARM AND ABORT	ENTRY	3		
VARALARM FC-2200 T4RUPT	CALLED	30		
VARALARM FC-2626 P32, P72 - CSI	CALLED	22		
VARALARM FC-2642 RETURN TO EARTH	CALLED	45		
VARDELAY FC-2060 WAITLIST	ENTRY	10		
VECPDINT FC-2340 ATTITUDE MANEUVER	ENTRY	5		
VECPDINT FC-2190 PINBALL	CALLED	5		
VECPDINT FC-2361 VR9 (R63)	CALLED	5		
VECSGNAG FC-2100 SINGLE PREC SUBROUTS	ENTRY	12		
VEHUPFLG FC-2550 P20 RENDEZVOUS NAV			C-3	T-4,5,21,24, 25,28,35
VEHUPFLG FC-2590 P22 ORBITAL NAV	S-15			
VEHUPFLG FC-2600 CISELUNAR MID NAV	S-12			
VEHUPFLG FC-2610 MEASUREMENT INCOR				T-10,11
VERR65 FC-2360 -S-BAND ANTENNA	ENTRY	2		
VFLAG FC-2720 IMU REALIGN PRDG	S-13,16		C-16	T-14,16
VGAMCALC FC-2320 TFFCOMICS	ENTRY	11		
VGAMCALC FC-2760 ENTRY PROGRAMS	CALLED	13		
VHFRFLAG FC-2550 P20 RENDEZVOUS NAV				T-20
VHFRFLG FC-2605 NAV EXTENDED VERBS	S-7		C-7	
VHHDOT FC-2540 EARTH ORBIT INSERT	ENTRY	18		
VHHDOT FC-2683 SERVICER	CALLED	15		
VINTFLAG FC-2290 INTEG INITIAL	S-4,6,7,16,19		C-4,6,7,18	T-R
VINTFLAG FC-2300 ORB INTEGRATION				T-33,38
VINTFLAG FC-2550 P20 RENDEZVOUS NAV	S-7		C-4,5,21	

VINTFLAG FC-2580 P21 GRD TRACK DET	S-3	C-3	
VINTFLAG FC-2590 P22 ORBITAL NAV	S-10,18		
VINTFLAG FC-2600 CISELUNAR MID NAV	S-14		
VNDSPLY FC-2644 P38-P78; P39-P79	ENTRY 12		
VNPD0H FC-2626 P37, P72 - CSI	CALLED 2,4		
VNPD0H FC-2627 P33, P73 - CDH	CALLED 1		
VN1645 FC-2626 P37, P72 - CSI	ENTRY 6		
VN1645 FC-2627 P33, P73 - CDH	CALLED 1,4		
VN1645 FC-2630 TPI TARGETTING	CALLED 3		
VN1645 FC-2640 TPM TARGETTING	CALLED 1,2		
VN1645 FC-2642 RETURN TO EARTH	CALLED 14		
V1ST02S FC-2340 ATTITUDE MANEUVER	CALLED 7		
V1ST02S FC-2350 MANEUVER CALC & STEER	CALLED 10		
V1ST02S FC-2540 EARTH ORBIT INSERT	CALLED 14		
V1ST02S FC-2340 ATTITUDE MANEUVER	CALLED 7		
V2T100 FC-2642 RETURN TO EARTH	ENTRY 17		
V37 FC-2020 FRESH START	ENTRY 30		
V37FLAG FC-2140 ALARM AND ABORT			T-5,11
V37FLAG FC-2320 TFFCONICS			T-14
V37FLAG FC-2325 RENDEZ PAR DISPLAY			T-8
V37FLAG FC-2683 SERVICER	S-3	C-19	
V37KLEAN FC-2020 FRESH START	ENTRY 7		
V37XED FC-2020 FRESH START	ENTRY 40		
V50N18FL FC-2550 P20 RENDEZVOUS NAV	S-3	C-10	T-16
V54E FC-2550 P20 RENDEZVOUS NAV	ENTRY 17		
V56E FC-2550 P20 RENDEZVOUS NAV	ENTRY 8		
V57E FC-2550 P20 RENDEZVOUS NAV	ENTRY 17		
V59FLAG FC-2242 OPTICS CAL ROUTINE	S-1,3	C-1,3	
V60 FC-2370 DAP INTER-SERV ROUT	ENTRY 12		

V61	FC-2370 DAP INTER-SERV ROUT	ENTRY	17		
V62	FC-2370 DAP INTER-SERV ROUT	ENTRY	12		
V63	FC-2370 DAP INTER-SERV ROUT	ENTRY	13		
VR2CALL	FC-2650 ORB PARAM DISPLAY	ENTRY	4		
VR2EMFLG	FC-2650 ORR PARAM DISPLAY	S-6,8,11		C-6,8,11	T-11,12,14
VR2FLAGS	FC-2650 ORR PARAM DISPLAY	S-10		C-4	T-4,14
VR2PERF	FC-2650 ORR PARAM DISPLAY	ENTRY	2		
VR9CALL	FC-2190 EXTENDED VERRS	ENTRY	2		
VR9CALL	FC-2361 VR9 (R63)	ENTRY	2		
VR9PERF	FC-2190 EXTENDED VERBS	ENTRY	2		
VR9PERF	FC-2361 VR9 (R63)	ENTRY	2		
V90PERF	FC-2631 R36 (V9D)	ENTRY	2		
V94FLAG	FC-2600 CISLUNAR MID MAV	S-R		C-3,9	
V960NFLG	FC-2290 INTEG INITIAL			C-3	
V97E	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	11		
V97P	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	10		
V97T	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	8		
V99E	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	7		
V99P	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	6		
V99T	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	5		
WAITLIST	FC-2060 WAITLIST	ENTRY	9		
XDELVFLG	FC-2620 P30, P31	S-1,6		C-10	
XDELVFLG	FC-2626 P32, P72 - CSI	S-9			
XDELVFLG	FC-2627 P33, P73 - CDH	S-6			
XDELVFLG	FC-2630 TPI TARGETTING			C-16	
XDELVFLG	FC-2642 RETURN TO EARTH			C-14	
XDELVFLG	FC-2644 P38-P78; P39-P79			C-7	
XDELVFLG	FC-2680 THRUST PROGRAMS				T-4,32
XDELVFLG	FC-2682 STEERING				T-6

YAWDAP	FC-2440 TVC DAP	ENTRY	6,9		
YAWTIM	FC-2400 RCS DAP JET SELECT	ENTRY	13		
YCOPY	FC-2430 TVC ROUTINES	CALLED	12		
YCOPY	FC-2440 TVC DAP	ENTRY	13		
ZERDICDU	FC-2200 T4RUPT	CALLED	34,36		
ZERDING	FC-2530 PRELAUNCH INIT	ENTRY	35		
ZEROJET	FC-2370 DAP INTER-SERV ROUT	CALLED	2,4		
ZEROJET	FC-2540 EARTH ORBIT INSERT	CALLED	19		
ZMEASURE	FC-2600 CISLUNAR MID NAV	S-17		C-17	T-15
(JETSFLG	FC-2370 DAP INTER SERV ROUT	S-9		C-9	
-1CHK	FC-2120 AGC SELFCHK	ENTRY	16		
1/PIPA	FC-2683 SERVICER	CALLED	13		
1S TO 2S	FC-2100 SINGLE PREC SUBROUTS	ENTRY	5		
1 TO SUB	FC-2100 SINGLE PREC SUBROUTS	ENTRY	8		
2ERANK	FC-2120 AGC SELFCHK	ENTRY	6		
2PHSCHNG	FC-2030 PHASE TABLE MAINT	ENTRY	11		
22DSPFLG	FC-2590 P22 ORBITAL NAV			C-16	T-16
2V1S TO	FC-2100 SINGLE PREC SUBROUTS	ENTRY	7		
3AXISFLG	FC-2190 EXTENDED VERBS			C-3	
3AXISFLG	FC-2330 CREW DEF MANEUVER	S-3			
3AXISFLG	FC-2340 ATTITUDE MANEUVER			C-4	T-2,3
3AXISFLG	FC-2361 VR9 (R63)			C-3	
3AXISFLG	FC-2550 P20 RENDEZVOUS NAV			C-10	
3AXISFLG	FC-2600 CISLUNAR MID NAV			C-7	
3AXISFLG	FC-2680 THRUST PROGRAMS			C-8	
340CHECK	FC-2310 CONIC SUBROUTINES	ENTRY	30		
3ELAYJOB	FC-2650 ORB PARAM DISPLAY	CALLED	12		
3DWT04DW	FC-2590 P22 ORBITAL NAV	ENTRY	33		
**ENDJOB					

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Group 23B	<u>J. Kaloostian</u> A. Bancroft A. Bartlett C. Beals N. Brodeur T. Crocker J. Goode	<u>IL7-221L</u> R. Haslam B. Ireland J. Laird N. Neville W. Ostanek R. Whittredge	12
Group 23B	<u>D. Lutkevich</u> J. Allen C. Babicki G. Beck W. Danforth R. Daniel F. Decain R. Entes N. Fisher J. Flaherty J. Glendenning J. Good	<u>IL7-228</u> H. Hubbard H. Maher H. Nayar G. Pope J. Reed (20) J. Seiler J. Klawsnik D. Sprague F. Williams P. Wolff	40
Group 23B	<u>C. Taylor</u> B. Bramlay A. Carter M. Cramer T. Crowley V. Demery D. Densmore S. Eliassen A. Engel (2) M. Hamilton	<u>IL7-221L</u> E. Hughes D. Hsiung S. Rosenberg P. Rye J. Saponaro J. Stoppelman J. Vella S. Zeldin	18
Group 23H	<u>B. Lynn</u> S. Goldberger G. Kossuth	<u>IL7-234A</u> J. O'Connor	3
Group 23C	<u>T. Carlton</u> R. Bairnsfather D. Fraser G. Kalan D. Keene	<u>IL11-102</u> A. Penchuk R. Schlundt R. Stengel J. Turnbull	8

Group 23D	<u>F. McGann</u> G. Dimock S. Drake J. Dunbar K. Griggs I. Johnson R. Kiburz F. Leone R. Metzinger	<u>IL7-332</u> E. Olsson S. Schroeder R. Schulte A. Sewall W. Starnicki F. Walsh W. Woolsey	15
Group 23D	<u>S. Prangley</u> J. Nevins	<u>IL7-209</u>	1
Group 23P	<u>C. Mitaris</u> G. Cherry S. Copps	<u>IL7-213</u> R. Larson	3
Group 23P	<u>A. Rubin</u> D. Hoag	<u>IL7-252</u> L. Larson	2
Group 23P	<u>E. Johnson</u> R. Ragan	<u>IL7-248</u> W. Stameris	2
Group 23S	<u>P. Amsler</u> M. Adams W. Day P. Felleman M. Johnston	<u>IL7-240</u> H. McOuat R. Strunce R. Werner R. White	8
Group 23T	<u>D. Farrell</u> G. Edmonds K. Goodwin E. Grace K. Kido A. Laats	<u>IL7-140</u> J. Lawrence R. Lones V. Megna P. Sarda N. Sears	10
Group 23N	<u>G. Grover</u> E. Blanchard L. B. Johnson G. Ogletree	<u>IL11-202</u> T. Parr W. Tanner	5
Group 23H	<u>S. Davis</u> S. Davis	<u>IL7-272</u> S. Deutsch	2
Group 33	<u>J. Hargrove</u> L. Drane K. Glick M. Johnson	<u>IL7-111</u> A. Kosmala P. Mimno S. Savatsky	6
Group 23P	<u>J. Sutherland</u> K. Greene	<u>IL7-266</u> G. Stupps	2
APOLLO Library			2
MIT/IL Library			2

INDEX - SECTION 17

ACCOMP	FC-2300 ORR INTEGRATION	ENTRY	9		
ACROLL	FC-2400 RCS DAP JET SELECT	ENTRY	5		
ACTIVE	FC-2626 P32, P72 - CSI	CALLED	16		
ACTIVE	FC-2627 P33, P73 - CDH	CALLED	2		
ACTLIM	FC-2440 TVC DAP	ENTRY	16		
ADVANCE	FC-2626 P32, P72 - CSI	ENTRY	9		
ADVANCE	FC-2627 P33, P73 - CDH	CALLED	2		
ADVORR	FC-2730 R52, R53, R56	ENTRY	5		
ADVORR	FC-2590 P22 ORBITAL NAV	CALLED	7		
ADVTRK	FC-2730 R52, R53, R56	S-5		C-2	T-R
AGAIN	FC-2680 THRUST PROGRAMS	ENTRY	38		
AGAIN	FC-2620 P30, P31	CALLED	7		
AHFNDROT	FC-2390 RCS DAP PHASE 2	ENTRY	4		
ALARM	FC-2020 FRESH START	CALLED	20,32		
ALARM	FC-2140 ALARM AND ABORT	ENTRY	3		
ALARM	FC-2200 T4RUPT	CALLED	6,15,16,29,32,33,41,42		
ALARM	FC-2627 P33, P73 - CDH	CALLED	3		
ALARM	FC-2682 STEERING	CALLED	10		
ALARM	FC-2683 SERVICER	CALLED	13		
ALARM	FC-2760 ENTRY PROGRAMS	CALLED	11		
ALARM2	FC-2140 ALARM AND ABORT	ENTRY	3		
ALARUMS	FC-2545 TPI SEARCH PROG	ENTRY	13		
ALFLT	FC-2530 PRELAUNCH INIT	ENTRY	16		
ALFLT1	FC-2530 PRELAUNCH INIT	ENTRY	16		
ALLOOP	FC-2530 PRELAUNCH INIT	ENTRY	15		
ALM/END	FC-2450 STROKE TEST PKG	CALLED	1		
ALM/FND	FC-2605 NAV EXTENDED VERBS	CALLED	2,6		
ALMXITA	FC-2626 P32, P72 - CSI	ENTRY	22		

ALWAYS	FC-2530 PRELAUNCH INIT	ENTRY	20		
AMRGUPDT	FC-2370 DAP INTER-SERV ROUT	ENTRY	17		
AMRGUPDT	FC-2380 RCS DAP INIT	CALLED	4,8		
AMRGUPDT	FC-2460 ROLL AUTOPILOT	CALLED	8		
AMQDNFLG	FC-2290 INTEG INITIAL	S-20		C-20	T-17,18
AMQDNFLG	FC-2540 EARTH ORBIT INSERT				T-18
AMQDNFLG	FC-2650 ORR PARAM DISPLAY				T-8,11
APSESW	FC-2310 CONIC SUBROUTINES	S-24		C-24	
APSIDES	FC-2310 CONIC SUBROUTINES	ENTRY	38		
ASTNFLAG	FC-2680 THRUST PROGRAMS				T-20
ASTNFLAG	FC-2681 CLOKTASK- CLOCKJOB	S-6		C-13	T-6
ATERJOB	FC-2540 EARTH ORBIT INSERT	ENTRY	10		
ATOPCSM	FC-2290 INTEG INITIAL	ENTRY	5		
ATOPCSM	FC-2300 ORR INTEGRATION	CALLED	33,38		
ATOPLEM	FC-2290 INTEG INITIAL	ENTRY	5		
ATOPLEM	FC-2300 ORR INTEGRATION	CALLED	33,38		
ATOPOTH	FC-2670 TARGET DELTA V PROG	CALLED	4		
ATTCHFLG	FC-2370 DAP INTER-SERV ROUT	S-8		C-8	
AUGEKUGL	FC-2320 TFFCONICS	ENTRY	15		
AUGEKUGL	FC-2642 RETURN TO EARTH	CALLED	31		
AVAFLAGA	FC-2644 P3R-P7R; P39-P79	CALLED	3,9		
AVEGFLAG	FC-2650 ORR PARAM DISPLAY				T-3,4
AVEGFLAG	FC-2683 SERVICER	S-3			T-7
AVEGFLAG	FC-2760 ENTRY PROGRAMS				T-10
AVEMIDSW	FC-2290 INTEG INITIAL	S-16			
AVETUMID	FC-2290 INTEG INITIAL	ENTRY	16		
AVETUMID	FC-2683 SERVICER	CALLED	19		
AVFLAG	FC-2545 TPI SEARCH PROG	S-4		C-4	T-3,4,8
AVFLAG	FC-2620 P30, P31	S-8			

AVFLAG	FC-2626 P32, P72 - CSI	S-2	C-2	
AVFLAG	FC-2627 P33, P73 - CDH	S-1	C-1	
AVFLAG	FC-2630 TPI TARGETTING	S-2	C-2	
AVFLAG	FC-2640 TPM TARGETTING	S-1	C-1	
AVFLAG	FC-2644 P38-P78; P39-P79	S-3	C-3	T-12
AVFLAG	FC-2680 THRUST PROGRAMS	S-33,36		
AVFLAGA	FC-2545 TPI SEARCH PROG	CALLED 3		
AVFLAGA	FC-2627 P33, P73 - CDH	CALLED 1		
AVFLAGA	FC-2630 TPI TARGETTING	CALLED 2		
AVFLAGA	FC-2640 TPM TARGETTING	CALLED 1		
AVFLAGP	FC-2545 TPI SEARCH PROG	CALLED 3		
AVFLAGP	FC-2626 P32, P72 - CSI	ENTRY 2		
AVFLAGP	FC-2627 P33, P73 - CDH	CALLED 1		
AVFLAGP	FC-2630 TPI TARGETTING	CALLED 2		
AVFLAGP	FC-2640 TPM TARGETTING	CALLED 1		
AVFLAGP	FC-2644 P38-P78; P39-P79	CALLED 3,9		
AVGEND	FC-2683 SERVICER	ENTRY 19		
AVKMIDSW	FC-2300 ORR INTEGRATION		C-40	
AXISGEN	FC-2710 P51, P53 IMU ORIENT	CALLED 6		
AXISGEN	FC-2720 IMU REALIGN PROG	CALLED 20		
AZMTHCG1	FC-2530 PRELAUNCH INIT	ENTRY 34		
A-PCHK	FC-2290 INTEG INITIAL	CALLED 21		
A-PCHK	FC-2300 ORR INTEGRATION	ENTRY 38		
RADEND	FC-2550 P20 RENDEZVOUS NAV	CALLED 34		
RAILOUT	FC-2140 ALARM AND ABORT	ENTRY 3		
RAILOUT	FC-2060 WAITLIST	CALLED 13		
RAILOUT	FC-2240 SXTMARK	CALLED 1		
RAILOUT	FC-2242 OPTICS CAL ROUTINE	CALLED 2		
RANKCALL	FC-2080 INT RNK COMMUN	ENTRY 1		

RANKJUMP	FC-2080 INT BNK COMMUN	ENTRY	2		
RDF27	FC-2400 RCS DAP JET SELECT	ENTRY	11		
RDROLL	FC-2400 RCS DAP JET SELECT	ENTRY	7		
RIGTIME	FC-2310 CONIC SUBROUTINES	ENTRY	21		
RLANKET	FC-2190 PINBALL	CALLED	5		
RLANKFT	FC-2242 OPTICS CAL ROUTINE	CALLED	3,4		
RLANKFT	FC-2360 -S-RAND ANTENNA	CALLED	5		
RLANKET	FC-2590 P22 ORBITAL NAV	CALLED	3,6,16		
RLANKET	FC-2595 LUNAR LAND SELECT	CALLED	9		
RLANKET	FC-2600 CISELUNAR MID NAV	CALLED	12		
RLANKET	FC-2626 P32, P72 - CSI	CALLED	2		
RLANKET	FC-2720 IMU REALIGN PRDG	CALLED	18		
RVECTORS	FC-2550 P20 RENDEZVOUS NAV	ENTRY	39		
RVECTORS	FC-2590 P22 ORBITAL NAV	CALLED	15		
CA+ECE	FC-2200 T4RUPT	CALLED	43		
CALCGA	FC-2720 IMU REALIGN PRDG	CALLED	9		
CALCGA	FC-2760 ENTRY PROGRAMS	CALLED	17		
CALCGRAV	FC-2680 THRUST PROGRAMS	CALLED	36		
CALCGRAV	FC-2683 SERVICER	ENTRY	17		
CALCGTA	FC-2540 EARTH ORBIT INSERT	CALLED	13		
CALCGTA	FC-2720 IMU REALIGN PRDG	CALLED	26		
CALCMAN2	FC-2350 MANEUV CALC & STEER	S-9		C-10	T-10
CALCMAN3	FC-2350 MANEUV CALC & STEER	S-9			
CALCNR3	FC-2700 P47 THRUST MONITOR	ENTRY	6		
CALCNR3	FC-2683 SERVICER	CALLED	15		
CALCRVG	FC-2683 SERVICER	ENTRY	16		
CALCSCA	FC-2730 R52, R53, R53	CALLED	7		
CALCSMSC	FC-2720 IMU REALIGN PRDG	ENTRY	25		
CALCTFF	FC-2650 ORB PARAM DISPLAY	CALLED	20		

CALCTFF	FC-2760	ENTRY PROGRAMS	CALLED 12,14
CALCTPER	FC-2320	TFCONICS	ENTRY 5
CALCTPER	FC-2650	ORB PARAM DISPLAY	CALLED 19
CALS3A	FC-2770	IMU REALIGN PROG	ENTRY 22
CCSHOLE	FC-2140	ALARM AND ABORT	ENTRY 3
CDHMVR	FC-2626	P32, P72 - CSI	CALLED 16
CDHMVR	FC-2627	P33, P73 - CDH	ENTRY 5
CDUINC	FC-2100	SINGLE PREC SUBROUTS	ENTRY 10
CDRVE	FC-2200	T4RUPT	ENTRY 4
CDULOGIC	FC-2100	SINGLE PREC SUBROUTS	ENTRY 3
CDULOGIC	FC-2350	MANEUV CALC & STEER	CALLED 22
CDUTOCSM	FC-2340	ATTITUDE MANEUVER	CALLED 5
CDUTODCM	FC-2350	MANEUV CALC & STEER	ENTRY 22
CDUTODCM	FC-2340	ATTITUDE MANEUVER	CALLED 5
CDUTRIG	FC-2325	RENDEZ PAR DISPLAY	CALLED 4
CDUTRIG	FC-2540	EARTH ORBIT INSERT	CALLED 13
CDUTRIG	FC-2550	P20 RENDEZVOUS NAV	CALLED 13,14
CDUTRIG	FC-2700	P47 THRUST MONITOR	CALLED 8
CDUTRIG	FC-2720	IMU REALIGN PROG	CALLED 9,13
CDUTRIG	FC-2730	R52, R53, R53	CALLED 7
CHAZFOGC	FC-2530	PRELAUNCH INIT	ENTRY 33
CHECKCTR	FC-2310	CONIC SUBROUTINES	ENTRY 19
CHECKG	FC-2530	PRELAUNCH INIT	ENTRY 39
CHECKMM	FC-2030	PHASE TABLE MAINT	ENTRY 3
CHECKMM	FC-2240	SXTMARK	CALLED 2,8
CHECKMM	FC-2605	NAV EXTENDED VERBS	CALLED 6
CHECKMM	FC-2730	R52, R53, R53	CALLED 11
CHKCOMED	FC-2530	PRELAUNCH INIT	ENTRY 13
CHKPOOH	FC-2190	PINBALL	CALLED 2

CHKPROH	FC-2330	CREW OFF MANEUVER	CALLED	2		
CHKPROH	FC-2360	-S-BAND ANTENNA	CALLED	2		
CHKPROH	FC-2361	VR9 (R63)	CALLED	2		
CHKPROH	FC-2595	LUNAR LAND SELECT	CALLED	3		
CHKSCODE	FC-2720	IMU REALIGN PRNG	CALLED	18		
CHKSCODE	FC-2730	R52, R53, R56	ENTRY	12		
CHKSDATA	FC-2710	P51, P53 IMU ORIENT	ENTRY	8		
CHKSDATA	FC-2720	IMU REALIGN PRNG	CALLED	20		
CKMID2	FC-2300	ORB INTEGRATION	ENTRY	36		
CKOPTVP	FC-2530	PRELAUNCH INIT	ENTRY	26		
CLEANDSP	FC-2760	ENTRY PROGRAMS	CALLED	6		
CLEARMRK	FC-2020	FRESH START	CALLED	24,36		
CLEARMRK	FC-2240	SXTMARK	CALLED	8		
CLEARMRK	FC-2730	R52, R53, R53	CALLED	5,14		
CLEARMRK	FC-2760	ENTRY PROGRAMS	CALLED	3		
CLOCKJOB	FC-2681	CLOCKTASK- CLOCKJOB	ENTRY	4		
CLOCKTASK	FC-2626	P32, P72 - CSI	CALLED	23		
CLOCKTASK	FC-2680	THRUST PROGRAMS	CALLED	12		
CLOCKTASK	FC-2681	CLOCKTASK- CLOCKJOB	ENTRY	3		
CM DAPARM	FC-2683	SERVICER				T-7
CMDSOUT	FC-2430	TVC ROUTINES	ENTRY	14		
CMOONFLG	FC-2290	INTEG INITIAL	S-5,18		C-5,18	T-5
CMOONFLG	FC-2550	P20 RENDEZVOUS NAV				T-35
CMOONFLG	FC-2590	P22 ORBITAL NAV				T-4,19,20,22 23,24,25,30
CMOONFLG	FC-2600	CISLUNAR MID NAV				T-11,12,17
CMOONFLG	FC-2630	TPI TARGETTING				T-14
CM/DAPIC	FC-2760	ENTRY PROGRAMS	CALLED	4		
CM/DAPON	FC-2760	ENTRY PROGRAMS	CALLED	4		

CM/DSTRY FC-2683 SERVICER		C-19	T-6
CM/DSTRY FC-2760 ENTRY PROGRAMS		C-9	
CM/POSE FC-2683 SERVICER	CALLED 15		
CNTNUP30 FC-2670 P30, P31	ENTRY 6		
CNTRCHK FC-2120 AGC SELF-CHECK	ENTRY 7		
COAALIGN FC-2530 PRELAUNCH INIT	ENTRY 36		
CNGAFLAG FC-2310 CONIC SUBROUTINES	S-22	C-22,33	
CNGAFLAG FC-2595 LUNAR LAND SELECT			T-13
COMPMAT FC-2670 TARGET DELTA V PROG	ENTRY 2		
COMPTGD FC-2620 P30, P31	CALLED 5,10		
COMPTGD FC-2626 P32, P72 - CSI	ENTRY 22		
COMPVER FC-2530 PRELAUNCH INIT	ENTRY 26		
CPHIFLAG FC-2760 ENTRY PROGRAMS		C-17	
CREWMANU FC-2330 CREW DEF MANEUVER	ENTRY 2		
CRS61.1 FC-2550 P20 RENDEZVOUS NAV	ENTRY 11		
CSI/A FC-2626 P32, P72 - CSI	ENTRY 11		
CSMCONIC FC-2190 PINBALL	CALLED 3,4		
CSMCONIC FC-2290 INTEG INITIAL	ENTRY 7		
CSMCONIC FC-2360 -S-BAND ANTENNA	CALLED 3		
CSMCONIC FC-2361 V89 (R63)	CALLED 4		
CSMCONIC FC-2545 TPI SEARCH PROG	CALLED 4,5		
CSMCONIC FC-2590 P22 ORBITAL NAV	CALLED 3		
CSMCONIC FC-2720 IMU REALIGN PROG	CALLED 11		
CSMCONIC FC-2730 R52, R53, R53	CALLED 8,9		
CSPMPREC FC-2290 INTEG INITIAL	ENTRY 6		
CSPMPREC FC-2325 RENDEZ PAR DISPLAY	CALLED 7		
CSPMPREC FC-2590 P22 ORBITAL NAV	CALLED 19		
CSPMPREC FC-2595 LUNAR LAND SELECT	CALLED 5		
CSPMPREC FC-2642 RETURN TO EARTH	CALLED 15		

CSMPREC	FC-2644	P3R-P7R; P39-P79	CALLED	12		
CSMPREC	FC-2720	IMU REALIGN PROG	CALLED	8,10		
CSMSTORE	FC-2545	TPI SFARCH PROG	CALLED	4		
CULTFLAG	FC-2720	IMU REALIGN PROG	S-17		C-17	T-14,15
CULTFLAG	FC-2730	R52, R53, R56				T-7
CURTAINS	FC-2140	ALARM AND ABORT	ENTRY	3		
C33TEST	FC-2200	T4RUPT	ENTRY	38		
DAPRIT1	FC-2370	DAP INTER-SERV ROUT	S-4		C-3	T-2,5,17
DAPRIT1	FC-2430	TVC ROUTINES				T-7
DAPRIT1	FC-2450	STROKE TEST PKG				T-1
DAPRIT1	FC-2540	EARTH ORBIT INSERT	S-19			T-10
DAPRIT1	FC-2680	THRUST PROGRAMS	S-22		C-21	T-27,44
DAPRIT2	FC-2370	DAP INTER-SERV ROUT	S-3,4			T-2,5,17
DAPRIT2	FC-2430	TVC ROUTINES				T-7
DAPRIT2	FC-2450	STROKE TEST PKG				T-1
DAPRIT2	FC-2540	EARTH ORBIT INSERT	S-19			T-10
DAPRIT2	FC-2680	THRUST PROGRAMS			C-21,22	T-27,44
DAPDATR1	FC-2680	THRUST PROGRAMS	S-25		C-7	
DAPDAIR1	FC-2682	STEERING				T-9
DAPDISP	FC-2370	DAP INTER-SERV ROUT	ENTRY	5		
DAPINIT	FC-2430	TVC ROUTINES	ENTRY	6		
DCMTOCDU	FC-2340	ATTITUDE MANEUVER	CALLED	7		
DCMTOCDU	FC-2350	MANEUV CALC & STEER	ENTRY	20		
DELAYJOB	FC-2020	FRESH START	CALLED	31		
DELAYJOB	FC-2070	SERVICE ROUTINES	ENTRY	8		
DELAYJOB	FC-2190	PINBALL	CALLED	5		
DELAYJOB	FC-2325	RENDEZ PAR DISPLAY	CALLED	3		
DELAYJOB	FC-2360	-S-BAND ANTENNA	CALLED	5		
DELAYJOB	FC-2550	P20 RENDEZVOUS NAV	CALLED	31		

DELAYJOB	FC-2626	P32, P72 - CSI	CALLED	6		
DELAYJOB	FC-2650	ORB PAR DISPLAY	CALLED	12		
DELAYJOB	FC-2760	ENTRY PROGRAMS	CALLED	11		
DFLCOMP	FC-2340	ATTITUDE MANEUVER	CALLED	6,7		
DELCOMP	FC-2350	MANEUV CALC & STEER	ENTRY	16		
DFLRSPL	FC-2320	TFFCOMICS	ENTRY	13		
DELRSP	FC-2650	ORB PARAM DISPLAY	CALLED	13		
DFLTME	FC-2310	CONIC SUBROUTINES	ENTRY	25		
DIFEQ+0	FC-2300	ORB INTEGRATION	ENTRY	27		
DIFEQ+1	FC-2300	ORB INTEGRATION	ENTRY	27		
DIFEQ+2	FC-2300	ORB INTEGRATION	ENTRY	32		
DIMDFLAG	FC-2290	INTEG INITIAL	S-4,16		C-3,6,7,8,19	
DIMDFLAG	FC-2300	ORB INTEGRATION			C-37	T-9,12,32
DIMDFLAG	FC-2550	P20 RENDEZVOUS NAV	S-4,21		C-7	
DIMDFLAG	FC-2580	P21 GRD TRACK DET			C-3,4	
DIMDFLAG	FC-2590	P22 ORBITAL NAV	S-10,18		C-11,18	
DIMDFLAG	FC-2600	CISLUNAR MID NAV	S-15		C-14	
DISDVLV	FC-2626	P32, P72 - CSI	ENTRY	8		
DISPLA	FC-2630	TPI TARGETTING	ENTRY	15		
DISPMGA	FC-2620	P30, P31	ENTRY	5		
DIVIDE	FC-2600	CISLUNAR MID NAV	ENTRY	22		
DLY2-1	FC-2060	WAITLIST	ENTRY	10		
DMENFLG	FC-2590	P22 ORBITAL NAV	S-15		C-12,26	T-13,18
DMENFLG	FC-2600	CISLUNAR MID NAV			C-11	
DMENFLG	FC-2610	MEASUREMENT INCOR				T-3,5,8,9,12
DINTFAST	FC-2200	T4RUPT	ENTRY	42		
DOFSTART	FC-2020	FRESH START	ENTRY	3		
DOJ..	FC-2300	ORB INTEGRATION	ENTRY	41		
DOJ..1	FC-2300	ORB INTEGRATION	ENTRY	42		

DOWNENT2	FC-2070	SERVICE ROUTINES	ENTRY	3	
DOWNFLAG	FC-2070	SERVICE ROUTINES	ENTRY	4	
DOWNFLAG	FC-2140	ALARM AND ABORT	CALLED	6,12	
DPAD1)	FC-2370	DAP INTER-SERV ROUT	ENTRY	18	
DPAGRFF	FC-2682	STEERING	CALLED	3	
DRIFTFLG	FC-2200	T4RUPT			C-31,32
DRIFTFLG	FC-2683	SERVICER	S-19		C-3
DRIFTFLG	FC-2710	P51, P53 IMU ORIENT	S-3		
DRIFTFLG	FC-2720	IMU REALIGN PROG	S-4,23		
DSKYFLAG	FC-2150	KEYRUPT AND UPRUPT	S-4		
DSKYFLAG	FC-2200	T4RUPT			T-4
DSPOUTSR	FC-2200	T4RUPT	ENTRY	47	
DSPTAB+1	FC-2070	SERVICE ROUTINES	S-13		C-13
DYNDISP	FC-2681	CLOKTASK- CLOCKJOB	ENTRY	4	
D6DR9FLG	FC-2290	INTEG INITIAL			C-3,16
D6DR9FLG	FC-2300	ORB INTEGRATION			T-33
D6DR9FLG	FC-2550	P20 RENDEZVOUS NAV			C-7
D6DR9FLG	FC-2590	P22 ORBITAL NAV	S-10,18		C-11,18
D6DR9FLG	FC-2600	CISLUNAR MID NAV			C-14
EARROT2	FC-2760	ENTRY PROGRAMS	CALLED	16	
EARTHTR	FC-2530	PRELAUNCH INIT	ENTRY	38	
FARTHTR+3	FC-2530	PRELAUNCH INIT	ENTRY	38	
EARTHTR+3	FC-2540	EARTH ORBIT INSERT	CALLED	5	
EARTHTR*	FC-2530	PRELAUNCH INIT	ENTRY	37	
ECSTEER	FC-2626	P32, P72 - CSI	S-2		
ENABL2	FC-2430	TVC ROUTINES	ENTRY	13	
ENATMA	FC-2370	DAP INTER-SERV ROUT	ENTRY	11	
ENDEXT	FC-2650	ORB PARAM DISPLAY	CALLED	14	
ENDMARK	FC-2242	OPTICS CAL ROUTINE	CALLED	5	

ENDTNON FC-2200 T4RUPT	ENTRY 35		
ENGINOFF FC-2630 TPI TARGETTING	ENTRY 24		
ENGINOFF FC-2682 STEERING	CALLED 3		
ENGNFLG FC-2680 THRUST PROGRAMS	S-20	C-77	
ENG2FLAG FC-2680 THRUST PROGRAMS	S-5	C-4	T-40
ENTRYDSP FC-2760 ENTRY PROGRAMS	S-5,7,8	C-7	
ERADFLAG FC-2320 TFFCONICS		C-14	
ERADFLAG FC-2540 EARTH ORBIT INSERT		C-7	
ERADFLAG FC-2580 P21 GRD TRACK DET		C-5	
ERADFLAG FC-2590 P27 ORBITAL NAV	S-4		
ERADFLAG FC-2595 LUNAR LAND SELECT	S-4,6		
ERADFLAG FC-2600 CISLUNAR MID NAV	S-16		
ERADFLAG FC-2642 RETURN TO EARTH		C-32	
ERADFLAG FC-2720 IMU REALIGN PRDG	S-7		
ERADFLAG FC-2730 R52, R53, R56	S-5		
ERADFLAG FC-2760 ENTRY PROGRAMS		C-9	
ERASCALC FC-2530 PRELAUNCH INIT	ENTRY 42		
ERRORLIM FC-2440 TVC DAP	ENTRY 11,15		
ERTHRVSE FC-2530 PRELAUNCH INIT	ENTRY 41		
ESTIMS FC-2530 PRELAUNCH INIT	ENTRY 11		
ETPIFLAG FC-2630 TPI TARGETTING	S-3	C-3	T-3,4,7
EXDAPOFF FC-2530 PRELAUNCH INIT	ENTRY 31		
EXRSTRT FC-2430 TVC ROUTINES	ENTRY 15		
EXTVBACT FC-2070 SERVICE ROUTINES		C-12	
EXTVBACT FC-2242 OPTICS CAL ROUTINE	S-2		T-2
EXTVBACT FC-2325 RENDEZ PAR DISPLAY	S-5		T-3,5
FXTVBACT FC-2450 ORB PARAM DISPLAY			T-12,14
FALTON FC-2020 FRESH START	CALLED 33		
FALTON FC-2190 PINBALL	CALLED 2		

FALTON	FC-2325 RENDEZ PAR DISPLAY	CALLED 2	
FALTON	FC-2330 CREW DEF MANEUVER	CALLED 2	
FALTON	FC-2360 -S-BAND ANTENNA	CALLED 2	
FALTON	FC-2361 V89 (R63)	CALLFD 2	
FALTON	FC-2550 P20 RENDEZVOUS NAV	CALLED 17	
FALTON	FC-2595 LUNAR LAND SELECT	CALLED 3	
FALTON	FC-2600 CISELUNAR MID NAV	CALLED 4	
FALTON	FC-2605 NAV EXTENDED VERBS	CALLED 2,6	
FALTON	FC-2650 ORR PARAM DISPLAY	CALLED 2	
FAZARS	FC-2290 INTEG INITIAL	CALLED 18	
FRR3	FC-2300 ORR INTEGRATION	ENTRY 28	
FINALFLG	FC-2626 P32, P72 - CSI	S-7	T-3,6
FINALFLG	FC-2627 P33, P73 - CDH		T-4
FINALFLG	FC-2630 TPI TARGETTING		T-16
FINALFLG	FC-2642 RETURN TO EARTH	S-14	
FINALFLG	FC-2644 P38-P78; P39-P79	S-7,9	T-5,6,7,9
FINETIME	FC-2530 PRELAUNCH INIT	ENTRY 40	
FIRSTFLG	FC-2680 THRUST PROGRAMS	S-32	
FIRSTFLG	FC-2682 STEERING		C-16 T-8,15
FISHCALC	FC-2320 TFFCONICS	ENTRY 12	
FISHCALC	FC-2760 ENTRY PROGRAMS	CALLED 12,13, 14	
FIXDELAY	FC-2060 WAITLIST	ENTRY 10	
FREEFLAG	FC-2710 P51, P53 IMU ORIENT	S-8,9	C-8,9 T-6,8
FRESHDAP	FC-2380 RCS DAP INIT	ENTRY 6	
FXFX	FC-2120 AGC SELF CHECK	ENTRY 10	
FWDFLTR	FC-2440 TVC DAP	ENTRY 4	
F2RTE	FC-2642 RETURN TO EARTH	S-20	C-17
GAMCOMP	FC-2300 ORR INTEGRATION	ENTRY 23	
GAMDV10	FC-2642 RETURN TO EARTH	ENTRY 23	

GENTRAN	FC-2020 FRESH START	CALLED 28
GENTRAN	FC-2070 SERVICE ROUTINES	ENTRY 11
GENTRAN	FC-2240 SXTMARK	CALLED 5
GENTRAN	FC-2550 P20 RENDEZVOUS NAV	CALLED 18,20
GENTRAN	FC-2683 SERVICER	CALLED 5,15
GENTRAN	FC-2700 P47 THRUST MONITOR	CALLED 7
GEOM	FC-2310 CONIC SUBROUTINES	ENTRY 34
GETERAD	FC-2320 TFFCONICS	CALLED 12
GETERAD	FC-2600 CISELUNAR MID NAV	CALLED 18
GETERAD	FC-2642 RETURN TO EARTH	CALLED 7
GET+MGA	FC-2620 P30, P31	CALLED 5,9
GET+MGA	FC-2626 P32, P72 - CSI	CALLED 6
GETUM	FC-2550 P20 RENDEZVOUS NAV	ENTRY 38
GETUM	FC-2590 P22 ORBITAL NAV	CALLED 12
GETX	FC-2310 CONIC SUBROUTINES	ENTRY 26
GLOCKMON	FC-2200 T4RUPT	ENTRY 43
GOESTIMS	FC-2530 PRELAUNCH INIT	ENTRY 5
GOINT	FC-2630 TPI TARGETTING	ENTRY 14
GOODEND	FC-2550 P20 RENDEZVOUS NAV	CALLED 34
GOPROG	FC-2020 FRESH START	ENTRY 13
GOPROG2	FC-2020 FRESH START	ENTRY 20
GOTOPROG	FC-2020 FRESH START	ENTRY 24
GTSCPSS1	FC-2530 PRELAUNCH INIT	ENTRY 2
GUESSW	FC-2310 CONIC SUBROUTINES	
GUESSW	FC-2682 STEERING	C-14
GYMDIFSW	FC-2760 ENTRY PROGRAMS	C-9
HACK	FC-2440 TVC DAP	CALLED 1,6
HACK	FC-2450 STROKE TEST PKG	ENTRY 2
HACKWLST	FC-2450 STROKE TEST PKG	ENTRY 2

T-11.16

HAVEGUIDS	FC-26A2	STEERING	CALLED	14		
HIENERGY	FC-2310	CONIC SUBROUTINES	ENTRY	21		
HORIZ	FC-2600	CISLUNAR MID NAV	ENTRY	18		
IRNKCALL	FC-20A0	INT HNK COMMUN	ENTRY	4		
IDLEFAIL	FC-26A1	CLOCKTASK- CLOCKJOB	S-10		C-10	
IDLEFAIL	FC-26A2	STEERING				T-13
IGNFLAG	FC-26A0	THRUST PROGRAMS	S-20			
IGNFLAG	FC-26A1	CLOCKTASK- CLOCKJOB	S-13			T-6
IGNITION	FC-2630	TPI TARGETTING	ENTRY	20		
IGNITION	FC-26A1	CLOCKTASK-CLOCKJOB	CALLED	6		
IMPULSW	FC-26A0	THRUST PROGRAMS	S-17		C-19,21	T-21
IMPULSW	FC-26A2	STEERING	S-13		C-4	T-4
IMURAD	FC-2200	T4RUPT	CALLED	35		
IMUCAGE	FC-2200	T4RUPT	ENTRY	31		
IMUCOARS	FC-2710	P51, P53 IMU ORIENT	CALLED	2		
IMUCOARS	FC-2720	IMU REALIGN PROG	CALLED	23		
IMUFINE2	FC-2710	P51, P53 IMU ORIENT	CALLED	3		
IMUFIN20	FC-2720	IMU REALIGN PROG	CALLED	23		
IMUMDN	FC-2200	T4RUPT	ENTRY	25		
IMUDP	FC-2200	T4RUPT	ENTRY	32		
IMUPII5E	FC-2720	IMU REALIGN PROG	CALLED	26		
IMUSE	FC-2550	P20 RENDEZVOUS NAV			C-8	
IMUSE	FC-2710	P51, P53 IMU ORIENT	S-2			
IMUSEFLA	FC-2200	T4RUPT			C-32	T-34,35
IMUSTALL	FC-2710	P51, P53 IMU ORIENT	CALLED	3		
IMUSTALL	FC-2720	IMU REALIGN PROG	CALLED	23,26		
IMUSTLLG	FC-2530	PRELAUNCH INIT	ENTRY	36		
INCORFLG	FC-2550	P20 RENDEZVOUS NAV	S-22,24		C-28	T-24,27,28
INCORFLG	FC-2590	P22 ORBITAL NAV	S-14		C-17	T-17

INCORP1	FC-2550	P20	RENDEZVOUS NAV	CALLED	26		
INCORP1	FC-2590	P22	ORBITAL NAV	CALLED	15		
INCORP1	FC-2600		CISLUNAR MID NAV	CALLED	11		
INCORP1	FC-2610		MEASUREMENT INCOR	ENTRY	3		
INCORP2	FC-2550	P20	RENDEZVOUS NAV	CALLED	27		
INCORP2	FC-2590	P22	ORBITAL NAV	CALLED	16		
INCORP2	FC-2600		CISLUNAR MID NAV	CALLED	12		
INCORP2	FC-2610		MEASUREMENT INCOR	ENTRY	9		
INCRDUS	FC-2100		SINGLE PREC SUBROUTS	ENTRY	9		
INFINFLG	FC-2310		CONIC SUBROUTINES	S-29		C-29	T-12,18,22
INFINFLG	FC-2595		LUNAR LAND SELECT				T-13
INFINITY	FC-2310		CONIC SUBROUTINES	ENTRY	29		
INITIALW	FC-2550	P20	RENDEZVOUS NAV	ENTRY	36		
INITSUR	FC-2020		FRESH START	ENTRY	25		
INITV	FC-2310		CONIC SUBROUTINES	ENTRY	20		
INITVEL	FC-2545		TPI SEARCH PROG	CALLED	8		
INITVEL	FC-2630		TPI TARGETTING	CALLED	12		
INITVEL	FC-2680		THRUST PROGRAMS	CALLED	39		
INSTALL	FC-2580	P21	GRD TRACK DET	CALLED	3		
INSTALL	FC-2610		MEASUREMENT INCORP	CALLED	7		
INTEGREV	FC-2580	P21	GRD TRACK DET	CALLED	4		
INTEGRV	FC-2290		INTEG INITIAL	ENTRY	8		
INTEGRV	FC-2550	P20	RENDEZVOUS NAV	CALLED	4,5,21,22		
INTEGRV	FC-2580	P21	GRD TRACK DET	CALLED	4		
INTEGRV	FC-2590	P22	ORBITAL NAV	CALLED	12		
INTEGRV	FC-2600		CISLUNAR MID NAV	CALLED	15		
INTEGRVS	FC-2290		INTEG INITIAL	ENTRY	8		
INTEGRVS	FC-2325		RENDEZ PAR DISPLAY	CALLED	9		
INTEGRVS	FC-2630		TPI TARGETTING	CALLED	15		

INTEGRVS FC-2642 RETURN TO EARTH	CALLED 44		
INTEGRV2 FC-2290 INTEG INITIAL	ENTRY 8		
INTEGRV2 FC-2300 ORB INTEGRATION	CALLED 35		
INTFLAG FC-2290 INTEG INITIAL	S-11	C-13	T-10
INTGRATE FC-2300 ORB INTEGRATION	ENTRY 8		
INTGRVS FC-2670 TARGET DELTA V PROG	CALLED 3		
INTINT FC-2626 P32, P72 - CSI	CALLED 3,15,16		
INTINT FC-2627 P33, P73 - CDH	CALLED 2		
INTINT FC-2630 TPI TARGETTING	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-2020 FRESH START	CALLED 35		
INTSTALL FC-2290 INTEG INITIAL	ENTRY 10		
INTSTALL FC-2325 RENDEZ PAR DISPLAY	CALLED 8,9,10		
INTSTALL FC-2550 P20 RENDEZVOUS NAV	CALLED 7,9		
INTSTALL FC-2590 P22 ORBITAL NAV	CALLED 10,18		
INTSTALL FC-2600 CISELUNAR MID NAV	CALLED 14		
INTSTALL FC-2605 NAV EXTENDED VERBS	CALLED 3		
INTSTALL FC-2642 RETURN TO EARTH	CALLED 42,43		
INTSTALL FC-2650 ORB PARAM DISPLAY	CALLED 13		
INTSTALL FC-2670 TARGET DELTA V PROG	CALLED 2,3		
INTWAKE FC-2290 INTEG INITIAL	ENTRY 12		
INTWAKE FC-2300 ORB INTEGRATION	CALLED 40		
INTWAKE FC-2320 TFFCONICS	CALLED 14		
INTWAKE FC-2605 NAV EXTENDED VERRS	CALLED 4		
INTWAKE FC-2610 MEASUREMENT INCORP	CALLED 12		
INTWAKE0 FC-2290 INTEG INITIAL	ENTRY 12		
INTWAKE0 FC-2320 TFFCONICS	CALLED 14		

INTWAKEU FC-2290 INTEG INITIAL	ENTRY 14		
INTWAKEI FC-2670 TARGET DELTA V PRNG	CALLED 4		
INTYPFLA FC-2670 TARGET DELTA V PRNG		C-7	
INTYPFLG FC-2290 INTEG INITIAL	S-7	C-3,6,20	T-8
INTYPFLG FC-2325 RENDEZ PAR DISPLAY	S-8,9	C-8,9	
INTYPFLG FC-2550 P20 RENDEZVOUS NAV		C-7	
INTYPFLG FC-2580 P21 GRD TRACK DET		C-4	
INTYPFLG FC-2590 P22 ORBITAL NAV		C-10,18	
INTYPFLG FC-2600 CISELUMAR MID NAV		C-14	
INTYPFLG FC-2630 TPI TARGETTING	S-14	C-14	
INTYPFLG FC-2642 RETURN TO FARTH	S-42	C-42,43	
ISWCALL FC-2080 INT BNK COMMUN	ENTRY 4		
ISWRETRN FC-2080 INT BNK COMMUN	ENTRY 4		
ITERATOR FC-2310 CONIC SUBROUTINES	ENTRY 36		
ITSWICH FC-2545 TPI SEARCH PRNG	S-10	C-7	T-10
ITSWICH FC-2627 P33, P73 - CDH	S-4		
ITSWICH FC-2630 TPI TARGETTING	S-3	C-3,4	T-4,7
ITURNOM FC-2200 T4RUPT	ENTRY 29		
JETSLFCT FC-2380 RCS DAP INIT	CALLED 2		
JETSLECT FC-2390 RCS DAP PHASE 2	CALLED 10		
JETSLECT FC-2400 RCS DAP JET SELECT	ENTRY 1		
JETSLECT FC-2460 ROLL AUTOPILOT	CALLED 2		
JORSLEEP FC-2290 INTEG INITIAL	CALLED 10		
JORWAKE FC-2290 INTEG INITIAL	CALLED 13		
JORWAKF FC-2670 TARGET DELTA V PRNG	CALLED 10		
JSWITCH FC-2300 ORB INTEGRATION	S-33	C-8	T-8,27
KALCMAN3 FC-2340 ATTITUDE MANEUVER	CALLED 4		
KEPLERN FC-2310 CONIC SUBROUTINES	ENTRY 4		
KEPLERN FC-2300 ORB INTEGRATION	CALLED 31		

KEPPREP	FC-2300 ORR INTEGRATION	ENTRY	29		
KEPPREP	FC-2290 INTEG INITIAL	CALLED	9		
KEYCOM	FC-2150 KEYRUPT AND UPRUPT	ENTRY	4		
KEYCOM	FC-2240 SXTMARK	CALLED	4		
KFYRUPT1	FC-2150 KEYRUPT AND UPRUPT	ENTRY	3		
KFLAG	FC-2545 TPI SEARCH PROG	S-4,5		C-4,5	T-5,6,7,10,11
KLEENEX	FC-2240 SXTMARK	CALLED	8		
KLEENEX	FC-2550 P20 RENDEZVOUS NAV	CALLED	18		
KLEENEX	FC-2730 R52, R53, R53	CALLED	5		
KNOWNFLG	FC-2590 P22 ORBITAL NAV	S-6		C-6	T-7,13
LALOTRV	FC-2320 TFFCONICS	CALLED	14		
LALOTRV	FC-2540 EARTH ORRIT INSERT	CALLED			
LALOTRV	FC-2590 P22 ORBITAL NAV	CALLED	23		
LALOTRV	FC-2600 CISLUNAR MID NAV	CALLED	16		
LALOTRV	FC-2720 IMU REALIGN PROG	CALLED	8		
LALOTRV	FC-2730 R52, R53, R53	CALLED	8		
LAMBERT	FC-2310 CONIC SUBROUTINES	ENTRY	14		
LAMENTER	FC-2310 CONIC SUBROUTINES	ENTRY	35		
LASTRIAS	FC-2683 SERVICER	CALLED	3		
LATAZCHK	FC-2530 PRELAUNCH INIT	ENTRY	47		
LAT-LONG	FC-2580 P21 GRD TRACK DET	CALLED	5		
LAT-LONG	FC-2590 P22 ORBITAL NAV	CALLED	7,20		
LAT-LONG	FC-2595 LUNAR LAND SELECT	CALLED	5,7,10		
LAT-LONG	FC-2642 RETURN TO EARTH	CALLED	33		
LAT-LONG	FC-2720 IMU REALIGN PROG	CALLED	7		
LAT-LONG	FC-2760 ENTRY PROGRAMS	CALLED	9		
LEMCONIC	FC-2190 PINBALL	CALLED	4		
LEMCONIC	FC-2361 V89 (R63)	CALLED	4		
LEMCONIC	FC-2545 TPI SEARCH PROG	CALLED	3,8		

LEMCONIC FC-2730 R52, R53, R53	CALLED R		
LEMPRFC FC-2290 INTEG INITIAL	ENTRY 6		
LEMPREC FC-2325 RENDEZ PAR DISPLAY	CALLED 7,10		
LEMSTORE FC-2545 TPI SFARCH PRG	CALLED 3		
LFTFLGON FC-2530 PRELAUNCH INIT	ENTRY 33		
LINUS FC-2340 ATTITUDE MANEUVER	CALLED R		
LINVEL FC-2300 ORR INTEGRATION	CALLED 44		
LISTINGO FC-2550 P20 RENDEZVOUS NAV	ENTRY 1		
LISTINGO FC-2580 P21 GRD TRACK DET	ENTRY 1		
LISTINGO FC-2605 NAV EXTENDED VFRBS	ENTRY 1		
LISTINGO FC-2760 ENTRY PROGRAMS	ENTRY 1		
LITLSUR FC-2530 PRELAUNCH INIT	ENTRY 46		
LLASRD FC-2720 IMU REALIGN PRG	CALLED 7		
LLASRDA FC-2720 IMU REALIGN PRG	CALLED R		
LMONINFLG FC-2290 INTEG INITIAL	S-5	C-5	T-5
LMONINFLG FC-2550 P20 RENDEZVOUS NAV			T-35
LMPREC FC-2644 P38-P78; P39-P79	CALLED 12		
LOADCOEF FC-2430 TVC ROUTINES	ENTRY 22		
LOADTIME FC-2100 SINGLE PREC SUBROUTS	ENTRY 2		
LOADTIME FC-2190 PINBALL	CALLED 3		
LOADTIME FC-2290 INTEG INITIAL	CALLED 3,19		
LOADTIME FC-2300 ORR INTEGRATION	CALLED 36		
LOADTIME FC-2360 -S-BAND ANTENNA	CALLED 3		
LOADTIME FC-2361 V89 (R63)	CALLED 3		
LOADTIME FC-2550 P20 RENDEZVOUS NAV	CALLED 3,11,19,20		
LOADTIME FC-2580 P21 GRD TRACK DET	CALLED 5		
LOADTIME FC-2590 P22 ORBITAL NAV	CALLED 3,7		
LOADTIME FC-2595 LUNAR LAND SELECT	CALLED 4		
LOADTIME FC-2600 CISELUNAR MID NAV	CALLED 7		

LOADTIME FC-2631 R36 (V90)	CALLED 3	
LOADTIME FC-2640 TPM TARGETTING	CALLED 1	
LOADTIME FC-2650 ORB PARAM DISPLAY	CALLED 6	
LOADTIME FC-2720 IMU REALIGN PROG	CALLFD 5,18	
LOADTIME FC-2730 R52, R53, R53	CALLED 6,9	
LOADTIME FC-2760 ENTRY PROGRAMS	CALLED 3	
LOCSAM FC-2710 P51, P53 IMU ORIENT	CALLFD 7	
LOCSAM FC-2720 IMU REALIGN PROG	ENTRY 11	
LODSAMPT FC-2150 KEYRUPT AND UPRUPT	CALLED 3,5	
LOMAT FC-2630 TPI TARGETTING	ENTRY 14,15	
LOMAT FC-2620 P30, P31	CALLED 3	
LONGCALL FC-2060 WAITLIST	ENTRY 21	
LOWMEMRY FC-2600 CISELUNAR MID NAV	ENTRY 5	
LSPDS FC-2300 ORB INTEGRATION	CALLED 11	
LSPDS FC-2720 IMU REALIGN PROG	CALLED 11	
LUMPOS FC-2300 ORB INTEGRATION	CALLED 45	
LUNAFLAG FC-2580 P21 GRD TRACK DET	S-4	C-4
LUNAFLAG FC-2590 P22 ORBITAL NAV	S-4,20,22,24	C-4,20,22,24
LUNAFLAG FC-2595 LUNAR LAND SELECT	S-4,7	T-10
LUNAFLAG FC-2600 CISELUNAR MID NAV	S-5	C-5 T-17,18
LUNAFLAG FC-2642 RETURN TO EARTH		C-32
LUNAFLAG FC-2730 R52, R53, R56	S-5	
LUNAFLAG FC-2760 ENTRY PROGRAMS		C-9
LUNAFLG FC-2720 IMU REALIGN PROG	S-7	
LUNPOS FC-2190 PINBALL	CALLED 3	
LUNPOS FC-2360 -S-BAND ANTENNA	CALLED 3	
LUNPOS FC-2600 CISELUNAR MID NAV	CALLED 15	
MAINRTNE FC-2644 P38-P78; P39-P79	ENTRY 6	
MAKECADR FC-2080 INT BNK COMMUN	ENTRY 2	

MAKECADR FC-2340 ATTITUDE MANEUVER	CALLFD 2		
MAKECADR FC-2550 P20 RENDEZVOUS NAV	CALLED 10		
MAKECADR FC-2670 TARGET DELTA V PROG	CALLFD 10		
MAKECADR FC-2720 IMU RFALIGN PROG	CALLED 13		
MAKECADR FC-2730 R52, R53, R53	CALLED 6		
MARKCNT FC-2240 SXTMARK	ENTRY 5		
MARKDIF FC-2240 SXTMARK	ENTRY 9		
MARKDISP FC-2240 SXTMARK	CALLED 5		
MARKDISP FC-2242 OPTICS CAL ROUTINE	ENTRY 4		
MARKINDX FC-2720 IMU REALIGN PROG	S-18		
MARKIT FC-2240 SXTMARK	ENTRY 9		
MARKRUPT FC-2240 SXTMARK	ENTRY 4		
MARK2 FC-2240 SXTMARK	ENTRY 6		
MASSPROP FC-2430 TVC ROUTINES	ENTRY 16		
MASSPROP FC-2020 FRESH START	CALLED 31		
MASSPROP FC-2370 DAP INTER-SERV ROUT	CALLED 7		
MASSPROP FC-2680 THRUST PROGRAMS	CALLED 25		
MATMOVE FC-2720 IMU REALIGN PROG	ENTRY 27		
MATMOVE FC-2710 P51, P53 IMU ORIENT	CALLED 6		
MATRXJOB FC-2540 EARTH ORBIT INSERT	ENTRY 7		
MAXCHK FC-2620 P30, P31	CALLED 4,8		
MAXDRFLG FC-2370 DAP INTER-SERV ROUT	S-6	C-6	
MIDAVFLG FC-2290 INTEG INITIAL	S-20		
MIDAVFLG FC-2300 ORB INTEGRATION		C-40	T-32
MIDFLAG FC-2300 ORB INTEGRATION	S-3	C-3	T-6, 10, 3R, 41
MIDGIM FC-2620 P30, P31	CALLED 8		
MIDGIM FC-2680 THRUST PROGRAMS	CALLFD 34,36		
MIDTOAV1 FC-2290 INTEG INITIAL	ENTRY 19		
MIDTOAV1 FC-2680 THRIUST PROGRAMS	CALLED 12		

MIDTNAV2 FC-2290 INTEG INITIAL	ENTRY 19		
MIDTNAV2 FC-2700 P47 THRUST MONITOR	CALLED 3		
MIDTNAV2 FC-2760 ENTRY PROGRAMS	CALLED 10		
MIDIFLAG FC-2290 INTEG INITIAL	S-19	C-19	
MIDIFLAG FC-2300 ORR INTEGRATION			T-36
MINIRFCT FC-2300 ORB INTEGRATION	ENTRY 43		
MINIRECT FC-2290 INTEG INITIAL	CALLED 17		
MINIRECT FC-2670 TARGFT DELTA V PROG	CALLED 4		
MKREJECT FC-2240 SXTMARK	ENTRY 7		
MKRELFAS FC-2240 SXTMARK	ENTRY 3		
MKRELEAS FC-2590 P22 ORBITAL NAV	CALLED 9		
MKRELEAS FC-2710 P51, P53 IMU ORIENT	CALLED 5		
MKRELEAS FC-2720 IMU REALIGN PRNG	CALLED 19		
MKRELEAS FC-2730 R52, R53, R53	CALLED 5		
MKRLEES FC-2550 P20 RENDEZVOUS NAV	CALLED 7		
MKVBS1 FC-2240 SXTMARK	ENTRY 8		
MMDSPLAY FC-2020 FRESH START	CALLED 21		
MOONTHIS FC-2325 RENDEZ PAR DISPLAY			T-8,9
MOONTHIS FC-2610 MEASUREMENT INCOR			T-10
MOVEACSM FC-2610 MEASUREMENT INCORP	CALLED 11		
MOVEALEM FC-2610 MEASUREMENT INCORP	CALLED 11		
MOVEPCSM FC-2610 MEASUREMENT INCORP	CALLED 10		
MOVEPLEM FC-2610 MEASUREMENT INCORP	CALLED 10		
MOONFLAG FC-2290 INTEG INITIAL	S-5,14,21	C-5,14	T-5,8
MOONFLAG FC-2300 ORR INTEGRATION	S-44	C-44	T-11,13,15,19
			31,40,41,44
			45
MOONFLAG FC-2325 RENDEZ PAR DISPLAY	S-8,9	C-8,9	
MOONFLAG FC-2580 P21 GRD TRACK DET	S-4	C-3	

MOONFLAG	FC-2630	TPI TARGETTING	S-14	C-14
MOONFLAG	FC-2642	RETURN TO EARTH		C-43
MOONFLAG	FC-2670	TARGET DELTA V PROG	S-2	C-2
MR.KLEAN	FC-2020	FRESH START	ENTRY	7
MR.KLEAN	FC-2140	ALARM AND ABORT	CALLED	6,13
MXM3	FC-2350	MANEUV CALC & STEER	ENTRY	25
MXM3	FC-2340	ATTITUDE MANEUVER	CALLED	6,7
NBDONLY	FC-2060	WAITLIST	CALLED	20
NBSM	FC-2550	P20 RENDEZVOUS NAV	CALLED	38
NBSM	FC-2730	R52, R53, R53	CALLED	13
*NBSM	FC-2325	RENDE7 PAR DISPLAY	CALLED	5
NEEDFLG	FC-2380	RCS DAP INIT		T-5
NEEDLER	FC-2380	RCS DAP INIT	CALLED	5
NEEDLER	FC-2430	TVC ROUTINES	CALLED	5,7
NEEDLER	FC-2460	ROLL AUTOPILOT	CALLED	5
NEEDLER	FC-2540	EARTH ORBIT INSERT	CALLED	4,16,17,20,21
NEEDLES3	FC-2370	DAP INTER-SERV ROUT	ENTRY	15
NEEDLFLG	FC-2680	DAP INTER SERV ROUT	S-12,13	C-12
NEGP	FC-2310	CONIC SUBROUTINES	ENTRY	21
NEWIFLG	FC-2290	INTEG INITIAL	S-R	
NEWIFLG	FC-2300	ORB INTEGRATION		C-6 T-6
NEWMODEA	FC-2030	PHASE TABLE MAINT	ENTRY	2
NEWMODEA	FC-2020	FRESH START	CALLED	42
NEWMODEX	FC-2030	PHASE TABLE MAINT	ENTRY	2
NEWMODEX	FC-2540	EARTH ORBIT INSERT	CALLED	4
NEWMODEX	FC-2760	ENTRY PROGRAMS	CALLED	3,6,7,8
NEWPHASE	FC-2030	PHASE TABLE MAINT	ENTRY	4
NEWSTATE	FC-2310	CONIC SUBROUTINES	ENTRY	35
NEXTCOL	FC-2300	ORB INTEGRATION	ENTRY	35

NJETSFLG FC-2370 DAP INTER SERV ROUT	S-9	C-9	
NJETSFLG FC-2680 THRUST PROGRAMS			T-5,17
NJFTSFLG FC-2642 RETURN TO EARTH			T-11
NOACY FC-2400 RCS DAP JET SELECT	ENTRY 8		
NOATTOFF FC-2200 T4RUPT	CALLED 34,35		
NORDZ FC-2400 RCS DAP JET SELECT	ENTRY 6		
NODOFLAG FC-2290 INTEG INITIAL	S-3	C-4	
NODOFLAG FC-2140 ALARM AND ABORT		C-6	
NODDOP01 FC-2540 EARTH ORBIT INSERT	S-4		
NOFRANK FC-2120 AGC SELFCECK	ENTRY 6		
NORFHOR FC-2600 CISELUNAR MID NAV	S-6	C-6	T-22
NORMLIZE FC-2683 SERVICER	ENTRY 5		
NORMLIZE FC-2540 EARTH ORBIT INSERT	CALLED 9		
NORMSW FC-2310 CONIC SUBROUTINES		C-33	T-34
NORMSW FC-2620 P30, P31		C-7	
NORMSW FC-2642 RETURN TO EARTH		C-14	
NORMSW FC-2680 THRUST PROGRAMS			T-38
NORMSW FC-2682 STEERING			T-14
NORMUNIT FC-2100 SINGLE PREC SUBROUTS	ENTRY 15		
NORMUNX1 FC-2100 SINGLE PREC SURROUTS	ENTRY 15		
NO2Y FC-2400 RCS DAP JET SELECT	ENTRY 10		
N22ORN17 FC-2370 DAP INTER-SERV ROUT	S-12	C-13	
N22ORN17 FC-2380 RCS DAP INIT			T-5
OPTMODES FC-2070 SERVICE ROUTINES	S-13		
OPTMON FC-2200 T4RUPT	ENTRY 11		
OPTNSW FC-2644 P38-P78; P39-P79	S-4	C-4	T-5
OPTSTALL FC-2730 R52, R53, R53	CALLED 11		
OPTTEST FC-2200 T4RUPT	ENTRY 6		
ORRWFLAG FC-2290 INTEG INITIAL		C-14	T-4,16

ORRWFLAG FC-2300 ORB INTEGRATIUN		C-37	
ORRWFLAG FC-2550 P20 RENDEZVOUS NAV		C-22	
ORRWFLAG FC-2590 P22 ORBITAL NAV		C-39	T-11,18
ORRWFLAG FC-2600 Cislunar MID NAV	S-15		T-14,15
ORRWFLAG FC-2605 NAV EXTENDED VERBS		C-5,7	
ORDFRSW FC-2310 CONIC SUBROUTINES			T-36,37
ORIGCHNG FC-2300 ORB INTEGRATION	ENTRY	44	
OTHPREC FC-2631 R36 (V90)	CALLED	4	
OTHPREC FC-2650 ORB PARAM DISPLAY	CALLED	7	
OVERFFIX FC-2530 PRELAUNCH INIT	FNTRY	36	
PARAM FC-2310 CONIC SUBROUTINES	ENTRY	33	
PARAM FC-2642 RETURN TO EARTH	CALLED	35	
PASSIVE FC-2626 P32, P72 - CSI	CALLED	3	
PASSIVE FC-2627 P33, P73 - CDH	CALLED	2	
PCOPY FC-2430 TVC ROUTINES	CALLED	12	
PCOPY FC-2440 TVC DAP	ENTRY	8	
PDSPFLAG FC-2340 ATTITUDE MANEUVER	S-8		T-4, R
PDSPFLAG FC-2550 P20 RENDEZVOUS NAV	S-10	C-10	T-34
PERIAPD FC-2545 TPI SEARCH PROG	CALLED	9	
PERIAPD FC-2626 P32, P72 - CSI	CALLED	13	
PERIAPD FC-2620 P30, P31	CALLED	4,8	
PERIAPD FC-2626 P32, P72 - CSI	CALLED	16	
PERIAPD FC-2630 TPI TARGETTING	CALLED	5	
PERIAPD FC-2644 P38-P78; P39-P79	CALLED	7	
PFAILOK FC-2200 T4RUPT	CALLED	37	
PFRATFLG FC-2680 THRUST PROGRAMS	S-6		
PFRATFLG FC-2720 IMU REALIGN PROG			C-4,20
PHASCHNG FC-2030 PHASE TABLE MAINT	ENTRY	5	
PICAPAR FC-2720 IMU REALIGN PROG	ENTRY	13	

PINBRNCH	FC-2370	DAP INTER-SERV ROUT	CALLFD	2,5	
PINBRNCH	FC-2605	NAV EXTENDED VERRS	CALLED	2,6,7	
PIPACHK	FC-2530	PRELAUNCH INIT	ENTRY	6	
PIPASR	FC-2683	SERVICER	ENTRY	9	
PIPATASK	FC-2530	PRELAUNCH INIT	ENTRY	7	
PIPFALL	FC-2200	T4RUPT	ENTRY	41	
PIPFREE	FC-2683	SERVICER	CALLED	19	
PIPJORB	FC-2530	PRELAUNCH INIT	ENTRY	8	
PITCHDAP	FC-2440	TVC DAP	ENTRY	2	
PITCHDAP	FC-2430	TVC ROUTINES	CALLED	6	
PITCHTIM	FC-2400	RCS DAP JET SELECT	ENTRY	11	
PLANET	FC-2710	P51, P53 IMU ORIENT	ENTRY	7	
PLANET	FC-2720	IMU REALIGN PRG	CALLED	18,19	
POINTAXS	FC-2600	CISLUNAR MID NAV	ENTRY	13	
POLY	FC-2310	CONIC SUBROUTINES	CALLED	25,28	
POLY	FC-2642	RETURN TO EARTH	CALLED	4,6,11	
POODOO	FC-2140	ALARM AND ABORT	ENTRY	3	
POODOO	FC-2060	WAITLIST	CALLED	9	
POODOO	FC-2300	ORB INTEGRATION	CALLED	22	
POOKLEAM	FC-2020	FRESH START	ENTRY	7	
POSN17C	FC-2530	PRELAUNCH INIT	ENTRY	36	
POSTURN	FC-2630	TPI TARGETTING	ENTRY	29	
POSTJUMP	FC-2080	INT BNK COMMUN	ENTRY	2	
POST41	FC-2630	TPI TARGETTING	ENTRY	30	
POST41	FC-2681	CLOCKTASK-CLOCKJOB	CALLED	5	
POWRSERS	FC-2540	EARTH ORBIT INSERT	CALLED	11	
PRECIFLG	FC-2290	INTEG INITIAL	S-4,6,8		C-4
PRECIFLG	FC-2300	ORB INTEGRATION			C-40 T-5
PRECOMP	FC-2440	TVC DAP	ENTRY	7	

PREC/TT	FC-2444 P38-P7R; P39-P79	ENTRY	11		
PRECSET	FC-2626 P32, P72 - CSI	CALLED	9		
PRECSET	FC-2630 TPI TARGETTING	CALLFD	4		
PRECSET	FC-2640 TPM TARGETTING	CALLFD	1		
PRECSET	FC-2644 P38-P7R; P39-P79	CALLLED	10,11		
PREC100	FC-2642 RETURN TO EARTH	ENTRY	34		
PREREAD	FC-2680 THRUST PROGRAMS	CALLLED	15		
PREREAD	FC-2683 SERVICER	ENTRY	3,4,11,15		
PREREAD	FC-2700 P47 THRUST MONITOR	CALLLED	4		
PREREAD	FC-2760 ENTRY PROGRAMS	CALLLED	11		
PREREAD1	FC-2683 SERVICER	ENTRY	3		
PREREAD1	FC-2540 EARTH ORBIT INSERT	CALLFD	4		
PRESWTCH	FC-2430 TVC ROUTINES	ENTRY	20		
PREVGAM	FC-2320 TFFCOMICS	ENTRY	11		
PREVGAM	FC-2760 ENTRY PROGRAMS	CALLLED	14,15		
PRE40.6	FC-2680 THRUST PROGRAMS	ENTRY	44		
PRE40.6	FC-2681 CLOKTASK-CLOCKJOB	CALLLED	13		
PRFTRKAT	FC-2190 EXTENDED VERRS	S-3		C-3	T-5
PRFTRKAT	FC-2361 VA9 (R63)	S-3		C-3	T-5
PRFTRKAT	FC-2550 P20 RENDEZVOUS NAV	S-3			
PRI0CHNG	FC-2340 ATTITUDE MANUEVER	CALLFD	8		
PRI0CHNG	FC-2370 DAP INTER-SERV ROUT	CALLLED	5		
PRI0CHNG	FC-2550 P20 RENDEZVOUS NAV	CALLLED	6,19,31		
PRI0CHNG	FC-2650 ORB PARAM DISPLAY	CALLLED	7		
PRI0CHNG	FC-2700 P47 THRUST MONITOR	CALLLED	5		
PRI0LARM	FC-2140 ALARM AND ABORT	ENTRY	3		
PROCKEY	FC-2200 T4RUPT	CALLLED	5		
PROG21	FC-2580 P21 GRD TRACK DET	ENTRY	2		
PROG20	FC-2550 P20 RENDEZVOUS NAV	ENTRY	3		

PROG22	FC-2590 P22 ORBITAL NAV	ENTRY 2
PROG57	FC-2720 IMU REALIGN PROG	ENTRY 1
PROUT	FC-2530 PRELAUNCH INIT	ENTRY 37
PROUT	FC-2540 EARTH ORBIT INSERT	CALLED 5
PTHPRFC	FC-2670 TARGET DELTA V PROG	CALLED 2
PTIACSM	FC-2290 INTEG INITIAL	ENTRY 5
PTDALFM	FC-2290 INTEG INITIAL	ENTRY 5
PULSEIMU	FC-2100 SINGLE PREC SUBROUTS	ENTRY 12
P11	FC-2540 EARTH ORBIT INSERT	ENTRY 3
P17	FC-2545 TPI SEARCH PROG	ENTRY 3
P17.1	FC-2545 TPI SEARCH PROG	ENTRY 3
P17.2	FC-2545 TPI SEARCH PROG	ENTRY 5
P17.3	FC-2545 TPI SEARCH PROG	ENTRY 12
P20FLGON	FC-2545 TPI SEARCH PROG	CALLED 3
P20FLGON	FC-2627 P33, P73 - CDH	CALLED 1
P20FLGON	FC-2630 TPI TARGETTING	CALLED 2
P20FLGON	FC-2640 TPM TARGETTING	CALLED 6
P20FLGON	FC-2644 P38-P78; P39-P79	CALLED 3,9
P21FLAG	FC-2580 P21 GRD TRACK DET	S-4
P22MKFLG	FC-2590 P22 ORBITAL NAV	S-9
P22SURRB	FC-2600 CISELUNAR MID NAV	CALLED 6
P23	FC-2600 CISELUNAR MID NAV	ENTRY 3
P3XORP7X	FC-2626 P32, P72 - CSI	ENTRY 23
P30	FC-2620 P30, P31	ENTRY 2
P30/P31	FC-2620 P30, P31	ENTRY 2
P31	FC-2620 P30, P31	ENTRY 7
P32	FC-2626 P32, P72 - CSI	ENTRY 2
P33	FC-2627 P33, P73 - CDH	ENTRY 1
P34	FC-2630 TPI TARGETTING	ENTRY 2

T-3

C-4

P35	EC-2640 TPM TARGETTING	ENTRY	1	
P37	FC-2642 RETURN TO EARTH	ENTRY	3	
P38	EC-2644 P38-P78; P39-P79	ENTRY	3	
P39	FC-2644 P38-P78; P39-P79	ENTRY	9	
P39/79SW	FC-2644 P38-P78; P39-P79	S-9		T-6,8
P40CNVR5	FC-2680 THRUST PROGRAMS	CALLED	11	
P40CNVR5	FC-2681 CLOKTASK-CLOCKJOB	CALLED	4	
P40CSM	FC-2630 TPI TARGETTING	ENTRY	4	
P40RCS	FC-2630 TPI TARGETTING	ENTRY	29	
P40RCS	FC-2681 CLOKTASK-CLOCKJOB	CALLED	7	
P41CSM	FC-2630 TPI TARGETTING	ENTRY	5	
P47RNDY	FC-2700 P47 THRUST MONITOR	ENTRY	5	
P47CSM	FC-2700 P47 THRUST MONITOR	ENTRY	3	
P51	FC-2710 P51, P53 IMU ORIENT	ENTRY	2	
P52LS	FC-2720 IMU REALIGN PRNG	ENTRY	7	
P72	FC-2626 P32, P72 - CSI	ENTRY	2	
P73	FC-2627 P33, P73 - CDH	ENTRY	1	
P74	FC-2630 TPI TARGETTING	ENTRY	2	
P75	FC-2640 TPM TARGETTING	ENTRY	1	
P76SUB1	FC-2670 TARGET DELTA V PRNG	ENTRY	3	
P77	FC-2545 TPI SEARCH PRNG	ENTRY	3	
P78	FC-2644 P38-P78; P39-P79	ENTRY	3	
P79	FC-2644 P38-P78; P39-P79	ENTRY	9	
QUICTRIG	FC-2681 CLOKTASK-CLOCKJOB	CALLED	4	
QUIKDSP	FC-2200 T4RUPT	ENTRY	46	
QUIKREAD	FC-2683 SERVICER	ENTRY	12	
QUITFLAG	FC-2290 INTEG INITIAL			C-3 T-3
QUITFLAG	FC-2300 ORB INTEGRATION			T-3
RADSTALL	FC-2550 P20 RENDEZVOUS NAV	CALLED	32	

RANGERD	FC-2550 P20 RENDEZVOUS NAV	ENTRY	32		
RATELIM	FC-2460 ROLL AUTOPILOT	ENTRY	4		
RCSATT	FC-2370 DAP INTER-SERV ROUT	CALLED	3		
RCSATT	FC-2380 RCS DAP INIT	ENTRY	2		
RCSATT	FC-2390 RCS DAP PHASE 2	CALLED	1,2		
RCSATT	FC-2400 RCS DAP JET SHEFT	CALLED	16		
RCSDAPDN	FC-2370 DAP INTER-SERV ROUT	ENTRY	3		
RCSDAPDN	FC-2020 FRESH START	CALLED	31		
RCSDAPDN	FC-2380 RCS DAP INIT	CALLED	2		
RCSDAPDN	FC-2460 ROLL AUTOPILOT	CALLED	2		
RCSDAPDN	FC-2680 THRUST PROGRAMS	CALLED	25		
RCSDAPDN	FC-2681 CLOKTASK-CLOCKJOB	CALLED	9,13		
RCSDAPUP	FC-2370 DAP INTER-SERV ROUT	ENTRY	3		
RCSFLAGS	FC-2350 MANEUV CALC & STEER	S-10		C-26	
RCSFLAGS	FC-2370 DAP INTER-SERV ROUT	S-3,15,14		C-14	T-14
RCSFLAGS	FC-2380 RCS DAP INIT	S-2,3,8,5		C-8,5	T-3,5
RCSFLAGS	FC-2390 RCS DAP PHASE 2	S-1		C-1,7	T-1,2,3,4,7
RCSFLAGS	FC-2400 RCS DAP JET SELECT	S-17		C-16	T-17
RCSFLAGS	FC-2430 TVC ROUTINES	S-5			
RCSFLAGS	FC-2540 EARTH ORBIT INSERT	S-4,17,20			
RCSIIP	FC-2380 RCS DAP INIT	ENTRY	2		
RDCDIUS	FC-2720 IMU REALIGN PRDG	ENTRY	27		
READACCS	FC-2683 SERVICER	ENTRY	6		
READCDIJK	FC-2350 MANEUV CALC & STEER	ENTRY	24		
READCDIJK	FC-2340 ATTITUDE MANEUVER	CALLED	5		
READPIPS	FC-2100 SINGLE PREC SUBROUTS	ENTRY	4		
RECT.1	FC-2600 CISELUNAR MID NAV	ENTRY	17		
RECTIFY	FC-2300 ORB INTEGRATION	ENTRY	43		
RECTIFY	FC-2290 INTEG INITIAL	CALLED	8,9		

RECTIFY	FC-2610 MEASUREMENT INCORP	CALLFD 11	
RECTIFY+	FC-2290 INTEG INITIAL	CALLFD 14	
RECTOUT	FC-2300 ORR INTEGRATION	ENTRY 40	
RECTOUT	FC-2290 INTEG INITIAL	CALLFD 9	
REDD	FC-2530 PRELAUNCH INIT	ENTRY 31	
REDDRCS	FC-2380 RCS DAP INIT	ENTRY 2	
REDDSAT	FC-2540 EARTH ORBIT INSERT	ENTRY 20	
REDDSAT	FC-2370 DAP INTER-SERV ROUT	CALLED 4	
REDDTVC	FC-2430 TVC ROUTINES	ENTRY 12	
REFFLG	FC-2720 IMU REALIGN PROG		T-20
REFAZE10	FC-2760 ENTRY PROGRAMS	CALLED 7	
REFSMFLG	FC-2200 T4RUPT		C-32,33
RFFSMFLG	FC-2540 EARTH ORBIT INSERT	S-8	
REFSMFLG	FC-2550 P20 RENDEZVOUS NAV		T-6,31
REFSMFLG	FC-2600 CISELUNAR MID NAV		T-4
REFSMFLG	FC-2620 P30, P31		T-5,9
RFFSMFLG	FC-2626 P32, P72 - CSI		T-6
REFSMFLG	FC-2710 P51, P53 IMU ORIENT	S-6	C-6
REFSMFLG	FC-2720 IMU REALIGN PROG	S-4,5	C-3
REINTFLA	FC-2670 TARGET DELTA V PROG	S-3	
REINTFLG	FC-2140 ALARM AND ABORT		C-6
REINTFLG	FC-2290 INTEG INITIAL		C-13
REINTFLG	FC-2300 ORR INTEGRATION	S-33,38	T-10,12
REINTFLG	FC-2610 MEASUREMENT INCOR	S-7	
RELDSP	FC-2020 FRESH START	CALLFD 32,37,42	
RENDWFLG	FC-2290 INTEG INITIAL		C-14
RENDWFLG	FC-2300 ORR INTEGRATION		C-37
RENDWFLG	FC-2550 P20 RENDEZVOUS NAV	S-23	T-4,21,23
RENDWFLG	FC-2590 P22 ORBITAL NAV		C-3,11

RENDWFLG FC-2600 CISLUNAR MID NAV		C-6	
RENDWFLG FC-2605 NAV EXTENDED VERRS		C-5,7	
REPLACER FC-2400 RCS DAP JET SELECT	ENTRY 19		
REPLACEY FC-2400 RCS DAP JET SELECT	ENTRY 19		
REP11 FC-2540 EARTH ORBIT INSERT	ENTRY 6		
REREADAC FC-2683 SERVICER	ENTRY 10		
RESETX2 FC-2310 CONIC SUBROUTINES	ENTRY 30		
RESTARTS FC-2020 FRESH START	ENTRY 43		
RETROFLG FC-2642 RETURN TO EARTH	S-16	C-16	T-31
RLIMTEST FC-2440 TVC DAP	ENTRY 15		
RNDREFDR FC-2200 T4RUPT	CALLED 31,32		
RNDVZFLG FC-2200 T4RUPT		C-33	
RNDVZFLG FC-2550 P20 RENDEZVOUS NAV	S-3	C-8	T-R,17
RNDVZFLG FC-2590 P22 ORBITAL NAV		C-3	
RNDVZFLG FC-2600 CISLUNAR MID NAV		C-3	
RNDVZFLG FC-2683 SERVICER			T-20
ROLLDAP FC-2460 ROLL AUTOPILOT	ENTRY 1		
ROLLTIME FC-2400 RCS DAP JET SELECT	ENTRY 9		
ROLLDAP FC-2430 TVC ROUTINES	CALLED 7		
ROTA FC-2730 R52, R53, R56	ENTRY 10		
ROTATE FC-2626 P32, P72 - CSI	ENTRY 9		
ROUTINER FC-2070 SERVICE ROUTINES	ENTRY 12		
RPOFLAG FC-2290 INTEG INITIAL	S-8		
RPOFLAG FC-2300 ORB INTEGRATION	S-22		T-44
RP-TO-R FC-2290 INTEG INITIAL	CALLED 21		
RP-TO-R FC-2300 ORB INTEGRATION	CALLED 20		
RP-TO-R FC-2590 P22 ORBITAL NAV	CALLED 7,14		
RP-TO-R FC-2595 LUNAR LAND SELECT	CALLED 10,11		
RP-TO-R FC-2720 IMU REALIGN PROG	CALLED 7		

RP-TD-R	FC-2730 R52, R53, R53	CALLED 9	
RTEVN	FC-2642 RETURN TO EARTH	ENTRY 28	
RVCON	FC-2290 INTEG INITIAL	ENTRY 9	
RVSW	FC-2310 CONIC SUBROUTINES		T-22
RVSW	FC-2545 TPI SEARCH PROG	S-6	
RVSW	FC-2595 LUNAR LAND SELFC	S-13	
RVSW	FC-2626 P32, P72 - CSI	S-13,14	
RVSW	FC-2627 P33, P73 - CDH		C-8
RVSW	FC-2630 TPI TARGETTING	S-4	
RVSW	FC-2642 RETURN TO EARTH	S-37	C-13,27
R-TD-RP	FC-2300 ORB INTEGRATION	CALLED 15	
R-TD-RP	FC-2590 P22 ORBITAL NAV	CALLED 13,21	
R02B0TH	FC-2190 PINBALL	CALLED 2,3	
R02B0TH	FC-2360 -S-BAND ANTENNA	CALLED 3	
R02B0TH	FC-2361 V89 (R63)	CALLED 2	
R02B0TH	FC-2550 P20 RENDEZVOUS NAV	CALLED 3	
R02B0TH	FC-2590 P22 ORBITAL NAV	CALLED 3	
R02B0TH	FC-2680 THRUST PROGRAMS	CALLED 6	
R02B0TH	FC-2700 P47 THRUST MONITOR	CALLED 3	
R02B0TH	FC-2720 IMU REALIGN PROG	CALLED 1	
R02B0TH	FC-2760 ENTRY PROGRAMS	CALLED 10	
R21MARK	FC-2550 P20 RENDEZVOUS NAV	S-18	C-18
R21MARK	FC-2780 ENT DIG AUTOPILOT		T-7
R22	FC-2550 P20 RENDEZVOUS NAV	ENTRY 19	
R23CSM	FC-2550 P20 RENDEZVOUS NAV	FNTRY 18	
R23FLG	FC-2550 P20 RENDEZVOUS NAV	S-17	C-17 T-17,18,25
R23.55	FC-2600 C1SLUNAR MID NAV	ENTRY 10	
R31FLAG	FC-2325 RENDEZ PAR DISPLAY	S-2	C-2 T-3,4
R36	FC-2631 R36 (V90)	ENTRY 3	

R51	FC-2720 IMU REALIGN PR0G	ENTRY	18		
R52	FC-2730 R52, R53, R56	ENTRY	2		
R52	FC-2550 P20 RENDEZVOUS NAV	CALLED	7		
R52	FC-2590 P22 ORBITAL NAV	CALLED	4		
R52	FC-2600 CISELUNAR MID NAV	CALLED	8		
R52	FC-2720 IMU REALIGN PR0G	CALLED	19		
R53	FC-2730 R52, R53, R56	ENTRY	11		
R53	FC-2600 CISELUNAR MID NAV	CALLED	4		
R53	FC-2710 P51, P53 IMU ORIENT	CALLED	4		
R53FLAG	FC-2730 R52, R53, R56	S-11			T-3
R55	FC-2720 IMU REALIGN PR0G	ENTRY	26		
R56	FC-2730 R52, R53, R56	ENTRY	14		
R56	FC-2710 P51, P53 IMU ORIENT	CALLED	4		
R56	FC-2720 IMU REALIGN PR0G	CALLED	19		
R57	FC-2242 OPTICS CAL ROUTINE	ENTRY	1		
R57	FC-2600 CISELUNAR MID NAV	CALLED	4,8		
R57FLAG	FC-2600 CISELUNAR MID NAV	S-8		C-3,9	T-8
R60CSM	FC-2340 ATTITUDE MANEUVER	ENTRY	2		
R60CSM	FC-2190 PINBALL	CALLED	3		
R60CSM	FC-2330 CREW DEF MANEUVER	CALLED	3		
R60CSM	FC-2361 V89 (R63)	CALLED	3		
R60CSM	FC-2550 P20 RENDEZVOUS NAV	CALLED	10		
R60CSM	FC-2600 CISELUNAR MID NAV	CALLED	8		
R60CSM	FC-2680 THRUST PROGRAMS	CALLED	8		
R61CSM	FC-2550 P20 RENDEZVOUS NAV	ENTRY	10		
R61CSM	FC-2730 R52, R53, R53	CALLED	4		
R62DISP	FC-2330 CREW DEF MANFUVER	ENTRY	3		
R63	FC-2190 EXTENDED VERRS	ENTRY	4		
R63	FC-2361 V89 (R63)	ENTRY	4		

REF3	FC-2550 P20 RENDEZVOUS NAV	CALLED 11
SATSTICK	FC-2540 EARTH ORBIT INSERT	ENTRY 21
SATSTKON	FC-2370 DAP INTER-SFRV ROUT	ENTRY 4
SATSTKON	FC-2540 EARTH ORBIT INSERT	ENTRY 19
SAVECFLG	FC-2600 CISLUNAR MID NAV	S-9
SRANDANT	FC-2360 -S-BAND ANTENNA	ENTRY 3
SCNDSIDL	FC-2626 P32, P72 - CSI	ENTRY 21
SELECTMU	FC-2630 TPI TARGETTING	ENTRY 17
SELECTMU	FC-2626 P32, P72 - CSI	CALLED 2
SELECTMU	FC-2627 P33, P73 - CDH	CALLED 1
SELECTMU	FC-2640 TPM TARGETTING	CALLED 1
SELECTMU	FC-2644 P3R-P7R; P39-P79	CALLED 4,9
SELFCCHK	FC-2080 INT BNK CUMMUN	ENTRY 3
SFLFCCHK	FC-2120 AGC SELFCECHK	ENTRY 2
SERVEXIT	FC-2683 SFRVICER	ENTRY 21
SERVEXIT	FC-2682 STEFRING	CALLED 4,5
SERVEXIT	FC-2700 P47 THRUST MONITOR	CALLED 7
SERVICER	FC-2683 SERVICER	ENTRY 13
SERVN(I)IT	FC-2760 ENTRY PROGRAMS	CALLED 7
SETCOARS	FC-2200 T4RIIPT	CALLED 43
SETGWLST	FC-2530 PRELAUNCH INIT	ENTRY 14
SETINTG	FC-2600 CISLUNAR MID NAV	ENTRY 14
SETISSW	FC-2200 T4RIIPT	ENTRY 30
SETJTAG	FC-2683 SERVICER	CALLED 7
SETMAXDR	FC-2370 DAP INTER-SERV ROUT	ENTRY 16
SETMAXDR	FC-2630 TPI TARGETTING	ENTRY 25
SETMAXDR	FC-2020 FRFSH START	CALLED 25
SETMINDR	FC-2370 DAP INTER-SERV ROUT	ENTRY 16
SETMINDR	FC-2630 TPI TARGETTING	ENTRY 7

C-4

T-6

SFTMINDR	FC-2020	FRFSH START		CALLED	25	
SETRF	FC-2590	P22 ORBITAL NAV		CALLED	24	
SETTS	FC-2380	RCS DAP INIT		ENTRY	2	
SFTVDARS	FC-2020	FRESH START		CALLED	19	
SET1/PDT	FC-2720	IMU REALIGN PRG		CALLED	23	
SGNAGRFE	FC-2100	SINGLE PREC SUBROUTS		ENTRY	5	
SGNAGRFE	FC-2300	ORB INTEGRATION		CALLED	4	
SGNAGRFE	FC-2631	R36 (V90)		CALLED	6	
SGNAGREE	FC-2710	P51, P53 IMU ORIENT		CALLED	9	
SHOW	FC-2530	PRELAUNCH INIT		ENTRY	25	
SIGNMPAC	FC-2100	SINGLE PREC SUBROUTS		ENTRY	14	
SIGNMPAC	FC-2300	ORB INTEGRATION		CALLED	5	
SIGNMPAC	FC-2320	IFFCONICS		CALLED	9	
SIGNMPAC	FC-2350	MANEUV CALC & STEER		CALLED	7,16,17,18,19,20	
SKIPVHF	FC-2550	P20 RENDEZVOUS NAV	C-32			T-34
SLAPI	FC-2020	FRFSH START		ENTRY	2	
SLOPESW	FC-2310	CONIC SUBROUTINES	S-10,14	C-36		T-12,18,36
SLOWFLG	FC-2642	RETURN TO EARTH	S-4	C-4		T-20
SMALLMP	FC-2370	DAP INTER-SERV ROUT		ENTRY	20	
SMCDURES	FC-2550	P20 RENDEZVOUS NAV		CALLED	13	
SMNR	FC-2190	PINBALL		CALLED	4	
SMNR	FC-2360	-S-BAND ANTENNA		CALLED	4	
SMNR	FC-2550	P20 RENDEZVOUS NAV		CALLED	14	
SMNR	FC-2682	STEERING		CALLED	11	
SMNR	FC-2700	P47 THRUST MONITOR		CALLED	8	
SOLNSW	FC-2310	CONIC SUBROUTINES	S-12,19,21,23	C-10,14,24		
SOMEERRR	FC-2530	PRELAUNCH INIT		ENTRY	37	
SOMERR2	FC-2530	PRELAUNCH INIT		ENTRY	37	
SOPTION	FC-2120	AGC SELFCHK		ENTRY	13	

SPCOS	FC-2110 SINGLE PREC SUBROUTS	ENTRY	2		
SPSIN	FC-2110 SINGLE PREC SUBROUTS	ENTRY	2		
SPSOFF	FC-2630 TPI TARGETTING	ENTRY	27		
SPSOFF	FC-2020 FRESH START	CALLED	30		
SPSOFF	FC-2681 CLOKTASK-CLOCKJOB	CALLED	9,17		
SR30.1	FC-2650 ORR PARAM DISPLAY	ENTRY	15		
SR52.1	FC-2730 R52, R53, R56	ENTRY	6		
STARLISH	FC-2370 DAP INTER-SERV ROUT	ENTRY	2		
STARIND	FC-2710 P51, P53 IMU ORIENT	S-6		C-4	T-5
STARIND	FC-2720 IMU REALIGN PRDG	S-18			T-19,20
SOURCLFG	FC-2550 P20 RENDEZVOUS NAV	S-33		C-20	T-24,26,27, 29,30
STARTFN1	FC-2760 ENTRY PROGRAMS	CALLED	2		
STARTSR2	FC-2020 FRESH START	ENTRY	8		
STARTSUB	FC-2020 FRESH START	ENTRY	8		
STARTSW	FC-2020 FRESH START	ENTRY	2		
STATEFLG	FC-2140 ALARM AND ABORT			C-6	
STATEFLG	FC-2290 INTEG INITIAL	S-3		C-3	
STATEFLG	FC-2300 ORR INTEGRATION	S-37		C-3,38	T-38
STATEFLG	FC-2550 P20 RENDEZVOUS NAV	S-7			
STATEFLG	FC-2590 P22 ORBITAL NAV	S-10,18			
STATEFLG	FC-2600 CISELUNAR MID NAV	S-14			
STATINT	FC-2290 INTEG INITIAL	ENTRY	3		
STATINT1	FC-2290 INTEG INITIAL	ENTRY	3		
STEERING	FC-2683 SERVICER	CALLFD	15		
STEERSW	FC-2680 THRUST PROGRAMS	S-23			
STEERSW	FC-2681 CLOKTASK- CLOKJOB	S-10			
STEERSW	FC-2682 STEERING			C-12,13	T-9
STICKCHK	FC-2370 DAP INTER-SERV ROUT	ENTRY	16		

STICKCHK	FC-2540	EARTH ORBIT INSERT	CALLED	21		
STIKFLAG	FC-2370	DAP INTER-SERV ROUT			C-11	
STIKFLAG	FC-2390	RCS DAP PHASE 2	S-2			
STOPRATE	FC-2350	MANEUV CALC & STEFR	ENTRY	26		
STOPRATE	FC-2020	FRESH START	CALLFD	21,25		
STOPRATE	FC-2550	P20 RENDEZVOUS NAV	CALLED	9		
STRTST1	FC-2450	STROKF TEST PKG	ENTRY	1		
STROKIN	FC-2450	STROKF TEST PKG	ENTRY	1		
STRULLSW	FC-2680	THRUST PROGRAMS	S-21		C-21	T-23
STSHUSIM	FC-2120	AGC SELFCECK	FNTRY	7		
SUPDACAL	FC-2080	INT BNK COMMUN	ENTRY	3		
SUPDACAL	FC-2170	AGC SELFCECK	CALLFD	9		
SUPERSW	FC-2080	INT BNK COMMUN	ENTRY	2		
SURFFLAG	FC-2290	INTEG INITIAL				T-4,5,18
SURFFLAG	FC-2325	RENDEZ PAR DISPLAY				T-8,9,10
SVDWN1	FC-2290	INTEG INITIAL	CALLFD	5		
SVDWN1	FC-2610	MEASUREMENT INCORP	CALLED	11		
SVDWN2	FC-2290	INTEG INITIAL	CALLED	5		
SVDWN2	FC-2610	MEASUREMENT INCORP	CALLED	11		
SWCALL	FC-2080	INT BNK COMMUN	ENTRY	1		
SWICHQVR	FC-2430	TVC ROUTINES	ENTRY	20		
SWICHQVR	FC-2370	DAP INTER-SERV ROUT	CALLED	2		
SWRETURN	FC-2080	INT BNK COMMUN	ENTRY	1		
SWTOVER	FC-2430	TVC ROUTINES	S-20		C-3	
SXTMARK	FC-2730	R52, R53, R53	CALLED	11,14		
SXTNR	FC-2325	RENDEZ PAR DISPLAY	CALLED	6		
SXTNR	FC-2550	P20 RENDEZVOUS NAV	CALLED	38		
SXTNR	FC-2730	R52, R53, R53	CALLED	13		
SXTSM	FC-2730	R52, R53, R56	ENTRY	13		

SXTSM	FC-2710 P51, P53 IMU ORIENT	CALLED	5		
SXTSM	FC-2720 IMU REALIGN PROG	CALLED	19		
SYSTEST	FC-2530 PRELAUNCH INIT	ENTRY	31		
S11.1	FC-2540 FARTH ORBIT INSERT	ENTRY	18		
S11.1	FC-2700 P47 THRUST MONITOR	CALLED	6		
S17.1	FC-2545 TPI SEARCH PROG	ENTRY	3		
S17.2	FC-2545 TPI SEARCH PROG	ENTRY	6		
S22.1	FC-2590 P22 ORBITAL NAV	ENTRY	9		
S30.1	FC-2620 P30, P31	ENTRY	2		
S31.1	FC-2620 P30, P31	ENTRY	7		
S32.1F1	FC-2626 P32, P72 - CSI			C-11,21	T-12
S32.1F2	FC-2626 P32, P72 - CSI	S-11,21		C-18	T-18
S32.1F3A	FC-2626 P32, P72 - CSI	S-18,19		C-11,21	T-12,18,21
S32/33.X	FC-2626 P32, P72 - CSI	ENTRY	8		
S32/33.1	FC-2626 P32, P72 - CSI	ENTRY	5		
S32/33.1	FC-2627 P33, P73 - CDH	CALLED	4		
S32.1F3B	FC-2626 P32, P72 - CSI	S-11,19		C-18,21	T-12,18,21
S33/34.1	FC-2630 TPI TARGETTING	ENTRY	6		
S33/34.1	FC-2627 P33, P73 - CDH	CALLED	3		
S33-34.1	FC-2630 TPI TARGETTING	ENTRY	6		
S34/35.1	FC-2630 TPI TARGETTING	ENTRY	6		
S34/35.1	FC-2640 TPM TARGETTING	CALLED	1		
S34/35.1	FC-2644 P38-P78; P39-P79	CALLED	11		
S34/35.2	FC-2630 TPI TARGETTING	ENTRY	11		
S34/35.2	FC-2640 TPM TARGETTING	CALLED	2		
S34/35.3	FC-2630 TPI TARGETTING	ENTRY	13		
S34/35.4	FC-2630 TPI TARGETTING	ENTRY	16		
S34/35.5	FC-2630 TPI TARGETTING	ENTRY	16		
S34/35.5	FC-2640 TPM TARGETTING	CALLED	2		

S3435.75	FC-2630 TPI TARGETTING	ENTRY	11
S3435.75	FC-2644 P38-P7R; P39-P79	CALLED	6,10
S40.1	FC-2680 THRUST PROGRAMS	ENTRY	32
S40.13	FC-2630 TPI TARGETTING	ENTRY	17
S40.13	FC-2681 CLOKTASK-CLOCKJOB	CALLED	14
S40.14	FC-2370 DAP INTER-SERV ROUT	ENTRY	10
S40.14	FC-2380 RCS DAP INIT	CALLED	6
S40.14	FC-2460 ROLL AUTOPILOT	CALLED	6
S40.15	FC-2430 TVC ROUTINES	CALLED	3,8
S40.2,3	FC-2680 THRUST PROGRAMS	ENTRY	40
S40.6	FC-2680 THRUST PROGRAMS	ENTRY	44
S41.1	FC-2700 P47 THRUST MONITOR	ENTRY	8
S41.1	FC-2682 STEERING	CALLED	5
S41.2	FC-2370 DAP INTER-SERV ROUT	ENTRY	8
S41.2	FC-2380 RCS DAP INIT	CALLED	6
S41.2	FC-2460 ROLL AUTOPILOT	CALLED	6
S50	FC-2720 IMU REALIGN PRDG	ENTRY	11
S52.2	FC-2720 IMU REALIGN PRDG	ENTRY	9
S52.3	FC-2720 IMU REALIGN PRDG	ENTRY	10
TAR/EREF	FC-2530 PRELAUNCH INIT	ENTRY	45
TARGDRVE	FC-2530 PRELAUNCH INIT	ENTRY	43
TARG1FLG	FC-2340 ATTITUDE MANEUVER		T-8
TARG1FLG	FC-2550 P20 RENDEZVOUS NAV	S-6	
TARG1FLG	FC-2590 P22 ORBITAL NAV		C-7
TARG1FLG	FC-2600 CISLUNAR MID NAV		C-3
TARG1FLG	FC-2720 IMU REALIGN PRDG	S-18	
TARG1FLG	FC-2730 R52, R53, R56		T-3,4,6
TARG2FLG	FC-2590 P22 ORBITAL NAV	S-7	
TARG2FLG	FC-2600 CISLUNAR MID NAV		C-3

TARG2FLG FC-2710 P51, P53 IMU ORIENT		C-4	
TARG2FLG FC-2720 IMU REALIGN PROG	S-18		
TARG2FLG FC-2730 R52, R53, R56			T-6
TASKOVER FC-2060 WAITLIST	ENTRY 18		
TERMINFL FC-2730 R52, R53, R56		C-2,12	T-4
TESTLOOP FC-2300 ORB INTEGRATION	ENTRY 3		
TESTLOOP FC-2290 INTEG INITIAL	CALLED 8		
TFSTXACT FC-2190 PINBALL	CALLED 2		
TESTXACT FC-2325 RENDEZ PAR DISPLAY	CALLED 2		
TESTXACT FC-2330 CREW DEF MANFUVER	CALLED 2		
TESTXACT FC-2360 -S-BAND ANTENNA	CALLED 2		
TESTXACT FC-2361 V89 (R63)	CALLED 2		
TESTXACT FC-2370 DAP INTER-SERV ROUT	CALLED 5		
TESTXACT FC-2595 LUNAR LAND SFLECT	CALLED 3		
TESTXACT FC-2605 NAV EXTENDED VERBS	CALLED 2		
TFSTXACT FC-2631 R36 (V90)	CALLED 2		
TFSTXACT FC-2650 ORB PARAM DISPLAY	CALLED 2		
TFFCONIC FC-2320 TFFCONICS	ENTRY 3		
TFFCONIC FC-2760 ENTRY PROGRAMS	CALLED 12		
TFFCONMU FC-2320 TFFCONICS	ENTRY 3		
TFFCONMU FC-2650 ORB PARAM DISPLAY	CALLED 16		
TFFRP/RA FC-2320 TFFCONICS	ENTRY 4		
TFFRP/RA FC-2650 ORB PARAM DISPLAY	CALLED 16		
TFF/TRIG FC-2320 TFFCONICS	ENTRY 11		
TFF/TRIG FC-2760 ENTRY PROGRAMS	CALLED 12,14		
TFFSW FC-2320 TFFCONICS	S-5	C-5	T-5
THISPREC FC-2620 P30, P31	CALLED 3		
THISPREC FC-2631 R36 (V90)	CALLED 4		
THISPREC FC-2650 ORB PARAM DISPLAY	CALLED 7		

THISPREC	FC-2680 THRUST PROGRAMS	CALLED	38	
TICKTEST	FC-2650 ORB PARAM DISPLAY	ENTRY	14	
TIGAVEG	FC-2630 TPI TARGETTING	ENTRY	15	
TIGBLNK	FC-2630 TPI TARGETTING	ENTRY	14	
TIGNOW	FC-2630 TPI TARGETTING	ENTRY	30	
TIGON	FC-2700 P47 THRUST MONITOR	ENTRY	4	
TIG-0	FC-2630 TPI TARGETTING	ENTRY	20	
TIG-5	FC-2630 TPI TARGETTING	ENTRY	16	
TIMERAD	FC-2310 CONIC SUBROUTINES	ENTRY	23	
TIMERAD	FC-2642 RETURN TO EARTH	CALLED	27,37	
TIMERFLG	FC-2620 P30, P31	S-6,10		C-6,10
TIMESTEP	FC-2300 ORB INTEGRATION	ENTRY	6	
TIMFTHET	FC-2310 CONIC SUBROUTINES	ENTRY	22	
TIMETHET	FC-2545 TPI SEARCH PRNG	CALLED	7	
TIMETHET	FC-2595 LUNAR LAND SELECT	CALLED	13	
TIMETHET	FC-2626 P32, P72 - CSI	CALLED	13,14	
TIMETHET	FC-2627 P33, P73 - CDH	CALLED	5	
TIMETHET	FC-2630 TPI TARGETTING	CALLED	5	
TIMETHET	FC-2642 RETURN TO EARTH	CALLED	13	
TIMETHET	FC-2644 P38-P78; P39-P79	CALLED	11	
TIMFLAG	FC-2681 CLCKTASK- CLOCKJOB			T-3
TIMRFLAG	FC-2680 THRUST PROGRAMS	S-R		C-28,31
TLIM	FC-2200 T4RUPT	ENTRY	28	
TNONTEST	FC-2200 T4RUPT	ENTRY	33	
TORQUE	FC-2530 PRELAUNCH INIT	ENTRY	25	
TPAGKEE	FC-2680 THRUST PROGRAMS	CALLED	19	
TRACKFLG	FC-2200 T4RUPT			C-32,33
TRACKFLG	FC-2340 ATTITUDE MANEUVER			T-8
TRACKFLG	FC-2545 TPI SEARCH PRNG	S-3		

TRACKFLG FC-2550 P20 RENDEZVOUS NAV	S-3	C-8	T-6, 8, 17, 31
TRACKFLG FC-2620 P30, P31	S-2, 7		
TRACKFLG FC-2626 P32, P77 - CSI	S-2		
TRACKFLG FC-2627 P33, P73 - CDH	S-1		
TRACKFLG FC-2630 TPI TARGETTING		S-2	
TRACKFLG FC-2640 TPM TARGETTING	S-1		
TRACKFLG FC-2644 P3R-P78; P39-P79	S-3		
TRACKFLG FC-2670 TARGET DELTA V PROG	S-1		
TRACKFLG FC-2720 IMU RFALIGN PROG		C-1	
TRACKFLG FC-2730 R52, R53, R56			T-4
TRANSANG FC-2545 TPI SEARCH PROG	ENTRY 14		
TRANSP1 FC-2100 SINGLE PREC SUBROUTS	ENTRY 13		
TRANSP2 FC-2100 SINGLE PREC SUBROUTS	FNTRY 13		
TRFAILDF FC-2070 SERVICE ROUTINES	ENTRY 13		
TRFAILDF FC-2550 P20 RENDEZVOUS NAV	CALLED 33		
TRFAILDF FC-2605 NAV EXTENDED VERRS	CALLED 7		
TRFAILON FC-2070 SERVICE ROUTINES	ENTRY 13		
TRFAILON FC-2550 P20 RENDEZVOUS NAV	CALLED 32		
TRUNFLAG FC-2730 R52, R53, R56	S-2, 3	C-3	T-3
TTG/O FC-2630 TPI TARGETTING	ENTRY 31		
TVCADAPON FC-2430 TVC ROUTINES	ENTRY 1		
TVCADAPON FC-2680 THRUST PROGRAMS	CALLED 72		
TVCXEC FC-2430 TVC ROUTINES	ENTRY 7		
TVCINIT FC-2430 TVC ROUTINES	ENTRY 1		
TVCZAP FC-2630 TPI TARGETTING	ENTRY 28		
TVCZAP FC-2020 FRESH START	CALLED 31		
TVCZAP-1 FC-2681 CLOKTASK-CLOCKJOB	CALLED 5, 7		
TWIDDLE FC-2060 WAITLIST	ENTRY 9		
T3RUPT FC-2060 WAITLIST	ENTRY 16		

T4RUPT	FC-2200	T4RUPT	ENTRY	3		
T5IDLOC	FC-2020	FRFSH START	ENTRY	17		
T5IDLOC	FC-2380	RCS DAP INIT	ENTRY	2		
T5PHASE	FC-2460	ROLL AUTOPILOT	CALLED	2		
T5PHASE2	FC-2390	RCS DAP PHASE 2	ENTRY	1		
T5PHASE2	FC-2380	RCS DAP INIT	CALLED	2		
T6PRDCM	FC-2390		ENTRY	10		
T6SFUIP	FC-2400	RCS DAP JET SELECT	ENTRY	15		
T6START	FC-2400	RCS DAP JET SELECT	ENTRY	17		
T6START	FC-2380	RCS DAP INIT	CALLED	7		
T6START	FC-2460	ROLL AUTOPILOT	CALLED	7		
UPACTOFF	FC-2020	FRESH START	CALLED	36		
UPACTOFF	FC-2550	P20 RENDEZVOUS NAV	CALLED	12		
UPDATFLG	FC-2545	TPI SEARCH PRNG	S-3,4,12,13	C-3,5		
UPDATFLG	FC-2550	P20 RENDEZVOUS NAV	S-3	C-R		T-31,34
UPDATFLG	FC-2620	P30, P31	S-2,7	C-2,7		
UPDATFLG	FC-2626	P32, P72 - CSI	S-2,3	C-7		
UPDATFLG	FC-2627	P33, P73 - CDH	S-4			
UPDATFLG	FC-2630	TPI TARGETTING	S-2,16			
UPDATFLG	FC-2640	TPM TARGETTING	S-1			
UPDATFLG	FC-2644	P38-P78; P39-P79	S-3,6,7	C-7,9		
UPDATFLG	FC-2720	IMU REALIGN PRG		C-1		
UPDATFLG	FC-2730	R52, R53, R56				T-4
UPENT2	FC-2070	SERVICE ROUTINES	ENTRY	2		
UPFLAG	FC-2070	SERVICE ROUTINES	ENTRY	4		
UPLCKFL	FC-2150	KEYRUPT AND UPRUPT	S-7	C-R		T-R
UPRUPT	FC-2150	KEYRUPT AND UPRUPT	ENTRY	5		
UPSVFLAG	FC-2290	INTEG INITIAL		C-15		T-14
UPTMFAST	FC-2200	T4RUPT	ENTRY	42		

USEPIOS FC-2290 INTFG INITIAL	ENTRY 21		
USPRCADR FC-2080 INT ANK COMMUN	ENTRY 5		
VAC5STDR FC-2020 FRESH START	ENTRY 27		
VAC5STDR FC-2140 ALARM AND ABORT	CALLED 3,5		
VALMIS FC-2530 PRELAUNCH INIT	ENTRY 24		
VARALARM FC-2140 ALARM AND ADORT	ENTRY 3		
VARALARM FC-2200 T4RUPT	CALLED 30		
VARALARM FC-2626 P32, P72 - CSI	CALLED 22		
VARALARM FC-2642 RETURN TO EARTH	CALLED 45		
VARDELAY FC-2060 WAITLIST	ENTRY 10		
VECPPOINT FC-2340 ATTITUDE MANEUVER	ENTRY 5		
VFCPOINT FC-2190 PINBALL	CALLED 5		
VFCPOINT FC-2361 V89 (R63)	CALLFD 5		
VECSGNAG FC-2100 SINGLE PREC SUBROJTS	ENTRY 12		
VEHUPFLG FC-2550 P20 RENDEZVOUS NAV		C-3	T-4,5,21,24, 25,28,35
VEHUPFLG FC-2590 P22 ORBITAL NAV	S-15		
VEHUPFLG FC-2600 C1SLUNAR MID NAV	S-12		
VEHUPFLG FC-2610 MEASUREMENT INCOR			T-10,11
VERR65 FC-2360 -S-BAND ANTENNA	ENTRY 2		
VFLAG FC-2720 IMU RFALIGN PROG	S-13,16	C-16	T-14,16
VGAMCALC FC-2320 TFFCONICS	ENTRY 11		
VGAMCALC FC-2760 ENTRY PROGRAMS	CALLFD 13		
VHFRFLAG FC-2550 P20 RENDEZVOUS NAV			T-20
VHFRFLG FC-2605 NAV EXTENDED VERBS	S-7	C-7	
VHHDOT FC-2540 EARTH ORBIT INSERT	ENTRY 18		
VHHDOT FC-2683 SERVICER	CALLED 15		
VINTFLAG FC-2290 INTEG INITIAL	S-4,6,7,16,19	C-4,6,7,18	T-8
VINTFLAG FC-2300 ORB INTEGRATION			T-33,38

VINTFLAG FC-2550 P20 RENDEZVOUS NAV	S-7	C-4,5,21
VINTFLAG FC-2580 P21 GRD TRACK DFT	S-3	C-3
VINTFLAG FC-2590 P22 ORBITAL NAV	S-10,18	
VINTFLAG FC-2600 CISLUMAR MID NAV	S-14	
VNDSPLY FC-2644 P38-P78; P39-P79	ENTRY 12	
VNPN0H FC-2626 P32, P72 - CSI	CALLED 2,4	
VNPN0H FC-2627 P33, P73 - CDH	CALLED 1	
VN1645 FC-2626 P32, P72 - CSI	ENTRY 6	
VN1645 FC-2627 P33, P73 - CDH	CALLED 1,4	
VN1645 FC-2630 TPI TARGETTING	CALLED 3	
VN1645 FC-2640 TPM TARGETTING	CALLED 1,2	
VN1645 FC-2642 RETURN TO EARTH	CALLED 14	
V1ST07 FC-2100 SINGLE PREC SUBROUTS	ENTRY 6	
V1ST02S FC-2340 ATTITUDE MANEUVER	CALLED 7	
V1ST02S FC-2350 MANEUV CALC & STEFR	CALLED 10	
V1ST02S FC-2540 EARTH ORBIT INSERT	CALLED 14	
V2T100 FC-2642 RETURN TO EARTH	ENTRY 17	
V37 FC-2020 FRESH START	ENTRY 30	
V37FLAG FC-2140 ALARM AND ABORT		T-5,11
V37FLAG FC-2320 TFFCONICS		T-14
V37FLAG FC-2325 RENDEZ PAR DISPLAY		T-8
V37FLAG FC-2683 SERVICER	S-3	C-19
V37KLEAFN FC-2020 FRESH START	ENTRY 7	
V37XED FC-2020 FRESH START	ENTRY 40	
V50N1RFL FC-2550 P20 RENDEZVOUS NAV	S-3	C-10 T-16
V54E FC-2550 P20 RENDEZVOUS NAV	ENTRY 17	
V56E FC-2550 P20 RENDEZVOUS NAV	ENTRY 8	
V57E FC-2550 P20 RENDEZVOUS NAV	ENTRY 17	
V59FLAG FC-2242 OPTICS CAL ROUTINE	S-1,3	C-1,3

V60	FC-2370 DAP INTER-SERV ROUT	ENTRY	12		
V61	FC-2370 DAP INTER-SERV ROUT	ENTRY	12		
V62	FC-2370 DAP INTER-SERV ROUT	ENTRY	12		
V63	FC-2370 DAP INTER-SERV ROUT	ENTRY	13		
VB2CALL	FC-2650 ORB PARAM DISPLAY	ENTRY	4		
VB2EMFLG	FC-2650 ORB PARAM DISPLAY	S-6,8,11		C-6,8,11	T-11,12,18
VB2FLAGS	FC-2650 ORB PARAM DISPLAY	S-10		C-4	T-4,14
VB2PERF	FC-2650 ORB PARAM DISPLAY	ENTRY	2		
VB9CALL	FC-2190 EXTENDED VFRS	ENTRY	2		
VB9CALL	FC-2361 VB9 (R63)	ENTRY	2		
VB9PERF	FC-2190 EXTENDED VFRS	ENTRY	2		
VB9PERF	FC-2361 VB9 (R63)	ENTRY	2		
V90PERF	FC-2631 R36 (V90)	ENTRY	2		
V94FLAG	FC-2600 CISELUNAR MID MAV	S-8		C-3,9	
V960NFLG	FC-2290 INTEG INITIAL			C-3	
V97F	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	11		
V97P	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	10		
V97T	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	8		
V99E	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	7		
V99P	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	6		
V99T	FC-2681 CLOKTASK- CLOCKJOB	ENTRY	5		
WAITLIST	FC-2060 WAITLIST	ENTRY	9		
XDELVFLG	FC-2620 P30, P31	S-1,6		C-10	
XDELVFLG	FC-2626 P32, P72 - CSI	S-9			
XDELVFLG	FC-2627 P33, P73 - CDH	S-6			
XDELVFLG	FC-2630 TPI TARGETTING			C-16	
XDELVFLG	FC-2642 RETURN TO EARTH			C-14	
XDELVFLG	FC-2644 P38-P78; P39-P79			C-7	
XDELVFLG	FC-2680 THRUST PROGRAMS				T-4,32

XDELVFLG	FC-2682	STEERING			T-6
YAWDAP	FC-2440	TVC DAP	ENTRY	6,9	
YAWTIM	FC-2400	RCS DAP JET SELECT	ENTRY	13	
YCOPY	FC-2430	TVC ROUTINES	CALLED	12	
YCOPY	FC-2440	TVC DAP	ENTRY	13	
ZERUICDU	FC-2200	T4RIIPT	CALLED	34,36	
ZERDING	FC-2530	PRELAUNCH INIT	ENTRY	35	
ZEROJET	FC-2370	DAP INTER-SERV RDUT	CALLED	2,4	
ZEROJET	FC-2540	EARTH ORBIT INSERT	CALLED	19	
ZMEASURE	FC-2600	CISLUNAR MID NAV	S-17		C-17 T-15
-1CHK	FC-2120	AGC SELFCECK	ENTRY	16	
1/PIPA	FC-2683	SERVICER	CALLED	13	
1ST02S	FC-2100	SINGLE PREC SUBROUTS	ENTRY	5	
1TUSUB	FC-2100	SINGLE PREC SUBROUTS	ENTRY	8	
2ERANK	FC-2120	AGC SELFCECK	ENTRY	6	
2PHSCHNG	FC-2030	PHASE TABLE MAINT	ENTRY	11	
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2V1S TO	FC-2100	SINGLE PREC SUBROUTS	ENTRY	7	
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3AXISFLG	FC-2340	ATTITUDE MANEUVER			C-4 T-2,3
3AXISFLG	FC-2361	V89 (R63)			C-3
3AXISFLG	FC-2550	P20 RENDEZVOUS NAV			C-10
3AXISFLG	FC-2600	CISLUNAR MID NAV			C-7
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