December 1969

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

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

INSTRUMENTATION LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139
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The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.
FOREWORD

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

Jack C. Reed
Group Leader
APOLLO Documentation
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**VIA VERB 36**

**FRESH START**

**ASTRONAUT INITIATED FRESH START**

1. **SLAPI**
2. **INHINT**
3. **STARTSUB**
   - **INITIALIZE**
   - **REGISTERS**
4. **SHB**
5. **STARTSW**
6. **SKIPSIM**
7. **(DSPTAB + 11D) → 0**
   - **15, 7, 5, 3-1**
8. **(DSPTAB + 11D) → 1**
9. **ERCOUNT → 0**
10. **FAILREG → 0**
11. **FAILREG+1 → 0**
12. **FAILREG+2 → 0**
13. **REDOCTR → 0**

**NEXT SHEET**

**REGISTERS COMMON TO BOTH FRESH START AND RESTART**

**THIS LOCATION IS USED TO PATCH FOR SIMULATION PURPOSES ONLY**

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

**THIS IS A SIGN TO PROGRAM T4RPT TO TRANSMIT THE CURRENT CONTENTS (JUST SET) OF DSPTAB 11D TO CHANNEL 10 — THAT A CHANGE HAS OCCURRED IN BIT-POSITIONS 11-1 SINCE THE LAST TIME DSPTAB + 11D WAS PROCESSED BY T4RPT.**

**INDICATES NO MALFUNCTIONS**

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

**RESTART COUNTER INDICATES NO RESTARTS, SINCE THIS IS A FRESH START, THE COUNTING OF RESTARTS BEGINS WITH 0**
FROM PRECEDING SHEET

DSRUPTSW ← OCT65777

CAUSES PROGRAM T4RUPPT TO CYCLE THROUGH ITS DISPLAY PROCEDURES IN ORDER TO BLANK THE DSKY WINDOWS BEFORE PERFORMING ITS NORMAL T4 FUNCTIONS

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

DOFSTART

ERESTORE ← 0

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

SMODE ← 0

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

CLEAR UPSVFLAG

ZERO UPDATE STATE VECTOR REQUEST FLAGWORD

CLEAR ALL BITS OF CHAN 5

TURN OFF RCS JETS

CLEAR ALL BITS OF CHAN 6

TURN OFF RCS JETS

NEXT SHEET

FRESH START AND RESTART

COLOSSUS

FC-2020
FROM PRECEDING SHEET

CLEAR ALL BITS OF CHAN 11

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

CLEAR ALL BITS OF CHAN 12

TERMINATES THE DRIVING OF MISCELLANEOUS NAVIGATION AND SPACECRAFT HARDWARE

CLEAR ALL BITS OF CHAN 13

TERMINATES THE CONTROL OF MISCELLANEOUS NAVIGATION SYSTEM FUNCTIONS

CLEAR ALL BITS OF CHAN 14

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

WTOPTION ← +0

INDICATES THAT ZOPTICS MUST BEGIN OVER AGAIN

DNLSTCOD ← +0

SELECT COAST AND ALIGNMENT DOWNLIST

NVSAVE ← +0

CLEAR DISPLAY INTERFACEROUTINES

EBAKTEM ← +0

SAVE REGISTERS

RATEINDX ← +0

INITIALIZE MANEUVER RATE TO 0.5 DEG/SEC

TRMKCNT ← +0

INITIALIZE NUMBER OF OPTICS MARKS

VHFCNT ← +0

INITIALIZE NUMBER OF VHF MARKS

EXTVBCNT ← +0

RELEASES EXTENDED VERB AND MARK ACTIVITY

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

NO

MAKE ALL GROUPS INACTIVE VIA SUBROUTINE MR KLEAN

YES

SET BOTH BIT 6 AND 4 OF (OEPTAB +110) ← 1

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

ALLOPGROUPS ← KILL ALL GROUP RESTARTS

NEXT SHEET
FROM PRECEDING SHEET

MODREG ← OCT77777

RESTREG ← OCT30000

IMODES30 ← OCT27411

OPTIND ← OCT77776

OPTMODES ← OCT00130

IMODES33 ← OCT16000

TS1OLOC

SPECIFIED FOR NEXT T5R UPT SH17

CAUSES
MAJOR MODE DISPLAY WINDOW
TO BE BLANKED

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

FRESH START IMU INITIALIZATION
PROGRAM T4R UPT WILL PROCESS
THE CONTENTS OF IMODES30

NO OPTICS IN PROCESS. CAUSES
PROGRAM T4R UPT TO BYPASS THE
OPTICS CDU ORIVING FUNCTION

FRESH START OPTICS INITIALIZATION.
PROGRAM T4R UPT WILL PROCESS THE
CONTENTS OF OPTMODES

INITIALIZATION OF BITS USED FOR
VARIOUS HARDWARE DATA. A ONE IN THE
FOLLOWING BIT-POSITIONS INDICATE:
BIT 13 - NO ACCELERATION - FAIL
INDICATION
BIT 12 - NO TELEMETRY ENOPULSE REJECTED
BIT 11 - NO EXCESSIVE UPLINK BIT RATE

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

CLEAR FLAGWRD0

CLEAR BITS 15-13 AND 11-1 OF FLAGWRD1

CLEAR FLAGWRD2

CLEAR BITS 15,14 AND 12-1 OF FLAGWRD3

CLEAR FLAGWRD4

CLEAR BITS 15-9 AND 7-1 OF FLAGWRD5

SET BIT 8 OF FLAGWRD6

SET BIT 3 OF FLAGWRD6

CLEAR BITS 15-4, 2 AND 1 OF FLAGWRD6

CLEAR FLAGWRD7

CLEAR BITS 15-13, 10, 9 AND 7-1 OF FLAGWRD8

CLEAR FLAGWRD9

CLEAR FLAGWRD10

CLEAR FLAGWRD11

END RT START

VIA POSTJUMP

DUMMY JOB + 2

STATUS OF NODORP1 FLAG (BIT 12) REMAINS INTACT

STATUS OF REFSMFLG (BIT 13) REMAINS INTACT

INITIALIZE ALL FLAGWRDs BY SETTING APPROPRIATE
SWINIT VALUES INTO EACH FLAG.

SWINIT VALUES ARE SUCH AS TO ZERO ALL BITS
EXCEPT BIT 8 (COMPUTER) OF FLAGWRDS WHICH IS
SET TO ONE. ALSO BIT 12 (NODORP1) OF FLAGWRD1,
BIT 13 (REFSMMAT FLAG) OF FLAGWRD3, BITS 12
(CMOUNFLG), 11 (LMOUNFLG) AND 8 (SURF FLAG) OF
FLAGWRDB WHICH REMAIN INTACT

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

DRAG OVER 0.05G
0.056 SW FLAG

STATUS OF CMOUNFLG (BIT 12),
LMOUNFLG (BIT 11), AND SURF FLAG (BIT 8)
REMAIN INTACT
FROM Routine DEFSTART
OF Program SLAP1
ON Sheet 4

MR. KLEAN

SUBROUTINE FOR MAKING
ALL GROUPS INACTIVE

GROUP2.0

GROUP 2 IS
INACTIVE

KILL GROUP 2
RESTARTS

POOKLEAN

SUBROUTINE FOR MAKING
GROUPS 1, 3, 4, 5 AND 6
INACTIVE

GROUPS1&4

GROUPS 1 AND 4
ARE INACTIVE

KILL GROUPS
1 & 4 RESTARTS

V37KLEAN

SUBROUTINE FOR MAKING
GROUPS 3, 5 AND 6
INACTIVE

GROUPS3,5&6

GROUPS 3, 5 AND 6 ARE INACTIVE

KILL GROUPS
3, 5 & 6 RESTARTS

RETURN VIA Q

---

FRESH START AND RESTART
COLOSSUS II-D FC-2020
FROM SLAP1 AND GOPROG

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

INITIALIZES PROGRAM DOWN TELEMETRY

WILL CAUSE TIME COUNTER TIME5 TO OVERFLOW
IN 40 MILLION SECONDS FROM NOW TO IN TURN INITIATE
THE EXECUTION OF TSRRUP INTERRUMP

WILL CAUSE TIME COUNTER TIME4 TO OVERFLOW
IN 30 MILLION SECONDS FROM NOW TO IN TURN INITIATE
THE EXECUTION OF INTERRUPT PROGRAM TSRRUP
ENTERED BY "SOFTWARE" RESTART, I.E., EXECUTION
OF RESTART PROCEDURE UNDER PROGRAM CONTROL.
FROM ROUTINE GOPROG (ELEMMA)

STARTS82

CLEAR BITS
7-3 OF
CHAN1

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

WILL CAUSE TIME COUNTER TIME3 TO OVERFLOW
IN 10 MILLION SECONDS FROM NOW TO IN TURN INITIATE
THE EXECUTION OF INTERRUPT PROGRAM TSRRUP

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

OPTION 2 FOR MARKRRUP
FLAG R21MARK

CALCULATE BASE VECTOR DURING 1ST PASS THROUGH P21
STEERING OMITTED
P21FLAGS

DISREGARD RADAR READ BECAUSE OF SOFTWARE OR
HARDWARE RESTART
FLAG SKIPVF

LST1 AND LST2 ARE IN EBANK 3

EBANK ← ECADR LST1

NEXT SHEET
FROM PRECEDING SHEET

SCHEDULE TASK SVCT3 IN WAITLIST TO BE EXECUTED 81.93 SECONDS FROM NOW AND EVERY 81.93 SECONDS THEREAFTER UNTIL A REGULAR TASK HAS BEEN SCHEDULED. T3RUPT WILL PLACE OCT 77777 (OCT 57777 PLUS OCT 37777) INTO COUNTER TIME3 WHICH WILL RESULT IN 81.93 SECONDS

[LIST2+0, LIST2+1]
[LIST2+2, LIST2+3]
...
[LIST2+140, LIST2+150]
[LIST2+160, LIST2+170]

2CADR SVCT3

T3RUPT WILL CAUSE THE EXECUTION OF TASK SVCT3 WHOSE COMPLETE ADDRESS IS IN THE ADDRESS LIST LIST2. TASK SVCT3 CHECKS GYRO DRIFT AND COMPENSATES IF NECESSARY AND RESUMES INTERRUPTED ROUTINE VIA TASKOVER.

PRIORITY+0
PRIORITY+12D
PRIORITY+240
...
 PRIORITY+600
PRIORITY+72D

OCT 77777

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

DSRUPTSW ← OCT 77777

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

NEWJOB ← OCT 77777

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

VAC1USE ← "VAC1USE"
VAC2USE ← "VAC2USE"
VAC3USE ← "VAC3USE"
VAC4USE ← "VAC4USE"
VAC5USE ← "VAC5USE"

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

NEXT SHEET

FRESH START AND RESTART

COLOSSUS X-D FC-2020

Page 9 of 50

INSTRUMENTATION LAB LARAMIE, WY

A. T. Eppelt, Spec

APPD BY H. V. D. Humm

REV 8
FROM PRECEDING SHEET

DSPOFF

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

OCT73777

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

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

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

CLEAR THE INLINK COUNTER OF ALL UPLINK DATA

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

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

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

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

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

TERMINATES THE DISPLAY MONITOR ACTIVITY

TERMINATES THE DISPLAY MONITOR ACTIVITY

INDICATES TO PINBALL THAT THE VERB DISPLAY WINDOW IS BLANK

NEXT SHEET
FROM PRECEDING SHEET

NOUNREG ← 0

Indicates to pinball that the noun display window is blank.

DISPLIST ← 0

Indicates that no job is using routine NVSUBUSY (no internal routine is asleep waiting for the operator to release the display system).

MARKSTAT ← 0

Indicates that no optics mark operations have been requested and leaves the Mark system free to immediately recognize a Mark request (Mark system now available).

IMUCADR ← 0

Indicates to program IMU mode switching routines that no job is in the dormant state awaiting the completion of an IMU mode switch. The system is prepared to put a job requesting a mode change into a dormant state until the switch has been completed. See note below.

OPTCADR ← 0

Indicates to program mode switching routines that no job is in the dormant state awaiting the completion of an optics mode switch. The system is prepared to put a job requesting a mode change into a dormant state until the switch has been completed. See note below.

RADCADR ← 0

Indicates to program mode switching routines that no job is in the dormant state awaiting the completion of a radar mode switch. The system is prepared to put a job requesting a mode change into a dormant state until the switch has been completed. See note below.

ATTCADR ← 0

Indicates that program KALCMANU is available (free). See note below.

Next Sheet

Note:
These four "Cadr" registers are used to store return addresses of jobs using the various mode change and maneuver routines.

[Signature and stamp]
FROM PRECEDING SHEET

LGYRO ← 0

INDICATES THE GYROS ARE AVAILABLE TO BE PULSED

CLEAR FLAGWR04

TURNS OFF INTERFACE DISPLAYS

NOUT ← DEC11

INDICATES TO PROGRAM TURP THAT THERE ARE ELEVEN CHANGES IN THE DSPTAB REGISTER TABLE (ELEVEN RELAY CODES TO BE TRANSMITTED VIA CHANNEL 1D, I.E. OUT 0)

CLEAR BITS 15 AND 13-1 OF EXTVERB

IT INHIBITS OTHER EXTENDED VERB ACTIVITY AFTER AN R62 OR R63 RESTART

SELFRET ← "SELFCHK"

CLEAR EXTENDED VERB AND MARK ACTIVITY. LEAVE EXTENDED VERB RESTART FLAG (BIT 14) INTACT

DSPCOUNT ← DCT-25

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

RETURN VIA Q

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

END OF SUBROUTINE STARTSUB
FROM PRECEDING SHEET

SUBROUTINE LIGHTSET

LIGHTSET

IS BIT 7 OF INPUT CHAN 16 = 1?

NO

IS THE OPTICS MARK REJECT SIGNAL PRESENT?

YES

ARE BITS 5-1 OF CHAN 16 = OCT22?

NO

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

YES

ARE BITS 5-1 OF CHAN 15 = OCT22?

NO

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

NONAVKEY+1

STARTSUB

INITIALIZE REGISTERS

SH8

NONAVKEY+2

DOFSTART

SH3

RETURN VIA Q

NEXT SHEET
FROM PRECEDING SHEET

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

DOUBT E MEMORY DO FRESH START

NO

IS ERESTORE = C0CT2000?

YES

STARTSUB INITIALIZE REGISTERS SH5

NONAVKEY+2

DOFSTART SH3

NO

IS ERESTORE ≠ 0?

YES

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

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

NO INTERRUPT, CONTINUE WITH RESTART

ELRSKIP-1 SH16

NO

IS ERESTORE = SKEEP7?

YES

IS E MEMORY SATISFACTORY?

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

ERESTORE = SKEEP7

NONAVKEY+2

STARTSUB INITIALIZE REGISTERS SH5

NONAVKEY+2

DOFSTART SH3

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

E E+1 SLEEP 6

E+1 SLEEP 6

RESTORE ORIGINAL CONTENTS: SINE A ROUTINE WAS INTERRUPTED BY A MEMORY LOCATION WHOSE ADDRESS IS DEFINED AS, OCT 1461, 8 OR OCT 1776 IN EBANK 1, OCT 400, 8 OR OCT 1776 IN EBANK 2, OR OCT 1460, 8 OR OCT 1772 IN EBANK 2.

RESTORE ORIGINAL CONTENTS AS RESTORED TO LOCATIONS E AND E+1 WHERE E IS THE MEMORY LOCATION WHOSE ADDRESS WAS STORED INTO REGISTERS SLEEP 6 AND RESTORE.
From preceding sheet

Elrskip

See tsidler table
Specified for next tsr ipt
See flow chart table

Tsloc is set to appropriate restart address, depending upon which DAP (Digital Auto Pilot) is operating. Normally (no restart) Tsloc is set by programs using the DAP or by the DAP routines.

Time 5 was set in startsub to initiate execution of tsr ipt routine in 40 ms

Tsidler table

<table>
<thead>
<tr>
<th>Tsr ipt routine (determined by bits 15 and 14 of flagwr06)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bits</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

Next sheet

Flow chart table

From interrupted routine via tsr ipt

Tsidloc

A ← L

Return via resume

To interrupted routine

Idling routine (DAP routines inactive)

Blank of interrupted routine

Redords FC - 2380
Redovt FC - 2430
Redosat FC - 2540
Tsidloc This sheet
FROM PRECEDING SHEET

CLEAR BIT 14 OF RASFLAG

INTEGRATION NOT IN PROGRESS
INTFLAG

OPTMODES 10, 3-1 0

INITIALIZE OPTICS STATUS BITS.
REMOVE ANY OPTICS FAILURE DETECTED
(BIT 7). LEAVE INTACT COARSE OPTICS,
ZERO OPTICS AND CMC CONTROL
(BITS 6, 5, 4)

OPTMODES 7

LEAVE DAP ENABLE
SWITCH INTACT (BIT 6)

IMODES 15-7, 5-1 0

NO ACCELEROMETER FAIL.
DOWN TELEMETRY AND UPLINK
RATES ARE NORMAL

IMODES 13-11 7

NO OPTICS COU MALFUNCTION.
PROGRAM ALARM, Gimbal lock and
NO-ATTITUDE LAMPS REMAIN INTACT
(BITS 9, 6, 4)

(DSPTAB + 11D) 8 0

THIS IS A SIGN TO PROGRAM T4RUP
TO TRANSMIT THE CURRENT CONTENTS
(JUST SET) OF DSPTAB + 11D TO
CHANNEL 10 TO FORCE AGREEMENT
BETWEEN DSPTAB + 11D AND THE
DESKY RELAY SETTINGS. CHANNEL 10
WAS CLEARED BY RESTART HARDWARE
ACTION

(DSPTAB + 11D) 15 1

NEXT SHEET

FRESH START AND RESTART

COLOSSEUS II + D

FC-2020
FROM PRECEDING SHEET

IS NO-ATTITUDE LIGHT ON?

YES

VIA IBHKCALL

ENABLE COARSE ALIGNMENT IMU MODE SWITCHING ROUTINE

IMU MODE SWITCHING ROUTINE

CA+ECE

WAITLIST TASK
SET BIT 6 OF CHANNEL 12
\( \Delta T = 60 \text{ MS} \)
FC-2210

NO COARSE

IMODES30 \(=0\)

IMODES30 \(=0\) OCT77

INITIALIZE FAILURE CODES AND TURN-ON REQUEST. FAILURE INHIBITS REMAIN INTACT (BITS 5-3 AND 1)

NEXT SHEET
FROM PRECEDING SHEET

CLEAR MPAC+6

RESET PHASE ACTIVITY FLAG TO INDICATE INACTIVE STATUS

MMDISPLAY
DISPLAY MAJOR MODE VIA DSPMMDJOB
FC-2030

IN PHASE TABLE MAINTENANCE PROGRAM

INHIBIT INTERRUPTS

ARE BITS 15 AND 14 OF FLAGWRD6 = 0 AND RESPECTIVELY

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

YES

STOP RATE
ZERO INPUTS TO AUTOPILOT
FC-2350

STOP ALL AUTOMATIC MANEUVERING
IN KALCMANU STEERING PROGRAM

NO

NEXTRTST = 1

INITIALIZE INDEX FOR SIX GROUPS

A ← 5
FROM PRECEDING SHEET

SEARCH FOR ACTIVE GROUP

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

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

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

MPAC ← (PHASE1+X3)

NO

A > +0 ?

YES

PACTIVE

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

MPAC ← (PHASE1+X3)

INCREMENT MPAC+6

SET PHASE ACTIVITY FLAG BY INCREMENTING MPAC+6

VIA SWCALL

RESTARTS

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

VIA SWRETURN

PINACT

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

IS MPAC+5 = +0 ?

NO

A ← (MPAC+5) DECREMENT A

HAVE ALL GROUPS BEEN TESTED FOR ACTIVE STATUS?

YES

NEXT SHEET
FROM PRECEDING SHEET

IS MPAC+67+6 > 0 ?

ARE ANY GROUPS ACTIVE?

IS BIT 15 OF MODREG = 0 ?

WAS A MAJOR MODE IN PROGRESS?

GOTOPOOH SHEET

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

ENDRSTART

END OF RESTART (GOPROG AND GOPRO62)

END NODE VIA POSTJUMP

DUMMYJOB+2

IN THE EXECUTIVE PROGRAM FC-2050
FROM 7 LOCATIONS

GOTOPOOH

GROUP-1
SET UP RESTARTS TO RETURN TO THE LAST DISPLAY

VIA POSTJUMP

GOPOOPIX

INITSUB
SET DEADBAND, CLEAR 15 FLAGS AND ZERO INPUTS TO AUTOPILOT

SUBROUTINE ON FC-2130

CLEARMRK+2
INHIBIT INTERRUPTS

CLEAR BIT 1 OF FLAGWRD4
RELEASE INTERRUPT INHIBIT

VIA BANKCALL

GOFFLASH
FLASH V37 ON DSKY WAIT FOR RESPONSE FROM OPERATOR

IN INTERFACE DISPLAY ROUTINE

IN DISPLAY INTERFACE ROUTINE

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

NO SPECIAL MARK INFORMATION XDSPFLAG

RECYCLE

FRESH START AND RESTART
FROM PRECEDING SHEET

- CLEAR BIT 12 OF FLAGWRD7
- CLEAR BIT 11 OF FLAGWRD7
- CLEAR BIT 10 OF FLAGWRD6
- CLEAR BIT 12 OF FLAGWRD5
- CLEAR BIT 7 OF FLAGWRD5
- CLEAR BIT 6 OF FLAGWRD5
- CLEAR BIT 14 OF FLAGWRD5
- CLEAR BIT 8 OF FLAGWRD5

- ASTRONAUT HAS NOT APPROVED IGNITION
  - ASTNFLAG
- CLOCKTASK
  - INOPERATIVE
  - TIMRFLAG
- DO ULAGEOFF ONLY
  - STRUL5W FLAG
- NORMAL MARKING
  - FOR P23
  - V59FLAG
- ENGINE TURNED OFF
  - ENSONFLG
- MANEUVER SPECIFIED BY ONE AXIS
  - 3AXISFLG
- NOT IN GIMBAL LOCK
  - GLOKFAIL FLAG
- ALLOW BACKWARDS INTEGRATION
  - FOOPFLAG

- 1ST PASS THROUGH P21, CALCULATE BASE VECTOR, STEERING OMITTED
  - P21FLAG
- NO STEERING
  - STEERSW
- ENABLE R41 (ENGFAIL)
  - IDLEFAIL
- RELEASE INTERUPT INHIBIT
- VIA SUBROUTINE UPFLAG (SERVICE ROUTINE)
  - FLAG IMPULSW
- NO OPTICS IN PROGRESS, CAUSES PROGRAM T4RUP TO BYPASS THE OPTICS CDU DRIVING FUNCTION

END OF SUBROUTINE INITSUB
SUBROUTINE VAC5STOR
ENTERED FROM 4 LOCATIONS
(3 IN PROGRAM ALARM AND ABORT
AND 1 ON SHEET 18 OF THIS PROGRAM)

ENTERED VIA BANKCALL

CALLING
SEQUENCE:
\$+0 TC BANKCALL
\$+1 CADR VAC5STOR
\$+2 RETURN HERE

SUBROUTINE VAC5STOR STORES
CONTENTS OF CERTAIN LOCATIONS
IN MEMORY FOR DEBUGGING

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

ROUTINE V5LOOP1 STORES THE
2CADR, PRIORITY AND VAC AREA
ADDRESS OF EACH JOB (PRESENTLY
SCHEDULED) INTO VAC5+0 THROUGH
VAC5+20

VAC5+X6 \rightarrow (LOC+X5)
VAC5+1+X6 \rightarrow (LOC+1+X5)

HAVE ALL PASSES
BEEN COMPLETED?

NO

ITEMP2 = 18

YES

INCREMENT
ITEMP1
BY 12

INCREMENT
ITEMP2
BY 3

SET INDEXES
FOR NEXT PASS

PASS    OPERATION
1ST     \{ VAC5 \rightarrow LOC
        \{ VAC5+1 \rightarrow (LOC+1)
        \{ VAC5+2 \rightarrow PRIORITY
2ND     \{ VAC5+3 \rightarrow (LOC+2)
        \{ VAC5+4 \rightarrow (LOC+3)
        \{ VAC5+5 \rightarrow (PRIORITY+12)
3RD     \{ VAC5+6 \rightarrow (LOC+24)
        \{ VAC5+7 \rightarrow (LOC+25)
        \{ VAC5+8 \rightarrow (PRIORITY+2)
4TH     \{ VAC5+9 \rightarrow (LOC+36)
        \{ VAC5+10 \rightarrow (LOC+37)
        \{ VAC5+11 \rightarrow (PRIORITY+36)
5TH     \{ VAC5+12 \rightarrow (LOC+48)
        \{ VAC5+13 \rightarrow (LOC+49)
        \{ VAC5+14 \rightarrow (PRIORITY+49)
6TH     \{ VAC5+15 \rightarrow (LOC+60)
        \{ VAC5+16 \rightarrow (LOC+61)
        \{ VAC5+17 \rightarrow (PRIORITY+60)
7TH     \{ VAC5+18 \rightarrow (LOC+72)
        \{ VAC5+19 \rightarrow (LOC+73)
        \{ VAC5+20 \rightarrow (PRIORITY+72)

NEXT SHEET

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FRESH START AND RESTART
ROUTE V5OUT1 STORES
THE 2CADR OF RESTART
ADDRESS OF EACH RESTART
GROUP INTO VAC5+210
THROUGH VAC5+320

PHSNAME AND PHSBB REGISTERS
ARE IN EBANK 3

NOTE A:
VAC5+220 → PHSBB6
VAC5+210 → PHSNAME6
VAC5+320 → PHSBB5
VAC5+290 → PHSNAME5
VAC5+280 → PHSBB4
VAC5+270 → PHSNAME4
VAC5+260 → PHSBB3
VAC5+250 → PHSNAME3
VAC5+240 → PHSBB2
VAC5+230 → PHSNAME2
VAC5+220 → PHSBB1
VAC5+210 → PHSNAME1

INITIALIZE INDEXES
FOR ROUTINE V5LOOP2

FROM
PRECEDEING SHEET

V5OUT1

EBANK ← EBANK3

GENTRAN
COPY AND STORE
2CADR OF RESTART
ADDRESS PER
NOTE A
FG=2070

ITEMP1 ← 0
ITEMP2 ← 0

NEXT SHEET
ROUTINE VSLOOP2 STORES
RESTART PHASE DATA (IN PHASE REGISTERS)
INTO VAC5+33D THROUGH VAC5+38D

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

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

HAVE ALL PASSES BEEN COMPLETED?

NO

INCREMENT INTEMP1 BY 2
SET INDEXES FOR NEXT PASS

YES

INCREMENT INTEMP2 BY 1

IS INTEMP2 = 5?

ROUTINE VSOUT2 STORES
JOB INFORMATION

VAC5+33D ← (MPAC+3)
VAC5+34D ← NEWLOC
VAC5+35D ← NEWLOC+1
VAC5+36D ← NEWJOB
VAC5+37D ← NEWPRI0

RETURN VIA SWRETURN

2CADR OF JOB LAST SCHEDULED
OR AWAKENED.
JOB ACTIVITY STATUS INDICATOR.
PRIORITY OF JOB LAST SCHEDULED
OR AWAKENED.
RETURN TO CALLING
SEQUENCE AT X + 2
WHERE X = TC BANKCALL
AND X+1 = CADR VAC5STOR
END OF SUBROUTINE VAC5STOR
CONTROL COMES HERE FROM MMCHANG OF THE PINBALL PROGRAM VIA POST-JUMP AS THE RESULT OF VERB 37

V37

MMNUMBER ← A

RESTREG ← OCT 30000

IS BIT 6 OF IMODES 30 = 1?

TO CANTROO ON SHEET 31

IS BIT 13 OF CHAN 11 = 1?

SET UP FOR POO

ARE BITS 15 AND 14 OF FLAGWR06 = 1 AND 0 RESPECTIVELY?

TO ISITPOO ON NEXT SHEET

YES, TVC DAP IS ON

ROOTPOO

INHINT

MASSTMP ← CGMMASS

VIA IBANKCALL

SPS0FF

TURN OFF MAIN PROPULSION ENGINE

FC-2680

VIA ISWRETURN

NEXT SHEET

CHANGE MAJOR MODE

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

STORE MAJOR MODE

SUPER BANK AND PRIORITY FOR DISPLAY INTERFACE Routines. SUPER BANK IS 50 IN BIT-POSITIONS 7-5 AND PRIORITY IS 30 IN BIT-POSITIONS 14-10

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

IS ENGINE ON?

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

GSM MASS STORED TEMPORARILY (COPY CYCLE) FOR SUBROUTINE SPS0FF FOR RESTART PROTECTION

SUBROUTINE IN P40-P47
SUBROUTINE IN TVCMASSPROP

FROM PRECEDING SHEET
VIA 1BANKCALL

MASSPROP
UPDATE VEHICLE
MASS ESTIMATES
FC-2430
VIA ISWRETURN

A ← OCT 37312
VIA 1BANKCALL

RCSDAPON+I
START RCS
DAP
IN 3.1 SECONDS
FC-2680
VIA ISWRETURN
VIA 1BANKCALL

TVGCAP
TERMINATE
TVC DAP
FC-2680

MMNUMBER ← 0

RELEASE INTERRUPT INHIBIT

DELAYJOB
THIS JOB IS PUT
TO SLEEP FOR 50
MS AND THEN AWAKENED
AT NEXT LOCATION
ROOTTOP00+21
FC-2070

(ROOTTOP00+21)

CLEAR CHAN5
CLEAR CHAN6

NEXT SHEET

SUBROUTINE IN P40-P47

SET FOR POO

SCHEDULES TASK TO BE
EXECUTED IN 50 MS, THEN
PUTS THIS JOB TO SLEEP AND
TASK WILL AWaken THIS JOB
A SERVICE ROUTINE

THE REACTION CONTROL
SYSTEM (RCS) JETS
1-8 ARE TURNED OFF
(PITCH AND YAW)

THE RCS JETS 9-16
ARE TURNED OFF (ROLL)
FROM PRECEDING SHEET AND SHEET 32

ISSERVON

IS BIT 6 OF FLAGWRD7 #1? NO

INHINT

IS AVERAGEG (SERVICER) RUNNING? (IS V37FLAG SET?) YES

INHIBIT INTERRUPT PROGRAMS

CLEAR BIT 1 OF FLAGWRD1

DISCONTINUE THE AVERAGEG ROUTINE (CLEAR AVEGFLAG)

ENDOFJOB

IN EXECUTIVE PROGRAM FC-2050

AVERAGEG ROUTINE WILL TRANSFER
CONTROL TO CANV37 WHEN IT TERMINATES

SELECT DOWNLIST ADDRESS
CORRESPONDING TO THE MAJOR MODE

CANV37

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

TEMPFLSH ← CADR.DUMMYAD

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

GROUP 4:1

SET UP RESTARTS TO RETURN TO
THE LAST DISPLAY

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

NEXT SHEET
FROM PREcedING SHEET

ROO

VIA INTPRET

INSTALL

WAIT FOR COMPLETION OF INTEGRATION

FC-2290

VIA EXIT

DUMMYAD

CLEAR BIT 10 OF
CHAN11

CLEAR BIT 9 OF
CHAN11

CLEAR BIT 14 OF
CHAN12

CLEAR BIT 13 OF
CHAN12

CLEAR BIT 11 OF
CHAN12

CLEAR BIT 10 OF
CHAN12

CLEAR BIT 8 OF
CHAN12

CLEAR BIT 3 OF
CHAN12

CLEAR BIT 2 OF
CHAN12

CLEAR BIT 9 OF
CHAN13

Determine if stall area is available.
If so, stall area is grabbed. If not, wait (this job is put to sleep).
INSTALL is a routine in the integration initialization program

Cleans caution reset signal

Average - G is not running

Terminate S48 cutoff

Terminate S48 injection sequence

Engage optics digital to analog converter (DAC)

Zero optics terminated

Terminate TVC (Thrust vector control) enable

Terminate star tracker

Enable optics CDU error counters are cleared to zero

Not assigned

NEXT SHEET
FROM PRECEEDING SHEET

DID THE KEYBOARD REQUEST POOH?

YES

IS MNNUMBER = + 0 ?

NO

POOH

PICK UP NEW PROGRAM

NOUVEAU

RELSDP

RELEASES DISPLAY SYSTEM FROM OPERATOR CONTROL AND MAKES IT AVAILABLE TO INTERNAL ROUTINE REQUESTS

FC-2150

PHSPRDT2 OCT 05000

INHINT

INHIBIT INTERRUPT PROGRAMS

CLEAR BIT 1 OF FLGWRD02

TURN OFF NODEO FLAG TO PERMIT VERB 37

0 V37 PERMITTED

1 V37 NOT PERMITTED

GROUP 2,5

SET UP RESTARTS TO SCHEDULE STATINT1 AS A FINDVAC JDB WITH PRIORITY 05

ROUTINE STATINT1 IS IN THE INTEGRATION INITIALIZATION PROGRAM

CLEAR BIT 7 OF FLGWRD0

INDICATES P20 PROGRAM TERMINATED

RNODV2FLG FLAG

CLEAR BIT 8 OF FLGWRD0

INDICATES IMU NOT IN USE

IMUSE FLAG

A = DNLADMM1 + X4

SELECT CSM COAST AND ALIGNMENT (POO, PO1, PO6, PS0, PS2, PS3, PS4) DOWNLIST FOR RADIO TELEMETRY PROGRAM

ONLADPOO OCT 0

INHIBIT INTERRUPTS

NEXT SHEET

HAS PROGRAM P20 BEEN INITIATED?

(IS RNDVZFLG ON?)

SUBROUTINE DOWNFLAG

INDICATES IMU NOT IN USE

IMUSE FLAG

X4 IS A NOTATION FOR THE MAJOR MODE INDEX AND IS EQUAL TO THE CONTENTS OF XINDEX

SELECT THE DOWNLIST THAT APPLIES TO THE KEYED-IN MAJOR MODE

INDEX X4 DOWNLIST ADDRESS

0-7 DNLADMM1 ADRES RENDEZFW P79, P78 P77, P76, P75, P74, P73, P72

8 " " ENTRYURD P62

9 " " POWERED P61

10-13 " " COSTALIN P54, P53, P52, P51, P50, P49

14-16 " " POWERED P47, P46, P45

17-26 " " RENDEZFW P39, P38, P37, P35, P34, P33, P32, P31, P30, P29

27 " " P22DNLIST P22

28-30 " " RENDEZFW P21, P20, P19

31, 32 " " COSTALIN P06, P05

DOWNLIST

COSTALIN = 0 CSM COAST AND ALIGNMENT

ENTRYURD = 1 CSM ENTRY AND UPDATE

RENDEZFW = 2 CSM RENDEZvous AND PRETHRUST

POWERED = 3 CSM POWERED FLIGHT

P22DNLIST = 4 P22

NMIT INSTRUMENTATION LAB

AMHERST, MASS.

FRESH START AND RESTART

COLOSSUS II-D

DCL-2020

DATE: 37 45 50
SET UP APPROPRIATE DOWNLIST ADDRESS, CONTAINS 0, 1, 2, 3 OR 4 WHICH WILL BE USED AS AN INDEX IN DOWN-TELEMETRY PROGRAM TO SELECT DOWNLIST ADDRESS.

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

CLEAR BIT 5 OF FLAGWRD1 INDICATES TRACKING NOT ALLOWED TRACKFLG

CLEAR BIT 7 OF FLAGWRD1 INDICATES UPDATING BY MARKS NOT ALLOWED UPDATFLG

CLEAR BIT 10 OF FLAGWRD1 INDICATES NOT SIGHTING LEM TARG1FLG

NEXT SHEET
PART OF INTERFACE DISPLAY ROUTINES.
A = CADR V37XEQ
TEMPFLSH WAS SET TO CADR V37XEQ + 3 IN ROUTINE REV37 OF PROGRAM V37 ON SHEET 39

PREPARE THE CALLING SEQUENCE (SEE BOTTOM) FOR ROUTINE FINDVAC IN LOCATIONS G0LOC-1 TO G0LOC+2 AND THE ACCUMULATOR. FINDVAC WILL REQUEST THE EXECUTIVE TO INITIATE THE EXECUTION OF THE KEYED-IN MAJOR MODE ACCORDING TO THE PRIORITY IN THE ACCUMULATOR.

INHIBIT INTERRUPT PROGRAMS

X4 IS A NOTATION FOR INDEX AND IS EQUAL TO THE CONTENTS OF MINDEX.
PRIORITY FOR GROUP 4 RESTART

REGISTER PHSPRT4 IS IN VARIABLE PHASE TABLE.
PRIORITY OF KEYED-IN MAJOR MODE.
PRIORITY FOR SPVAC ENTRY TO THE EXECUTIVE PROGRAM

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

A = GENADR
L = BBCON
NEWPRIO = PRIORITY

OF KEYED-IN MAJOR MODE

A = A + OCT 02000
VIA SPVAC

NEXT SHEET

FRESH START AND RESTART
COLOSSUS
II.0
FC-2020
```
FROM PRECEDING SHEET

VIA SPVAC
WITH:

A = GENAO
L = BBCON
NEWPrio = PRIORITY

SEE FCAFOMM1 TABLE
FINDVAC JOB
PRIORITY IS IN
THE PREMM1 TABLE

OF KEYEO-IN
MAJOR MODE

REQUEST THE EXECUTIVE PROGRAM TO
INITIATE THE EXECUTION OF THE KEYEO-IN
MAJOR MODE ACCORDING TO THE PRIORITY
IN NEWPrio. THE 2CADR AND PRIORITY OF
THE KEYED-IN MAJOR MODE WERE DERIVED
ABOVE FROM THE FCAFOMM1 AND PREMM1
TABLES AS FOLLOWS:

PREMM1 15-11 = PRIORITY
PREMM1 10-8 = E BANK NUMBER
PREMM1 7-1 = MAJOR MODE NUMBER
FCAFOMM1 = FCAFOR OF THE MAJOR MODE

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TO V37XEQC
ON NEXT SHEET
```
TO SHEET 438.44
FROM PRECEEDING SHEET
FROM PRECEEDING SHEET
FROM PRECEEDING SHEET

A ← A + 1

SUBTRACT DELTA TIME FROM ELAPSED TIME

A = ELAPSED TIME MINUS DELTA TIME
= COMPLEMENT OF REVISED (UNEXPIRED, UNEXPIRED OR REMAINING) DELTA TIME

SHOULD TASK BE EXECUTED IMMEDIATELY?
HAS DELTA TIME COMpletely EXPIRED?)

IF YES A > 0 OR A = 0
IF NO A < 0

DELTA TIME HAS COMpletely EXPIRED
OR
DELTA TIME HAS PARTIALLY EXPIRED

A = +0 DELTA TIME EXPIRED PREVIOUSLY.
ELAPSED TIME > DELTA TIME
OR
A = -0 DELTA TIME EXPIRED LESS THAN
10 MILLISECONDS AGO. DELTA TIME = ELAPSED TIME

A ← +1

ONE WILL CAUSE THE TASK TO BE EXECUTED WITHIN 10 MILLISECONDS FROM NOW

A ← Delta TIME, THE TIME MEASURED FROM NOW FOR SCHEDULING THE EXECUTION OF THE WAITLIST TASK

LSGC, 1 ← TC LONGCALL

SET VARIABLE CALLING SEQUENCE FOR THE LONGCALL TASK

REVISED (UNEXPIRED) DELTA TIME IN DOUBLE PRECISION, THE TIME MEASURED FROM NOW FOR SCHEDULING THE EXECUTION OF THE LONGCALL TASK

GOLOC - 1 ← TC LONGCALL

A ← LONGTIME
L ← LONGTIME + 1

JOB OR TASK TO BE RESTARTED IS NOW SCHEDULED USING THE FOLLOWING VARIABLE CALLING SEQUENCE AS SET PREVIOUSLY:

GOLOC - 1 = EITHER TC FINVAC, TC NOVAC, TC WAITLIST OR TC LONGCALL
GOLOC - 0 = GENADR 2CAR OF RESTART ADDRESS (JOB OR TASK)
GOLOC + 1 = BBCON 2CAR OF RESTART ADDRESS (JOB OR TASK)
GOLOC + 2 = EITHER TC GETPARTS, TC PHSPARTS OR TC SWRETURN
A = PRIORITY OR DELTA TIME (WAITLIST)

[A, L] = DELTA TIME (LONGCALL) IN DOUBLE PRECISION

RETURN VIA GOLOC + 1

RETURN TO FINACT VIA SWRETURN (SHEET 22)

TYPE A
TYPE B

RETURN TO PRECEEDING SHEET

FRESH START AND RESTART

FC-2020
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>WHERE CALLED</th>
<th>DESCRIPTION</th>
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<tbody>
<tr>
<td>SETCOARS</td>
<td>FC-2210</td>
<td>SH. 19</td>
<td>ENABLE COARSE ALIGNMENT</td>
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<tr>
<td>ALARM</td>
<td>FC-2140</td>
<td>SH. 20, 32</td>
<td>SETS A FAILREG REGISTER WITH ALARM CODE AND TURNS ON PROGRAM ALARM LIGHT</td>
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<td>MMDSFLAY</td>
<td>FC-2030</td>
<td>SH. 21</td>
<td>DISPLAY MAJOR MODE VIA DSPMMJOB</td>
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<td>STOPRATE</td>
<td>FC-2350</td>
<td>SH. 21, 25</td>
<td>ZERO INPUTS TO AUTOPILOT</td>
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<tr>
<td>CLEAR MK+2</td>
<td>FC-2130</td>
<td>SH. 24</td>
<td>CLEAR XDSPFLAG (NO SPECIAL MARK INFORMATION)</td>
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<tr>
<td>SETMAXDB</td>
<td>FC-2680</td>
<td>SH. 25</td>
<td>SET DEADBAND TO MAXIMUM VALUE FOR AUTOPILOT</td>
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<tr>
<td>SETMINDB</td>
<td>FC-2680</td>
<td>SH. 25</td>
<td>SET DEADBAND TO MINIMUM VALUE FOR AUTOPILOT</td>
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<td>GENTRAN</td>
<td>FC-2070</td>
<td>SH. 28</td>
<td>COPY AND STOR 2CADR OF ALL VARIABLE RESTART ADDRESSES</td>
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<td>SPOFF</td>
<td>FC-2680</td>
<td>SH. 30</td>
<td>TURN OFF MAIN PROPULSION ENGINE</td>
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<td>MASSPROP</td>
<td>FC-2430</td>
<td>SH. 31</td>
<td>UPDATE VEHICLE MASS ESTIMATES</td>
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<td>RCS DAPON+1</td>
<td>FC-2680</td>
<td>SH. 31</td>
<td>START RCS DAP IN 3.1 SECONDS</td>
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<td>TERMINATE TVC DAP</td>
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<td>DELAYJOB</td>
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<td>SH. 31</td>
<td>THIS JOB IS PUT TO SLEEP FOR 30 MS AND THEN AWAKENED AT NEXT LOCATION ROOTPOO-21</td>
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<tr>
<td>RELDSP</td>
<td>FC-2180</td>
<td>SH. 32, 37, 42</td>
<td>RELEASES DISPLAY SYSTEM FROM OPERATOR'S CONTROL AND MAKES IT AVAILABLE TO INTERNAL ROUTINE REQUESTS</td>
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<td>FALTON</td>
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<td>UPDATE MODREG WITH NEW MAJOR MODE NUMBER AND DISPLAY IT</td>
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<td>DSPLOCK</td>
<td>10</td>
<td>DSOFF</td>
<td>FLAGWRD9</td>
</tr>
<tr>
<td>DSPLOCK</td>
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<td>FLAGWRD9</td>
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<tr>
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<td>3</td>
<td>SKIPSIM</td>
<td>FLAGWRD9</td>
</tr>
<tr>
<td>DSURTSW</td>
<td>9</td>
<td>STARTSB2</td>
<td>FLAGWRD9</td>
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<tr>
<td>DUMMYAD</td>
<td>34</td>
<td>CANV3?</td>
<td>FLAGWRD9</td>
</tr>
<tr>
<td>EBAKTEM</td>
<td>4</td>
<td>DOFSTART</td>
<td>FLAGWRD11</td>
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<tr>
<td>EBAKTEM</td>
<td>38</td>
<td>SEUDOPPO</td>
<td>FCADRMM1</td>
</tr>
<tr>
<td>ERCOUNT</td>
<td>2</td>
<td>SKIPSIM</td>
<td>FCADRMM1</td>
</tr>
<tr>
<td>ERESTORE</td>
<td>3</td>
<td>DOFSTART</td>
<td>GROUP 1,6,0</td>
</tr>
<tr>
<td>ERESTORE</td>
<td>15</td>
<td>BUTTONS</td>
<td>GROUP 1,2,0</td>
</tr>
<tr>
<td>ERESTORE</td>
<td>16</td>
<td>BUTTONS</td>
<td>GROUP 1,3,4,5,6,0</td>
</tr>
<tr>
<td>REGISTER</td>
<td>SHEET</td>
<td>ROUTINE</td>
<td>REGISTER</td>
</tr>
<tr>
<td>----------</td>
<td>-------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>OPTIND</td>
<td>26</td>
<td>RAKE</td>
<td>PRIORITY</td>
</tr>
<tr>
<td>OPTMODES</td>
<td>5</td>
<td>DOFSTART</td>
<td>PRIORITY</td>
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<tr>
<td>OPTMODES</td>
<td>18</td>
<td>ELRSKIP</td>
<td>RADCADR</td>
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<tr>
<td>PHASE1-6</td>
<td>20</td>
<td>PCLOOP</td>
<td>RASFLAG</td>
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<td>20</td>
<td>V5LOOP2</td>
<td>RASFLAG</td>
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<tr>
<td>PHSBR1-6</td>
<td>28</td>
<td>V5OUT1</td>
<td>RATEIDX</td>
</tr>
<tr>
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<td>28</td>
<td>V5OUT1</td>
<td>REDOCTR</td>
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<td>43</td>
<td>ITSAVAR</td>
<td>REDOCTR</td>
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<tr>
<td>PHSNAME1-6</td>
<td>43</td>
<td>ITSLIKEB</td>
<td>REDORCS</td>
</tr>
<tr>
<td>PHSPRDT1</td>
<td>44</td>
<td>ITSAJOB</td>
<td>REDOSAT</td>
</tr>
<tr>
<td>PHSPRDT1</td>
<td>44</td>
<td>ITSAWAIT</td>
<td>RedotVC</td>
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<tr>
<td>PHSPRDT1</td>
<td>44</td>
<td>ITSNGCL</td>
<td>REQRET</td>
</tr>
<tr>
<td>PHSPRDT2</td>
<td>37</td>
<td>POOH</td>
<td>RESTREG</td>
</tr>
<tr>
<td>PHSPRDT4</td>
<td>40</td>
<td>V37XEQ</td>
<td>RESTREG</td>
</tr>
<tr>
<td>PHSPRDT4</td>
<td>40</td>
<td>V37XEQ</td>
<td>RSBK</td>
</tr>
<tr>
<td>POINTER</td>
<td>43</td>
<td>ITSATBL</td>
<td>RISEQ</td>
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<td>ITSEVEN</td>
<td>RISEQ</td>
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<td>44</td>
<td>PSIPART2</td>
<td>SELFRET</td>
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<td>44</td>
<td>CONTBL2</td>
<td>SIZEAB</td>
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<td>44</td>
<td>ITSAJOB</td>
<td>SIZETAB</td>
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<td>44</td>
<td>ITSWTSLT</td>
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<td>PREMM1</td>
<td>33</td>
<td>AGAINM</td>
<td>SKEEP6</td>
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<tr>
<td>PREMM1</td>
<td>40</td>
<td>V37XEQ</td>
<td>SMODE</td>
</tr>
<tr>
<td>PREMM1</td>
<td>42</td>
<td>V37XEQC</td>
<td>TBASE1-6</td>
</tr>
</tbody>
</table>

**INDEX OF REGISTERS AND CHANNELS (cont'd)**
PHASE TABLE MAINTENANCE

THERE HAVE BEEN NO CHANGES (EXCEPT PAGE NUMBERING) FROM THE COLOSSUS 237 FLOWCHART, FC-2030, REV.0, TO THE COLOSSUS II FLOWCHART, FC-2030, REV.1.
CONTROL ARRIVES HERE FROM ANY OF 12 LOCATIONS (Z) WITH Q = Z + 1, THE ADDRESS OF THE LOCATION CONTAINING THE NEW MAJOR MODE NUMBER

NEWMODEX

A ← (Z + 1)

INCR Q

Q ← Z + 2, THE RETURN ADDRESS

FROM ROUTINE V37XEQC (FC-2020, SHEET 30) OF V37.IS IN THE FRESH START AND START PROGRAM AND FROM ROUTINE UPDOUT (FC-2150, SHEET 7) OF UPDATE PROGRAM AND FROM ROUTINE ENDTST1 OF IMU CALIBRATION AND ALIGNMENT PROGRAM. ENTRY MADE WITH A = THE NEW MAJOR MODE NUMBER

NEWMODEA IS SAME AS NEWMODEX + 1

MODREG ← NEW MAJOR MODE

MODREG ← A

MMDDSLAY

PREBUMP

VIA BANKJUMP

SETUPDSP

INHIBIT INTERUPTS

DSPMMAJOB

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

NOVAC JOB PRIORITY 30

ALLOW INTERUPTS

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

RETURN VIA Q
CONTROL ARRIVES HERE FROM ANY OF 12 LOCATIONS

CHECKMM

YES

IS

MODREG =

X + 1

AND CURRENT

MAJOR MODES

THE SAME?

NO

INCR

Q

TWICE

RETURN VIA

Q

RETURN TO CALLER

AT X + 3

RETURN VIA

Q

RETURN TO CALLER AT X + 2

SUBROUTINE FOR COMPARING NEW MAJOR MODE WITH CURRENT MAJOR MODE

CALLING SEQUENCE:

X + 0 TO CHECKMM

X + 1 MM (THE NEW MAJOR MODE)

X + 2 RETURN HERE IF NEW MAJOR MODE AND CURRENT MAJOR MODE (IN MODREG) ARE NOT THE SAME

X + 3 RETURN HERE IF THEY ARE THE SAME - THEY MATCH
CONTROL ARRIVES HERE FROM ANY OF 9 LOCATIONS (Z) WITH THE PHASE NUMBER IN A AND ADDRESS Z+1 IN Q.

NEWPHASE

INHIBIT INTERRUPTS

L ← A

INCR Q

TEMP ← 2.Z+1

IS L = 0 ?

NO

NUFAX+10

L ← L

TIME ← TBASE 1.Z+1 + X1

-PHASE 1.Z+1 + X1

-PHASE 1.Z+1 + X1

ALLOW INTERRUPTS

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

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

CALLING SEQUENCE:

Z+1 CA(WS CS) Z+1
Z+1 TO NEWPHASE
Z+1 OCT XX XX (GROUP)
Z+1 RETURN HERE UNCONDITIONALLY

Z+1 OCT YY YY (PHASE)

CS IF TBASE IS NOT TO BE SET
CS IF TBASE IS TO BE SET
OCT XXXX = BINARY 0000 0000 0000
OCT YY YY = BINARY 0000 0000 0000
WHERE G IS THE GROUP NUMBER AND P IS THE PHASE NUMBER.

INHIBIT INTERRUPT PROGRAMS

L = PHASE NUMBER

Q = Z+2, THE RETURN ADDRESS

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

SHOULD TBASE BE SET?

(NO THE PHASE NUMBER NEGATIVE?)

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

STORE THE COMPLEMENT OF THE CONTENTS OF TIME COUNTER TIME1 INTO THE LOCATION OF THE TBASE TABLE ASSOCIATED WITH THE GROUP NUMBER.

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

RELEASE INTERRUPT PROGRAM INHIBIT.

PHASE TABLE MAINTENANCE

PHASE 1

PHASE 1

PHASE 2

PHASE 2

PHASE 3

PHASE 3

PHASE 4

PHASE 4

PHASE 5

PHASE 5

PHASE 6

PHASE 6

PHASE 7

PHASE 7

PHASE 8

PHASE 8

TBASE 1

TBASE 1

TBASE 2

TBASE 2

TBASE 3

TBASE 3

TBASE 4

TBASE 4

TBASE 5

TBASE 5

TBASE 6

TBASE 6

PHSPRT1

PHSPRT1

PHSPRT2

PHSPRT2

PHSPRT3

PHSPRT3

PHSPRT4

PHSPRT4

PHSPRT5

PHSPRT5

PHSPRT6

PHSPRT6

COLOSSUS II FC-2030

20/07/17 14:34:11
SUBROUTINE FOR MAKING ANY
OF SEVERAL TYPE PHASE CHANGES
FOR RESTARTS. A PHASE IDENTIFIES
ONE OF SEVERAL PLACES WITHIN A
ROUTINE TO RESTART THAT ROUTINE
WHEN THAT ROUTINE HAS BEEN
INTERRUPTED BY A HARDWARE FAILURE

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

TYPE A FIXED PHASE CHANGES
STORED IN PERMANENT FORM

TYPE B COMBINATION OF FIXED AND
VARIABLE PHASE CHANGES

TYPE C VARIABLE PHASE CHANGE INFORMATION
STORED IN ERASABLE LOCATION

THE BINARY REPRESENTATION OF OCT XXXXX IS:

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

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

PHSCNG2

\[ \text{TEMPG} \leftarrow 2 \cdot \text{TPSFW} \]

\[ \text{TPMPP} \leftarrow \text{TPSFW} \]

\[ 10 - 1 \]

\[ 12 - 4 \]

\[ 13 - 1 \]

\[ 0 \]

DOUBLE THE GROUP NUMBER IN BIT-POSITIONS 8-1 AND STORE IT FOR LATER USE AS AN INDEX. (HEREAFTER THE INDEXING WORD "TEMPG" WILL BE REFERRED TO AS X2)

GET THE RESTART TYPE AND/OR PHASE NUMBER

CLEAR ALL TPSFW EXCEPT TBASE AND LONGBASE BITS (15, 14)

HENCEFORTE WHEN TEMPP OR TPSFW ARE USED IN THE PROGRAM, THIS DIAGRAM WILL REFER INSTEAD TO THE BITS OF THE ORIGINAL OCTAL WORD IN X+1 WHICH WILL LESSEN CONFUSION

DOES X+1 CONTAIN TYPE A PHASE INFORMATION?

\[ \text{ARE} \]

\[ \text{BITS 13} \neq 0 \]

\[ 12 \text{OF} \quad X+1 \]

\[ 0 \text{?} \]

\[ \text{NO} (\text{TYPE B OR C}) \]

\[ \text{YES} (\text{TYPE A}) \]

\[ (\text{PHASE } 1 - 2 \times \text{x}) \]

\[ \frac{10 - 1}{12} (x + 1) \]

\[ 19 \]

\[ 0 \]

\[ \text{STORE THE PHASE NUMBER INTO THE PHASE TABLE IN TRUE FROM} \]

\[ \text{BPH} \]

\[ \text{WAS ENTRY VIA PHASCGN?} \]

\[ \text{IS} \]

\[ \text{TEMPG2} \]

\[ = 2 ? \]

\[ \text{NO} (\text{VIA PHASCGN}) \]

\[ \text{YES} (\text{VIA PHASCGN}) \]

\[ \text{NEXT SHEET} \]

\[ \text{CONTROL CANNOT COME HERE SINCE THIS DIAGRAM APPLIES TO PHASCGN} \]

\[ \text{PHASE TABLE MAINTENANCE} \]

\[ \text{COLOSSUS II} \]

\[ \text{FC-2030} \]
FROM PRECEDING SHEET

BELOWE

NO

BIT IS OF

YES

Z+1

= 1?

TBASE1 = Z + X2 → TIME1

IS

NO

BIT IS OF

YES

17?

Z+1

BELOW3

LONGBASE ← TIME2

LONGBASE + 1 ← TIME1

BELOW4

STORE THE COMPLEMENT FROM OF

- PHASE1 = Z + X2 ← (Z+1)3 - 4

BBANK ← TEMPBBCN

RETURN VIA Q

IF

TYPE A

RESTART ADDRESS
IS ONE OF LOCATIONS
IN THE CALLING
SEQUENCE
(A = 0)

THEN THE
RETURN
TO THE
CALLING
SEQUENCE
IS AT
LOCATION

X

X

PRIO.RED (OR DELTA
TIME) TO BE USED IS:

OLD (D+0) NEW (D+3)

X

X

PHASE TABLE
MAINTENANCE

COLOSSUS II FC-2030

3/14/90

P. K. Reck

G. M. Mars 2/24/90

3/14/90

P. K. Reck

3/16/90

G. M. Mars
FROM PRECEDING SHEET

TOCON2

CON2

TEMPBCHN ← BBANK

PHASE1-2 +X2 ← (X+1)3-4

PHSPROT1-2+X2 ← TEMPPR

PHSNAME1-2+X2 ← TEMPPN

PHSNAME1+1+X2 ← TEMPB

BELLOW1

SH7

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

SAVE CALLER'S BBANK

STORE THE TRUE FORM OF THE PHASE
NUMBER INTO THE PHASE TABLE IN
THE LOCATION ASSOCIATED WITH THE
GROUP NUMBER IN (X+1)3-1

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

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

THE PHASE-CHANGE TABLES ARE AS FOLLOWS:

<table>
<thead>
<tr>
<th>PHASES</th>
<th>TBASE AND PRIORITY (OR DELTA TIME)</th>
<th>2CAODR OF RESTART ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>-PHASE1</td>
<td>TBASE 1  PHSPROT1</td>
<td>PHSNAME 1  PHSB1</td>
</tr>
<tr>
<td>PHASE 1</td>
<td>TBASE 2  PHSPROT2</td>
<td>PHSNAME 2  PHSB2</td>
</tr>
<tr>
<td>-PHASE 2</td>
<td>TBASE 3  PHSPROT3</td>
<td>PHSNAME 3  PHSB3</td>
</tr>
<tr>
<td>PHASE 2</td>
<td>TBASE 4  PHSPROT4</td>
<td>PHSNAME 4  PHSB4</td>
</tr>
<tr>
<td>-PHASE 3</td>
<td>TBASE 5  PHSPROT5</td>
<td>PHSNAME 5  PHSB5</td>
</tr>
<tr>
<td>PHASE 3</td>
<td>TBASE 6  PHSPROT6</td>
<td>PHSNAME 6  PHSB6</td>
</tr>
</tbody>
</table>

PHASE TABLE MAINTENANCE

COLOSSUS II FC-2030
SUBROUTINE FOR CHANGING TWO GROUPS AT ONCE
IN FIXED-FIXED MEMORY

THE CALLING SEQUENCE IS:
Z+O TC 3PHSCHNG
Z+1 OCT XXXXX(TYPE A)
Z+2 OCT YYYY(TYPE A, B OR C)

AND PRIORITY (OR AT) IS

TYPE A TYPE B OR C

AND THE VARIABLE (IF ANY) RESTART ADDRESS IS

Z+3 RETURN HERE (A=O, D=O) IF
Z+4 RETURN HERE (A=O, D=1) IF
Z+5 RETURN HERE (A=1, D=O) IF
Z+6 RETURN HERE (A=1, D=1) IF

*NOTE: A IS BIT-POSITION 11 OF Z+2 (TYPE B OR C) AND
D IS 10 (IF TYPE C) OR 12 (IF TYPE B), SEE PAGE 4 FOR
BINARY REPRESENTATION OF OCT XXXXX AND
OCT YYYY

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

Q=Z+2

FORM THE INDEX.
DOUBLE THE GROUP NUMBER IN BIT-POSITIONS
B-1 AND STORE IT FOR LATER USE AS AN INDEX.
(HEREAFTER THE INDEXING WORD "TEMPG2" WILL BE REFERRED TO AS "X3")

GET THE PHASE NUMBER

HENCEFORTH WHEN TEMP2 OR TEMPSW2 ARE USED IN THE PROGRAM, THIS DIAGRAM WILL REFER INSTEAD TO THE BITS OF THE ORIGINAL OCTAL WORD IN Z+1 WHICH WILL LESSEN CONFUSION. AN EXCEPTION IS TEMPSW2 USED IN ROUTINE BELOW 1 TO INDICATE THE ENTRY

SAVE TBASE INDICATOR (BIT 13)
1 = TBASE SHOULD BE SET
0 = TBASE SHOULD NOT BE SET

NEXT SHEET
FROM PRECEDING SHEET

PHSCHNG + B

IN FIXED-FIXED MEMORY

STORE OCTAL CODE WHICH IS IN LOCATION Z+2 OF THE CALLING SEQUENCE

Q = Z+3

STORE BBANK OF CALLER (Z)

IN BANK 10

DOUBLE THE GROUP NUMBER IN BIT-POSITIONS 3-1 AND STORE IT FOR LATER USE AS AN INDEX. (HEREAFTER THE INDEXING WORD "TEMPS" WILL BE REFERRED TO AS X4)

GET THE RESTART TYPE AND/OR PHASE NUMBER

HENCEFOROHT WHEN TEMPP OR TEMPSW ARE USED IN THE PROGRAM, THIS DIAGRAM WILL REFER INSTEAD TO THE BITS OF THE ORIGINAL OCTAL WORD IN Z+2 WHICH WILL LLESS CONFUSION

CLEAR ALL TEMPSW EXCEPT THE TBASE AND LONGBASE BITS (19, 14)

DOES Z+2 CONTAIN TYPE A PHASE INFORMATION?

YES (TYPE A)

NO (TYPE B OR C)

ARE BITs 12 & 0 BOTH 0?

STORE THE PHASE NUMBER INTO THE PHASE TABLE IN TRUE FORM

NEXT SHEET

PHASE TABLE MAINTENANCE
FROM PRECEDING SHEET

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

IS TEMPz+2 ≠ 1 ?

WAS ENTRY MADE VIA ZPHSCNG ?

NO (VIA ZPHSCNG) (1)

YES (VIA ZPHSCNG) (+00000 OR +00000)

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

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

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

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

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

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

SHOULD LONGBASE BE SET ?

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

LONGBASE ← TIME2
LONGBASE +1 ← TIME1

NEXT SHEET
Determine applicable priority or delta time and store it in fixed-fixed memory.

Temporarily restore BBank of the caller of EPHSCH to obtain, if required, the new priority (or delta time) and/or ZCA Dr of the restart location because these are contained in caller locations where BBank of Z+0 and Z+1 used at execution of TC

EPHSCNB: ZCA Dr = BBank of PHSCHNG

Does Z+2 contain type B phase information?

Will a new priority (or new delta time) be used?

(If the priority or delta time bit is "0" in Z+2, yes.)

The new priority (or delta time) is situated in location Z+3 and the old priority (or delta time) is situated in the PHSPRT1 table.

Temporarily store new or old priority (or delta time).

Determine restart address and store its ZCA Dr.

Is the ZCA Dr of the restart address situated in the next two locations of the calling sequence? (If the restart address bit 11 of Z+2 designated as "A" equal to 1?)

No, restart address is the location where EPHSCH returns to the caller.

Store the ZCA Dr of the restart address provided by caller.

Save the caller's BBank and Superbank.

Next sheet.
THE EXECUTIVE

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

FINDVAC: USED TO SCHEDULE A JOB NEEDING A SET OF ERASABLE LOCATIONS, CALLED THE VAC AREA. SH. 3

SPVAC: SAME AS FINDVAC, EXCEPT THAT NEWPrio IS ALREADY LOADED, A, L = 2CAD, OF JOB TO BE SCHEDULED, AND INTERRUPTS ALREADY INHIBITED. SH. 3

NOVAC: USED TO SCHEDULE A JOB NOT NEEDING A VAC AREA. SH. 4

ENDOFJOB: USED TO TERMINATE A JOB. FREES CORESET AND VAC AREA, IF ANY, AND SCANS FOR ACTIVE JOB OF HIGHEST PRIORITY. IF IT FINDS ONE, IT PASSES CONTROL TO IT; OTHERWISE, CONTROL IS TRANSFERRED TO DUMMYJOB. SH. 6

PRIORING: USED TO CHANGE A JOB'S PRIORITY. IF CHANGED PRIORITY IS STILL HIGHEST, CONTROL IS RETURNED TO CALLER, OTHERWISE, JOB WITH HIGHEST ACTIVE PRIORITY IS GIVEN CONTROL. SH. 10

JOBSLEEP: USED TO MAKE THE CALLING JOB TEMPORARILY INACTIVE UNTIL SOME EVENT (LIKE I/O) HAS OCCURRED. CONTROL IS TRANSFERRED TO JOB WITH HIGHEST ACTIVE PRIORITY, OR TO DUMMYJOB, IF THERE ARE NO ACTIVE JOBS. SH. 10

JOBWAKE: USED TO WAKE UP A SLEEPING JOB. IF JOB IS NOT FOUND, -1 IS LOADED INTO LOCCTR. SH. 11

CHANG1: USED BY A BASIC JOB TO GIVE CONTROL TO JOB POINTED TO BY NEWJOB. SH. 13

CHANG2: USED BY THE INTERPRETER TO GIVE CONTROL TO JOB POINTED TO BY NEWJOB. SH. 13

ADVAN: CHECK ON NEWJOB CALLED BY SELF CHECKING ROUTINE SH. 18

SPECIAL CONVENTION: DOUBLE ARROW MEANS EXCHANGE OPERATION

ENCLOSED ARE REPLACEMENT SHEETS NEEDED TO UPDATE THE COLOSSUS IIA FLOWCHART FC-2030, REV. 0, TO THE COLOSSUS IIC FLOWCHART FC-2050, REV. 1.

EFFECTIVE SHEETS NOW ARE:

<table>
<thead>
<tr>
<th>SHEET</th>
<th>REV.</th>
</tr>
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<tbody>
<tr>
<td>SH. 1-2</td>
<td>0</td>
</tr>
<tr>
<td>SH. 3-4</td>
<td>1</td>
</tr>
<tr>
<td>SH. 5-20</td>
<td>0</td>
</tr>
</tbody>
</table>
RESTART.

PUT +0 INTO VAC AREA'S VACUSE REGISTER, LOW 9 OF NCWRLO - ADDRESS OF VACUSE REGISTER + 1.

NEWPrio = A

STORE JOB'S 2CADDR
(2CADDR = FIRST 2 LOCATIONS AFTER TO FINDVAC)

SPVACIN

STORE SCHEDULING JOB'S FBANK, FOR STORAGE
SET FBANK FOR EXECUTE

FINDVAC2

EXECTEM = A

STORE SCHEDULING JOB'S FBANK

VACUSE REGISTERS HAVE TAGS: VACUSE
VACUSE
VACUSE
VACUSE
VACUSE

THE SYMBOL USED IN THIS FLOWCHART FOR A PARTICULAR VACUSE REGISTER IS VACUSE, WHERE X MAY BE ANY INTEGER FROM 1 TO 5.

NOTE: VACUSE REGISTERS CONTAIN THEIR OWN ADDRESS, IF THE CORRESPONDING VACAREA IS FREE; OTHERWISE THEY CONTAIN +0. (VACUSE REGISTERS ARE INITIALIZED BY FRESH START, AND RESTART.)

FREE ONE FOUND

BAILOUT

FC-2040

(NO VAC AREAS AVAILABLE)

PROG ALARM LIGHT
ALARM CODE 34204

VACFOUND

VACUSE = +0

NEWPrio = NEWPrio + ADDR(VACUSE) + 1

PUT +0 INTO VAC AREA'S VACUSE REGISTER,
TO SHOW THAT IT IS IN USE,
LOW 9 OF NEWPrio = ADDRESS OF VACUSE REGISTER + 1.

NEXT SHEET
FROM PRECEDING SHEET

NOVAC

INHIBIT INTERUPTS

NEWPRO = A + 110o

NEWLOC = Q#Q

EXECTEM1 = FRANK

EXECBANK

FAKEPRT = OCTAL 110. TAKES PLACE OF VACARDS. SEEMS TO ALLOW QPRT TO BE SET TO MPAC + 6, PERMITTING A NOVAC JOB TO DO AN INTERPRETIVE "CALL ORDER," FOR EXAMPLE.

STORE 2GADR OF NEW JOB.

STORE SCHEDULING JOBS FRANK FOR RETURN SET FRANK FOR EXECUTIVE.

NOVAC2

LOCCTR = 0

A = 6

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

NOVAC3

START OF CORE SEARCH LOOP

EXECTEM2 = A

A = EXECTEM2 - 1

IS CORE SET POINTED TO BY LOCCTR AVAILABLE?

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

NEXTCORE

ADD 120 TO LOCCTR

LOCCTR = LOCCTR + COREINC

PRIORITY = LOCCTR = NEWPRO

PUSHLOC = LOCCTR + BITS 1-9 OF NEWPRO

INSERT PRIORITY & VACADD+1 OR FAKEPRT.

GIVE PUSHLOC ITS STARTING VALUE.

BAILOUT TURNS ON

PROG ALARM LIGHT, DISPLAYS

ALARM CODE 31202

(NO CORE SETS AVAILABLE), FORCES RESTART.

NEXT SHEET
FROM PRECEDING SHEET

IF CORE SET ZED IS BEING LOADED
FIXLOC AND OVFIND ARE SET UP IMMEDIATELY.
(IMPORTANT FOR RESTARTS)

NO

IS

LOCCTR = 40

YES

OVFIND ← LOCCTR
FIXLOC ← PUSHLOC
INITIALIZE
FIXLOG AND OVFIND

SPECTEST

IS THERE AN ACTIVE JOB WAITING?
(THIS WOULD BE RARE)

> 0

ACTIVE JOB
WAITING

> 0

< 0

NEWJOB ← +0
LOC₀ ← NEWLOC₀

DDUMYJOB SETS NEWJOB ← -0.
IN OTHER JOBS, NEWJOB IS
TESTED FROM TIME TO TIME.
IF >0, A JOB OF HIGHER
PRIORITY IS WAITING.
LOC₀ SET AS LOCATION OF
THIS JOB.

CCSHOLE ← +2000

CCSHOLE TURNS
PROSALRM ON AND
CAUSES A RESTART

SETLOC

LOC₀ ← LOCCTR ← NEWLOC₀
LOAD JOB OF JOB INTO PROPER CELLS.

IS

NEWPRIORITY ≤
PRIORITY ≤
NEWJOB

YES

SCHEDULED JOB HAS HIGHEST PRIORITY OF ACTIVE JOBS.
LOAD NEWJOB WITH CORESET INDEX VALUE AS TAG.

NO

NEWJOB ← LOCCTR

ENDFIND

ENDFIND

FBANK ← EXECTEX

REPLACE SCHEDULING JOB'S FBANK

RETURN VIA C(0)+2
ET1: Succeeding entrances (consider 12A to be positive, non-zero multiple of 12D)

**INPUT:**
- \(A_2 = (\text{PRIORITY} + 12x) - 1\)
- \(\text{BUF} + 1 = -\text{HIGHEST PRIORITY YET FOUND}\)
- \(\text{BUF} = 0\) if entered via probing, or changed priority still high.
- \(Q = \text{HIGHEST YET FOUND, otherwise}\)

**OUTPUT:**
- If \([A]\) is strictly larger than \([\text{BUF} + 1]\), \(\text{BUF} = -A, \text{BUF} = Q\)
- No change otherwise.

**ET1**
- \(A \rightarrow (\text{PRIORITY} + 24D) - 1\)
- \(\text{TEST PRIORITY} + 24D \leq 0\)
- \(\text{COSSHOLE FC-2140}\)
- \(\text{EXECUTE}\)
- \(\text{NEXT SHEET}\)

**ET2**
- \(A \rightarrow (\text{PRIORITY} + 36D) - 1\)
- \(\text{TEST PRIORITY} + 36D > 0\)
- \(\text{NO COSSHOLE BRANCH HERE}\)
- \(\text{EXECUTE}\)
- \(\text{NEXT SHEET}\)

**ET3**
- \(A \rightarrow (\text{PRIORITY} + 48D) - 1\)
- \(\text{TEST PRIORITY} + 48D \leq 0\)
- \(\text{COSSHOLE FC-2140}\)
- \(\text{EXECUTE}\)
- \(\text{NEXT SHEET}\)
(BUF+2) → A

SAVE INCOMING (PRIORITY + 12X) = 1

IS THIS NEW POSITIVE PRIORITY GREATER THAN HIGHEST
PREVIOUS POSITIVE PRIORITY ?
(BUF+1 = 0 FOR 1ST TIME IF NOT PRI CHANGE.)

(Note: Test is on whole priority word (including the
address of vac area, if any). 1100 for novac.)
Therefore, Findvac jobs will run before Novac
jobs of same nominal priority.)

NO

BUF+2 < [BUF+1] ?

YES

RETURN TO
C(3)+2

A ← -(BUF+2)

EJ2

BUF+1 ← A
BUF ← Q

SAVE Q FOR LOADING NEW JOB,
WITH PROPER INDEX VALUE.

RETURN VIA
BUF
BEGIN

**PRIQCHNG**

- **INHIBIT INTERRUPTS**

- **NEWPRIO** ← **A**
  - **BANKSET** ← **BBANK**
  - **EBANK** ← **EXECBANK**
  - **LOC** ← **Q**

  *Prepare for priority change.*
  - Set **BANKSET** to prepare **ECADR** of return location.
  - Set **EBANK** to **EXECBANK**.
  - Set **Q** register of **ECADR**.

**PRIQCH2**

- **BUF** ← **ZERO**
- **PRIORITY** ← (bits 3-1 of **PRIORITY**) + **NEWPRIO**
- **A** ← **PRIORITY**

  *Set Buf+0 for tag to EJSCAN: indicates entry via PRIQCHNG.*
  - Set up new priority with address of vax area (ex. 123).
  - Priority put into Buf+1 for comparison with other priority words.

**JOBSLEEP**

- **LOC** ← **A**
- **FBANK** ← **EXECBANK**

  *A = CADR of first instruction to be performed upon awakening.*
  - Set **FBANK**.

**JOBSLP1**

- **INHIBIT INTERRUPTS**

  *Negate priority indicates a dormant job.*
  - Get **EBANK**.

**SUPERBANK INTO**

- **A** ← **5**

  *Get SUPERBANK bits.*

**BANKSET** ← **A**

- **A** ← **ZERO**

  *Minus zero, subsequently loaded into Buf+1, will indicate to EJSCAN that no jobs are awake, if it remains untouched.*

**JOBSLP2**

- **BUF+1** ← **A**

  *Entry for PRIQCHNG.*

**EJSCAN**

- **SH6**

  *Find highest job priority, and put it on. (Or go to dummy job).*

END
INHIBIT INTERUPTS

Q ← Q - 2
RETURN IS TO TWO LOCATIONS BEYOND ADDRESS IN Q.

NEWLOC ← A
A ←FBANK
FBANK ← EXECBANK

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

JOBWAKE2

EXECMEM ← A
LOCCTR ← Q
A ← 6
STORE CALLING FBANK
INITIALIZE SEARCH LOOP

NEXT SHEET
FROM PRECEDING SHEET

JOBWAKE4

EXECM2 ← A

TEST
PRIORITY = LOCCTR

< 0 OR = 0

NEGATIVE PRIORITY MEANS SLEEPING JOB

WAKETEST

IS THIS THE RIGHT SLEEPING JOB?

NO

IS NEWLOC = LOC? LOCCTR ?

YES

JOBWAKE4

LOCCTR ← LOCCTR + COREINC

IS EXECM2 = 0 ?

NO

WAS THAT LAST CORE ?

A ← EXECM2 - 1

DECREMENT COUNTER

YES

SET LOCCTR = 0

ONE AS A TAQ: SLEEPING CORESET NOT FOUND.

LOCCTR ← 0

ENDFINISH

NEXT SHEET
NEWPRIO ← -PRIORITY -LOCCTR
PRIORITY -LOCCTR ← -PRIORITY -LOCCTR
NEWLOC +1 ← BANKSET -LOCCTR + BITS 15-11 OF NEWLOC
NEWLOC ← BITII + BITS 10-1 OF NEWLOC

1) SET POSITIVE PRIORITY INTO NEWPRIO.
   (WAKENED JOBS USE FINDAC-NONAC ROUTINE)
2) MAKE AWAKENED PRIORITY
   POSITIVE.
3) FORM 2CADR OF AWAKENING LOCATION.

IS AWAKENED JOB IN CORESET 0?

NO

A ← LOCCTR -1
SETLOC
SH5

YES

IS LOCCTR,≥ 0?

A ← LOCCTR -1
SETLOC
SH5

SET UP ONFIND AND FIXLOC IMMEDIATELY

CHANG1

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

L ← Q
A ← BBANK
BBANK ← EXECBBANK

SAVE RETURN ADDRESS CADR
SAVE BBANK

CHANJOB
SH14

CHANG2

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

NEGATIVE LOC IN L INDICATES THIS
WAS AN INTERPRETIVE JOB.

L ← LOC

CHANGE+2

BBANK ← EXECBBANK

SET EXECUTIVE BBANK.

CHANJOB-1
SH14
NOTE: DUMMYJOB IS NOT A JOB; IT DOES NOT OCCUPY A VAC AREA. IT IS, RATHER, A SUBROUTINE OF THE EXECUTIVE.

NEWJOB → 0
NEWJOB = 0 INDICATES NO ACTIVE JOBS

ALLOW INTERRUPTS

BIT 2 OF DSALMOUT = 0
TURN OFF COMPUTER ACTIVITY LIGHT.

ADVAN
ENTRANCE FROM SELF CHECK ROUTINE.

IS THERE AN ACTIVE JOB?

NO

TEST NEWJOB

> 0
YES: ONE IN CORESET 0

YES, ONE NOT IN CORESET 0, REQUIRES CHANJOB

NUCHANZ

SHIT

ADVAN + 2

POSSIBLE ENTRY FROM NUCHANZ

NUDIRECT

SET BIT 2 OF DSALMOUT

TURN ON ACTIVITY LIGHT

SELFRET = RETURN ADDRESS OF SELFCHECK (TO PICK UP NEXT ERASABLE LOCATION), OR SELFRET = ADDRES SELFORK)

SELFRET → SELFRET

A ← SELFRET

SET BIT 2 OF DSALMOUT

GET STARTING LOCATION OF JOB

A → J

SUPIXCHI

EXCHANGE DONE FOR CHANNEL OPERATION

NEXT SHEET
FROM PRECEDING SHEET

A (BIT 7-5) INTO SUPERBANK

SET SUPERBANK BITS

BBANK ← A

SET BBANK

GO TO ADDRESS IN L

UNCHANGE

INHIBIT INTERRUPTS

HAS NEWJOB BEEN CHANGED TO +0 ?

(POSSIBLE, BUT UNLIKELY: AN INTERRUPT MUST HAVE OCCURRED LESS THAN 1 MCT BEFORE INITIATING THE JOB IN CORESET 0.)

NEWJOB = +0 ?

NO: STILL >0

SET BIT OF DEALLOCATION

TURN ON ACTIVITY LIGHT

ALLOW INTERRUPTS

ADVANCE SH16

AL ← LOC+1

THERE MAY BE A SLEEPING JOB IN CORESET 0. BETTER SAVE ADDRESS INFORMATION.

CHANJOBSH4

SH14
### Diagram of Coresets:

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<tr>
<th>MPAC: 17 REGISTERS</th>
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<tbody>
<tr>
<td>MODE</td>
</tr>
<tr>
<td>LOC</td>
</tr>
<tr>
<td>BANKSET</td>
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<tr>
<td>PUSHLLOC</td>
</tr>
<tr>
<td>PRIORITY</td>
</tr>
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</table>

The active job, if any, occupies first coreset. There are six other coresets, occupying the next 16 loc. jobs, for non-active jobs, all identical, and accessible by indexing.
ERASABLE LOCATIONS USED

AGC
TAG
MEANING

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

BANKSET

ACTIVE: Bank associated with loc in interpreter. Otherwise, unsaved storage cell.
Not active: Bank (and superbank) associated with loc; ebank and superbank if from jobsleep.

BBANK

BUF

BUFF IN EJS CAN

BUF +1

BUFF IN EJS CAN

BUF +2

BUFF IN EJS CAN

DSALMOUT

CHANNEL 11: Written into by dummyjob to turn on and off the activity light.

EXTCH1

Temporary storage, usually holds Q.

EXTCH2

Temporary storage.

FIANK

FIXLOC

Contains absolute address of start of vac area.

LOC

ACTIVE: Address information for operand in interpreter; unsaved otherwise.
Not active: (1) Active contents, if job was running in interpreter;
(2) starting location of basic language job; or (3) - cdr of waking address for sleeping job.

LOCCHR

MPAC

MPAC +2

ETC.

NEWJOB

-0 if in dummyjob, and no non-dormant job scheduled
+0 if currently active job has highest priority. Positive index value of the coreset of highest priority non-sleeping job, otherwise.

NEWLOC

STARTING LOCATION OF JOB BEING SCHEDULED

NEWPRI

Prioriry of job being scheduled (or New Priority in Privod)

OVFIND

Overflow register (interpreter)

PRIORITY

Priority of job (in high order bits) and in low order bits: address of the vac area (or 110b if a novac job)

PUSHLOC

ACTIVE: Current address of next cell to be loaded in pushlist, if interpreter.
Not active: If ovfind = 0, set to -pshloc, same as active, otherwise.

SELFRET

RETURN ADDRESS TO SELF CHECK ROUTINE

VAC1USE

VAC2USE

VAC3USE

CONTAIN OWN ADDRESS IF VAC AREA NOT IN USE. OTHERWISE, CONTAIN +0.

VAC4USE

VAC5USE
<table>
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<th>MEANING</th>
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<td>-AGC TAG -CCSPR</td>
<td>COMPLEMENT OF A CCS PRIORITY INSTRUCTION, TO OBTAIN THE CORRECT INDEX VALUE IN EJSCAN</td>
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<tr>
<td>CORINC</td>
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<td>OCT. 110, TO BE LOADED INTO PRIORITY, IN LIEU OF A VAC AREA ADDRESS</td>
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<tr>
<td>NO. CORES</td>
<td>DEC. 6, FOR INDEXING CORESETS</td>
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WAITLIST PROGRAM SECTION

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<th>ENTRIES</th>
<th>SHEET</th>
<th>DESCRIPTION</th>
</tr>
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<tbody>
<tr>
<td>TWIDDLE</td>
<td>9</td>
<td>SCHEDULES TASK IN SAME BANK. GENADR OF TASK IS GIVEN IN LOCATION ( x+1 ), WHERE ( x = TC TWIDDLE ). DELTA TIME IS IN A. RETURNS TO LOCATION ( x+2 ) OF CALLING SEQUENCE. SINGLE-PRECISION DELTA TIME.</td>
</tr>
<tr>
<td>WAITLIST</td>
<td>9</td>
<td>SCHEDULES TASK IN ANOTHER BANK. 2CADR OF TASK IS GIVEN IN LOCATIONS ( x+1 ) AND ( x+2 ), WHERE ( x = TC WAITLIST ). DELTA TIME IS IN A. RETURNS TO LOCATION ( x+3 ) OF CALLING SEQUENCE.</td>
</tr>
<tr>
<td>DLY2-1</td>
<td>10</td>
<td>SCHEDULES TASK WITH 2CADR OF TASK GIVEN IN A AND L. DELTA TIME IS IN Q. RETURN ADDRESS IS IN WAITEXIT.</td>
</tr>
<tr>
<td>FIXDELAY</td>
<td>10</td>
<td>DELAYS EXECUTION OF LOCATION ( x+2 ) BY SCHEDULING LOCATION ( x+2 ) OF CALLING SEQUENCE AS A TASK WHERE ( x = TC FIXDELAY ). DELTA TIME IS GIVEN IN ( x+1 ). CALLING SEQUENCE IS A TASK WHICH CONTINUES INTO FIXDELAY, WHERE THIS TASK IS TERMINATED WITH A TRANSFER TO TASKOVER, UNTIL RESUMED AT ( x+2 ).</td>
</tr>
<tr>
<td>VARDELAY</td>
<td>10</td>
<td>DELAYS EXECUTION OF LOCATION ( x+1 ) BY SCHEDULING LOCATION ( x+1 ) OF CALLING SEQUENCE AS A TASK WHERE ( x = TC VARDELAY ). DELTA TIME IS GIVEN IN A. LIKE FIXDELAY, THE CALLING SEQUENCE IS A TASK WHICH CONTINUES INTO VARDELAY, WHERE THIS TASK IS TERMINATED WITH A TRANSFER TO TASKOVER UNTIL RESUMED AT ( x+1 ).</td>
</tr>
<tr>
<td>T3RUP</td>
<td>16</td>
<td>TRANSFERS CONTROL TO TASK WHOSE 2CADR IS IN LOCATION LST2+0 AND LST2+1. BEFORE EXECUTION OF TASK, TIMES IS SET FOR NEXT TASK, TABLES LST1 AND LST2 SHIFTED UPWARD, DUMMY JOB TIME INTERVAL, AND 2CADR ADDED TO BOTTOM OF BOTH TABLES. AFTER EXECUTION OF TASK, CONTROL GOES TO TASKOVER, EITHER RETURN TO T3RUP FOR NEXT TASK OR TO RESUME INTERRUPTED ROUTINE.</td>
</tr>
<tr>
<td>TASKOVER</td>
<td>18</td>
<td>ALL TASKS TERMINATE BY TRANSFERRING CONTROL TO TASKOVER, WHICH RETURNS CONTROL TO T3RUP TO EXECUTE ANY TASK WHICH MAY HAVE BEEN WAITING TO BE PERFORMED DURING THE SAME INTERRUPT, IF NO OTHER TASK IS TO BE PERFORMED AT THIS TIME, CONTROL IS RETURNED TO THE INTERRUPTED ROUTINE AFTER RESTORING ORIGINAL CONTENTS TO CERTAIN REGISTERS. SCHEDULES TASK WITH DOUBLE-PRECISION DELTA TIME GIVEN IN A AND L AND ITS 2CADR IN LOCATIONS ( x+1 ) AND ( x+2 ), WHERE ( x = TC LONGCALL ). RETURNS TO LOCATION ( x+3 ) OF CALLING SEQUENCE.</td>
</tr>
<tr>
<td>LONGCALL</td>
<td>21</td>
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<td>DESCRIPTION</td>
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REV
1. update col II A to col II C (Sh. 9. 13.)
2. Sh. 7 20 23
WAITLIST PROGRAM SECTION

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

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

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

SCHEDULING CONSISTS OF COMPARING THE EXECUTION TIME \( T_\alpha \) OF THE NEW TASK TO BE SCHEDULED WITH THE EXECUTION TIME \( T_1 \) OF TASK 1 (SO NUMBERED BECAUSE IT IS THE FIRST TO BE EXECUTED OF THOSE TASKS THAT WERE SCHEDULED AND NOT EXECUTED YET). TASKS 1, 2, 3, ..., 8 AND 9 WILL BE EXECUTED AT TIMES \( T_1, T_2, T_3, ..., T_8 \) AND \( T_9 \), ASSUME \( T_9 > T_8 > T_7 \), ETC. UNTIL TASK \( n \) IS SCHEDULED, TIME3 COUNTER WILL HAVE BEEN SET TO OVERFLOW AT TIME \( T_3 \) FOR EXECUTION OF TASK 1 (TIME3 = OCT 40000 - (\( T_3 \) - 1)). THE TIME INTERVAL BETWEEN THE EXECUTION TIME OF EACH TASK AND THE NEXT TASK WILL HAVE BEEN PLACED INTO THE LST1 TABLE AND THE 2CADR OF EACH TASK INTO THE LST2 TABLE AS FOLLOWS:
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<th>TASK</th>
<th>LST1 TABLE</th>
<th>LST2 TABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TIME3 = OCT 40000 - (T₁ - T)</td>
<td>LST2+0 = GENADR OF TASK 1</td>
</tr>
<tr>
<td></td>
<td>LST2+1 = BBCON OF TASK 1</td>
<td>LST2+2</td>
</tr>
<tr>
<td>2</td>
<td>LST1+0 = -(T₂ - T₁) + 1</td>
<td>LST2+3</td>
</tr>
<tr>
<td></td>
<td>LST2+4 = 2CADR OF TASK 2</td>
<td>LST2+5</td>
</tr>
<tr>
<td>3</td>
<td>LST1+1 = -(T₃ - T₂) + 1</td>
<td>LST2+6</td>
</tr>
<tr>
<td></td>
<td>LST2+7 = 2CADR OF TASK 3</td>
<td>LST2+9</td>
</tr>
<tr>
<td>4</td>
<td>LST1+2 = -(T₄ - T₃) + 1</td>
<td>LST2+8</td>
</tr>
<tr>
<td></td>
<td>LST2+10 = 2CADR OF TASK 4</td>
<td>LST2+11</td>
</tr>
<tr>
<td>5</td>
<td>LST1+3 = -(T₅ - T₄) + 1</td>
<td>LST2+12</td>
</tr>
<tr>
<td></td>
<td>LST2+13 = 2CADR OF TASK 5</td>
<td>LST2+15</td>
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<tr>
<td>6</td>
<td>LST1+4 = -(T₆ - T₅) + 1</td>
<td>LST2+14</td>
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<td></td>
<td>LST2+16 = 2CADR OF TASK 9</td>
<td>LST2+17</td>
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<td>7</td>
<td>LST1+5 = -(T₇ - T₆) + 1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>LST1+6 = -(T₈ - T₇) + 1</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>LST1+7 = -(T₉ - T₈) + 1</td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>LST1 + a - 2 = -(T₀ - T₀ - 1) + 1</td>
<td>LST2 + 2a - 2 = 2CADR OF TASK a</td>
</tr>
</tbody>
</table>

A search is made of the LST1 table to find where the new task should be placed such that T_a > T_N > T_a-1

If the new task (task N) should be executed before task I (T₁ > Tₙ), then

1. OCT 40000 - (Tₙ - T) is set into TIME3.
2. -(T₁ - Tₙ) + 1 is set into LST1+0; -(T₂ - T₁) + 1 is shifted from LST1+0 to LST1+1; -(T₃ - T₂) + 1 is shifted from LST1+1 to LST1+2; etc. and -(T₉ - T₈) + 1 is discarded.
3. The 2CADR of the new task is placed into LST2+0 and LST2+1; the 2CADR of task I is shifted from LST2+0 and LST2+1 to LST2+2 and LST2+3, etc.; the 2CADR of task 9 is discarded.
4. If the 2CADR of task 9 was a 2CADR of a regular task (not a dummy task), a restart is initiated via bailout (an abort), otherwise return to the caller.

Assuming that T₉ > Tₙ > T₅, then the time interval -(T₅ - T₉) + 1 would be computed and placed into LST1+4. Also, the time interval -(T₆ - T₅) + 1 would be computed and placed into LST1+5 replacing -(T₇ - T₆) + 1, which would be shifted into LST1+6, and the time intervals of the succeeding tasks would be likewise shifted down until the last one, -(T₉ - T₈) + 1 would be discarded. Also, the 2CADR of the new task would be inserted into LST2+10 and LST2+11, replacing the 2CADR of task 6, which would be shifted into LST2+12 and LST2+13 and the 2CADR's of the succeeding tasks would be likewise shifted down until the last one. If the last one is the 2CADR of a regular task (not a dummy task), a restart is initiated via bailout (an abort); otherwise return to the caller. The time intervals and 2CADR's for tasks 1 through 5 will remain intact in their LST1 and LST2 registers.

Assuming that T₉ > T₅, then task 5 would be executed before the new task. Tasks whose times of execution are the same are executed in the same order that they were scheduled - the first one scheduled is the first one to be executed and so forth.
ASSUMING THAT T₁ > T₂, THE SEARCH IN THE LST1 TABLE WILL REVEAL THAT THERE IS NO ROOM IN THE TABLE FOR THE NEW TASK, AND A RESTART IS INITIATED VIA BAILOUT.

THE LONGCALL TASK IS USED TO SCHEDULE TASKS WHOSE DELTA TIME IS IN DOUBLE PRECISION, WHICH CANNOT BE HANDLED BY THE WAITLIST (SINGLE-PRECISION) ENTRY. LONGCALL WILL HANDLE DELTA TIMES FROM OCT 00001 (0.01 SECOND) TO [OCT 37777, OCT 37777] (2,684,554.55 SECONDS OR 745 HOURS, 39 MINUTES, AND 14.55 SECONDS). THE LONGCALL ROUTINE SCHEDULES ROUTINE LONGCYCLE AS A WAITLIST TASK EVERY 81.92 SECONDS (OCT = 81.92 SECONDS) IN A LOOP UNTIL THE UNUSED (REMAINING OR UNEXPIRED) PORTION OF THE DELTA TIME IS LESS THAN OR EQUAL TO 81.92 SECONDS. THEN ROUTINE GETCADR IS SCHEDULED AS A WAITLIST TASK TO BE EXECUTED AT THE END OF A TIME PERIOD EQUAL TO THE UNUSED LONGCALL DELTA TIME, THUS USING UP THE ENTIRE LONGCALL DELTA TIME. ROUTINE GETCADR WILL TRANSFER CONTROL DIRECTLY TO THE LONGCALL TASK, WHICH WILL TERMINATE WITH ROUTINE TASKOVER.

EXECUTION OF THE TASKS USES THE T3RUPT ENTRY. ASSUME TASKS 1 THROUGH 9 ARE SCHEDULED AND T3RUPT TIME DATA AND 2CADRS ARE IN THE TIMES (TASK 1) COUNTER AND LST1 AND LST2 TABLES. THEN CONTROL IS TRANSFERRED TO ENTR Y T3RUPT VIA THE LEAD-IN INTERRUPT ROUTINE AFTER INTERRUPTING SOME ROUTINE ELSEWHERE. WHEN T > T₁, THEN OCT 40000 - (T₁ - T) IN TIME COUNTER TIMES WILL EQUAL OCT 40000, THE OVERFLOW CONDITION. ACTUALLY, TIMES WILL CHANGE FROM OCT 37777 TO OCT 00000 WITH THE LAST (BEFORE T > T₁) INCREMENT OF THE TIME COUNTER. UPON OVERFLOW, INTERRUPT CONDITION IS STARTED. THIS CAUSES (1) THE INSTRUCTION AFTER THE INSTRUCTION BEING EXECUTED AT THE MOMENT THE INTERRUPT TOOK PLACE TO BE SAVED IN REGISTER BRUPT, AND (2) THE ADDRESS OF THE LOCATION AFTER THE LOCATION CONTAINING THE INSTRUCTION IN BRUPT TO BE SAVED IN REGISTER ZRUPT (THIS LOCATION AND THIS ADDRESS ARE LATER RESTORED BY INSTRUCTION RESUME WHEN THE INTERRUPTED ROUTINE IS RESUMED). THEN INTERRUPT CAUSES CONTROL TO BE TRANSFERRED TO THE T3RUPT LEAD-IN ROUTINE FOR SAVING CONTENTS OF CERTAIN REGISTERS. CONTROL IS THEN TRANSFERRED TO ROUTINE T3RUPT. BEFORE TASK 1 IS EXECUTED, TIMES WILL BE SET FOR TASK 2. THE TIME INTERVALS FOR EACH TASK WILL BE SHIFTED UPWARD ONE REGISTER, AND THE TIME INTERVAL (81.92 SECONDS) BETWEEN TASK 2 AND A DUMMY TASK WILL BE PLACED INTO THE LAST REGISTER LST1. IN ORDER TO SET TIMES FOR TASK 2, THE CONTENTS (T₁ - T₁) OF TIMES, OCT 37777, AND THE TIME INTERVAL -(T₂ - T₁) + 1 FOR TASK 2 ARE ALL ADDED TOGETHER TO OBTAIN OCT 40000 -(T₂ - T₁) WHICH IS PLACED INTO TIMES. IF TASK 2 WAS SCHEDULED FOR THE SAME TIME AS TASK 1 (T₁ = T₂) OR THE T3RUPT WAS DELAYED BY AN INTERRUPT OR ANOTHER INTERRUPT (T > T₁), THEN ROUTINE TASKOVER IS NOTIFIED THAT TASK 2 SHOULD BE EXECUTED IMMEDIATELY AFTER TASK 1 INSTEAD OF RESUMING THE INTERRUPTED ROUTINE. THE 2CADRS IN THE LST2 ADDRESS TABLE ARE SHIFTED UPWARD, AND THE 2CADR OF A DUMMY TASK IS PLACED INTO THE LAST TWO REGISTERS LST2+16D AND LST2+17D. CONTROL IS THEN TRANSFERRED TO TASK 1 AT THE LOCATION WROE 2CADRS WAS IN REGISTERS LST2+0 AND LST2+1 (THE TOP OF THE LIST). THEN THE TASK IS EXECUTED.

ALL TASKS TERMINATE IN A TRANSFER OF CONTROL TO ROUTINE TASKOVER. IF T = T₂ WHEN CONTROL ARRIVED AT T3RUPT TO EXECUTE TASK 1, THEN CONTROL WILL PASS FROM ROUTINE TASKOVER TO T3RUPT LOCATION OF T3RUPT TO INITIATE THE EXECUTION OF TASK 2, SET TIMES FOR TASK 3, AND SHIFT THE LST1 AND LST2 TABLES UPWARD. OTHERWISE, ROUTINE TASKOVER WILL TRANSFER CONTROL TO ROUTINE RESUME TO RESTORE ORIGINAL CONTENTS OF CERTAIN REGISTERS FOR RESUMING THE EXECUTION OF THE INTERRUPTED ROUTINE. LAST, CONTROL IS TRANSFERRED TO THE INTERRUPTED ROUTINE.
IF THE TASK TO BE EXECUTED WERE NOT A REGULAR TASK, BUT INSTEAD A DUMMY TASK, THEN DUMMY TASK SVCT3 WOULD BE EXECUTED. IF NO GYRO COMPENSATION IS REQUIRED, CONTROL IS TRANSFERRED TO ROUTINE TASKOVER. OTHERWISE, SVCT3 SCHEDULES (VIA TC NOVAC) ROUTINE NBDONLY AS A JOB (PRIORITY 35) TO COMPENSATE FOR NBD COEFFICIENTS ONLY. IF IMUSTALL IS NOT AVAILABLE, THEN A REGULAR TASK WILL BE SET UP VIA FXDELAY WITH A DELTA TIME OF FIVE SECONDS TO COME BACK AND AGAIN ATTEMPT TO SCHEDULE JOB NBDONLY. IF IMUSTALL IS STILL NOT AVAILABLE, ANOTHER TASK WITH FIVE-SECOND DELAY IS SCHEDULED. AFTER THE DELAY IS SET UP OR AFTER THE JOB NBDONLY IS SCHEDULED, CONTROL IS TRANSFERRED TO TASKOVER.

SUMMARY OF THE TWO SALIENT OPERATIONS

SCHEDULING A NEW TASK

THE DELTA TIME OF THE NEW TASK IS $T_{N} - T + \Delta T_{N}$.

IF $T_{N} - 1 < T_{N} < T_{N} + 1$, THE TIME INTERVAL $(T_{N} - T_{N-1}) + 1$ REPLACES $(T_{N} - T_{N-1}) + 1$ AND $(T_{N} - T_{N+1}) + 1$ REPLACES $(T_{N} - T_{N+1}) + 1$; WHICH IN TURN REPLACES $(T_{N+2} - T_{N+1}) + 1$, ETC., IN THE LST1 TABLE.

IF $T_{N} > T_{N}$, THE TIME INTERVAL COUNTER VALUE OCT 40000 - $(T_{N} - T)$ REPLACES OCT 40000 - $(T_{N} - T)$ IN TIME COUNTER TIME3 AND $(T_{N} - T_{N-1}) + 1$ REPLACES $(T_{N} - T_{N+1}) + 1$, WHICH IN TURN REPLACES $(T_{N} - T_{N+2}) + 1$, ETC., IN THE LST1 TABLE. IF $T_{N} > T_{N}$, THERE IS NO ROOM IN THE LIST TABLES FOR THE NEW TASK, AND A RESTART IS INITIATED.

INITIATING THE EXECUTION OF A TASK (TASK3):

$(T_{2} - T_{1}) + 1$ IN THE TOP OF THE LST1 TABLE, THE $(T - T_{1})$ IN TIMES $(T > T_{1})$ AND OCT 37777 ARE ADDED TOGETHER TO OBTAIN OCT 40000 - $(T_{2} - T)$ TO BE SET INTO TIME3 FOR TASK 2 AND ALL OTHER TIME INTERVALS IN THE LST1 TABLE ARE MOVED UP.
FUNCTIONAL FLOW CHART OF WAITLIST TASK SCHEDULING

NOTE: THE TASK TO BE SCHEDULED IS REFERRED TO AS THE NEW TASK (TASK N). TASK 1 IS SO NUMBERED BECAUSE IT IS THE FIRST TASK TO BE EXECUTED AMONG THOSE TASKS (TASKS 1, 2, 3, ..., B, AND) THAT HAVE BEEN SCHEDULED, BUT NOT EXECUTED YET. T1, T2, T3, ..., T8, T9, AND Tn ARE THE EXECUTION TIMES OF TASKS 1, 2, 3, ..., B, 9, AND N, RESPECTIVELY. ASSUME T1 < T2 < T3 < ... < TB < T9. T IS CURRENT TIME.

DELAY RETURN LOCATION BY A FIXED ΔT

FIXDELAY

#1

WAITLIST

#2, 3

BOTH ENTRIES TERMINATE WITH ROUTINE TASKOVER

BOTH ENTRIES ARE A CONTINUATION OF A TASK

WAITLSTO

PROCEDURE

FC-2143

DLY2

= 0

EXECUTE NEW TASK BEFORE TASK 1

T1 > Tn

COMPUTE

- (T1 - Tn) - 1

TIMEB

= (T1 - Tn) - 1

NO

WTLST4

SHIFT DATA IN LST1 BY ONE REGISTER

LST1 + 1

= (T1 - Tn) + 1

EXECUTE NEW TASK FIRST

EXECUTE TASK 1 FIRST

SCHEDULE TASK IN SAME BANK

#4

SCHEDULE TASK IN ANY BANK

EXECUTE NEW TASK FIRST

EXECUTE TASK 1 FIRST

SHIFT ZCODS OF TASKS IN LSTS TO TABLE DOWN TWO REGISTERS

LSTS240, 241

ZCOD OF NEW TASK

LSTS + < - 2 + T4 - 1

= ZCOD OF NEW TASK N

THERE IS ROOM FOR NEW TASK

NORMAL EXIT RETURN TO CALLING SEQUENCE IF ENTERED VIA TWIDDLE OR WAITLIST

GO TO TASKOVER IF ENTERED VIA FIXDELAY OR WAITLIST

NO

Tcof NEW TASK IS A REGULAR TASK

TOO MANY TASKS (TASK N IS A REGULAR TASK)

WAIT2

= 11

DLY2

= 10

EXECUTE NEW TASK FIRST

EXECUTE TASK 1 FIRST

SHIFT ZCODS OF TASKS IN LSTS+4 TO TABLE DOWN AND AFTER DOWN BY TWO REGISTERS

WTLST5

PLACE FOR NEW TASK

NO

COMPUTE AND LST1 + < - 1

= (T1 - Tn) + 1

NO ROOM FOR NEW TASK

WTLST2

BAILOUT

FC-2143

SOFTWARE RESTART

LST1 + 1

= (T1 - Tn) + 1

NO

WTLST4

SHIFT DATA IN LST1 BY ONE REGISTER

LST1 + 1

= (T1 - Tn) + 1

EXECUTE NEW TASK FIRST

EXECUTE TASK 1 FIRST

W OPERATIONS PERFORMED ARE INDICATED BY NUMBER AS FOLLOWS:

1. OBTAIN RETURN ADDRESS AND DELTA TIME

2. SAVE DELTA TIME AND ZCOD OF TASK (CALLING SEQUENCE)

3. SET EXIT FOR TASKOVER INSTEAD OF RETURN TO CALLING SEQUENCE

4. INHIBIT INTERRUPTS: OBTAIN RETURN ADDRESS TO CALLING SEQUENCE, BBCON AND SUPER BANK OF TASK (IN SAME BANK)

5. INHIBIT INTERRUPTS

6. OBTAIN DELTA TIME AND GENAD OF RETURN ADDRESS TO CALLING SEQUENCE

7. OBTAIN ZCOD OF TASK

8. OBTAIN BBANK OF TASK (IF VIA WAITLIST)

9. SAVE ZCOD OF TASK

10. OBTAIN BBANK OF RETURN ADDRESS TO CALLING SEQUENCE

11. SAVE BBANK OF RETURN ADDRESS TO CALLING SEQUENCE
FUNCTIONAL FLOW CHART FOR EXECUTION OF TASK

PREPARE TO EXECUTE TASK (ASSUME TASK 1) WHOSE composite (T = T1) BECAUSE TIMES OVERFLOWED, ENTERS FROM INTERRUPTED ROUTINE VIA LEAD-IN INTERRUPT ROUTINE WHICH SAVES CONTENTS OF CERTAIN REGISTERS.

T3RUP

SAVE BBANK, Q AND SUPER BANK OF INTERRUPTED ROUTINE

T3RUP2

SHIFT DATA IN LST1 TABLE UPWARD BY ONE REGISTER

- ΔT = OCT 0047

ΔT = OCT 20001 OR 81.93 SECONDS

LST1 + OCT 57777

TIME INTERVAL BETWEEN TASK 0 AND DUMMY TASK

-(T1 - T2) + 1 WHICH WAS SHIFTED OUT OF LST1 =O IS USED TO COMPUTE TIMES.

TIME3 = SMTP3 + OCT 00047

FORMER CONTENTS OF LST1 = O SO THAT TIME3 = SMTP3 + OCT 00047

IS DELTA TIME FOR TASK 2 EXPIRED?

YES

RUPTAGN = -1

THIS NOTIFIES TASKOVER TO INITIATE EXECUTION OF TASK 2 IMMEDIATELY AFTER TASK 1

NO

SHIFT 2 CADRS OF TASKS IN LST2 TABLE UPWARD BY TWO REGISTERS

RUPTAGN = 0

THIS NOTIFIES TASKOVER TO RESUME EXECUTION OF THE INTERRUPTED ROUTINE

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

SVCT3

NO SYRO COMPENSATION REQUIRED

YES

NO

IMUSTALL IN PROGRESS

YES

NO

RESUME INTERRUPTED ROUTINE

SVC3X + 2 SECONDS LATER

SVC3X

[LSCT2 + 160, +170] 2 CADRS OF DUMMY TASK

SVCT3

IF TASK IS THE DUMMY TASK, SEE TOP CENTER

TASKOVER

ROUTINE WHERE [2 CADR WAS IN LST2 + T1 IS EXECUTED]

SHOULD TASK 2 BE EXECUTED?

YES

RUPTAGN = +1

NO

RUPTAGN = -0

NOW?

EXECUTE INTERRUPTED ROUTINE

RESTORE SUPER BANK OF INTERRUPTED ROUTINE

RESUME

RESTORE BBANK

RESTORE Q

RESTORE SQRM

NOB RSM

RELEASE INTERRUPT INHIBIT. RESTORE A, L, B AND Z TO INTERRUPTED ROUTINE

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MIT GUIDANCE AND NAVIGATION
WAITLIST

REVIEW

REV 2

SMIT 7-524
FUNCTIONAL FLOW CHART OF LONGCALL

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

LONGCALL

SAVE DOUBLE-PRECISION DELTA TIME AND 2CADR OF LONGCALL TASK

LNGCALL2

SAVE 2CADR OF RETURN ADDRESS

LONGCYCL

SUBTRACT 81.92 SECONDS (OCT 20000) FROM THE DELTA TIME (OR THE REMAINING OR UNUSED PORTION OF THE DELTA TIME)

IS UNUSED PORTION OF AT > 81.92?

YES

LASTTIME

NO, AT ≤ 81.92 SECONDS

GETCADR

WAITLIST TASK AT = UNUSED AT THIS SHEET

GETCADR

LONGRTRN

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

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

MUNITIME

LONGCYCL

WAITLIST TASK AT = 81.92 SEC. THIS SHEET

FC-2060
TIME3 = OCT 40000 - (T1 - T) IF TIME3 DID NOT OVERTFLOU DURING CURRENT INHINT.
T1 > Tm
TIME3 = T - T1 IF TIME3 OVERFLOWED DURING CURRENT INHINT. Tm > T1
WHERE T = CURRENT (NOW) TIME
T0, T1, T2, T3, ETC = TIME FOR NEXT/NEXT TASK TO BE EXECUTED.

OCT 200 (OEC 129) IS A VALUE GREATER THAN THE HIGHEST POSSIBLE VALUE TIME3 COULD HAVE IF OVERFLOW OCCURRED SINCE CURRENT INHINT OF INTERRUPTS WAS STARTED. IF THE NEXT TASK HAS THE LARGEST ALLOWABLE DELTA TIME, 162.5 SECONDS, TIME3 WOULD CONTAIN OCT 206. THEREFORE, OCT 200 IS A VALUE LESS THAN THE SMALLEST VALUE TIME3 COULD HAVE IF OVERFLOW DID NOT OCCUR. THIS OCT 200 IS ACCEPTABLE TO USE AS A BREAK POINT.

PROCEED TO COMPUTE -(T1 - T) + 1 FOR EITHER OVERFLOW OR NO OVERFLOW CONDITION.

Q10 TIME3 OVERFLOW DURING CURRENT INHIBIT OF INTERRUPTS?

NO

A < 0?

A = OCT 200 - OCT 40000 + T1 - T
= OCT 40177 + T1 - T

A = A + 1

YES

A = OCT 200 + T1 - T

A = OCT 37600 + T - T1 - 1
= T - T1 + OCT 37577

A = OCT 40000 + T1 - T
+ OCT 177
= T1 - T + OCT 40200

A = OCT 37577

A = T - T1 + OCT 40201
= T - T1 + OCT 37577 - OCT 37576
= T - T1 + 1 = -(T1 - T) + 1

A = OCT 40201

A = [T - T1 + 1] + [Tn - T] = Tn - T1 + 1
Tn - T1 IS THE DIFFERENCE BETWEEN THE TIMES OF EXECUTION OF THE NEW TASK AND TASK 1 (1ST TASK)
FROM PRECEDING SHEET

\[ A = T_n - T_i + 1 \]

\[ T_n - T_i \] is the difference between the times of execution of new task and task 1.

Should task 1 be executed prior to this new task? (Is \( T_n \geq T_i \)?)

**Note:**

If two tasks are scheduled to be executed at the same time, such as \( T_n = T_i \), the new task will be executed after task 1.

Task 1 remains as the next task to be executed \( T_i \leq T_n \)

**Note A:** Set time counter \( \text{TIME3} \) to overflow delta time centiseconds from now (at time \( T_n \))

\[ \text{TIME3} = \text{OCT 40000} - \text{DELTA TIME} = \text{OCT 40000} - (T_n - T) \]

\( \text{TIME3} \) is now set for the new task.

**Note B:** Set index hereafter referred to as \( x_1 \).

\( x_1 = 0 \)

**Algorithm Diagram:**

1. **NEW TASK SHOULD BE EXECUTED NEXT (SOONER THAN TASK 1)**
2. Compute time interval between new task and task 1.
3. **FROM PRECEDING SHEET**
   \[ A = T_n - T_i + 1 \]
4. **IS** \( A > 0 \) **?**
5. **NO**
   - \( T_i > T_n \)
   - **SET TIME FOR NEW TASK**
     - \( \text{TIME3} = \text{OCT 40000} - Q \)
     - **SEE NOTE A BELOW**
6. **YES**
   - **SET TIME FOR NEW TASK**
     - \( \text{TIME3} = \text{OCT 40000} - Q \)
     - **SEE NOTE B BELOW**
   - \[ A = -(T_i - T_n) + 1 \]
   - \[ Q \rightarrow 0 \]
   - **SEE NOTE B BELOW**
   - \[ WTLST4, SH14 \]
   - **NEXT SHEET**
7. **SET TIME COUNTER TIME3 TO OVERFLOW DELTA TIME CENTISECONDS FROM NOW (AT TIME Tn)**
8. \[ A = T_n - T_i \]
9. **LST1 = T_i - T_2 + 1**
10. **A = \lfloor T_n - T_1 \rfloor + \lfloor T_1 - T_2 + 1 \rfloor = T_n - T_2 + 1**
FROM PRECEDING SHEET

WTLISTS

A = T_N - T_3 + 1

SHOULD TASK 2 BE EXECUTED PRIOR TO THE NEW TASK?
(IS T_2 ≤ T_N ?)

T_3 > T_N ≥ T_1

INDEX X1 = 1

A = A - 1 + (LST1 + 1)

YES T_N ≥ T_2

IS A > +0

LST1 + 1 = T_2 - T_3 + 1

SHOULD TASK 3 BE EXECUTED PRIOR TO THE NEW TASK?
(IS T_3 ≤ T_N ?)

T_2 > T_N ≥ T_2

INDEX X1 = 2

A = A - 1 + (LST1 + 2)

YES T_N ≥ T_3

LST1 + 2 = T_3 - T_4 + 1

SHOULD TASK 4 BE EXECUTED PRIOR TO THE NEW TASK?
(IS T_4 ≤ T_N ?)

T_4 > T_N ≥ T_2

INDEX X1 = 3

A = A - 1 + (LST1 + 3)

YES T_N ≥ T_4

LST1 + 3 = T_4 - T_5 + 1

SHOULD TASK 5 BE EXECUTED PRIOR TO THE NEW TASK?
(IS T_5 ≤ T_N ?)

T_5 > T_N ≥ T_4

INDEX X1 = 4

A = A - 1 + (LST1 + 4)

YES T_N ≥ T_5

LST1 + 4 = T_5 - T_6 + 1

SHOULD TASK 6 BE EXECUTED PRIOR TO THE NEW TASK?
(IS T_6 ≤ T_N ?)

T_6 > T_N ≥ T_5

INDEX X1 = 5

A = A - 1 + (LST1 + 5)

YES T_N ≥ T_6

LST1 + 5 = T_6 - T_7 + 1

SHOULD TASK 7 BE EXECUTED PRIOR TO THE NEW TASK?
(IS T_7 ≤ T_N ?)

T_7 > T_N ≥ T_6

INDEX X1 = 6

A = A - 1 + (LST1 + 6)

YES T_N ≥ T_7

LST1 + 6 = T_7 - T_8 + 1

SHOULD TASK 8 BE EXECUTED PRIOR TO THE NEW TASK?
(IS T_8 ≤ T_N ?)

T_8 > T_N ≥ T_7

INDEX X1 = 7

A = A - 1 + (LST1 + 7)

YES T_N ≥ T_8

LST1 + 7 = T_8 - T_9 + 1

SHOULD TASK 9 (LAST) BE EXECUTED PRIOR TO THE NEW TASK?
(IS T_9 ≤ T_N ?)

A = T_2 - T_N - 1

IF X1 = 1

A = T_3 - T_N - 1

IF X1 = 2

A = T_4 - T_N - 1

IF X1 = 3

A = T_5 - T_N - 1

IF X1 = 4

A = T_6 - T_N - 1

IF X1 = 5

A = T_7 - T_N - 1

IF X1 = 6

A = T_8 - T_N - 1

IF X1 = 7

A = T_9 - T_N - 1

IF X1 = 8

* FROM SHEET 15

NEXT SHEET

A ← A

WTABORT

TURN ON PROGRAM ALARM LIGHT
AND SET ALARM CODE OCT 51Q03
INTO ONE OF THE FAILREG
REGISTERS SO IT IS AVAILABLE
FOR DISPLAY.

RESULTS IN RESTART
VIA GOPROG

MIT
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GUIDANCE AND NAVIGATION

WAITLIST

COLLOSSUS

FC-2060

FC-2140

 signed by
A. Sampson
7/16/67

MIT

E. Samuel
6/16/67

MIT

10/4/67

MIT

10/5/67

MIT

10/8/67

MIT

10/19/67
From preceding sheet

Note: 
Q will be used as an index and is hereafter referred to as X1. See table at right for its value.

A = T\_n - T\_\(\alpha\) + 1

New task waiting execution

Shift the contents of each of some or all LST1 registers to the next LST1 register to accommodate the value for the new task.

The value for the new task is T\_n - T\_\(\alpha\) + 1 in A. \(\alpha\) is determined by the condition T\_\(\alpha\) > T\_n - T\_x, x = 1. The value T\_n - T\_\(\alpha\) + 1 is placed into register LST1 + \(\alpha\) - 1 so that task n will be executed T\_n - T\_\(\alpha\) - 1 CENTI-SECONDS after task \(\alpha - 1\) and T\_\(\alpha\) - T\_n CENTI-SECONDS before task \(\alpha\). The former contents of LST1 + \(\alpha\) - 1 will be shifted to LST1 + \(\alpha\) + 1. The former contents of LST1 + \(\alpha\) + 0 to LST1 + \(\alpha\) + 1, LST1 + \(\alpha\) + 2, etc., to the end where the former content of LST1 + 7 is left in A and lost thereafter. \(\alpha\) is either 1, 2, 3, ..., 7, 8 or 9. LST1 registers, if any, preceding LST1 + \(\alpha\) - 1 remain unchanged.

LST1 + \(\alpha\) - 1 = -(T\_\(\alpha\) - T\_n) + 1, if X1 = \(\alpha\) - 1 upon arrival

List

\[\begin{array}{ll}
\text{X1} & \text{LST1 + X1} \\
1 & -(T_\alpha - T_n) + 1, \quad \text{if } T_\alpha > T_n - T_1, \text{ LST1 + 0} \\
2 & -(T_\alpha - T_n) + 1, \quad \text{if } T_\alpha > T_n - T_2, \text{ LST1 + 1} \\
3 & -(T_\alpha - T_n) + 1, \quad \text{if } T_\alpha > T_n - T_3, \text{ LST1 + 2} \\
4 & -(T_\alpha - T_n) + 1, \quad \text{if } T_\alpha > T_n - T_4, \text{ LST1 + 3} \\
5 & -(T_\alpha - T_n) + 1, \quad \text{if } T_\alpha > T_n - T_5, \text{ LST1 + 4} \\
6 & -(T_\alpha - T_n) + 1, \quad \text{if } T_\alpha > T_n - T_6, \text{ LST1 + 5} \\
7 & -(T_\alpha - T_n) + 1, \quad \text{if } T_\alpha > T_n - T_7, \text{ LST1 + 6} \\
8 & -(T_\alpha - T_n) + 1, \quad \text{if } T_\alpha > T_n - T_8, \text{ LST1 + 7} \\
\end{array}\]
SHIFTING OF ADDRESSES OF THE TASKS
IN THE LST2 LIST IS DONE IN THE SAME
MANNER AS THE TIME DATA WAS SHIFTED
IN THE LST1 LIST.

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

RETURN TO CALLING SEQUENCE
afi+2 WHERE ae=TC TWIDDLE,
rf+3 WHERE ae=TC WAITLIST
OR GO TO TASKOVER ON SHEET 18
IF ENTERED VIA FIXDELAY OR VARDELAY

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

FROM
PRECEDING SHEET
A ← WAITADR

IF X1 = 0, T1 > Tn NEW TASK IS WAITING EXECUTION

IF X1 = 1
T6 > Tn ≥ T1
[LST2, LST2+1] ← [A, L]

IF X1 = 2
T5 > Tn ≥ T6
[LST2+2, LST2+3] ← [A, L]

IF X1 = 3
T4 > Tn ≥ T5
[LST2+4, LST2+5] ← [A, L]

IF X1 = 4
T3 > Tn ≥ T4
[LST2+6, LST2+7] ← [A, L]

IF X1 = 5
T2 > Tn ≥ T3
[LST2+8, LST2+9] ← [A, L]

IF X1 = 6
T1 > Tn ≥ T2
[LST2+10, LST2+11] ← [A, L]

IF X1 = 7
T0 > Tn ≥ T1
[LST2+12, LST2+13] ← [A, L]

IF X1 = 8
Tn ≥ T0
[LST2+14, LST2+15] ← [A, L]

[LST2+16, LST2+17] ← [A, L]

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

TOO
MANY
TASKS
NO
YES
A ← GENADR OF SVCT3
LST2+16 PREVIOUSLY CONTAINED GENADR
SVCT3, THE DUMMY TASK

WTABORT
SH13

LVWTLIST
RETURN VIA
WAITEXIT

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

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GUDANCE AND NAVIGATION

A(0)

FC-2060
DRAFT

DRAWN

APPROVED

REV 2

T SHEET 18 OF 24
T+1 (IS INSTRUCTION TO BE EXECUTED FIRST UPON RESUMING INTERRUPTED ROUTINE)

T+2

SAVE NEXT INSTRUCTION B AND ADDRESS Z+2 IN BRupt AND ZRupt, RESPECTIVELY.

HARDWARE ACTION AUTOMATICALLY PERFORMED AT BEGINNING OF INTERRUPT. SEE NOTE AT BOTTOM RIGHT OF SHEET 19.

NOTE:

IF, WHEN TIME COUNTER TIME3 OVERFLOWS, INTERRUPTS ARE INHIBITED BY AN INHINT OR ANOTHER INTERRUPT IS IN PROGRESS AND/OR WAITING (T6, T7), TRANSFER OF PROGRAM CONTROL TO LOCATION 4014 WILL BE DELAYED UNTIL THE INHIBIT IS RELEASED (RELINT) OR INTERRUPT IN PROGRESS IS TERMINATED AND/OR T6 OR T5 INTERRUPT IS ALSO COMPLETED IF WAITING.

INTERRUPT LEAD IN ROUTINE

ROUTINE T3Rupt CAUSES PROGRAM CONTROL TO BE TRANSFERRED TO TASK 1. ALSO, IT MOVES THE TIME INTERVAL DATA AND 2CADR FOR THE REMAINING SCHEDULED TASKS UPWARD ONE PLACE IN THE LST2 AND LST2 TASKS SO TASK 2 WILL BE READY NEXT TIME TIME3 OVERFLOWS.

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

SAVE Q FROM ROUTINE TASKOVER ON SHEET 18

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

MOVE TIME DATA UPWARD ONE REGISTER IN LST1 TABLE

<table>
<thead>
<tr>
<th>LST1+7</th>
<th>OCT 57777</th>
</tr>
</thead>
<tbody>
<tr>
<td>LST1+6</td>
<td>OCT 57777</td>
</tr>
<tr>
<td>LST1+5</td>
<td>OCT 57777</td>
</tr>
<tr>
<td>LST1+4</td>
<td>OCT 57777</td>
</tr>
<tr>
<td>LST1+3</td>
<td>OCT 57777</td>
</tr>
<tr>
<td>LST1+2</td>
<td>OCT 57777</td>
</tr>
<tr>
<td>LST1+1</td>
<td>OCT 57777</td>
</tr>
<tr>
<td>LST1+0</td>
<td>OCT 57777</td>
</tr>
</tbody>
</table>

A = -(T2 - T1) + 1

T0 20.001 OR 81.93 SECONDS WHERE T0 IS EXECUTION TIME OF DUMMY TASK SVCT3 (WILL BE EXECUTED 81.93 SECONDS AFTER TASK 9).
FROM PRECEDING SHEET

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

\[ A = \frac{(T_2 - T_1) + 1}{T} \]

\[ T = \text{CURRENT TIME (NOW)} \]

\[ T_1 = \text{EXECUTION TIME OF TASK 1} \]

\[ T_2 = \text{EXECUTION TIME OF TASK 2} \]

A \leftarrow \text{OCT 37777} + A

A \leftarrow \text{TIME3} + A

THIS OPERATION WILL PRODUCE AN OVERFLOW CONDITION IN A ONLY IF \( T_2 = T_1 \)

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

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

\[ (T - T_1) > (T_2 - T_1) \]

\[ T > T_2 \]

YES

DOES A CONTAIN OVERFLOW?

\[ \frac{(T - T_1) - (T_2 - T_1)}{T - T_2} \]

NO

\[ \frac{(T_2 - T_1)}{T} > (T - T_1) \]

Ruptag \leftarrow +1

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

Ruptag \leftarrow -0

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

NEXT SHEET
ERED FROM 73 ATI ONS DIRECTLY.

AFTLIST JS FC-2060 ~

SUPERBNK ← L 7-5

IF TASK 1 IS DUMMY TASK

EXECUTE INSTRUCTIONS CONTAINED IN CODING FOR THIS ROUTINE

SUPERBNK ← BANKRPT 7-5

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

SET SUPERNK WITH SUPER BANK OF TASK 1.

EXECUTE TASK WHOSE 2CADR IS IN A AND L TO SVCT3 (DUMMY TASK) ON SHEET 20.

NOTE: PROGRAM CONTROL IS TRANSFERRED TO THE LOCATION WHOSE 2CADR IS IN A (GENADR) AND L (B8CON).

THUS TASK 1 IS NOW EXECUTED. TASK 1 IS ANY ROUTINE THAT WAS SCHEDULED AT CENTSECONDS AGO BY WAITLIST. THE TIME NOW IS T2-T1, THE EXECUTION TIME OF TASK 1.

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

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

SHOULD TASK 2 BE EXECUTED NOW BEFORE RETURN TO INTERRUPTED ROUTINE? (DID DELTA TIME FOR TASK 2 EXPIRE WHEN RUPAHI WAS SET IN ROUTINE T3RUP2 ON PRECEDING SHEET?)

RESTORE SUPER BANK OF INTERRUPTED ROUTINE

* ROUTINE TASKOVER IS ENTERED FROM 73 LOCATIONS DIRECTLY.
FROM PRECEDING SHEET

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

RESUME

Q ← QRUPT

RESTORE Q

NOQRSM

BBANK ← 15-11, 3-1

RESTORE BBANK

BANKRUPT ← 15-11, 3-1

NOQRSM

A ← ARUPT

RESTORE A AND L

L ← LRUPT

RELEASE INTERRUPT

NOW LEAVING INTERRUPT MODE

\{ INSTRUCTION RESUME (COMPRIS ES THESE TWO OPERATIONS) \}

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

NOTE:


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

# IF NEXT INSTRUCTION IS AN EXTEND INSTRUCTION, THE INTERRUPT IS DELAYED UNTIL THE NEXT INSTRUCTION IS NOT AN EXTEND INSTRUCTION.
Routine SVCT3 is the dummy task. It is scheduled in T3RUP2.

From T3RUP2 on Sheet 18

SVCT3

Is gyro compensation required?
(Is DRIFTLG = 1?)

NO

---

BIT # 15 OF FLAGWRD = 1?

YES

---

Is IMU install in progress?

YES, check again 5 seconds from now.

---

IMUCADR ≠ 0?

NO, IMUCADR = +0, IMU install is available

A ← OCT 35000

---

NBDONLY

NOVAC job
PRIORITY = 35

FC-2230

---

SCHEDULE ROUTINE NBDONLY AS A JOB
ROUTINE NBDONLY WILL COMPENSATE
FOR NBD COEFFICIENTS ONLY

---

ROUTINE NBDONLY IS IN PROGRAM
SECTION IMU COMPENSATION
PACKAGE

---

SVCT3X

---

FIXDELAY IS AN ENTRY
OF WAITLIST WHICH CAUSES
WAITLIST TO SCHEDULE THE
LOCATION SVCT3X+2 TO BE
EXECUTED AS A TASK 5.0
SECONDS FROM NOW.

---

FIXDELAY ALSO CAUSES
WAITLIST TO TERMINATE
INTERNALLY AS A TASK.
THE TASK THAT CALLED
FIXDELAY THUS TERMINATES
AND THE INTERRUPTED
ROUTINE IS RESUMED.

---

This location is executed
as a task 5.0 seconds
after it was scheduled in
FIXDELAY.

---

TASKOVER

SH18

---

SVCT3X+2

---

SUMMARY

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---

GUIDANCE AND CONTROL

W A I T L I S T

COLOSSUS II

FC-2060
LONGCALL IS USED TO SCHEDULE TASKS WHOSE DELTA TIME IS IN DOUBLE PRECISION WHICH CANNOT BE HANDLED BY WAITLIST (SINGLE PRECISION) ROUTINE. LONGCALL WILL HANDLE DELTA TIMES FROM OCT00000 (0.01 SECOND) TO OCT37777, OCT37777 (2,684,354.55 SECONDS OR 745 HOURS 39 MINUTES AND 14.55 SECONDS OR APPROXIMATELY ONE MONTH).

\[ \text{OCT37777, OCT37777 = OCT1,777,777,777 = DEC 268,438,455} \]

CALLING SEQUENCE:

\[ \% - 2 \quad \text{EXTEND} \]
\[ \% - 1 \quad \text{DCA } \% + N \]
\[ \% + 0 \quad \text{TC } \text{LONGCALL} \]
\[ \% + 1 \quad \text{GENADR OF TASK} \]
\[ \% + 2 \quad \text{BBCON OF TASK} \]
\[ \% + 3 \quad \text{RETURN HERE UNCONDITIONALLY} \]

\[ \% \geq N \quad 2 \text{DEC } \Delta \text{T CENTISECONDS} \]
\[ \% \geq N + 1 \]

**DOUBLE-PRECISION DELTA TIME**

\[ \text{LONGTIME} \rightarrow A \]
\[ \text{LONGTIME} + 1 \rightarrow L \]

\[ \text{LONGCALL} \]

\[ \text{LONGEXIT} + 1 \rightarrow \text{BBCON OF } \% \]

\[ \text{LONGEXIT} \rightarrow \text{GENADR OF } \% + 3 \]
\[ Q \rightarrow \text{GENADR OF } \% + 3 \]

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

\[ \text{LONGTIME, LONGTIME} + 1 \rightarrow \text{LONGTIME, LONGTIME} + 1 - \text{OCT} 20000 \]

SUBTRACT B1.92 SECONDS FROM DELTA TIME (OR REMAINING DELTA TIME).


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

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

YES, (AT ≥ 81.92 SECONDS)

IS LONGTIME > 0?

YES, (LONGTIME + 1 CONTAINS LOW-ORDER MAGNITUDE)

CHECK FURTHER
(LONGTIME + 1 ≤ 0)

IS LONGTIME > 0?

YES, ΔT ≥ 163.84 SECONDS

NO, (LONGTIME = 0)

THE UNUSED (REMAINING) PORTION OF
ΔT IS LESS THAN 81.93 SECONDS

LUCHTIME

LASTTIME

A ← OCT 20000 WHICH
WAS SUBTRACTED IN
LONGCYCL ON PRECEDING
SHEET.

A ← (LONGTIME + 1) + OCT 20000

GETCADR

WAITLIST TASK
ΔT IS IN A
THIS SHEET

GETCADR

WAITLIST TASK
ΔT =
81.92 SEC.
PRECEDING SHEET

LONGCYCL

SET FOR ALL EXITS
EXCEPT THE FIRST
EXIT

LONGRTRM

A ← GENADR OF TASKOVER

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

ZCADR OF THE RETURN
LOCATION ≠ +3
(WHERE ≠ TC
LONGCALL) FOR 1ST
EXIT, TASKOVER FOR
SUCCEEDING EXITS.

RETURN VIA A AND L

RETURN TO ≠ +3 (WHERE ≠ TC LONGCALL)
IF THIS IS FIRST EXIT.

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

THE NUMBER (N) OF
PASSES THROUGH ROUT-
TIME MUGHTIME IS SUCH
THAT 81.92 N+ΔT = DELTA
TIME FOR THE LONGCALL
TASK WHERE ΔT IS THE
UNUSED PORTION (CON-
TENTS OF A WHEN TASK
GETCADR IS SCHEDULED
AT LOWEST LEFT) OF
THE DELTA TIME.
ΔT ≤ 81.92
DLY DELAY EXECUTION
LONGCALL TASK
81.92 SECONDS
(OR ANOTHER
81.92 SECONDS)

SET ΔT = 81.92
SECONDS FOR
TASK LONGCYCL

GETCADR IS A TASK
WHICH WILL BE EXEC-
UTED DELTA TIME
CENTISSECONDS FROM
THE TIME INSTRU-
CTION "TC LONGCALL"
WAS EXECUTED.

LONGCALL TASK
WILL NOW BEGIN.
THE LONGCALL
TASK THEAP-
SEARS TO BE THE
CONTINUATION
OF TASK
GETCADR

EXIT VIA A
TO ROUTINE
AND L
SCHEDULED
AS A
LONGCALL TASK

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FC-2060

WAITLIST

APPLIED
GUIDANCE AND NAVIGATION
SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAILOUT</td>
<td>FC-2140</td>
<td>TURNS ON PROGRAM ALARM LIGHT AND SETS ALARM CODE OCT 1203 INTO ONE OF THE FAILREG REGISTERS SO IT IS AVAILABLE FOR DISPLAY. EXITS TO DO SOFTWARE RESTART VIA GOPROG.</td>
<td>SH, 13</td>
</tr>
<tr>
<td>POOODO</td>
<td>FC-2140</td>
<td>TURNS ON PROGRAM ALARM LIGHT AND SET ALARM CODE OCT 1204 INTO ONE OF THE FAILREG REGISTERS SO IT IS AVAILABLE FOR DISPLAY. EXITS TO DO SOFTWARE RESTART VIA GOPROG. IF SERVICER IS NOT RUNNING, ALL RESTART GROUPS ARE MADE INACTIVE.</td>
<td>SH, 9</td>
</tr>
<tr>
<td>NBONLY (JOB)</td>
<td>FC-2230</td>
<td>COMPENSTATES FOR NBD COEFFICIENTS ONLY.</td>
<td>SH, 20</td>
</tr>
</tbody>
</table>

ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAITEXIT</td>
<td>GENDR OF CALLING SEQUENCE OR EXIT ADDRESS</td>
</tr>
<tr>
<td>WATBANK (WAITEXIT+1)</td>
<td>BBCON OF CALLING SEQUENCE</td>
</tr>
<tr>
<td>WAITADR</td>
<td>GENDR OF TASK</td>
</tr>
<tr>
<td>WAITADR+1</td>
<td>BBCON OF TASK</td>
</tr>
<tr>
<td>WATTEMP</td>
<td>TIME INTERVAL BETWEEN TASKS</td>
</tr>
<tr>
<td>LST1+0 TO +7</td>
<td>TIME INTERVAL TABLE</td>
</tr>
<tr>
<td>LST2+0 TO +17D</td>
<td>2CADR OF TASKS TABLE</td>
</tr>
<tr>
<td>BANKRUPT</td>
<td>SAVE BBCON AND SUPER BANK OF ROUTINE INTERRUPTED BY T3RUP</td>
</tr>
<tr>
<td>RQRUPT</td>
<td>SAVE Q OF ROUTINE INTERRUPTED BY T3RUP</td>
</tr>
<tr>
<td>RUPTAGN</td>
<td>INDICATES TO TASKOVER WHETHER (+1) THE NEXT TASK SHOULD BE EXECUTED IMMEDIATELY AFTER THE CURRENT TASK OR WHETHER (-0) THE INTERRUPTED ROUTINE SHOULD BE EXECUTED IMMEDIATELY AFTER THE CURRENT TASK</td>
</tr>
<tr>
<td>ARUPT</td>
<td>SAVE A OF ROUTINE INTERRUPTED BY T3RUP</td>
</tr>
<tr>
<td>LRUPT</td>
<td>SAVE L OF ROUTINE INTERRUPTED BY T3RUP</td>
</tr>
<tr>
<td>LONGCADR+0, +1</td>
<td>2CADR OF LONGCALL TASK</td>
</tr>
<tr>
<td>LONGTIME+0, -1</td>
<td>DP DELTA TIME FOR LONGCALL TASK</td>
</tr>
<tr>
<td>LONGEXIT+0, +1</td>
<td>2CADR OF RETURN ADDRESS TO CALLING SEQUENCE</td>
</tr>
</tbody>
</table>

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APOLLO GUIDANCE AND NAVIGATION

WAITLIST

COLOSSUS INC.
FC-2060
## SERVICE ROUTINES

<table>
<thead>
<tr>
<th>ENTRY</th>
<th>TABLE OF CONTENTS</th>
<th>BRIEF DESCRIPTION</th>
<th>SHEET</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBROUTINE UPENT2</td>
<td>SETS SELECTED BIT POSITIONS OF A SELECTED FLAG WORD (LIMITED SELECTION BY CODE)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>SUBROUTINE DOWNT2</td>
<td>CLEARS SELECTED BIT POSITIONS OF A SELECTED FLAG WORD (LIMITED SELECTION BY CODE)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>SUBROUTINE UPFLAG</td>
<td>SETS A BIT POSITION OF A FLAG WORD (BOTH DETERMINED BY THE FLAG NAME)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>SUBROUTINE DOWNFLAG</td>
<td>CLEARS A BIT POSITION OF A FLAG WORD (BOTH DETERMINED BY THE FLAG NAME)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>LIST OF FLAG CODES VERSUS BIT-POSITION OF FLAG WORD</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>LIST OF FLAG NAMES VERSUS FLAG CODES</td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>SUBROUTINE DELAYJOB</td>
<td>PLACES CURRENT JOB TO SLEEP FOR AT CENTISECONDS, AND IS AWAKENED AT LOCATION '24-2' (CONTAINS TC DELAYJOB)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>SUBROUTINE GENTRAN</td>
<td>COPIES CONTENTS OF N CONSECUTIVE LOCATIONS INTO ANY N CONSECUTIVE LOCATIONS</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>ROUTINE BSOFF</td>
<td>CLEARS BIT-POSITION 5 OF REGISTER EXT BACT AND TERMINATES AS A JOB, INDICATES THAT THE DISPLAY HAS BEEN ANSWERED</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>SUBROUTINE TRFAILON</td>
<td>TURNS TRACKER FAIL LIGHT (OPTICS CDU FAIL) ON</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>SUBROUTINE TRFAILOF</td>
<td>TURNS TRACKER FAIL LIGHT (OPTICS CDU FAIL) OFF</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

## LIST OF REVISIONS

<table>
<thead>
<tr>
<th>REV NO.</th>
<th>REVISION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UPDATED COLOSSUS II TO COLOSSUS II-C (SHEET 9 REVISED)</td>
</tr>
<tr>
<td>2</td>
<td>UPDATED COLOSSUS II C TO COLOSSUS II D (SHEET 7 REVISED)</td>
</tr>
</tbody>
</table>
SERVICE ROUTINES (UPENT2)

ENTERED FROM 4 LOCATIONS IN THE DISPLAY INTERFACE ROUTINES WITH A = THE CODE FOR SELECTING A FLAG WORD (FLAGWRO: 1, 2, ... 6 OR7) AND ALSO FOR SELECTING THE BIT POSITION (15, 14, 13, ... 5 OR 4) IN THE FLAG WORD TO BE SET.

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

THE BIT POSITIONS SELECTED TO BE SET ARE THE SAME AS THOSE BIT POSITIONS OF A15-4 WHICH CONTAIN A ONE.

THE FLAG WORD SELECTED IS DETERMINED BY THE CONTENTS OF A3-1. THE CONTENTS ARE USED AS AN INDEX TO SELECT FLAG WORDS AS SHOWN IN THE FOLLOWING TABLE:

<table>
<thead>
<tr>
<th>A3-1</th>
<th>FLAG WORD SELECTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>FLAGWRO+0 OR FLAGWRO</td>
</tr>
<tr>
<td>1</td>
<td>&quot;+1 OR FLAGWRO1</td>
</tr>
<tr>
<td>2</td>
<td>&quot;+2 OR FLAGWRO2</td>
</tr>
<tr>
<td>3</td>
<td>&quot;+3 OR FLAGWRO3</td>
</tr>
<tr>
<td>4</td>
<td>&quot;+4 OR FLAGWRO4</td>
</tr>
<tr>
<td>5</td>
<td>&quot;+5 OR FLAGWRO5</td>
</tr>
<tr>
<td>6</td>
<td>&quot;+6 OR FLAGWRO6</td>
</tr>
<tr>
<td>7</td>
<td>&quot;+7 OR FLAGWRO7</td>
</tr>
</tbody>
</table>

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

EXAMPLE OF CALLING SEQUENCE:

<table>
<thead>
<tr>
<th>CODE</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESTSLEP</td>
<td>CA GENMASK</td>
</tr>
<tr>
<td>MSK</td>
<td>ASTROMSK</td>
</tr>
<tr>
<td>TC</td>
<td>UPENT2</td>
</tr>
<tr>
<td>OCT24100</td>
<td>OCT 24100</td>
</tr>
<tr>
<td>NDX</td>
<td>COPINDEX</td>
</tr>
<tr>
<td>CAF</td>
<td>NYCADR</td>
</tr>
<tr>
<td>&quot; &quot;</td>
<td>&quot; &quot;</td>
</tr>
</tbody>
</table>

Q = x + 2 OF CALLING SEQUENCE

CALLING SEQUENCE:

x + 0 TC UPENT2
x + 1 OCT ANY DATA
x + 2 RETURN HERE UNCONDITIONALLY

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

NOTE:
THIS SUBROUTINE IS APPLICABLE TO ONLY THE FIRST EIGHT FLAG WORDS (BIT-POSITIONS 15 THROUGH 4). BIT-POSITIONS 3 THROUGH 1 OF THE FIRST EIGHT FLAG WORDS AND ALL BIT POSITIONS OF FLAGWRO8, 9, 10 AND 11 CANNOT BE SET BY UPENT2.
SERVICE ROUTINES (DOWNENT2)

Entered from 3 locations in display interface routines with A = the code for selecting a flag word (FLAGWROD, 1, 2, ..., 6 or 7) and also for selecting the bit position (15, 14, 13, ..., 5 or 4) in the flag word to be cleared.

Subroutine for clearing selected bit positions of a selected flag word.

Calling sequence:
%1 + 0 TG DOWNENT2
%1 + 1 OCT ANY DATA
%1 + 2 RETURN HERE UNCONDITIONALLY

Note:
Upon execution of instruction "TG DOWNENT2", the accumulator contains the flag and bit code.

The bit positions selected to be cleared are the same as those bit positions of A15-4 which contains a one.

The Flag word selected is determined by the contents of A3-1. The contents are used as an index to select flag words as shown in the following table:

<table>
<thead>
<tr>
<th>A3-1</th>
<th>Flag Word Selected</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>FLAGWROD + 0 OR FLAGWROD</td>
</tr>
<tr>
<td>1</td>
<td>&quot; + 1 OR FLAGWRO1</td>
</tr>
<tr>
<td>2</td>
<td>&quot; + 2 OR FLAGWRO2</td>
</tr>
<tr>
<td>3</td>
<td>&quot; + 3 OR FLAGWRO3</td>
</tr>
<tr>
<td>4</td>
<td>&quot; + 4 OR FLAGWRO4</td>
</tr>
<tr>
<td>5</td>
<td>&quot; + 5 OR FLAGWRO5</td>
</tr>
<tr>
<td>6</td>
<td>&quot; + 6 OR FLAGWRO6</td>
</tr>
<tr>
<td>7</td>
<td>&quot; + 7 OR FLAGWRO7</td>
</tr>
</tbody>
</table>

Q = X + 2 of calling sequence where X is the location containing instruction "TG DOWNENT2".

Note:
This subroutine is applicable to only the first eight flag words (bit-positions 15 through 4), bit-positions 3 through 1 of the first eight flag words and all bit positions of flagwrod 8, 9, 10 and 11 cannot be cleared by downent2.

This subroutine will be shown as follows in programs using it:

Example of calling sequence:
ENDRET + 7 CA GENMASK
MSK PINIDMSK
TG DOWNENT2
PINIDMSK OCT 74044
CS THREES
TS NYSUB
* *
* *

Note:

SERVICE ROUTINES

Colossus II-D FC-2070

R. E. Bude 3-14-64
SERVICE ROUTINES (UPFLAG AND DOWNFLAG)

These subroutines, UPFLAG and DOWNFLAG, are used for setting and clearing, respectively, any flag. A flag is any bit position that has a name such as "midavflg" for example. These bit positions are bit-positions 15-1 of consecutive flag words `flagwrd0`, `flagwrd1`, `flagwrd2`, ... , `flagwrd10` and `flagwrd11`. A few of the latter do not yet have names. Each flag has a code number which determines the flag word and the bit position in that flag word to be set or cleared. The flag word (flagwrd`k` where `k` is 0, 1, 2, ..., 10 or 11) and the bit position `β` (where `β` is 15, 14, 13, ..., 2 or 1) are obtained by dividing the code by 15 so that the flag word will be `flagwrd0` + the quotient (the quotient is `k`) and the bit position of that flag word will be `β` (where `β` is 15 minus `r`, the remainder). Thus, the code number is `15k + r` or `15k + 15 - β`. As an example, the code number for midavflg is 148. The quotient of 148 + 15 is 9 and the remainder is 13 (k = 9, r = 13, β = 15 - 13 = 2). Thus, the flag midavflg is in flag word `flagwrd9` which is `flagwrd9`. Flag midavflg is bit-position 2 of flagwrd9.

These subroutines will be shown as follows in programs using it.

**Calling Sequence:**

\[ \text{Z0} \text{ TC UPFLAG} \]
\[ \text{Z1} \text{ ADRES FLAG NAME} \]
\[ \text{Z2} \text{ RETURN HERE UNCONDITIONALLY} \]

Entered here from 55 locations

**Upflag**

\[ a \leftarrow \text{TC UPFLAG} + 2 \]
\[ q \leftarrow a \]

A = Z + 1 of calling sequence

**Debit**

Increment A by 1

Inhibit interrupts

Next sheet

**Calling Sequence:**

\[ \text{Z0} \text{ TC DOWNFLAG} \]
\[ \text{Z1} \text{ ADRES FLAG NAME} \]
\[ \text{Z2} \text{ RETURN HERE UNCONDITIONALLY} \]

Entered here from 60 locations

**Downflag**

\[ a \leftarrow \text{TC DOWNFLAG} + 2 \]
\[ q \leftarrow a \]

A = Z + 2 of calling sequence

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

Apollo
GUIDANCE AND NAVIGATION
SERVICE ROUTINES

COLOSSUS II D

DINAMICS

BU A. Mares 21 MARESY 20

FG-2070
FROM PRECEDING SHEET

\[ \text{ITEMP1} \leftarrow \text{A} \]

\[ \text{ITEMP1} \leftarrow \text{QUOTIENT OF } (x + 1) \div 15 \]

\[ \text{ITEMP2} \leftarrow \text{REMAINDER OF } (x + 1) \div 15 \]

\[ L \leftarrow \text{(FLAGWRDO + XL)} \]

\[ A \leftarrow \text{(BIT15 + X2)} \]

SERVICE ROUTINES
(UPFLAG AND DOWNFLAG)

\[ \text{ITEMP3} = x + 2 \text{ (THE RETURN ADDRESS) IN THE CALLING SEQUENCE.} \]

\[ \text{ITEMP1} = \kappa \text{ (THE QUOTIENT)} \]

The quotient will be used as an index for selecting the flag word and will be referred to as "x1".

\[ \text{ITEMP2} = \varphi \text{ (THE REMAINDER)} \]

The remainder will be used as an index for selecting the bit position in the selected flag word and will be referred to as "x2".

\[ L = \text{CONTENTS OF FLAG WORD ASSOCIATED WITH THE FLAG NAME IN LOCATION } x + 1 \text{ OF THE CALLING SEQUENCE.} \]

INDEX | FLAG WORD
-------|-------------------
X1     | WORD

FLAGWRDO + 0 | FLAGWRD0
" + 1 | FLAGWRD1
" + 2 | FLAGWRD2
" + 3 | FLAGWRD3
" + 4 | FLAGWRD4
" + 5 | FLAGWRD5
" + 6 | FLAGWRD6
" + 7 | FLAGWRD7
" + 8 | FLAGWRD8
" + 9 | FLAGWRD9
" +10 | FLAGWRD10
" +11 | FLAGWRD11

A = ONES IN ALL BIT POSITIONS EXCEPT THE BIT POSITION ASSOCIATED WITH THE FLAG NAME IN LOCATION x + 1 OF THE CALLING SEQUENCE.

INDEX | REGISTER CONTENTS | BIT POSITION SET OR CLEARED |
-------|-------------------|-----------------------------|
X2     | OCT | 00000 | 15 |
" +0 | BIT15 | OCT 40000 |
" +1 | BIT14 | OCT 20000 |
" +2 | BIT13 | OCT 10000 |
" +3 | BIT12 | OCT 04000 |
" +4 | BIT11 | OCT 02000 |
" +5 | BIT10 | OCT 01000 |
" +6 | BIT9  | OCT 00400 |
" +7 | BIT8  | OCT 00200 |
" +8 | BIT7  | OCT 00100 |
" +9 | BIT6  | OCT 00040 |
" +10 | BIT5  | OCT 00020 |
" +11 | BIT4  | OCT 00010 |
" +12 | BIT3  | OCT 00004 |
" +13 | BIT2  | OCT 00002 |
" +14 | BIT1  | OCT 00001 |
SERVICE ROUTINES
(UPFLAG AND DOWNFLAG)

FROM PRECEDING SHEET

L = COMPLETE ORIGINAL FLAG WORD (CONTENTS OF FLAG
WORD ASSOCIATED WITH THE FLAG NAME IN LOCATA-
TION x+1 OF THE CALLING SEQUENCE).
Q = UPFLAG + 2

Q = DOWNFLAG + 2

A = ALL ONES EXCEPT A ZERO
IN THE BIT POSITION
ASSOCIATED WITH THE
FLAG NAME IN LOCATION
x+1 OF THE CALLING
SEQUENCE.

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

L CONTAINS COMPLETE ORIGINAL FLAG WORD.
A = SAME AS CONTENTS OF FLAG WORD
ASSOCIATED WITH THE FLAG NAME IN x+1
EXCEPT THAT A ONE IS IN THE BIT POSITION
WHOSE FLAG NAME IS IN x+1.

A = ALL ZEROES EXCEPT A ONE
IN THE BIT POSITION ASSOCI-
ATED WITH THE FLAG NAME
IN LOCATION x+1 OF THE
CALLING SEQUENCE.

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

COMFLAG

(FLAGWRD0 + x1) ← A

RELEASE INTERRUPT

INHIBIT

RETURN VIA

ITEMP3

RETURN TO CALLER
AT x+2

RESTORE THE ORIGINAL CONTENTS OF
THE FLAG WORD CONTAINING THE BIT
POSITION WHOSE FLAG NAME IS IN
x+1 EXCEPT FOR THAT SAME BIT
POSITION WHICH IS NOW SET IF
ENTRY WAS VIA UPFLAG AND CLEARED
IF ENTRY WAS VIA DOWNFLAG.
<table>
<thead>
<tr>
<th>CODE</th>
<th>FLAG NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>CPU1FLAG</td>
</tr>
<tr>
<td>1</td>
<td>JSWITCH</td>
</tr>
<tr>
<td>2</td>
<td>MIDFLAG</td>
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<td>VMONFLAG</td>
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<td>MOPFRAG</td>
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<td>5</td>
<td>ZMEASURE</td>
</tr>
<tr>
<td>6</td>
<td>NEEDFLG</td>
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<td>7</td>
<td>IHUSE</td>
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<td>RNDVZFLG</td>
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<td>FREEFLG</td>
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<td>NJFTSFLG</td>
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<td>M&quot;D&quot;F1&quot;</td>
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<td>43</td>
<td>CALCA12</td>
</tr>
<tr>
<td>44</td>
<td>RZDGFLAG</td>
</tr>
</tbody>
</table>

*ALSO CODE FLAG NAME |
| 21 | R23FLAG |
| 38 | FIRSTEL |
| 40 | OPTNSW |
| 97 | KNOWNFL |

**SERVICE ROUTINES (UPFLAG AND DOWNFLAG)**

**CODES FOR EACH FLAG (DECIMAL)**

<table>
<thead>
<tr>
<th>BIT-POSITION</th>
<th>15</th>
<th>14</th>
<th>13</th>
<th>12</th>
<th>11</th>
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<td>17</td>
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</tbody>
</table>

**SERVICE ROUTINES**

**GOLOSUS**

**FC-2070**
SERVICE ROUTINES (DELAYJOB)

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

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

CALLING SEQUENCE:

A+1 CAF N
A+0 TC BANKCALL
A+1 CADR DELAYJOB
A+2 RETURN HERE AFTER A DELAY OF AT CENTISECONDS

Z+1 OEC AT CENTISECONDS

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

DELAYJOB

PUT CURRENT JOB TO SLEEP FOR AT CENTISECONDS. IT IS AWAKENED AT THE NEXT LOCATION (Z+2)

FC-2070

NORMAL EXIT

TASKOVER

FC-2060

RESTART

NO DELAYLOC REGISTER AVAILABLE FOR STORING Z+2 (DELAY ROUTINE BUSY)

VIA BAILOUT (CODE OCT 1104)

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

DELAYJOB

INHIBIT INTERRUPTS

Q ← A

Q = AT CENTISECONDS (TIME CURRENT JOB WILL BE DELAYED)

A ← 3

SET FOR LOOP WHICH SEARCHES TABLE OF 4 DELAYLOC REGISTERS

NEXT SHEET
ENTRY SUBROUTINE WAITLIST AT DLY2-1
ENTRY TO SCHEDULE TASK WAKER TO BE EXECUTED AT CENTISECONDS FROM NOW.
AT WAS STORED IN Q AT BEGINNING OF DELAYJOB
CONTENTS OF L15 STORED INTO THE LIST2 LIST BY WAITLIST AND THEN PLACED INTO BANK BY TBRAPRT.

WAITLIST TASK ΔT = CONTENTS OF Q
SH3
EXIT VIA WAITEXIT TO TGGETCAD ON NEXT SHEET.
SERVICE ROUTINES (DELAYJOB)

FROM PRECEDING SHEET

TCGETCAD

MAKEADR
CONSTRUCT THE CADR OF z+2 FROM GENADR IN BUF+1 AND LEAVE IT IN A.

A = CADR OF z+2 OF CALLING SEQUENCE

ADDRESS OF z+2, THE LOCATION TO BE AWAKENED AT CENTISECONDS AFTER CURRENT JOB IS PUT TO SLEEP

(DELAYLOC+X1) ← A

J OBSLEEP

PUT CURRENT JOB (NOW BEING EXECUTED) TO SLEEP.
IT WILL BE ASLEEP UNTIL IT IS AWAKENED AT LOCATION z+2 BY TASK WAKER BELOW

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

WAKER

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

A ← (DELAYLOC+X1)

X1 IS AN INDEX AND IS EQUAL TO THE CONTENTS OF RUPTRG1 AND OF BIT-POSITIONS 3-1 OF BBANK (BBANK MUST REMAIN 00)

OBTAIN CADR OF LOCATION z+2 WHICH IS TO BE AWAKENED

(DELAYLOC+X1) ← +0

MAKE THIS DELAYLOC REGISTER AVAILABLE

JOBWAKE

WAKE UP JOB (z+2) WHOSE CADR IS IN A.

LOCATION z+2 OF THE CALLING SEQUENCE IS AWAKENED. IT WILL BE EXECUTED WHEN ITS PRIORITY IS HIGHER THAN THE PRIORITIES OF OTHER SCHEDULED JOBS

FC-2050

TASKOVER

TERMINATE TASK WAKER AND RESUME EXECUTION OF INTERRUPTED ROUTINE

END OF DELAYJOB
SERVICE ROUTINES (GENTRAN)

This subroutine is used for copying contents of n consecutive locations whose initial address is M into n consecutive locations whose initial address is W.

The calling sequence is:

\[
\begin{align*}
&Z-1 \quad \text{CAF} \quad Z \star \star \\
&Z+0 \quad \text{TC} \quad \text{GENTRAN} \\
&Z+1 \quad \text{ADRES} \quad M \\
&Z+2 \quad \text{ADRES} \quad W \\
&Z+3 \quad \text{RETURN HERE UNCONDITIONALLY} \\
&Z+4 \quad \text{OCT} \quad N-1
\end{align*}
\]

Example of calling sequence:

\[
\begin{align*}
&\text{MARKIT1 CAF SIX} \\
&\quad \text{TC} \quad \text{GENTRAN} \\
&\quad \text{ADRES MRKBUF1} \\
&\quad \text{ADRES MRKBUF2}
\end{align*}
\]

Entered from 13 locations with A = OCT N-1

Set for next pass

A ← ITEMPL

Decrement A by 1

(GENTRAN+1)

ITEMPL ← A

A ← (A + 1) + ITEMPL

L ← Contents of location whose GENADR is in A

(location whose GENADR is in A) ← L

Is ITEMPL = 0?

Yes: Return via routine OK

No: 

Has all data been copied? (All passes completed)

Return to caller at Z + 3

This subroutine will be shown as follows in programs using it:

\[
\begin{align*}
&M+1 \quad \rightarrow \quad (M+N) \\
&M+2 \quad \rightarrow \quad (M+N+1) \\
&M+3 \quad \rightarrow \quad (M+N+2) \\
&\vdots
\end{align*}
\]

ITEMPL = (N-1) for 1st pass, (N-2) for 2nd pass, (N-3) for 3rd, ..., and 0 for last pass

A = ADRES (M+N-1) for 1st pass, ADRES (M+N-2) for 2nd pass, ADRES (M+N-3) for 3rd pass, ..., ADRES M for last pass

L = Contents of location (M+N-1) for the 1st pass, (M+N-2) for 2nd, (M+N-3) for 3rd, ..., and M for the last pass

A ← ADRES W for last pass

A ← ADRES (W+N-1) for 1st pass, ADRES (W+N-2) for 2nd pass, ADRES (W+N-3) for 3rd pass, ...

ADRES W for last pass

W+1 ← M+N-1 for 1st pass, W+2 ← M+N-2 for 2nd pass, W+3 ← M+N-3 for 3rd pass, ...

M for last pass

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

SERVICE ROUTINES

COLOSSUS II-D: FC-2070

John A. Meine in 04-14
SERVICE ROUTINES (B50FF)

ROUTINE B50FF CLEARS BIT-POSITION 5 OF REGISTER EXTVBACT AND TERMINATES AS A JOB. A ZERO IN BIT-POSITION 5 INDICATES THAT THE DISPLAY HAS BEEN ANSWERED.

CALLING SEQUENCE:
E+0 TO B50FF

ENTERED FROM 8 LOCATIONS

\[ B50FF \]

\[ \text{(EXTVBACT) }_5 \rightarrow 0 \]

DISPLAY HAS BEEN ANSWERED

\[ \text{ENDOFJOB} \]

FC-2050

TERMINATE AS A JOB
SERVICE ROUTINES
(TRFAILON AND TRFAILOF)

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

THE CALLING SEQUENCES ARE:

\[ x+0 \text{ TC TRFAILON } \]
\[ x+1 \text{ TC TRFAILOF } \]
\[ x+1 \text{ RETURN HERE UNCONDITIONALLY } \]

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

\[ \text{TRFAILON} \]
\[ \text{TURN TRACKER FAIL LIGHT ON} \]
\[ FC-2070 \text{ SH12} \]

\[ \text{TRFAILOF} \]
\[ \text{TURN TRACKER FAIL LIGHT OFF} \]
\[ FC-2070 \text{ SH12} \]

ENTERED FROM ROUTINE LIGHTON OF PROGRAM P20-P25

TRFAILON
\[ \text{INHIBIT INTERRUPTS} \]
\[ (\text{DSPTAB+11D}) \rightarrow 1 \]
\[ (\text{DSPTAB+11D}) \rightarrow 0 \]
\[ (\text{DSPTAB+11D}) \rightarrow 15 \]
\[ (\text{OPTMODES}) \rightarrow 1 \]

REQ
ALLOW INTERRUPTS
RETURN VIA Q

RETURN TO CALLER AT \[ x+1 \]

ENTERED FROM ROUTINE RANGE0D OF PROGRAM P20-P25 AND FROM ROUTINE RESETVHF OF EXTENDED VERBS (VERB 88)

TRFAILOF
\[ \text{INHIBIT INTERRUPTS} \]
\[ (\text{DSPTAB+11D}) \rightarrow 0 \]
\[ (\text{DSPTAB+11D}) \rightarrow 15 \]
\[ (\text{OPTMODES}) \rightarrow 1 \]

TURN TRACKER FAIL LIGHT OFF.
NO OPTICS CPU MALFUNCTION

INDICATES TO PROGRAM T4RUPT THAT A CHANGE HAS OCCURRED IN BIT-POSITIONS 11-1 SINCE THE LAST TIME DSPTAB+110 WAS PROCESSED BY T4RUPT

TRACKER FAIL LIGHT STATUS INDICATOR (INVERTED LOGIC). IT IS USED FOR MONITORING THE OPTICS IN ROUTINE OPTMON OF PROGRAM T4RUPT. NORMALLY IT IS THE LAST SAMPLED CONTENT OF BIT-POSITION 7 OF CHANNEL 30. THIS "1" MEANS THAT NO OPTICS CPU FAIL INDICATION HAS BEEN GENERATED BY THE OPTICS CPU FAILURE

NOTE: THESE ROUTINES ARE ENTERED DUE TO THE USE OF THE TRACKER LIGHT FOR VHF RANGE DATA STATUS.
## SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAKECADR</td>
<td>FC-2080</td>
<td>CONSTRUCT THE CADR OF A LOCATION WHOSE GENADR IS IN BUF AND F' BANCIS IN BUF+1 AND LEAVE IT IN A</td>
<td>SH. 10</td>
</tr>
<tr>
<td>JQWAKE</td>
<td>FC-2050</td>
<td>WAKE UP JOB WHOSE CADR IS IN A</td>
<td>SH. 10</td>
</tr>
</tbody>
</table>

## FLAGS

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

NOTE:
DOUBLE ARROW INDICATES EXCHANGE

SWCALL

BANCKCALL

BUF2 ← A
BUF2+1 ← L

A ← CONTENTS OF THE ADDRESS IN Q

Q ← Q + 1

L ← A
L2 ← 11 ← FBANK

A ← A10-1

A ← Q

A ← BUF2
L ← BUF2+1

GO TO 10000#Q

SAVE DP DATA

PICK UP CADR OF SUBROUTINE

INCREMENT Q

SET FBANK FOR CADR

RELATIVE ADDRESS OF CADR

A AND L NOW CONTAIN DP RETURN, Q CONTAINS RELATIVE ADDRESS OF CADR

GET DP DATA, STORE RETURN ADDRESS

PUT RELATIVE ADDRESS IN BITS 10-1 OF S-REGISTER, SET FIXED-SWITCHABLE INDICATOR BITS 12 AND 11 IN S-REGISTER EQUAL TO 01. EXECUTE SUBROUTINE. Q CONTAINS ADDRESS OF SWRETURN.

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

SWRETURN

A ← BUF2+1
A ← FBANK

A ← BUF2+1

C(A, L) NOW RESTORED FOR RETURN.

INTERBANK COMMUNICATION

COLOSSUS II FC-2080
THE POSTJUMP AND BANKJUMP ROUTINES PERMIT UNIDIRECTIONAL JUMPS TO ANOTHER BANK. POSTJUMP PROTECTS C(A) WITH THE CADR IMMEDIATELY FOLLOWING THE TC POSTJUMP INSTRUCTION. BANKJUMP DOES NOT PROTECT C(A). ENTERS WITH CADR OF SUBROUTINE IN A.

**BANKJUMP**

**POSTJUMP**

SAVE C(A)

PICK UP CADR OF SUBROUTINE

SET FBANK (BITS 15-11 OF A)

RELATIVE ADDRESS OF SUBROUTINE IN Q. RESTORE CALLER'S (A).

PUT RELATIVE ADDRESS IN BITS 10-1 OF S-REGISTER. SET FIXED-SWITCHABLE INDICATOR BITS 12 AND 11 IN S-REGISTER EQUAL TO 01.

EXECUTE SUBROUTINE.

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

GET RELATIVE ADDRESS OF RETURN FBANK ADDRESS OF RETURN (BITS 10-1 OF BUF2+1=0)

RETURN VIA Q

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

SET SUPERBITS

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

1. **SUPDACAL**
   - \( \text{MTEMP} \rightarrow A \)
   - \( A_{15-11} \rightarrow \text{FBANK} \)
   - **STORE CADR**
   - **SET FBANK AND KEEP OLD FBANK SETTING FOR RETURN.**

2. **SUPERBANK "OR" A**
   - **SAVE OLD SUPERBANK SETTING FOR RETURN.**
   - "OR" is logical "OR," where the result of this instruction will leave A having all bits on that were on in either A or SUPERBANK, or both.

3. **RETRIEVE CADR AND STORE FBANK-SUPERBANK INFO.**
   - **PREPARE TO SET SUPERBANK (L CONTAINS SUPERBITS) A RECEIVES SUPERBANK BITS, L RECEIVES RELATIVE ADDRESS.**

4. **INHIBIT INTERRUPTS**

5. **A_{7-6} INTO SUPERBANK**
   - **SET SUPERBANK**

6. **A \rightarrow 10000\#L**
   - **GET DATA**
   - **STORE DATA, GET FBANK-SUPERBANK INFORMATION**

7. **A_{7-6} INTO SUPERBANK**
   - **RESET SUPERBANK**

8. **ALLOW INTERRUPTS**

9. **FBANK \rightarrow A_{15-11}**
   - **RESET FBANK**
   - **RETRIEVE DATA**

10. **RETURN VIA Q**
ISWCALL; ISWCALL; AND ISWRETRN; USED IN INTERRUPT, PERFORM THE SAME FUNCTIONS AS BAKNCALL; SWCALL; SWRETURN.

ISWCALL

IBNKCALL

RUPTRG3 ← A
RUPTRG4 ← L

A ← CONTENTS OF THE ADDRESS IN Q

Q ← Q + 1

INCREMENT RETURN

L ← A
L ← (A + 1)

FBANK

RETURN ADDRESS IN A;
CAVR RELATIVE ADDRESS IN Q.

A ← RUPTRG3
L ← RUPTRG4

GO TO 100000H0

SAVE DP DATA
PICK UP CADR OF SUBROUTINE
SAVE CALLER'S FBANK;
SET CADR FBANK.

PICK UP DP DATA
STORE RETURN ADDRESS
PUT RELATIVE ADDRESS IN BITS 10-1
OF S-REGISTER, SET FIXED-SWITCHABLE
INDICATOR BITS 12 AND 11 IN S-REGISTER
EQUAL TO 01, EXECUTE SUBROUTINE.
Q CONTAINS ADDRESS OF ISWRETRN.

ISWRETRN

A ← RUPTRG4
A ← FBANK

C(A) NOW RESTORED
FOR RETURN. (L UNTouched BY
ISWRETRN)

A ← RUPTRG4

RETURN VIA RUPTRG3
USPRCADR PROVIDES ACCESS FROM BASIC CODING TO INTERPRETIVE CODING WHICH DOES NOT USE THE ENTERING CONTENTS OF Q AND WHICH EXITS VIA DANZIG. THE CALLER'S (A) IS SAVED. USPRCADR CHANGES FBANK, ENTER WITH CADR INTERPRET X IMMEDIATELY FOLLOWING THE TO USPRCADR INSTRUCTION.

```
USPRCADR

LOC ← A

EDOP ← BIT8

BANKSET ← BBANK

A ← CONTENTS OF THE ADDRESS IN Q

FBANK ← A_{15-4}

A ← A_{10-1}

Q ← A

A ← LOC

Q + 10000

10000#Q

SAVE CALLER'S (A)

PREPARE FOR EXIT FROM INTERPRETIVE ROUTINE VIA DANZIG

SAVE CALLER'S FBANK.

PICK UP CADR OF INTERPRETIVE SUBROUTINE

SET FBANK OF SUBROUTINE

OBTAIN RELATIVE ADDRESS OF INTERPRETIVE ROUTINE.

PUT RELATIVE ADDRESS IN Q.

RESTORE CALLER'S (A), PUT Q IN LOC.
```
RTB OP CODES

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

\[ A, L \leftarrow \text{TIME 2, TIME 1} \]

SLOAD 2

\[ \text{mpac} \leftarrow A \]
\[ \text{mpac} + 1 \leftarrow L \]
\[ \text{mpac} + 2 \leftarrow 0 \]

STORE CURRENT TIME

NEWMODE

\[ \text{mode} \leftarrow 0 \]

DECLARE MPAC IN DP MODE

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

If 2's complement value is positive, same as 1's complement.

Change scaling and convert to 1's complement.

Return via DANZIG.
Reads the PIPA's into MPAC without changing them

MPAC ← PIPAX
MPAC +3 ← PIPAY
A ← PIPAZ

Release Interrupts

MPAC +5 ← PIPAZ

Clear least significant part of each dp component

MPAC +1 ← 0
MPAC +4 ← 0
MPAC +6 ← 0

VECMODE

VMODE

A ← -1

NEWMODE

MODE ← -1

Return via DANZIG

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<td>PROGRAM:</td>
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<td>ANALYST:</td>
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<td>DOCMR: R.M. Etna 1/22/69</td>
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SGNAGREE

TPAGREE
Force sign agreement in MPACT
FC-2090

Return via DANZIG

ISTO2S

1 to 2 SUB
Convert the d.p. 1's complement angle in revs $\times 2^\circ$ to a single precision 2's complement angle in revs $\times 2^{-1}$

Input:
MPAC_D = 1's complement angle in revs $\times 2^\circ$

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

MPAC +1 $\xrightarrow{+0}$

NEWMODE

Mode $\xrightarrow{+0}$

Return via DANZIG

Forces sign agreement in MPAC_T

Converts the d.p. 1's complement angle in revs $\times 2^\circ$ to a single precision 2's complement angle in revs $\times 2^{-1}$

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

Input:

\[ \text{MPAC}_D = \text{1st 1's complement angle in revs @ 2°} \]

Output:

\[ A = \text{MPAC} = 2's \text{ complement angle in revs @ 2^{-1}} \]

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

Input:

\[ \text{MPAC}_D = \text{3rd 1's complement angle in revs @ 2°} \]

Output:

\[ A = \text{MPAC} = 2's \text{ complement angle in revs @ 2^{-1}} \]

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

Input:

\[ \text{MPAC}_D = \text{2nd 1's complement angle in revs @ 2°} \]

Output:

\[ A = \text{MPAC} = 2's \text{ complement angle in revs @ 2^{-2}} \]

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

Next Sheet

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CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

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From Preceding Sheet

TPMODE

A → +1

NEWMODE

MODE ← +1

Return via DANZIG

Declare MPAC in t.p. mode

2VISTO2S

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

1TO2SUB

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

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

\[ \text{MPAC}_D = ( MPAC + 3 )_D \]

\[ \text{MPAC + 3} \quad A \]

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

1TO2SUB

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

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

Sh. 8

Sh. 8

\[ L \leftarrow A \quad A \leftarrow MPAC + 3 \]

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

Next Sheet
From Preceding Sheet

SLOAD2

MPAC ← A
MPAC +1 ← L
MPAC +2 ← +0

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

NEWMODE

MODE ← +0

Declare MPAC in d.p. mode

Return via DANZIG

Input:
MPACD = angle in 1's complement in revs
Output:
A = MPAC = angle in 2's complement in revs

A, L ← 2^n × MPAC

Change scaling to 2^{-n}

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

Test A

A = 0

A ← +0
MPAC ← +0

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

MPAC ← A

Should bit 15 = 0?

Overflow

No ... No

Overflow

Yes

Yes

A ← POSMAX + MPAC
POSMAX = 377778

MPAC ← POSMAX + MPAC

Overflow

No

Yes

A ← NEglmAX + MPAC
NEglMAX = 40000

Restore 1 to bit 15
Lost if overflow

Fix "overflow corrected" result

Return via Q

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APOLLO GUIDANCE AND NAVIGATION

RTB Op Codes

COLOSSUS 2D

DOCUMENT NO.
FC-2100

REV
SHEET 8 OF 17
INCREMENT THETAD

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

CDUINC
Increment THETAD in 2's complement by l's complement quantity in A
Sh. 10

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

CDUINC
Increment THETAD in 2's complement by l's complement quantity in A
Sh. 10

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

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APOLLO GUIDANCE AND NAVIGATION

DRAWN: [signature] 12/21/69
PRGMR
ANALST
DOCMT R. Lyman, Jr. 12/12/67
APR'D R. Lyman, Jr.

RTB Op Codes
COLOSSUS 2D: FC-2100

DOCUMENT NO. REV SHEET 9 OF 11
From Preceding Sheet

\\( \text{VECMODE} \)

\\( \text{VMODE} \)

\\( A \leftarrow -1 \)

\\( \text{NEWMODE} \)

\\( \text{MODE} \leftarrow -1 \)

Declare THETAD in vector mode

Return via DANZIG

\\( \text{CDUINC} \)

\\( \text{TEM2} \leftarrow A \)

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

Test

\\( ADR^{-1}(BUF) \)

\\( = +0 \)

\\( \leq -0 \)

\\( > +0 \)

\\( A \leftarrow +0 \)

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

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

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

A \leftarrow A + TEM2

Increment by input value

Next Sheet
From Preceding Sheet

= 0

Test

A

< 0

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

> 0

A ← A + 1

TEM2 ← A

Store incremented 2's complement value

Overflow ?

No

If overflow, fix bit 15 by adding POSMAX(37777\text{\textsubscript{8}}) or NEGMAX (40000\text{\textsubscript{8}}) (quantity \(2^{-1}\))

A ← POSMAX

A ← NEGMAX

A ← A + TEM2

ADR\textsuperscript{-1}(BUF) ← A

Store new angle in 2's complement

Return via Q

0 must be +0 in 2's complement
PulseIMU

A ← X1

IMUPULSE

Torque gyro by angles specified at address in A

FC-2210

Return via DANZIG

Load the address of \( \mathcal{L} \), where \( \mathcal{L}_D, \mathcal{L}_{+2D}, \mathcal{L}_{+4D} \) contain gyro torquing angles in revs \( \pm 2^\circ \)

via BANKCALL

VECGNAG

Forces sign agreement of MPACV

via BANKCALL

VECAGREE

Forces sign agreement in each component of MPACV

FC-2090

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

TRANSP1

\[(XNB +2)_D \leftrightarrow (XNB +6)_D\]
\[(XNB +4)_D \leftrightarrow (XNB +12D)_D\]
\[(XNB +10D)_D \leftrightarrow (XNB +14D)_D\]

Return via DANZIG

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

TRANSP2

\[(XNB1 +2)_D \leftrightarrow (XNB1 +6)_D\]
\[(XNB1 +4)_D \leftrightarrow (XNB1 +12D)_D\]
\[(XNB1 +10D)_D \leftrightarrow (XNB1 +14D)_D\]

Return via DANZIG
SIGNMPAC

A, L ← MPAC_D
MPAC_D ← DPOSMAX

Test A

≥ +0

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

DPMODE

SLOAD2

MPAC_D ← -DPOSMAX

MPAC +2 ← +0

NEWMODE

MODE ← +0

Declare MPAC in d.p. mode

Return via DANZIG

Output:
MPAC_D containing
DPOSMAX or -DPOSMAX

Sets contents of MPAC_D to DPOSMAX if MPAC is positive and to -DPOSMAX if MPAC is negative.
Input: MPAC_D
DPOSMAX = 3777, 37778
Performs unit operation but also
works for very small vectors
s-\ (high-order half = 0)
(NORMUNXl)

S
\
^NORMUNny

/ Forces sign
\
/agreement in each \
V:omponent of MPACy/

Test 1st component (high-order half)

Test 2nd Component (high-order half)

Test 3rd component (hlgh-oi

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

---*-■
MPACn
MPACn + (MPAC +1) • 2"1
u
u
(MPAC +3)^
(MPAC +3)j-j +
(MPAC+4) • 2'1
(MPAC +5)Dt-(MPAC +5)d +
a<l_15
(MPAC +6) • 2'1

'■u/if I

RTB Op Codes

COLOSSUS 2D


From Preceding Sheet

Which entry?

Test

MPAC +2

ADR (PL0)

(NORMUNIT)

(NORMUNx1) ADR (PL1)

PL38 = X1

X1 ← A

PL37 ← A

OFFTUNIT

via POSTJUMP

UNIT +1

FC-2090

Perform unit operation on MPACY and return via DANZIG
# Subroutines Called Which Are Flowed on Other Flowcharts

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Where Flowed</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMUPULSE</td>
<td>FC-2210</td>
<td>Torques gyros</td>
<td>Sh. 12</td>
</tr>
<tr>
<td>TPAGREE</td>
<td>FC-2090</td>
<td>Forces sign agreement in MPACₜ</td>
<td>Sh. 5</td>
</tr>
<tr>
<td>UNIT</td>
<td>FC-2090</td>
<td>Performs unit operation</td>
<td>Sh. 16</td>
</tr>
<tr>
<td>VECAGREE</td>
<td>FC-2090</td>
<td>Forces sign agreement in each component of MPACᵧ</td>
<td>Sh. 12, 15</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>DR.</th>
<th>PRGMR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

APOLLO GUIDANCE AND NAVIGATION

<table>
<thead>
<tr>
<th>DOCUMENT NO.</th>
<th>RTB Op Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC-2100</td>
<td>COLOSSUS 2D</td>
</tr>
</tbody>
</table>

REV | SHEET 17 OF 17

---

APPR'D R.M. Cota

Dated 4/16/67
Single Precision Subroutines

SPCOS    Sh. 2
SPSIN    Sh. 2
SPCOS

Input:
angle in A in revs $\times 2^{-1}$

$A \leftarrow A + \frac{1}{4} \text{ rev}$

$\sin \left( \text{angle} + \frac{1}{4} \text{ rev} \right) = \cos \text{ of angle}$

If sin of angle is desired, enter here (SPSIN)

SPSIN

TEMK $\leftarrow A$

If overflow, result in TEMK differs from real arg by $\frac{1}{2} \text{ rev}$

No

Overflow?

Yes

A $\leftarrow$ TEMK

Negative of result in TEMK has same sin as input to SPSIN

SPT

TEMK $\leftarrow 2^{1} \times A$

Now scaled $@2^{-2}$
From Preceding Sheet

Overflow here means
$180^\circ \geq |\text{arg}| \geq 90^\circ$

+ 

Overflow ?

No

$180^\circ < \text{arg} \leq 90^\circ$

$\text{TEMK} \leftarrow (-\text{TEMK} + \text{NEGMAX}) + 1$

$\text{TEMK} \leftarrow (\text{TEMK} + \text{POSMAX}) - 1$

Overflow ?

No

arg is $-90^\circ$

A $\leftarrow +1$

A $\leftarrow -1$

ARG90

'Sh. 4

Next Sheet
From Preceding Sheet

\[
A = \text{TEMK} \\
\text{arg} = \text{angle in revs } \times 2^{-2} \\
|\text{arg}| < 90^\circ
\]

\[
A \leftarrow 2(C5/2 \cdot \text{TEMK}^5 + C3/2 \cdot \text{TEMK}^3 + C1/2 \cdot \text{TEMK})
\]

\[
C5/2 = \frac{1}{5!} (2\pi)^5 \times 2^{11} \\
C3/2 = \frac{1}{3!} (2\pi)^3 \times 2^7 \\
C1/2 = 1 \cdot 2 \pi \times 2^3
\]

2\pi is conversion factor to convert from revs to radians. A is in radians \( \times 2^2 \)

Flowchart:

- **Overflow**: No, Return via Q; Yes, ARG90

**Test angle**:
- \( \text{Sin} = 1 \)
  - POSMAX = NEGMAX = 40000_8 is as close as can get to \(-1 \times 2^0\)
  - A \leftarrow -\text{POSMAX}

- **Sin = -1**
  - NEGMAX = POSMAX = 37777_8 is as close as can get to \(+1 \times 2^0\)
  - A \leftarrow \text{NEGMAX}

Output:

\( A = \sin \text{ of input to SPSIN} \)
\( = \cos \text{ of input to SPCOS } \times 2^2 \)
<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SELFRET:</td>
<td>Erasable location containing return addresses to self check</td>
<td>SH. 2</td>
</tr>
<tr>
<td>SELFCHEK:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STSHOSUM:</td>
<td>Entry from Showsum routine</td>
<td>SH. 7</td>
</tr>
</tbody>
</table>
SELFCHK

Q = ADRES(0, ERASCHK)

SMODECHK

SAVE Q IN SKEEP1

CHECKN1

STORE Q IN SELFRET

ADVAN FC-2050

IF NEWJOB = -0, VIA SELFRET

+0

TEST SMODE

>0 ?

SCOUNT ← SCOUNT + 1

<0

GO TO ROPECHK OR ERASCHK VIA SKEEP1

0

SORTIONS

>8 NOT A VALID VALUE

SMODE > 8?

YES

NO

SCOUNT ← SCOUNT + 1

SIDLOOP

SMODE ← +0

NEXT SHEET

SELFCHK
FROM PRECEDING SHEET

SMODE = ±4
SOPTION1

SMODE = ±3
SOPTION2

GO TO ROPECHK OR ERASCHK VIA SLEEP1

SMODE = ±2
SOPTION3

SMODE = ±1
SOPTION4

ROPECHK

SH8

SMODE = ±8
SOPTION8

SMODE = ±7
SOPTION7

SMODE = ±6
SOPTION6

SMODE = ±5
SOPTION5

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

SKEEP2 ← +1

SKEEP2

GESBANK

EBANK ← +0
SKEEP7 ← 014610
SKEEP3 ← 017770

EBANK 0
STARTING ADDRESS
ENDING ADDRESS

ERASLOOP
START OF ERASABLE CHECK LOOP

INHIBIT INTERRUPTS

SKEEP ← EBANK
SKEEP5 ← 00001 SKEEP7
ERESTORE ← SKEEP7
D SKEEP7 ← SKEEP7
1# SKEEP7 ← (SKEEP7+1)

SAVE EBANK SETTING
SAVE CONTENTS OF DP REGISTER POINTED TO BY SKEEP7
MAKE ERESTORE NON-ZERO, TO INDICATE ERASABLE MUST BE RESTORED
PUT INTO REGISTER POINTED TO BY SKEEP7 OWN ADDRESS
LIKEWISE WITH NEXT REGISTER

A ← D#SKEEP7-1#SKEEP7

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

NEXT SHEET

SELF CHECK ROUTINE

COLOSSUS II FC-2120
NOEBANK

CHECKS UNSWITCHED ERASABLE

SKEEP2 ← A
SKEEP1 ← 0061₈
SKEEP3 ← 0137₈

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

ERASLOOP
SH₃

REBANK

CHECKS SECONDO EBANK

SKEEP7 ← 0140₀₈
SKEEP3 ← 0177₇₈

STARTING ADDRESS
ENDING ADDRESS

ERASLOOP
SH₃

E134567₈

SKEEP7 ← 0140₀₈
SKEEP3 ← 0177₇₈

STARTING ADDRESS
ENDING ADDRESS

ERASLOOP
SH₃
PERFORMS "CS" ON ALL REGISTERS FROM \(60_8\) TO \(10_8\)
A PARITY FAILURE WILL CAUSE A HARDWARE RESTART

ADDRESS OF FIRST COUNTER

A \(\leftarrow 00050_8\)

\(\text{CNTRLCHK}\)

\(\text{CNTRLLOOP}\)

\(\text{SKEEP2} \leftarrow A\)

\(A \leftarrow (10_8\#A)\)

\(\text{NO IS SKEEP2} = 0\) ?

\(A \leftarrow \text{SKEEP2} - 1\)

\(\text{YES}\)

\(\text{CYCLEFT}\)

\(A \leftarrow 25525_8\)

\(\text{CYR} \leftarrow A\)

\(\text{CYL} \leftarrow A\)

\(\text{SR} \leftarrow A\)

\(\text{EDOP} \leftarrow A\)

\(A \leftarrow \text{CYR} + \text{CYL} + \text{SR} + \text{EDOP} + 52400\)

\(\text{C(CYR)} = 12525_8\)

\(\text{C(CYL)} = 52524_8\)

\(\text{C(SR)} = 12525_8\)

\(\text{C(EDOP)} = 00125\)

TOTAL \(= 52400 - 1\)

SENSING OPERATIONS LEAVE THESE VALUES IN THE REGISTERS:
\(\text{C(CYR)} = 45252\)
\(\text{C(CYL)} = 25251\)
\(\text{C(SR)} = 05252\)
\(\text{C(EDOP)} = 00000\)

TOTAL \(= -2\)

-1CHK

A = 1? IF SO, RETURN, IF NOT BRANCH TO PRERRORS

5H16

A \(\leftarrow \text{CYR} + \text{CYL} + \text{SR} + \text{EDOP} + 1\)

SHOULD \(= -1\)

NEXT SHEET

SELF CHECK ROUTINE

COLOSBUS II FC-2120
**COMAORS**

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

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

**SUPDACAL**

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

**ADSUM**

SKEEP2 ← A

YES: DOES A SKEEP CAUSE OVERFLOW?

SKEEP4 ← SKEEP4+A X 1 BIT
RESULT IS OVERFLOW CORRECTED
SIGN OF 1 BIT = SIGN(A+SKEEP)

A ← SKEEP3-SKEEP2
PREPARE FOR TEST FOR "TC SELF" WORD

RETURN VIA Q

A ← 02000 + A
SWITCHED FIXED MEMORY ADDRESSES START WITH 2000

**ADDRCHK** SH:11
SKEEP≤0 returns to FIXADDR, ≥0 transfers to COMMADDR.

Which bank?

YES

DOES A = 0?

NO

SKEEP3 ← 06000
BANK 03 starting address

SKEEP3 ← 04000
BANK 02 starting address

SKEEP1 ← +0
SKEEP5 ← +1

INITIALIZE SUM
INITIALIZE FOR "TC SELF" WORDS COUNT

FXADDR

A ← 0000#SKEEP3
GET CONTENTS OF CELL

ADSUM

ADD CONTENTS TO SKEEP1.

SKEEP2 ← A

YES

DOES SKEEP1+A CAUSE OVERFLOW?

NO

SKEEP1 ← SKEEP1+A+1BIT
RESULT IS OVERFLOW CORRECTED
SIGN OF 1BIT = SIGN(A+SKEEP2)

SKEEP1 ← A+SKEEP1

A ← SKEEP3-SKEEP2
PREPARE FOR TEST FOR "TC SELF" WORD

RETURN VIA Q

NEXT SHEET

A "TC SELF" WORD CONTAINS ITS OWN ADDRESS.
FROM PRECEDING SHEET

ADRSCHK

L ← A

PREPARE FOR "TC SELF" CHECK

EN OF THE BANK?

IS SKEEPS<(MAXADR)?

NO

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

YES

IS SKEEPS<0?

NO

SOPTION

5H53

IS L="D"?

ND

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

YES

FIRST OR SECOND

TEST SKEEPS

+0

SECOND

<0 FIRST

A ← -1

A ← +0

CONTINU

(CONTINU+1)

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

NEXT SHEET
SOPTION

A ← SKEEP4,16-11

GET BANK NUMBER

LEFTS

CYCLE BITS
15-11 INTO BITS
5-1

FC-2180

L ← A

PUT BANK NUMBER IN LOW ORDER BITS

PUT IT IN L, TO PREPARE FOR -1 CHK

ARE SUPERBITS CLEAR?

YES BITSO=10 SKEEP4=0

NO

SR ← SKEEP4=9-4

L ← L3-4+SR

SHIFT THEM RIGHT 1 BIT,
AND ADD THEM TO LOW ORDER 3 BITS OF FBANK SETTING

SOFT

IS SKEEP6=0

YES SHOWSUM OR ROPECHK

SHOWSUM OR ROPECHK?

NO SHOWSUM

SDDISPLAY

FC-2120

YES ROPECHK

SKEEP1 ← SKEEP1

NEXT SHEET

self check routine
-1CHK

YES

A = -1 ?

NO

RETURN VIA Q

PRERRORS

IS IT NECESSARY TO RESTORE ERASABLE?

NO

YES

ERESTORE? +0 INDICATES THIS HAS BEEN DONE.

00000 #SKEEP ← SKEEPS 0
ERESTORE ← +0

RESTORE ERASABLE

ERRORS

INHIBIT INTERRUPTS

SPAIL ← Q
ALMCADR ← Q
ERECOUNT ← ERECOUNT +1

Q FOR RETURN WITHIN SELFCHK
Q FOR ALARM ROUTINES
ANOTHER ALARM ANOTHER ERROR

NEXT SHEET

SELF CHECK ROUTINE

COLOSSUS II FC-2120
FROM PRECEEDING SHEET

TCALARM2

ALARM2

PLACES ALARM CODE 04102 INTO A FAILREG REGISTER
FC-2140

ALARM2 TURNS ON PROALARM; IF NOT ON

<0

TEST SMODE

=0

≥+0

RETURN VIA SFAIL

SIDLOOP

GMODE ← +0

SELFCHK

SH2
# ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>CYR</td>
<td></td>
<td>Pointer for Starting ROPECHK or ERASCHK (depending also on SMODE);</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CYL</td>
<td></td>
<td>CONTROLS CHECKING OF NON-SWITCHABLE ERASABLE, WITH EBANK SET; STORES EBANK CELL DATA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td></td>
<td>HOLES ADDRESS FOR ROPECHK, ENDING ADDRESS FOR EBANK CHECK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDOP</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKEEP1</td>
<td></td>
<td>HOLES HIGH ORDER HALF OF ERASABLE LOCATIONS BEING CHECKED; COUNTS DOWN TWO TO SELF WORDS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKEEP2</td>
<td></td>
<td>HOLES LOW ORDER HALF OF ERASABLE LOCATIONS BEING CHECKED; SHOWSUM-ROPECHK INDICATOR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKEEP3</td>
<td></td>
<td>FXFX-COMMFX INDICATOR; ADDRESS POINTER FOR ERASCHK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKEEP4</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKEEP5</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKEEP6</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKEEP7</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMODE</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SELFRET</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCOUNT</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCOUNT+1</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SFAIL</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERCOUNT</td>
<td></td>
<td>HOLES EBANK AND EBANK SETTINGS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ALARM AND ABORT

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

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

Alarm conditions are due to program failures (not hardware failures). If the failure is not serious, control returns to the calling sequence. If the failure is serious, no return is made, and an abort is made resulting in a software restart. Failures which are not serious use the following entries: PRIOLARM, VARALARM, CURTAINS, ALARM and ALARM2. Failures which are serious use the following entries: BAILOUT, POODOO, and CCSHOLE.
Each entry will make the alarm code available for display and turn on the program alarm light (if off). Only entry PRIOLARM will display the alarm codes in the three FAILREG registers. The return location and the location containing the alarm code is given in the calling sequence for each entry shown below.

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

<table>
<thead>
<tr>
<th>Entry</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRIOLARM</td>
<td>Displays the alarm codes via PRIODSPR (V05N09) and returns. Used by the &quot;target out of view&quot; alarm condition.</td>
</tr>
<tr>
<td>VARALARM</td>
<td>Calling sequence obtains a variable alarm code from an applicable register. Returns to calling sequence.</td>
</tr>
<tr>
<td>CURTAINS</td>
<td>Alarm code OCT 217 is only one used. Used for bad returns from stall routines. Returns to calling sequence.</td>
</tr>
<tr>
<td>ALARM</td>
<td>Used for alarm conditions such as improper input data, etc. Returns to calling sequence.</td>
</tr>
<tr>
<td>BAILOUT</td>
<td>Terminates in a software restart. Used by alarm conditions such as no vac areas available, too many tasks, etc.</td>
</tr>
<tr>
<td>POODOO</td>
<td>Clears AVEGFLAG and V37FLAG. Inactivates all restart groups and terminates in a software restart, and GOTOPOOH and flash verb 37 for operator to select new major mode. Used by alarm conditions such as an attempt to take the square root of a negative number, illegal flashing display, etc.</td>
</tr>
<tr>
<td>CCDSHOLE</td>
<td>Alarm code OCT 21103 is only code used. Clears AVEGFLAG and V37FLAG, inactivates all restart groups and terminates in a software restart, and GOTOPOOH and flash verb 37 for operator to select new major mode. Used when unused CCS branch is executed.</td>
</tr>
<tr>
<td>ALARM2</td>
<td>Alarm code OCT 1102 is only code used. Used only by self check program when an error is detected.</td>
</tr>
</tbody>
</table>
Two Of The Five
Non-Abortive Entries with Return

Displays Alarm Code
From location R52L+5 of P51-P53 via BANKCALL with A = ALARM code. \[\text{BUF2, BUF2+1} = 2\text{CADR}\] of \(x+2\)

Calling sequence
\(x+0\) TC BANKCALL
\(x+1\) CADR PRIOLARM
\(x+2\) TERMINATE
\(x+3\) PROCEED
\(x+4\) ENTER
\(x+5\) IMMEDIATE RETURN

From 3 locations with \(A = \text{alarm code}\)

Calling sequence
\(x+0\) TC VARALARM
\(x+1\) Return

Inhibit
Alarm Code

PRIOLARM

Inhibit interrupts

Alarm Code

L \(\leftarrow\) A

GENADR of \(x+2\)

ALMCADR \(\leftarrow\) BUF2

BBCON of \(x+2\)

A \(\leftarrow\) (BUF2+1)

PRIOENT +1
Sh. 6

VARALARM

Inhibit interrupts

Alarm Code

L \(\leftarrow\) A

ALMCADR \(\leftarrow\) Q

Q = \(x+1\)
(Return Address)

A return address of the calling sequence (BBCON is in bit positions 15-11 and 3-11)

Note: Symbol "\(\rightarrow\)" means "contains" in this flow chart.

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

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APOLLO GUIDANCE AND NAVIGATION

<table>
<thead>
<tr>
<th>DRAWN</th>
<th>Alarm and Abort</th>
</tr>
</thead>
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<tr>
<td>12-93</td>
<td></td>
</tr>
<tr>
<td>PRGMR</td>
<td></td>
</tr>
<tr>
<td>S. Banning</td>
<td></td>
</tr>
<tr>
<td>ANALGT</td>
<td></td>
</tr>
<tr>
<td>O. D. B.</td>
<td></td>
</tr>
<tr>
<td>DOCMR</td>
<td>COLOSSUS II-D</td>
</tr>
<tr>
<td>11/4/67</td>
<td>FC-2140</td>
</tr>
<tr>
<td>APPR'D</td>
<td></td>
</tr>
<tr>
<td>R. S. K. Estes</td>
<td>11/4/69</td>
</tr>
<tr>
<td>REV</td>
<td>2</td>
</tr>
<tr>
<td>SHEET</td>
<td>3</td>
</tr>
<tr>
<td>NO</td>
<td>16</td>
</tr>
</tbody>
</table>
Three of the five Non-Abortive Entries with Return

From 6 locations
Calling sequence
$X + 0 \text{ TC CURTAINS}$
$X + 1 \text{ Return}$
One Alarm Code
(OCT 0217) in CURTAINS +3

From 41 locations
Calling sequence
$X + 0 \text{ TC ALARM}$
$X + 1 \text{ OCT CODE}$
$X + 2 \text{ Return}$

ALARM2 entry
Entered from location TCALARM2 of self check program with A = address of failure location
Calling sequence is:
$X + 0 \text{ TC ALARM2}$
$X + 1 \text{ OCT 01102}$
$X + 2 \text{ Return}$
A = address of failure location
$A = X + 1$

The Alarm Code for ALARM2 entry from self check is in location TCALARM2 +1 and is OCT 01102

ALARM2

ALARM

The Alarm Code for CURTAINS entry is in location CURTAINS +3 and is OCT 0217

From BAILOUT, POODOO (via ABORT2) and CSSHOLE (via ABORT2) on Sheet 5

BORTENT

L $\leftarrow A$

PRIOENT

Sh. 6

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

**Calling sequence**

1. Abortive Entries Ending in Restart
   - Calling sequence
     - $x + 0$ TC **BAILOUT**
     - $x + 1$ OCT CODE
     - No Return

2. Calling sequence
   - $x + 0$ TC **POODOO**
   - $x + 1$ OCT CODE
   - No Return

3. Calling sequence
   - $x + 0$ TC **CCSHOLE**
   - No Return
   - One Alarm Code (OCT Code 21103) in **CCSHOLE**+3

---

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

---

**MIT INSTRUMENTATION LAB**

CAMBRIDGE, MASS.

**APOLO GUIDANCE AND NAVIGATION**

**Alarm and Abort**

<table>
<thead>
<tr>
<th>DRAWN</th>
<th>2/9/69</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROGR</td>
<td>1/6-69</td>
</tr>
<tr>
<td>ANALST</td>
<td>1/6-69</td>
</tr>
<tr>
<td>DOCMR</td>
<td>1/6-69</td>
</tr>
<tr>
<td>APPRD</td>
<td>1/6-69</td>
</tr>
</tbody>
</table>

**COLOSSUS II-D**

**FC-2140**

**REV 2**

**SHEET 5 OF 18**
From Sheets 3 and 4

PRIOENT

A_{15-11,3-1} \leftarrow BBANK_{15-11,3-1} \quad \text{BBCON of the Return Address of the calling sequence}

\text{From Sheet 3}

\text{PRIOENT} + 1

\begin{align*}
A_{7-5} & \leftarrow \text{SUPERBNK}_{7-5} \\
\text{ALMCADR} + 1 & \leftarrow A
\end{align*}

\text{SUPER BANK of the Return Address of the calling sequence included with the BCON}

\text{Store BCON and SUPER BANK}

Next Sheet
Return Address to either the entry calling sequence or the BORTENT (or PRIOENT) calling sequence. ITEM1 contains one of the following Return Addresses depending upon which entry was used:

- \( \text{ITEMP1} = \text{PRIOLARM} + 6 \)
- \( \text{ITEMP1} = \text{VARALARM} + 5 \)
- \( \text{ITEMP1} = \text{CURTAINS} + 3 \)
- \( \text{ITEMP1} = X + 1 \) where \( X = \text{TC ALARM} \)
- \( \text{ITEMP1} = \text{BAILOUT} + 8 \)
- \( \text{ITEMP1} = \text{ABORT2} + 1 \) if via POODOO or CSSHOLE
- \( \text{ITEMP1} = X + 1 \) where \( X = \text{TC ALARM2} \)

Save for debugging

Next Sheet

NOTE: Symbol " ~ " means "contains" in this flowchart
Update Table of Alarm conditions. Registers FAILREG and FAILREG+1 are set with the first and second ALARM CODES, respectively, since these registers were last cleared. FAILREG+2 is set with each ALARM CODE, thus it will contain the last ALARM CODE.

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

Yes

FAILREG ← L

Alarm Code (1st)

No

Is this the second alarm?

No

Is (FAILREG+1) = +0?

Yes

(FAILREG +1) ← L

Alarm Code (2nd)

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

Next Sheet
From Preceding Sheet

PROGLARM

(FAILREG +2) ← L

(DSPTAB +11D)9 ← 1

(DSPTAB +11D)15 ← 1

MULTEXIT

A ← ITMP1

Release interrupt inhibit

Increment A by 1

Return via A

Most recent Alarm Code

Turn on Program Alarm light

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

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

A = PRIOLARM +7
A = VARALARM +6
A = CURTAINS +4
A = (L +2) where L = TC ALARM
A = BAILOUT +9
A = ABORT2 +2 if via POODOO or CCSHOLE.
A = (L+2) Where L = TC ALARM2
From Preceding Sheet

PRIOLARM+7

A -- V05N09

PRIODSPR

V05N09 Displays Alarm Codes in R1, R2, R3

FC-2130

Verb 05 and noun 09 initiated by program control

V05N09 VNI 0509
V05N09 OCT 01211

Displays the contents (Alarm Codes) of registers FAILREG, FAILREG+1 and FAILREG+2

Location of PRIOLARM calling sequence (Sh. 3)

(only 7 + 5 is used where 7 = TC BANKCALL and 7 + 1 = CADR PRIOLARM)

From Preceding Sheet

VARALARM+6

Return via ALMCADR

To 7 + 1 location of VARALARM calling sequence where 7 = TC VARALARM

From Preceding Sheet

CURTAINS+4

Return via ALMCADR

To 7 + 1 location of CURTAINS calling sequence where 7 = TC CURTAINS
Is AVERAGEG (Servicer) running? (Is V37FLAG on?)

Is bit 6 of FLAGWRD7 = 1?

no

next sheet

next sheet

Yes

Inhibit interrupts

WHIMPER

BRUPT ← Z + 2

Cause "Resume" to go to following location

To get out of interrupt mode if in it

via POSTJUMP

RESUME

Software Restart

From Sheet 9

From Sheet 9

ABORT2 + 2

POODOO or CCSHOLE entry

(BAILOUT + 9)
Subroutine FC-2070 (Service Routines)

**STATEFLG**
- Permanent State vector not updated

**REINTFLG**
- Integration routine not to be restarted

**NODOFLAG**
- V37 Permitted

Next Sheet
From Preceding Sheet

```
MR. KLEIN
```

Subroutine FC-2020 (fresh start and restart)

```
ALLGROUPS
kill all group (1-6) restarts
```

```
WHIMPER
```

```
BRUPT ← Z + 2
```

Cause "Resume" to go to following location

```
RESUME
```

To get out of interrupt mode if in it via POSTJUMP

```
GOPROG2
FC-2020
Sh. 20
```

See Note A

---

Note A: Go to routine GOTOPOOH and display flashing verb 37 unless no major mode was active in which case control goes to DUMMY JOB +2 (see restart, Sheet 23 of FC-2020).
<table>
<thead>
<tr>
<th>ALARM CODE</th>
<th>ALARM CONDITION</th>
<th>SET BY</th>
<th>ALARM ENTRY USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>00110</td>
<td>No mark since last mark reject</td>
<td>SXTMARK</td>
<td>ALARM</td>
</tr>
<tr>
<td>00112</td>
<td>Mark not being accepted</td>
<td>SXTMARK</td>
<td>ALARM</td>
</tr>
<tr>
<td>00113</td>
<td>No inbits</td>
<td>SXTMARK</td>
<td>ALARM</td>
</tr>
<tr>
<td>00114</td>
<td>Mark made, but not desired</td>
<td>SXTMARK</td>
<td>ALARM</td>
</tr>
<tr>
<td>00115</td>
<td>Optics torque request with switch not at CMG</td>
<td>EXT VERB, OPTICS CDU</td>
<td>ALARM</td>
</tr>
<tr>
<td>00116</td>
<td>Optics switch altered before 15 sec zero time elapsed</td>
<td>T4RUPT</td>
<td>ALARM</td>
</tr>
<tr>
<td>00117</td>
<td>Optics torque request with optics not available (OPTIND = -0)</td>
<td>EXT VERB, OPTICS CDU</td>
<td>ALARM</td>
</tr>
<tr>
<td>00120</td>
<td>Optics torque request with optics not zeroed</td>
<td>T4RUPT</td>
<td>ALARM</td>
</tr>
<tr>
<td>00121</td>
<td>CDUS no good at time of mark</td>
<td>SXTMARK</td>
<td>ALARM</td>
</tr>
<tr>
<td>00122</td>
<td>Marking not called for</td>
<td>P17, P77</td>
<td>ALARM</td>
</tr>
<tr>
<td>00124</td>
<td>TPI search - no safe perictr here</td>
<td>SERVICER</td>
<td>ALARM</td>
</tr>
<tr>
<td>00205</td>
<td>Bad PIPA reading</td>
<td>IMU MODE SWITCH, IMU-2</td>
<td>ALARM</td>
</tr>
<tr>
<td>00206</td>
<td>Zero encode not allowed with coarse align +gimbal lock</td>
<td>T4RUPT</td>
<td>ALARM</td>
</tr>
<tr>
<td>00207</td>
<td>ISS turn-on request not present for 90 sec</td>
<td>T4RUPT</td>
<td>ALARM</td>
</tr>
<tr>
<td>00210</td>
<td>IMU not operating</td>
<td>IMU MODE SWITCH, IMU-2, R02, P51</td>
<td>ALARM</td>
</tr>
<tr>
<td>00211</td>
<td>Coarse align error - drive &gt;2 degrees</td>
<td>IMU MODE SWITCH</td>
<td>ALARM</td>
</tr>
<tr>
<td>00212</td>
<td>PIPA fail but PIPA is not being used</td>
<td>IMU MODE SWITCH</td>
<td>ALARM</td>
</tr>
<tr>
<td>00213</td>
<td>IMU not operating with turn-on request</td>
<td>T4RUPT</td>
<td>ALARM</td>
</tr>
<tr>
<td>00214</td>
<td>Program using IMU when turned off</td>
<td>T4RUPT</td>
<td>ALARM</td>
</tr>
<tr>
<td>00215</td>
<td>Preferred orientation selected but not specified</td>
<td>P52, P54</td>
<td>ALARM</td>
</tr>
<tr>
<td>00217</td>
<td>Bad return from stall routines</td>
<td>CURTAINS</td>
<td>ALARM2</td>
</tr>
<tr>
<td>00220</td>
<td>IMU not aligned - no REFSMMAT</td>
<td>R02, P51</td>
<td>VARALARM</td>
</tr>
<tr>
<td>00401</td>
<td>Desired gimbal angles yield gimbal lock</td>
<td>INF ALIGN, IMU-2</td>
<td>ALARM</td>
</tr>
<tr>
<td>ALARM CODE</td>
<td>ALARM CONDITION</td>
<td>SET BY</td>
<td>ALARM ENTRY USED</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>--------</td>
<td>------------------</td>
</tr>
<tr>
<td>00404</td>
<td>Target out of view - trunnion angle &gt; 90 deg</td>
<td>R52</td>
<td>PRIORITY ALARM</td>
</tr>
<tr>
<td>00405</td>
<td>Two stars not available</td>
<td>P52, P54</td>
<td>ALARM</td>
</tr>
<tr>
<td>00406</td>
<td>Rend navigation not operating</td>
<td>R21, R23</td>
<td>ALARM</td>
</tr>
<tr>
<td>00407</td>
<td>Auto optics request trunnion angle ≥ 50 deg (target out of view)</td>
<td>R52</td>
<td>ALARM</td>
</tr>
<tr>
<td>00421</td>
<td>W-matrix overflow</td>
<td>INTEGRV</td>
<td>ALARM</td>
</tr>
<tr>
<td>00600</td>
<td>Imaginary roots on first iteration</td>
<td>P32, P72</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00601</td>
<td>Perigee altitude LT PMIN1</td>
<td>P32, P72</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00602</td>
<td>Perigee altitude LT PMIN2</td>
<td>P32, P72</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00603</td>
<td>CSI to CDH time LT PMIN22</td>
<td>P32, P72</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00604</td>
<td>CDH to TPI time LT PMIN23</td>
<td>P32, P72</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00605</td>
<td>Number of iterations exceeds loop maximum</td>
<td>P32, P37, P72</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00606</td>
<td>DV exceeds maximum</td>
<td>P32, P72</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00611</td>
<td>No TIG for given elev angle</td>
<td>P34, P74</td>
<td>ALARM</td>
</tr>
<tr>
<td>00612</td>
<td>State vector in wrong sphere of influence</td>
<td>P37</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00613</td>
<td>Reentry angle out of limits</td>
<td>P37</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>00777</td>
<td>PIPA fail caused the ISS warning</td>
<td>T4RUPT</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>01102</td>
<td>CMC self test error</td>
<td>SELFCHECK</td>
<td>ALARM</td>
</tr>
<tr>
<td>01105</td>
<td>Downlink too fast</td>
<td>T4RUPT</td>
<td>ALARM</td>
</tr>
<tr>
<td>01106</td>
<td>Uplink too fast</td>
<td>T4RUPT</td>
<td>ALARM</td>
</tr>
<tr>
<td>01107</td>
<td>Phase table failure. Assume erasable memory is destroyed</td>
<td>INTERPRETER</td>
<td>ALARM</td>
</tr>
<tr>
<td>01301</td>
<td>ARCSIN-ARCCOS input angle too large</td>
<td>S40.8</td>
<td>ALARM</td>
</tr>
<tr>
<td>01407</td>
<td>VG increasing</td>
<td>P61, P62</td>
<td>ALARM</td>
</tr>
<tr>
<td>01426</td>
<td>IMU unsatisfactory</td>
<td>P61, P62</td>
<td>ALARM</td>
</tr>
<tr>
<td>01520</td>
<td>V37 request not permitted at this time</td>
<td>V37</td>
<td>ALARM</td>
</tr>
<tr>
<td>01600</td>
<td>Overflow in drift test</td>
<td>OPT PREALIGN CALIB</td>
<td>ALARM</td>
</tr>
<tr>
<td>01601</td>
<td>Bad IMU torque</td>
<td>OPT PREALIGN CALIB</td>
<td>ALARM</td>
</tr>
<tr>
<td>01602</td>
<td>Bad optics during verification</td>
<td>OPTALIGN CALIB (CSM)</td>
<td>ALARM</td>
</tr>
<tr>
<td>01703</td>
<td>Insuf. time for integr. TIG has slipped</td>
<td>R41</td>
<td>ALARM</td>
</tr>
<tr>
<td>03777</td>
<td>ICDU fail caused the ISS warning</td>
<td>T4RUPT</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>04777</td>
<td>ICDU, PIPA fails caused the ISS warning</td>
<td>T4RUPT</td>
<td>VARIABLE ALARM</td>
</tr>
<tr>
<td>ALARM CODE</td>
<td>ALARM CONDITION</td>
<td>SET BY</td>
<td>ALARM ENTRY USED</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>---------------</td>
<td>------------------</td>
</tr>
<tr>
<td>07777</td>
<td>IMU fail caused the ISS warning</td>
<td>T4RUPT</td>
<td>VARALARM</td>
</tr>
<tr>
<td>10777</td>
<td>IMU, PIPA fails caused the ISS warning</td>
<td>T4RUPT</td>
<td>VARALARM</td>
</tr>
<tr>
<td>13777</td>
<td>IMU, ICDU fails caused the ISS warning</td>
<td>T4RUPT</td>
<td>VARALARM</td>
</tr>
<tr>
<td>14777</td>
<td>IMU, ICDU, PIPA fails caused the ISS warning</td>
<td>T4RUPT</td>
<td>VARALARM</td>
</tr>
<tr>
<td>20430*</td>
<td>Integ. abort due to subsurface s.v.</td>
<td>ALL CALLS TO INTEGRATION</td>
<td>POODOO</td>
</tr>
<tr>
<td>20607*</td>
<td>No solution from time theta or time radius routine</td>
<td>TIMETHET, TIMERAD</td>
<td>POODOO</td>
</tr>
<tr>
<td>20610*</td>
<td>Lamda less than unity</td>
<td>P37</td>
<td>POODOO</td>
</tr>
<tr>
<td>21103*</td>
<td>Unused CCS branch executed</td>
<td>CCSHOLE</td>
<td>ABORT2</td>
</tr>
<tr>
<td>21204*</td>
<td>Negative or zero delta time - waitlist call</td>
<td>WAITLIST</td>
<td>POODOO</td>
</tr>
<tr>
<td>21205*</td>
<td>Second job attempts to go to sleep via keyboard and display program</td>
<td>PINBALL</td>
<td>POODOO</td>
</tr>
<tr>
<td>21210*</td>
<td>Two programs using device at same time</td>
<td>IMU MODE SWITCH</td>
<td>POODOO</td>
</tr>
<tr>
<td>21302*</td>
<td>SQRT called with negative argument, Abort</td>
<td>INTERPRETER</td>
<td>POODOO</td>
</tr>
<tr>
<td>21302*</td>
<td>SQRT called with negative argument, Abort</td>
<td>INTERPRETER</td>
<td>POODOO</td>
</tr>
<tr>
<td>21501*</td>
<td>Keyboard and display alarm during internal use (NVSUB). Abort</td>
<td>PINBALL</td>
<td>POODOO</td>
</tr>
<tr>
<td>21502*</td>
<td>Illegal flashing display</td>
<td>GOPLAY</td>
<td>POODOO</td>
</tr>
<tr>
<td>21521*</td>
<td>P01 or P07 illegally selected</td>
<td>P01, P07</td>
<td>POODOO</td>
</tr>
<tr>
<td>31104*</td>
<td>Delay routine busy</td>
<td>SERVICE ROUTINES</td>
<td>BAILOUT</td>
</tr>
<tr>
<td>31201*</td>
<td>Executive overflow - no vac areas</td>
<td>EXEC</td>
<td>BAILOUT</td>
</tr>
<tr>
<td>31202*</td>
<td>Executive overflow - no core sets</td>
<td>EXEC</td>
<td>BAILOUT</td>
</tr>
<tr>
<td>31203*</td>
<td>Waitlist overflow - too many tasks</td>
<td>WAITLIST</td>
<td>BAILOUT</td>
</tr>
<tr>
<td>31207*</td>
<td>No vac area for marks</td>
<td>SXTMARK</td>
<td>BAILOUT</td>
</tr>
<tr>
<td>31211*</td>
<td>Illegal interrupt of extended verb</td>
<td>SXTMARK</td>
<td>BAILOUT</td>
</tr>
</tbody>
</table>

* Indicates abort type. All others are non-abortive.
When the operator or the ground communicates with the computer, the information being transmitted is first received by this program KEYRUPT and UPRUPT.

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

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

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

When uplink counter INLINK overflows, the routine being executed is interrupted by interrupt program No. 7. A key code word (uplink word) representing the character transmitted from the ground is serially loaded from the uplink receiver into INLINK. The key code word is a 16-bit word consisting of a one in bit-position 16 and the key code (5-bit configuration) is in bit position 15-11 and 5-1 and its complement in 10-6. When the one in bit-position 16 of the 16-bit word reaches
bit-position 16 of INLINK during the serial loading (shifting left in INLINK one bit-position at a time), overflow occurs causing interrupt No. 7. Control will arrive at routine UPRUPT via its lead-in interrupt routine.

The characters are represented by the following key codes:

<table>
<thead>
<tr>
<th>Character (or action)</th>
<th>Key Code (binary)</th>
<th>Character (or action)</th>
<th>Key Code (binary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10 000</td>
<td>VERB</td>
<td>10 001</td>
</tr>
<tr>
<td>1</td>
<td>00 001</td>
<td>ERROR RESET</td>
<td>10 010</td>
</tr>
<tr>
<td>2</td>
<td>00 010</td>
<td>KEY RELEASE</td>
<td>11 001</td>
</tr>
<tr>
<td>3</td>
<td>00 011</td>
<td>+</td>
<td>11 010</td>
</tr>
<tr>
<td>4</td>
<td>00 100</td>
<td>-</td>
<td>11 011</td>
</tr>
<tr>
<td>5</td>
<td>00 101</td>
<td>ENTER</td>
<td>11 100</td>
</tr>
<tr>
<td>6</td>
<td>00 110</td>
<td>CLEAR</td>
<td>11 110</td>
</tr>
<tr>
<td>7</td>
<td>00 111</td>
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<td>8</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>01 001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

KEYRUPT also sets DSKYFLAG (indicates that displays are to be sent to the Dsky) and schedules routine CHARIN of program Pinball as a job at priority 30.

UPRUPT also clears INLINK for the next key code, turns on uplink activity light and tests the key code for triple character redundancy. The key code is satisfactory if the original contents of bit-positions 15-11 of INLINK are the same as the original contents of bit-positions 5-1 and the complement of the original contents of bit-positions 10-6. If the key code is not satisfactory, UPLOCKFL flag is set and the interrupted routine is resumed. If the key code is satisfactory and it is the error reset code, then the UPLOCKFL flag is cleared and routine CHARIN of program Pinball is scheduled as a job at priority 30 and the interrupted routine is resumed. If the key code is not the error reset code and the UPLOCKFL flag is cleared, then routine CHARIN is scheduled as a job. If the UPLOCKFL flag was not cleared, CHARIN will not be scheduled and the interrupted routine will be resumed because an error reset code must be sent since the last unsatisfactory key code before subsequent key codes can be accepted.
Control arrives here from the interrupted routine when a key on the keyboard of the DSKY is depressed to transmit a character.

As control arrives, the 5-bit key code of the character is in bit-positions 5-1 of channel 15

\[
ARUPT, LRUPT \rightarrow [A, L] \\
A \rightarrow BBANK \\
BBANK \rightarrow BBCON of KEYRUPT1
\]

Interrupt lead-in routine (not a part of KEYRUPT1)

Between interrupted routine and lead-in routine, hardware action causes BRUPT \( \rightarrow \) B and ZRUPT \( \rightarrow \) Z so that BRUPT contains instruction \( \beta \) and ZRUPT contains address \( d+2 \) of interrupted routine sequence as follows:

\[
\begin{align*}
L + 0 & \quad a (a \text{ is instruction being executed when interrupt began}) \\
L + 1 & \quad \beta (\beta \text{ is instruction to be executed first upon resuming interrupted routine})
\end{align*}
\]

The current time is saved in double precision

Key Code

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

KEYRUPT AND UPRUPT

COLOSSUS II-C

DOCUMENT NO.
FC-2150

REV
SHEET 3 OF 9
Set DSKYFLAG
Indicates that displays were sent to the DSKY.

Key Code (0-0-K)

Set bit 15 of FLAGWRD5
Control arrives here from the interrupted routine each time a character is transmitted from the ground.

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

Interrupt lead-in routine (not part of UPRUPT)

Between interrupted routine and lead-in routine, hardware action causes BRUPT ← B and ZRUPT ← Z so that BRUPT contains instruction \( \beta \) and ZRUPT contains address \( \alpha + 2 \) of interrupted routine sequence as follows:

\[ \alpha + 0 \alpha \] (\( \alpha \) is instruction being executed when interrupt began)

\[ \alpha + 1 \beta \] (\( \beta \) is instruction to be executed first upon resuming interrupted routine)

The current time is saved in double precision

\[ \text{InLINK}_{5-1} = \text{Key code in true form} \]
\[ \text{InLINK}_{10-6} = \text{Key code in complement form} \]
\[ \text{InLINK}_{15-11} = \text{Key code in true form} \]

InLINK is cleared to allow the next key code word to be processed

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

Key code (three in K-K-K arrangement)

KEYTEMP1<sub>15-6</sub> = Key code in true form
KEYTEMP1<sub>15-6</sub> = 0

Shift key code arrangement to the right 5 bit positions so that A contains the 0-K-K arrangement

Key code arranged 0-K-K will be used for second part of redundancy test.

A<sub>5-1</sub> = Key code in complement form
A<sub>15-6</sub> = Binary 111 111 111 1
From Preceding Sheet

Subroutine

UPTEST

\[ A \leftarrow A + \text{KEYTEMP1} \]

Was the key code in INLINK* equal to the complement of INLINK\(^{10-6}\)?

No

Exit via Q

Is \( A = -0 \)?

Yes

\[ A_{5-1} \leftarrow \text{KEYTEMP2}_{10-6} \]

Shift key code 5 bit positions to the right

\[ A_{15-11} = \text{Binary 11111} \]

\[ A_{10-6} = \text{Binary 11111} \]

\[ A_{5-1} = \text{INLINK*} \]

Key code in complement form

Subroutine

UPTEST

\[ A \leftarrow A + \text{KEYTEMP1} \]

Was the key code in INLINK* equal to the key code in INLINK\(^{5-1}\)?

No

TMFAIL2

Set bit 4 of FLGWRD flag

Indicates K-K test failed

Set UPLOCKFL flag

Yes

Exit via Q

Is \( A = -0 \)?

Yes

Next Sheet

RESUME

FC-2060

Resume interrupted routine

\*Original contents of INLINK when control arrived at UPRUPT
From Preceding Sheet

UPOK

Is this key code the error reset code?

No

CLUPLOCK

Clear bit 4 of
FLAGWRD7?

Clear UPLOCKFL
flag to allow
subsequent
transmissions
of key codes
from ground

Yes

ACCEPTU

Sh. 9

RESUME

Resume the interrupted routine

Note: If the transmission of a key code was not satisfactory (K-K-K failure) the UPLOCKFL flag will be set to prevent further transmission of a key until it is preceded by the transmission of an error reset code which will result in clearing the UPLOCKFL flag to allow subsequent transmissions of key codes from the ground.

Is X. Has the ground transmitted an error reset code since the last unsatisfactory key code?—Are key codes now permitted from the ground? (Is UPLOCKFL flag cleared?)

Has the ground transmitted an error reset code since the last unsatisfactory key code?—Are key codes now permitted from the ground? (Is UPLOCKFL flag cleared?)
From Sheets 4 and 8

Acceptup

Charin

Novac job
priority = 30
FC-2180

Location Charin is the beginning of program PINBALL (its entry point)
Program PINBALL executes the requests for displays from the operator (keyboard) and the ground

(MPAC # Locctr) ← Ruptreg4

Ruptreg4 = Keytemp1 and contains the key code in the 0-0-K arrangement

Resume

Resume the interrupted routine
## Major Subroutines and External Entry Points

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T4RUPT</td>
<td>Service routine which processes display requests and monitors various hardware systems</td>
</tr>
<tr>
<td>CDRVE</td>
<td>Branch of T4RUPT entered every 120 ms; executes cyclically functions listed above for T4RUPT</td>
</tr>
<tr>
<td>OPTTEST</td>
<td>Branch of CDRVE entered every 480 ms; does coarse alignment of optics shaft and trunnion</td>
</tr>
<tr>
<td>OPTMON</td>
<td>Branch of CDRVE entered every 480 ms; monitors changes in optics CDSU failure status, optics switch position</td>
</tr>
<tr>
<td>IMUMON</td>
<td>Branch of CDRVE entered every 480 ms; monitors IMU status changes</td>
</tr>
<tr>
<td>TLM</td>
<td>Monitors change in IMU temperature status</td>
</tr>
<tr>
<td>ITURNON</td>
<td>Monitors change in ISS turn-on request status</td>
</tr>
<tr>
<td>SETISSW</td>
<td>Sets ISS warning lamp as appropriate</td>
</tr>
<tr>
<td>IMUCAGE</td>
<td>Monitors change in IMU cage switch status</td>
</tr>
<tr>
<td>IMUOP</td>
<td>Monitors change in IMU operate status</td>
</tr>
<tr>
<td>TNONTEST</td>
<td>Entered from IMUMON every 480 ms; does ISS initialization if appropriate</td>
</tr>
<tr>
<td>ENDTNON</td>
<td>Ends ISS turn-on sequence</td>
</tr>
<tr>
<td>C33TEST</td>
<td>Entered from TNONTEST every 480 ms; monitors channel 33 bits 11 - 13</td>
</tr>
<tr>
<td>PIPFAIL</td>
<td>Monitors change in PIPA failure status</td>
</tr>
<tr>
<td>DNTMFAST</td>
<td>Monitors change in down telemetry speed status</td>
</tr>
<tr>
<td>UPTMFAST</td>
<td>Monitors change in up telemetry speed status</td>
</tr>
<tr>
<td>GLOCKMON</td>
<td>Entered from C33TEST every 480 ms; monitors middle IMU gimbal angle for possible gimbal lock</td>
</tr>
<tr>
<td>QUIKDSP</td>
<td>Branch of T4RUPT entered between 120 ms passes, executes display function's only</td>
</tr>
<tr>
<td>DSPOUTSB</td>
<td>Finds and processes one display request</td>
</tr>
</tbody>
</table>

### Special Conventions:
- $\oplus$ Modular subtraction
- $\oplus\ominus$ Logical "exclusive or"
- $\ominus$ Logical complement of $a$
SERVICE ROUTINE WHICH PROCESSES DISPLAY COMMANDS AND MONITORS VARIOUS SYSTEMS
ENTERED VIA HARDWARE WHENEVER TIME4 COUNTER OVERFLOWS
(AT LEAST EVERY 120 MS—OFTENER WHEN DISPLAY COMMANDS ARE PROCESSED)
SAVE REGISTERS FOR INTERRUPTED PROGRAM

ARUPT ← A
LRUPT ← L
A ← BBANK
T4RUPT

BANKRUPT ← A
QRUPT ← Q

Determine path for this pass through T4RUPT

TEST DSRUPTSW

NORMT4
QUICKDSP

SH46

FOR NORMAL (MONITOR) PASSES, DSRUPTSW AND RUPTREG1
INDICATE PRESENT POINT IN AN EIGHT-PASS CYCLE,
BY A VALUE OF 0–7
VALUE IS UPDATED HERE—UPON ENTRY TO THIS BRANCH

< 0
INTERMEDIATE DISPLAY—ONLY PASS
DISPLAY COMMAND WAS PROCESSED DURING LAST PASS THROUGH CDRVE BRANCH.
NORMAL (DISPLAY AND SYSTEM MONITOR)
BRANCH OF T4RUPT
ENTERED EVERY 120 MS

< 0 : DISPLAY TO BE DONE

TEST DSPTAB+11D

MAKE DSPTAB+11D POSITIVE; TO SHOW DISPLAY REQUEST HAS BEEN PROCESSED

NOW OUTPUT DESIRED DISPLAY:
CHANNEL 10
BITS 15-12
Determine WHICH ROW OF DISPLAY RELAYS ARE TO BE SET
BITS 11-1
Determine RELAY SETTINGS FOR THAT ROW

RETURN IF DISPLAY REQUEST PROCESSED

CHANNEL 10
BITS 15-12

DSPOUT

DSKYP SET ?

NO

NUMBER OF DISPLAY REQUESTS ?
TEST NOUT -10 > 0

A ← NOUT -1

DSPOUTS

PROCESS ONE (IF ANY) DISPLAY REQUEST
SH47

RETURN IF NO DISPLAY REQUESTS FOUND

DSRPTSW ← DSRPTSW-2400A

SET DSRPTSW (NOW 0-7) NEGATIVE SO THAT NEXT PASS THROUGH T4RUPT, WILL TAKE QUIKDBP BRANCH;
SUFFICIENTLY NEGATIVE SO THAT NEXT PASS THROUGH CDRIVE BRANCH WILL BE IN 120 MS (SEE QUIKDBP (SH44))
NOTE: DSRPTSW BIT 14 NOW CLEAR

A ← 377768

WANT T4RUPT IN 20 MS, SO SET TIME4 COUNTER 2 CSEC FROM OVERFLOW

SETTIME4

TIME4 ← A

SET TIME4 COUNTER TO OVERFLOW AT DESIRED TIME

NEXT SHEET
COARSE ALIGNMENT OF OPTICS
ENTERED EVERY 480 MS FROM T4RUPT

READ OPTICS SHAFT ANGLE (2's COMPLEMENT)
IN REV @ 2^-1

-45° ≤ SHAFT ANGLE ≤ +45° ?

CDUS/≤ ½ REV ?

YES: IN ZONE 0

NO

IF ZONE IS ALREADY NON-ZERO,
DON'T CHANGE IT

ZONE HAS SIGN CORRESPONDING TO
DIRECTION IN WHICH
SHAFT ANGLE MOVED
OUT OF THE -45° TO +45°
REGION

YES: GIVE ZONE
SIGN OF
CDUS

A ← L

ZONE ← A

CONTDRIVE

IS COARSE ALIGNMENT ENABLED?

NO

OPTIND≥ +0 ?

YES

RESUME

RETURNS CONTROL TO INTERRUPTED
PROGRAM

IS OPTICS SWITCH IN "CMG" POSITION ?

NO

SWSAMPLE≥ +0 ?

YES

RESUME

RETURNS CONTROL TO INTERRUPTED
PROGRAM

HAVE OPTICS CDU'S BEEN ZEROED SINCE LAST FRESH START?

NO

OPTMODES
BIT 10 SET?

YES

INPUT: ALARM CODE 120
(OPTICS TORQUING REQUEST WITH OPTICS CDU'S NOT
ZEROED)

ALARM
TURN ON
PROGRAM ALARM
LIGHT; SET
ALARM CODE
FC-2140

NEXT SHEET
FROM PRECEDING SHEET

INITIALIZE NUMBER OF COMMANDS TO BE SENT

SEE IF DESIRED COMMAND FOR SHAFT ANGLE MIGHT RUN INTO STOPS:
(MAGNITUDE OF SHAFT ANGLE MAY NOT BE DRIVEN TO GREATER THAN ABOUT 270°)

IS PRESENT SHAFT ANGLE IN 1ST OR 4TH QUADRANT?
(IF SO, COMMAND COULD NOT BE LARGE ENOUGH TO DRIVE ANGLE INTO STOP)

YES

CDUS/\frac{1}{4}+\frac{15}{8} \text{ REV}

NO

YES

ZONE = 0

NO

ZONE CANNOT BE ZERO IF SHAFT ANGLE IS IN 2ND OR 3RD QUADRANT

YES

IF SHAFT ANGLE CONTINUES TO INCREASE IN THE SAME DIRECTION IN WHICH IT HAS BEEN GOING, MAGNITUDE MIGHT BE APPROACHING 270°

NO

ZONE AND COMMANDO+1 HAVE SAME SIGN?

YES

IS DESIRED SHAFT ANGLE IN 1ST OR 4TH QUADRANT?
IF SO, DESIRED COMMAND WOULD RUN INTO A STOP

IN THIS CASE, MUST DRIVE ANGLE IN OPPOSITE DIRECTION SO THAT CAN EVENTUALLY (GENERALLY IN A LATER PASS) REACH DESIRED ANGLE WITHOUT RUNNING INTO STOPS

NO

DESOPTS/\frac{1}{2}+\frac{15}{8} \text{ REV}

YES

COMMANDO+1 ← (COMMANDO+1)

SO REPLACE SHAFT ANGLE COMMAND WITH ITS NEGATIVE

CMDSETUP

A ← +1

initialize index value to process shaft angle command first

NEXT SHEET
FROM PRECEDING SHEET

CMDSETUP

STORE INDEX VALUE

OPTIND ← A

0

TEST

COMMANDO#OPTIND

< 0

POSOPCMD

> 0

NEGOPCMD

MAKE SURE THAT COMMANDED NUMBER OF PULSES IS NOT GREATER THAN MAXIMUM (1650 PULSES)

NOTE: CORRESPONDING ANGLE IS ~ 0.02 REV FOR SHAFT;

~ 0.005 REV FOR TRUNNION

COMMANDO#OPTIND

≥ 1650 PULSES

NO

DELOPCMD

COMMANDO#OPTIND

< 1650 PULSES

YES

TEMP1 ← TEMPl

INCLEMENT NUMBER OF COMMANDS TO BE SENT

A ← +O

A ← 1650

A ← COMMANDO#OPTIND

A ← COMMANDO#OPTIND

A ← ~ 1650

NEXOPT

PREVENT +O COMMAND

A ← A - O

STORE COMMAND IN APPROPRIATE COUNTER

COUTCMD#OPTIND ← A

+ 1

TEST

OPTIND

A ← OPTIND - 1

HAVE DONE BOTH SHAFT AND TRUNNION COMMANDS

GO BACK AND SET UP TRUNNION COMMAND

NEXT SHEET
FROM PRECEDING SHEET

ARE THERE ANY COMMANDS TO BE SENT?

NO

TEMP1 > 0

YES

SEND CMD

SET CHANNEL 14
BITS 11,12

CAUSE TRUNNION SHAFT ANGLE COMMANDS TO BE OUTPUT FROM CDUTCMD, CDUSCMD

RESUME

RETURNS CONTROL TO INTERRUPTED PROGRAM
OPTICS MONITOR

ENTRERED EVERY 480 MS FROM T4RUPT

IS THERE A CHANGE IN OPTICS CDU FAILURE

NO

YES

SET UP RECORD OF
CHANGES FOR UPDATE
(LATER) OF OPTMODES

RUPTEST1
BIT 7 → 1
B15-B16 → 0

PROCESS
CHANGE IN OPTICS
CDU FAILURE
STATUS
SH24

RUPTEST1

33OPTMON

OPTICS COUNTERS BEING USED FOR
THRUST VECTOR CONTROL?

YES: NOT USING OPTICS

NO

RESUME

RECORD ANY CHANGE IN OPTICS
SWITCH POSITION

BIT 4 REFERS TO ZERO-OPTICS
BIT 5 REFERS TO COMPUTER CONTROL

RUPTEST1
BIT 4 ← BIT 4 OF OPTMODES
BIT 5 ← BIT 5 OF OPTMODES

UPDATE BITS 4, 5, 7 OF OPTMODES
(OPTICS CDU FAILURE STATUS, OPTICS SWITCH POSITION)

I.E.: INVERT BITS WHERE CHANGES HAVE BEEN
DETECTED

DETERMINE PRESENT POSITION OF OPTICS SWITCH

TEST
OPTMODES
OPTMODES ← RUPTEST1

10
ZERO OPTICS

(BITS 5, 4)

CMC

11
MANUAL

A ← -1
A ← +0
A ← +6

NEXT SHEET
FROM PRECEDING SHEET

SET SAMP

SET UP INDICATOR OF SWITCH POSITION:
- < 0: ZERO OPTICS
- + 0: MANUAL
- > 0: CMC

SWSAMPLE ← A

PROCESS SW

PROCESS ANY CHANGE IN SWITCH POSITION

DETERMINE WHAT SWITCH POSITION WAS AT LAST PASS (480 MS AGO)

< 0: ZERO OPTICS

TEST DESOPMOD

+ 0: MANUAL

> 0: CMC

ZOPTDES
SH13

MANUDES
SH16

C5CDES
SH21
ZOPTDES

ENTERED FROM OPTMON IF OPTICS SWITCH WAS IN "ZERO OPTICS" POSITION AT LAST PASS

WHAT IS PRESENT SWITCH POSITION?

+0: MANUAL

TEST SWSAMPLE

<0: STILL IN ZERO OPTICS MODE

RETURN IF FINISHED

ZOTOMAN SH16

<0: STILL IN ZERO OPTICS MODE

RETURN IF NOT FINISHED

ZTOCSC SH16

NOTE: WILL NOT RETURN AT ALL IF ENZOPT IS SCHEDULED

ZOPFINI

RETURN IF FINISHED

Determine whether optics zeroing finished

SH17

NO: >0

ZOPTCNT = 0?

YES: TIME TO FINISH UP OPTICS ZEROING

COUNT DOWN THROUGH ENOUGH CYCLES TO ALLOW MECHANICAL ZEROING OF OPTICS ANGLES BEFORE SYNCHRONIZING COUNTERS

ZOPTCNT ← ZOPTCNT - 1

SETZEND

SET CHANNEL 12
BIT 1

ZERO OPTICS CDU'S

ENDZOPT WAITLIST TASK IN 200 MS SH14

SET OPTMODES BIT 1

INDICATE THAT ENZOPT HAS BEEN SCHEDULED

SETDESMD SH23

T4RUPT

CDLDSUS II-A FC-2200
FINISH UP OPTICS ZEROING
SCHEDULED AS A TASK WHEN HAVING BEEN IN "ZERO OPTICS" MODE FOR SUFFICIENT TIME (≈ 15 SEC) TO ALLOW MECHANICAL ZEROING OF OPTICS ANGLES

INITIALIZE VARIABLES FOR ZERO ANGLE CONDITIONS

ZERO SHAFT ANGLE (IN REVS @ 2⁻¹)

HENCE SHAFT ANGLE ZONE MUST BE ZERO

-20° OFFSET BETWEEN VALUE MEASURED AND THAT USED IN COMPUTATIONS FOR TRUNNION ANGLE
20DEGS = 7199X2⁻¹⁷ REVS (≈ 20°) @ 2⁻³

RETURN VIA Q

ALLOW CDUS; CDUT TO RECEIVE ACTUAL OPTICS SHAFT; TRUNNION ANGLE DATA

WAIT FOR RESYNCHRONIZATION OF COUNTERS (CDUS; COUT) AND OPTICS CDU'S (COUNTERS COUNT UP TO TRUE VALUES)

OPTICS HAVE BEEN ZEROED SINCE LAST FRESH START

OPTICS ZEROING FINISHED
ALLOW OPTICS CDU FAILURE SIGNAL ENDOZOPT NO LONGER SCHEDULED

CHECK ON OPTICS CDU FAILURE STATUS
SH24

FAILURE SIGNAL INHIBIT (OPTMODES BIT 2) MAY HAVE PREVENTED SIGNAL WHEN CHECKED PREVIOUSLY, SO CHECK AGAIN.

TASKOVER
ENTERED IF OPTICS SWITCH CHANGED FROM "ZERO OPTICS" TO "MANUAL"

RETURN IF FINISHED

ZOPFINI
Determine whether optics zeroing is finished
SH17

RETURN IF NOT FINISHED

ZOPALARM
INPUT: ALARM CODE = 116 (OPTICS SWITCH CHANGED BEFORE OPTICS ZEROING FINISHED)

ALARMS
TURN ON ALARM LIGHT;
SET ALARM CODE
FC-2240

WTOPTION ← 110

IF ASTRONAUT RETURNS SWITCH TO "ZERO OPTICS" POSITION WITHIN 11 CYCLES (≈ 5 SEC),
OPTICS ZEROING MAY CONTINUE WITHOUT WAITING THE ENTIRE 32 CYCLES (≈ 15 SEC)
ALL OVER AGAIN

CANZOPT
CANCEL OPTICS ZEROING
SH17

SETDESMD
SH23

NOTE: WILL NOT RETURN AT ALL IF ENDZOPT IS SCHEDULED

T4RUPT
ENTERED IF OPTICS SWITCH CHANGED FROM "ZERO OPTICS" TO "COMPUTER" POSITION

ZOPFINI

RETURN IF FINISHED

Determine whether optics zeroing is finished

SH17

RETURN IF NOT FINISHED

NOTE: WILL NOT RETURN AT ALL IF ENDZOPT IS SCHEDULED

MANTOCSC +3

SH20

SET UP FOR COMPUTER MODE

ALARM

INPUT: ALARM CODE 116

(OPTICS SWITCH CHANGED BEFORE OPTICS ZEROING FINISHED)

(CANCEL OPTICS ZEROING)

SH17

ZERO WPTION

(50 THAT RETURN TO "ZERO OPTICS" MODE MUST INCLUDE THE WHOLE 32 CYCLE WAIT AS OPTICS MAY BE DRIVEN WHILE IN "COMPUTER" MODE)

THEN SET UP COMPUTER MODE

MANTOCSC

SH20

T4RUPT
ZOPFINI

CHECK PROGRESS OF OPTICS ZEROING

IS ENDZOPT SCHEDULED?

YES: DON'T WASTE TIME - LET ENDOZOPT GET DONE

RESUME

RETURNS CONTROL TO INTERRUPTED PROGRAM - NOW ENDOZOPT MAY INTERRUPT

OPTMODES BIT 1 SET?

NO

IS OPTICS ZEROING FINISHED?

YES

OPTMODES BIT 3 CLEAR?

RETURN VIA Q

RETURN VIA Q+1

RETURNS TO 1 LOCATION BEYOND USUAL RETURN

RETURN VIA Q

CANCEL OPTICS ZEROING

OPTMODES CLEAR

BIT 3, BIT 2

DISCONTINUE ZEROING OF OPTICS CDU'S (ENABLING COUNTERS CDU5, CDUT TO RECEIVE OPTICS SHAFT, TRUNION ANGLE DATA)

RETURN VIA Q
ENTERED FROM OPTMON IF OPTICS SWITCH WAS IN "MANUAL" POSITION AT LAST PASS

WHAT IS PRESENT SWITCH POSITION?

<0: ZERO OPTICS
>0: CMC

TEST SWSAMPLE

+0: STILL MANUAL

-0: STILL MANUAL

MANTOMAN

COUNT DOWN THROUGH DESIRED NUMBER OF CYCLES TO INDICATE IF HAVE SWITCHED TO "MANUAL" FROM "ZERO OPTICS" MODE TOO SOON; HOW LONG HAVE BEEN IN MANUAL MODE, I.E., WHETHER MORE OR LESS THAN NUMBER OF CYCLES (ELEVEN) SET IN WTOPTION WHEN ABOVE SITUATION OCCURS

WTOPTION

NO

YES

WTOPTION > 0

WTOPTION ← WTOPTION - 1

SETDESMD

SH23
Entered if optics switch changed from "manual" to "zero optics" position

Has switch been moved back to "zero" position with 11 cycles (~5 sec) due to having left this position too soon?

No! Begin optics zeroing from scratch

Yes: Don't reinitialize ZOPTCNT - let optics zeroing continue where it left off

Opt Zero

WT OPTION > 0

Init ZOPT

Set up optics zzeroing mode

SH22

ZOPTCNT -- 320

Initialize ZOPTCNT to cause a wait of 32 cycles (~15 sec) for mechanical zeroing of optics angles

Set DESMD

SH23
ENTERED WHEN OPTICS SWITCH CHANGED FROM "MANUAL" TO "CMC" POSITION OR FROM ZTOCSC (SH16)

WTOPTION ← +0

IN CASE WTOPTION WAS SET >0 TO ALLOW RETURN TO "ZERO OPTICS" MODE WITHOUT FULL DELAY, CANCEL THIS OPTION

ZOPTCNT ← +0

MANTOCSC ← +3

MAY ALSO BE ENTERED FROM ZTOCSC (SH16)

COARSLOK

HAS THERE BEEN COARSE ALIGNMENT OF OPTICS SINCE LAST FRESH START?

NO

RETURN VIA Q

YES: COARSE ALIGNMENT WAS ENABLED WHEN LAST IN "COMPUTER" MODE

OPTMODES BIT 9 SET?

RETURN VIA Q +1

OPTINO ← +1

INDICATE COARSE ALIGNMENT ALLOWED

SET BIT 2 OF CHANNEL ERROR COUNTERS

SETESMD SH23

T4RUPT
PRESENT SWITCH POSITION?

>0: STILL CMC

TEST SWSAMPLE

<0: ZERO OPTICS

CSTCZDP

INITIALIZE ZOPTCNT TO CAUSE A WAIT OF 32 CYCLES (≈ 15 SEC) FOR MECHANICAL ZEROING OF OPTICS ANGLES

INITZOPT

SET OPTICS ZEROING SH22

CSTCQMAN

IS COARSE ALIGNMENT ENABLED?

OPTIND ≥+0?

YES

CANCOARS

DISABLE COARSE ALIGNMENT OF OPTICS

OPTIND ← -1

CLEAR BIT 2 OF CHANNEL 12

CLEAR AND DISABLE OPTICS CCD ERROR COUNTERS

SET OPT MODES BIT 9

INDICATE COARSE ALIGNMENT SINCE LAST FRESH START (SO WILL RE-ENABLE COARSE ALIGNMENT WHEN RETURN TO COMPUTER MODE)

SETDESW SH23
SET UP "ZERO OPTICS" MODE

UNLESS WTOPTION IS RESET >0,
MUST BEGIN WITH FULL DELAY
IF SWITCH LEAVES AND RETURNS
TO "ZERO OPTICS" POSITION

OPTICS ZEROING IN PROGRESS
INHIBIT OPTICS CDU FAILURE SIGNAL

RETURN VIA Q
SETDESMD

COMMON END OF OPTMON BRANCHES

DESOPTION SAMPLE

UPDATE DESOPMOD TO INDICATE OPTIC SWITCH POSITION AS OF THIS PASS

RESUME

RETURNS CONTROL TO INTERRUPTED PROGRAM
IMU MONITOR
ENTERED EVERY 480 MS. FROM T4RUPT

DETERMINE BITS (OF 15-11,9) WHERE
CHANNEL 30 AND IMODES30
(RECORD OF CHANNEL 30 AT LAST PASS)
ARE DIFFERENT: THE BITS WHERE
CHANGES OCCURRED NOW CONTAIN 1'S

HAVE ANY CHANGES OCCURRED?

A ≠ 0?

NO: NONE TO PROCESS -
GO TO NEXT STEP

A ≠ 0?

YES

TNONTST
SH33

SAVE RECORD OF CHANGED BITS

IMODES30 ← IMODES30 + A

UPDATE RECORD OF IMU STATUS
BY INVERTING BITS WHERE CHANGES OCCURRED

A ← Ruptreg1

Ruptreg1 ← 1

INITIALIZE INDEX VALUE

BIT IS
OF A
SET?

NO

TLIM
SH28

HAS THERE BEEN A CHANGE IN IMU TEMPERATURE STATUS?
FROM PRECEDING SHEET

**SCAN CHANGED BITS**

RUPTRG1 ← RUPTRG1 + 1  **INCREMENT INDEX VALUES**

A ← A × 2^1  **SHIFT LEFT 1 BIT**

NO

BIT IS OF A SET?  **SINCE A ≠ 0, MUST EVENTUALLY LEAVE THIS LOOP**

YES

Now RUPTRG1 = 14D - 8,
where 8 is the (next) highest
bit (of 15-11, 9) of channel 30
where change occurred

RUPTRG2 ← RUPTRG1 - 15

SAVE RECORD OF REMAINING BIT CHANGES

A_8 IMODES 30
A_8 OTHER BIT

LOAD STATUS FLAG FOR APPROPRIATE BIT CHANGE

Q ← ADR(NXTFAIL)

SET UP APPROPRIATE RETURN FROM SETISSW

WHICH BIT CHANGE TO BE PROCESSED?

TEST

14

15, 12

11

ITURNON

6H29

SETISSW

SH30

IMUCAGE

SH31

IMUOP

SH32
ENTRY TO FIND AND PROCESS NEXT BIT CHANGE

HAVE ALL BIT CHANGES BEEN PROCESSED?
YES: GO ON TO NEXT STEP

RUPTREG2 +0

NO

A ← RUPTREG2

NXTIFBIT
SNH26

TNONTST
SNH33
ENTERED FROM IMUMON (SH25)
WHEN A CHANGE IS DETECTED IN
BIT 15 OF CHANNEL 30 (IMU TEMPERATURE STATUS)

RUPTRGREG14-1
RUPTRGREG 15

SAVE RECORD OF REMAINING BIT CHANGES

IS IMU TEMPERATURE WITHIN PROPER LIMITS?

NO

IMODES3
BIT 15
CLEAR

YES

TEMPOK

LAMPTST

IS LAMP TEST IN PROGRESS?

NO

IMODES33
BIT 1
SET?

YES

Q ← Q + 1

RETURN VIA Q

RETURN VIA Q

SET
BIT 4
OF
CHANNEL 11

TURN ON TEMP LAMP

CLEAR
BIT 4
OF
CHANNEL 11

TURN OF TEMP LAMP

NXTIFAIL
5H27

RETURN TO FIND AND PROCESS NEXT BIT CHANGE
ENTERED FROM IMUMON (SH 26) WHEN A CHANGE IS DETECTED IN BIT 14 OF CHANNEL 30 (ISS TURN-ON REQUEST STATUS)

HAS THERE BEEN A TURN-ON DELAY SEQUENCE FAILURE?

DID ISS TURN-ON REQUEST JUST COME ON?

BIT 15 OF CHANNEL 42 SET?

HAS TURN-ON DELAY COMPLETE SIGNAL BEEN GIVEN?

SET IMODES30 BIT 2

TURN-ON DELAY SEQUENCE FAILURE

INPUT: ALARM CODE = 207 (ISS TURN-ON REQUEST NOT ON FOR 90 SEC.)

ALARM TURN ON PROGRAM ALARM LIGHT; SET ALARM CODE FC-2140

RETURN TO FIND AND PROCESS NEXT BIT CHANGE
ENTERED FROM IMUMON (SH26) WHEN A CHANGE IS DETECTED IN BIT 12 OR 13 OF CHANNEL 30
ALSO CALLED BY ENDTNON (SH37) AND BY PIPFAIL (SH41) WHEN A CHANGE IS DETECTED IN BIT 13 OF CHANNEL 33

1. IF IMU FAILURE DETECTED AND FAILURE SIGNAL ALLOWED
2. IF ICUDU FAILURE DETECTED AND FAILURE SIGNAL ALLOWED
3. IF PIPA FAILURE DETECTED AND ISS WARNING FAILURE SIGNAL ALLOWED

HAVE ANY OF THESE FAILURES BEEN DETECTED, WITH ISS WARNING SIGNAL ALLOWED?

YES

A ≠ 0?

NO

A ← A - 1

SET UP ALARM CODE

ISSWON

SAVE Q IN ITEMP6

VARALARM

TURN ON PROGRAM ALARM LIGHT; SET ALARM CODE FC-2140

INPUT: A = APPROPRIATE ALARM CODE:

00777 PIPA FAILURE
03777 ICUDU FAILURE
04777 ICUDU, PIPA FAILURES
07777 IMU FAILURE
10777 IMU, PIPA FAILURES
13777 IMU, ICUDU FAILURES
14777 IMU, ICUDU, PIPA FAILURES

SET BIT 1 OF CHANNEL 11

RETURN VIA ITEMP6

ISSWOFF

LAMP TEST IN PROGRESS?

YES

IMODE33 BIT 1 SET?

NO

CLEAR BIT 1 OF CHANNEL 11

RETURN VIA Q

TURN OFF ISS WARNING LIGHT

RETURN VIA Q
ENTEREO FROM IMUMON (SH 26)
WHEN A CHANGE IS DETECTED IN
BIT 14 OF CHANNEL 30 (IMU CASE SWITCH STATUS)
WITH $A_{11} = IMODES \text{,}
A_{14-12, 10-1} = 0, 0, 0, \ldots, 0$
IMU CASE SWITCH ON?
NO
YES
CLEAR CHANNEL 14
BIT 15, 14, 13, 11, 10
INHIBIT COMMANDS
TO IMU CDU ERROR COUNTERS
TO RR/SPS ENGINE GIMBAL/OPTICS ERROR COUNTERS
FOR IMU GYRO TORQUING
CLEAR CHANNEL 12
BIT 8, 7, 6, 5, 4, 3, 2
DISABLE TVC
CLEAR AND DISABLE IMU CDU ERROR COUNTERS
DON'T ZERO IMU CDU'S
DISABLE IMU COARSE ALIGNMENT
DISABLE OPTICS ERROR COUNTERS
CLEAR BIT 13 OF CHANNEL 11
TURN OFF SPS ENGINE
CAGESUB1
SIGNAL NO ATTITUDE,
INHIBIT RELEVANT FAILURE SIGNALS,
DISABLE DAP
SH 45
RNDREFDR
CLEAR TRACKFLG
DRIFTFLG
REFSMFLG
FC-2210
TRACKING NOT ALLOWED
GYRO COMPENSATION NOT TO BE DONE
REFSMAT MATRIX INVALID
CDUXCMO ← 0
COYCMO ← 0
CDUXCMO ← 0
GYROCMO ← 0
ZERO
IMU CDU COMMAND VALUES
GYRO TORQUING COMMAND VALUE
CLEAR CHANNEL 14
BIT 9, 8, 7, 6
GYRO TORQUING COMMAND POLARITY UNSPECIFIED
NO TORQUE OUTPUT (NO AXIS)
DISABLE POWER SUPPLY FOR TORQUING PULSES
RETURN TO FIND AND PROCESS NEXT BIT CHANGE

MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

T4RUPT
COLOSSUS II-A
FC-2200

DOCUMENT NO.

SH 27
ENTERED FROM IMUMON (SH 26) WHEN A CHANGE IS DETECTED IN BIT 9 OF CHANNEL 30 (IMU OPERATE STATUS) WITH $A_9 = IMODES_{30,9}$

$A_{15-10}, B_{-1} = 0, \ldots, 0, 0, \ldots, 0$

IMU ON AND OPERATING PROPERLY?

YES

$A = 0$?

NO

SET IMODES_{33} BIT 6

DISABLE DAP

HAS ISS TURN-ON DELAY SEQUENCE FAILED?

YES: WAIT

NO: GO DIRECTLY TO INITIAPLIZE TURN-ON SEQUENCE

IMUOP2

IMODES_{33} BIT 2 SET?

TURNON2 SH 28

RNDREFD

CLEAR TRACKFLG, DRIFTFLG, REFSGFLG, FC-2240

TRACKING NOT ALLOWED SYRO COMPANSATION NOT TO BE DONE REFSSMAT MATRIX INVALID

A $B$

$A_{15-9}, 7-$

$0, 0, \ldots, 0$

SAVE OLD VALUE OF FLAG IMUSE

CLEAR IMUSE, RNDV2FLG

IMU NOT IN USE P20 NOT RUNNING

WAS IMU IN USE?

NO

YES

$A = 0$?

INPUT: ALARM CODE 214 (PROGRAM USING IMU WHEN TURNED)

ALARM TURN ON PROGRAM ALARM LIGHT; SET
ALARM CODE

FC-2140

RETURN TO FIND AND PROCESS NEXT BIT CHANGE

NXTFAIL SH 27
ISS INITIALIZATION ROUTINE ENTERED EVERY 480 MS FROM T4RUPT (VIA IMUMON) (ENTERED AT A LOWER POINT IF IMU CAGE SWITCH TURNED OFF)

HAS FIRST TURN-ON CYCLE ARRIVED?
NO

IMODES30
BIT 7
SET?
YES

HAS SECOND TURN-ON CYCLE ARRIVED?
NO: NOT YET—SET IT UP NOW

IMODES30
BIT 8
SET?
YES:
PROCEED WITH TURN-ON

S33TEST
SH38

PROCNON

CLEAR
IMODES30
BIT 7, 8

REINITIALIZE TURN-ON CYCLE FLAGS

IMODES30
BIT 14
CLEAR

HAS ISS TURN-ON BEEN REQUESTED?
NO: IMU OPERATING ONLY

IMU ON AND OPERATING PROPERLY?

IMODES30
BIT 9
CLEAR

YES

ALARM
TURN ON PROGRAM ALARM LIGHT; SET ALARM CODE FC-2140

INPUT: ALARM CODE 213
ISS TURN-ON REQUEST (WHEN IMU NOT OPERATING)

CASESUB
INITIALIZE IMU AND CORRESPONDING SIGNALS

SH45

ENDTNON
WAITLIST TASK IN 90 SECONDS

SH35

AFTER 90 SECONDS, END TURN-ON SEQUENCE
ENDTNON

TASK SCHEDULED BY TNONTEST (SH33) WHEN TURN-ON INITIATED (30 SECONDS AGO)

A ← IMODES30
SAVE OLO FLAG STATUS

CLEAR
IMODES30
BIT 2

REINITIALIZE FLAG TO INDICATE NO TURN-ON DELAY SEQUENCE FAILURE

WAS THERE A TURN-DN DELAY SEQUENCE FAILURE?

BIT 2 OF A SET?

YES

ISS TURN-ON REQUESTED?

IMODES30
BIT 14
CLEAR

RETNON

VARDELAY
WAIT
90 SECONDS

FC-2060

WILL
AND

TRY AGAIN

NO

ISS TURN-ON DELAY COMPLETE
(ALSO SETS BIT 14 OF CHANNEL 30− REMOVING ISS TURN-ON REQUEST)

FC-2210

ENDTNON
SH35

ENDTNON2

SET
BIT 15
OF
CHANNEL 12

NOATTOFF

TURN
OFF
"NO ATT"
LAMP

FC-2210

NEXT SHEET

IMU IN USE?

YES

IMUSE SET?

NO

TASKOVER

FC-2210

APOLLO
GUIDANCE AND NAVIGATION

COLOSSUS
II-A

FC-2200

DOCUMENT NO.
FROM PRECEDING SHEET

UNZ2

THIS POINT ALSO SCHEDULED BY OPONLY (SH34)

ZERO IMU
GIMBAL ANGLE
COUNTERS
FC-2210

CLEAR
CHANNEL
12
BITS 4,
5

DISABLE COARSE ALIGNMENT OF IMU
ALLOW IMU GIMBAL ANGLE COUNTERS TO RECEIVE TRUE DATA

VARDELAY
WAIT
10.24
SECONDS
FC-2060

WAIT FOR COUNTERS TO COUNT UP

ISSUP

CLEAR
IMODES30
BITS 3,
4,
6

ALLOW ICDU FAILURE SIGNAL
ALLOW IMU FAILURE SIGNAL
IMU NOT BEING INITIALIZED

CLEAR
IMODES33
BITS

ENABLE DAP

NEXT SHEET
FROM PRECEDING SHEET

SET IBW
SET
ISS WARNING
LIGHT IS NECESSARY
SH/30

ISS WARNING SIGNAL MAY HAVE BEEN INHIBITED BEFORE NOW ALLOWED

CLEAR
BIT 15
OF
CHANNEL 12

REINITIALIZE SITUATION:
ISS TURN-ON DELAY SEQUENCE NOT COMPLETE

PFAILOK
WAITLIST
TASK
IN
4 SECONDS
FC-2210

AFTER 4 SECONDS, PIPA FAILURE PROGRAM ALARM SIGNAL WILL BE ALLOWED.

TASKOVER
Monitor of Channel 33 (Bits 11-13) entered every 480 ms from T4RUPT (via IMUMON and TNONTEST)

Read old PIPA failure status, downlink speed status, uplink speed status

Read new status

Reinitialize channel bits since failures (if any) processed now

Now have 1/8 in Bits (13-11) where changes have occurred

Have there been any changes?

A ≠ 0?

Yes

GLOCKMON 5H43

Save record of which bits have changed

IMODES33 ← IMODES33 + A

Update record of present status by inverting bits where changes have occurred

A ← RUPTREG1

Initialize index value

A ← A × 2

Shift left one bit

Next sheet
FROM PRECEDING SHEET

NXTIBT +1

SCAN BITS FOR CHANGE

A → A×2↑1

SHIFT LEFT ONE BIT

NO

BIT 13 OF A SET?

YES

NXTIBT

INCREMENT INDEX VALUE

RUPTRG1 ← RUPTRG1 +1

SINCE A≠0, MUST EVENTUALLY
LEAVE THIS LOOP

RUPTRG1 = 13D - \(\gamma\),
WHERE \(\gamma\) IS THE (NEXT)
HIGHEST BIT (OF 13-11)
OF CHANNEL 33 WHERE
CHANGE OCCURRED

\(\gamma \equiv 13D \rightarrow RUPTRG1\)

SAVE RECORD OF REMAINING
BIT CHANGES

RUPTRG2[14-1] \(\rightarrow \gamma - 1\)

RUPTRG2[15] \(\rightarrow 0\)

LOAD VALUE OF ACTUAL STATUS
FOR APPROPRIATE BIT

A_\(\gamma\) ← IMODES33_\(\gamma\)

A OTHER BITS \(\rightarrow 0, ..., 0\)

WHICH BIT HAS CHANGED?

13

TEST

11

12

PIPFAIL SH41

DNTFAST SH42

UPTFAST SH42
FIND AND PROCESS REMAINING BIT CHANGES

HAVE ALL CHANGES BEEN PROCESSED?

LOAD RECORD OF REMAINING CHANGES

A ← RUPREG2

NO

RUPREG2≠0

YES

GLOCKMON

SH43

SH39

NXTB33

NXTFL33
ENTERED FROM C33TEST (SH39) WHEN A CHANGE IS DETECTED IN BIT 13 OF CHANNEL 33 (PIPA FAILURE) WITH $A_{13} = IMODE33_{13}$

$A_{15-14, 12-1} = 0, 0, 0, \ldots, 0$

HAS PIPA FAILURE OCCURRED?

YES

SET IMODE30 BIT 10

CLEAR IMODE30 BIT 10 UPDATE OTHER PIPA FAILURE FLAG APPROPRIATELY

SET ISSSW
SET ISS WARNING LIGHT IF NECESSARY

SH30

PIPA FAILURE ISS WARNING SIGNAL INHIBITED?

NO

IMODE30 BIT 1
SET?

YES - THEN SET ISSSW DID NOT TURN ON LAMP

PIPA FAILURE PROGRAM ALARM SIGNAL ALLOWED AND NOT IN FIRST OR SECOND TURN-ON CYCLE AND IMU OPERATING AND CAGING REQUESTED?

NO

IMODE30 BITS 5, 7, 8, 9, 10 ALL CLEAR?

YES

INPUT: ALARM CODE = 212
PIPA FAILURE BUT PIPAS NOT BEING USED

ALARM TURN ON PROGRAM ALARM LIGHT; SET ALARM CODE FC-2140

RETURN TO FIND AND PROCESS REMAINING CHANGES.
ENTERED FROM C33TEST (SH39) WHEN A CHANGE IS DETECTED IN
BIT 12 OF CHANNEL 33 (DOWN TELEMETRY)
WITH $A_{12} = 100\ldots0,
A_{15-13,11-1} = 0;\ldots,0,0;\ldots,0$
DOWN TELEMETRY TOO FAST?

NO

A = 0? YES

ALARM
TURN ON
PROGRAM ALARM
LIGHT; SET
ALARM CODE
FC-2140

INPUT: ALARM CODE = 1105

RETURN TO FIND AND PROCESS
REMAINING CHANGES

ENTERED FROM C33TEST (SH39) WHEN A CHANGE IS DETECTED IN
BIT 11 OF CHANNEL 33 (UP TELEMETRY)
(SPEED STATUS)
WITH $A_{11} = 100\ldots0,$
$A_{15-12,10-1} = 0;\ldots,0,0;\ldots,0$

NO

A = 0? YES

ALARM
TURN ON
PROGRAM ALARM
LIGHT; SET
ALARM CODE
FC-2140

INPUT: ALARM CODE = 1106

RETURN TO FIND AND PROCESS
REMAINING CHANGES (NONE AT THIS POINT)
MIDDLE IMU GIMBAL ANGLE MONITOR (CHECKS FOR POSSIBLE GIMBAL LOCK) ENTERED EVERY 480 MS FROM T4RUPT (VIA IMUMON, TNONTST, AND C3STST)

MIDDLE IMU GIMBAL ANGLE = 0 ?

YES COUZ=0 ?

NO GLOCKCHK

YES |CDUZ| < 15 REV

-70DEGS 
-50DEGS 

NO MIDDLE IMU GIMBAL ANGLE ≤ 70.04° IN MAGNITUDE ?

(-70DEGS = -70° IN REV $@ 2^{-1}$)

|CDUZ| > 15 REV

-70DEGS
-15DEGS
-20 DEGS

NO: APPROACHING GIMBAL LOCK

YES MIDDLE IMU GIMBAL ANGLE ≤ 85.007° IN MAGNITUDE ?

(-15DEGS = -15° IN REV $= 1/3 \times 2^{-15} \text{REV} @ 2^{-1}$)

YES: JUST SIGNAL MGA > 70° — DON'T REALIGN IMU YET

NO: COARSE ALIGNMENT ENABLED ?

BIT 4 OF CHANNEL 12 SET ?

NO SETCOARS

SET UP COARSE ALIGNMENT OF IMU FC-2210

CA+FCE WAITLIST TASK IN .06 SEC FC-2210

AFTER 60 MS; WILL REENABLE IMU CDU ERROR COUNTERS

WANT GIMBAL LOCK LIGHT OFF

A 0

WANT GIMBAL LOCK LIGHT ON

A 1

NEXT SHEET
FROM PRECEDING SHEET

SETGLCK

GIMBAL LOCK LAMP ALREADY SET AS DESIRED?

YES

BIT 6 OF DSPTAB+11D SAME AS BIT 6 OF A?

NO

GIMBAL LOCK LAMP NOW ON?

YES

NO

BIT 6 OF DSPTAB+11D SET?

GLAMPTST

IMU BEING INITIALIZED?

NO

IMODES30 BIT 6 SET?

YES

GLINVERT

RETURN IF NOT IN PROGRESS

RETURN IF TEST IN PROGRESS

REQUEST PROPER (REVERSE) SETTING OF GIMBAL LOCK LAMP CAUSE REQUEST TO BE PROCESSED

RESUME

RETURNS CONTROL TO INTERRUPTED PROGRAM
ENTRY CALLED BY TNONTEST (SH33)

CLEAR CHANNEL 12 BIT 6, 15
CLEAR AND DISABLE IMU CDU ERRDR COUNTERS 153 TURN-ON DELAY NOT DND

SET CHANNEL 12 BIT 4, 5
ENABLE COARSE ALIGNMENT OF IMU ZERO IMU CDU'S

ENTRY CALLED BY IMUCAGE (SH31)

REQUEST "NO ATT" LIGHT TURN-ON CAUSE REQUEST TO BE PROCESSED

ENTRY CALLED BY COPONLY (SH34)

SET IMODES30 BIT 5
INHIBIT PIPA FAILURE 153 WARNING SIGNAL INHIBIT ICDU FAILURE SIGNAL
INHIBIT IMU FAILURE SIGNAL INHIBIT PIPA FAILURE PROGRAM ALARM SIGNAL
IMU BEING INITIALIZED

SET IMODES33 BIT 6
DISABLE DAP

RETURN VIA Q
FIND AND PROCESS ONE DISPLAY REQUEST

STORE UPDATED (DECREMENTED) VALUE FOR NUMBER OF DISPLAY REQUESTS WAITING

INITIALIZE INDICATOR TO SIGNAL FIRST PASS

DSPCNT IS INDEX VALUE (0-10D) POINTING TO CURRENT PLACE IN DISPLAY REQUEST TABLE

PREVENT +O VALUE

STORE CURRENT INDEX VALUE

SCAN DISPLAY TABLE

DOES THIS ENTRY REQUIRE SERVICING?

DISPLAY 5H4B

DPSTAB #DSPCNT < 0?

YES

NO

HAVE REACHED END OF TABLE

TEST DSPCNT

> 0

DECIMENT INDEX VALUE

A ← DSPCNT - 1

< 0

2ND PASS

NO DISPLAY REQUESTS HAVE BEEN FOUND

VALUE FOR CHANNEL 10 OUTPUT

A ← +O

INDICATE NO DISPLAY REQUESTS TO BE PROCESSED

NOUT ← +O

RETURN VIA Q

2ND PASS

NO DISPLAY REQUESTS HAVE BEEN FOUND

VALUE FOR CHANNEL 10 OUTPUT

A ← +O

SET INDEX VALUE TO BEGIN AT END OF DISPLAY TABLE

DSPCNT ← 0

1ST PASS

DSPUCT ← +0

NOW
PROCESS DISPLAY REQUEST FOUND BY DSPSCAN

MAKE TABLE ENTRY NONNEGATIVE TO SHOW REQUEST HAS BEEN PROCESSED

DSRCTAB #DSPCNT

DSRCTAB #DSPCNT

MAKE OUT BITS 11-1, WHICH GIVE DESIRED DISPLAY RELAY SETTINGS FOR ONE ROW (OF RELAYS)

DSRUPTEM

BITS 15-12

BITS 0

BITS 11-1

BITS 11-1

OUTPUT DISPLAY COMMAND VIA CHANNEL 10

BITS 15-12 SPECIFY RELAY ROW

BITS 11-1 SPECIFY SETTINGS FOR RELAY IN THAT ROW

CHANNEL 10

RELTAB #DSPCNT

RELTAB #DSPCNT

RETURN VIA Q+1

RETTURNS TO 2 LOCATIONS BEYOND SUBROUTINE CALL
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALARM</td>
<td>FC-2140</td>
<td>TURN ON PROGRAM ALARM LIGHTS; SET ALARM CODE</td>
<td>SH.6,15, 16,29,32, 33,41,42</td>
</tr>
<tr>
<td>CA+ECE</td>
<td>FC-2210</td>
<td>ENABLE IMU CDU ERROR COUNTERS</td>
<td>SH.43</td>
</tr>
<tr>
<td>IMUBAD</td>
<td>FC-2210</td>
<td>ERROR END OF IMU TASK</td>
<td>SH.35</td>
</tr>
<tr>
<td>NOATTOFF</td>
<td>FC-2210</td>
<td>TURN OFF &quot;NO ATT&quot; LAMP</td>
<td>SH.34,35</td>
</tr>
<tr>
<td>PFAILOK</td>
<td>FC-2210</td>
<td>ALLOW PROGRAM ALARM IN CASE OF PIPA FAILURE</td>
<td>SH.37</td>
</tr>
<tr>
<td>PROKEY</td>
<td>FC-2160</td>
<td>PROCESS ASTRONAUT'S &quot;PROCEED&quot; SIGNAL</td>
<td>SH.5</td>
</tr>
<tr>
<td>RNDREFDR</td>
<td>FC-2210</td>
<td>CLEAR TRACKFLG (NO TRACKING), DRIFTFLG (NO GYRO COMPENSATION), REFSMFLG (REFSMAT MATRIX INVALID)</td>
<td>SH.31,32</td>
</tr>
<tr>
<td>SETCOARS</td>
<td>FC-2210</td>
<td>SET UP COARSE ALIGNMENT OF IMU</td>
<td>SH.43</td>
</tr>
<tr>
<td>VARALARM</td>
<td>FC-2140</td>
<td>TURN ON PROGRAM ALARM LIGHT; SET ALARM CODE</td>
<td>SH.30</td>
</tr>
<tr>
<td>ZEROICDU</td>
<td>FC-2210</td>
<td>ZERO IMU GIMBAL ANGLE COUNTERS</td>
<td>SH.34,36</td>
</tr>
</tbody>
</table>

**FLAGS**

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRIFTFLG FLAGWR12</td>
<td>T3RUP CALLS GYRO COMPENSATION</td>
<td>T3RUP DOES NO GYRO COMPENSATION</td>
<td>SH.31,32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAGWR12 BIT 15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSKYFLAG FLAGWRD5</td>
<td>DISPLAY SENT TO DSKY</td>
<td>NO DISPLAY SENT TO DSKY</td>
<td></td>
<td>SH.4</td>
<td></td>
</tr>
<tr>
<td>FLAGWRD5 BIT 15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DISRUPTSW BIT 14</td>
<td>DISPLAY RELAYS TURNED OFF LAST PASS THROUGH T3RUP</td>
<td>DISPLAY DONE AT LAST PASS - TURN OFF RELAYS</td>
<td>SH.46</td>
<td>SH.4,46</td>
<td>SH.46</td>
</tr>
<tr>
<td>IMODES30 BIT 1</td>
<td>PIPA FAILURE NOT TO CAUSE ISS WARNING</td>
<td>PIPA FAILURE SIGNAL ALLOWED</td>
<td>SH.45</td>
<td>SH.30,41</td>
<td></td>
</tr>
<tr>
<td>IMODES30 BIT 2</td>
<td>ISS DELAY-SEQUENCE FAILURE</td>
<td>NO ISS DELAY-SEQUENCE FAILURE</td>
<td>SH.28</td>
<td>SH.35</td>
<td>SH.28,32,33</td>
</tr>
<tr>
<td>IMODES30 BIT 3</td>
<td>ICDU Failure SIGNAL INHIBITED</td>
<td>ICDU Failure SIGNAL ALLOWED</td>
<td>SH.45</td>
<td>SH.36</td>
<td>SH.30</td>
</tr>
<tr>
<td>IMODES30 BIT 4</td>
<td>IMU Failure SIGNAL INHIBITED</td>
<td>IMU Failure SIGNAL ALLOWED</td>
<td>SH.45</td>
<td>SH.36</td>
<td>SH.30</td>
</tr>
<tr>
<td>IMODES30 BIT 5</td>
<td>PIPA Failure NOT TO CAUSE PROG ALARM</td>
<td>PIPA Failure SIGNAL ALLOWED</td>
<td>SH.45</td>
<td>SH.31</td>
<td></td>
</tr>
<tr>
<td>IMODES30 BIT 6</td>
<td>IMU NOT BEING INITIALIZED</td>
<td>IMU NOT BEING INITIALIZED</td>
<td>SH.45</td>
<td>SH.36</td>
<td>SH.44</td>
</tr>
<tr>
<td>IMODES30 BIT 7</td>
<td>FIRST ISS TURN-ON CYCLE HAS ARRIVED</td>
<td>FIRST ISS TURN-ON CYCLE HAS NOT ARRIVED</td>
<td>SH.28</td>
<td>SH.33</td>
<td>SH.33,41</td>
</tr>
<tr>
<td>IMODES30 BIT 8</td>
<td>SECOND ISS TURN-ON CYCLE HAS ARRIVED</td>
<td>SECOND ISS TURN-ON CYCLE HAS NOT ARRIVED</td>
<td>SH.33</td>
<td>SH.33</td>
<td>SH.33,41</td>
</tr>
<tr>
<td>NAME</td>
<td>MEANING WHEN SET</td>
<td>MEANING WHEN CLEAR</td>
<td>WHERE SET</td>
<td>WHERE CLEARED</td>
<td>WHERE TESTED</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------</td>
<td>--------------------</td>
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<td>---------------</td>
<td>--------------</td>
</tr>
<tr>
<td>IMODES30 BIT 9</td>
<td>ISS NOT OPERATING</td>
<td>ISS OPERATING</td>
<td>SH, 25</td>
<td>SH, 25</td>
<td>SH, 32, 33, 41</td>
</tr>
<tr>
<td>IMODES30 BIT 10</td>
<td>NO PIPA FAILURE</td>
<td>PIPA FAILURE</td>
<td>SH, 41</td>
<td>SH, 41</td>
<td>SH, 30, 41</td>
</tr>
<tr>
<td>IMODES30 BIT 11</td>
<td>IMU CAGE NOT REQUESTED</td>
<td>IMU CAGE REQUESTED</td>
<td>SH, 25</td>
<td>SH, 25</td>
<td>SH, 31</td>
</tr>
<tr>
<td>IMODES30 BIT 12</td>
<td>NO ICDU FAILURE</td>
<td>ICDU FAILURE</td>
<td>SH, 25</td>
<td>SH, 25</td>
<td>SH, 30</td>
</tr>
<tr>
<td>IMODES30 BIT 13</td>
<td>NO IMU FAILURE</td>
<td>IMU FAILURE</td>
<td>SH, 25</td>
<td>SH, 25</td>
<td>SH, 30</td>
</tr>
<tr>
<td>IMODES30 BIT 14</td>
<td>ISS TURN-ON NOT REQUESTED</td>
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<td>CDU5CMDC (CDUTCMDC+1)</td>
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<td>CDUT</td>
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<td>CDUTCMD</td>
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<td>CDUXCMD</td>
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<td>AGC SCALING</td>
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<td>CDUZCMD</td>
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<td>DESOPMOD</td>
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<td>INDICATES WHETHER OPTICS SWITCH WAS IN CMC, MANUAL, OR ZERO POSITION (BY POSITIVE, 0, OR NEGATIVE VALUE, RESPECTIVELY) AT LAST PASS THROUGH OPTMOD</td>
<td>DEGREES</td>
<td>REVS</td>
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<tr>
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<tr>
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<td>DEGREES</td>
<td>REVS</td>
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<td>LRUPT</td>
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<td>TEMPORARY STORAGE FOR L (ABOVE) DURING INTERRUPT</td>
<td>DEGREES</td>
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<tr>
<td>NOUT</td>
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<td>NUMBER OF OUTPUT DISPLAY REQUESTS TO BE PROCESSED</td>
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<td>OPTIND</td>
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<td>INDICATES WHETHER COARSE ALIGNMENT OF OPTICS MAY BE PERFORMED OR NOT, BY VALUE X+0 OR X-0, RESPECTIVELY, IF X+0, +1 INDICATES SHAFT ANGLE IS UNDER CONSIDERATION, AND +0 INDICATES TRUNNION ANGLE IS UNDER CONSIDERATION. IF X-0, -1 INDICATES OPTICS NOT BEING USED AS OPTICS ERROR COUNTERS ARE BEING USED FOR THRUST VECTOR CONTROL, AND X-0 MERELY ENABLES COARSE ALIGNMENT.</td>
<td>DEGREES</td>
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<tr>
<td><strong>TAG</strong></td>
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<td>SWSAMPLE</td>
<td>SWSAMPLE</td>
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<td>COUNTER WHICH CONTROLS TIMING OF T4RUPT</td>
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<td>NUMBER OF 480 MS CYCLES WITH OPTICS IN MANUAL MODE BEFORE A CHANGE TO ZERO MODE WOULD REQUIRE THE FULL INITIALIZATION DELAY</td>
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<td>2^14</td>
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<td>ZONE</td>
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<td>INDICATES WHETHER MAGNITUDE OF OPTICS SHAFT ANGLE IS &lt; 45° (IF SO, ZONE = 0) AND IF NOT, IN WHICH DIRECTION SHAFT ANGLE LEFT THAT REGION (BY POSITIVE OR NEGATIVE VALUE).</td>
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<td>ZOPTCNT</td>
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<td>PIPA FAILURE</td>
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<td>IMU CDU ERROR COUNTERS CLEARED AND DISABLED</td>
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<td>IMU GYRO TORQUING COMMAND TRANSMITTED</td>
<td>IMU GYRO TORQUING COMMAND INHIBITED</td>
<td>SH, 31</td>
<td>SH, 31</td>
<td>SH, 31</td>
</tr>
<tr>
<td>BIT 2</td>
<td>IMU GYRO TORQUING COMMAND TRANSMITTED</td>
<td>IMU GYRO TORQUING COMMAND INHIBITED</td>
<td>SH, 31</td>
<td>SH, 31</td>
<td>SH, 31</td>
</tr>
<tr>
<td>BIT 1</td>
<td>IMU GYRO TORQUING COMMAND TRANSMITTED</td>
<td>IMU GYRO TORQUING COMMAND INHIBITED</td>
<td>SH, 31</td>
<td>SH, 31</td>
<td>SH, 31</td>
</tr>
<tr>
<td>CHANNEL BITS</td>
<td>MEANING WHEN SET</td>
<td>MEANING WHEN CLEAR</td>
<td>WHERE SET</td>
<td>WHERE CLEARED</td>
<td>WHERE TESTED</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------</td>
<td>--------------------</td>
<td>-----------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>CHANNEL 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIT 2</td>
<td>OPTICS ERROR COUNTERS ENABLED</td>
<td>OPTICS ERROR COUNTERS DISABLED</td>
<td>SH. 7,20</td>
<td>SH. 21,31</td>
<td>SH. 7</td>
</tr>
<tr>
<td>BIT 1</td>
<td>ZERO OPTICS CDU'S</td>
<td>OPTICS ANGLE COUNTERS MAY RECEIVE DATA</td>
<td>SH. 13</td>
<td>SH. 14,17</td>
<td></td>
</tr>
<tr>
<td>CHANNEL 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIT 13</td>
<td>SPS ENGINE ON</td>
<td>SPS ENGINE OFF</td>
<td></td>
<td>SH. 31</td>
<td></td>
</tr>
<tr>
<td>BIT 4</td>
<td>TEMP LIGHT ON</td>
<td>TEMP LIGHT OFF</td>
<td></td>
<td>SH. 28</td>
<td>SH. 30</td>
</tr>
<tr>
<td>BIT 1</td>
<td>ISS WARNING LIGHT ON</td>
<td>ISS WARNING LIGHT OFF</td>
<td>SH. 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHANNEL 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BITS 15-12</td>
<td>SPECIFY RELAY ROW FOR DSKY LIGHTS</td>
<td></td>
<td>SH. 4,48</td>
<td>SH. 4,48,48,48</td>
<td></td>
</tr>
<tr>
<td>BITS 11-1</td>
<td>SPECIFY SETTING OF RELAYS OF ROW DETERMINED BY BITS 15-12</td>
<td></td>
<td>SH. 4,48</td>
<td>SH. 4,48,48,48</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: IF CHANNEL 10 BITS 15-1 ALL CROSSED AND ALL DISPLAY RELAYS TURNED OFF (THIS DOES NOT TURN OFF THE LIGHTS)
P06 GNCS Power Down

SCALPREP  Sh. 7
POSTAND  Sh. 4
The function of the P06 routine is to set up and execute (via GOPERF1) a CMC STANDBY. P06 also gives a time counter update after the STANDBY execution.

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

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

Incompatibility error return to PRESTAND

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

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

Put old TIME1, TIME2 into MPAC and store scaler.
From Preceding Sheet

Clear TRACKFLG
REFSMFLG
DRIFTFLG

Bit 6, FLAGWRD1
Inhibit tracking.
Bit 13, FLAGWRD3
REFSMMAT is no good.
Bit 15, FLAGWRD2
Inhibit gyro compensation.
Accomplished via
BANKCALL to RNDREFDR

Clear IMUSE
RNDVZFLG

Bit 8, FLAGWRD0
IMU not in use.
Bit 7, FLAGWRD0
P20 not running.
Accomplished via subroutine
DOWNFLAG.

Set bit 1 of
channel 13

GROUP 4
Set up
POSTAND as
Job with
priority 20
after restart

Request performance of CMC Standby
(Verbs 32, 33, 34 not relevant)

V32, V33, V34

GOPERFL
V50 N25
R1 = 00062

Proceed

STANDBY ENABLE DISCRETE

Next Sheet
POSTAND recovers the time after STANDBY and
snapshots the scaler while setting TIME1, TIME2;
insures compatibility between the scaler reading and
the clearing of the time counter. POSTAND then
computes the d.p. difference in scaler values and
increments the previously snapshotted values TIME1,
TIME2 by the difference. The updated result is then
placed into the time counters.

Clear STANDBY ENABLE bit
From Preceding Sheet

Inhibit Interrupts

TIME1_D ← ZERO

SCALPREP

Scale times and time interval

Sh. 6

MPAC_D ← SCALSAV_D

A ← BIT10

SHORTMP

Multiply a t.p. number by a s.p. number with a t.p. result

FC-2090

MPAC +2 ← ZERO

TPAGREE

Make the sign difference agree

FC-2090

Next Sheet

Clear TIME1, TIME2 clocks.

Inputs: See Sh. 1

Outputs: See Sh. 1

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

Align bits with TIME1, TIME2

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

Output: The triple precision quotient in MPAC

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

Is MPAC > 0? [Yes/No]

If yes, clear NODOFLAG, flag WRD2, permit V37 via reset NODOFLAG.

If no, if double precision difference net is positive, there is no scaler overflow between pre- and post-STANDBY times.

MPAC\(_D\) ← MPAC\(_D\) + BIT10

Contents of MPAC +1 is the magnitude of the time increment's scaler.

POSTCOM

If the difference net is negative scaler overflowed. To correct, add 01000\(_8\) to high order part of the difference.

MPAC\(_D\) ← MPAC\(_D\) + TIME2SAV\(_D\)

Fetch and add pre-STANDBY time.

TPAGREE

Make the sign difference agree

FC-2090

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

TIME2\(_D\) ← MPAC\(_D\) + TIME2\(_D\)

Update value of time counter.

Clear NODOFLAG

Bit 1, FLAGWRD2

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

Save return address in third cell in MPAC.

Input: Return address.

Output: Readings from computer clock in A, L.

Put times into MPAC.

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

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

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

Exit via address in MPAC +2.
### FLAGS

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>NODOFLAG</td>
<td>V37 not permitted</td>
<td>V37 permitted</td>
<td>Sh. 2</td>
<td>Sh. 6</td>
<td></td>
</tr>
<tr>
<td>TRACKFLG</td>
<td>Tracking allowed</td>
<td>Tracking not Allowed</td>
<td></td>
<td>Sh. 3</td>
<td></td>
</tr>
<tr>
<td>REFSMFLG</td>
<td>REFSMMAT good</td>
<td>REFSMMAT no good</td>
<td>Sh. 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRIFTFLG</td>
<td>T3RUPT calls gyrocompensation</td>
<td>T3RUPT does no good</td>
<td>Sh. 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMUSE</td>
<td>IMU in use</td>
<td>IMU not in use</td>
<td>Sh. 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RNDVZFLG</td>
<td>P20 running</td>
<td>P20 not running</td>
<td>Sh. 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Where Flowed</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOPERF1</td>
<td>FC -2130</td>
<td>Perform CMC Standby</td>
<td>Sh. 3</td>
</tr>
<tr>
<td>SHORTMP</td>
<td>FC -2090</td>
<td>Multiplies a triple precision number by a single precision number with a t. p. result.</td>
<td>Sh. 5</td>
</tr>
<tr>
<td>TPAGREE</td>
<td>FC -2090</td>
<td>Makes sign difference of two numbers agree.</td>
<td>Sh. 5, 6</td>
</tr>
<tr>
<td>FINETIME + 1</td>
<td>FC -2210</td>
<td>Read computer clock time pulses</td>
<td>Sh. 7</td>
</tr>
</tbody>
</table>
IMU EXTENDED VERBS

VBZERO Sh. 2
VBCOARK Sh. 4
IMUFINEK Sh. 8
VBZERO

OP/INERT

A<-2478+NOUNREG

No, NOUN 91; A=71
Q - Q + 1 Increment Q for return

A-A + OPIMDIFF A now = 0

Test A
40 illegal
= 0 via XACTOQ

CKMODCAD
Sh. 3
Is MODECADR in use?

IMUZEROK

via XACTOQ (FC-2520)

ALM/END
FC-2190

Turn on operator error light and go to PINBRNCH (FC-2130)

Next Sheet
From Preceding Sheet

via BANKCALL

GOXDSPF

Display Flashing

V25 N22

THETAD:

CDU degrees

xxx.xx degrees

Terminate

Proceed or
Enter

ICORK2

TERMEXTV ( = ENDEXT )

via BANKCALL

EXDSPRF

Re-display coarse
align verb ( V41 )

Marking display

V41 N00

via BANKCALL

IMUCOARS

IMU

coarse align

FC-2210

via BANKCALL

IMUSTALL

Allow time
for data
transfer

FC-2210

ENDEXTVB ( = ENDEXT )
IMUFINEK

CKMODCAD
Is MODECADR in use?
Sh. 3

Yes

TESTXACT
Is extended verb display system in use?
FC-2190

No

ALM/END
FC-2190

via BANKCALL

GOXDSPE
Display Flashing
V25 N93

Delta gyro angles:
\{ R1 \}
\{ R2 \}
\{ R3 \}  xx, xxx deg.

Terminate

Proceed or Enter

via BANKCALL

EXDSPRET
Marking display
V42 N00

Next Sheet
From Preceding Sheet

**IMUFINE**
IMU fine align mode switch
FC-2210

via BANKCALL

**IMUSTALL**
Is I/O complete and good?
FC-2210

via BANKCALL

No, complete but not good

ENDEXTVB

Yes

**PINEK2**

A - ECADR(OGC)

via BANKCALL

**IMUPULSE**
Torque IRIG's according to d.p. inputs in 6 registers beginning at ECADR arriving in A; OGC, IGC MGC
FC-2210

via BANKCALL

**IMUSTALL**
Wait for pulses to get out
FC-2210

ENDEXTVB
## SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Where Flowed</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALARM</td>
<td>FC-2140</td>
<td>Light program alarm light</td>
<td>6, 7</td>
</tr>
<tr>
<td>ALM/END</td>
<td>FC-2190</td>
<td>Turn on operator error light and return via PINBRNCH (FC-2130)</td>
<td>2, 3, 4, 6, 8</td>
</tr>
<tr>
<td>FALTON</td>
<td>FC-2180</td>
<td>Turn on operator error light</td>
<td>6</td>
</tr>
<tr>
<td>IMUCOARS</td>
<td>FC-2210</td>
<td>IMU coarse align mode switch</td>
<td>5</td>
</tr>
<tr>
<td>IMUFINE</td>
<td>FC-2210</td>
<td>IMU fine align mode switch</td>
<td>9</td>
</tr>
<tr>
<td>IMUPULSE</td>
<td>FC-2210</td>
<td>Torque IRIG's</td>
<td>9</td>
</tr>
<tr>
<td>MUSTALL</td>
<td>FC-2210</td>
<td>Delays further execution of the calling routine until its selected I/O function is complete</td>
<td>3, 5, 9</td>
</tr>
<tr>
<td>IMUZERO</td>
<td>FC-2210</td>
<td>Zero IMU CDU angles</td>
<td>3</td>
</tr>
<tr>
<td>TESTXACT</td>
<td>FC-2190</td>
<td>Test extended verb display system</td>
<td>4, 6, 8</td>
</tr>
</tbody>
</table>

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

<table>
<thead>
<tr>
<th>MIT INSTRUMENTATION LAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAWN:</td>
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<tr>
<td>PROGRN:</td>
</tr>
<tr>
<td>ANALST:</td>
</tr>
<tr>
<td>DOCMR:</td>
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<tr>
<td>APPR'D:</td>
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</table>

APOLLO GUIDANCE AND NAVIGATION

<table>
<thead>
<tr>
<th>IMU Extended Verbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLOSSUS 2D</td>
</tr>
<tr>
<td>DOCUMENT NO.</td>
</tr>
<tr>
<td>FC-2235</td>
</tr>
</tbody>
</table>

REV SHEET 10 OF 10
ENCLOSED IS A REPLACEMENT SHEET TO UPDATE THE COLOSSUS II FLOWCHART FC-2240, REV. 0, TO THE COLOSSUS IIIC FLOWCHART FC-2240, REV. 1.

EFFECTIVE SHEETS FOR THE COLOSSUS IIIC FLOWCHART FC-2240, REV. 1, ARE:

SH. 1
REV. 1

SH. 2-9
REV. 0
SXTMARK is called from internal routines which may require star or landmark markings by the astronaut. If the mark system is not in use, SXTMARK reserves a vac area for marking and requests execution of the MKVB31 routine via the executive job priority list. P21 uses this routine to determine if the mark system can be used.

STORE NO OF MARKS REQUESTED IN RUPTRG1

IS EXTENDED VERB OR MARKING SYSTEM IN USE?

**YES** - ABORT

**NO**

SET EXTQBACT

SET MARKING SYSTEM IN USE

BAILOUT

31211

FC-2140

MARKOK

FIND VACANT AREA

VAC1USE +1

VAC2USE +1

VAC3USE +1

VAC4USE +1

VAC5USE +1

NO VAC AREAS AVAILABLE FOR MARKS

NEXT SHEET

BAILOUT

31207

FC-2140
FROM PRECEDING SHEET

MARKSTAT ← A+2
QPRET ← A+2
-1(MARKSTAT) ← 0

VAC AREA ADDRESS
VAC AREA POINTER VALUE
1ST WORD SET TO +0
(VAC AREA OCCUPIED)

CHECKHM
MODREG ← 53

IS BACKUP MARKING PROGRAM (P53) OPERATING?
YES → BACKUP

CHECKHM
MODREG ← 54

IS BACKUP MARKING PROGRAM (P54) OPERATING?
YES → BACKUP

MARKSTAT ← MARKSTAT + BIT12 × RUP T REG1
ADD NO. OF MARKS REQUESTED (VAC AREA ADDR AND MARK VALUE)

MKVB51
NOVAC PRIORITY 52

REQUEST THAT MKVB51 BE PLACED ON PRIORITY LIST FOR JOB EXECUTION

RELINT

SWRETURN

MIT INSTRUMENTATION, AE
CAMBRIDGE, MA 01380

COLOSSUS II C

SXT MARK

FC-2240
This routine is executed by internal routines to release the Mark system to make it available to other internal system routines. It also clears the coarse optics flag bit and disables the optics error counter.

1st word of Vac area set to Vac address to signify availability
Clear Markstat

\[ \text{MKRELEASES} \]

\[ \text{MARKSTAT} \rightarrow +0 \]

\[ \text{MKRELEASES} \]

\[ \text{INHINT} \]

\[ \text{CLEAR OPTMODES (BIT2)} \]

\[ \text{OPTIND}=1 \]

\[ \text{CLEAR CH2 (BIT2)} \]

\[ \text{RELINT} \]

\[ \text{return via swreturn} \]
MARKRUPT stores CDUs, optics, and time and transfers control to the MARKIT, MKREJECT, or KEYCOM routines if required bits in channel 16 are set.

STORE optics, CDUs, and time

TEST bit 6 of channel 16 for mark

MARK key (bit 6) set

TEST bit 7 of channel 16 for mark reject

MARK key (bit 7) set

KEYCALL

TEST bit 1-5 of channel 16 for keycode

MARK key (bits 1-5) set

ALARM

NO INBTS

113

RESUME

 INTERRUPT is not a mark, mark reject, or keycode

EXIT FROM MARKRUPT via RESUME
MARKCONT is used to perform a special mark function for R21, to execute a special display of optics and time or to perform a mark of a star or land sightings based upon flashing V-N.

Yes - Special marking for R21

No - Regular marking

MARKIT1

GENTRAN

Input: MRKBUF1

Transfer data

Output: MRKBUF2

GENTRAN

Input: MKT 2+1

Transfer data

Output: MRKBUF1

Taskover

Have marks been called for?

Yes

MARKSTAT set?

No

MARK 2

No

EXTMARK (BIT) set?

Yes

MARK SYSTEM IN USE?

IS MARK SYSTEM IN USE?

Yes

IS MARK SET?

No

MARKDP

NOVA C priority 5

Go to NOVA C routine to request job execution of MARKDP calibration mark set for R2S special display job

Parameter for GENTRAN

MARKS

Alarm

122

MARKING NOT called for

Taskover

IS CALIBRATION MARK SET?

NO

V59FLAG set?

Yes

Parameter for GENTRAN

Transfer +1 words of data

A ← 6

Parameter for GENTRAN

Transfer +1 words of data

Input: MKTET1 = 1ST word to be transferred

MARKDOWN = 1ST word to be transferred to

Input: MKTET1 = 1ST word to be transferred

MRKBUF1 = 1ST word to be transferred to

Taskover

A ← 6

Taskover
TRANSFER REQUESTED MARK DATA FROM
INPUT BUFFERS TO TEMPORARY STORAGE
AND INCREMENT COUNTER

ARE MARKS WANTED?

YES - MARK WANTED
SET MARKSTAT
BIT 10
ENABLE REJECT

NO

114 ALM
ALARM
114
MARK NOT WANTED
TASKOVER

ITEM1
ITEM2
QPRET MARKSTAT BIT 1-9
QPRET(ITEM1) → ITEM2+7

SAVE CURRENT MARK SLOT-POINTER
INCREMENT POINTER

VACSTOR

0ITEM2 → MKT2+1
1ITEM2 → MKCDUY
2ITEM2 → MKCDUS
3ITEM2 → MKCDU3
4ITEM2 → MKCDUX
5ITEM2 → MKCDU2
6ITEM2 → MKCDUX

ANYMORE MARKS REQUESTED?

NO

MARKSTAT
BIT 10-14
2111

YES

MKV50
NOVAK
PRIORITY 50

ADDITIONAL MARKS NOT REQUESTED.
GO TO NOVAC TO REQUEST THAT
MKV50 BE PLACED ON PRIORITY
LIST FOR JOB EXECUTION TO
DETERMINE IF FURTHER MARKING
IS DESIRED

TASKOVER
allows operator to reject mark made prior to acceptance and allows a new mark to be made by astronaut

is this an R21 call?

Is R21MARK SET?

Yes

MRKBUF1 ← -1

FOR R22

MRKREJECT

is MARKSTAT SET?

No

ALARM 112

MARKS NOT BEING ACCEPTED

is MARKSTAT (0) SET?

Yes

ALARM 110

NO MARK SINCE LAST REJECT

MARKS ACCEPTED

 LEGAL MARK REJECT

Decrement VAC AREA pointer by 7

QPRET (ITEMP1) ← QPRET (ITEMP1)

A ← MARKSTAT (12..14)

MARKSTAT ← MARKSTAT + BIT16

Was MARKSTAT (12..14) CLEAN?

No

YES

MKVB51

PRIORITY 52

REQUEST THAT MKVB51 BE PLACED ON PRIORITY LIST FOR JOB EXECUTION

Resume

Exit via Resume
FLASH VS1NOO TO REQUEST MARKING AND VS0N25
R1=00016 TO REQUEST TERMINATE MARKING

MKV851

KLEENEX
CLEAN OUT EXTENDED VERBS

R1-BLANK
R2-BLANK
R3-BLANK

GOVARK4
VS1NOO
ENTER-RECYCLE DISPLAY
TERMINATE

PROCEED MARKING DONE

ENTANSWR
TERMSXT

MARKSTAT→MARKSTAT
BIT3→A
VAC ADDR
NO OF MARKS X 7

A→QPRET
(MARKSTAT)→A
SET TRM03FLG
SET FOR POS
TERMSPOS
YES-POS
CHECKSUM
MODREG=03
ANY MARKS MADE?
NO-NO MARKS
MADE
A > 0

A→AX BIT 12+1
NO OF MARKS MADE
JAMIT

QPRET
(MARKSTAT)→A
STORE NO OF MARKS MADE

INHINT

ENDMARKS

ENDMARKS
WANTLIST 5 SECONDS

GOODEND

MARKSTAT (12-14)
SET
ANYMORE MARKS WANTED?
YES

DSPTEMP1=00016
A→VS0N25
REQUEST TERMINATE MARKING

SXTMARK

COLOSSUS 11C
FC-2240
IF DIFFERENCE BETWEEN PRESENT ICDO AND MARK VALUES EXCEEDS 5 BITS THEN ALARM IS ACTIVATED AND MARK IS NOT ACCEPTED.

MARKIT

DOES CDUCHKWD EQUAL ZERO

CDUCHKWD = 0

AT LEAST 10 MSEC

A ← 1

MARKDIF

WAIT LIST NO OF MSEC IN CDUCHKWD

MARKDIF

RESUME

CDUCHKWD = 0

MKNDX ← -1

INCREMENT INDEX

MKNDX ← MKNDX + 1

A ← A - CDUX(MKNOS)

CHECK DIFFERENCE BETWEEN MARK AND CURRENT ICDO

RETURN VIA Q

A ← MKCDUX

DIFFCHK

CHECK DIFFERENCE

OK

A ← MKCDUX

DIFFCHK

CHECK DIFFERENCE

OK

MKACPT

MARKCONT SH**

ALARM CDUS NO GOOD DATETIME OF MARK IT?

YES

A ≥ 3

IS DIFFERENCE GREATER THAN 3?

NO-LESS THAN 3

TASKOVER

RETURN VIA Q

A ← MKCDUX

DIFFCHK

CHECK DIFFERENCE

OK

A ← MKCDUX

DIFFCHK

CHECK DIFFERENCE

OK

MKACPT

MARKCONT SH**
Optics Calibration Routine
- called by P23 (FC-2600)

Save QPRET in EGRESS

Is the extended verb system available?

No

P23ABRT

Light PROG ALARM light; set alarm code (31211: illegal interrupt of extended verb); cause software restart.

Yes

Bits 2, 3 of ETVBACT both clear?

Set bit 2 of ETVBACT

Extended verb system in use for mark taking

Next Sheet
MARKDISP

Immediate Return

MARKING DISPLAY job
- set up by MARKCONT (FC-2240)

GOMARKFR

Display Flashing V06N87

BLANKET
Blank DSKY registers R1, R3
FC-2130

ENDOJOB

Now do display

GOTOOOH

Display V06N87:
R1: blank
R2: xx.xxx deg
(optics trunnion angle: MRKBUF1 +5)
R3: blank

Recycle

GOTOPOOH

Recalibrate

R57A
Sh. 3

INCORPORATE CALIBRATION

TRUNBIAS ← (MRKBUF1 +5) - 19.77° Store corrected trunnion bias value in revs @ 2^-3

ENDR57
Sh. 5
ENDR57

Clear V59FLAG

ENDMARK

NOVAC job with priority 14
FC-2130

Terminate display interface for marking

Return via EGRESS

Terminate R57

Normal marking for P23
### Subroutines Called which are on Other Flow Charts

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAILOUT</td>
<td>FC-2140</td>
<td>Light PROG ALARM light; set alarm code; cause software restart.</td>
<td>Sh. 2</td>
</tr>
<tr>
<td>BLANKET</td>
<td>FC-2130</td>
<td>Blank R1, R2, and/or R3</td>
<td>Sh. 3, 4</td>
</tr>
<tr>
<td>ENDMARK</td>
<td>FC-2130</td>
<td>Terminate marking display interface</td>
<td>Sh. 5</td>
</tr>
</tbody>
</table>

### Displays

<table>
<thead>
<tr>
<th>Verb-Noun</th>
<th>Type of Display</th>
<th>Description of Registers</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>V59</td>
<td>Flashing</td>
<td>Please perform optics calibration mark. R1, R2, R3 blank.</td>
<td>Sh. 3</td>
</tr>
</tbody>
</table>
| V06N87    | Flashing        | R1: blank  
R2: xx. xxx deg (optics trunnion angle MRKBUF1 +5)  
R3: blank | Sh. 4 |
Flags

<table>
<thead>
<tr>
<th>Flag</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXTVBACT bit 2</td>
<td>Extended verb system in use for marking</td>
<td>Extended verb system not in use for marking</td>
<td>Sh. 2</td>
<td>Sh. 2</td>
<td>Sh. 2</td>
</tr>
<tr>
<td>EXTVBACT bit 3</td>
<td>Extended verb system in use for extended verb</td>
<td>Extended verb system not in use for extended verb</td>
<td></td>
<td></td>
<td>Sh. 2</td>
</tr>
<tr>
<td>V59FLAG (FLAGWRDS bit 12)</td>
<td>Calibrating for P23</td>
<td>Normal marking for P23</td>
<td>Sh. 3</td>
<td>Sh. 5</td>
<td></td>
</tr>
</tbody>
</table>

Erasable Locations Used:

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scale Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRKBUF1 +5</td>
<td>Optics trunnion angle displayed in noun 87</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-3}$</td>
</tr>
<tr>
<td>TRUNBIAS</td>
<td>Trunnion bias angle</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-3}$</td>
</tr>
</tbody>
</table>
LATITUDE LONGITUDE SUBROUTINES

LAT-LONG Sh. 2
LALOTORY Sh. 7
GETERAD Sh. 9
Vector to latitude, longitude, altitude subroutine

Save return address

Initialize push-down pointer

Time in csec $2^{28}$

$|\text{position vector}|$ in m $2^{29}$

Set for earth

Is LUNAFLAG clear?

No, moon

Use cos 0-1 to make MPAC non-zero for moon

Yes, earth

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

Output: \( \text{MPAC}_V = \hat{r}_p \) vector
in m \(@ 2^{+27}\) for earth
in m \(@ 2^{+27}\) for moon

Input:
LUNAFLAG:
- clear for earth
- set for moon

Output:
GAMRP containing
- \( B_2/A_2 \) (earth \( \gamma \)) \(@ 2^{+1}\)
- or \( 1B_1 = 1 \), (moon \( \gamma \)) \(@ 2^{+1}\)

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

\[
\cosh_D \leftarrow 2^1 \cdot \text{GAMRP} \sqrt{(\text{ALPHAV}_D)^2 + (\text{ALPHAV}_D + 2^1)^2}
\]

\[
\sinh_D \leftarrow \text{ALPHAV}_D + 4^1 D
\]

Next Sheet
From Preceding Sheet

ARCTAN
Compute \( \tan^{-1}(LAT) \)
Sh. 5

\[ \text{LAT} \leftarrow \text{THETA}_D \]
\[ \text{LAT} \in \text{revs} @ 2^0 \]
\[-1/2 \leq \theta \leq 1/2 \]

\[ \cos(\text{LONG}) @ 2^{+1} (= u_0) \]
\[ \sin(\text{LONG}) @ 2^{+1} (= u_1) \]

\[ \text{COSTH}_D \leftarrow \text{ALPHAV}_D \]
\[ \text{SINTH}_D \leftarrow \text{ALPHAV} + _2 D \]

ARCTAN
Compute \( \tan^{-1}(\text{LONG}) \)
Sh. 5

\[ \text{LONG} \leftarrow \text{THETA}_D \]
\[ \text{LONG} \in \text{revs} @ 2^0 \]
\[-1/2 \leq \theta \leq 1/2 \]

\[ \text{ALT}_D \leftarrow \text{ALPHAM} - \text{ERADM} \]
\[ \text{ALT} = \frac{r - r_0}{m @ 2^{+28} 0} \]

Return via INCORPEX

INCORPEX contains QPRET

INCORPEX contains QPRET

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

Latitude Longitude Subroutines

COLOSSUS 2D

DOCUMENT NO.
FC-2280

SHEET 4 OF 13
Multiply by $2^1$ for scaling. THETA_D is in PL2_D

\[
\text{THETA}_D = \sin^{-1} \left( \frac{1}{2} \cdot \sqrt{\sinh^2 + \cosh^2} \right)
\]

\[
\text{MPAC}_D = \cosh \text{THETA}_D
\]

\[
\text{Is} \quad \cosh \text{THETA}_D < 0 \quad \text{?}
\]

\[
\text{No} \quad \Rightarrow \text{Return via QPRET}
\]

\[
\text{Yes} \quad \Rightarrow \text{NEGcos}
\]

\[
\text{MPAC}_D = -\cosh \text{THETA}_D
\]

\[
\text{Is} \quad -\text{THETA}_D \geq 0 \quad \text{?}
\]

\[
\text{Yes} \quad \Rightarrow \text{NEGout}
\]

\[
\text{MPAC}_D = -\text{THETA}_D - \frac{1}{2} \quad \text{MPAC}_D = \text{THETA}_D + \frac{1}{2}
\]

\[
\text{ARCTANXX}
\]

\[
\text{THETA}_D = \text{MPAC}_D
\]

\[
\text{Return via QPRET}
\]
Latitude, longitude, altitude to vector subroutine

Save return address

Initialize Push-down pointer

Time in csec @ 2^28

Input:
LUNAFLAG: clear for earth
set for moon
Output:
GAMRP containing E2/A2 (earth \( \gamma \)) @ 2^{+1}
or 1B1 (moon \( \gamma \)) @ 2^{+1}

Set earth or moon
Sh. 10

\[ \text{PL}_D \leftarrow \text{GAMRP} \cdot \sin(\text{LAT}) \]
\[ \text{PL}_D \leftarrow \sin(\text{LONG}) \cdot \cos(\text{LAT}) \]
\[ \text{MPAC}_D \leftarrow \cos(\text{LONG}) \cdot \cos(\text{LAT}) \]

Next Sheet
From Preceding Sheet

\[ \begin{align*}
\text{PL}_0 V & \leftarrow \text{Unit}(\text{MPAC}_D, \text{PL}_2 D, \text{PL}_0 D) \\
\text{ALPHA}_V & \leftarrow \text{PL}_0 V
\end{align*} \]

\[ \text{ALPHA}_V = \begin{bmatrix}
\cos(\text{LONG}) \cos(\text{LAT}) \\
\sin(\text{LONG}) \cos(\text{LAT}) \\
\gamma \sin(\text{LAT})
\end{bmatrix} \]

**Output:**
\[ \text{ERADM}_D = \text{earth or moon radius in m} @ 2^{+29} \]

**Input:**
\[ \text{MPAC} = 0 \text{ for earth} \]
\[ = 1 \text{ for moon} \]
\[ \text{PL}_0 V = \text{unit r vector } @ 2^{+29} \]
\[ \text{PL}_6 D = \text{time in csec } @ 2^{+26} \]

**Output:**
\[ \text{MPAC}_V = \text{unit r vector } @ 2^{+29} \text{ for earth} \]
\[ @ 2^{+27} \text{ for moon} \]

**Setre**
Set earth or moon radius
Sh. 11

**MPAC}_D \leftarrow 0, 0
Set for earth

**Is LUNAFLAG clear?**
Yes, earth

**Use cos 0=1 to make MPAC non-zero for moon**

**CALLRPRTR**

**Input:**
\[ \text{MPAC} = 0 \text{ for earth} \]
\[ = 1 \text{ for moon} \]
\[ \text{PL}_0 V = \text{unit r vector } @ 2^{+29} \]
\[ \text{PL}_6 D = \text{time in csec } @ 2^{+26} \]

**Output:**
\[ \text{MPAC}_V = \text{unit r vector } @ 2^{+29} \text{ for earth} \]
\[ @ 2^{+27} \text{ for moon} \]

**Next Sheet**
From Preceding Sheet

\[ \text{ALPHAV}_V \leftarrow \text{MPAC}_V \]

Unit \( r \) vector \( @2^{+2} \)

\[ \text{MPAC}_D \leftarrow \text{ERADM}_D \]

Earth or moon radius in \( m@2^{+29} \)

\[ \text{ALPHAV}_V \leftarrow 2(\text{ERADM} + \text{ALT})(\text{ALPHAV}_V) \]

Shift left (multiply by \( 2^{+5} \)) for scaling:

\( r \) vector in \( m@2^{+29} \)

\[ \text{Return via INCORPEX} \]

INCORPEX contains QPRET

\[ r_F^2 = \frac{b^2}{a^2} - (1 - \frac{b^2}{a^2})(1 - \sin^2 \ell) \]

\[ \text{MPAC}_D \leftarrow 2^{-4} \left[ b_2 x s_2 / 1/2 - e_2 (1/2 - 2^1(\text{ALPHAV} + 4)^2) \right] \]

\[ \text{ERADM}_D \leftarrow \text{MPAC}_D \]

Radius of Fischer ellipsoid.

- \( a \): semi-major axis
- \( b \): semi-minor axis

Earth radius in \( m@2^{+29} \)

\[ \text{Return via QPRET} \]
SETGAMMA

Determine $\gamma$

$\frac{b^2}{a^2} = \gamma$ for earth @ $2^1$

MPAC ← $\frac{B2}{A2}$

Is LUNAFLAG clear?

No, get moon $\gamma$

Moon $\gamma = 1 @ 2^1$

MPAC ← 1B1

Yes, store earth $\gamma$

SETGMEX

Earth or moon $\gamma @ 2^1$

(GAMRP = PL8)

GAMRP ← MPAC

Return via QPRET
SETRE
- Set earth or moon radius

SETREX
- QPRET
  - Save return address

MPAC_D ← 504RM
- Moon radius in m @ 2^{+29}

Is LUNAFLAG set?

Yes
- TSTRSLRM
  - Sh. 12

No, get earth radius

MPAC_D ← ERAD_D
- Fixed earth radius in m @ 2^{+29}

Is ERADFLG set?

No, fixed earth radius

Yes, computed earth radius

GETERAD
- Compute earth radius
  - (Fischer ellipsoid)
  - Sh. 12

Output:
- Computed earth radius
  - in MPAC_D and ERADM_D
  - in m @ 2^{+29}

SETRXX
- Sh. 12

Store radius in ERADM_D
and return.
TSTRLSRM

Yes, \( r_0 = r_M \)
Compute altitude above mean lunar radius

Is ERADFLAG set?

No, \( r_0 = r_{LS} \)

\[ MPAC_D \leftarrow 2^{-2|R_{LS}|} \]
\( r_{LS} \) rescaled from \( 2^{+27} \) to \( 2^{+29} \)

SETRXX

\[ ERADM_D \leftarrow MPAC_D \]
Store radius in \( m @ 2^{+29} \)

Return via SETREX

SETREX contains QPRET
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Where Flowed</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-TO-RP</td>
<td>FC-2283</td>
<td>Converts $r$ vector to $r_p$ vector</td>
<td>Sh. 3</td>
</tr>
<tr>
<td>RP-TO-R</td>
<td>FC-2283</td>
<td>Converts $r_p$ vector to $r$ vector</td>
<td>Sh. 8</td>
</tr>
</tbody>
</table>

### FLAGS

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERADFLAG</td>
<td>Earth: compute Fischer ellipsoid radius</td>
<td>Earth: use fixed radius</td>
<td></td>
<td></td>
<td>Sh. 11, 12</td>
</tr>
<tr>
<td>flag 1 bit 13</td>
<td>Moon: use fixed radius</td>
<td>Moon: use $r_{LS}$ for lunar radius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LUNAFLAG</td>
<td>Lunar LAT-LONG</td>
<td>Earth LAT-LONG</td>
<td></td>
<td></td>
<td>Sh. 2, 8, 10, 11</td>
</tr>
</tbody>
</table>
PLANTEARY INERTIAL ORIENTATION SUBROUTINE (PIOS)

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

RP-TO-R      SH. 2
R-TO-RP      SH. 3
EARTHMX      SH. 4
MOONMX       SH. 5

1. GUIDANCE SYSTEM OPERATIONS PLAN USING PROGRAM COLOSSUS 2C.
   (GSOP),R-557, SECTION 5, GUIDANCE EQUATIONS, (REV. 8), JULY 1988
INVERTS THE BASIC REFERENCE COORDINATE SYSTEM TO THE SAME VECTOR EXPRESSED IN THE PLANETARY (EARTH FIXED OR MOON FIXED) COORDINATE SYSTEM.

INPUT
1. MPAC = \( \begin{cases} 0 & \text{for Earth} \\ \neq 0 & \text{for Moon} \end{cases} \)
2. PLO_v = \( \tau \) at 2^n
3. PL6_p = \( t \), TIME OF CPCE, AT 2^n

OUTPUT
1. MPAC = \( \tau_p \) at 2^n FOR EARTH SAME SCALING AS INPUT \( \tau \) FOR MOON

R-TO-RP

RPREXIT <- QPRET

SAVE RETURN ADDRESS

SET UP FOR EARTH

RTORPA

INPUT
1. PL6_e = \( t \)
2. AXO_D = \( A \)
3. WEARTH = \( w \)

OUTPUT
1. MMATRIX = \( \begin{pmatrix} P & 2 L_0 \end{pmatrix} \) \( \tau \) @ 2^n

EARTHMX

FOR EARTH

SH4

COMPUTE \( M^* (t) \)

INPUT
1. AXO_D = \( A \)
2. AXO_D = \( -A \)

OUTPUT
1. MPAC = \( \tau_p \) @ 2^n

RTORPB

COMPUTE \( M^* (t) \)

FOR MOON

SH5

INPUT
1. PLO_v = \( \tau \)
2. SUBO_D = \( B \)
3. DOT_D = \( \dot{B} \)

OUTPUT
1. MMATRIX = \( \begin{pmatrix} P & 2 L_0 \end{pmatrix} \) \( \tau \) @ 2^n

MOONMX

FOR MOON

SH5

THIS IS EQUIVALENT TO \( M^* (t) \) FOR \( \tau \), WHERE \( \tau_p = \frac{\tau}{2^m} \). EQ 5.2.6

EQ 5.2.1

504 RPR = PLO

RPRPX***

SHIFT MPAC = \( \tau_p \) TO 2^n

SET PUSH LIST POINTER TO 0

RETURN VIA RPREXIT

RPREXIT CONTAINS QPRET

PRELIMINARY
COLOSSUS computes the transformation matrix $M^s(t)$ for the Earth, where $M^s(t)$ describes a rotation of the coordinates system about the polar axis ($z$-axis) of the Earth.

**Input**
1. $PL6_0 = t$, time since AGC clock was zeroed, in sec at 218.
2. $A_20 = A_20$, angle between x-axis of basic system and x-axis of Earth system at July 1, 1968.
3. $WEARTH = W_E$, angular velocity of Earth in revs/sec at 218.
4. $TIMSUBO = t_0$, elapsed time from July 1, 1968, to zeroing of AGC clock, in sec at 218.

**Output**
1. $M^s(t) = PL20(s)$, where
   $$M^s(t) = \begin{bmatrix}
   \cos A_2 & -\sin A_2 & 0 \\
   \sin A_2 & \cos A_2 & 0 \\
   0 & 0 & 1
   \end{bmatrix}$$

**Input**
1. $PL6_0 = A_20$ in revs at 2.
2. $PL10_0 = W_E$ in revs/sec at 213.
3. $X1 = 0$, shift value.
4. $PL6_0 = t$ in sec at 218.
5. $TIMSUBO = t_0$ in sec at 218.

**Output**
1. $MPAC_0 = A_2$ in rev at 2 at time $t$.

$M_{11}$ through $M_{33}$ are the elements of matrix $M^s(t)$.

Earthl computes the rotation vector $\vec{a}$ for Earth in the basic reference coordinate system.

**Input**
1. $AXD_0 = A_x$ in revs at 2.
2. $AYD_0 = A_y$ in revs at 2.

**Output**
1. $MPAC_0 = \vec{a} = (-A_x, A_y, 0)$ at 2.

$A_x$ and $A_y$ (and hence $\vec{a}$) are considered constant throughout the mission.

**PRELIMINARY**
INPUT
1. \( \Omega_{10} \) IN REVS AT 2°
2. \( \Delta_{1} \) IN REVS/CSEC AT 2°-28
3. \( x_{1} = 5 \), SHIFT VALUE
4. \( \phi_{6} = t \) IN CSEC AT 2°-28
5. \( \text{TMSUB} = t_{0} \) IN CSEC AT 2°-28

STORE \( \Omega_{1} \) IN TEMPORARY STORAGE

OUTPUT
1. \( \text{MPAC}_{0} = \Omega_{1} \)

IN REVS AT 2° AT TIME t

\[\begin{align*}
\alpha_{1} &= \cos \Omega_{1} \\
\phi_{10} &= \text{MPAC}_{0} - \cos (\text{MPAC}_{0}) \\
\text{AVECTR}_{0} &= \text{MPAC}_{0} \cdot \Omega_{1} \\
\beta_{0} &= \cos B - \cos \Omega_{1} \\
\text{BVECTR}_{0} &= \text{COB}_{0} - \text{MPAC}_{0} \\text{SHIF TED \( \Omega_{1} \)} \\
\beta_{2} &= \sin B - \cos \Omega_{1} \\
\text{BVECTR}_{0} + 4 &= \text{SOB}_{0} - \phi_{10} \\text{SHIF TED \( \Omega_{1} \)} \\
\sin \Omega_{1} &= \text{PL8}_{0} - \text{MPAC}_{0} - \sin (\text{PL8}_{0}) \\
\beta_{1} &= -\sin \Omega_{1} \\
\text{BVECTR}_{0} &= - (\text{MPAC}_{0}) \\text{SHIF TED \( \Omega_{1} \)} \\
\text{SOB}_{0} &= \text{PL6} - \text{AVECTR}_{0} + 2 \\
\text{SINNOI} &= \text{PL8} \\
\text{CVECTR} &= \text{PL8} \\
\end{align*}\]

PRELIMINARY

\( S_{2} = \sin B_{1} \), \( C_{2} = \cos B_{1} \), WHERE \( B_{1} = 1° 32.1' \), THE CONSTANT ANGLE BETWEEN THE LUNAR EQUATORIAL PLANE AND THE PLANE OF THE ECLIPTIC
FROM PRECEDING SHEET

\[ \mathbf{M}_2 = b \mathbf{c}_I + \mathbf{c}_I \mathbf{C}_I \]
\[ \mathbf{MMATRIX}_{M+12} \rightarrow \mathbf{PL14}_v \mathbf{+ VECTR}_v \mathbf{\cdot COS}_D \]
\[ \text{SHIFTED @ } 2^1 \]

\[ \mathbf{E} \cdot \mathbf{S}_I \]
\[ \mathbf{PL8}_v \rightarrow \mathbf{PL8}_v \cdot \mathbf{SIN}_D \]
\[ \text{SHIFTED @ } 2^1 \]

\[ d = b \cdot c_2 - c_1 \cdot c_3 \]
\[ \mathbf{PL8}_v \rightarrow \mathbf{VECTR}_v \cdot \mathbf{COS}_D \cdot \mathbf{PL8}_v \]
\[ \text{SHIFTED @ } 2^1 \]

\[ d \cdot \mathbf{COSF} \]
\[ \mathbf{PL14}_v \rightarrow \mathbf{VECTR}_v \cdot \mathbf{COS(504F_D)} \]
\[ \text{SHIFTED @ } 2^1 \]

\[ d \cdot \mathbf{COSF} \]
\[ \mathbf{MMATRIX}_{M+6} \rightarrow \mathbf{VECTR}_v \cdot \mathbf{SIN(504F_D)} - \mathbf{PL14}_v \]
\[ \text{SHIFTED @ } 2^1 \]

\[ m_1 = a \cdot \mathbf{COSF} - d \cdot \mathbf{COSF} \]
\[ \mathbf{MMATRIX}_{M+6} \rightarrow \mathbf{VECTR}_v \cdot \mathbf{SIN(504F_D)} - \mathbf{PL14}_v \]
\[ \text{SHIFTED @ } 2^1 \]

\[ d \cdot \mathbf{SINF} \]
\[ \mathbf{PL8}_v \rightarrow \mathbf{PL8}_v \cdot \mathbf{SIN(504F_D)} \]
\[ \text{SHIFTED @ } 2^1 \]

\[ m_2 = - (a \cdot \mathbf{COSF} + d \cdot \mathbf{SINF}) \]
\[ \mathbf{MMATRIX}_{M} \rightarrow \mathbf{-VECTR}_v \cdot \mathbf{COS(504F_D)} + \mathbf{PL8}_v \]
\[ \text{SHIFTED @ } 2^1 \]

RETURN VIA EARTHXXX

EARTHXXX CONTAINS QPRT

PRELIMINARY
NEWANGLE IS A GENERAL PURPOSE SUBROUTINE FOR EVALUATING THE FUNCTION:

\[ x = x_0 + \dot{x}(t+t_0) \]

INPUT
1. PL8o = x_0 in revs at 2^9
2. PL10o = \dot{x} in revs/csec at 2^{-2}/2^{-28}/2^{-27}
3. X1 = shift value of 0/5/4 corresponding to \dot{x} scaling
4. PL6o = t, time in csec at 2^9
5. TIMSUBO = t_0, time in csec at 2^9

OUTPUT
1. MPACo = x in revs at 2^9

\[ \text{TUMSUBM} = PL14 \]

MINOR PART OF \( x(t+t_0) \)

FROM \( x_0 \) PLUS MINOR PART OF \( x(t+t_0) \)

\[ \dot{x}(t+t_0) \]

\[ x_0 + \dot{x}(t+t_0) \]

\[ PL8o \rightarrow PL8o + MPACo \]

MAJOR PART OF \( \dot{x}(t+t_0) \)

FORM \( x_0 \) PLUS MAJOR AND MINOR PARTS OF \( \dot{x}(t+t_0) \)

CLEAR OVFIND

TURN OFF THE OVERFLOW INDICATOR

PRELIMINARY
PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>H6ZEROS_v</td>
<td></td>
<td>THE VECTOR (0, 0, 0)</td>
<td>(0, 0, 0)</td>
<td>(0, 0, 0)</td>
<td>^2_0</td>
</tr>
<tr>
<td>HIDPHALF_d</td>
<td></td>
<td>THE NUMBER 1</td>
<td>1.0</td>
<td>0.5</td>
<td>^2_1</td>
</tr>
<tr>
<td>NODIO_d</td>
<td>( \alpha )</td>
<td>LONGITUDE OF NODE OF LUNAR ORBIT IN BASIC REFERENCE SYSTEM, AT JULY 1.0, 1968</td>
<td>(-6.03249419 \text{ RADS})</td>
<td>(-960101269 \text{ REV})</td>
<td>^2_0</td>
</tr>
<tr>
<td>NODDOT_d</td>
<td>( \dot{\alpha} )</td>
<td>DERIVATIVE OF LONGITUDE OF NODE</td>
<td>(-1.07047016 \times 10^{-8} \text{ RAD/SEC})</td>
<td>(-4.57335143 \times 10^{-2} \text{ REV/CSEC})</td>
<td>^2_28</td>
</tr>
<tr>
<td>FSUBO_d</td>
<td>( F )</td>
<td>ANGLE FROM MEAN ASCENDING NODE OF LUNAR ORBIT TO THE MOON, AT JULY 1.0, 1968</td>
<td>(2.61379488 \text{ RADS})</td>
<td>(4.15090837 \text{ REV})</td>
<td>^2_0</td>
</tr>
<tr>
<td>FDOT_d</td>
<td>( \dot{F} )</td>
<td>DERIVATIVE OF ANGLE F</td>
<td>(2.67240019 \times 10^{-6} \text{ RAD/SEC})</td>
<td>(5.70862941 \text{ REV/CSEC})</td>
<td>^2_27</td>
</tr>
<tr>
<td>BSUBO_d</td>
<td>( B )</td>
<td>OBLIQUITY, ANGLE BETWEEN MEAN EARTH EQUATORIAL PLANE AND ECLIPTIC, AT JULY 1.0, 1968</td>
<td>(0.09164173 \text{ RADS})</td>
<td>(0.651205006 \text{ REV})</td>
<td>^2_0</td>
</tr>
<tr>
<td>BDOT_d</td>
<td>( \dot{B} )</td>
<td>DERIVATIVE OF OBLIQUITY</td>
<td>(-7.19758666 \times 10^{-14} \text{ RAD/SEC})</td>
<td>(-3.07500412 \times 10^{-8} \text{ REV/CSEC})</td>
<td>^2_28</td>
</tr>
<tr>
<td>WEARTH_d</td>
<td>( \omega_E )</td>
<td>ANGULAR VELOCITY OF THE EARTH</td>
<td>(7.29211515 \times 10^{-5} \text{ RAD/SEC})</td>
<td>(9.7365855 \text{ REV/CSEC})</td>
<td>^2_23</td>
</tr>
<tr>
<td>COSI_d</td>
<td>( C_i )</td>
<td>( \cos 1 ) WHERE 1 IS ANGLE BETWEEN MEAN LUNAR EQUATORIAL PLANE AND ECLIPTIC (1^\circ 32, 1^\circ)</td>
<td>(0.99994115)</td>
<td>\text{SAME})</td>
<td>^2_1</td>
</tr>
<tr>
<td>SNI_d</td>
<td>( S_i )</td>
<td>( \sin 1 )</td>
<td>(0.02678760)</td>
<td>\text{SAME})</td>
<td>^2_1</td>
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PAD LOADS

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<tr>
<th>AGC TAG</th>
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<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
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<tr>
<td>504LM_v</td>
<td>1M</td>
<td>VECTOR LIBRATION ( \Gamma ) IN MOON SYSTEM</td>
<td>RADS</td>
<td>RADS</td>
<td>^2_0</td>
<td></td>
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<tr>
<td>AXO_d</td>
<td>( \Delta x )</td>
<td>ANGLES ABOUT X-AXES OF BASIC SYSTEM DESCRIBING PRECESSION AND NUTATION</td>
<td>(4.652450 \times 10^{-5} \text{ RADS})</td>
<td>RADS</td>
<td>^2_0</td>
<td></td>
</tr>
<tr>
<td>AYO_d</td>
<td>( \Delta y )</td>
<td>ANGLE BETWEEN X-AXIS OF BASIC SYSTEM AND EARTH SYSTEM, JULY 1.0, 1968</td>
<td>(2.147535 \times 10^{-5} \text{ RADS})</td>
<td>RADS</td>
<td>^2_0</td>
<td></td>
</tr>
<tr>
<td>AZO_d</td>
<td>( \Delta z )</td>
<td>ANGLE BETWEEN X-AXIS OF BASIC SYSTEM AND EARTH SYSTEM, JULY 1.0, 1968</td>
<td>(7.753206164 \text{ REV})</td>
<td>RREV</td>
<td>^2_0</td>
<td></td>
</tr>
</tbody>
</table>

PRELIMINARY
LUNAR AND SOLAR EPHEMERIDES SUBROUTINE

These subroutines are used to determine the position and velocity vectors of the sun and moon relative to the earth at the specified ground elapsed time input by the user.

INPUT: GET-GROUND ELAPSED TIME

TEPHEM - elapsed time between July 1, 0, 1968 Universal time and the time that the computer clock was zeroed
TIMEMO - elapsed time between July 1, 0, 1968 Universal time and the time at the center of the range over which the lunar-position polynomial is valid
VECOEM - vector coefficients of the lunar position polynomial loaded in descending sequence
RESO - position vector of the sun relative to the earth at TIMEMO
VESCO - velocity vector of the sun relative to the earth at TIMEMO
OMEGAES - angular velocity of the vector RESO at TIMEMO

OUTPUT: LSPOS
VAC02D - position vector of the sun relative to the earth at input by user
MPAC - position vector of the moon relative to the earth at time input by user
LUNPOS
MPAC - position vector of the moon relative to the earth at time input by user
LUNVEL
MPAC - velocity vector of the moon relative to the earth at time input
SOLPOS
MPAC - position vector of the sun relative to the earth at time input by user

NOTE: All input except GET is included in the pre-launch erasable data load.
THIS AREA LOOPS TO OBTAIN NINTH DEGREE POLYNOMIAL

1ST PASS

2ND PASS

9TH PASS

\[ Y_{EM} = \sum_{i=1}^{n} L_i \dot{r}_m \times t_i \]

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

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

\[ \text{RESO}_0 = \text{POSITION VECTOR OF SUN AT } T_0 \]
\[ \text{VELO}_0 = \text{VELOCITY VECTOR OF SUN AT } T_0 \]
\[ \theta = \text{VELO}_0 \cdot \Delta t \]

\[ \text{RES} = \text{RESO}_0 \cos \theta \left[ \text{UNIT RESO} + \text{RESO} \sin \theta \right] (k) \]

WHERE \[ K = \text{UNIT} \left[ \text{RESO} \times (\text{VELO}_0 \times \text{RESO}) \right] \]
\[ = \text{RESO} \cos \theta + \text{RESO} \times \left[ \text{UNIT} (\text{VELO}_0 \times \text{RESO}) \right] \sin \theta \]
## INTEGRATION INITIALIZATION

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<td>SCHEDULES STATINT1</td>
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<td>UPDATE PERMANENT CSM STATE VECTOR</td>
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<td>ATOPELM</td>
<td>UPDATE PERMANENT LM STATE VECTOR</td>
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<td>PTOACSM</td>
<td>MOVE PERMANENT CSM STATE VECTOR TO WORKING STORAGE</td>
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<td>MOVE PERMANENT LM STATE VECTOR TO WORKING STORAGE</td>
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<td>INSTALL</td>
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<tr>
<td>INTAKEU</td>
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<tr>
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<td>CALCULATES THE LM STATE VECTOR USING THE PLANETARY INERTIAL ORIENTATION SUBROUTINE WHEN LM ON LUNAR SURFACE</td>
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## REFERENCES FOR INTEGRATION INITIALIZATION

1. GUIDANCE SYSTEM OPERATIONS PLAN USING PROGRAM COLOSSUS (GSOP), R-577, SECTION 5, GUIDANCE EQUATIONS, MAY, 1968.
2. OSTANEK, W. F., USER'S GUIDE FOR ORBITAL INTEGRATION ROUTINE FOR FLIGHT 504, FLIGHT 504 MEMO 5, REV 1, JUNE, 1967.
3. OSTANEK AND KEFAUER, LEVEL II TEST PACKAGE FOR COASTING INTEGRATION SUBROUTINE, MIT/IL, NOVEMBER, 1967.
STATEINT IS SCHEDULED TO BE EXECUTED EVERY 600 SECONDS DURING THE IDLING PROGRAM POO. THUS BOTH STATE VECTORS ARE PRECISION INTEGRATED AND UPDATED TO WITHIN 600 SECONDS OF CURRENT TIME.

STATEINT

GROUP 2.1
SET UP RESTARTS TO SCHEDULE STATEINT AS A FINDVAC JOB WITH PRIORITY 5

STATEINT1
FINDVAC JOB PRIORITY 5
SH3

TASKOVER

SETIFLAGS

SET STATEFLG
CLEAR INTYPFLG
CLEAR DIMGFLG
CLEAR D60RFLG
RETURN VIA QPRET

NOINT

GROUP 2.0
KILL GROUP 2 RESTARTS
CLEAR QUITFLAG
ENDOFJOB

START

QUITFLAG
CLEAR
LOADTIME
LOAD CURRENT TIME INTO MPAC
FC-E100

OUTPUT
1.0 MPAC = \( t_o \) CURRENT TIME

INTEGRATE TO CURRENT TIME

PDO INTEGRATION PROCEEDING REGULARLY

INSTALL
WAIT TILL INTEGRATION SYSTEM AVAILABLE
SH10

SET NOOFLAG

SETIFLAGS
SET UP FLAGS FOR PRECISION INTEGRATION
SH3

POOFLAG

STATEUP
Sh. 4

ENDINT

GROUP 2.3
SET UP RESTARTS TO SCHEDULE STATEINT AS A LONGCALL TASK IN 600 SEC.
LOGIC

STATEINT
LONGCALL TASK IN 600 SEC
SH3

ENDOFJOB

THIS FLAG IS ALWAYS LEFT CLEARED FOLLOWING INTEGRATION

SETUP

PERFORM UPDATE OF STATE VECTOR
DO A PRECISION INTEGRATION
DO NOT INTEGRATE THE W-MATRIX
W-MATRIX DIMENSION IS 6 x 6
RETURN VIA QPRET

NO INTEGRATION IF V96 EXECUTED
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.

- **STATEUP**
  - SET VINTFLAG
  - INTEGRATE THE CSM STATE VECTOR

- **W-MATRIX IS VALID FOR ORBITAL NAVIGATION**
  - ORBFLAG SET
  - CLEAR W-MATRIX IS INVALID

- **SET DMOFLAG**
  - INTEGRATE W-MATRIX

- **CLEAR PRECIFLG**
  - PRECISION INTEGRATE CSM PERMANENT STATE VECTOR TO CURRENT TIME

- **SURFFLAG**
  - SET
  - DO NOT INTEGRATE LM STATE VECTOR IF LM IS ON LUNAR SURFACE

- **INPUT**
  - PERMANENT CSM STATE VECTOR
  - TDEC1 = t_c

- **OUTPUT**
  - PERMANENT CSM STATE VECTOR AT t_c

- **TDEC1 = TETCSTM0**
  - SET UP TO INTEGRATE LM TO SAME TIME

- **INSTALL WAIT UNTIL INTEGRATION SYSTEM IS AVAILABLE**
  - SH30

- **CLEAR VINTFLAG**
  - INTEGRATE THE LM STATE VECTOR

- **A**
  - SET IFLGS
  - SET UP FOR PRECISION INTEGRATION, NO W-MATRIX, WITH STATE VECTOR UPDATE

- **SH3**
  - SET
  - INTEGRATE W-MATRIX

- **RENDFLAG**
  - CLEAR
  - W-MATRIX IS VALID FOR RENDEVOUS NAVIGATION

- **SET DMOFLAG**
  - INTEGRATE W-MATRIX

- **SET PRECIFLG**
  - PRECISION INTEGRATE LM PERMANENT STATE VECTOR TO CURRENT TIME

- **STATEND**
  - CLEAR NOOFFLAG

- **PERMIT VERB 37**
  - SH3

**INTEGRATION INITIALIZATION**
CSMPREC and LEMPREC are entries to the integration routine for performing orbit integration by the precision (ENCKE) method of the permanent state vector of the CSM and LM respectively. Accelerations due to oblateness are included, no W-matrix integration is performed. A final state vector update is optional. The caller must store the time to integrate to in TOECL", T." The entries automatically load the appropriate state vector and time of validity from permanent storage into RV, VCV, and TET,. These entries set up all the flags required by the integration routine and perform the call to INSTALL. Output includes the integrated state vector stored in the push list in locations RATT, VATT, and the time actually integrated to in push list location TAT."
CSCCONIC 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 TDECI = T0. The entries automatically load the appropriate state vector and time of validity for permanent storage into RCV, VC, and TET, these entries set up all the flags required by the integration routine and perform the call to INSTALL. Output includes the integrated state vector stored in the push list in locations RATE, VATT, VATT, and the time actually integrated to in push list location TAP.
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 INSTALL, set up the flags INTPFGL, MOONFLAG and load the state vector to be integrated and time into locations RCV1, VCV1, and TET1. The time to integrate must be loaded in TDEC1o = t1.

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 INSTALL and set up the flags INTPFGL, VINTFLAG, DIMOFGL, DBEOPFGL and STATEFLG. The time to integrate must be loaded in TDEC1, = t1. This entry loads the appropriate state vector and time from permanent storage into RCV1, VCV1, and TET1. This is the only entry that permits w-matrix integration as an option. This entry is used generally by the navigation programs.

INTEGRVS

1. SET PRECFGL
2. DO NORMAL INTEGRATION IN POO.

INTEGRV

1. IRETURN - QPRET
2. SAVE RETURN ADDRESS
3. THIS IS THE ENTRY POINT FROM CSMPREC, LEMPREC, CSMCONIC AND LEMCONIC
4. RPQ NOT YET COMPUTED
5. THIS INDICATES IT IS THE INITIAL PASS THRU INTEGRATION
6. THIS IS THE ENTRY POINT FROM RELOADSV, FC-2300

RECTIFY

1. DEFINE NEW REFERENCE CONIC AND ZERO THE DEVIATIONS
2. FC-2300
3. CLEAR DIMOFGL
4. DO NOT INTEGRATE W-MATRIX
5. THIS INDICATES INITIAL PASS THRU INTEGRATION
6. RPQ NOT YET COMPUTED
7. SET NEWIFGL
8. SET RPQFGL

ALOAD

1. STORE t1, THE TIME TO INTEGRATE TO.

INTEGRATION INITIALIZATION

INTEGRVS

1. SET PRECFGL
2. DO NORMAL INTEGRATION IN POO.

INTEGRV

1. IRETURN - QPRET
2. SAVE RETURN ADDRESS
3. THIS IS THE ENTRY POINT FROM CSMPREC, LEMPREC, CSMCONIC AND LEMCONIC
4. RPQ NOT YET COMPUTED
5. THIS INDICATES IT IS THE INITIAL PASS THRU INTEGRATION
6. THIS IS THE ENTRY POINT FROM RELOADSV, FC-2300

RECTIFY

1. DEFINE NEW REFERENCE CONIC AND ZERO THE DEVIATIONS
2. FC-2300
3. CLEAR DIMOFGL
4. DO NOT INTEGRATE W-MATRIX
5. THIS INDICATES INITIAL PASS THRU INTEGRATION
6. RPQ NOT YET COMPUTED
7. SET NEWIFGL
8. SET RPQFGL

ALOAD

1. STORE t1, THE TIME TO INTEGRATE TO.

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

\[ \tau = t_2 - t_1 \]

TAU_0 = TETD - TETD

TAU_0 IS INPUT TO KEPPREP

TETD IS TIME OF VALIDITY OF PRESENT CONIC STATE VECOR \( \mathbf{r}_{\text{con}} \), \( \mathbf{v}_{\text{con}} \)

TDEG IS TIME TO INTEGRATE TO

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

RECTIFY

DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS 

FC-2300

INPUT

1. RCV = \( \mathbf{r}_{\text{con}} \)
2. VCV = \( \mathbf{v}_{\text{con}} \)
3. TDELTAV = \( \delta \)
4. TNUV = \( \gamma \)
5. XG = PBODY

OUTPUT

1. RRECTV = \( \mathbf{r}_{\text{new}} \)
2. VRECTV = \( \mathbf{v}_{\text{new}} \)
3. RCV = \( \mathbf{r}_{\text{new}} \) NEW \( \mathbf{r}_{\text{con}} \)
4. TNUV = \( \gamma \) NEW \( \mathbf{v}_{\text{con}} \)
5. XKEP = \( x = 0 \)

DO A CONIC INTEGRATION USING KEPLER ROUTINE, OVER INTERVAL TAU_0

FC-2300

INPUT

1. RCV = \( \mathbf{r}_{\text{con}} \)
2. VCV = \( \mathbf{v}_{\text{con}} \)
3. TAU_0 = \( t_2 - t_1 \)
4. XPREV = \( x_{\text{prev}} \)
5. XKEP = \( x = 0 \)

OUTPUT

1. RCV = \( \mathbf{r}_{\text{con}} \)
2. VCV = \( \mathbf{v}_{\text{con}} \)
3. TCO = \( t_2 \) TIME TO WHICH ITERATION CONVERGED \( t_0 \)
4. XPREV = \( x_{\text{prev}} \)
5. XKEP = \( x = 0 \)

NOTE: OUTPUT IS FOR ENTIRE KEPPREP AND KEPLER COMPUTATIONS

6. PBODY = 0 FOR EARTH, = 2 FOR MOON

7. MOONFLG = CLEAR FOR EARTH, SET FOR MOON

COMPUTE THE TIME OF VALIDITY OF THE KEPLER OUTPUT \( \mathbf{r}_{\text{con}} \), \( \mathbf{v}_{\text{con}} \), \( t_0 \) IS THE TIME INCREMENT THAT KEPLER ACTUALLY INTEGRATED OVER

FC-2300

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

```
     INSTALL
        |__ INSTALL+1__
          |__ A__ O__
             |__ INSTALL__

     ERASTALL1
        |__ ERASTALL+1__
          |__ A__ 1__
             |__ ALLSTALL__

     ERASTALL2
        |__ ERASTALL+2__
          |__ A__ 2__
             |__ ALLSTALL__

L__ A__
      |__ WHICH ENTRY?__
          |__ TEST L__

  O__
      |__ BOTH CLEAR__
          |__ REINTLE, INTFLAG__

  O__
      |__ BOTH CLEAR__
          |__ FLOWRDI0, BITS 6,15__

  O__
      |__ BOTH CLEAR__
          |__ FLOWRDI0, BITS 5,12__

  O__
      |__ TEST L__
          |__ WHICH ENTRY?__

  O__
      |__ BOTH CLEAR__
          |__ CAIR (INSTALL+1)__

  O__
      |__ BOTH CLEAR__
          |__ CAIR (ERASTALL+1)__

  O__
      |__ BOTH CLEAR__
          |__ CAIR (ERASTALL+2)__

JOSLEF
P__ 2050__
      |__ PUT THIS JOB TO SLEEP__
          |__ WAKE-UP ADDRESS IN A__
```
THE INTEGRATION WAKE ROUTINE WAKES UP ALL PROGRAMS THAT HAVE BEEN
PUT TO SLEEP (I.E. STALLED) BY THE INTEGRATION STALL ROUTINE INSTALL.

ENTRY FROM BASIC CODING, THE CALLER MUST
GUARANTEE A RETURN ADDRESS IS STORED
IN QPRET

REINTFLG

CLEAR

SET

DO NOT RESTART PROTECT

REINTFLG

SET

RESTART

PROTECT

TBASE2 ← QPRET

GROUP 2

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

QPRET ← TBASE2

RESTORE RETURN ADDRESS

CLEAR

REINTFLG

INDICATES WAKE
ROUTINE HAS ALREADY
BEEN IMPLEMENTED.
I.E. A RESTART MUST
HAVE TAKEN PLACE

G0BAC

RETURN
VIA QPRET

INTWAKE0

ENTRY FROM
INTERPRETIVE CODING

INTWAKE1

PROCEED TO WAKE UP
ALL STALLED PROGRAMS

ERASWAK2

SET E ← 2
A ← 0

ERASWAK1

SET E ← 1
A ← 1

NEXT SHEET
FROM PRECEDING SHEET

WAKE

STORE \( \frac{1}{\text{STALTEM}} \rightarrow A \)

THE VALUE \( \frac{1}{\text{STALTEM}} \) IS USED FOR INDEXING

WAKE1

TEST

STALTEM

\( \text{A} \leftarrow \text{CADR(ERASTAL1+1)} \)

\( \text{A} \leftarrow \text{CADR(INTSTAL+1)} \)

\( \text{A} \leftarrow \text{CADR(ERASTAL2+1)} \)

INHINT

LOCK OUT

INTERRUPTS

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

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

JOY WAKE

WAKE UP A STALLED PROGRAM

FC-2050

NO

LOCCTR = -1

YES

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

TEST

STALTEM

\( \text{CLEAR FLGWRD10 BITS 5, 13} \)

\( \text{CLEAR FLGWRD10 BITS 5, 12} \)

RELINT

ALLOW INTERRUPTS

RETURN VIA QPRET

RETURN TO THE CALLING PROGRAM AT THE INTERPRETER LEVEL

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

COLOSSUS 2D
FC-2290
This routine is called once by PZ7 (the update program) to release its grab made via install of the integration routine.

Allow interrupts.

Save return address.

This flag is set if a CSM/LM state vector update is requested.

Prepare for updating by setting:

\[ \begin{align*}
\Gamma_{\text{CON}} &= \Gamma_0 \\
\nu_{\text{CON}} &= \nu_0 \\
\rho &= (0,0,0) \\
\nu &= (0,0,0) \\
t &= 0 \\
x &= 0
\end{align*} \]

Determine if state vector is in the earth's sphere of influence or moon's sphere of influence.

Do not update state vector.

Rectify [13D]

Store [VCC, \Delta TDLTA, TNU, \Delta TCR, \Delta TC]

Rectify [2500]

\[ \uparrow \text{PSVFLAG} \]

NO

YES

Intwakem

[PSVFLAG] = 2

Intwakec

\( x_2 \rightarrow 0 \)

Clear moonflag

\( x_2 \rightarrow 2 \)

Set moonflag

Intwake

Indicates w-matrix invalid for orbital navigation

Intwakek

Indicates w-matrix invalid for rendezvous navigation

Intwakup

Next sheet
FROM PRECEDING SHEET

UPSFLAG = 0

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

INTWAKED

WAKE UP ALL STALLED PROGRAMS

SHIE

GROUPS

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

RETURN VIA INTWAKED

INTEGRATION INITIALIZATION
AVETOMIC 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.

SAVE RETURN ADDRESS

THE W-MATRIX IS VALID FOR EITHER RENOEVUS OR ORBITAL NAVIGATION SO INTEGRATE IT TO PIPTIME.

LOAD LAST AVG TIME

INSTALL
WAIT UNTIL INTEGRATION SYSTEM AVAILABLE
SH10
INTEGRATION IS NOW RESERVE0

SET
OMDMSK
INTEGRATE THE W-MATRIX

PREVENT UPDATING THE DOWNLINK DATA RN, VN, PIPTIME0 IN SW01

DEFINE W-MATRIX AS 6 X 6

CLEAR
DGOR9FLG
INTEGRATE CSM STATE VECTOR

SET
VINTFLG
SET TDELL0
MPAC0
INTEGRATE PRETHRUST CSM STATE VECTOR AND W-MATRIX TO PIPTIME
SH8

SET TIME TO INTEGRATE TO EQUAL TO PIPTIME WHEN AVETOMIC CALLED

INPUT
1. PERMANENT CSM STATE VECT0R
2. TDELL = t5
3. W-MATRIX

OUTPUT
1. RAY = \frac{1}{t5} (t2)
2. VAY = \frac{v}{t5} (t2)
3. TAT0 \approx t5
4. W-MATRIX

NOW GO SET UP COASTING FLIGHT VARIABLES NEXT SHEET
FROM PRECEDING SHEET

SETCOAST

X2 ← 2

INSTALL
WAIT UNTIL INTEGRATION SYSTEM AVAILABLE
SH10

SET AMOONFLG CLEAR

X2 ← 0

RRECTV ← RNV · 2X2
RCVV ← RNV · 2X2

TETO ← PIPTIME_D

MPAV ← VṄ V · 2X2

MINIRECT
SET
VRECTV, VCVV, TOELTAV, TNUVV, TC0, XKEPD
FC-2300

MOVTHIS
DO AN UPDATE OF PERMANENT CSM STATE VECTOR
SH22

TRMKCNT ← 0

NEXT SHEET

ADJUST SCALING TO 2^29/2^27
AS APPROPRIATE FOR SPHERE OF INFLUENCE

@ 2^29

ADJUST SCALING TO 2^7/2^5
AS APPROPRIATE FOR SPHERE OF INFLUENCE

IN COLOSSUS MOVTHIS = MOVEACSM

SET TRACKING RADAR MARK COUNT TO ZERO
FROM PRECEDING SHEET

SET CMOONFLG LIKE AMOONFLG

SET: LM ON LUNAR SURFACE

SURFFLAG CLEAR

RETURN TO CALLER VIA CODING IN MEASUREMENT INCORPORATION ROUTINE.

FA2ABS
FC-2640

TDEC1 - PIPTIME0

SETIFLGS INITIALIZE FLAGS

SH3

CLEAR VINTFLAG

INTEGRATE LM STATE VECTOR

INTEGRV
INTEGRATE PRETHRUST LM STATE VECTOR TO PIPTIME

SH8

RETURN VIA EGRESS
MIDTOAV1 does precision integration of the CSM permanent state vector to the time \( t_2 \) specified in TDEC1. If this time is less than current time plus 10 seconds it is automatically set to this value. ALARM 1703 is set and following the integration return is to the return address plus one. MIDTOAV2 does a 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 \( FNV, VNV, PPTIME \).

MIDTOAV1

**INTEGRATE TO TIME**

\( t_2 \) in TDEC1

**RETURN** QPRET

SAVE RETURN ADDRESS

INSTALL

WAIT UNTIL INTEGRATION SYSTEM AVAILABLE

SH10

SET MIDIFLAG

INTEGRATE TO TIME IN TDEC1

LOADTIME

GET CURRENT TIME \( t_c \)

FC-2100

\( \Delta t_{12.5} = 12.5 \) sec

\( t_2 = t_2 + \Delta t \)

THE TIME \( t_2 \) IS OK TO USE

YES

NOTIME

CLEAR MIDIFLAG

IRETURN IRETURN +1

ERROR RETURN

ALARM 1703

T-TO-ADD \( \Delta t_{12.5} \)

RETURN VIA QPRET

ENTMID1

**DO NOT INTEGRATE THE W-MATRIX**

**SET** VINTFLAG

INTEGRATE CSM STATE VECTOR

RETURN VIA QPRET

NEXT SHEET

MIDTOAV2

**INTEGRATE TO CURRENT TIME**

\( t_c \) plus 12.5 SEC

**RETURN** QPRET

SAVE RETURN ADDRESS

INSTALL

WAIT UNTIL INTEGRATION SYSTEM AVAILABLE

SH10

CLEAR MIDIFLAG

INTEGRATE TO \( t_c + \Delta t \)

T-TO-ADD \( \Delta t_{12.5} \)

\( \Delta t = \Delta t_{12.5} = 12.5 \) sec

LOADTIME

GET CURRENT TIME \( t_c \)

FC-2100

\( 1.\text{MPAC}_D = t_c = \text{CURRENT TIME} \)

\( t_2 = t_2 + \Delta t \)

TDEC1 \( \rightarrow \text{MPAC}_D + T-\text{TO-ADD}_D \)

TIME TO INTEGRATE TO EQUALS CURRENT TIME + 12.5 SEC

PDRM

ERROR RETURN

INSUFFICIENT TIME, SLIP IT 10 SEC.

RETURN VIA QPRET

ENTMID2

**DO NOT INTEGRATE THE W-MATRIX**

**SET** VINTFLAG

INTEGRATE CSM STATE VECTOR

RETURN VIA QPRET

NEXT SHEET
DO PRECISION INTEGRATION

INDICATE TO INTEGRATION THAT IT WAS CALLED BY THE MIDTOAVE ROUTINE

INPUT
1. PERMANENT CSM STATE VECTOR
2. TDEC1 = t2
3. INTERPRETIVE FLAGS

OUTPUT
1. RATT = \mathbf{f}(t2)
2. VATT = \mathbf{v}(t2)
3. TATD \approx t2

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

STORE THE OUTPUT OF INTEGRY

INHIBIT INTERRUPTS

COMPUTE A DELTA TIME EQUAL TO TIME ACTUALLY INTEGRATED TO MINUS THE CURRENT TIME IN TIME 2, TIME1

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

INTEGRATION INITIALIZATION
USEPIOS IS EXECUTED INSTEAD OF THE NORMAL CODING IN PTOALEM IF THE LM IS ON THE SURFACE OF THE MOON. THE LM POSITION AND VELOCITY VECTORS ARE CALCULATED USING THE PLANETARY INERTIAL ORIENTATION SUBROUTINE INSTEAD OF USING THE NORMAL INTEGRATION ROUTINES. SINCE THE LANDING SITE MOVES RELATIVE TO THE BASIC REFERENCE SYSTEM BECAUSE OF LUNAR ROTATION IT IS MORE CONVENIENT TO STORE THE LM STATE VECTOR IN THE MOON FIXED COORDINATE SYSTEM WHERE IT DOES NOT CHANGE IN TIME. THIS ROUTINE CONVERTS THE RLS TO THE BASIC REFERENCE COORDINATE SYSTEM.
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOADTIME</td>
<td>2100</td>
<td>LOAD TIME1 AND TIME2 (CURRENT TIME) INTO MPAC</td>
<td>SH, 3, 19</td>
</tr>
<tr>
<td>JOBSLEEP</td>
<td>2050</td>
<td>PUT CALLING PROGRAM TO SLEEP</td>
<td>SH, 10</td>
</tr>
<tr>
<td>SVDDWN1</td>
<td>2250</td>
<td>GET RECTIFIED CSM STATE VECTOR FOR DOWNLINK</td>
<td>SH, 5</td>
</tr>
<tr>
<td>SVDDWN2</td>
<td>2250</td>
<td>GET RECTIFIED LM STATE VECTOR FOR DOWNLINK</td>
<td>SH, 5</td>
</tr>
<tr>
<td>RECTIFY</td>
<td>2300</td>
<td>DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS</td>
<td>SH, 8, 9</td>
</tr>
<tr>
<td>RECTIFY +13D</td>
<td>2300</td>
<td>SPECIAL ENTRY TO RECTIFY (ABOVE)</td>
<td>SH, 14</td>
</tr>
<tr>
<td>TESTLOOP</td>
<td>2300</td>
<td>ENTRY POINT FOR PRECISION INTEGRATION</td>
<td>SH, 8</td>
</tr>
<tr>
<td>MINIRECT</td>
<td>2300</td>
<td>SPECIAL ENTRY TO RECTIFY (ABOVE)</td>
<td>SH, 17</td>
</tr>
<tr>
<td>KEPREP</td>
<td>2300</td>
<td>ENTRY POINT FOR CONIC (KEPLER) INTEGRATION</td>
<td>SH, 9</td>
</tr>
<tr>
<td>RECTOUT</td>
<td>2300</td>
<td>ENTRY POINT FOR COMPLETING AN INTEGRATION</td>
<td>SH, 9</td>
</tr>
<tr>
<td>JOBWAKE</td>
<td>2050</td>
<td>WAKE UP A SLEEPING JOB</td>
<td>SH, 13</td>
</tr>
<tr>
<td>FAZAB5</td>
<td>2610</td>
<td>ENTRY POINT IN INCORP ROUTINE FOR ENDING AVIATOR ROUTINE</td>
<td>SH, 18</td>
</tr>
<tr>
<td>RP TO P</td>
<td>2283</td>
<td>CONVERT A VECTOR FROM MOON COORDINATES TO BASIC REFERENCE COORDINATES</td>
<td>SH, 21</td>
</tr>
<tr>
<td>A-CHK</td>
<td>2300</td>
<td>ENTRY POINT FOR PERFORMING AN UPDATE AND RECTIFICATION</td>
<td>SH, 21</td>
</tr>
</tbody>
</table>

### FLAGS

<table>
<thead>
<tr>
<th>NAME (BIT, FLAGW)</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTYPFGLG (4, 3)</td>
<td>DO CONIC (KEPLER) INTEGRATION</td>
<td>DO PRECISION (ENCE) INTEGRATION</td>
<td>SH, 7</td>
<td>SH, 3, 6, 10</td>
<td>SH, 8</td>
</tr>
<tr>
<td>VINTFLAG (3, 3)</td>
<td>INTEGRATE THE CSM STATE VECTOR</td>
<td>INTEGRATE THE LM STATE VECTOR</td>
<td>SH, 4, 6</td>
<td>SH, 4, 6, 7, 10</td>
<td>SH, 8</td>
</tr>
<tr>
<td>DIMOFGLG (1, 3)</td>
<td>INTEGRATE THE W-MATRIX</td>
<td>DO NOT INTEGRATE THE W-MATRIX</td>
<td>SH, 4, 16</td>
<td>SH, 3, 6, 7, 18</td>
<td>SH, 8</td>
</tr>
<tr>
<td>D50R5FLG (2, 3)</td>
<td>W-MATRIX IS 5x5</td>
<td>W-MATRIX IS 5x5</td>
<td>SH, 4, 16</td>
<td>SH, 3, 6, 7, 18</td>
<td>SH, 8</td>
</tr>
<tr>
<td>STATEFLG (5, 3)</td>
<td>UPDATE PERMANENT CSM/LM STATE VECTOR</td>
<td>DO NOT UPDATE PERMANENT CSM/LM STATE VECTOR</td>
<td>SH, 3</td>
<td>SH, 3</td>
<td>SH, 3</td>
</tr>
<tr>
<td>NODOFLAG (1, 2)</td>
<td>VERB 37 IS NOT PERMITTED</td>
<td>VERB 37 IS PERMITTED</td>
<td>SH, 3</td>
<td>SH, 4</td>
<td>SH, 3</td>
</tr>
<tr>
<td>QUITFLAG (5, 8)</td>
<td>DISCONTINUE INTEGRATION AT START OF NEXT TIMESTEP</td>
<td>CONTINUE INTEGRATION</td>
<td>SH, 3</td>
<td>SH, 4</td>
<td>SH, 4</td>
</tr>
<tr>
<td>SURFFLAG (8, 8)</td>
<td>LM IS ON LUNAR SURFACE</td>
<td>LM IS NOT ON LUNAR SURFACE</td>
<td>SH, 4, 5, 14</td>
<td>SH, 4, 16</td>
<td>SH, 4, 16</td>
</tr>
<tr>
<td>RENWFLG (1, 5)</td>
<td>W-MATRIX IS VALID FOR RENDEZVOUS NAVIGATION</td>
<td>W-MATRIX IS INVALID FOR RENDEZVOUS NAVIGATION</td>
<td>SH, 14</td>
<td>SH, 4, 16</td>
<td>SH, 4, 16</td>
</tr>
<tr>
<td>NAME (BIT, FLAGWRD)</td>
<td>MEANING WHEN SET</td>
<td>MEANING WHEN CLEAR</td>
<td>WHERE SET</td>
<td>WHERE CLEARED</td>
<td>WHERE TESTED</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>-----------</td>
<td>---------------</td>
<td>--------------</td>
</tr>
<tr>
<td>PRECIFLG (8, 3)</td>
<td>CSMPREOR LEMPREC WAS CALLED</td>
<td>INTEGRV OR INTEGRV'S WAS CALLED</td>
<td>SH, 4, 6, 8</td>
<td>SH, 4</td>
<td></td>
</tr>
<tr>
<td>MOONFLAG (12, 0)</td>
<td>INSIDE LUNAR SPHERE OF INFLUENCE</td>
<td>OUTSIDE LUNAR SPHERE OF INFLUENCE</td>
<td>SH, 5, 14, 21</td>
<td>SH, 5, 8</td>
<td></td>
</tr>
<tr>
<td>CMOONFLG (12, 8)</td>
<td>(PERMANENT CSM REPRESENTATION OF MOONFLAG)</td>
<td></td>
<td>SH, 5, 18</td>
<td>SH, 5</td>
<td></td>
</tr>
<tr>
<td>LMoonFLG (11, 8)</td>
<td>(PERMANENT LM REPRESENTATION OF MOONFLAG)</td>
<td></td>
<td>SH, 5</td>
<td>SH, 5</td>
<td></td>
</tr>
<tr>
<td>NEWFLG (13, 8)</td>
<td>INITIAL PASS THROUGH INTEGRATION LOOP</td>
<td>SUBSEQUENT PASS THROUGH INTEGRATION LOOP</td>
<td>SH, 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPQFLAG (15, 8)</td>
<td>RPQ NOT COMPUTED</td>
<td>RPQ COMPUTED</td>
<td>SH, 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INTFLAG (11, 10)</td>
<td>INTEGRATION IS IN PROGRESS</td>
<td>INTEGRATION IS NOT IN PROGRESS</td>
<td>SH, 11</td>
<td>SH, 13</td>
<td>SH, 10</td>
</tr>
<tr>
<td>REINTFLG (7, 10)</td>
<td>RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS</td>
<td>DO NOT RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS</td>
<td>SH, 13</td>
<td>SH, 10, 12</td>
<td></td>
</tr>
<tr>
<td>MIDAVFLG (2, 9)</td>
<td>INTEGRATION WAS CALLED BY THE MIDTOAV ROUTINE</td>
<td>INTEGRATION WAS NOT CALLED BY THE MIDTOAV ROUTINE</td>
<td>SH, 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIDIFLAG (3, 9)</td>
<td>INTEGRATE TO TIME IN TDEC</td>
<td>INTEGRATE TO CURRENT TIME PLUS 10 SECONDS</td>
<td>SH, 19</td>
<td>SH, 19</td>
<td></td>
</tr>
<tr>
<td>V9S0NFLG (5, 8)</td>
<td>POO INTEGRATION INHIBITED BY V9S0</td>
<td>POO INTEGRATION PROCEEDING REGULARLY</td>
<td>SH, 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVEMIDSW (1, 9)</td>
<td>PREVENT UPDATING THE CSM DOWNLINK DATA RN, VN, PIETME</td>
<td>ALLOW UPDATING THE CSM DOWNLINK DATA RN, VN, PIETME</td>
<td>SH, 16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPSVFLAG (6, 3)</td>
<td>CSM/LM STATE VECTOR UPDATE IS REQUESTED</td>
<td>CSM/LM STATE VECTOR UPDATE NOT REQUESTED</td>
<td>SH, 15</td>
<td>SH, 14</td>
<td></td>
</tr>
<tr>
<td>GRBWFLAG (6, 3)</td>
<td>W-MATRIX IS VALID FOR ORBITAL NAVIGATION</td>
<td>W-MATRIX IS INVALID FOR ORBITAL NAVIGATION</td>
<td>SH, 14</td>
<td>SH, 4, 16</td>
<td></td>
</tr>
<tr>
<td>AMOONFLG (2, 0)</td>
<td>STATE VECTOR IN EARTH SPHERE AT MIDTOAVE</td>
<td>STATE VECTOR IN EARTH SPHERE AT MIDTOAVE</td>
<td>SH, 20</td>
<td>SH, 17, 18</td>
<td></td>
</tr>
<tr>
<td>POOFLAG (9, 3)</td>
<td>IN PROGRAM POO</td>
<td>NOT IN PROGRAM POO</td>
<td>SH, 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VERB-NOUN</th>
<th>TYPE OF DISPLAY</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALARM</td>
<td>ALARM CODE = 1703</td>
<td>INSUFFICIENT TIME FOR INTEGRATION, TIG WAS SLIPPED</td>
<td>SH, 19</td>
</tr>
<tr>
<td>AGC TAG</td>
<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING UNITS</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>---------</td>
<td>-------------------</td>
</tr>
<tr>
<td>TDEC1D</td>
<td>t</td>
<td>TIME TO INTEGRATE TO</td>
<td>CSEC</td>
</tr>
<tr>
<td>TETCSM1D</td>
<td>t</td>
<td>TIME TO INTEGRATE TO IN P00</td>
<td>CSEC</td>
</tr>
<tr>
<td>RcV_V</td>
<td>r_con</td>
<td>CONIC POSITION VECTOR</td>
<td>M</td>
</tr>
<tr>
<td>VcV_V</td>
<td>v_con</td>
<td>CONIC VELOCITY VECTOR</td>
<td>M/CSEC</td>
</tr>
<tr>
<td>TETD</td>
<td>t</td>
<td>TIME OF VALIDITY OF STATE VECTOR</td>
<td>CSEC</td>
</tr>
<tr>
<td>RRECTV</td>
<td>r_o</td>
<td>POSITION VECTOR AT RECTIFICATION</td>
<td>M</td>
</tr>
<tr>
<td>VRECTV</td>
<td>v_o</td>
<td>VELOCITY VECTOR AT RECTIFICATION</td>
<td>M/CSEC</td>
</tr>
<tr>
<td>TDELTAV_V</td>
<td>e</td>
<td>POSITION DEVIATION VECTOR</td>
<td>M</td>
</tr>
<tr>
<td>TNUV_V</td>
<td>u</td>
<td>VELOCITY DEVIATION VECTOR</td>
<td>M/CSEC</td>
</tr>
<tr>
<td>TCD</td>
<td>t_{21}</td>
<td>TIME SINCE RECTIFICATION</td>
<td>CSEC</td>
</tr>
<tr>
<td>XKEP_D</td>
<td>x</td>
<td>UNIVERSAL VARIABLE</td>
<td>M^{1/2}</td>
</tr>
<tr>
<td>TDEC_D</td>
<td>t</td>
<td>TIME TO INTEGRATE TO</td>
<td>CSEC</td>
</tr>
<tr>
<td>PBOY</td>
<td>P</td>
<td>PRIMARY BODY INDICATOR</td>
<td>INTEGER</td>
</tr>
<tr>
<td>RETURN</td>
<td></td>
<td>LOCATION FOR STORING RETURN ADDRESS</td>
<td>INTEGER</td>
</tr>
<tr>
<td>TAU_D</td>
<td>r</td>
<td>TIME INTERVAL FOR CONIC INTEGRATION</td>
<td>CSEC</td>
</tr>
<tr>
<td>TBASE2</td>
<td></td>
<td>TEMPORARY STORAGE FOR RETURN ADDRESS</td>
<td>INTEGER</td>
</tr>
<tr>
<td>STALTEN</td>
<td></td>
<td>TEMPORARY STORAGE FOR SUBSCRIPT k</td>
<td>INTEGER</td>
</tr>
<tr>
<td>EGRESS</td>
<td></td>
<td>LOCATION FOR STORING RETURN ADDRESS</td>
<td>INTEGER</td>
</tr>
<tr>
<td>PIPTIME_D</td>
<td>t</td>
<td>BURN TIME</td>
<td>CSEC</td>
</tr>
<tr>
<td>TAT_D</td>
<td>t</td>
<td>TIME ACTUALLY INTEGRATED TO</td>
<td>CSEC</td>
</tr>
<tr>
<td>TRMKCNT</td>
<td></td>
<td>TRACKING RADAR MARK COUNT</td>
<td>INTEGER</td>
</tr>
<tr>
<td>RN_V</td>
<td>r_con</td>
<td>POSITION VECTOR OF CSM FOR DOWNLINK</td>
<td>M</td>
</tr>
<tr>
<td>VN_V</td>
<td>v_con</td>
<td>VELOCITY VECTOR OF CSM FOR DOWNLINK</td>
<td>M/CSEC</td>
</tr>
<tr>
<td>R-OTHER_V</td>
<td>r_con</td>
<td>POSITION VECTOR OF LM FOR DOWNLINK</td>
<td>M</td>
</tr>
<tr>
<td>V-OTHER_V</td>
<td>v_con</td>
<td>VELOCITY VECTOR OF LM FOR DOWNLINK</td>
<td>M/CSEC</td>
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</tbody>
</table>
### PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΩMOON</td>
<td>(0, 0, 0)</td>
<td>THE ZERO VECTOR</td>
<td>2.66169847 x 10^{-8}</td>
<td>(0, 0, 0, 0, 0)</td>
<td>2^{-23}</td>
</tr>
<tr>
<td>ZEROVEC</td>
<td>(0, 0, 0)</td>
<td>INTEGER 2</td>
<td>2</td>
<td>2</td>
<td>ANY</td>
</tr>
<tr>
<td>UPMSVCD</td>
<td>Δt12.5</td>
<td>USED IN TEST TO DETERMINE IF TIME TO INTEGRATE TO MUST BE SLIPPED</td>
<td>12.5 SEC</td>
<td>1250 CSEC</td>
<td>2^{28}</td>
</tr>
<tr>
<td>S/8</td>
<td>Δt12.5</td>
<td>A NON-ZERO CONSTANT</td>
<td>5/8</td>
<td>5/8</td>
<td>2^{3}</td>
</tr>
</tbody>
</table>

### PAD LOADS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
<th>OCTAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSL</td>
<td>rLS</td>
<td>LUNAR LANDING SIGHT VECTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Orbital Integration

## Major Subroutines and External Entry Points

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<th>Subroutine</th>
<th>Description</th>
<th>Page</th>
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<td>TESTLOOP</td>
<td>Entry to Actual Integration Loop</td>
<td>SH. 3</td>
</tr>
<tr>
<td>TIMESTEP</td>
<td>Intermediate Entry Point in Integration Loop</td>
<td>SH. 6</td>
</tr>
<tr>
<td>INTEGRATE</td>
<td>Intermediate Entry Point in Integration Loop that initializes locations for first pass through loop</td>
<td>SH. 8</td>
</tr>
<tr>
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## References for Orbital Integration

THE TIME TO INTEGRATE TO $t_2$ IS STORED IN TDEC0.

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

STOP THE INTEGRATION BECAUSE FLAG IS SET AS A RESULT OF REQUESTING VERE 30. STATEFLG MUST BE LEFT IN A CLEAR CONDITION UPON RETURN FROM INTEGRATION.

THIS clears SEVEflS flags and goes to INTAKE, FC-2290.

SET PULL LIST

POINTER TO PL10

X2 = PBODY

PRIMARY BODY INDICATOR IS STORED IN X2.

CON = $\frac{R_{\text{CON}}}{2}$

$\frac{R_{\text{CON}}}{2}$

RCV = $\frac{R_{\text{CV}}}{2}$

RCV = $\frac{R_{\text{CV}}}{2}$

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FROM PRECEDING SHEET

SHIFT AND LOAD MPAC SUCH THAT $\frac{3\sqrt{3}}{\mu_p}$ IS TRUNCATED TO A MULTIPLE OF 128 CSECS, SCALED AT $2^{20}$

$$\Delta t_{\text{max}} = \frac{3\sqrt{3}}{\mu_p} \text{CON} \frac{1}{\text{FL120}} \rightarrow \text{MPACD}$$

OVERFLOW YES

NO

DT/2 MAX = 4000 SECS AT 2^{20}

$\Delta t_{\text{max}} > 4000$ SECS YES

LIMIT $\Delta t_{\text{max}}$ TO THE MAXIMUM VALUE ALLOWED

NO

$\Delta t_{\text{max}} = 4000$ SEC

$$\text{FL120} \rightarrow \frac{\text{DT}}{\text{E MAX D}} @ 2^{20}$$

AT THIS POINT $\Delta t_{\text{max}} < \Delta t_{\text{min}}$

$\left(\frac{3\sqrt{3}}{\mu_p}, 4000 \text{ SEC}\right)$

CALCULATE $\Delta t$, GUARANTEEING THAT $\Delta t \leq \Delta t_{\text{max}}$

$\Delta t = t_2 - t_1$

MPACD \rightarrow TDEC1 - TETD @ 2^{20}

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

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

SHIFTCMP LEFT 8 PLACES TO SCALE $\Delta t$ AT $2^{20}$ AND STORE IN DT/2D

STORE $\Delta t$ AT $2^{20}$, THIS CAN ALSO BE CONSIDERED AS $4\frac{1}{2}$ AT $2^{19}$

NEXT SHEET

ORBITAL INTEGRATION

COLOSSUS FC-2300
FROM PRECEDING SHEET

CLEAR

NEWIFLG

SET

CLEAR NEWIFLG

$\Delta t \geq t_1$ NO

FORM $t_\Delta - t_1$

$PL_0 \rightarrow TDEC_0 - TET_0$

@ $2^{20}$

DO NOT INTEGRATE

$SH\_40$

$T_\Delta$ is the time interval between present time as used in integration loop (TET) and upper limit (TDEC) in POO.$t_\Delta$ equals current real time, approx

FORM $4\Delta t$

$MPAC_0 \rightarrow DT/2^0$

SHIFTED AND ROUNDED @ $2^{20}$

$DT/2^0$ contains at @ $2^{20}$

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

YES

$SH\_40$

INTEXIT

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

PERFORM A SERIES OF TESTS TO DETERMINE IF RECTIFICATION IS REQUIRED

Timestep

MIDFLAG

SET

CLEAR SKIP ORIGIN CHANGE LOGIC

CHKS WITCH

CHECK FOR SPHERE OF INFLUENCE

$SH\_45$

OUTPUT: $MPAC_0 = \text{DISTANCE FROM LUNAR SPHERE}$

NO $MPAC_0 < 0$

YES

NO SOLAR PERTURBATIONS

RECTEST

NEXT SHEET

IN LUNAR SPHERE SO CHANGE ORIGIN OF COORDINATES

DOSWITCH

NEXT SHEET

ORBITAL INTEGRATION

FC-2300
This is the entry sequence for initializing locations for the first pass through the integration loop. Locations are set up for integrating the state vector since the state vector is always integrated first.

\[ ZV \leftarrow TNV @ z^{n/2} \]
\[ YV \leftarrow TDELTA V @ z^{3/2} \]

Store \( u, \delta \) in working storage prior to integrating the state vector.

Initialize to indicate the state vector and not the \( W \)-matrix is being integrated.

This is the entry point for initializing locations prior to making three passes through the integration loop (for \( i = 1, 2, 3 \)) to the vector being integrated over a time interval of \( \Delta t \) is either a state vector or a vector in the \( W \)-matrix.

\[ j = 1 \]
\[ DIFEQCNT \leftarrow 0 \]

\[ \frac{\Delta y}{\Delta x} = \frac{\delta V}{YV} @ z^{3/2} \]

\[ \delta j \] is the estimate of \( \delta \) used on each of the three passes through the integration loop.

\[ \Delta x = 0 \]
\[ \delta V = 0 \]

Initialize \( j \).

\( j \) takes on the values \( 1, 2, 3 \) corresponding to the left point, midpoint, and right point of an interval of length \( \Delta t \).

DIFEQCNt takes on the value 0, 120, -240.

\[ \delta j \] takes on the values 0, \( \delta^* \), \( \delta^* \) corresponding to the left point, midpoint, and right point value of the interval \( \Delta t \).

\[ \Delta x = 0 \]
\[ \delta V = 0 \]

Clear JSWITCH SET

INTEGRATE THE STATE VECTOR

INCOMP SH9

Integrate a vector from the \( W \)-matrix

DOW SH41

Orbital Integration

FC-2300

FROM PRECEDING SHEET

CALCULATE THE DISTURBING ACCELERATIONS
\[ a_{de} + a_{ds} \]

INPUT:
1. MPAC0 = GROUND ELAPSED TIME

OUTPUT:
1. MPACV = \( \Gamma_{EM} \) POSITION OF MOON, 2
2. PL2V = \( \Gamma_{ES} \) POSITION OF SUN, 2

X1 \( \rightarrow \) 62

CLEAR MOONFLAG SET

X2 \( \rightarrow \) 2

SET UP FOR EARTH PRIMARY
\( \Gamma_{PS} = \Gamma_{EM} \)

\( \Gamma_{PS} \rightarrow -\Gamma_{EM} \)

MPACV \( \rightarrow \) \( \text{MPACV} \)

X2 \( \rightarrow \) 0

STORE \( \Gamma_{PS} \)

RPQV, BETAV, MPACV @ 2

NEXT SHEET

SET UP FOR MOON PRIMARY
EQ 2.2.19, PAGE
FROM PRECEDING SHEET

STORE \( r_{ES} \)

\[ \text{RPSV} \leftarrow \text{PL2V} \]

\( @ 2^{18} \)

DIMOFLAG

CLEAR

SET

\( x_2 \rightarrow \text{DIFQGNT} \)

NO W-MATRIX INTEGRATION

\[ x_2 = 0, -12D, -24D \]

LOAD \( x_2 \) WITH POINTER

\[ r_{ac} = r - r_{pe} \]

\[ MPAC = \alpha + \alpha \] \( \text{ALPHA}_V + \alpha \] \( \text{BETA}_V \)

\( @ 2^{18} \)

\[ \frac{\text{VECTOR} + 6 \# x_2}{V} \rightarrow MPAC \]

STORE \( r_{ac} \) IN TABLE

\[ x_2 \rightarrow \text{DIFQGNT} \]

RESTORE VALUES

NEXT SHEET

EQA 2.2.21,

PAGE 5.2-19
FROM PRECEDING SHEET

OBLATE

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

SET PUSH LIST POINTER TO ZERO

\( \Gamma \) IS THE MAGNITUDE OF THE LATEST ESTIMATE OF THE PRECISION POSITION. IT EQUALS \( R \); \( \Gamma_{dp} \) IS THE RADII OF RELEVANCE OF THE PRIMARY BODY. IF THE SPACECRAFT IS OUTSIDE OF THIS SPHERE THEN THE ACCELERATION \( \Phi_{dp} \) IS IGNORED.

\[ \gamma \geq \Gamma_{dp} \]

YES

SPACECRAFT IS INSIDE SPHERE OF RELEVANCE SO CALCULATE \( \Phi_{dp} \)

NO

SPACECRAFT IS OUTSIDE SPHERE OF RELEVANCE

\[ \text{NBRANCH} \]

\[ \text{SH21} \]

DO NOT CALCULATE \( \Phi_{dp} \)

NEXT SHEET
FROM PRECEDING SHEET

\[ f_j = f_j + \frac{d_h}{d_w} \]

\[ MPAC_y = FV_y + MPAC_y \cdot \text{2ED-XI} \]

\[ a_{LDMC} + \text{ZONAL OBLATE} \]

OVERFLOW

YES

GOBAQUE

SH 22

NO

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

MOONFLAG

CLEAR

SET

NBRANCH

SH 21

THE FOLLOWING CALCULATIONS VALID FOR MOON ONLY

form \[ \frac{5(\xi^2 - \eta^2)}{R_s \cdot R_m} \]

\[ PL_2 V = \frac{5(\text{URPV} + 2 \cdot \text{URPV}) \cdot \text{ALPHA}_V}{\text{SCALED @ 2}^3} \]

\[ \text{equivalent to} \quad \frac{2 \xi M}{R_s} + \frac{5(\xi^2 - \eta^2)}{R_s^2} \]

\[ PL_2 V = PL_2 V + \text{URPV} \cdot PL_3 V \cdot \text{SCALED @ 2}^3 \]

\[ \text{equivalent to} \quad \frac{5(\xi^2 - \eta^2)}{R_s^2} + \frac{2 \xi M}{R_s} + \frac{2 \eta M \cdot \frac{\xi}{R_s}}{R_s} \]

\[ PL_2 V = PL_2 V + 2 \cdot (\text{URPV} + 2) \cdot (PL_3 V \cdot \text{XUZ}_V) \]

\[ MPAC_0 = \text{COSP}H / 2 \]

NEXT SHEET
GOBAQUE IS ENTERED IF EITHER:
1. OVERFLOW OCCURRED IN GAMCOMP WHEN THE SECOND DERIVATIVE INCREMENT WAS ADDED TO $E_2$ OR,
2. OVERFLOW OCCURRED IN OBLATE WHEN $Q_{dp}$ WAS ADDED TO $O_{dp}$.
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.

$\lambda = 0, \frac{\pi}{2}, \pi$

$t_d =$ DESIRED TRANSFER TIME. IT MUST BE REDUCED BY $\lambda$ TO MAKE IT CORRESPOND TO THE PREVIOUS VALUE OF $\lambda$ SINCE RESULTS WERE VALID FOR THAT VALUE OF $\lambda$ (I.E., THERE WAS NO OVERFLOW).

$t_d$ IS REDUCED BY $\lambda$ TO MAKE IT AGREE WITH TIME OF VALIDITY OF $RCV_{V}, VCV_{V}$.

INPUT
1. PBODY = 0 FOR EARTH
2. $RCV_{V} =$ (t)
3. $VCV_{V} =$ (t)
4. $KEP_{D} =$ CONVERGED
5. TAU =$t_{D}, \text{DESIRED TIME}$
6. $TC_{D} =$ \text{XPREV} \times x KEP_{D}
7. MOONFLAG = SET FOR MOON

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

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

THIS INDICATES THE VECTOR RPQ MUST BE CALCULATED.

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

POO0000 CLEANS OUT ALL RESTARTS (EXCEPT THOSE ASSOCIATED WITH SERVICER, IF RUNNING).
DOES A RESTART, RESULTING IN POO.
LIGHTS ALARM LIGHT, SETS ALARM CODE (OCT 20430; POSITION DEVIATION VECTOR = 0)

ORBITAL INTEGRATION

FC-2300
GAMCOMP

SET PUSH LIST
POINTER TO ZERO

STORE ρ_i^2 = β_i^2 \cdot |E|^2
PLD0 = β_WV \cdot β_WV
SHIFTED AND NORMALIZED

STORE ρ_i = ρ_i \cdot |E|_i
PLD0 = ALPHAMO
NORMALIZED AND SHIFTED

θ_i = (ρ_i)UNIT = Λ_i
ρ_i = |β_i| = r
β_WV = UNIT (β_WV)
β_WMO = [β_WV]

NORMALIZE β_i
MPACO = β_WMO
NORMALIZED

ρ_j = ρ_i \cdot \frac{5}{r}
PLD0 = PLD0 \cdot \frac{MPACO @ 2^{m+n+1}}{PLD0}

X1 = 0
S1 ← -7
S2 ← -6
FOR EARTH

EXCHANGE X2 AND S1

X2 = -7/2

FORM SCALING VALUE -7/2 + MPACO
X2 ← X2 + PL32 - PL33

LOAD AND SHIFT β_i
MPACO ← PLD0 \cdot 2^{m+n}

NEXT SHEET

THE VALUE ρ_i^2 IS NORMALIZED AND ROUNDED BEFORE IT IS STORED. THE NORMALIZING VALUE -M IS STORED IN PL31

THE NORMALIZING VALUE -M IS STORED IN PL32

THE NORMALIZING VALUE -M IS STORED IN PL33

ORBITAL INTEGRATION
FC-2300
FROM PRECEDING SHEET

EXCHANGE S1 AND X2

STORE $P_j$

$PL_0 \leftarrow UPACD @ 2^1$

STORE $P_j$

$PL_0 = MPACD$ shifted @ $2^2$

FORM $2^{W_J + H_J}$

$MPACD = 2 \alpha \alpha \alpha + 2 \beta \beta \beta @ 2^1$

FORM $P_j \leftarrow 2^{W_j + H_j}$

$PL_0 = MPACD = PL_0 + MPACD @ 2^2$

$\gamma_j = (P_j + 2^{W_j + H_j} P_j)$

$PL_0 = MPACD = MPACD \cdot PL_0$

shifted @ $2^2$

FORM $1 + Q_j$

$PL_0 = MPACD = DQUARTERD + MPACD$

shifted @ $2^2$

FORM $(1 - \frac{Q_j}{2})^{\frac{1}{2}}$

$PL_0 = MPACD = PL_0 + MPACD$

@ $2^3$

FORM $1 + (1 \cdot \frac{Q_j}{2})^{\frac{1}{2}}$

$PL_0 = DQUARTERD + MPACD$

shifted @ $2^2$

FORM $(1 + Q_j + 2^{W_j + H_j})$

$5 + 3 \gamma_j + \gamma_j^2 = f(j)$

$1 + (1 + \frac{Q_j}{2})^{\frac{1}{2}}$

$1 + (1 + \frac{Q_j}{2})^{\frac{1}{2}}$

$\gamma_j$

$MPACD = (PL_0 + HALFDPD) \cdot PL_0 + THREE \cdot PL_1^4 D @ 2^5$

MULTIPLICATION BY $2$ IS ACCOMPLISHED BY A LEFT SHIFT OF ONE PLACE

DQUARTERD = $1.0 @ 2^2$

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

EQ 2.2.10, REF 1
HALFDPD = $2.0 @ 2^2$
THREE/BD = $3.0 @ 2^3$
The numerator is shifted left 1 place prior to adding THREE/BD

NEX SHEET

ORBITAL INTEGRATION

COLOSSUS FC-2300
FROM PRECEDING SHEET

\[
\begin{align*}
\text{FORM } & \frac{f(x_j)}{x_j} = f(x_j) \\
\text{MPAC}_D & \leftarrow \text{MPAC}_D \cdot \text{PL6}_D @ z^3
\end{align*}
\]

\[
\begin{align*}
\text{FORM } & \frac{f(x_j)}{x_j^2} \text{ UJa} + Ujk \\
\text{PL16}_V & \leftarrow \text{MPAC}_D \cdot \text{BETA}_D \cdot \text{ALPHA}_V @ z^4
\end{align*}
\]

\[
\begin{align*}
\text{FORM } & \frac{\beta_j}{x_j^2} \frac{(1+q_j)^{3/2}}{x_j^2} \\
\text{MPAC}_D & \leftarrow \text{PL6}_D \cdot \text{PL12}_D \text{ NORMALIZED AND ROUNDED}
\end{align*}
\]

\[
\begin{align*}
\text{FORM } & \frac{\beta_j}{x_j^2} \frac{(1+q_j)^{3/2}}{x_j^2} \\
\text{MPAC}_D & \leftarrow \text{MPAC}_D
\end{align*}
\]

\[
\begin{align*}
\text{FORM } & \frac{\mu_p}{x_j^2} \frac{R_j}{x_j^2} \frac{(1+q_j)^{3/2}}{x_j^2} \\
\text{MPAC}_E & \leftarrow (\text{MEARTH} \cdot x)_D \cdot \text{MPAC}_D
\end{align*}
\]

\[
\begin{align*}
\text{FORM } & -\frac{\mu_p}{x_j} \frac{R_j}{x_j} \frac{(1+q_j)^{3/2}}{x_j^2} \left[ f(x_j) \text{ UJa} + Ujk \right] \\
\text{MPAC}_V & \leftarrow \text{MPAC}_D \cdot \text{PL16}_V
\end{align*}
\]

EXCHANGE XE AND S31

LOAD -7/-9 INTO XE

FORM\((-7/-9)+(6/-9)-(5/-9)-(1/-9)=-13.5m\) \[\text{XE} = \text{XE} + \text{S2} - \text{PL30} - \text{PL31}\]

THIS IS THE UNNORMALIZING VALUE

CLEAR OVFIND

TURN OFF OVERFLOW INDICATOR

NEXT SHEET
FROM PRECEEDING SHEET

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

EXCHANGE XE AND S1

RESTORE XE

\[ L_j = \frac{\Delta p_i}{B_j^2 (1+q_j)} \left[ \frac{f(j)}{f_j} \right] \left[ \frac{u_j}{u_j + u_j} \right] \]

FW = FW + MPACV

THIS ADDS TO THE SECOND DERIVATIVE \( \frac{d^2}{dx} \varphi(t) \) THE

AMOUNT = \( \frac{\Delta p_i}{B_j^2 (1+q_j)} \left[ f(j) \varphi(t) + \varphi'(t) \right] \)

EQ 2.2.7

OVERFLOW

YES

RETURN VIA GORET

NO

GOBAQUE SH22

GO BACK AND DO A KEPPLER UPDATE, RECTIFY AND ATTEMPT INTEGRATING AGAIN

THE DIFFERENTIAL EQUATION FOR THE ENCKE VARIABLE \( \varphi(t) \) CAN BE WRITTEN AS:

\[ \frac{d^2}{dt^2} \varphi(t) = \frac{\Delta p_i}{B_j^2 (1+q_j)} \left[ f(j) \varphi(t) + \varphi'(t) \right] + 2 \Delta p(t) \]  

EQ 2.2.7

THE FIRST TERM ON THE RIGHT, CALLED \( \gamma_j \), IS EVALUATED IN GACOMP AS PART OF THE NYSTRÖM INTEGRATION SCHEME IN THE SUBSCRIPTED FORM:

\[ \gamma_j = -\frac{\Delta p_i}{B_j^2 (1+q_j)} \left[ f(j) \right] \left[ \frac{u_j}{u_j + u_j} \right], \text{ FOR A GIVEN } j. \]

THE FOLLOWING SHOWS THAT \( \gamma_j \) IS EQUIVALENT TO THE FIRST TERM IN 2.2.7. LET \( \varphi(t) = \alpha_j \) \( \beta_j \) AND \( \varphi'(t) = \alpha_j \) \( \beta_j \), WHERE \( \alpha_j \) AND \( \beta_j \) ARE MAGNITUDES OF THE RESPECTIVE VECTORS, DEFINE \( \beta_j = \alpha_j / \beta_j \). THEN \( \gamma_j \) CAN BE WRITTEN AS

\[ \gamma_j = -\frac{\Delta p_i}{B_j^2 (1+q_j)} \left[ f(j) \beta_j + \alpha_j \right], \text{ WHERE } \beta_j \text{ HAS BEEN REPLACED BY } \beta_j \left( 1+q_j \right), \text{ CONTINUING } \]

\[ \gamma_j = -\frac{\Delta p_i}{B_j^2 (1+q_j)} \left[ f(j) \alpha_j \beta_j + \beta_j \right] \]

\[ = -\frac{\Delta p_i}{B_j^2 (1+q_j)} \left[ f(j) \beta_j + \alpha_j \beta_j \right] \]

\[ = -\frac{\Delta p_i}{B_j^2 (1+q_j)} \left[ f(j) \beta_j + \alpha_j \beta_j \right] \]

THE VARIABLE \( q_j \) IS EVALUATED AS:

\[ q_j = \left( \frac{\alpha_j - 2 \beta_j}{\beta_j} \right) \left( \frac{\alpha_j}{\beta_j} \right) = \left( \frac{\alpha_j \beta_j - 2 \beta_j \beta_j}{\beta_j} \right) \cdot \alpha_j \beta_j \]

\[ = \left( \frac{\alpha_j}{\beta_j} \right) \beta_j - \left( \frac{\alpha_j}{\beta_j} \right) \beta_j \]

\[ = \beta_j \left( \frac{\alpha_j}{\beta_j} \right) \beta_j = \beta_j \]
FBR3 IS ENTERED FOR STATE VECTOR INTEGRATION ONLY. IT SETS UP VALUES OF TIME CORRESPONDING TO THE MIDPOINT AND RIGHT HAND POINT \((j = 2, 3)\) AND CALLS THE KEPLER ROUTINE TO CALCULATE THE CONIC STATE VECTOR FOR THESE TIMES \(j = 2, 3\) CORRESPONDS TO \(X_1 = -12, -24\)

\[
\frac{\Delta t}{20} \text{ CONTAINS } \frac{\Delta t}{2}\text{ AT } X_1
\]

\[
\text{DT/20 CONTAINS } \frac{\Delta t}{2} \text{ AT } X_1
\]

\[
\text{STORE } \frac{\Delta t}{2} \text{ IN TEMPORARY STORAGE}
\]

\[
\text{COMPUTE TIMES FOR USE BY THE KEPLER ROUTINE FOR THE MIDPOINT AND RIGHT HAND POINT}
\]

\[
t_1 \text{ IS INCREMENTED BY } \frac{\Delta t}{2} \text{ FOR } j = 2 \text{ AND }
\]

\[
t_1 \text{ CORRESPONDING TO THE MIDPOINT AND RIGHT HAND POINT}
\]

\[
\text{INPUT}
\]

\[
1. \text{ BODY } = 0 \text{ OR } 2
\]

\[
2. \text{ TAUO} = t_0
\]

\[
3. \text{ RCVO} = \{t_1\}
\]

\[
4. \text{ SVC} = \{t_1\}
\]

\[
5. \text{ XKEPO} = X
\]

\[
6. \text{ TC} = t_1
\]

\[
7. \text{ MOONFLAG} = \text{ CLEAR OR SET}
\]

\[
\text{NOTE: OUTPUT IS FOR ENTIRE KEPPREP AND KEPLERN COMPUTATIONS (SEE FC-2310; CONIC SUBROUTINES)}
\]

\[
\text{GO THRU INTEGRATION LOOP AGAIN FOR }
\]

\[
\text{FOR STATE VECTOR INTEGRATION}
\]

\[
\text{ACCOMP SH} 9
\]

\[
\text{ORBITAL INTEGRATION FC-2300}
\]

2d. Chalmers
Wm. Robertson, 12/20/70, COLOSSUS
THE SUBROUTINE COMPUTES AN ESTIMATE OF THE VARIABLE X AT TIME T0 BASED ON THE VALUES X', Y', Z' AT TIME T0 FROM THE PREVIOUS COMPUTATION CYCLE. THIS INITIAL ESTIMATE OF X IS USED AS INPUT TO KEEPER TO SPEED UP CONVERGENCE.

INPUT:
1. PBODY: ID OF PRIMARY 2 FOR MOON OR EARTH PRIMARY 3 FOR FOR EARTH PRIMARY
2. RCW = [COS(\theta - \phi)] THE STATE VECTOR CORRECTED AMOUNT
3. X = \frac{x}{y} = \frac{\cos(\theta - \phi)}{\sin(\theta - \phi)} ORIENTATION
4. KEPX = x' = x(t, t0) CYCLE
5. TAU = t - t0, DESIRED TRANSFER TIME
6. TC = t + t0, PREVIOUS TRANSFER TIME
7. MOONFLAG: CLEAR FOR EARTH, SET FOR MOON FOR OUTPUT (OUTPUT FOR KEEPER ONLY)
8. KEPNEW = x', FIRST ESTIMATE OF X CORRESPONDING TO THE TRANSFER TIME T0
9. X1 = X - TABLE POINTER, Z FOR EARTH, 10 FOR MOON FOR MOON
10. PUSH LIST POINTER AT PL4

\( \gamma' \) IS STORED IN NORMALIZED FORM AND THE NORMALIZING VALUE \( \gamma \) IS STORED IN X1. THE UNIT OPERATIONS ALSO STORES \( \gamma' \) IN PL56 @ 2^52/2^64

A COMPLETE INTEGRATION STEP CORRESPONDS TO TWO INCREMENTS. THE VALUE \( \Delta x \) IS NORMALIZED AND THE NORMALIZING VALUE \( \gamma \) IS STORED IN X1.

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

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

NEXT SHEET
FROM PRECEDING SHEET

\[ \frac{d}{dt} \left( \frac{1}{2} \frac{v^2}{r} \right) = -\frac{C}{r^2} \]

MPAC0 = PLOD * MPAC0
SHIFTED @ \[ \frac{1}{2} \]

TURN OFF OVERFLOW INDICATOR

\[ x_t = x + 5 \left[ 1 - 2(1 + 3)^{-0.5} \left( \frac{1}{2} - \alpha \right) \right] \]

XKEPNEW0 = MPAC + PLAD @ \[ \frac{1}{2} \]

KEPRTN = QBRET

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

CLEAR MOONFLAG SET EARTH IS PRIMARY BODY

X1 = 2 MOON IS PRIMARY BODY

KEPLERN(TC=2310)

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

CALCULATE CONIC STATE VECTOR AT TIME TAU_0 = t_0 = \omega

\[ (I, \gamma) = (RCV, VCV) \text{ AFTER KEPLERN COMPUTATIONS} \]

\[ x_t = x_{KEPNEW0} \]

\[ t_{0} - t_{\text{EL}} = \frac{\delta t}{2} \]

\[ (I', \gamma') = (RCV, VCV) \]

\[ (I_0, \gamma_0) = (\text{RECT}, \text{VRECT}) \]

\[ x_{t_0}, \gamma_{t_0}, \gamma'_{t_0} \text{ CORRESPOND TO THE PREVIOUS TIME } t_0, \text{ A VALUE OF } x \text{ FOR TIME } t_0 \text{ IS CALCULATED BY A TAYLOR EXPANSION TYPE METHOD FOR AN INTERVAL OF TIME } \frac{\delta t}{2} = t_0 - t_{\text{EL}} \text{ TO GET AN ESTIMATE } x_t \text{ FOR TIME } t_0. \]
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 4T

SET REINTFLG

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

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

QPRET ← CADR(AMOVED)

CLEAR VINTFLAG
SET

ATOPLEM DO UPDATE OF LM STATE VECTOR FC-2230

LM STATE VECTOR WAS INTEGRATED

ATOPCSM DO UPDATE OF CSM STATE VECTOR FC-2230

CSM STATE VECTOR WAS INTEGRATED

AMOVED

SET NSWITCH

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

CLEAR DSORSFLG
SET

W-MATRIX IS 6x6
W-MATRIX IS 9x9

INITIALIZE L TO 5
COLREG ← -730D

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

INITIALIZE L TO 9
COLREG ← -46D

NEXTCOL ← 05
BEGIN THE PROCESS OF INTEGRATING THE W-MATRIX
COME HERE FROM SHEET 32

CONTINUE WITH INTEGRATION OF THE W-MATRIX

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

A

GRP2PC

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

LOAD L
XZ ← COLREG

W4 + 1 ← 2 × n0
(W + 540) / XZ ← 2 × W0
SHIFTED @ 2°

STORE THE NEW VELOCITY VECTOR INTO ITS PROPER SPOT IN EITHER SUBMATRIX W3, W4, OR W5 OF W-MATRIX

LOAD Y + 1
MPACV ← YV
SHIFTED @ 2°

Ýn + 1 IS SHIFTED FROM 2° TO 2°

OVERFLOW

YES

I IF OVERFLOW OCCURS AS A RESULT OF SHIFTING LEFT THEN AT LEAST ONE COMPONENT OF Ŷn+1 IS ≥ 2°

STORE THE NEW POSITION VECTOR INTO ITS PROPER SPOT IN EITHER SUBMATRIX W0, W1, OR W2 OF W-MATRIX

GRP2PC

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

LOAD L
XZ ← COLREG

SH37

NEXT SHEET

L IS THE W VECTOR POINTER FOR W-MATRIX OPERATIONS

SET 32 TO ZERO FOR SUBSEQUENT USE IN TEST FOR L = 0

CHANGE POINTER TO POINT AT NEXT VECTOR Wl+1

ORBITAL INTEGRATION

2.S. Chmielowski

40TH M. Robertson

FC-2300

COLLOSSUS

54 50
FROM PRECEDING SHEET

STORE i
YV ← XZ

STORE i IN TEMPORARY STORAGE

TEST W-MATRIX POINTERS

X2 > 99
YES
NO

GROUP 3

GET READY TO GO THROUGH LOOP AGAIN

RELOADS

RELOAD TIME AND STATE VECTOR FROM PERMANENT STORAGE TO WORKING STORAGE. THE STATE VECTOR IS LOADED BY ENTERING AT LOCATION INTEGRATE AND GO THROUGH INTEGRATE AGAIN FOR THE NEXT INTERVAL.

GROUP 2

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

STORE i BACK INTO ITS PERMANENT LOCATION

BEGIN THE INTEGRATION OF THE i-th COLUMN VECTOR IN THE W-MATRIX

GROUP 2

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

LOAD i
X2 ← COLREG

LOAD THE W-MATRIX COLUMN POINTER

W0+i
YW ← (W0+i)SHFTED @ 23

LOAD THE NEXT POSITION VECTOR FROM SUBMATRX W0, W1, OR W2 FOR INTEGRATION

W0+i
ZV ← (W0+i)SHFTED @ 23

LOAD THE NEXT VELOCITY VECTOR FROM SUBMATRX W0, W1, OR W2 FOR INTEGRATION

X1 ← 0

DI населенности
SHB

X1 IS SET TO ZERO FOR SUBROUTINE DOW...1 FOR SELECTING THE CORRECT VECTOR FROM VECTAB TABLE.

GO THROUGH INTEGRATION CYCLE FOR NEXT VECTOR FROM THE W-MATRIX

INTRODUCTION TO

COLossus FC-2300

ORBITAL INTEGRATION

D1. Chinnayya

10th October 1963

GOLOSSUS

FC-2300
CKMIDZ is only entered during integration if integration was called by midoav routine. TDECO contains time to integrate to.

INTEGRATE TO CURRENT TIME PLUS 10 SECS.

TEST IF TETO IS WITHIN 1.25 SECS OF TDECO?

LOADTIME CURRENT TIME \( t_2 \) IN MPAC

IF \( t_2 \) IS AHEAD OF \( t_1 \), CURRENT TIME BY AT LEAST 8.5 - 12.5 SECS?

NOTIME SIGNAL NOT ENOUGH TIME FOR INTEGRATION

TC1 - TO_ADD TO_ADD + TIMEDEL

END INTEGRATION

CONTINUE THE INTEGRATION

LOADTIME CURRENT TIME \( t_3 \) IN MPAC

\( t_3 - t_c \geq 5.6 \) SEC?

YES

T-TO_ADD

END INTEGRATION

CONTINUE WITH INTEGRATION

TIMEINC

OUTPUT 1. MPAC0 - TC3, CURRENT TIME

TIME TO INTEGRATE TO (TIME OF IGNITION) IS SLIPPED BY AT MOST 10 SECS

TESTLOOP

SH3

CONTINUE WITH INTEGRATION

ORBITAL INTEGRATION

FC-2300

M. Robert, 22nd May COLOSUS

L. Cline, 22nd May COLOSUS
This routine is entered from D1F EQ+2. If overflow occurred during integration of the W-matrix, this routine ends W-matrix integration.

Because overflow occurred, this flag is cleared so the integration routine will no longer integrate the W-matrix as it continues integrating the state vector.

Clear both flags to indicate to both orbital navigation and rendezvous navigation that the W-matrix is invalid.

Set flag to force a state vector update in A-PCHK, Sheet 84.

Alarm 00421 indicates a W-matrix overflow.

Continue integrating without the W-matrix.
A-PCHK checks to see if an update is desired and, if so, performs it. Come here from P00CHK if \( |\Delta t| \leq 2 \text{ sec} \) or if \( \Delta t < \Delta t_{\text{max}} \) and integration was called by P00.

- **A-PCHK**
  - **CLEAR**
  - **SET**
  - **MIDFLAG**
  - **CHKSWITCH**
    - **Check for necessity of origin switch**
    - **SH45**
  - **YES**
    - **MPAC \geq 0**
  - **NO**
    - **ORIGCHNG**
      - **Change origin of coordinate system**
      - **SH44**
  - **ANDOUT**

**NEXT SHEET**
FROM PRECEDING SHEET

PERFORM A STATE VECTOR UPDATE

STATE FLG
- CLEAR
- SET

FLAG IS CLEARED BECAUSE AN UPDATE IS ABOUT TO BE DONE AND A SUBSEQUENT UPDATE IS UNNECESSARY

DO NOT PERFORM AN UPDATE

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

SET REINTFLG

SETTING THIS BIT INDICATES THAT THIS ROUTINE, IF STALLED, IS TO BE RESTARTED AT THIS POINT IF A PHASE CHANGE OCCURRED BETWEEN INSTALL AND INTAKE

QPRET ← CADR(PHEXIT)

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

CLEAR VINTFLG
- SET

CSM STATE VECTOR WAS INTEGRATED

ATOPCOM DO UPDATE OF CSM STATE VECTOR
FC-2290

LM STATE VECTOR WAS INTEGRATED

ATOPLEM DO UPDATE OF LM STATE VECTOR
FC-2290

PHEXIT

GRP2PC

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

NEXT SHEET

MIT INSTRUMENTATION LAB
NAVIGATION

ORBITAL INTEGRATION

COLOSSUS

FC-2300
FROM PRECEDING SHEET

RECTOUT

SET PUSH LIST POINTER TO ZERO

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

PLOV ← RRECTV SHIFTED @ 2°
PL6V ← VRECT @ TETO @ 2°
PL8V ← RRECT @ 2°/2°
PL2O ← VM @ 2° @ 2°
PLG0 ← (MUEARTH / XE) O

CLEAR MOONFLAG
SET

X1 ← -2

EARTH IS PRIMARY BODY

INEXIT

SET PUSH LIST POINTER TO ZERO

TURN OFF OVERFLOW INDICATOR

CLEAR MIAVLFLG
CLEAR AVEMIOSW
CLEAR PREGFLG

RETURN

QPRET ← RETURN

INTAKE FC-2300

INPUT
1. RCVV = I con
2. RCVV = Y con
3. TDELAVV = $\theta$
4. TNUV = $\nu$

OUTPUT
1. XZ = PBODY
2. RRECTV = $\theta$
3. VRECTV = Y con
4. RCVV = E con
5. RCVV = NEW
6. TDELAVV = $(0,0,0)$
7. TNUV = $\nu$
8. TO = $t$
9. XKEP = $y$

STORE INTEGRATION OUTPUT IN PUSH LIST. THIS INCLUDES $I_o, x_o, t_o, 4\pi$

COME HERE DIRECTLY FROM POOCHK IF $t_o > t + 4\pi$

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

STORE RETURN ADDRESS INTO QPRET 90 IN TIAKE CAN RETURN TO CALLING ROUTINE BY USING THE RVQ INSTRUCTION

RETURN TO CALLING ROUTINE VIA INTAKE

ORBITAL INTEGRATION

FC-2300
DO AN INTERGRATION OF W-DOUBLE-DOT (THE W-MATRIX) ROUTINE CALCULATES A VALUE OF THE ACCELERATION "j" * \( \partial W(t) \) BEFORE GOING THRU A NYSTROM CALCULATION. THE SUBSCRIPT "j" = 1, 2, 3 CORRESPONDS TO LEFT POINT, MID POINT, OR RIGHT POINT. SUBSCRIPT "j" REFERS TO "j" VECTOR IN THE W-MATRIX.

INPUT
1. \( \alpha(t) \)
2. \( \beta(t) \)
3. \( \mathbf{x} \), VECTOR POINTER FOR VECTABV (\( x_{1} = 0 \) IN SUNLAND)

OUTPUT
1. \( \mathbf{P} \), \( \mathbf{q} \), \( \mathbf{r} \), \( \mathbf{e} \)".

INCLUDE SOLAR PERTURBATIONS

GET ACCELERATION \( \mathbf{q}_{p} \) DUE TO PRIMARY BODY

\( \mathbf{q}_{p} = \mathbf{F}_{p} / \mathbf{M}_{p} \)

CLEAR

SET

POINT AT VECTOR IN VECTABV

NO NEED TO CALCULATE SECOND COMPONENT \( \mathbf{q}_{2} \), GO THRU NYSTROM CALCULATION FOR A VALUE OF "j" = 1, 2, 3

INPUT
1. \( \alpha(t) \)
2. \( \beta(t) \)
3. \( \mathbf{x} \), VECTOR POINTER

OUTPUT
1. \( \mathbf{P} \), \( \mathbf{q} \), \( \mathbf{r} \), \( \mathbf{e} \)".

INSIDE LUNAR SPHERE OF INFLUENCE

GET ACCELERATION \( \mathbf{q}_{a} \) DUE TO THE SECONDARY BODY

\( \mathbf{q}_{a} = \mathbf{F}_{a} / \mathbf{M}_{a} \)

CLEAR

SET

SHIFT \( \mathbf{q}_{a} \) RIGHT 6 PLACES TO SCALE \( \mathbf{P} / \mathbf{q}_{a} \)

\( \mathbf{q}_{a} = \alpha \cdot \beta \cdot \gamma(t) \)

GO THRU NYSTROM CALCULATION FOR A VALUE OF "j" = 1, 2, 3

INPUT
1. \( \alpha(t) \)
2. \( \beta(t) \)
3. \( \mathbf{x} \), VECTOR POINTER FOR VECTABV (\( x_{1} = 0 \) IN SUNLAND)

OUTPUT
1. \( \mathbf{P} \), \( \mathbf{q} \), \( \mathbf{r} \), \( \mathbf{e} \)".

OUTSIDE LUNAR SPHERE OF INFLUENCE

\( \mathbf{q}_{a} = \alpha \cdot \beta \cdot \gamma(t) \)

\( \mathbf{q}_{a} \) IS THE ACCELERATION DUE TO THE MOON

M2 INTEGRATION}

ORBITAL INTEGRATION

FC-2300

COLossus
CALCULATE THE ACCELERATION COMPONENT \( \mathbf{a} \) OR \( \mathbf{g} \) FOR A GIVEN \( \mathbf{u} \).

\( x_1 \) IS A POINTER USED TO SELECT EITHER \( \mathbf{I}(t) \) OR \( \mathbf{g}(t) \) FROM A TABLE IN SUNDANCE \( x_1 = 0 \).

PROJECT \( \mathbf{u} \) onto \( \mathbf{i} \) WHERE \( \mathbf{u} \cdot \mathbf{w} \) IS THE MAGNITUDE OF \( \mathbf{w} \), IN THE DIRECTION OF \( \mathbf{i} \).

\[ \frac{3}{4} = 3.0 \times 2^2 \]

THE NORMALIZING COUNT \( -m \) IS STORED IN \( SL \).

THE NORMALIZING COUNT \( -n \) IS STORED IN \( PL54 \).

THIS IS THE ACCELERATION COMPONENT \( \mathbf{a}_P \) OR \( \mathbf{a}_C \).

EQ 2.2.31, PAGE 5.2-23

\( -3m - n \) IS THE UNNORMALIZING COUNT

ORBITAL INTEGRATION

COLOSSUS FC-2300

\( \text{RECEIVED} \)

\( \text{MARCH 15, 1961} \)

\( \text{RECEIVED} \)

\( \text{MARCH 22, 1961} \)
THE RECTIFY SUBROUTINE IS CALLED BY THE INTEGRATION ROUTINE AND OCCASIONALLY BY THE MEASUREMENT INCORPORATION ROUTINES TO DEFINE A NEW REFERENCE CONIC.

RECTIFY

\[ x_2 \rightarrow PBODY \]

\[ MPAW_v \rightarrow TDELTAV, \] shifted from \( 2^{21}/2^{16} \) to \( 2^{20}/2^{27} \)

\[ \tilde{I}_0 = I_{CON} + \tilde{\nu} \]

COMPUTE THE RECTIFIED POSITION VECTOR

\[ RRECT_v = UPACV - RCV_v + MPACV \] at \( 2^{27}/2^{20} \)

\[ I_{CON} = \tilde{I}_0 \]

THIS DEFINES THE NEW CONIC POSITION VECTOR

\[ RCV_v \leftarrow UPACV \] at \( 2^{27}/2^{20} \)

\[ MPACv \rightarrow TUHV, \] shifted from \( 2^{21}/2^{16} \) to \( 2^{20}/2^{27} \)

\[ \bar{V}_0 = V_{CON} + \bar{\nu} \]

COMPUTE THE RECTIFIED VELOCITY VECTOR

\[ MPACv \leftarrow VCV_v + MPACv \] at \( 2^{27}/2^{20} \)

MINIRECT

STORE \( \bar{V}_0 \)

\[ VRECT_v \leftarrow MPAC_v \] at \( 2^{20}/2^{20} \)

\( \sqrt{y + 130} \)

THIS DEFINES THE NEW CONIC VELOCITY VECTOR

\[ \bar{\nu} = (0, 0, 0) \]

\[ \bar{\nu} = (0, 0, 0) \]

\[ \nu = 0 \]

\[ TDELTAV \rightarrow ZEROVECV \]

\[ TUHV \rightarrow ZEROVECV \]

\[ TC_{0} \rightarrow ZEROVEC_{0} \]

\[ XKEP \rightarrow ZEROVEC_{0} \]

\[ \bar{E} \leftarrow 0 \]

ZERO THE DEVIATIONS, TIME SINCE RECTIFICATION, AND UNIVERSAL VARIABLE \( \bar{\nu} \).

\( \bar{\nu} \leftarrow 0 \)

\( \nu \leftarrow 0 \)

\( X \leftarrow 0 \)

\( TDELTAV \rightarrow ZEROVECV \)

\( TUHV \rightarrow ZEROVECV \)

\( TC_{0} \rightarrow ZEROVEC_{0} \)

\[ XKEP \rightarrow ZEROVEC_{0} \]

RETURN VIA QPRET
CHKS WITCH
STORE QPRET IN ORIGEX

CLEAR
RPQFLAG
SET
MPAC_D \rightarrow TET_D

LUNPOS
GET LUNAR POSITION AT TET
FC-2286

CLEAR
MOONFLAG
SET
MPAC_V \rightarrow MPAC_V

RPQV_V \rightarrow MPAC_V

RPQOK

X2 \rightarrow PBODY

MPAC_V \rightarrow TDELTAY_V \cdot 2^{7 \cdot X2} SCALED @

MPAC_V \rightarrow MPAC_V + RCY_V SCALED @

CLEAR
MOONFLAG
SET
EAR5PH

MPAC_D \rightarrow MPAC_V = RPQV_V - RSPHERE_B

RETURN VIA ORIGEX

INPUT: TET TIME IN CSEC \(2^{28}\)
OUTPUT: MOON'S POSITION IN BASIC REF. COORD., IN M. \(2^{29}\) STORED IN MPAC

YIELDS EARTH POS

RESTORE X2 AFTER USING LUNPOS
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

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</tr>
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<td>LOADTIME</td>
<td>FC2100</td>
<td>LOAD TIME1 AND TIME2 (CURRENT TIME) INTO MPAC</td>
<td>SH 36</td>
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<tr>
<td>INTAKE</td>
<td>FC2290</td>
<td>ENTRY POINT FOR WAKING UP ALL INTEGRATION STALLED PROGRAMS, WHEN PRESENT INTEGRATION IS COMPLETED</td>
<td>SH 40</td>
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<tr>
<td>LSPOS</td>
<td>FC2285</td>
<td>CALCULATE POSITION OF SUN, MOON</td>
<td>SH 11</td>
</tr>
<tr>
<td>LUNPOS</td>
<td>FC2286</td>
<td>CALCULATE POSITION OF MOON</td>
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<tr>
<td>LUNVEL</td>
<td>FC2285</td>
<td>CALCULATE VELOCITY OF MOON</td>
<td>SH 44</td>
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<tr>
<td>POOODOO</td>
<td>FC2140</td>
<td>TERMINATE MAJOR MODE IN RESTART</td>
<td>SH 22</td>
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### FLGS

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<thead>
<tr>
<th>NAME (BIT FLAGWORD)</th>
<th>MEANING WHEN SET</th>
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<th>WHERE SET</th>
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<tr>
<td>VINTFLAG (3, 3)</td>
<td>INTEGRATE THE CSM STATE VECTOR</td>
<td>INTEGRATE THE LM STATE VECTOR</td>
<td>SH 33, 38</td>
<td>SH 33, 38</td>
<td>SH 33, 38</td>
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<tr>
<td>DMOFLAG (1, 3)</td>
<td>INTEGRATE THE W-MATRIX</td>
<td>DO NOT INTEGRATE THE W-MATRIX</td>
<td>SH 37, 32</td>
<td>SH 37, 32</td>
<td>SH 37, 32</td>
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<tr>
<td>D6OR9FLG (2, 3)</td>
<td>W-MATRIX IS 9X9</td>
<td>W-MATRIX IS 6X6</td>
<td>SH 31</td>
<td>SH 31</td>
<td>SH 31</td>
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<tr>
<td>STATEFLG (3, 3)</td>
<td>UPDATE PERMANENT CSM/LM STATE VECTOR</td>
<td>DO NOT UPDATE PERMANENT CSM/LM STATE VECTOR</td>
<td>SH 37, 38</td>
<td>SH 37, 38</td>
<td>SH 37, 38</td>
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<tr>
<td>QUITFLAG (5, 9)</td>
<td>DISCONTINUE INTEGRATION AT START OF NEXT TIMESTAMP</td>
<td>CONTINUE INTEGRATION</td>
<td>SH 3</td>
<td>SH 3</td>
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<tr>
<td>MIDFLAG (13, 0)</td>
<td>INTEGRATE WITH SOLAR PERTURBATIONS</td>
<td>INTEGRATE WITHOUT SOLAR PERTURBATIONS</td>
<td>SH 3, 34, 36, 43</td>
<td>SH 3, 34, 36, 43</td>
<td>SH 3, 34, 36, 43</td>
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<tr>
<td>PRECFLG (8, 3)</td>
<td>CSMPREC OR LEMPREC CALLED</td>
<td>INTEGRITY OR INTEGRYS CALLED</td>
<td>SH 40</td>
<td>SH 40</td>
<td>SH 40</td>
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<tr>
<td>NEWFLG (13, 8)</td>
<td>FIRST PASS THROUGH INTEGRATION LOOP</td>
<td>SUBSEQUENT PASS THROUGH INTEGRATION LOOP</td>
<td>SH 6</td>
<td>SH 6</td>
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<td>JSWITCH (14, 6)</td>
<td>INTEGRATE A VECTOR FROM THE W-MATRIX</td>
<td>INTEGRATE THE STATE VECTOR</td>
<td>SH 33, 8, 32</td>
<td>SH 33, 8, 32</td>
<td>SH 33, 8, 32</td>
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<tr>
<td>POOFLAG (0, 3)</td>
<td>IN PROGRAM POO</td>
<td>NOT IN PROGRAM POO</td>
<td>SH 5</td>
<td>SH 5</td>
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MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION ORBITAL INTEGRATION

DRAWN: S. Truettner 1/9/71
CHECKED: W. R. Nettles 1/22/71
APPROVED: L. J. Blum 2/1/71

DOCUMENT NO. COLOSSUS 211 FC 2300

REV 1 SHEET 4 OF 50
### Flags (continued)

<table>
<thead>
<tr>
<th>NAME (BIT, FLAGWORD)</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
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<th>WHERE CLEARED</th>
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<td>MOONFLAG (12, 0)</td>
<td>INSIDE LUNAR SPHERE OF INFLUENCE</td>
<td>OUTSIDE LUNAR SPHERE OF INFLUENCE</td>
<td>SH. 44</td>
<td>SH. 44</td>
<td>SH. 11, 13, 15, 19, 31, 40, 41, 44, 45</td>
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<tr>
<td>RPQFLAG (15, 8)</td>
<td>CALCULATE THE VECTOR RPQ</td>
<td>DO NOT CALCULATE THE VECTOR RPQ</td>
<td>SH. 22</td>
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<tr>
<td>MIDAVFLG (2, 0)</td>
<td>INTEGRATION CALLED BY THE MIDTOAV ROUTINE</td>
<td>INTEGRATION NOT CALLED BY THE MIDTOAV ROUTINE</td>
<td>SH. 40</td>
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<td>SH. 32</td>
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<tr>
<td>REINTFLG (7, 10)</td>
<td>RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS</td>
<td>DO NOT RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS</td>
<td>SH. 33, 36</td>
<td>SH. 33, 36</td>
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<tr>
<td>MINDIFLAG (3, 9)</td>
<td>INTEGRATE TO A SPECIFIED TIME ( t_2 ) STORED IN TDEC</td>
<td>INTEGRATE TO CURRENT TIME PLUS 10 SECONDS</td>
<td>SH. 36</td>
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<tr>
<td>ORBWFLAG (6, 3)</td>
<td>W-MATRIX IS VALID FOR ORBITAL NAVIGATION</td>
<td>W-MATRIX IS INVALID FOR ORBITAL NAVIGATION</td>
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<tr>
<td>RENDWFLG (1, 5)</td>
<td>W-MATRIX IS VALID FOR RENDEZVOUS NAVIGATION</td>
<td>W-MATRIX IS INVALID FOR RENDEZVOUS NAVIGATION</td>
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<tr>
<td>AVEMIDSW (1, 9)</td>
<td>PREVENT UPDATING THE CSM DOWNLINK DATA RN, VN, PIPTIME</td>
<td>ALLOW UPDATING THE CSM DOWNLINK DATA RN, VN, PIPTIME</td>
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### Displays

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<tr>
<th>VERB-NOUN</th>
<th>TYPE OF DISPLAY</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
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<tr>
<td>ALARM</td>
<td>PROG ALARM LIGHT ON; R1, R2, R3, NOT AFFECTED</td>
<td>SH. 37</td>
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### Erasable Locations Used

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<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
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<th>AGC SCALING</th>
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<tbody>
<tr>
<td>DT/2D</td>
<td>t</td>
<td>TIME INTERVAL FOR ONE INTEGRATION CYCLE</td>
<td>CSEC</td>
<td>CSEC</td>
<td>( 2^{20} )</td>
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<tr>
<td>TDEC1D</td>
<td>t_2</td>
<td>TIME TO INTEGRATE TO</td>
<td>CSEC</td>
<td>CSEC</td>
<td>( 2^{26} )</td>
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<tr>
<td>RCV_V</td>
<td>( r_{con} )</td>
<td>CONIC POSITION VECTOR</td>
<td>M</td>
<td>M</td>
<td>( 2^{29} )</td>
</tr>
<tr>
<td>VCV_V</td>
<td>( v_{con} )</td>
<td>CONIC VELOCITY VECTOR</td>
<td>M/CSEC</td>
<td>M/CSEC</td>
<td>( 2^{7/2} )</td>
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<tr>
<td>TET_D</td>
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<td>TIME OF VALIDITY OF STATE VECTOR</td>
<td>CSEC</td>
<td>CSEC</td>
<td>( 2^{28} )</td>
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<tr>
<td>RRRECT_V</td>
<td>( r_{0} )</td>
<td>POSITION VECTOR AT RECTIFICATION</td>
<td>M</td>
<td>M</td>
<td>( 2^{29/2} )</td>
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**INSTRUMENTATION LAB
CAMBRIDGE, MASS.

ORBITAL INTEGRATION

COLOSSUS FC-2300**
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
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<th>AGC UNITS</th>
<th>AGC SCALING</th>
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<tr>
<td>VRECT</td>
<td>v</td>
<td>VELOCITY VECTOR AT RECTIFICATION</td>
<td>M/CSEC</td>
<td>M/CSEC</td>
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<tr>
<td>TDELTAV</td>
<td>$\Delta$</td>
<td>POSITION DEVIATION VECTOR</td>
<td>M</td>
<td>M</td>
<td>$2^{22/2^{18}}$</td>
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<td>TNUV</td>
<td>$\nu$</td>
<td>VELOCITY DEVIATION VECTOR</td>
<td>M/CSEC</td>
<td>M/CSEC</td>
<td>$2^{3/2^{-4}}$</td>
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<tr>
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<td>TIME SINCE RECTIFICATION</td>
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<td>CSEC</td>
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<td>$M^{1/2}$</td>
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<td>ZV_V</td>
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<td>M/CSEC</td>
<td>$2^{3/2^{-4}}$</td>
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<td>JIFFQNCIT</td>
<td>j</td>
<td>SUBSCRIPT FOR LEFT, MID, AND RIGHT POINTS</td>
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<td>ALPHAV_D</td>
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<td>M</td>
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<td>ND</td>
<td>h</td>
<td>RUNNING TIME INCREMENT EQUALS $0, \Delta t_1, \Delta t_2$</td>
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<td>EV_V</td>
<td>$r_{21}$</td>
<td>VALUE OF SECOND DERIVATIVE AT POINT 1</td>
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<td>$M/(CSEC)^2$</td>
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<td>$\beta_{21}$</td>
<td>WORKING STORAGE FOR $\beta_{21}$</td>
<td>M</td>
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<td>\beta_j</td>
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<td>$u_z$</td>
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<td>M</td>
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<td>$M/(CSEC)^2$</td>
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<td>URPV_V</td>
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<td>M</td>
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<td>RUNNING SUM OF $k_1 + 2k_2$</td>
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<td>$M/(CSEC)^2$</td>
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<td>PSIIV_V</td>
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<td>SECOND HARMONIC, RADIUS AND MU OF EARTH</td>
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### PROGRAM CONSTANTS (CONTINUED)

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<th>AGC VALUE AND UNITS</th>
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<td>MUEARTH_D</td>
<td>uE</td>
<td>GRAVITATIONAL PARAMETER OF EARTH</td>
<td>3.9860032 x 10^10 M^3/CSEC^2</td>
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<td>MUEARTH_-2</td>
<td>uM</td>
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<td>4.902778 x 10^8 M^3/CSEC^2</td>
<td>SAME</td>
<td>2^30</td>
</tr>
<tr>
<td>MUEARTH_D</td>
<td>uS</td>
<td>GRAVITATIONAL PARAMETER OF SUN</td>
<td>1.32715445 x 10^{-16} M^3/CSEC^2</td>
<td>SAME</td>
<td>2^54</td>
</tr>
<tr>
<td>DP2/3</td>
<td></td>
<td></td>
<td>1/6</td>
<td>.66...67</td>
<td>2^0</td>
</tr>
<tr>
<td>3CSECS</td>
<td></td>
<td></td>
<td>3 CSEC</td>
<td>3 CSEC</td>
<td>2^28</td>
</tr>
<tr>
<td>RME_D</td>
<td>r_ME</td>
<td>RADIUS OF INFLUENCE OF EARTH</td>
<td>7178165 M</td>
<td>SAME</td>
<td>2^29</td>
</tr>
<tr>
<td>RMM_D</td>
<td>r_MN</td>
<td>RADIUS OF INFLUENCE OF MOON</td>
<td>2536090 M</td>
<td>SAME</td>
<td>2^27</td>
</tr>
</tbody>
</table>

### PAD LOADS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP TAG</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
<th>OCTAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>504LM_V</td>
<td>M</td>
<td>MOON LIBRATION VECTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TFFCONIC SUBROUTINES, AND DELRSPL

**SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS**

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIGNMPAC</td>
<td>2100</td>
<td>AFFIXES SIGN OF MPAC TO POSMAX</td>
<td>SH. 9</td>
</tr>
<tr>
<td>GETERAD</td>
<td>2280</td>
<td>COMPUTE RADIUS ON FISCHER ELLIPSOID, GIVEN A PARTICULAR LATITUDE</td>
<td>SH. 12</td>
</tr>
<tr>
<td>LALOTORYV</td>
<td>2280</td>
<td>GIVEN ALTITUDE, LATITUDE, AND LONGITUDE &amp; TIME; COMPUTE RADIUS VECTOR FOR FIXED OR FISCHER</td>
<td>SH. 14</td>
</tr>
<tr>
<td>INTWAKEO</td>
<td>2300</td>
<td>PERMIT INTEGRATION TO BE USED AGAIN</td>
<td>SH. 14</td>
</tr>
</tbody>
</table>

### MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

- **TFFCONIC:**
  - THIS SUBROUTINE IS CALLED TO COMPUTE THOSE CONIC PARAMETERS REQUIRED BY THE TFF CONICS, AND TO ESTABLISH THEM IN THE PUSHLIST AREA.
  - **Where:** SH. 3

- **TFFCONMU:**
  - SAME AS TFFCONIC, EXCEPT THAT TFP/RTMU IS ALREADY LOADED.
  - **Where:** SH. 3

- **TFFRP/RA:**
  - CALCULATE PERIGEE RADIUS AND ALSO APOGEE RADIUS FOR A GENERAL CONIC.
  - **Where:** SH. 4

- **CALCUPER:**
  - PROGRAM CALCULATES THE FREE-FALL TIME OF FLIGHT FROM PRESENT POSITION RN AND VELOCITY VN TO A RADIUS LENGTH SPECIFIED BY RTERM, SUPPLIED BY THE USER IN MPAC. THE POSITION RN VECTOR MAY BE ON EITHER SIDE OF THE CONIC, BUT RTERM IS CONSIDERED ON THE INBOUND SIDE.
  - **Where:** SH. 5

- **VGAMCALC:**
  - EARTH CENTERED VIS VIVA CALCULATION OF TERMINAL VELOCITY AND GAMMA (REL. TO HORIZONTAL), GIVEN THE SCALAR QUANTITIES: PRESENT RADIUS AND VELOCITY AND THE TERMINAL RADIUS. THE USER MUST APPEND PROPER SIGN TO GAMMA, SINCE IT IS CALCULATED AS A POSITIVE NUMBER.
  - **Where:** SH. 11

- **PREVGAM:**
  - SAME AS VGAMCALC, EXCEPT THAT IT IS ENTERED WITH NEW RTERM IN MPAC.
  - **Where:** SH. 11

- **TFF/TRIG:**
  - CALCULATE SINE, COSINE OF TRANSFER ANGLE FROM DATA LEFT IN THE PUSHLIST BY TFF SUBROUTINES.
  - **Where:** SH. 11

- **FISHCALC:**
  - GIVEN THE PRESENT POSITION, UNTR, CALCULATE A NEW UNTR THAT IS ROTATED THROUGH TRANSFER ANGLE (THETA, ALONG TRAJECTORY). THEN CALCULATE SIN(LAT) AND USE TO OBTAIN FISCHER RADIUS.
  - **Where:** SH. 12

- **DELRSPL:**
  - A SUBROUTINE OF EXTENDED VEB 82: CALCULATE (FOR DISPLAY ON CALL) AN APPROXIMATE MEASURE OF IN-PLANE SPLASHDOWN ERROR. IF THE FREE-FALL TRANSFER ANGLE TO 300K FT ABOVE PAD RADIUS IS POSITIVE: SPLASH ERROR = RANGE TO TARGET + FREE-FALL TRANSFER ANGLE + ESTIMATED ENTRY ANGLE. THE TARGET LOCATION AT ESTIMATED TIME OF IMPACT IS USED. IF THE FREE-FALL TRANSFER ANGLE IS NEGATIVE: SPLASH ERROR = RANGE TO TARGET. THE PRESENT TARGET LOCATION IS USED.
  - **Where:** SH. 13

- **AUGEKUGL:**
  - CALCULATES TIME FROM ENTRY AT 300K FT TO SPLASH, AND RANGE FROM 300K FT ENTRY TO SPLASH, GIVEN VELOCITY AND FLIGHT-PATH ANGLE AT 300K FT.
  - **Where:** SH. 15
SINCE CONIC CALCULATIONS REQUIRE FLOATING POINT ARITHMETIC, THESE CHARTS ATTEMPT TO INDICATE WHERE SUCH OPERATIONS ARE EMPLOYED. LET REGISTER \( M \) BE NORMALIZED SO THAT \( 1 < M \geq 0.5 \).

LET THE NUMBER OF LEFT SHIFTS REQUIRED TO BRINGS THIS ABOUT BE \(-X_1\). THEN THE CONVENTION USED HEREIN IS THAT THE NORMALIZED CMC VARIABLE \( TFFM(E, R) \) IS RELATED TO THE UNNORMALIZED CMC VARIABLE IN \( M \) BY: \( TFFM = M^2 \cdot X_1 \) AND \( M = NORM_4(TFFM) \).

R30 APPLICATION: THE SPHERICAL VALUES OF GRAVITATIONAL CONSTANT \( \mu \) ARE USED DEPENDING ON EARTH/MOON CENTERED COORDINATES:

- EARTH: \( \sqrt{\mu} = 8.00877529 \times 10^{-8} \times 2^{17} \text{ cgs} / (M)^{3/2} \)
- MOON: \( \sqrt{\mu} = 4.5162585 \times 10^{-4} \times 2^{-14} \text{ cgs} / (M)^{3/2} \)

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

\[ \sqrt{\mu} = 8.005750274 \times 10^{-8} \times 2^{17} \text{ cgs} / (M)^{3/2} \]

**TFPCONIC**

- CALCULATES:
  - A) ANGULAR MOMENTUM
  - B) SEMI LATUS RECTUM
  - C) RECIPROCAL OF SEMI MAJOR AXIS

RETURN

**TFFRP/RA**

- CALCULATE PERIGEE AND APOGEE RADII

RETURN

**CALCOTP**

ENTER WITH PERIGEE RADIUS

**CALCOTT**

ENTER WITH ARBITRARY TERMINAL RADIUS

CAN CONIC INTERSECT TERMINAL RADIUS? NO

SET \( T \) TO MAXIMUM MACHINE VALUE

COMPUTE INTERMEDIATE QUANTITIES USED IN CALCULATION OF TIME OF FREE FALL FOR AN OUTBOUND CONIC NO

CONIC INBOUND?

COMPUTE INTERMEDIATE QUANTITIES USED IN CALCULATION OF TIME OF FREE FALL FOR AN INBOUND CONIC

IS PRESENT POSITION ESSENTIALLY AT APOGEE OR PERIGEE? NO

TERMINAL RADIUS AND PRESENT RADIUS ARE BOTH AT PERIGEE ON A PARABOLA OR HYPERBOLA \( T = 0 \)

RECPROCAL OF SEMI MAJOR AXIS \( > 0 \)

YES

YES-ASSUME APOGEE

COMPUTE TIME FOR \( |E| < 90^\circ \) NO

DIFFERENCE IN ECCENTRIC ANOMALIES < 90

CORRECT FOR ORBITAL PERIOD, IF TIME CO AND IP CONIC IS ELLIPTIC AND IP TERMINAL RADIUS HAS NOT BEEN PASSES

RETURN
CALLED BY VB2 SEQUENCE (FC-2650) OR
681.2 (FC-2760) TO COMPUTE THOSE CONIC
PARAMETERS REQUIRED BY THE TFF SUBROUTINES
AND ESTABLISH THEM IN THE PUSH LIST AREA.

INPUTS: 
- EME = \vec{E}_0: PRESENT POSITION VECTOR IN METERS
- \vec{V}_0: PRESENT VELOCITY VECTOR IN METERS/SECOND
- \vec{F}_0 = \vec{F}_0 \cdot \vec{F}_0 FOR MOON OR EARTH

OUTPUTS: 
- RMAI = \vec{R}_0
- NRMAG = \vec{N}_0
- TFN = \vec{P} = PL2D \cdot P = SEMI-LATUS RECTUM
- VONE = \vec{V}_0 / \sqrt{\mu}
- TFVSN = \vec{V}_0 \cdot \vec{N}_0 / \sqrt{\mu}
- TFALFA = \sqrt{(SMAJ MAJOR AXIS)^2} / \sqrt{\mu}
- TFRTALF = \sqrt{\mu}
- TFALF = \vec{L}_0 = PL2D
- X1 = - NORM COUNT OF RMAI
- X2 = - NORM COUNT OF RMAI

TFFCONIC

TFF/RTMU → MPAC

TFFCONIC

ENTER HERE WITH
1/\sqrt{\mu} ALREADY IN TFFRTMU.

P = \left( E_0 \cdot V_0 \right)^2 / \mu
V_0^2 = V_0 / \mu
\omega_0 = \frac{2}{\mu} \cdot \sqrt{V_0^2}
\sqrt{\mu} = \sqrt{(\mu)}

RMAI = \vec{R}_0
NRMAG = \vec{N}_0
VONE = \vec{V}_0 / \sqrt{\mu}
TFVSN = \vec{V}_0 \cdot \vec{N}_0
TFALFA = \left(\text{NRMAG} \cdot \text{VONE} \times \text{UNIT}(\text{RMAI})\right) / \mu

TEST IS ACTUALLY MADE ON (TFRTALF)²

YES

NO

1/\mu

TFALF = 0

TFALF = \frac{1}{\mu}

RETURN VIA QPRET
CALLED BY V'S SEQUENCE (FC-2650).
CALCULATES APOGEE AND PERIGEE
FOR A GENERAL CONIC.

INPUT: TFFNR = SEMI-LATUS RECTUM
       TFFAL = RECIPROCAL SEMI-MAJOR AXIS
       X1, X2

OUTPUT: RAP = APOGEE
        RP = PERIGEE
        IN METERS @ 2^9/2^7

TFFNR/RA

FORM 1 + e = 1 + \sqrt{1 - p}\cdot \alpha

P = TFF/4/2 + \sqrt{[DP2(-4)/2 - 2^8 + 1] \cdot TFFNL/2 \cdot TFFNR}

P = \frac{P}{(1 + e)}

RP = 2^{8 + 2 \cdot X1} (TFFFR/PL2)

CLEAR OF FIND, IF ON

\[ \tau = 1 + e \]

\[ MP = PL2 \cdot TFF/ALFA \]

THE FOLLOWING ARE ALL TESTS ON THE VALIDITY OF
THE \( \tau \) CALCULATION. IF ONE IS FAILED, POSMAX IS
LOADED AS TAU.

IS \( MP = 0 \)? IF SO, TRAJECTORY IS SO
CLOSE TO PARABOLIC THAT TFF/ALFA
WAS SET TO ZERO AS A TAG.
(SEE TFFCONIC SH.3)

IS \( \tau \) TOO BIG?

\[ MP = 2^{-8} \cdot X2 \cdot MP \]
SCALE TO 2^9/2^7

\[ \tau \] TOO BIG YES

MPCA = MP

\[ MP = 2^{-8} \cdot X2 \cdot MP \]

\[ MP > 0 \]

IS CONIC ELLIPTIC?

\[ MP = 0 \]

HYPERBOLIC NO (CO)

\[ \tau \] UNDEFINED

\[ \tau = \text{POSMAX} \]

RAPO = NEARONE

\[ \text{POSMAX} \cdot (2^{-8} \cdot X2 \cdot MP) = \text{MAXIMUM POSITIVE} \]
\[ \text{D.P. VALUE} \]

RAPO = MP

STORE \( \tau \) = APOGEE IN M @ 2^9/2^7
(MAXIMUM POSITIVE VALUE) WHEN \( \tau \) UNDEFINED

RETURN VIA QPRET
CALLED BY Y82 SEQUENCE (FC-2650) AND
861.2 (FC-2760),
CALCULATES THE TIME OF FREE FALL FLIGHT FROM PRESENT
POSITION (Rn) AND VELOCITY (Vn) TO A RADIUS LENGTH
SPECIFIED BY R0, SUPPLIED BY THE USER.
INPUT: MPAC = PERIGEE OR TERMINAL RADIUS (Rn)
TFFALPHA, TFFPNP,
RMAG, RMAG XI, X2 FROM TFFCONIC
TFFAF, TFFTRALF,
RONE, VONE, STATE VECTORS AT PRESENT
OUTPUT: MPAC = TIME OF FLIGHT TO PERIGEE OR TERMINAL RADIUS
NTERM = NORMALIZED MAGNITUDE OF TERMINAL R.
TFFTEM = y = P (ZT1) OR P (KX SN(2n + R0/2))
TFFX = KX ZT1 OR 1/KX ZT1

CALCIFPER ENTER WITH
MPAC = PERIGEE RADIUS
SET TFFSW INDICATES CALCIFPER IS ENTRY POINT
CLEAR TFFSW

CALCIFPP ENTER WITH
MPAC = TERMINAL RADIUS
INDICATES CALCIFPP IS ENTRY POINT

TEM1 = 2 - Rn
TEM2 = TEM1 Rn
RTERMX = RTERM
NTERMX = RTERM RTERM X1
PLOC = TFFM + TFFALPHA / NTERM
PLOC X2 = TFFX
TFFTEM = y = P (ZT1) OR P (KX SN(2n + R0/2))
TFFX = KX ZT1 OR 1/KX ZT1

YES
IS THIS CALCIFPP?

CALCIFPP
TFFSW CLEAR?

CALCIFPER

TEM = TEMPE - P
MPACX = [PLOC + 2] X1 / TFFPNP X1

MPAC CO ?

YES

CLEAR ONFIND IF ON

MAX TFF1

NO

RESTORE PL POINTER TO ENTRY LOC.

L = POSMAX
MPAC = NEARONE
POS MAX = [POSMAX] X 2**18
POS MAX LOADED AS TAG.

NEXT SHEET

MINUS SIGN IN Qn SIGNIFIES THAT R0 IS ASSUMED TO BE ON
THE RETURN SIDE OF CONIC.
(I.E. R0 < 0).
Qh = 0 IF ROUTINE ENTERED
AT CALCIFPER.
Qh AND Qn = TFFQ1 ARE
INTERMEDIATE QUANTITIES USED
IN COMPUTING THE TIME OF
FREE FALL TO THE SPECIFIED
RADIUS.)

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

TIME OF FREE FALL

DRAWN: A. WILLIAMS
CHECKED: STEVENSON
ANALYSIS: D. REYNOLDS
REVIEW: A. MANN
APPROVED:

MODIFIED:
REV 4
5-1975 8-20
T(x) = POLYNOMIAL APPROXIMATION TO THE SERIES:
1/3 - x/5 + x^3/7 - x^5/9 ...... 

POLYNOMIAL IS OF 5TH ORDER HAVING COEFFICIENTS
A_0 = 1/3 
A_1 = -1.099819335 E-1 
A_2 = 1.416448447 E-1 
A_3 = -1.01310997 E-1 
A_4 = 5.600004596 E-2 
A_5 = -1.354156925 E-2

RANGE OF POLYNOMIAL FIT X = (0, +1), MAXIMUM DEVIATION OF FIT 2E-5,
RANGE OF X SATISFYING ABOVE DEVIATION IS (-0.08, +1).
CALCULATE RADIUS OF FISCHER ELLIPSOID AT LATITUDE OF ESTIMATED TERMINAL RADIUS

USED BY PE1 (FC-2760)

FISHCALC

INPUT:
- MPAC_0 = SINE(θ) FROM TFF/TRIG
- CEELT/2 = COS(θ) FROM AVERAGE
- UNIT(θ) = UNIT(θ) FROM TARGETING

OUTPUT:
- MPAC = RADIUS OF THE EARTH (R_E) AT THE LATITUDE OF θ

UNIT(a) = UNIT(a) X UNIT(θ) X UNIT(θ) X UNIT(θ) X UNIT(θ) X MPAC_0

CALCULATE UNIT VECTOR ALONG R_E (TERMINAL RADIUS)

UH_ν = UH_ν X CEELT/2 + (UH_ν X UH_ν) X MPAC_0

CALCULATE LATITUDE OF THE TERMINAL RADIUS.

SIN(LAT) = UNIT(a) X UNIT(θ) X UNIT(θ) X UNIT(θ) X UNIT(θ)

ALPHA + 4 = 2 X UNITW_ν X UH_ν

GETERAD

CALCULATE RADIUS OF THE FISCHER ELLIPSOID AT THE GIVEN LATITUDE (EARTH RADIUS CORRECTED FOR FLATTENING AT THE POLES)

FC-2260

RETURN VIA QPRET

INPUT:
- ALPHA + 4 = SIN(LAT) @ z

OUTPUT:
- ERAD_0 = MPAC_0 RADIUS OF THE EARTH AT THE GIVEN LATITUDE (R_E) IN N @ 2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

A.C.WILLIAMS DECEMBER 31, 1969

COLOSSUS II

FC-2320
Called as part of V85 Sequence (FC-2050)
If in CSM and if P11 or P00 running,
Inputs are computed by TFF/Conic
(SH.8) CALC TFF (SH.5), which must be
called earlier.

MPAC contains \( t_{ff} \) - time of free fall from now
until 300 k ft. altitude

Has craft passed entry altitude?

Yes

\[ t_{ff} \leq 0 \]

\[ \phi \geq \frac{\pi}{2} \]

\[ \text{MPAC} \leq 0 \]

No

\[ t_{ff} = \text{NEMAX} \]

\[ \text{MPAC} \leq 0 \]

Yes

\[ t_{ff} = \text{NEMAX} \]

No

\[ t_{ff} = \text{NEMAX} \]

\( t_{ff} = \text{NEGA} \]

Test is in reality: Does MPAC - 1 * 10^12, cause overflow?

\[ \text{VGAM} = \text{CALCULATE} \]

\[ \text{TFF/TRIG} = \frac{1}{2} \text{in} (\text{M/s/csec}) \]

\[ \text{MPAC} \]

\[ \text{PLOD} \]

\[ \text{MPAC} \]

\[ \text{GETARG} \]

\[ \text{SH.14} \]

\[ \text{TFF} = \text{TRIG} \]

\[ \text{CALCULATE} \]

\[ \text{COS} \theta, \text{SIN} \theta \]

\[ \text{SH.11} \]

\[ \text{LEFT BY} \]

\[ \text{MMDC 15} \]

\[ \text{SH.16} \]

\[ \text{OUTPUT} \]

\[ \text{MPAC} \]

\[ \text{CSE} \]

\[ \text{PLAD} \]

\[ \text{PLD} \]

\[ \text{NEXT SHEET} \]
FROM PRECEDING SHEET

\[ \text{RANGE} = \frac{\sqrt{\text{ARC} \cos \left( \cos \theta \right) + \rho^2}}{\text{PLDn}} \]
\[ \text{MPACn} \]
\[ \text{ACOS} \left( \text{DELX} \theta \right) \text{PLdn} + \text{PLdn} \]

STORE \( T_o \)
RANGE IN REVS \( @ 2^\circ \)

GETARGS

ALT=0

- \( \text{THETA}_n \)
- \( \text{MPACn} \)
- \( \text{LAT}_n \)
- \( \text{LAT} \text{ (SPL)}_n \)
- \( \text{LONG}_n \)
- \( \text{ALT}_n \)

RANGE
INPUT TO LALOTORY:
(OBTAINED IN ORDER BY A "LOAD"
SPASH HAS ZERO ALTITUDE.

REVx \( @ 2^\circ \)

SET

VLOFLAG

CLEAR

COMPUTE \( T = \left( \text{STATE VECTOR TIME} \right) T_{pp} + T_e \)
= PREDICTED IMPACT TIME

P11 RUNNING

MPAC = PIPTIME - PLD + PLDn

POO RUNNING

MPAC = TSTART, PLD + PLDn

TIME OF SPLASH

TSTART, = STATE VECTOR TIME

PIPTIME = STATE VECTOR TIME

MPAC = PIPTIME - PLD + PLDn

*NOTE: IF THIS CODING IS ACCESSED
VIA CANDID, THEN PLD IS
IN REALITY PLD2D.

CLEAR ERAFLAG

COMPUTE FOR FIXED EARTH RADIUS

LALOTORY COMPUTES RADIUS VECTOR GIVEN TIME; LATITUDE
LONGITUDE AND ALTITUDE

INPUT:
MPAC = PREDICTED IMPACT TIME
\( \text{LAT}_n = \text{LATITUDE IN REVS} @ 2^\circ \)
\( \text{LONG}_n = \text{LONGITUDE IN REVS} @ 2^\circ \)
\( \text{ALT}_n = \text{ALITUDE} @ 0 \)
ERAFLAG = CLEAR MEANS USE FIXED EARTH RADIUS.

OUTPUT:
MPAC = RADIUS VECTOR AT PREDICTED IMPACT POINT
IN METERS \( @ 2^\circ \)

\[ \text{SPLERROR} = \frac{\text{ARCOS} \left( \text{UNIT} \left( \text{RCON} \right) \cdot \text{UNIT} \left( \text{MPAC} \right) \right) - \text{RANGE}}{\rho} \]
\[ \text{RSP} = \text{REC} \]
\[ \text{THETA}_n = \text{ARCOS} \left( \text{UNIT} \left( \text{RCON} \right) \cdot \text{UNIT} \left( \text{MPAC} \right) \right) \]

NOTE: NEGATIVE VALUE INDICATES
THAT IMPACT POINT FALLS
SHORT OF TARGET POINT

RANGE ERROR: REVx \( @ 2^\circ \)

INWAMED

PERMIT INTEGRATION TO OCCUR
FC-2280

SPLRET
FC-2250

RETURN TO R30 (V62 SEQUENCE)

MIT
INSTRUMENTATION LAB
CAMBRIDGE, M.A.

D. WILLIAMS
PREPARED
UNIV.

COLGRIUS II
FC-2320

TIME OF FREE FALL

6/26/63

REV. 1

4-14-60

John A. Storey
### Subroutines Called Which Are Flowed on Other Flow Charts

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>GETERAD</td>
<td>2280</td>
<td>Compute radius of Fischer ellipsoid, given a particular latitude</td>
<td>SH. 12</td>
</tr>
<tr>
<td>SIGNMPAC</td>
<td>2100</td>
<td>Put POSMAX into MPAC, using current sign of MPAC</td>
<td>SH. 9</td>
</tr>
<tr>
<td>INTAKE0</td>
<td>2290</td>
<td>Permit integration to be used, again</td>
<td>SH. 14</td>
</tr>
<tr>
<td>LALOTORY</td>
<td>2280</td>
<td>Given altitude, latitude, longitude, and time, compute radius vector for fixed or Fischer</td>
<td></td>
</tr>
</tbody>
</table>

### Flags

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERADFLAG</td>
<td>Compute for Fischer ellipsoid</td>
<td>Compute with fixed radius</td>
<td>SH. 14</td>
<td>SH. 5</td>
<td>SH. 5</td>
</tr>
<tr>
<td>TFFSW</td>
<td>CALCTPER</td>
<td>CALCTFF</td>
<td>SH. 5</td>
<td>SH. 5</td>
<td>SH. 5</td>
</tr>
<tr>
<td>V37FLAG</td>
<td>AVERAGEG RUNNING</td>
<td>AVERAGEG OFF</td>
<td></td>
<td></td>
<td>SH. 14</td>
</tr>
</tbody>
</table>

### Erasable Locations Used

<table>
<thead>
<tr>
<th>TAG</th>
<th>SYMBOL</th>
<th>MEANING</th>
<th>UNITS</th>
<th>ENGINEERING</th>
<th>AGC</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPHAY+4</td>
<td>sin(lat)</td>
<td>Sine of latitude of terminal radius</td>
<td>DEGREES</td>
<td>REV</td>
<td>2^1</td>
<td></td>
</tr>
<tr>
<td>ALT</td>
<td>ALT</td>
<td>Altitude, for LALOTORY (equals zero)</td>
<td>FEET</td>
<td>METERS</td>
<td>2^1</td>
<td></td>
</tr>
<tr>
<td>CDERF/2</td>
<td>COS(m)</td>
<td>Cosine of transfer angle</td>
<td>DEGREES</td>
<td>REV</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>LAT</td>
<td>LATs</td>
<td>Input for LALOTORY: LATITUDE</td>
<td>DEGREES</td>
<td>REV</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>LATs</td>
<td>LATs</td>
<td>Target location, loaded into LAT</td>
<td>DEGREES</td>
<td>REV</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>LNG</td>
<td>LNGs</td>
<td>Target location, loaded into LONG</td>
<td>DEGREES</td>
<td>REV</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>LONG</td>
<td>LONGs</td>
<td>Input for LALOTORY: LONGITUDE</td>
<td>DEGREES</td>
<td>REV</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>NRMAG</td>
<td>NRMAG</td>
<td>Normalized magnitude of r</td>
<td>FEET</td>
<td>METERS</td>
<td>2^29-X1/2^27-X1</td>
<td></td>
</tr>
<tr>
<td>NRTERM</td>
<td>NRTERM</td>
<td>Normalized terminal radius</td>
<td>FEET</td>
<td>METERS</td>
<td>2^29-X1/2^27-X2</td>
<td></td>
</tr>
<tr>
<td>PIOTIME</td>
<td>PIOTIME</td>
<td>Time of state vector computed by automatic</td>
<td>SECONDS</td>
<td>CSC</td>
<td>2^28</td>
<td></td>
</tr>
<tr>
<td>RMAG</td>
<td>RMAG</td>
<td>Current radius magnitude</td>
<td>FEET</td>
<td>METERS</td>
<td>2^29, 2^27</td>
<td></td>
</tr>
<tr>
<td>RONE</td>
<td>RONE</td>
<td>Current radius state vector</td>
<td>FEET</td>
<td>METERS</td>
<td>2^29, 2^27</td>
<td></td>
</tr>
<tr>
<td>RPER</td>
<td>RPER</td>
<td>Magnitude of perigee</td>
<td>FEET</td>
<td>METERS</td>
<td>2^29, 2^27</td>
<td></td>
</tr>
<tr>
<td>RSP-RREC</td>
<td>SPLITERR</td>
<td>Range error</td>
<td>DEGREES</td>
<td>REV</td>
<td>2^0</td>
<td></td>
</tr>
</tbody>
</table>

---

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

TIME OF FREE FALL

COLOSSUS II

FC-2320
### ERASABLE LOCATIONS USED (CONTINUED)

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>RTERM_D</td>
<td>( r_h )</td>
<td>TERMINAL RADIUS</td>
<td>FEET</td>
<td>METERS</td>
<td>( 2^{20} / 2^{27} )</td>
</tr>
<tr>
<td>TFFALFAD</td>
<td>( \alpha )</td>
<td>INVERSE OF SEMI-MAJOR AXIIS OF CONIC</td>
<td>1/FEET</td>
<td>1/METERS</td>
<td>( 2^{-26} + X_1 / 2^{-24} + X_1 )</td>
</tr>
<tr>
<td>TFFDELAQD</td>
<td>( Q_a - Q_0 )</td>
<td>TEMPORARY VARIABLE</td>
<td>FEET(^{1/2} )</td>
<td>METERS(^{1/2} )</td>
<td>( 2^{16} / 2^{15} )</td>
</tr>
<tr>
<td>TFFNP_D</td>
<td>( \rho )</td>
<td>SEMI-LATUS RECTUM, WEIGHTED BY ( X_1 )</td>
<td>FEET</td>
<td>METERS</td>
<td>( 2^{38} + 2X_1 / 2^{36} + X_1 )</td>
</tr>
<tr>
<td>TFFQLD</td>
<td>( Q_0 ) ( (\frac{r_0 \cdot q_0}{\sqrt{\mu}}) )</td>
<td>SQUARE ROOT OF INVERSE OF SEMI-MAJOR AXIS</td>
<td>FEET(^{1/2} )</td>
<td>METERS(^{1/2} )</td>
<td>( 2^{18} / 2^{15} )</td>
</tr>
<tr>
<td>TFFRTALFD</td>
<td>( \sqrt{\mu} )</td>
<td>TEMPORARY VARIABLE LOCATION</td>
<td>1/FEET(^{1/2} )</td>
<td>1/METERS(^{1/2} )</td>
<td>( 2^{-10} + X_2 )</td>
</tr>
<tr>
<td>TFFTEM_D</td>
<td>( \sqrt{\mu} )</td>
<td>TEMPORARY VARIABLE LOCATION</td>
<td>DEGREES</td>
<td>REVS</td>
<td>( 2^0 )</td>
</tr>
<tr>
<td>TFFVSOQD</td>
<td>( -(\frac{V_o}{\mu})^2 )</td>
<td>MINUS SQUARE OF VELOCITY OVER ( \mu )</td>
<td>FEET</td>
<td>METERS</td>
<td>( 2^{-21} )</td>
</tr>
<tr>
<td>TFFX_D</td>
<td>( x )</td>
<td>( 1/\alpha^2 ) OR ( a^2 )</td>
<td>( 2^0 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TFF1/ALF_D</td>
<td>( 1/\alpha )</td>
<td>INVERSE OF ALPHA: SEMI-MAJOR AXIS</td>
<td>FEET</td>
<td>METERS</td>
<td>( 2^{22} - 2X_2 )</td>
</tr>
<tr>
<td>THEETA D</td>
<td>( \theta )</td>
<td>TRANSFER ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>( 2^0 )</td>
</tr>
<tr>
<td>UNIV</td>
<td>UNIT(( V_o \times R_o ))</td>
<td>UNIT NORMAL TO FLIGHT PATH PLANE</td>
<td>( 2^1 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>URH_V</td>
<td>UNIT(( R_h ))</td>
<td>UNIT VECTOR OF TERMINAL</td>
<td>( 2^1 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>URONE_V</td>
<td>UNIT(( R_{o} ))</td>
<td>UNIT VECTOR OF CURRENT POSITION</td>
<td>( 2^1 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VONE_V</td>
<td>( \frac{V_o}{\mu} )</td>
<td>CURRENT VELOCITY VECTOR</td>
<td>FEET/SEC</td>
<td>METERS/CSEC</td>
<td>( 2^{7/3} )</td>
</tr>
<tr>
<td>VONE_V</td>
<td>( \frac{V_o}{\mu} )</td>
<td>CURRENT VELOCITY VECTOR OVER ( \mu^{1/2} )</td>
<td>FEET(^{-1/2} )</td>
<td>METERS(^{-1/2} )</td>
<td>( 2^{-10} / 2^{-9} )</td>
</tr>
</tbody>
</table>

### PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP(-22)_D</td>
<td>( 1 @ 2^3 )</td>
<td>ONE</td>
<td>( 2^{-22} )</td>
<td>1</td>
<td>( 2^{22} )</td>
</tr>
<tr>
<td>DPX(-3)_D</td>
<td>( 1 @ 2^4 )</td>
<td>ONE</td>
<td>( 1 @ 2^4 )</td>
<td>1</td>
<td>( 2^{3} )</td>
</tr>
<tr>
<td>DPX(-4)_D</td>
<td>( 1 @ 2^4 )</td>
<td>ONE</td>
<td>( 1 @ 2^4 )</td>
<td>1</td>
<td>( 2^{4} )</td>
</tr>
<tr>
<td>HIDPHALF_D</td>
<td>( 1/2 )</td>
<td>( 1/2 )</td>
<td>( 5 )</td>
<td>( 2^{0} )</td>
<td></td>
</tr>
<tr>
<td>HISZEROS_D</td>
<td>( 0 )</td>
<td>ZERO</td>
<td>000000000.0</td>
<td>00000000</td>
<td>( 2^{0} )</td>
</tr>
</tbody>
</table>
## Program Constants (Continued)

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Value and Units</th>
<th>AGC Value and Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIM(-22)_D</td>
<td>1-2^22</td>
<td>Test Constant for</td>
<td>1-2^22</td>
<td>1-2^22</td>
<td>2^0</td>
</tr>
<tr>
<td>NEARONE_D</td>
<td>2^28-1</td>
<td>Machine Positive Maximum</td>
<td>2^28-1</td>
<td>.9999999999</td>
<td>2^0</td>
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<tr>
<td>PI/16_D</td>
<td>π</td>
<td>PI</td>
<td>π</td>
<td>π</td>
<td>2^4</td>
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<tr>
<td>TFFZEROS_D</td>
<td>0</td>
<td>Zero</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>TFF1/4_D</td>
<td>2</td>
<td>Two</td>
<td>2@2^3</td>
<td>2</td>
<td>2^3</td>
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</table>

## For DELRSPL and AUGEKUOL

Note: This table is indexed. All values in the table are empirically derived curve-fitting coefficients, except that some may also be test constants, in which case they are so labeled.

<table>
<thead>
<tr>
<th>CK1K2</th>
<th>5500</th>
<th>7.07304526 x 10^-4</th>
<th>2^0</th>
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</thead>
<tbody>
<tr>
<td>CK1K2 -10D_D</td>
<td>2400</td>
<td>3.08641975 x 10^-4</td>
<td>2^0</td>
</tr>
<tr>
<td>CK1K2 -8D_D</td>
<td>2400</td>
<td>3.08641975 x 10^-4</td>
<td>2^0</td>
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<tr>
<td>CK1K2 -6D_D</td>
<td>2400</td>
<td>3.08641975 x 10^-4</td>
<td>2^0</td>
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<tr>
<td>CK1K2 -4D_D</td>
<td>-3.2</td>
<td>-8.8888888 x 10^-3</td>
<td>2^0</td>
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<tr>
<td>CK1K2 -2D_D</td>
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<td>2.7777777 x 10^-3</td>
<td>2^0</td>
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<td>CK1K2</td>
<td>2.4</td>
<td>6.666666 x 10^-3</td>
<td>2^0</td>
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<tr>
<td>CK1K2 +2D_D</td>
<td>0</td>
<td>0</td>
<td>2^0</td>
</tr>
<tr>
<td>CK1K2 +4D_D</td>
<td>-4.43</td>
<td>-1.86909989 x 10^-5</td>
<td>2^-7</td>
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<tr>
<td>CK1K2 +6D_D</td>
<td>0</td>
<td>0</td>
<td>2^0</td>
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<tr>
<td>CK1K2 +8D_D</td>
<td>.001225</td>
<td>1.11639691 x 10^-3</td>
<td>2^-7</td>
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<tr>
<td>CK1K2 +10D_D</td>
<td>.00105</td>
<td>9.56010363 x 10^-4</td>
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<td>YK1K2</td>
<td>.000285</td>
<td>2.59733157 x 10^-4</td>
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<tr>
<td>V(400)</td>
<td></td>
<td>400 FT/SEC</td>
<td>2^-7</td>
</tr>
<tr>
<td>V(28K)</td>
<td></td>
<td>28000 FT/SEC</td>
<td>2^-7</td>
</tr>
<tr>
<td>V(3K)</td>
<td></td>
<td>3000 FT/SEC</td>
<td>2^-7</td>
</tr>
<tr>
<td>AGC TAG</td>
<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING VALUE AND UNITS</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>---------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>V(24K)</td>
<td></td>
<td></td>
<td>24000 FT/SEC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>28000 FT/SEC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>32000 FT/SEC</td>
</tr>
<tr>
<td>V(32K)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>V(4K)</td>
<td></td>
<td>TEST CONSTANT</td>
<td>4000 FT/SEC</td>
</tr>
<tr>
<td>V(21K)</td>
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<td>TEST CONSTANT</td>
<td>20997.3 FT/SEC</td>
</tr>
<tr>
<td>TLESS25</td>
<td></td>
<td>CURVE FIT CONSTANT</td>
<td>8660</td>
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<td>TGR26CON</td>
<td></td>
<td>CURVE FIT CONSTANT</td>
<td>PHI/3</td>
</tr>
<tr>
<td>V(25K)</td>
<td></td>
<td>TEST CONSTANT</td>
<td>26000 FT/SEC</td>
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<tr>
<td>XICON</td>
<td></td>
<td>INDEX AND STEP REGISTER INITIAL VALUES</td>
<td>X1, X2, S1</td>
</tr>
<tr>
<td>MAXPH2I</td>
<td></td>
<td>2000 NAUTICAL MILES FOR MAXIMUM PHI ENTRY</td>
<td>2000 N.M.</td>
</tr>
</tbody>
</table>

END OF THE INDEXED TABLE
RENDEZVOUS PARAMETERS DISPLAYS

MAJOR ROUTINES AND EXTERNAL ENTRY POINTS

V83PERF: REQUEST FOR VERB 83, (R31), KEYED IN BY ASTRONAUT

V85PERF: REQUEST FOR VERB 85, (R34), KEYED IN BY ASTRONAUT

SH. 2

THERE HAVE BEEN NO CHANGES FROM THE COLOSSUS II
FLOWCHART FC-2325, REV. 0, TO THE COLOSSUS III FLOW-
CHART FC-2325, REV. 1
NOVAC JOB SCHEDULED AFTER V83E OR V85E KEystroke

V85Call
AND NOVAC JOB
PRIORITY 5
SH 4

DSPDELAY
DELAY THE DISPLAY UNTIL V83CALL
HAS DONE ITS FIRST PASS

DELAY JOB
1 SEC
FC-2070

IS
BIT 12 OF
EXTBACT
SET?

CAN DISPLAY START?

YES

DISPN5X
IS
IS THIS R31 OR R34?

YES
R31
NO
R34

USE NOUN 54

USE NOUN 53

GOMARKF
V16 NOUN 53 OR 54
R1 RANGE
DISPLAY R2 RANGE RATE
R3 $ OR +

RECYLE

TERMINATE
PROCEED
B5OFF

ENDS EXTENDED VERB
WHICH HAS CALLED TESTKACT

RENDEZVOUS PARAMETERS
DISPLAY

COLOSSUS II
FC-2325
PRIORITY 3 JOB
SCHEDULED BY R31CALL

INPUT:
- LOADTIME: PRESENT TIME
- LAST COMPUTED STATE VECTOR

OUTPUT:
- BASEOTPV: BASE POSITION VECTOR OF LEM IN M@X7/2°
- BASEOTTV: BASE VELOCITY VECTOR OF LEM IN M/CSEC@X7/2°
- BASETHPV: BASE POSITION VECTOR OF CSM IN M@X7/2°
- BASETHTV: BASE VELOCITY VECTOR OF CSM IN M/CSEC@X7/2°
- BASETIME: TIME OF ALL "BASE" VECTORS IN CSEC @ X7/2°
- RATT: EXTRAPOLATION METERS @ 2°
- VATT: OF LEM STATE VECTOR M/CSEC @ X7/2°
- VONE: EXTRAPOLATION Meters @ 2°
- VONE: OF CSM STATE VECTOR M/CSEC @ X7/2°
- TAT: TIME OF RONE, VONE, RATT, VATT IN CSEC @ X7/2°

METERS @ X7/2°
M/CSEC @ X7/2°

NOTE: (RATT - RONE) IS SHIFTED LEFT BY
THE NORM COUNT FOR (RATT - RONE)
TO AVOID PROBLEMS IN THE
INTERPRETER

CDUTRIG

INPUT:
- CONTENTS OF CDU REGISTERS

OUTPUT:
- SINCDUX COSCDUX @ X7/2°
- SINCDUX COSCDUX @ X7/2°

R34LOS CALLS SXTNB. IT PUTS SHAFT AND TRUINION
ANGLES TO RELATIVE ADDRESSES EXPECTED BY SXTNB,
AND SETS X1 TO THE PROPER VAC AREA ADDRESS.

INPUT:
- CDUS - SHAFT ANGLE
- CDUT - TRUINION ANGLE
- FIXLOG - ADDRESS OF VAC AREA

OUTPUT:
- PLZEDV = 1/2 UNIT LINE-OF-SIGHT VECTOR REFERENCED
TO THE NAVIGATION BASE, COORDINATE SYSTEM
COINCIDENT WITH THE SEXTANT LINE-OF-SIGHT

R31FLG RUNNING?

NO

R34FLG RUNNING?

LOAD X-AXIS UNIT VECTOR

MPACV = THISAXISV

NEXT SHEET
FROM PRECEDING SHEET

CONVERT MPACn FROM NAV. BASE COORDINATES TO STABLE MEMBER

INPUT:
SIND, C0S, SIND, C0S
SIND, C0S
MPACn IN N.B. COORDINATES

OUTPUT:
MPACn IN S.M. COORDINATES

\[ \theta = \cos^{-1} \left( \frac{u_y \cdot u_x \cdot \text{SIGN}(u_x \cdot u_y \cdot u_z)}{|u_x| \cdot |u_y| \cdot |u_z|} \right) \]
where \( u_y \cdot u_x = \text{UNIT} \left( \frac{r_y \cdot f_x}{r_y \cdot f_x} \right) \)

\[ \text{PLOD}_2 = -\text{MPACn} \cdot \text{REMMAT} \]

\[ \text{RTHETA}_2 = \arccos \left[ \text{SIGN} \left( \frac{4\left(\text{PLOD}_2 \cdot -\text{PLOD}_2 + \text{PLOD}_2 \cdot \text{PLOD}_2 \cdot \text{PLOD}_2 \cdot \text{PLOD}_2 \right)}{\text{UNIT}(\text{RONE}_2 \cdot \text{VONE}_2) \cdot \text{UNIT}(\text{RONE}_2 \cdot -\text{PLOD}_2 \cdot \text{PLOD}_2 \cdot \text{PLOD}_2 \cdot \text{PLOD}_2)} \right) \]
where \( \text{UNIT}(\text{RONE}_2 \cdot \text{VONE}_2) \)

\$S\$ is an intermediate variable, not an AGC tag

INSURE POSITIVE ANGLE

YES

\[ 15 \text{ RONEV} \cdot \text{PLOD} > 2.0 \]

NO

\[ \text{RTHETA}_2 = \text{OPP} \cdot \text{MAX} \cdot \text{RTHETA}_2 \]

DOES ASTRONAUT WISH TO TERMINATE?

TERM:ENATE

BIT 5 OF EXTVBACT OFF?

YES

NO

ALLOW DISPLAY TO START

SET BIT 32 OF EXTVBACT

VB3 UPDATE STATE VECTORS

HABBASE SHB

RENEZVOUS PARAMETERS
DISPLAY

COLOSSUS II* FC-2325
LOAD CDU SHAFT ANGLE
LOAD CDU TRUNNION ANGLE
PUT ABSOLUTE ADDRESS INTO X1
(5XTNB EXPECTS TO FIND CDUS IN -X1 +5 AND CDUT IN -X1 +5)

INPUT:
CDUS = PL9D
CDUT = PL10D
X1 = (FIXLOC +G)

OUTPUT:
MPACV = UNIT LINE OF SIGHT VECTOR = LOS VECTOR

SAVE LOS VECTOR
STATE_XTP

MPAC ← TIME_ZD

IS AVERAGEG RUNNING?

NO

IS V37FLAG ON?

YES: OBTAIN UPDATED STATE VECTOR

GETRPN

VNR, VNN, AND PIPTIME

ON?

OUTPUT:

MPAC = TIME OF RONEV & VONEV

STORE EITHER PIPTIME OR TIME ZD

LEMPREC

UPDATE LEM STATE VECTOR TO TDEC1;

FC-2320

STORE UPDATED LEM VECTOR FOR USE AS BASE REFERENCE

IS V37FLAG ON?

YES

IS AVERAGEG RUNNING?

NO

COWPDISP

SN 4

TDEC1 D ← TAT D

LEMPREC

UPDATE LEM STATE VECTOR TO TDEC1;

FC-2320

STORE FOR BASE REFERENCE

NEXT SHEET
FROM PRECEDING SHEET

HAVEBASE

IS AVERAGEG RUNNING?

YES

GETRVM
SH10

TDEC1_D ← TIME2_D

LOAD CURRENT TIME

INSTALL
STALL THIS
PROGRAM TILL
INTEGRATION IS FREE
FROM USING ORBITAL INTEGRATION.

INTSTALL PROHIBITS MORE THAN ONE PROGRAM
FROM USING ORBITAL INTEGRATION.

NO

RCV_D ← BASETHP_D

LOAD CSM POSITION BASE VECTOR INTO LOCATION
EXPECTED BY INTEGRVS. (M/s^2/s)

VCV_D ← BASETHV_D

CLEAR
MOONFLAG

LOAD CSM VELOCITY BASE VECTOR INTO
INTEGRVS LOCATION
LOAD TIME OF RCV_D & VCV_D
(M/CSEC @ s^2/s)

TET_D ← BASETIME_D

IS MOONTHIS SPHERE? (FOR INTEGRVS)

NO

EARTH'S SPHERE

YES

SET MOONFLAG

CLEAR
INTYPFLG

PREPARE FOR "SURFFLAG" TEST

IS SURFFLAG SET?

YES

LEM ON MOON'S SURFACE

NO

CONIC INTEGRATION

PRECISION
INTEGRATION IF LEM ON SURFACE

SET INTYPFLG

NEXT SHEET
FROM PRECEDING SHEET

INTEGRVS:
UPDATE
CSM VECTOR
TO TDEC1
FC-2E90

INTEGRVS:
UPDATE
LEM VECTOR
TO TDEC1
FC-2E90

INPUT:
TDEC1 = BASE TIME D IN CSEC @ 2.29
RCV = BASE Trophy IN METERS @ 2.27/2.29
VCV = BASE VIN IN M/CSEC @ 2.27
MOONFLAG
INFLAG

OUTPUT: RATT, VATT, TATD

STORE OUTPUT FOR COMPDISP
SAVE TIME OF RATT & VATT

IS LEM ON MOON’S SURFACE?

GET RVNS
5H10

INTSTALL
STALL THIS
PROGRAM UNTIL
INTEGRATION IS
FREE
FC-2E90

SET
INTYPFLG

CONIC INTEGRATION

OTHINT

TDEC1 = MPAC

RCV = BASE TV

USE TIME OF RONEV & VONEV FOR LEM UPDATE
BASE LEM POSITION VECTOR: M@ 2.29/2.27

CLEAR
MOONFLAG

PREPARE FOR MOONTHIS’ TEST

VCV = BASE TV

BASE LEM VELOCITY VECTOR: M/CSEC @ 2.27/2.29
BASE TIME: CSEC @ 2.29

TOE = BASE TIME E

IS IN THE MOON’S SPHERE?

NO

EARTH

YES

MOON

MOONFLAG

INTEGRVS
UPDATE LEM
VECTOR
FC-2E90

INPUT: RCV, VCV, TOT, MOONFLAG, INTYPFLG
OUTPUT: VATT, @ 2.27, RATT, @ 2.29

RENEZVOUS PARAMETERS
DISPLAY

ARTICVA WAYS

COLOSSEUS II FC-2325
GETRVNS

ENTER HERE FROM HAVEBASE WITH V37FLAG SET

GETRVN

OBTAIN RONE, VONE, PIPTIME SH41

IS LEM ON MOON'S SURFACE?

YES

SURFFLAG SET

NO

INSTALL

STALL THIS PROGRAM UNTIL INTEGRATION FREE FC-0200

CLEAR INTYFNG

PRECISION INTEGRATION OF LEM STATE VECTOR

OTHINT SH9

UPDATE LEM STATE VECTOR

GETRVN6

ENTER HERE FROM HAVEBASE & WITH SURFFLAG SET FROM GETRVNS

TDEC1 ← MPACD

TIME TO BE INTEGRATED TO

LEMFREC

LEM STATE VECTOR TO FC-0200

COMPOISP SH4

OUTPUT:

RONEV = RNV = POSITION VECTOR IN M @ 259
VONEV = VNV = VELOCITY VECTOR IN M/SEC @ 259
MPAC = PIPTIME • TIME OF RONEV & VONEV IN SEC @ 259

RENNDEVOUS PARAMETERS
DISPLAY

COLOSSUS IIIC FC-2325

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.
GETRVN

STORE QP RET IN FLOD

PONE_V VN_VN , MPAC PI TIME

RETURN VIA FLOD

THIS SELECTION IS CODED IN SUCH A WAY AS TO PERMIT A CONSISTENT SET OF RN, VN AND PI TIME TO BE LOADED.

PONE = M @ 2.09
VONE = M/CSEC @ 2.7
MPAC = CSEC @ 2.28
### Displays

<table>
<thead>
<tr>
<th>Verb-Noun</th>
<th>Type of Display</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-53 OR 54</td>
<td>FALTON</td>
<td>Turn on Operator Error Light: Previous Extended Verb Active.</td>
<td>SH. 2</td>
</tr>
<tr>
<td>GOMARKP</td>
<td>R1 RANGE: XXX.XX D NAUT MILES</td>
<td>R2 RANGE RATE: XXX.XX D FEET/SEC</td>
<td>SH. 3</td>
</tr>
<tr>
<td></td>
<td>R3 0 OR φ</td>
<td>XXX.XX D DEGREES</td>
<td></td>
</tr>
</tbody>
</table>

### Flags

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIT 4 OF FLAGWORD</td>
<td>R31 RUNNING</td>
<td>R34 RUNNING</td>
<td>SH. 2</td>
<td>SH. 2</td>
<td>SH. 3</td>
</tr>
<tr>
<td>BIT 5 OF EYTVBACT</td>
<td>DO NOT TERMINATE EXTENDED VERB</td>
<td>TERMINATE EXTENDED VERB</td>
<td>SH. 2</td>
<td>SH. 2</td>
<td>SH. 3</td>
</tr>
<tr>
<td>BIT 12 OF EYTVBACT</td>
<td>START DISPNSX DISPLAY</td>
<td>DO NOT START DISPNSX DISPLAY</td>
<td>SH. 5</td>
<td>SH. 5</td>
<td>SH. 3</td>
</tr>
<tr>
<td>INTPF</td>
<td>CONIC INTEGRATION</td>
<td>PRECISION INTEGRATION</td>
<td>SH. 6.9</td>
<td>SH. 8.9</td>
<td>SH. 3</td>
</tr>
<tr>
<td>MOONFLAG</td>
<td>IN MOON'S SPHERE</td>
<td>IN EARTH'S SPHERE</td>
<td>SH. 6.9</td>
<td>SH. 8.9</td>
<td>SH. 3</td>
</tr>
<tr>
<td>MOONTHS</td>
<td>IN MOON'S SPHERE</td>
<td>IN EARTH'S SPHERE</td>
<td>SH. 6.9</td>
<td>SH. 8.9</td>
<td>SH. 3</td>
</tr>
<tr>
<td>R31FLG</td>
<td>R31 RUNNING</td>
<td>R34 RUNNING</td>
<td>SH. 4</td>
<td>SH. 4</td>
<td>SH. 5.9, 10</td>
</tr>
<tr>
<td>SURFFLG</td>
<td>LEM ON SURFACE</td>
<td>LEM NOT ON SURFACE</td>
<td>SH. 5</td>
<td>SH. 5</td>
<td>SH. 5</td>
</tr>
<tr>
<td>V37FLG</td>
<td>AVERAGEG RUNNING</td>
<td>AVERAGEG NOT RUNNING</td>
<td>SH. 5</td>
<td>SH. 5</td>
<td>SH. 5</td>
</tr>
</tbody>
</table>

### Subroutines Called Which Are Followed on Other Flow Charts

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>4NBSM*</td>
<td>2270</td>
<td>Converts Navbase to Stable Member Coordinates</td>
<td>SH. 5</td>
</tr>
<tr>
<td>CDUTRIG</td>
<td>2270</td>
<td>Converts Contents of CDO Registers to Sines and Cosines</td>
<td>SH. 4</td>
</tr>
<tr>
<td>CSMPREC</td>
<td>2300</td>
<td>Update CSM State Vector to a Particular Time</td>
<td>SH. 7</td>
</tr>
<tr>
<td>DELAYJOB</td>
<td>2070</td>
<td>Delays a Job for a Particular Time Period</td>
<td>SH. 3</td>
</tr>
<tr>
<td>FALTON</td>
<td>2130</td>
<td>Turns on Operator Error Light</td>
<td>SH. 2</td>
</tr>
<tr>
<td>INTEGRVS</td>
<td>2300</td>
<td>Orbital Integration Routine</td>
<td>SH. 9</td>
</tr>
<tr>
<td>INSTALL</td>
<td>2300</td>
<td>Stalls Calling Program Until Integration is Not Being Used, Then Stalls Any Other Programs Wishing to Use Integration Until Inwake Is Called</td>
<td>SH. 8, 9, 10</td>
</tr>
<tr>
<td>LEMPREC</td>
<td>2300</td>
<td>Update LEM Vector to a Particular Time</td>
<td>SH. 7, 10</td>
</tr>
<tr>
<td>SXTNB</td>
<td>2250</td>
<td>Change Sextant Line of Sight to Navbase Coordinates</td>
<td>SH. 6</td>
</tr>
<tr>
<td>TESTXACT</td>
<td>2150</td>
<td>Test for Extended Verb Activity</td>
<td>SH. 2</td>
</tr>
<tr>
<td>AGC TAG</td>
<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING UNITS</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
<td>--------------------------------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>BASETOPV</td>
<td>L</td>
<td>POSITION VECTOR OF LEM AT BASETIME</td>
<td>FEET</td>
</tr>
<tr>
<td>BASEOTV</td>
<td>L</td>
<td>VELOCITY VECTOR OF LEM AT BASETIME</td>
<td>FEET/SEC</td>
</tr>
<tr>
<td>BASETHPV</td>
<td>C</td>
<td>POSITION VECTOR OF CSM AT BASETIME</td>
<td>FEET</td>
</tr>
<tr>
<td>BASETHV</td>
<td>C</td>
<td>VELOCITY VECTOR OF CSM AT BASETIME</td>
<td>FEET/SEC</td>
</tr>
<tr>
<td>BASETIME</td>
<td>D</td>
<td>REFERENCE TIME FOR ORIGINAL PRECISION STATE VECTORS</td>
<td>MIN/SEC</td>
</tr>
<tr>
<td>CDUS</td>
<td></td>
<td>SHAFT ANGLE</td>
<td>DEGREES</td>
</tr>
<tr>
<td>CDUT</td>
<td></td>
<td>TRUNNION ANGLE</td>
<td>DEGREES</td>
</tr>
<tr>
<td>COSCDUX</td>
<td></td>
<td>OUTPUT OF CDUTRIG ROUTINE</td>
<td></td>
</tr>
<tr>
<td>COSCDUY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COSCDUZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FIXLOC</td>
<td></td>
<td>ADDRESS OF VAC AREA</td>
<td></td>
</tr>
<tr>
<td>PIPTIME</td>
<td>D</td>
<td>TIME CORRESPONDING TO CURRENT STATE VECTOR (WHEN AVERAGE IS RUNNING)</td>
<td>SECONDS</td>
</tr>
<tr>
<td>RANGE</td>
<td>D</td>
<td>RANGE DISTANCE BETWEEN THE TWO VEHICLES</td>
<td>FEET</td>
</tr>
<tr>
<td>RATT</td>
<td>V</td>
<td>RADIUS VECTOR OUTPUT OF INTEGRATION</td>
<td>FEET</td>
</tr>
<tr>
<td>RATTE</td>
<td>V</td>
<td>SAME AS RATT, BUT VARIABLE SCALING</td>
<td>FEET</td>
</tr>
<tr>
<td>RCV</td>
<td>V</td>
<td>POSITION VECTOR FROM WHICH TO START INTEGRATION</td>
<td>FEET</td>
</tr>
<tr>
<td>REFSMMAT</td>
<td>M</td>
<td>TRANSFORMATION MATRIX FOR REFERENCE TO STABLE MEMBER CONVERSION</td>
<td></td>
</tr>
<tr>
<td>RN</td>
<td>V</td>
<td>RADIUS VECTOR AS GIVEN BY AVERAGE</td>
<td>FEET</td>
</tr>
<tr>
<td>RONE</td>
<td>V</td>
<td>RADIUS VECTOR INPUT TO INTEGRATION</td>
<td>FEET</td>
</tr>
<tr>
<td>RRATE</td>
<td>D</td>
<td>RANGE RATE</td>
<td>FEET/SEC</td>
</tr>
<tr>
<td>RTHETA</td>
<td>D</td>
<td>THETA</td>
<td>DEGREES</td>
</tr>
<tr>
<td>SINCDUX</td>
<td></td>
<td>OUTPUT OF CDUTRIG</td>
<td></td>
</tr>
<tr>
<td>SINCDUY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SINDUZ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TAT</td>
<td>D</td>
<td>TIME OF THE OUTPUT OF ORBITAL INTEGRATION</td>
<td>SECONDS</td>
</tr>
<tr>
<td>TDECL</td>
<td>D</td>
<td>TIME TO BE INTEGRATED TO</td>
<td>SECONDS</td>
</tr>
<tr>
<td>TET</td>
<td>D</td>
<td>TIME TO BE INTEGRATED FROM</td>
<td>SECONDS</td>
</tr>
</tbody>
</table>
### Erasable Locations Used (Continued)

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>THISAXIS&lt;sub&gt;V&lt;/sub&gt;</td>
<td>UNIT X VECTOR</td>
<td>SECONDS</td>
<td>CSEC</td>
<td>$2^{28}$</td>
<td></td>
</tr>
<tr>
<td>TIME2&lt;sub&gt;D&lt;/sub&gt;</td>
<td>TIMING REGISTERS</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>$2^{7}$</td>
<td></td>
</tr>
<tr>
<td>VELOCITY OUTPUT OF</td>
<td>VELOCITY OUTPUT OF</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>$2^{5/2}$</td>
<td>$2^{5/2}$</td>
</tr>
<tr>
<td>VATT&lt;sub&gt;V&lt;/sub&gt;</td>
<td>INTEGRATION ROUTINES</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>$2^{7}$</td>
<td></td>
</tr>
<tr>
<td>VATT1&lt;sub&gt;V&lt;/sub&gt;</td>
<td>VELOCITY OUTPUT OF</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>$2^{5/2}$</td>
<td>$2^{5/2}$</td>
</tr>
<tr>
<td>VCV&lt;sub&gt;V&lt;/sub&gt;</td>
<td>INTEGRATION ROUTINES</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>$2^{7}$</td>
<td></td>
</tr>
<tr>
<td>VN&lt;sub&gt;V&lt;/sub&gt;</td>
<td>VELOCITY VECTOR</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>$2^{7}$</td>
<td></td>
</tr>
<tr>
<td>VONE&lt;sub&gt;V&lt;/sub&gt;</td>
<td>VELOCITY VECTOR</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>$2^{7}$</td>
<td></td>
</tr>
</tbody>
</table>

### Program Constants

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Value and Units</th>
<th>AGC Value and Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPPOSMAX&lt;sub&gt;D&lt;/sub&gt;</td>
<td>LARGEST POSITIVE VALUE AVAILABLE TO COMPUTER DP</td>
<td>1-$2^{28}$</td>
<td>1-$2^{28}$</td>
<td>$2^{0}$</td>
<td></td>
</tr>
</tbody>
</table>
R62 CREW DEFINED MANEUVER

MAJOR SUBROUTINE ON THIS CHART

EXTENDED: CREWMANU START AUTO ATTITUDE MANEUVER

VERB 49:

R62.DISP CREW DEFINED MANEUVER

SH2

SH3

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

THE EFFECTIVE SHEETS FOR COLOSSUS II ARE

1  REV 1
2  REV 1
3  REV 0
4  REV 0
EXTENDED VERB 49: CREW DEFINED MANEUVER

PURPOSE: TO PROVIDE THE CREW WITH THE ABILITY TO SPECIFY A FINAL VELOCITY ATTITUDE FOR USE BY A CMC-CONTROLLED ATTITUDE MANEUVER

KEYED IN BY ASTRONAUT

V49E
START AUTO ATTITUDE MANEUVER

CREWMANU

CHKPOOH
TEST FOR IDLING PROGRAM FC-2190

CURRENT PROGRAM NOT IDLED ERROR EXIT

TESTXACT
TEST FOR EXTENDED VERB OR PRIORITY DISPLAY ACTIVE FC-2190

PREVIOUS EXTENDED VERB ACTIVE ERROR EXIT

NO OTHER EXTENDED VERBS ACTIVE

R22EDISP
FIND VAC JOB PRIORITY 10 SH-3

SCHEDULE CREW DEFINED MANEUVER

ENDOFJOB

INPUT: MROG
OUTPUT: RETURNS IF MROG=0

INPUT: EXTVEBC
OUTPUT: RETURNS WITH BITS 3 AND 5 OF EXTVEBC SET TO INDICATE EXTENDED VERB ACTIVITY

ALM/END

FALTON TURN ON OPERATOR ERROR LIGHT FC-2180

PINE/RCCH FC-2130

R62 CREW DEFINED MANEUVER

FC-2330
R62 DISP

ENTER

NEW GIMBAL ANGLES

DISPLAY DESIRED GIMBAL ANGLES FOR MANEUVER

GOFLASH

DISPLAY DESIRED GIMBAL ANGLES (OUTER)

R1 - CPHI = XXX.XX DEG. - ROLL
R2 - CTHETA = XXX.XX DEG. - PITCH
R3 - CPS1 = XXX.XX DEG. - YAW

ENTER

FC-2190

MANEUVER SPECIFIED BY THREE AXES

INPUT: 3AXISFLG, DESIRED GIMBAL ANGLES
OUTPUT: SPACECRAFT MANEUVERED TO SPECIFIED ATTITUDE

PERFORM AUTO ATTITUDE MANEUVER

R60CSM

INPUT: 3AXISFLG

PERFORM AUTO ATTITUDE MANEUVER

FC-2340

SET 3AXISFLG

PROCEED

GO MOVE

END EXT

FC-2190
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHKPOOL</td>
<td>FC-2190</td>
<td>TEST FOR IDLING PROGRAM</td>
<td>SH 2</td>
</tr>
<tr>
<td>FALDO</td>
<td>FC-2180</td>
<td>TURN ON OPERATOR ERROR LIGHT</td>
<td>SH 2</td>
</tr>
<tr>
<td>RS2RSM</td>
<td>FC-2240</td>
<td>PERFORM AUTO ATTITUDE MANEUVER</td>
<td>SH 3</td>
</tr>
<tr>
<td>TESTXACT</td>
<td>FC-2190</td>
<td>TEST FOR EXTENDED VERB ON PRIORITY DISPLAY ACTIVE</td>
<td>SH 2</td>
</tr>
</tbody>
</table>

**FLAGS**

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>3AXISFLG</td>
<td>MANEUVER SPECIFIED BY THREE AXES</td>
<td>MANEUVER SPECIFIED BY ONE AXIS</td>
<td>SH 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DISPLAYS**

<table>
<thead>
<tr>
<th>VERBNDN</th>
<th>TYPE OF DISPLAYS</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>V06N22</td>
<td>FLASHING</td>
<td>R1 - CPHI - XXX.XX Deg. - ROLL (OUTER) DESIRED</td>
<td>SH 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2 - CTHETA - XXX.XX Deg. - PITCH (INNER) GIMBAL</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3 - CPSI - XXX.XX Deg. - YAW (MIDDLE) ANGLES</td>
<td></td>
</tr>
</tbody>
</table>
R60 ATTITUDE MANEUVER

MAJOR SUBROUTINE IN THIS FLOW CHART
R60CSM ATTITUDE MANEUVER
VECPNPNT COMPUTE ONE AXIS MANEUVER ANGLES

SH2

SH5

THE ENCLOSED REPLACEMENT SHEETS WILL UPDATE THE COLOSSUS I (REV. 29T) FLOWCHART, FC-2340, REV.0, TO COLOSSUS II, FC-2340, REV. 1.

THE EFFECTIVE SHEETS FOR COLOSSUS II ARE:

1 REV.0
2-7 REV.1
8 REV.0
9 REV.1

R60 ATTITUDE MANEUVER

COLOSSUS II FC-2340
ATTITUDE MANEUVER

PURPOSE: TO MANEUVER THE LM/CSM OR CSM ALONE TO AN ATTITUDE SPECIFIED BY THE PROGRAM IN PROGRESS.

INPUT:
(a) THE FINAL ATTITUDE DESIRED IS SPECIFIED BASED ON THE SETTING OF 3AXISFLG.
(b) 3AXISFLG IS SET
SCAXIS = SPECIFIED SPACECRAFT AXIS TO BE MANEUVERED.
POINTSM = DIRECTION OF FINAL ATTITUDE
CPhi = DESIRED FINAL GIMBAL ANGLES

OUTPUT: A = CAOR OF RETURN ADDRESS

SAVE RETURN IN TEMPREG

REGDAIR

MANEUVER SPECIFIED BY THREE AXES

YES

MANEUVER SPECIFIED BY ONE AXIS

NO

INPUT: SCAXIS = SPECIFIED S/C AXIS TO BE ORIENTED.
POINTSM = DIRECTION IN WHICH S/C AXIS IS TO BE POINTED IN SM COORDINATES.
OUTPUT: MPAC = DESIRED 3 GIMBAL ANGLES.
STORE DESIRED GIMBAL ANGLES FOR 618 DISPLAY

DISPLAY FINAL DESIRED GIMBAL ANGLES
R1 - CPHI = XXX.XX OEG. - PDL (OUTER GIMBAL)
R2 - CTHETA = XXX.XX OEG. - PITCH (INNER GIMBAL)
R3 - CPSI = XXX.XX OEG. - YAW (MIDDLE GIMBAL)
(GOPERF ONE PASTES THE V50 IMPERF RETURN)

FINISHED WITH R60

ENDMANU ENTER

TERMINATE

CHECK FOR PRIORITY DISPLAYS

ENDOFJEND

NEXT SHEET

R60 ATTITUDE MANEUVER

COLOSSUS II FC-2340
FROM PRECEDING SHEET

ATTCA0 = BUF2
ATTCA0 +1 = ATTCA0 + EBAN
ATTIPRD = PRIORITY (BIT 14-10)

SAVE FINAL RETURN TO ENDMANUV FOR KALCMAN3

SET EBANK FOR KALCMAN3

EBANK = KALEBON

KALCMAN3

PERFORM MANEUVER CALCULATION AND STEERING
FG-2350 SH5

INPUT: CPHT = DESIRED FINAL GIMBAL ANGLES
OUTPUT: SPACECRAFT MANEUVERED TO SPECIFIED ATTITUDE
NOTE: KALCMAN3 SETS UP A CALL TO ENDMANUV AS A JOB AT THE END OF THE MANEUVER

ENDMANUV

T0B0L

SH2

R6IITEST

R6OCSM WAS CALLED BY EXTENDED VERB49 OR VERB88
ARE WE IN POO? (MODE = 0)

YES

ENDMANUV

CLEAR 3AXISFLG
RETURN VIA TEMPR60

NO

R6OCSM WAS CALLED BY P4OCSM (P40), P23(P23), R61CSM (P20) OR P4OCSM (P41).

R61CSM (P20)

IS PDSPFLAG SET?

YES

P4OCSM (P40)

GOTOV26

NO

GOTOPODH

MANEUVER SPECIFIED BY ONE AXIS

R60 ATTITUDE MANEUVER
COMPUTE ONE AXIS MANEUVER ANGLES

INPUTS: sCAxis = SC Axis to be pointed
        POINTVSm = Direction % is to be pointed
        in SC, coord.

OUTPUTS: DESIRED GIMBAL ANGLES
         IN MPAC_t (2'S COMP)
         MPAC = OUTER
         MPAC+1 = INNER
         MPAC+2 = MIDDLE

VECGPOINT
  SAVE QPRET IN
  VECQTEMP

RESET OVERFLOW
  FLAG

VECGCLEAR

X2
  AO(MIS_m)

READOOUX
  READ PRESENT
  CDU ANGLES
  FC-2300 SH

PL25_t = MPAC_t

CDU TO OCM
  COMPUTE DIRECTION
  COSINE MATRIX
  STORE RESULT IN MIS_m
  FC-2350 SH

PL28_v = UNIT(POINTVSm, MIS_m)

VEF_s/c

VF x VI
  S/c WHERE VI = sCAxis s/c

MPAC_v = UNIT(PL28_v x sCAxis_v)

YES

OVERFLOW ?

NO

PICKAXIS

VF x VI = 0
  UNIT OPERATION

INVALID

IS

SCAxis_v x PL28_v < 0 ?

NO

VF = VI

YES

IS

PL36_v < 2.14 ?

NO

DESIRED CDU ANGLES
  = PRESENT CDU ANGLES

NO

STORE COMPLEMENT
  OF RESULT IN COF

VF x VI = 0
  UNIT OPERATION

YES

IS

PL36_v < 2.14

NO

PL36_v = /PL28_x sCAxis/
  (PL36_v IN 2.14 RADIANs)

VF X VI = [VF X VI] S/C

MPAC_t = PL25_t

RETURN VIA
  VECQTEMP

NEXT SHEET

NEXT SHEET
FROM PRECEDING SHEET

ROT180

MPACᵥ = UNIT [UNIT [Μₛ₃ × (1,0,0)] x SCAXISᵥ]

IF YES, VI ARE ANTI-PARALLEL, 180° ROTATION IS REQUIRED.
PIECE VECTOR IN THE PLANE OF X-AXIS Y-MAX
AXIS PERPENDICULAR TO VI

FROM PRECEDING SHEET

MPACᵥ = cos⁻¹ (SCAXISᵥ · PLᵥ₂₈ᵥ)

COMPUTE ANGLE OF ROTATION

COMPDATA

DECOMP

COMPUTE TRANSFORMATION FROM FINAL S/C AXES TO INITIAL S/C AXES
FC-2350 SH

X1 = AD(Μₛ₃₄)
X2 = AD(DECᵥ₄₃₄)

INPUTS: A-ANGLE IN MPACᵥ
COF-UNIT VECTOR
OUTPUTS: ROTATION ABOUT A UNIT VECTOR BY AN ANGLE A.
STORE RESULTS IN DEL WHERE DEL = MFI

MULTIPLY TWO 3X3 MATRICES, LEAVE RESULTS IN PUSHLIST
FC-2350 SH

COMPUTE TRANSFORMATION FROM FINAL S/C AXES TO STABLE MEMBER AXES
MFS = MIFS

NO GIMBAL LOCK

IS CPSI < 50°?

STORE AXIS OF ROTATION IN COF

LOAD 180° ROTATION ANGLE

COFᵥ → MPACᵥ

MPACᵥ → 180°

STORE MFS

LOCATE THE INNER GIMBAL AXES DIRECTION CLOSEST TO THE FINAL X₅C AXES

IS MIS₃ ≥ 0?

NO

IS MIS₃ < 0?

YES

IGSAMEX

NO

X COMPONENT OF MPACᵥ X (SCAXISᵥ)

COFᵥ → SCAXISᵥ

R60 ATTITUDE MANEUVER

COLOSSUS II FC-2340
FROM PRECEDING SHEET

CHECKAXIS

\( \text{SCAXIS} = x \text{ COMPONENT OF SCAXIS}_0 \)

\( \text{SCAXIS} \neq 2 \sin 10^\circ.5^\circ \) NO

YES

**LOAD 35^\circ ROTATION ANGLE**

**LOAD 50^\circ ROTATION ANGLE**

PICKANG1

MPAC_0 \rightarrow 50^\circ

COMP/MFSN

DELCOMP

COMPUTE ROTATION ABOUT UNIT VECTOR
STORE RESULTS IN DEL
FC-2350 SH

\[ x_1 \rightarrow AD(MFS) \]
\[ x_2 \rightarrow AD(DEL) \]

MXXM3

MULTIPLY TWO 3x3 MATRICES LEAVE RESULT IN PUSHLIST
FC-2350 SH

FINDGIMB

\[ x_1 \rightarrow AD(MFS) \]

SET X1 TO PLO

DCMTOCDU

EXTRACT DESIRED CDU ANGLES FROM MATRIX
FC-2350 SH

V1ST02S

CONVERT ANGLES TO 1's COMPLEMENT FORM
FC-2100 SH

SET PUSHLIST TO ZERO

RETURN VIA VECQ/TEMP

**INPUT**: ANGLE IN MPAC, COF=UNIT VECTOR
**OUTPUT**: NEW TRANSFORMATION FROM FINAL S/C AXES TO INITIAL S/C AXES

**INPUT**: X1 = AD(MFS)
**OUTPUT**: MPAC_D = DESIRED CDU ANGLES IN 1's COMPLEMENT FORM

**INPUT**: MPAC_V = CDU ANGLES,D
**OUTPUT**: MPAC_T = CDU ANGLES_S

COMPUTE NEW TRANSFORMATION ABOUT SCAXIS S/C TO BRING MFS OUT OF GIMBAL LOCK

COMPUTE NEW TRANSFORMATION FROM DESIRED S/C AXES TO STABLE MEMBER AXES WHICH WILL ALIGN VI WITH VF AND AVOID GIMBAL LOCK NEW MFS = OLD MFS DEL

COLOSSUS II FC-2340
CHKLINUS

IS PDSFLG SET?

TEST PRIORITY DISPLAY

YES

MPAC+2

Q

SAVE RETURN IN MPAC+2

STORE LOCATION OF LAST DISPLAY FOR RESTART

TBASE1 ← BUF2-3

GROUP1.7

RESTART JOB

RELINUS WITH PRIORITY 10

A ← 001000B

LOAD BIT 7

LINUS

SET BIT FOR PRIORITY DISPLAY

FC-2130

RETURN VIA MPAC+2

RELINUS

IS TRACKFLG SET?

YES

SET PDSFLG

SET TARG1FLG

SET PRIORITY DISPLAY FLAG

SIGHTING LM

OPTINO ← 0

PRIORCHG

CHANGE PRIORITY TO 14

FC-2050

RETURN VIA TBASE1

RETURN TO LAST DISPLAY

RETURN VIA Q

GORED0020

GROUP1.11

RESTART JOB

PICKUP20 WITH PRIORITY 10

ENDOFJOB

R62 ATTITUDE MANEUVER

COLOSSUS II FC-2340
SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

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<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
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<td>FC-2350</td>
<td>COMPUTE DIRECTION COSINE MATRIX</td>
<td>SH5</td>
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<tr>
<td>DCM2TOCU</td>
<td>FC-2350</td>
<td>EXTRACT DESIRED CDU ANGLES FROM MATRIX</td>
<td>SH7</td>
</tr>
<tr>
<td>DELCOMP</td>
<td>FC-2350</td>
<td>COMPUTE TRANSFORMATION MATRIX</td>
<td>SH6,7</td>
</tr>
<tr>
<td>KALCMAN3</td>
<td>FC-2350</td>
<td>MANEUVER CALCULATIONS AND STEERING</td>
<td>SH4</td>
</tr>
<tr>
<td>LINUS</td>
<td>FC-2100</td>
<td>SET BIT FOR PRIORITY DISPLAY</td>
<td>SH8</td>
</tr>
<tr>
<td>MAKECDR</td>
<td>FC-2000</td>
<td>LOAD RETURN CADR SAVED BY BANCALL</td>
<td>SH2</td>
</tr>
<tr>
<td>MIX3</td>
<td>FC-2350</td>
<td>MULTIPLY TWO 3X3 MATRICES</td>
<td>SH6,7</td>
</tr>
<tr>
<td>PRIQCHNG</td>
<td>FC-2350</td>
<td>CHANGE PRIORITY OF JOB IN EXECUTION</td>
<td>SH8</td>
</tr>
<tr>
<td>READDCO</td>
<td>FC-2350</td>
<td>READ PRESENT CDU ANGLES</td>
<td>SH5</td>
</tr>
<tr>
<td>VIST025</td>
<td>FC-2100</td>
<td>CONVERT 1'S COMPLEMENT ANGLES TO 2'S COMPLEMENT ANGLES</td>
<td>SH7</td>
</tr>
</tbody>
</table>

FLAGS

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
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<tbody>
<tr>
<td>3AXISFLG</td>
<td>MANEUVER SPECIFIED BY THREE AXES</td>
<td>MANEUVER SPECIFIED BY ONE AXIS</td>
<td>SH4</td>
<td>SH2, 3</td>
<td></td>
</tr>
<tr>
<td>PDEPFLAG</td>
<td>CANNOT INTERRUPT PRIORITY DISPLAY</td>
<td>MAY INTERRUPT NO PRIORITY DISPLAY</td>
<td>SH8</td>
<td>SH4, 9</td>
<td></td>
</tr>
<tr>
<td>TARG1FLG</td>
<td>SIGHTING LM ALLOWED</td>
<td>NOT SIGHTING LM NOT ALLOWED</td>
<td>SH8</td>
<td>SH8</td>
<td></td>
</tr>
<tr>
<td>TRACKFLG</td>
<td>TRACKING ALLOWED</td>
<td></td>
<td>SH8</td>
<td>SH8</td>
<td></td>
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</tbody>
</table>

DISPLAYS

<table>
<thead>
<tr>
<th>VERB-NOUN</th>
<th>TYPE OF DISPLAYS</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
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<tbody>
<tr>
<td>V5ON18</td>
<td>FLASHING PLEASE PERFORM</td>
<td>R1 - CPHI - XXX, XX DEG. - ROLL (OUTER GIMBAL) FINAL DESIRED R2 - CTHETA - XXX, XX DEG. - PITCH (INNER GIMBAL) GIMBAL ANGLES R3 - CPSI - XXX, XX DEG. - YAW (MIDDLE GIMBAL)</td>
<td>SH2</td>
</tr>
<tr>
<td>V06N18</td>
<td>NON FLASHING</td>
<td>R1 - CPHI - XXX, XX DEG. - ROLL (OUTER GIMBAL) FINAL DESIRED R2 - CTHETA - XXX, XX DEG. - PITCH (INNER GIMBAL) GIMBAL ANGLES R3 - CPSI - XXX, XX DEG. - YAW (MIDDLE GIMBAL)</td>
<td>SH3</td>
</tr>
<tr>
<td>PROGRAM ALARM</td>
<td>NON FLASHING ALARM</td>
<td>ALARM CODE = 1210: TWO PROGRAMS USING DEVICE AT SAME TIME</td>
<td>SH3</td>
</tr>
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ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPHI, SCAXIS, POINTVSM</td>
<td></td>
<td>DESIRED FINAL GIMBAL ANGLES SPECIFIED SPACECRAFT AXIS TO BE MANEUVERED * DIRECTION OF FINAL ATTITUDE IN STABLE MEMBER COORDINATES</td>
<td>REV UNIT = VECTOR UNIT - VECTOR</td>
<td>2^-1</td>
<td>2^-1</td>
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* SEE DESCRIPTION ON SHEET 3
### MAJOR SUBROUTINES ON THIS CHART

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<th>Subroutine</th>
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<tr>
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<td>SH, 20</td>
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<tr>
<td>DELCOMP</td>
<td>Compute Rotation Matrix</td>
<td>SH, 16</td>
</tr>
<tr>
<td>KALCMAN3</td>
<td>Maneuver Calculations and Steering</td>
<td>SH, 5</td>
</tr>
<tr>
<td>MXM3</td>
<td>Multiply Two 3 x 3 Matrices</td>
<td>SH, 25</td>
</tr>
<tr>
<td>READCDUK</td>
<td>Read Current CDU Angles</td>
<td>SH, 24</td>
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<tr>
<td>STOPRATE</td>
<td>Zero Inputs to Autopilot</td>
<td>SH, 26</td>
</tr>
</tbody>
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**THE ENCLOSED REPLACEMENT SHEETS WILL UPDATE THE COLOSSUS I (REV. 237) FLOW CHART FC-2350, REV. 0, TO COLOSSUS II FC-2350, REV. 2**

**THE EFFECTIVE SHEETS FOR COLOSSUS II ARE:**

1 - 2    REV 0  
3        REV 1  
4 - 5    REV 0  
6        REV 2  
7 - 11   REV 0  
12       REV 2  
13 - 14  REV 0  
15       REV 1  
16       REV 0  
17       REV 1  
18 - 26  REV 0  
27       REV 2  

---

**MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.**

**APOLLO GUIDANCE AND NAVIGATION**

**MANEUVER CALCULATIONS AND STEERING**

**COLLOSSUS II FC-2350**

**DRAWN BY:**

**CHECKED BY:**

**ANALYST:**

**APPROVED:**

**REV:**

**SHEET 1 OF 27**
SIMPLIFIED FLOW: MANEUVER CALCULATIONS AND STEERING

INPUT: CPH1 = DESIRED FINAL GIMBAL ANGLES

OUTPUT: SPACECRAFT MANEUVERED TO SPECIFIED ATTITUDE

KALCMAN

SH 5

READ CURRENT CDU ANGLES INTO BODY

SECAD

SH 5

TRANSFORM INITIAL S/C AXES TO STABLE MEMBER; STORE IN MIS

TRANSFORM FINAL S/C AXES TO STABLE MEMBER; STORE IN MFS

USE TMI AND MFS TO COMPUTE MANEUVER TRANSFORMATION; STORE IN MFI

EXTRACT AXIS OF EQUIVALENT ROTATION FROM SKEW SYMMETRIC COMPONENTS OF MFI; STORE IN COF

COMPUTE ANGLE OF MANEUVER; STORE IN AMO

IS AM > 25° ?

NO GO DIRECTLY INTO ATTITUDE HOLD ABOUT COMMANDED ANGLES

YES

CHECKMAX

SH 6

IS AM > 170° ?

NO

YES

ALTCALC

SH 17

DETERMINE COF USING AN ALTERNATE METHOD EMPLOYING SYMMETRIC PART OF MFI

NEXT SHEET
FROM PRECEDING SHEET

MANUSTOP
SCHEDULE TASK MANUSTOP IN C/A CSEC VIA WAITLIST

ZERO PITCH AND YAW INPUTS TO AUTOPILOT
STORE FINAL ANGLES FOR PITCH AND YAW INTO COMMAND ANGLES

ENOROLL SH14
STORE CPNI INTO CDUXD
ZERO ROLL INPUTS

ENOMANU SH14
PREPARE FOR RETURN TO PROGRAM USING GOMANU

ENOMANUV RESCHEDULE JOB ENOMANUV WITH PREVIOUS PRIORITY VIA SPVAC FC-2340 SH4

TASKOVER
MANEUVER CALCULATIONS AND STEERING

INPUT: \( \text{CPHIT} = \text{DESIRED FINAL GIMBAL ANGLES} \)
OUTPUT: SPACECRAFT MANEUVERED TO SPECIFIED ATTITUDE

OUTPUT: \( \text{MPAC}\_T = \text{CDUX, CDUY, CDUZ} \)

STORE INITIAL SPACECRAFT ANGLES

COMPUTE THE TRANSFORMATION FROM INITIAL S/C AXES TO STABLE MEMBER AXES.

INPUT: \( \text{MPAC}\_T = \text{CDU ANGLES} \)
\( x_2 = \text{ADR(RESULTING MATRIX)} \)

OUTPUT: \( \text{MIS}\_M = \text{TRANSFORMATION MATRIX} \)

LOAD DESIRED FINAL GIMBAL ANGLES

COMPUTE THE TRANSFORMATION FROM FINAL S/C AXES TO STABLE MEMBER AXES.

INPUT: \( \text{MPAC}\_T = \text{FINAL GIMBAL ANGLES} \)
\( x_2 = \text{ADR(RESULTING MATRIX)} \)

OUTPUT: \( \text{MFS}\_M = \text{TRANSFORMATION MATRIX} \)

\( x_2 = \text{ADR(MIS}\_M) \)

\( x_1 = \text{ADR(MFS}\_M) \)

\( x_2 = \text{ADR(MFS}\_M) \)

STORE MATRIX

\( x_1 = \text{ADR(TMIS}\_M) \)
\( x_2 = \text{ADR(MFS}\_M) \)

OUTPUT: \( \text{PLO}_M = \text{TMIS}_M \text{ MF}\_S_M \)

NEXT SHEET
FROM PRECEDING SHEET

ALTCALC

MFI\_SYM = MFI\_M + TMFI\_M / 2

PLO\_0 = CAM\_0 / 2

DOES 1 - CAM \_ OVERFLOW?

YES

SIGN\_MPAC

LIMIT SIZE OF MPAC ON OVERFLOW

FC-2100

OUTPUT: MPAC\_0 = ± MAXIMUM BASED ON SIGN OF MPAC

NO

MPAC\_0 = 1 - CAM\_0

PLQ\_0 = MPAC\_0

COFZ = \( \frac{\sqrt{MFI\_SYM - CAM}}{1 - CAM} \)

PL6\_0 = \( \frac{\sqrt{MFI\_SYM + 8D_0 - PLQ\_0}}{PL2\_0} \)

COFY = \( \frac{\sqrt{MFI\_SYM - CAM}}{1 - CAM} \)

PL6\_0 = \( \frac{\sqrt{MFI\_SYM + 8D_0 - PLQ\_0}}{PL2\_0} \)

COFX = \( \frac{\sqrt{MFI\_SYM - CAM}}{1 - CAM} \)

MPAC\_0 = \( \frac{\sqrt{MFI\_SYM - PLQ\_0}}{PL2\_0} \)

COFV = \( \frac{\text{UNIT}(MPAC\_0, PL6\_0, PL4\_0)}{\text{COFZ}} \)

NEXT SHEET

DETERMINE COF\_V USING AN ALTERNATE METHOD USING THE SYMMETRIC PART OF MFI\_M
Determine largest term in COF and adjust accordingly.

**METHOD 1**

- IF COFSKEW = 0, UX
  - IF UFIFSYM > 0, UX
    - COFX = COFX
    - COFY = COFY
  - ELSE UX OPPOSITE TO UX
    - OKU12

**METHOD 2**

- IF COFSKEW = 0, UY
  - IF UFIFSYM > 0, UY
    - COFX = COFX
    - COFU = COFU
  - ELSE UY OPPOSITE TO UY
    - OKU21

**METHOD 3**

- IF COFSKEW = 0, UZ
  - IF UFIFSYM > 0, UZ
    - COFY = COFY
    - COFX = COFX
  - ELSE UZ OPPOSITE TO UZ
    - OKU31

NEXT SHEET
FROM PRECEDING SHEET

\[ M_{\text{in}} \leftarrow P_{\text{lo}} \quad x_1 \leftarrow \text{ADR}(M_{\text{in}}) \]

STORE MATRIX

EXTRACT NEW DESIRED CDU ANGLES FROM MATRIX

INPUT: \( x_1 = \text{ADR}(M_{\text{in}}) \)

OUTPUT: \( \text{MPAC}_v = \text{CDU ANGLES (1's COMPLEMENT)} \)

VISTO2S

CONVEXT 1's COMPLEMENT

ANGLS TO 2's COMPLEMENT

FC-2400

\[ \text{NCDUT} \leftarrow \text{MPAC}_T \]

STORE NEW ANGLES

IS \( \text{CALCMAN} 2 \) SET?

NO

BYPASS STARTING MANEUVER

YES

CLEAR \( \text{CALCMAN} 2 \)

BYPASS STARTING MANEUVER

\( \text{MANUSTAT} \)

\[ \text{TM}_0 \leftarrow \text{TM}_0 + \text{TIME}_0 - 1 \text{ SEC} \]

MANEUVER COMPLETION TIME - 1 SEC.

\( \text{INHIBIT INTERUPT} \)

\( \text{SET HOLDFLAG} \)

\( \text{ENABLE AUTOPilot} \)

IS \( \text{RATEINDEX} = 6 \) ?

NO

HIGH GAIN

SET BIT 15 OF RCS FLAGS

YES

NEXT SHEET
FROM PRECEDING SHEET

\[ W_{BODY} \rightarrow \text{RATE} \]
\[ W_{BODY1} \rightarrow \text{RATE} + 2 \]
\[ W_{BODY2} \rightarrow \text{RATE} + 4 \]
\[ \text{BIAS} \rightarrow \text{BIAS}_{\text{TEMP}+1} \]
\[ \text{BIAS1} \rightarrow \text{BIAS}_{\text{TEMP}+3} \]
\[ \text{BIAS2} \rightarrow \text{BIAS}_{\text{TEMP}+5} \]

\[ X \text{ AXIS} \\{ \text{MANEUVER RATE} \]
\[ Y \text{ AXiS} \]
\[ Z \text{ AXiS} \{ \text{INSERT ATTITUDE ERROR BIASES INTO AUTOPILOT} \]

\[ \text{NEXT TIME} \rightarrow \text{TIME1} + \text{1SEC.} \]

\[ \text{STORE TIME INCREMENT} \]

\[ \text{(INCRDCDU+1)} \]

\[ A \rightarrow 2 \]

\[ \text{LOAD INDEX VALUE FOR THREE AXES} \]

\[ \text{LOOP TO COMPUTE ANGLE INCREMENTS, DESIRED AND COMMAND CDU ANGLES FOR THREE AXES} \]
\[ \text{NCU} = \text{NEW DESIRED CDU ANGLES} \]
\[ \text{BCU} = \text{INITIAL S/C ANGLES OR PREVIOUS DESIRED CDU ANGLES} \]

\[ \text{SET K\textsubscript{S} INDEX FOR EACH AXIS} \]

\[ \text{SET K\textsubscript{D} INDEX FOR EACH AXIS} \]

\[ \text{DELCDUX} \# \text{KOPNDX} \rightarrow D.1 \left( \text{NCU} \# \text{KSPNDX} - \text{BCU} \# \text{KSPNDX} \right) \]

\[ \text{CDUXD} \# \text{KOPNDX} \rightarrow \text{BCU} \# \text{KSPNDX} \]
\[ \text{BCU} \# \text{KSPNDX} \rightarrow \text{NCU} \# \text{KSPNDX} \]

\[ \text{ANGLE INCREMENTS TO BE ADDED TO CDU EVERY TENTH SECOND BY LM DAP.} \]

\[ \text{UPDATE COMMANDED CDU ANGLES} \]
\[ \text{UPDATE DESIRED CDU ANGLES} \]

\[ \text{IS KSPNDX > 0?} \]

\[ \text{YES} \]

\[ \text{ALLOW INTERRUPTS} \]

\[ \text{NEXT SHEET} \]
OUTPUT: ZERO INCREMENTAL ANGLES, RATES AND BIASES FOR PITCH AND YAW

SUBROUTINE TO STORE FINAL ANGLES INTO Commanded ANGLES FOR PITCH AND YAW

LOADYZ

CDUYO ← CTHETA
COUZO ← CPSI

RETURN VIA Q

ENDROLL

COUXO ← GPHI

STORE FINAL ANGLE INTO Commanded ANGLE FOR ROLL

STOPRATE

ZERO INPUTS TO AUTOPILOT

SH26

ENDMANU

NEWPRIO ← ATTPRI
A_L ← ATTCAO_R
ATTCAOR ← 0

RESTORE USERS PRIORITY
LOAD RETURN ADDRESS

ENDMANUV

SPVAC JOB WITH PRIORITY NEWPRIO
FC-2340 SH4

SCHEDULE RETURN TO R60CSM JOB

TASKOVER

MANUSTOP

STOPYZ

ZERO INPUTS TO AUTOPILOT

SH26

OUTPUT: ZERO INCREMENTAL ANGLES, RATES AND BIASES FOR PITCH AND YAW

SUBROUTINE TO STORE FINAL ANGLES INTO Commanded ANGLES FOR PITCH AND YAW

LOADYZ

CDUYO ← CTHETA
COUZO ← CPSI

RETURN VIA Q

ENDROLL

COUXO ← GPHI

STORE FINAL ANGLE INTO Commanded ANGLE FOR ROLL

STOPRATE

ZERO INPUTS TO AUTOPILOT

SH26

ENDMANU

NEWPRIO ← ATTPRI
A_L ← ATTCAO_R
ATTCAOR ← 0

RESTORE USERS PRIORITY
LOAD RETURN ADDRESS

ENDMANUV

SPVAC JOB WITH PRIORITY NEWPRIO
FC-2340 SH4

SCHEDULE RETURN TO R60CSM JOB

TASKOVER
INPUT: TM = END OF MANEUVER TIME (T_{end}) + 1 SEC.
OUTPUT: THREE RETURN BASED ON REMAINING MANEUVER TIME.
COMPUTE REMAINING TIME TO END OF MANEUVER + 1 SECOND

TIME PAST < 0
TERMINATE MANEUVER IMMEDIATELY

(TTEMP) > 0
CONTINUE MANEUVER

(TTEMP) < 0

(TTEMP + 1) > 0
MANNOFF

A \leftarrow \left\lfloor \frac{TTEMP + 1}{1} \right\rfloor

TIME PAST \leq 0
REMAINING MANEUVER TIME BETWEEN 0 AND 1 SECOND

A + 1 SEC > 0
INCREMENT Q

INCREMENT Q TWICE

RETURN VIA Q + 2
RETURN TO "z + 2"
0 \leq T_{end} \leq 1 SEC.

RETURN VIA Q
RETURN TO "z + 1"
T_{end} < 1 SEC.
CALCULATION OF MATRIX DEL_{\text{U}}

INPUTS: \text{COF} = UNIT VECTOR \text{U} ALONG AXIS OF ROTATION
MPAC = \text{ANGLE OF ROTATION}

OUTPUT: \text{DEL}_{\text{U}} = MATRIX REPRESENTING A ROTATION
ABOUT A UNIT VECTOR \text{U} BY AN ANGLE \text{A}

\text{COF}_{\text{x}} = \text{U}_x
\text{COF}_{\text{y}} = \text{U}_y
\text{COF}_{\text{z}} = \text{U}_z

UNIT VECTOR = \text{COF}_{\text{x}} = \text{U}_x
\text{COF}_{\text{z}} = \text{U}_z

\text{SET PUSHLIST TO 0}
\text{MPAC} \leftarrow \text{PL}_0
\text{MPAC} \leftarrow \text{PL}_0 \times \sin(\text{MPAC})
\text{PL}_2 \leftarrow \cos(\text{MPAC})
\text{MPAC} \leftarrow \frac{\text{PL}_2}{\cos(\text{MPAC})}
\text{EXCHANGE MPAC WITH PUSHLIST 2D}
\text{MPAC} \leftarrow 1 - \text{MPAC}
\text{OVERFLOW} ?
\text{NO}
\text{SIGN MPAC}
\text{LIMIT SIZE OF MPAC ON OVERFLOW FC-2100}
\text{SET MPAC TO} ± \text{MAXIMUM BASED ON SIGN OF MPAC}
\text{PL}_4 \leftarrow \text{MPAC}_0
\text{PL}_4 = 1 - \text{COF}_{\text{A}}
\text{OVERFLOW} ?
\text{NO}
\text{SIGN MPAC}
\text{LIMIT SIZE OF MPAC ON OVERFLOW FC-2100}
\text{SET MPAC TO} ± \text{MAXIMUM BASED ON SIGN OF MPAC}
\text{DEL}_0 \leftarrow \text{MPAC}_0
\text{DEL}_0 = \text{U}_x(1 - \text{COF}_{\text{A}}) + \cos \text{A}
\text{MPAC}_0 \leftarrow \text{COF}_{\text{A}}^3 \text{PL}_4 + \text{PL}_2
\text{NEXT SHEET}
FROM PRECEGING SHEET

OVERFLOW ?

YES

SET MPAC TO ± MAXIMUM BASED ON SIGN OF MPAC

SIGNMPAC LIMIT SIZE OF MPAC ON OVERFLOW
FC-2100

NO

DEL₄ ← MPAC₀

OEL₄ = Uₓ Uᵧ (1-COS A) - Uₓ SIN A

PL₆₀ ← (COF₃) (COF₂) PL₄

PL₆ = Uₓ Uₓ (1-COS A)

PL₈₀ ← (COF₁) PL₀

PL₈ = Uᵧ SIN A

MPAC₀ ← PL₆ + PL₈

OVERFLOW ?

YES

SET MPAC TO ± MAXIMUM BASED ON SIGN OF MPAC

SIGNMPAC LIMIT SIZE OF MPAC ON OVERFLOW
FC-2100

NO

OEL₂ ← MPAC₀

OEL₂ = Uₓ Uₓ (1-COS A) + Uᵧ SIN A

MPAC₀ ← PL₆ - PL₈

OVERFLOW ?

YES

SET MPAC TO ± MAXIMUM BASED ON SIGN OF MPAC

SIGNMPAC LIMIT SIZE OF MPAC ON OVERFLOW
FC-2100

NO

NEXT SHEET
COMPUTE CDU ANGLES FROM DIRECTION COSINE MATRIX

INPUT: X1 - ADR (\(M_w\)) - MATRIX RELATING S/C AXES TO STABLE MEMBER AXES
OUTPUT: MPACv - CDU ANGLES (1's COMPLEMENT)
PLO = PSI (MIDDLE GIMBAL ANGLE)

\[ PLO \leftarrow \sin^{-1} \left( \sin(\psi) \right) \]
\[ MPAC_0 \leftarrow \cos(\psi) \]

OVERFLOW?

YES

SIGNMPAC
LIMIT SIZE OF MPAC ON OVERFLOW
FC-2100

SET MPAC TO \( \pm \) MAXIMUM BASED ON SIGN OF MPAC

NO

\[ S4_0 \leftarrow MPAC_0 \]
\[ S4 = \cos(\psi) \]

PL2 \leftarrow \sin^{-1} \left( \frac{\sin \theta \cos \phi}{\cos \phi} \right)

PL2 = THETA (INNER GIMBAL ANGLE)

CHECK SIGN OF \( \cos(\theta) \) TO DETERMINE PROPER QUADRANT

\[ \cos(\theta) \cos(\phi) \geq 0 \]

NO

\[ MPAC_0 \leftarrow -\theta \]

\[ \text{IS} \ MPAC \geq 0 \]

NO

\[ \text{THETA IS POSITIVE (2\text{nd QUADRANT})} \]

\[ \text{MPAC} = 180^\circ - \theta \]

\[ \text{MPAC} \leftarrow \text{MPAC} + \frac{1}{2} \]

\[ \text{SUHALFA} \]

\[ MPAC_0 \leftarrow MPAC - \frac{1}{2} \]

CALC\( \phi \)

\[ PL2 \leftarrow MPAC_0 \]

\[ PL2 = \theta \] (ADJUSTED FOR 2\text{nd OR 3\text{rd QUADRANT})}

OKTHETA

NEXT SHEET
FROM PRECEDING SHEET

\[ \text{PL4} = \text{PL4} = \text{PHI (OUTER GIMBAL ANGLE)} \]

\[ \text{IS} \left( \frac{\sin \phi \cos \psi}{\cos \phi} \right) \gtrless 0 \]

\[ \text{OKPHI} \]

\[ \text{PL4} = \text{PHI} \]

\[ \text{MPACD} = \text{PHI} \]

\[ \text{IS} \left( \text{MPACD} \gtrless 0 \right) \]

\[ \text{NO} \]

\[ \text{PHI IS POSITIVE (2ND QUADRANT)} \]

\[ \text{MPACD} = \text{MPACD} = \frac{\phi}{2} \]

\[ \text{MPACD} = 180^\circ - \text{PHI} \]

\[ \text{SUHALFAP} \]

\[ \text{MPACD} = \text{MPACD} = \frac{\phi}{2} \]

\[ \text{VECOFANG} \]

\[ \text{MPACV} = \text{MPACV} = \text{PL2D}, \text{PL0D} \]

\[ \text{MPACV} = \text{PHI}, \text{THETA}, \text{PSI (1's COMPLEMENT)} \]

\[ \text{RETURN VIA QPRET} \]
COMPUTE DIRECTION COSINE MATRIX RELATING S/C AXES TO STABLE MEMBER AXES

INPUTS: MPACT - CDU ANGLES

X2 - ADR (RESULTING MATRIX)

OUTPUT: DIRECTION COSINE MATRIX MM

SET UP INDEX VALUES FOR THREE CDU ANGLES

STORE CDU ANGLES IN PUSHLIST

LOOP TO COMPUTE SINE AND COSINE VALUES OF THREE CDU ANGLES STORE RESULT IN PUSHLIST

LOAD MPAC WITH \( \begin{pmatrix} \phi \\ \theta \\ \psi \end{pmatrix} \) 2's COMPLEMENT FROM PUSHLIST

INPUT : MPAC = CDU ANGLE (2's COMPLEMENT)

OUTPUT : MPAC_0 = CDU ANGLE (1's COMPLEMENT)

STORE ANGLE IN PUSHLIST

PL0 = \( \sin \phi \)
PL4 = \( \sin \theta \)
PL8 = \( \sin \psi \)

LOAD ANGLE INTO MPAC

PL2 = \( \cos \phi \)
PL6 = \( \cos \theta \)
PL10 = \( \cos \psi \)

NO

\( X_1 \leq S_1 \)

YES

\( M_0 \rightarrow \cos \phi \cos \psi \)

NEXT SHEET
LOAD MPAC+ WITH CURRENT CDU ANGLES

READCDUK

INHIBIT INTERRUPTS

MPAC + 2 ← CDUZ

MPACD ← CDUXD

ALLOW INTERRUPTS

RETURN VIA TLOAD+6
### Subroutines Called Which Are Flowed on Other Flow Charts

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>COLOGIC</td>
<td>FC-2100</td>
<td>Convert 2's Complement Angle to 1's Complement Angle</td>
<td>SH22</td>
</tr>
<tr>
<td>SIGMPAC</td>
<td>FC-2100</td>
<td>Limit Size of MPAC on Overflow</td>
<td>SH7, 16, 17, SH18,19, 20</td>
</tr>
<tr>
<td>VISTO2S</td>
<td>FC-2100</td>
<td>Convert 1's Complement Angles to 2's Complement Angles</td>
<td>SH10</td>
</tr>
</tbody>
</table>

### Flags

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALCMAN2 (Flagword 2, Bit 2)</td>
<td>Perform Starting Maneuver</td>
<td>Bypass Starting Maneuver</td>
<td>SH9</td>
<td>SH10</td>
<td>SH10</td>
</tr>
<tr>
<td>CALCMAN3 (Flagword 2, Bit 3)</td>
<td>No Final Roll</td>
<td>Final Roll Is Necessary</td>
<td>SH9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCSFLG15</td>
<td>High Maneuver Rate</td>
<td>Low Maneuver Rate</td>
<td>SH10</td>
<td>SH26</td>
<td></td>
</tr>
</tbody>
</table>

### Erasable Locations Used

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCDUT</td>
<td></td>
<td>Initial S/C CDU Angles</td>
<td>REV</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>CDUXD</td>
<td></td>
<td>CDU Commanded Angles</td>
<td>REV</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>CDOYD</td>
<td></td>
<td>Maneuver Completion Time</td>
<td>CSEC</td>
<td>2^28</td>
<td></td>
</tr>
<tr>
<td>CDOUD</td>
<td></td>
<td>Roll Pitch Yaw Angle Increments</td>
<td>REV</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>DELCDUXD</td>
<td></td>
<td>Roll Pitch Yaw Angle Rates</td>
<td>REV</td>
<td>2^-2</td>
<td></td>
</tr>
<tr>
<td>DELCYD</td>
<td></td>
<td>Roll Pitch Yaw Angle Biases</td>
<td>REV</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>WDD0YD</td>
<td></td>
<td>Roll Pitch Yaw Angle Biases</td>
<td>REV</td>
<td>2^-3</td>
<td></td>
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<tr>
<td>WBDD0YD</td>
<td></td>
<td>Roll Pitch Yaw Angle Biases</td>
<td>REV</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>BIAS</td>
<td></td>
<td>Roll Pitch Yaw Angle Biases</td>
<td>REV</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>BIAS1</td>
<td></td>
<td>Roll Pitch Yaw Angle Biases</td>
<td>REV</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>BIAS2</td>
<td></td>
<td>Roll Pitch Yaw Angle Biases</td>
<td>REV</td>
<td>2^-1</td>
<td></td>
</tr>
</tbody>
</table>
RO5 S-BAND ANTENNA

MAJOR SUBROUTINE ON THIS FLOWCHART

EXTENDED VERB 64

START S-BAND ANTENNA ROUTINE SH2

S-BANDANT

COMPUTE AND DISPLAY S-BAND ANTENNA GIMBAL ANGLES SH3
EXTENDED VERB 64: S-BAND ANTENNA

PURPOSE: TO COMPUTE AND DISPLAY THE TWO STEERABLE S-BAND ANTENNA GIMBAL ANGLES WHICH WILL POINT THE ANTENNA TOWARD THE CENTER OF THE EARTH

KEYED IN BY ASTRONAUT

START S-BAND ANTENNA ROUTINE

V64E

INPUT: EVTMBACT
OUTPUT: RETURNS WITH BITS BANDS OF EVTMBACT SET TO INDICATE EXTENDED VERB ACTIVE

TEST XACT
TEST FOR EXTENDED VERB OR PRIORITY DISPLAY ACTIVE FC-2150

PREVIOUS EXTENDED VERB ACTIVE ERROR EXIT

NO OTHER EXTENDED VERB ACTIVE

S-BAND ANTENNA ROUTINE

FINDVAC JOB PRIORITY 04

SCHEDULE S-BAND ANTENNA ROUTINE

SHD

ENDOFJOB

ALM/END

FALTON
TURN ON OPERATOR ERROR LIGHT FC-2160

PINBRANCH FC-2130

MIT

RO5 S-BAND ANTENNA
COLLOSSUS II
FC-2360
FROM PRECEDING SHEET

(E1501 = 2)

SET PUSHLIST TO 2

RCMV ← REFSMMAT(MPACV)

LOS VECTOR IN STABLE MEMBER COORDINATES

YAWANG ← 0

MPACV ← RCMV

ZERO YAW ANGLE

*SMNB*

TRANSFORMATION FROM SM TO NB COORDINATES

INPUT: MPACV = VECTOR IN STABLE MEMBER COORDINATES
OUTPUT: MPACV = VECTOR IN NAV BASE COORDINATES

RV ← MPACV

URV ← UNIT(RV)

RV IN CM BODY AXES

RP = R - (R · Uz) Uz

MPACV ← RV - (RV · HUNITZ) HUNITZ

PROJECTION OF R INTO CM XY-PLANE

HUNITZ = (0, 0, 1)

CLEAR OVERFLOW INDICATOR

COVCNV

MPACV ← UNIT(MPACV)

UR = UNIT(RP)

TEST FOR NULL VECTOR

DID MPACV OVERFLOW?

NO

STORE UR

NEXT SHEET
### Subroutines Called Which Are Flowed on Other Flow Charts

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLANKET</td>
<td>FC-2130</td>
<td>Blank DSKY Registers</td>
<td>SH5</td>
</tr>
<tr>
<td>CHKPOOH</td>
<td>FC-2190</td>
<td>Test for IOLING Program</td>
<td>SH2</td>
</tr>
<tr>
<td>CSMTIC</td>
<td>FC-2290</td>
<td>Integrate CASM State Vector</td>
<td>SH3</td>
</tr>
<tr>
<td>OELAYOB</td>
<td>FC-2078</td>
<td>Delay Active Job Given Time Period</td>
<td>SH5</td>
</tr>
<tr>
<td>FALTON</td>
<td>FC-2180</td>
<td>Turn On Operator Error Light</td>
<td>SH2</td>
</tr>
<tr>
<td>LOADTIME</td>
<td>FC-2100</td>
<td>Load Present Time into HPAC</td>
<td>SH3</td>
</tr>
<tr>
<td>LUNPOS</td>
<td>FC-2286</td>
<td>Compute Position Vector of Moon</td>
<td>SH3</td>
</tr>
<tr>
<td>RO2BOTH</td>
<td>FC-2210</td>
<td>IMU Status Check</td>
<td>SH3</td>
</tr>
<tr>
<td>TESTACT</td>
<td>FC-2190</td>
<td>Test for EXTENDO Verb or Priority Display Active</td>
<td>SH2</td>
</tr>
<tr>
<td><em>SMNB</em></td>
<td>FC-2270</td>
<td>Transformation from SM to NB Coordinates</td>
<td>SH4</td>
</tr>
</tbody>
</table>

### Displays

<table>
<thead>
<tr>
<th>Verb-Noun</th>
<th>Type of Display</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
</tr>
</thead>
</table>
| V06H51    | Flashing        | R1-RH0SB - XXX.XX Deg. - Pitch Gimbal Angle  
R2-GAMMASB - XXX.XX Deg. - Yaw Gimbal Angle | SH5            |

### Erasable Locations Used

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<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH0SB</td>
<td>ρ</td>
<td>Pitch Gimbal Angle for S-Band Antenna</td>
<td>REV</td>
<td>2°</td>
<td></td>
</tr>
<tr>
<td>GAMMASB</td>
<td>γ</td>
<td>Yaw Gimbal Angle for S-Band Antenna</td>
<td>REV</td>
<td>2°</td>
<td></td>
</tr>
</tbody>
</table>
R63 - RENDEZVOUS FINAL ATTITUDE

MAJOR SUBROUTINES ON THIS CHART

| EXTENDED | V89PERF; REQUEST RENDEZVOUS FINAL ATTITUDE | SM 2 |
| VERB 83  | V89CALL: RENDEZVOUS FINAL ATTITUDE         | SM 2 |
| R63      | CALCULATE FINAL GIMBAL ANGLES              | SM 4 |

The enclosed replacement sheets will update the Colossus II flowchart, FC-2361, REV.0, to the Colossus II flowchart, FC-2361, REV.1.

The effective sheets for Colossus II, FC-2361, REV.1, are:

- 1-4: REV.0
- 5-6: REV.1
- 7: REV.0

Note: FC-2361 was previously called FC-2190.
PURPOSE: TO CALCULATE THE FINAL GIMBAL ANGLES REQUIRED TO POINT THE CSM +X AXIS OR PREFERRED TRACKING AX16 AT THE LM

KEYED IN BY ASTRONAUT

BEGIN

REQUEST RENDEZVOUS FINAL ATTITUDE

VOSER

REQUEST RENDEZVOUS FINAL ATTITUDE

V6SPERF

CHKPOOH

IS CURRENT PROGRAM PGO?

FC-2170

POO IS OPERATING

NO

YES

TESTXACT

CHECK EXTENDED VERB ACTIVITY

FC-2170

NO OTHER EXTENDED VERB IN USE

YES

INHIBIT INTERRUPTS

VOSCALL

FINDVAC JOB, PRIORITY 10

SH 1

ENDOPTOB

VOSCALL

RO2BOTH

IMU STATUS CHECK

FC-2170

NEXT

RETURN IF ORIENTATION KNOWN, ALARMS IF NOT

LOAD ASSUMED OPTION CODES

OPTION 1 ← 3

OPTION 2 ← 1

A ← VNO400

ENTER NEW DATA TERMINATE

GOFLASH

VNO400 OPTION CODE FOR ASSUMED TRACKING ATT.

DISPLAY OPTION CODE FOR ASSUMED TRACKING ATTITUDE

R1 = OPTION 1 - 00003 - OPTION CODE

R2 = OPTION 2 - 0000X - 1 - PREFERRED AXIS

NEXT SHEET

END

END

R6B - RENDEZVOUS FINAL ATTITUDE

FC-2361

A.C.Williams 9/69

Copydate 2/7 COLOSSUS II
SUBROUTINE TO CALCULATE THE FINAL GIMBAL ANGLES REQUIRED TO POINT THE CSM +X AXIS AT THE LM AND TO CALCULATE THE FINAL GIMBAL ANGLES REQUIRED TO POINT THE PREFERRED TRACKING AXIS AT THE LM.

INPUT: PTIMEp = PRESENT TIME + 1 MIN.
CSM AND LM STATE VECTORS
REFSMATm = TRANSFORMATION MATRIX:
BASIC REF COORD SYSTEM
TO IMU STABLE MEMBER
COORD. SYSTEM
PRETRKAT = SWITCH INDICATING ASTRONAUT
SELECTED S/C AXIS
OUTPUT:
POINTVM = LOS VECTOR IN SM COORDS
SCAIX = SELECTED S/C AXIS
THETA = DESIRED GIMBAL ANGLES
CPHIX = GIM. ANGLES FOR N96 DISPLAY
PRAX = GIM. ANGLES FOR N95 DISPLAY

SAVE RETURN IN G6111
STORE TIME FOR COMCONIC ROUTINE

TOECl -> PTIMEp
COMCONIC
EXTRAPOLATE CSM STATE VECTOR
FC-2290
HOLDA
SAVEPOS, RATT, SAVEVEL, VATT
CALCLEM

STORE EXTRAPOLATED POSITION AND VELOCITY

TOECl -> PTIMEp
STORE TIME FOR LEMCONIC ROUTINE

INPUT: TOECl, LM STATE VECTOR
EXTRAPOLATE LM STATE VECTOR
FC-2270
DCDU, VATT
SAVEPOS, UNIT(RATT - SAVEPOS), PTIMEp, PLDmp

POINTVM = LOS VECTOR IN STABLE MEMBER COORDINATES
SCAIX = SELECTED AXIS UNIT VECTOR
UNITX = (30, 0, 0) @ 2.4 (Y AXIS)
FROM PRECEDING SHEET

FROM PRECEDING SHEET

VECPoiNT
COMPUTE DESIRED GIMBAL ANGLES TO POINT VEHICLE
FC-2340 SHS

INPUT: SCAXIS_V = DESIRED S/C AXIS TO BE POINTED
POINTYSM_V = DESIRED POINTING DIRECTION

OUTPUT: MPAC_Y = 3 GIMBAL ANGLES TO POINT VEHICLE

STORE ANGLES FOR NOG DISPLAY

STORE PREFERRED TRACKING AXIS
UNIT VECTOR PRFUNIT_V = (.40957602, 0, .28678682) @ 21° (55° TRACKING AXIS)

INPUT: SCAXIS_V, POINTYSM_V
OUTPUT: MPAC_Y = 3 GIMBAL ANGLES TO POINT VEHICLE

STORE ANGLES FOR NOG DISPLAY

PRAXIS_Y = MPAC_Y

TEST TRACKING ATTITUDE SPECIFIED BY ASTRONAUT

PREFERRED TRACKING AXIS
YES
IS PRFTRKAT SET?

NO

CRSTOR1

STORE +X AXIS UNIT VECTOR IN SELECTED AXIS UNIT VECTOR

SCAXIS_V = UNITX_Y

LOAD ANGLES FOR N18 DISPLAY

MPAC_Y = CPHI_Y

CRSTOR

THETAD_Y = MPAC_Y

STORE SPECIFIED GIMBAL ANGLES FOR N18 DISPLAY
(THETAD_Y = CPHI, THETA, CPS)

RETURN VIA Q6111
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHKPOOH</td>
<td>FC-2190</td>
<td>TEST CONTENTS OF MODREG</td>
<td>SH2</td>
</tr>
<tr>
<td>CSMCONIC</td>
<td>FC-2290</td>
<td>EXTRAPOLATE CSM STATE VECTOR</td>
<td>SH4</td>
</tr>
<tr>
<td>FALTON</td>
<td>FC-2180</td>
<td>TURN ON OPERATOR ERROR LIGHT</td>
<td>SH2</td>
</tr>
<tr>
<td>LEMCONIC</td>
<td>FC-2290</td>
<td>EXTRAPOLATE LM STATE VECTOR</td>
<td>SH4</td>
</tr>
<tr>
<td>LOADTIME</td>
<td>FC-2110</td>
<td>LOAD PRESENT TIME INTO MPACD</td>
<td>SH3</td>
</tr>
<tr>
<td>ROBOTH</td>
<td>FC-2210</td>
<td>IMU STATUS CHECK</td>
<td>SH2</td>
</tr>
<tr>
<td>R50CSM</td>
<td>FC-2340</td>
<td>PERFORM AUTO ATTITUDE MANEUVER</td>
<td>SH3</td>
</tr>
<tr>
<td>TESTXACT</td>
<td>FC-2190</td>
<td>TEST EXTENDED VERB ACTIVITY OR PRIORITY DISPLAY USING DSKY</td>
<td>SH2</td>
</tr>
<tr>
<td>VECPOINT</td>
<td>FC-2340</td>
<td>COMPUTE DESIRED GIMBAL ANGLES TO POINT VEHICLE</td>
<td>SH5</td>
</tr>
</tbody>
</table>

### FLAGS

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRFTKAT</td>
<td>PREFERRED TRACKING ATTITUDE</td>
<td>+ x AXIS TRACKING ATTITUDE</td>
<td>SH3</td>
<td>SH2</td>
<td>SH5</td>
</tr>
<tr>
<td>RNGSCFLG FLAGWRD 5 BIT 10</td>
<td>MANEUVER SPECIFIED BY THREE AXES</td>
<td>MANEUVER SPECIFIED BY ONE AXIS</td>
<td>SH3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3AXISFLG FLAGWRD 5 BIT 6</td>
<td></td>
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<td></td>
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### DISPLAYS

<table>
<thead>
<tr>
<th>VERB-NOUN</th>
<th>TYPE OF DISPLAYS</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>V04N06</td>
<td>FLASHING</td>
<td>R1 - OPTION 1 - 00003 - OPTION CODE</td>
<td>SH2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2 - OPTION 2 - 0000x</td>
<td>DISPLAY ASSUMED TRACKING ATTITUDE</td>
</tr>
<tr>
<td>V06N18</td>
<td>FLASHING</td>
<td>R1 - CPHI</td>
<td>SH3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2 - CTHETA</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3 - CPSI</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>xxx, xx DEG</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>OUTER MIDDLE</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>DESIRED GIMBAL ANGLES</td>
<td></td>
</tr>
</tbody>
</table>

### ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
</tr>
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<tbody>
<tr>
<td>P21TIME</td>
<td>P21T</td>
<td>PRESENT TIME + 1 MIN.</td>
<td>CSEC</td>
<td>28</td>
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<tr>
<td>POINTS</td>
<td>P21T</td>
<td>LOS VECTOR IN SM COORDINATES</td>
<td>UNIT</td>
<td>1</td>
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<tr>
<td>SCAXIS</td>
<td>SCAXIS</td>
<td>SELECTED SPACECRAFT AXIS</td>
<td>UNIT</td>
<td>2</td>
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<td>THETA</td>
<td>THETA</td>
<td>DESIRED GIMBAL ANGLES</td>
<td>REV</td>
<td>2-1</td>
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<td>CPHI</td>
<td>CPHI</td>
<td>GIMBAL ANGLES FOR N6 DISPLAY</td>
<td>REV</td>
<td>2-1</td>
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<td>PRAXIS</td>
<td>PRAXIS</td>
<td>GIMBAL ANGLES FOR N95 DISPLAY</td>
<td>REV</td>
<td>2-1</td>
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<tr>
<td>TDEC</td>
<td>TDEC</td>
<td>INPUT TIME FOR INTEGRATION ROUTINES</td>
<td>CSEC</td>
<td>28</td>
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<tr>
<td>RATT</td>
<td>RAT</td>
<td>OUTPUT POSITION VECTOR FROM INTEGRATION</td>
<td>METERS</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>VATT</td>
<td>VAT</td>
<td>OUTPUT VELOCITY VECTOR FROM INTEGRATION</td>
<td>M/CSEC</td>
<td>27</td>
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</table>
### PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>ACC TAG</th>
<th>GSOV SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>ACC VALUE AND UNITS</th>
<th>ACC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNITXₜᵥ</td>
<td>+x AXIS UNIT VECTOR</td>
<td></td>
<td></td>
<td>(0, 0, 0) UNIT VECTOR</td>
<td>2¹</td>
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<tr>
<td>PRFUNITₜᵥ</td>
<td>55° TRACKING AXIS UNIT VECTOR</td>
<td></td>
<td></td>
<td>(0.40957602, 0, 0.28678822) UNIT VECTOR</td>
<td>2¹</td>
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</tbody>
</table>
V78, V77 SET/CLEAR PREFERRED ATTITUDE FLAG

SETPRFLG Sh. 2
RESETPRF Sh. 2
EXTENDED VERB 76

```
<table>
<thead>
<tr>
<th>SETPRFLG</th>
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<tbody>
<tr>
<td>Set PRFTRKAT Preferred Tracking Attitude</td>
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<tr>
<td>GOPIN FC-2190</td>
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```

EXTENDED VERB 77

```
<table>
<thead>
<tr>
<th>RESETPRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear PRFTRKAT +X-axis Tracking Attitude</td>
</tr>
<tr>
<td>GOPIN FC-2190</td>
</tr>
</tbody>
</table>
```
<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Cleared</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRFTRKAT</td>
<td>Preferred tracking attitude</td>
<td>+X-axis tracking attitude</td>
<td>Sh. 2</td>
<td>Sh. 2</td>
<td></td>
</tr>
<tr>
<td>Flag 5 Bit 10</td>
<td></td>
<td></td>
<td></td>
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</table>

**MIT INSTRUMENTATION LAB**
CAMBRIDGE, MASS.

**APOLLO GUIDANCE AND NAVIGATION**

<table>
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<td>N. Braddock</td>
<td>1/24/71</td>
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**PREPARED**

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<th>ANALYST</th>
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**REVIEWED**

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**APPROVED**

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</table>

**COLLOQUUS 2D**

**DOCUMENT NO.**
FC-2363

**SHEET 3 OF 3**
DAP INTERFACE AND SERVICE ROUTINES

STABLISH Sh. 2
GOPIN Sh. 3
RCSDAPUP Sh. 4
RCSDAPON Sh. 4
SATSTKON Sh. 5
DAPDISP Sh. 6
V79 Sh. 10
S41.2 Sh. 13
S40.14 Sh. 17
S40.15 Sh. 17
ENATMA Sh. 18
V80 Sh. 18
V81 Sh. 18
V82 Sh. 19
V83 Sh. 19
NEEDLER Sh. 20
NEEDLE3 Sh. 21
STICKCHK Sh. 23
SETMAXDB Sh. 24
SETMINDB Sh. 24
AMBGUPDT Sh. 25
DPADD Sh. 26
SMALLMP Sh. 28
Extended Verb 46: RCS DAP Turn-on

STABLISH

Test DAPBIT1 and DAPBIT2
Yes
TVC-DAP is on; can't turn RCS-DAP on
CSM and LM joined?

No - via POSTJUMP

DAPFIG

Are bits 15, 14 of FLAGWORDS 1, 0?

No - via POSTJUMP

Bit 14 of DAPDATR1 set?

Yes - via POSTJUMP

Clear bit 9 of channel 12

Turn off Saturn IVB Takeover

ALM/END

Turn on operator error light and then transfer control to PINBRNCH (FC-2130)

FC-2430

FC-2190

0, 1 RCS-DAP: CSM

1, 0 RCS-DAP: CSM/LM

Read bits 14, 13 of DAPDATR1

No DAPs 0, 0

RCS/DAPUP

Sh. 4

SATSTKON

Sh. 5

NODAPUP

Next Sheet
From Preceding Sheet

\( T5LOC \leftarrow 2CADR (T5IDLOC) \)

Idle; \( T5RUPT \) not in use

Clear bits 15 and 14 of \( FLAGWRD8 \)

No DAPs; clear DAPBIT1 and DAPBIT2

Inhibit interrupts

via IBNKCALL

\( ZEROJET \)

Zero jet selection variables

\( FC-2380 \)

Release interrupts

Set \( HOLDFLAG \) to + (to stop auto maneuver)

\( ENDFIG \)

via POSTJUMP

\( GOPIN \)

via POSTJUMP

\( PINBRNCH \)

\( FC-2130 \)
RCSDA PUP

Inhibit interrupts via IBNKCALL

RCSDA PON

Set bits 15, 14 of FLAGWORD6 to 0, 1.
Set bit 3 of RCSFLAGS T5PHASE

RCS ATT

Schedule FRESHDAP in 600ms via T5RUPT FC-2380

Return via Q

Release interrupts

GOPIN Sh. 3

RCS A/P

Initiate FDAI needles FRESHDAP

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APOLLO GUIDANCE AND NAVIGATION DAP Interface and Service Routines

COLOSSUS 2D DOCUMENT NO. PC-2370

DRAWN

PRGMR

ANALYS

DOCNR

APPR'D

REV

Sheet 4 of 34

10/16/69

CP Trumbull

Robert M. Easton 11/26/69

Robert M. Easton 11/26/69

2
SATSTKON

Inhibit interrupts via T5RUPT

REDOSAT
Schedule Saturn-DAP turn-on in 10ms FC-2540

Set bits 14, 15 of FLAGWORD8 Enable Saturn control of DAP

ZEROJET
Zero jet selection variables FC-2380

Release interrupts

GOPIN Sh. 3
Verb 48: Load Autopilot Data

DAPDISP

Is TVC DAP on? (FLAGWORD6 bits 15, 14)

Yes

No

TestXACT

Test/Set EXTVBACT

(bit 3)

FC-2190

Busy

Not busy - Set flag to show extended verb display system busy via BANKCALL

DAPDISP1

PRIOCHNG

Lower priority to 10

FC-2050

Next Sheet

Input: EXTVBACT

Output: Set EXTVBACT to indicate extended verb activity

ALM/END FC-2190

Turn on operator error light and then transfer control to PINBRNCH (FC-2130)
From Preceding Sheet

DONOUN 46

via BANKCALL

GOXDSPF
Display Flashing
V04 N46

Load Data
(recycle)

Terminate

Proceed

ENDEXT

Flashing V04 N46-Request Response
Autopilot Configuration (Octal Code)

R1-DAPDATR1
bits - Vehicle Configuration
15-13
0 - no DAP
2 - CSM/LM
1 - CSM
3 - CSM/SIVB
6 - CSM/LM (Ascent)
bits - X Trans Code Quad AC
12-10
0 - Fail Quad AC
1 - Use Quad AC
bits - X Trans Code Quad BD
9-7
0 - Fail Quad BD
1 - Use Quad BD
bits - Deadband
6-4
0 - ±0.5 deg
1 - ±5 deg
bits - Maneuver Rate
3-1
0 - 0.05 deg/sec
1 - 0.2 deg/sec
2 - 0.5 deg/sec
3 - 2 deg/sec

R2-DAPDATR2
bits - Quad AC Roll
15-13
0 - Fail Quad AC (i.e., use BI)
1 - Use Quad AC
bits - Quad A
12-10
0 - Fail Quad A
1 - Use Quad A
bits - Quad B
9-7
0 - Fail Quad B
1 - Use Quad B
bits - Quad C
6-4
0 - Fail Quad C
1 - Use Quad C
bits - Quad D
3-1
0 - Fail Quad D
1 - Use Quad D

Next Sheet
Wide deadband?

Yes

Is bit 4 of DAPDATR1 set?

No

via DOWNFLAG

Set MAXDBFLG

Clear MAXDBFLG

MAXOUT via BANKCALL

S41.2

Transfer data to DAP

Sh. 13

DONOUN47 via BANKCALL

GOXDSPF

Display Flashing V06N47

Terminate

Flashing V06N47 - Request Response
Stored Mass Parameters (Decimal Code)

R1-CSMMASS xxxx. Pounds-Mass of CSM
R2-LEMMASS xxxx. Pounds-Mass of LM
R3-Blank

Next Sheet
Bits 14, 13 of DAPDATR1

Configuration code?

0 - No DAP
1 - CSM alone
2 - CSM and LM
3 - Saturn DAP
6 - CSM and LM (ascent)

- 0, 1 (Configuration Codes 1, 2, and 6)

Inhibit interrupts via IENKCALL

MASSPROP
Update mass properties
FC-2340

Updates vehicle moments of inertia with respect to estimated mass of spacecraft

Release interrupts via BANKCALL

S40.14 Transfer data to DAP Sh. 17

Next Sheet
From Preceding Sheet

DONOUN48

GOXDSPF

Display Flashing V06N48

Load Data (recycle)

Proceed or Terminate

ENDEXT

(ENDEXT = ENDMARK)

Input: EXTVBACT

TESTXACT Test/Set EXTVBACT Test/SET EXTVBACT (bit 3)

Previous extended verb active, > 0

PC-2100

ALM/END

FC-2130

Turn on operator error light and then transfer control to PINBRNCH (FC-2130)

output: EXT VBACT to indicate extended verb activity.

= 0 No other extended verb active

Next Sheet
From Preceding Sheet

RATEMANU
via BANKCALL

GOMARKF
Display Flashing
V06N79
Proceed
Recycle

Terminate

ENDEXT

R1: RATEPTC x.xxxx deg/sec
Rate Passive Thermal Control
R2: DBPTC xxx.xxdeg.
Deadband Passive Thermal Control
R3: OPTPTC xxxxx.
X- or Y- axis option
± 0 → X axis
± nonzero → Y axis

Zero WBODY's, DELCDU's, and BIAS's.
(Zero incremental angles, rates, and biases for roll, pitch, and yaw).

CDUXD+THETADX
CDUUD+THETADY
CDUZD+THETADZ

Set steering angles
to the center of DAP
deadband.

Next Sheet
S41.2, S40.14 and S40.15 Decode DAP Data Nouns

Values After Doubling:

- $0 \rightarrow 0.06^\circ$/sec
- $2 \rightarrow 0.26^\circ$/sec
- $4 \rightarrow 0.52^\circ$/sec
- $6 \rightarrow 2.0^\circ$/sec

An interrupt occurring while a bit is being set could alter the flagword, and this alteration would be lost so must not allow interrupt.

```
RATEINDEX ← 2 ⋅ [bits 2, 1 of DAPDATR1]
```

Inhibit interrupts

```
Are bits 14, 13 of DAPDATR1 = 1, 0? 
```

If LM attached?

Yes

```
TOGETHER
```

Clear ATCHFLG

```
Release interrupts
```

No

```
Is LM attached? 
```

Set ATCHFLG

Flagword 7 bit 2

Next Sheet
From Preceding Sheet

Is bit 4 of DAPDATR1 cleared?

Yes, narrow deadband

No, wide deadband

ADB $\leftarrow 5.0^\circ$

ADB $\leftarrow 0.5^\circ$

Read bits 10, 7 of DAPDATR1

ACX, BDX

AC + 0.0
BD + 1.1

XTRANS $\leftarrow +1$
XTRANS $\leftarrow +0$
XTRANS $\leftarrow -1$

+1 $\rightarrow$ Use BD quad for X translations
-1 $\rightarrow$ Use AC quad for X translations
0 $\rightarrow$ Use both quads for X translations

Inhibit interrupts

Next Sheet
From Preceding Sheet

Is \( XTRANS = 0 \) ?
- Yes: 2-Jet X trans
- No: Clear NJETSFLG

Flagword 1 bit 15
Set NJETSFLG

Release interrupts

Is bit 13 of DAPDATR2 cleared?
- Yes: Set ACORBD to - A-C Roll
- No: Set ACORBD to + B-D Roll

Next Sheet
From Preceding Sheet

Read bits 10-4 of DAPDATR2

1, 0
Quad C fails

1, 1 No fails

0, 1
Quad A fails

0, 0

RACFAIL ← -1

RACFAIL ← +0

RACFAIL ← +1

BDFAIL

Read bits 7-1 of DAPDATR2

1, 0
Quad D fails

1, 1 No fails

0, 1
Quad B fails

0, 0

RBDFAIL ← -1

RBDFAIL ← +0

RBDFAIL ← +1

Return via Q
S40.14

J/M ← IX (0.662034)
J/M1 ← IAVG (0.662034)
J/M2 ← IAVG (0.662034)
KMJ ← 0.00118/IXX
KMJ1 ← 0.00118/IAVG
KMJ2 ← 0.00118/IAVG

Return via Q

S40.15

1/CONACC ← 8 • IX • 2PI/M

S40.15 +7

VARK ← 4 • KTLX/I • IAVG/TLX

Return via Q

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

Desired roll gain
in (rev/sec)^2 -1 @2+9

Variable gain (for pitch and yaw)
in rev/rev @2^4 • 1.07975 for CSM/LM
in rev/rev @2^4 • 1.07975 for CSM
Extended Verb 58-Enable Automatic Maneuvers

ENATMA (via DOWNFLAG)

Clear STIKFLAG

Set V50N18FL (via UPFLAG)

GOPIN Sh. 3

Extended Verb 58-Reset STIKFLAG

(Enable automatic maneuvers)

Reset flag so that R61 may perform automatic tracking maneuvers after interrupt by RHC activity (STIKFLAG - Flagwr 1 bit 14)

Flagword 3 bit 15

Extended Verbs 60-63 DAP Error Display Configuration

V60

CPHIX ← CDUX
CPHIX +1 ← CDUY
CPHIX +2 ← CDUZ

GOPIN Sh. 3

in revs $2^{-1}$

Extended Verb 60-Set N17 reference angles to current CDU readings

V61

via DOWNFLAG

Clear NEEDLFLG

GOPIN Sh. 3

Extended Verb 61-Clear NEEDLFLG for display of A/P following error (Display Mode 1)

Flagword 0 bit 9
Extended Verb 62-Set NEEDLFLG and set N22ORN17 for display of total attitude error (Display Mode 2)

V62
via UPFLAG
Set NEEDLFLG Flagword 0 bit 9
via UPFLAG
Set N22ORN17 Set bit 6 of Flagword 9 (Display Mode 2)

GOPIN Sh. 3

Extended Verb 63-Set NEEDLFLG and clear N22ORN17 for display of total attitude error (Display Mode 3)

V63
via UPFLAG
Set NEEDLFLG Flagword 0 bit 9
Clear N22ORN17 Clear bit 6 of Flagword 9 (Display Mode 3)

GOPIN Sh. 3
FDAI NEEDLE DRIVE ROUTINE

NEEDLER

Is IMU in coarse align mode?

Is bit 4 of channel 12 set?

No

Next Sheet

NEEDLER1

Initialization pass

1, 1

1, 0

Read bits 3, 2 of RCSFLAGS

0, 0

Pass 3 and after

0, 1

NEEDLES3

Sh. 21

Clear bit 6 of channel 12

Disable IMU error counters to zero DAC's

NEEDLE11

AK = 0
AK1 = 0
AK2 = 0
EDRIVERX = 0
EDRIVEY = 0
EDRIVEZ = 0
CDUXCMD = 0
CDUYCMD = 0
CDUZCMD = 0

Clear bit 3
Set bit 2 of RCSFLAGS

Set for Pass 2

NEEDLER2

Sh. 23

Return via Q
NEEDLESS

Is bit 6 of channel 12 cleared?

No

NEEDLESS

SPNDX=2 for loop control

Next Sheet

From Preceding Sheet

Are IMU error counters disabled?

Yes

Set bit 3 of RCSFLAGS

Set for initialization pass.

Return via Q
From Preceding Sheet

From Preceding Sheet

DACLOOP

L = AK2/4
If |L| > 384, L ← 384 sign (L)
CDUZCMD ← L - EDRIVEZ + CDUZCMD
EDRIVEZ ← L
L = AK1/4
If |L| > 384, L ← 384 sign (L)
CDUYCMD ← L - EDRIVEY + CDUYCMD
EDRIVEY ← L
L = AK/4
If |L| > 384, L ← 384 sign (L)
CDUXCMD ← L - EDRIVEX + CDUXCMD
EDRIVEX ← L

Set bits
15, 14, 13
of channel 14

Gate IMU error commands
in cells 50, 51, and 52
(CDUXCMD, CDUYCMD, CDUZCMD)
into CDU error counters.

Loop Pass 1
Z attitude error

Loop Pass 2
Y attitude error

Loop Pass 3
X attitude error

Return via Q
RCS-DAP Subroutines

NEEDLER2

Set bit 6 of channel 12
Enable IMU error counters

Clear bits 3, 2 of RCSFLAGS
Set for Pass 3

Return via Q

STICKCHK

PMANNDX ← compl. (bits 2-1 of A)
YMANNDX ← compl. (bits 4-3 of A)
RMANNDX ← compl. (bits 6-5 of A)

Decode stick commands
(A contains contents of channel 31 or 32)
Pitch
0 → No rotation
1 → + rotation

Yaw
2 → - rotation
3 → (No rotation)

Roll

Return via Q
SETMAXDB

ADB $\leftarrow 5.0^\circ$

Set maximum deadband

Wide deadband (in revs @2$^{-1}$)

Set bit 4 of DAPDATR1

Return via Q

SETMINDB

THETADX $\leftarrow$ CDUX
THETADY $\leftarrow$ CDUY
THETADZ $\leftarrow$ CDUZ

Set minimum deadband

Zero attitude errors to save propellant on switchover in revs @2$^{-1}$ to narrow deadband

ADB $\leftarrow 0.5^\circ$

Narrow deadband (in revs @2$^{-1}$)

Clear bit 4 of DAPDATR1

Return via Q
Matrix Update Subroutine

```
AMBGUPDT

Test bits 15, 14 of FLAGWORD6

Under RCS-DAP control?

0, 1 Yes

ENDOFJOB

Exit, RCS-DAP has been turned off since this job was scheduled.

```

Jets are offset by $7.25^\circ$ (QUADANGL= $7.25^\circ$) around the X-axis with respect to the navigation base axes.

AMGB1-AMGB7 @2

Sin and cos found via SPSIN (FC-2110) and SPCOS (FC-2110)

`Transformation matrix: gimbal angle differences to body angle differences`

$$
\begin{pmatrix}
1 & \sin (\text{CDUZ}) & 0 \\
0 & \cos (\text{CDUZ}) \cos (\text{CDUX}-7.25^\circ) \sin (\text{CDUX}-7.25^\circ) & 0 \\
0 & \cos (\text{CDUZ}) \sin (\text{CDUX}-7.25^\circ) \cos (\text{CDUX}-7.25^\circ) & 0 \\
\end{pmatrix}
$$

$$
\begin{pmatrix}
1 & \sin (\psi) & 0 \\
0 & \cos (\psi) \cos (\phi) & \sin (\phi) \\
0 & \cos (\psi) \sin (\phi) & \cos (\phi) \\
\end{pmatrix}
$$

```
```
MYSUBS Arithmetic Subroutines

\[ \text{KMPAC}_D \leftarrow \text{KMPAC}_D + [A, L] \]  \quad \text{in revs } \theta 2^{-1}

\begin{align*}
\text{Overflow?} \\
\text{Is } A \neq 0? \\
\text{Yes} & \quad \text{Return via Q} \\
\text{No, finished} & \\
\end{align*}

\begin{align*}
\text{Sign KMPAC} & \\
+ & \quad \text{DPADD+} \\
& \quad \text{KMPAC} \leftarrow \text{KMPAC} - (\text{POSMAX} + 1) \\
& \quad \text{KMPAC} + 1 \leftarrow \text{KMPAC} + 1 \\
& \quad \text{Return via Q} \\
\end{align*}

\begin{align*}
\text{Negative overflow} & \\
\text{DPADD} & \\
\text{KMPAC} & \leftarrow \text{KMPAC} + \text{POSMAX} + 1 \\
\text{KMPAC} + 1 & \leftarrow \text{KMPAC} + 1 \\
& \quad \text{Return via Q} \\
\end{align*}

Next Sheet
The real value of the angle stored in KMPAC lies always between ±360°. The storage capacity of KMPAC, however, is between ±180°. If positive overflow, the real value lies between +180° and +360°, while the stored value is 180° smaller. However, by subtracting 180° (POSMAX+1) from this stored value, it becomes equivalent to the real value (as θ−360°=θ). 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 are ±180°, then the real angle is 180°+180° and the closest approximation is double precision POSMAX.
Double precision product of KMPAC_d and A; Results in KMPAC_d

Calculation: A(X+Y)

A•Y(s. p., low order half lost)
A•X(d. p.)
High half \{ AX + AY

Low half

\[ \text{KMPTEMP} \leftarrow A \]
\[ \text{KMPAC} +1 \leftarrow A(\text{KMPAC} +1) \]
\[ A \leftarrow \text{KMPAC} \]
\[ [A, L] \leftarrow A(\text{KMPTEMP}) \]
\[ \text{KMPAC} \leftarrow A \]
\[ \text{KMPAC} +1 \leftarrow L + (\text{KMPAC} +1) \]

Return via Q
<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALM/END</td>
<td>2190</td>
<td>Turns on operator error light and then transfers control to PINBRNCH (FC-2130)</td>
<td>Sh. 2, 6, 10</td>
</tr>
<tr>
<td>MASSPROP</td>
<td>2340</td>
<td>Updates mass properties</td>
<td>Sh. 9</td>
</tr>
<tr>
<td>PINBRNCH</td>
<td>2130</td>
<td>Reestablishes last display</td>
<td>Sh. 3</td>
</tr>
<tr>
<td>PRIOCHNG</td>
<td>2050</td>
<td>Changes priority</td>
<td>Sh. 6</td>
</tr>
<tr>
<td>RCSATT</td>
<td>2380</td>
<td>Normal entry to RCS DAP initialization and Phase 1</td>
<td>Sh. 4</td>
</tr>
<tr>
<td>REDOSAT</td>
<td>2450</td>
<td>Initializes stick control of Saturn</td>
<td>Sh. 5</td>
</tr>
<tr>
<td>STOPRATE</td>
<td>2350</td>
<td>Zeroes incremental angles, rates, and biases for roll, pitch, and yaw</td>
<td>Sh. 11</td>
</tr>
<tr>
<td>SWICHOVR</td>
<td>2430</td>
<td>Switches from one set of filter gains to another</td>
<td>Sh. 2</td>
</tr>
<tr>
<td>TESTXACT</td>
<td>2190</td>
<td>Tests/sets EXTVBACT</td>
<td>Sh. 6, 10</td>
</tr>
<tr>
<td>ZEROJET</td>
<td>2380</td>
<td>Zeroes jet selection variables</td>
<td>Sh. 3, 5</td>
</tr>
</tbody>
</table>

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

DRAWN
PRGMR
ANALYST
DOCNR
APPR'D

DAP Interface and Service Routines
COLOSSUS 2D
DOCUMENT NO.
REV
SHEET 29 OF 34
<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAXDBFLG (Flagword 9</td>
<td>Maximum deadband selected</td>
<td>Minimum deadband selected</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>bit 12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N22CRN17 (Flagword 9</td>
<td>Compute total attitude errors with respect to</td>
<td>Compute total attitude errors with respect to</td>
<td>19</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>bit 6)</td>
<td>N22 V62</td>
<td>N17 V63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATTCFLG (Flagword 7</td>
<td>LM attached to CM</td>
<td>LM not attached to CM</td>
<td>13</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>bit 2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAPBIT 1 (Flagword 6</td>
<td>(bit 15, bit 14) • 1, 1: enable Saturn control</td>
<td>Enable R60 attitude maneuver</td>
<td>5</td>
<td>3, 4</td>
<td>2, 6, 25</td>
</tr>
<tr>
<td>bit 15)</td>
<td>RCS A/P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAPBIT 2 (Flagword 6</td>
<td>0, 1:</td>
<td>Inhibit R60 attitude maneuver</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 14)</td>
<td>0, 0: enable Saturn control of DAP, no DAP's</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V50N18FLG (Flagword 3</td>
<td>Enable R60 attitude maneuver</td>
<td>Inhibit R60 attitude maneuver</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NJETSFLG (Flagword 1</td>
<td>2 jet RCS burn</td>
<td>4 jet RCS burn</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>bit 15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STIKFLAG (Flagword 1</td>
<td>RHC control</td>
<td>CMC control</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 14)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEEDLFLG (Flagword 0</td>
<td>Total attitude error displayed</td>
<td>A/P following error displayed</td>
<td>19</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>bit 9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCSFLAGS bit 3</td>
<td>NEEDLER routine performs the initialization</td>
<td>NEEDLER routine does not perform initialization</td>
<td>4, 21</td>
<td>20, 30</td>
<td>20</td>
</tr>
<tr>
<td>for the FDAI display.</td>
<td>functions for the FDAI display.</td>
<td>functions for the FDAI display.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCSFLAGS bit 2</td>
<td>First pass of initialization function has been</td>
<td>First pass of initialization function has not</td>
<td>20</td>
<td>23</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>completed.</td>
<td>been completed.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## DISPLAYS

<table>
<thead>
<tr>
<th>Verb-Noun</th>
<th>Type of Display</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
</tr>
</thead>
<tbody>
<tr>
<td>V04N46</td>
<td>Flashing</td>
<td>R1: xxxxx DAPDATR1</td>
<td>Sh. 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2: xxxxx DAPDATR2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3: (octal code)</td>
<td></td>
</tr>
<tr>
<td>V06N47</td>
<td>Flashing</td>
<td>R1: xxxxx, pounds mass of CSM</td>
<td>Sh. 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2: xxxxx, pounds mass of LM</td>
<td></td>
</tr>
<tr>
<td>V06N48</td>
<td>Flashing</td>
<td>R1: xxx, xxdeg. pitch trim</td>
<td>Sh. 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2: xxx, xxdeg. yaw trim</td>
<td></td>
</tr>
<tr>
<td>V06N79</td>
<td>Flashing</td>
<td>R1: x, xxxdeg/sec rate passive</td>
<td>Sh. 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2: xxx, xxdeg. deadband passive</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3: xxxxx, x- or y- axis option</td>
<td></td>
</tr>
</tbody>
</table>
### ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>Tag</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACORBD</td>
<td>Specifies quad pair to be used for roll attitude control in RCS DAP.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+1 : B-D quad</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-4096 : A-C quad</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADB</td>
<td>Attitude error deadband</td>
<td>deg</td>
<td>rev</td>
<td>2^-1</td>
</tr>
<tr>
<td>AK</td>
<td>Attitude errors</td>
<td>deg</td>
<td>rev</td>
<td>2^-1</td>
</tr>
<tr>
<td>AK1, AK2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMGB1, AMGB4, AMGB5, AMGB7, AMGB8</td>
<td>Matrix elements which are used by RCS DAP to transform information from gimbal to control axes.</td>
<td></td>
<td></td>
<td>2^0</td>
</tr>
<tr>
<td>CDUXCMD</td>
<td>Value to be transmitted to CDU IMU error counters and/or to FDAI needles.</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>CDUXD, CDUYD, CDUZD</td>
<td>Values of desired DAP CDU angles for automatic maneuver.</td>
<td></td>
<td></td>
<td>2^-1</td>
</tr>
<tr>
<td>DAPDATR1, DAPDATR2</td>
<td>see end of Erasable Locations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELCDUXD</td>
<td>CDUX change; calculated every decisecond.</td>
<td>deg</td>
<td>rev</td>
<td>2^-1</td>
</tr>
<tr>
<td>EDRIVEX, EDRIVEY, EDRIVEZ</td>
<td>Buffer register used in communicating DAP attitude errors to needles.</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>HOLDFLAG</td>
<td>Controls nature of attitude hold performed by RCS DAP.</td>
<td></td>
<td></td>
<td>2^14</td>
</tr>
<tr>
<td>IAVG</td>
<td>Average moment of inertia about y and z axes</td>
<td>kg·m^2</td>
<td>kg·m^2</td>
<td>2^20</td>
</tr>
<tr>
<td>IAVG/TLX</td>
<td>IAVG/&quot;thrust moment&quot;)</td>
<td>sec^2</td>
<td>sec^2</td>
<td>2^2</td>
</tr>
<tr>
<td>IXX</td>
<td>Moment of inertia about x axis</td>
<td>kg·m^2</td>
<td>kg·m^2</td>
<td>2^20</td>
</tr>
</tbody>
</table>
### AGC Tags and Meanings

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/M</td>
<td>S/C inertia to torque ratio - x axis</td>
<td>(deg/decisec-sec^-1)</td>
<td>(rev/decisec-sec^-1)</td>
<td>2^23</td>
</tr>
<tr>
<td>J/M1</td>
<td>S/C inertia to torque ratio - y axis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J/M2</td>
<td>S/C inertia to torque ratio - z axis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KMJ</td>
<td>S/C torque to inertia ratio - x axis</td>
<td>deg/decisec</td>
<td>rev/decisec</td>
<td>2^-13</td>
</tr>
<tr>
<td>KMJ1</td>
<td>S/C torque to inertia ratio - y axis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KMJ2</td>
<td>S/C torque to inertia ratio - z axis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KTLX/I</td>
<td>K: DAP gain factor T: thrust LX: distance from engine gimbal point to c.g. of vehicle I: average of moments of inertia about pitch and yaw axes</td>
<td>deg</td>
<td>rev</td>
<td>CSM/LM: 2^2 x 1.07975 CSM: 2^4 x 1.07975</td>
</tr>
<tr>
<td>PMANNDX</td>
<td>Pitch decode stick command (bits 2,1) = 0,0 = no maneuver 0,1 = positive maneuver 1,0 = negative maneuver 1,1 = no maneuver</td>
<td></td>
<td></td>
<td>2^14</td>
</tr>
<tr>
<td>RACFAIL</td>
<td>A-C Quad Failures (see DAPDATR2 bits 10,4)</td>
<td></td>
<td></td>
<td>2^14</td>
</tr>
<tr>
<td>RBDFAIL</td>
<td>B-D Quad Failures (see DAPDATR2 bits 7,1)</td>
<td></td>
<td></td>
<td>2^14</td>
</tr>
<tr>
<td>RMANNDX</td>
<td>Roll decode stick command (see PMANNDX above)</td>
<td></td>
<td></td>
<td>2^14</td>
</tr>
<tr>
<td>THETADX</td>
<td>CDU angles in DAP used for attitude errors.</td>
<td>deg</td>
<td>rev</td>
<td>2^-1</td>
</tr>
<tr>
<td>THETADY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>THETADZ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VARK</td>
<td>Variable gain (for pitch and yaw)</td>
<td>deg/deg</td>
<td>rev/rev</td>
<td>CSM/LM: 2^2 x 1.07975 CSM: 2^4 x 1.07975</td>
</tr>
<tr>
<td>WBODY_D</td>
<td>Desired angular rates</td>
<td>deg/decisec</td>
<td>rev/decisec</td>
<td>2^-3</td>
</tr>
<tr>
<td>XTRANS</td>
<td>Used with DAPDATR1, bits 10,7 +1: use B-D quad for x translations. -1: use A-C quad for x translations. 0: use both quads for x translations.</td>
<td></td>
<td></td>
<td>2^14</td>
</tr>
<tr>
<td>YMANNDX</td>
<td>Yaw decode stick command (see PMANNDX above)</td>
<td></td>
<td></td>
<td>2^14</td>
</tr>
<tr>
<td>l/CONACC</td>
<td>Reciprocal of roll axis acceleration</td>
<td>(deg/sec)^-1</td>
<td>(rev/sec)^2-1</td>
<td>2^8</td>
</tr>
<tr>
<td>AGC Tag</td>
<td>Meaning</td>
<td>Engineering Units</td>
<td>AGC Units</td>
<td>AGC Scaling</td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>-------------------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>DAPDATR1</td>
<td>Specifies vehicle configuration and desire DAP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 10</td>
<td>1: allow use of A-C quad for x-translations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 7</td>
<td>1: allow use of B-D quad for x-translation  If bits 10, 7=0, -0, allow use of both quads.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 4</td>
<td>0: narrow deadband (0, 5°) 1: wide deadband (5, 0°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bits 2, -1</td>
<td>0: 0.05 deg/sec 1: 0.2 deg/sec 2: 0.5 deg/sec 3: 2.0 deg/sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAPDATR2</td>
<td>Control for RCS DAP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 13</td>
<td>0: B-D roll 1: A-C roll</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 10</td>
<td>1: quad A may be used 0: quad A may not be used</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 7</td>
<td>1: quad B may be used 0: quad B may not be used</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 4</td>
<td>1: quad C may be used</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 1</td>
<td>1: quad D may be used</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RCS DAP INITIALIZATION AND PHASE 1

THE ENCLOSED SHEETS UPDATE THE COLOSSUS II FLOWCHART FC-2380, REV. 0, TO THE COLOSSUS IIIA FLOWCHART FC-2380, REV. 1.

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

EFFECTIVE SHEETS FOR COLOSSUS IIIA FC-2380,
REV. 1 ARE:

<table>
<thead>
<tr>
<th>SHEET</th>
<th>REV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH. 1</td>
<td>REV. 1</td>
</tr>
<tr>
<td>SH. 2-5</td>
<td>REV. 0</td>
</tr>
<tr>
<td>SH. 6</td>
<td>REV. 1</td>
</tr>
<tr>
<td>SH. 7-8</td>
<td>REV. 0</td>
</tr>
</tbody>
</table>
FROM PRECEDING SHEET

K MATRIX

IS THIS THE TENTH PASS SINCE THE LAST MATRIX UPDATE?

YES

ATTSEC = 0?

NO

DECREMENT COUNTER

ATTSEC ← ATTSEC - 1

AMBDURDT SCHEDULE MATRIX UPDATE AS NOVAC JOB WITH PRIOR 34 FC-2370

ATTSEC = 9

UPDATE MATRIX FOR TRANSFORMATION OF GIMBAL ANGLES TO S/C CO-ORDINATE ANGLES.

INITIALIZE COUNTER

TENTHSEX

IS AUTOMATIC MANEUVERS?

NO

HOLDFLAG = -?

YES

SIGNXZ FOR LOOP CONTROL

DE LOOP

THETADE ← CDUO + DELCDUZ CDUZD ← THETADE THETADY ← CDUO + DELCDUY CDUYD ← THETADY THETADX ← CDUO + DELCDUX CDUXD ← THETADX

LOOP CONTROL VIA SINDX

ON AUTOMATIC MANEUVERS ADD ΔCDU ANGLES TO DESIRED ANGLES TO GET NEW DESIRED ANGLES.
STORE IN THETADX, THETADY, AND THETADE FOR USE BY AUTOPILOT ATTITUDE ERROR LOGIC

TO NEXT PAGE
DAP INITIALIZATION

EXECUTED AT TURN-ON, AND IF G/N SWITCH CHANGED TO ON POSITION WHILE DAP IS ON

ESTABLISH HOLD

ENTRY IS TO HERE ON RESTART

OUTPUTS: RATE INDEX: 0→0.05 sec, 2→0.2 sec, 4→0.5 sec, 6→2.0 sec
OF S41.2

FLAGWRD7 BIT 7: SET = LM ATTACHED
ADD: DEADBAND = 5 sec OR 5 deg.
XTRANS±1 = USE QUADS BD FOR X TRANSLATIONS
-1 = USE QUADS AC FOR X TRANSLATIONS
0 = USE ALL QUADS
FLAGWRD1 BIT 15: SET = 2-JET TRANSLATIONS
CLEAR = 4-JET TRANSLATIONS
RACFAIL±1 = QUAD A FAIL; -1 = QUAD C FAIL.
0 = NO FAILS
RBDFAIL±1 = QUAD B FAIL; -1 = QUAD D FAIL.
0 = NO FAILS

OUTPUTS: J/M, J/M2, J/M2, S/C MOMENTS OF INERTIA
ABOUT X, Y AND Z AXES
KMJ, KMJ, KMJ, S/C TORQUE TO INERTIA RATIOS
S41.2 AND S40.14 ARE EXECUTED HERE TO RESTORE DAP VARIABLES THAT MAY HAVE BEEN WALLOPED BY TVC DAP

S40.14
DECODE
NOUN 47
FC 2370

S41.2
DECODE
DAPDAT1 AND DAPDAT2
FC 2370

SPNDX = 30 FOR LOOP CONTROL

ZERO5

LOOP CONTROL VIA SPNDX

SET TO 10: WBODY, WBODY1, WBODY2,
ADOT, ADOT1, ADOT2, MERRRX,
MERRRY, MERRRZ, DET, DET1, DET9,
DRHO, DRH01, DRH02, ATTSEC, TAU,
TAU1, TAU2, BIAS1, BIAS2,
ERRORX, ERORY, ERRORZ

ZERO RCS-DAP VARIABLES

TO NEXT PAGE
FROM PRECEIVING PAGE

ZEROJET

SPNOX = 11 FOR LOOP CONTROL

LOOP CONTROL VIA SPNOX

SET TO 40: BLAST1, BLAST2, YWORD1, YWORD2, PWORD1, PWORD2, RWORD1, RWORD2

BLAST1 + 1 —— 40
BLAST2 + 1 —— 110

CLEAR BIT 1 OF RC5FLAGS

TSTART SCHEDULE TURUPT IN 14 MS (FC-24000)

SET BIT 18 OF CHW31

CHANTEMP ——— 0
CH31TEMP ——— 0
SLOPE ——— 0.24
TSTIME ——— 40 MS
ATTKALMN ——— 110

ZEROJET SELECTION VARIABLES

BRANCH INDICES FOR JET SELECTION LOGIC

START TIMECOUNTER

END OF SUBROUTINE

MINIMUM IMPULSE COMMANDS
PHC COMMANDS
SWITCHING LOGIC SLOPE DELAY TIME *
INITIAL KALMANN FILTER GAINS

* TIMING LOGIC
1. PHASE 2 BEGINS IN 40 MS (SEE NEXT SHEET)
2. PHASE 2 SUBTRACTS TSTIME FROM 80 MS AND SETS PHASE 1 TO BEGIN AT THAT TIME.
3. THIS PHASE 1 BEGINS (80-40) = 40 MS AFTER PHASE 2.
4. AND PHASE 1 BEGINS (40+40) = 100 MS AFTER INITIAL PHASE. SO THAT THE 0.1 SEC FILTER SAMPLE TIME AND 1.0 SEC MATRIX UPDATING ARE CORRECTLY TIMED.

NEXT PAGE
FROM PRECEDING SHEET

\[
\begin{align*}
\text{Rho} &\leftrightarrow \text{CDUX} \\
\text{Rho1} &\leftrightarrow \text{CDUy} \\
\text{Rho2} &\leftrightarrow \text{CDUz} \\
\text{OUTER GIMBAL ANGLE} &\leftrightarrow \text{INITIAL VALUES FOR RATE FILTER} \\
\text{INNER GIMBAL ANGLE} &\leftrightarrow \text{FOR RATE FILTER} \\
\text{MIDDLE GIMBAL ANGLE} &\leftrightarrow \text{FOR RATE FILTER}
\end{align*}
\]

SET TS\text{PHASE TD+}

PHASE 2

IS IMU IN INERTIAL REFERENCE MODE?

\[
\begin{align*}
\text{NO} &\rightarrow \text{ATTKALMN=0}\text{STEP RATE FILTER SO MANUAL COMMANDS WILL OPERATE WITHOUT 1.1 DELAY FOR INITIALIZATION}\text{YES} &\rightarrow \text{IMUADK}
\end{align*}
\]

AMBGUPD

(Prio 94)

SCHEDULE MATRIX UPDATE

FC 2370

initialize translation matrix
cdu angles to s/c coordinates

\[
\begin{align*}
A &\leftrightarrow \text{RCINIT}\text{(TO SET RCSFLAGS)}\text{A} &\leftrightarrow \text{RCINITB}\text{(TO SET RCSFLAGS)}
\end{align*}
\]

RCSSWIT

IF IMU IN FINE ALIGN, BIT 14 - CLEAR
IF IMU NOT IN FINE ALIGN, BIT 14 - SET
IN EITHER CASE:
BIT 1 - CLEAR: INITIALIZE T6 PROGRAM
BIT 3 - SET: INITIALIZE NEEDLES
BIT 4 - CLEAR: FDAIDSP1

RCS SCHEDULE

PHASE 2 IN
60 MS VIA TS RUP
SH 1

RESUME

END OF FRESHDAP
RCS DAP - Phase 2

T5 PHASE2 Sh. 2

Special Convention: \( \lor \) indicates "exclusive or" operation.
FROM PRECEDING SHEET

NOCHANGE

ANY ZEROS BITS 1-6?
CHAN 31?

ANY RHC COMMANDS AT ALL?

AHFRORD SET
SHL

MAINTAIN ATTITUDE HOLD
WHEN RHC COMMANDS CEASE

STICK CHK

DECODE RHC
COMMANDS
FC-2390

INPUT: CHAN 31
OUTPUT: YMANINDX (YAW INDEX),
PMANINDX (PITCH INDEX),
RMANINDX (ROLL INDEX)

MANNIDX ROTATION
+0 | NONE
+1 | ↑
+2 | ↓

SET BIT 14 OF FLGWR, INDICATING ASTRONAUT HAS
TAKEN OVER CIC CONTROL

SET STIKFLAG

FREEFNC

YES (FREE)

SELECT TAU, TAU1,
AND TAU2 FROM LOCATIONS RMANINDX,
PMANINDX AND YMANINDX OF
FREE TAU TRECLE (CH. 9)

T6PROG SHL

IS BIT 14 OF CHAN
31 CLEARED?

ND (HOLD OR AUTO)

IS NO-RATE FLAG SET?

YES

IS CMG MODE SWITCH IN FREE?

SET (TD14 DK)

REINIT

TILT, CIC IN HOLD OR
AUTO WITHOUT IMU
BEING USABLE

RDATT

SCHEDULE FRESHDAP
IN 200 MS
VIA TRSRIPT
FC-2390

RESUME

HIGH-RATE MANEUVERS?

SELECT HIGH-RATE FILTER
ATTXALNM ← -1

NOT

IS RATE INDEX = 6?

15

LOOP PERFORMED THREE
TIMES USING
1) YMANINDX (YAW) AND WBOODY (SPNIDX = 2)
2) PMANINDX (PITCH) AND WBOODY (SPNIDX = 1)
3) RMANINDX (ROLL) AND WBOODY (SPNIDX = 0)
SPNIDX IS INDEXING FACTOR FOR LOOP CONTROL

SPNIDX ← 2 FOR LOOP
CONTROL

SET WBOODY

NEXT SHEET

FROM SHEETY

FROM SHEET 4

COLDSSUS 21

J. C. WILLIAMS

J. D. TURNBULL

J. D. K. \& R.

FC-2390
FROM PRECEDING SHEET

ATTIHLD

ERRORx ← (CDyX - THETAx) + AMGB(CDyX - THETAy)
ERRORy ← AMGB4(CDyX - THETAy) + AMG05(CDUZ - THETAz)
ERRORz ← AMGB7(CDUZ - THETAy) + AMG06(CDUZ - THETAz)

ROLL ERROR PITCH ERROR YAW ERROR RESOLVED INTO VEHICLE CO-ORDINATES VIA KMATRX (P) (P) (P)

AUTOMATIC MANEUVERS ?

NO

HOLDFLAG = ?

YES

ERRORx ← ERRORx + BIAS
ERRORy ← ERRORy + BIAS1
ERRORz ← ERRORz + BIAS

ADD IN BIASES (BIASES COMPUTED IN KALMANU)

NEXT SHEET
DEADBAND + FLAT REGION

INDEXED VARIABLES IN JLOOP

<table>
<thead>
<tr>
<th>PASS 1</th>
<th>PASS 2</th>
<th>PASS 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADOT1</td>
<td>ADOT1</td>
<td>ADOT1</td>
</tr>
<tr>
<td>WBODY1</td>
<td>WBODY1</td>
<td>WBODY1</td>
</tr>
<tr>
<td>ERROR1</td>
<td>ERROR1</td>
<td>ERROR1</td>
</tr>
<tr>
<td>TAU1</td>
<td>TAU1</td>
<td>TAU1</td>
</tr>
<tr>
<td>J/M2</td>
<td>J/M2</td>
<td>J/M2</td>
</tr>
</tbody>
</table>

JLOOP IS EXECUTED ONCE FOR EACH AXIS

S/C ANGULAR RATE (ESTIMATE)

INCLUDE AUTOMATIC MANEUVER RATES

S/C ATTITUDE ERROR

Since the phase plane is symmetric about the origin, the rate is taken as positive and the signs of EDOT, TSTEMP and AERR adjusted accordingly. The suffix "vel" in the mnemonic designates the adjusted values.
PHASE PLANE LOGIC

DECISION LOGIC

<table>
<thead>
<tr>
<th>DECISION LINE (DL) ON GRAPH</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECISION POINT IN LOGIC</td>
<td>J7</td>
<td>J6 + 1</td>
<td>J6</td>
<td>J6</td>
<td>J6 + 2</td>
<td>J6</td>
<td>J6</td>
<td>J6 + 2 + 1</td>
</tr>
<tr>
<td>OUTCOME LOGICAL &quot;YES&quot;</td>
<td>LEFT</td>
<td>LEFT</td>
<td>RIGHT</td>
<td>LEFT</td>
<td>LEFT</td>
<td>RIGHT</td>
<td>LEFT</td>
<td>BELOW</td>
</tr>
<tr>
<td>LOGICAL &quot;NO&quot;</td>
<td>RIGHT</td>
<td>RIGHT</td>
<td>LEFT</td>
<td>RIGHT</td>
<td>LEFT</td>
<td>RIGHT</td>
<td>LEFT</td>
<td>ABOVE</td>
</tr>
</tbody>
</table>

LOGICAL PATHS

<table>
<thead>
<tr>
<th>DECISION AREA (DA)</th>
<th>LOGICAL PATHS</th>
<th>RESPONSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA 1</td>
<td>J6 - J8 - NJ22 - NJ22 + 1 - NJ23 - J22</td>
<td>DRIVE RATE TO +WL</td>
</tr>
<tr>
<td>DA 2</td>
<td>J6 - J8 - J22</td>
<td>DRIVE RATE TO +WL</td>
</tr>
<tr>
<td>DA 3</td>
<td>J6 - J8 - NJ22 - NJ22 + 1 - J23</td>
<td>NO ACTION*</td>
</tr>
<tr>
<td>DA 4</td>
<td>J6 - J6 - NJ22 - NJ22 + 1 - NJ23 - J24</td>
<td>DRIVE RATE TO SLOPE 2</td>
</tr>
<tr>
<td>DA 5</td>
<td>J6 - J8 - J23</td>
<td>NO ACTION*</td>
</tr>
<tr>
<td>DA 6</td>
<td>J6 - J6 + 1 - J6 + 2 - J23</td>
<td>NO ACTION*</td>
</tr>
<tr>
<td>DA 7</td>
<td>J6 - J6 + 1 - J6 + 2 - J18</td>
<td>DRIVE RATE TO ZERO</td>
</tr>
<tr>
<td>DA 8</td>
<td>J6 - J6 + 1 - J7</td>
<td>DRIVE RATE TO SLOPE 2</td>
</tr>
<tr>
<td>DA 9</td>
<td>J6 - J6 + 1 - J7</td>
<td>DRIVE RATE TO -WL</td>
</tr>
</tbody>
</table>

* IF THERE ARE ANY BHC COMMANDS, THEN THE RATE IS DRIVEN TO ZERO BEFORE EXECUTION OF THE COMMANDS.
From Sheet 8

\[ \text{JTIME} \]

\[ \text{KMPAC} \leftarrow \text{KMPAC} \frac{(y/m^2) \times \text{BIT11}}{dp} \]

\[ \text{SIGN} \quad \text{KMPAC}_{dp} \]

\[ \text{TAU} \text{NORM} \]

\[ A \leftarrow \text{NEGMAX} \]

\[ A \leftarrow \text{KMPAC} + 1 \]

\[ A \leftarrow \text{POSMAX} \]

\[ \text{DOJET} \]

\[ \text{TAU2} \leftarrow A \]

\[ \text{IS} \quad \text{SPNDX} = 0? \]

\[ \text{NO, RECYCLE LOOP} \]

\[ \text{YES} \]

\[ \text{T6 PROG} \]

\[ \text{Sh. 11} \]

\[ \text{IS} \quad \text{SPRDJ} = 0? \]

\[ \text{NO, RECYCLE LOOP} \]

\[ \text{YES} \]

\[ \text{SPRDJ} \leftarrow \text{SPRDJ} - 1 \]

\[ \text{JLOOP} \]

\[ \text{Sh. 7} \]

\[ \text{MULTIPLICATION BY SMALLMP (SUBROUTINE (PC-23700) )} \]

\[ \text{\( \Delta \) RATE TIMES S/C MOMENT OF INERTIA, SHIFTED RIGHT 4 FOR SCALING} \]

\[ \text{TAU'S ARE LIMITED TO} |\text{TAU}| / \text{POSMAX}_{dp} \]

\[ \text{FOR SINGLE PRECISION STORAGE} \]

\[ \text{JET ON TIMES IN TERMS OF} \]

\[ \text{ONE JET OPERATION} \]

\[ \text{NOTE THAT RETURN HERE THROUGH} \]

\[ \text{J23 LEAVES TAU2 ALONE} \]

\[ \text{EACH AXIS IS TREATED IN TURN} \]

\[ \text{WITH THE SAME LOGIC} \]
ZERO ATTITUDE ERROR IF IN FREE MODE, OR IF MANUAL COMMANDS ARE BEING RECOGNIZED.
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Where Flowed</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>JETSLECT</td>
<td>FC-2400</td>
<td>Entry to RCS DAP jet selection logic</td>
<td>Sh. 11</td>
</tr>
<tr>
<td>KMATRIX</td>
<td>FC-2380</td>
<td>Resolve roll, pitch, &amp; yaw errors into vehicle co-ordinates</td>
<td>Sh. 6</td>
</tr>
<tr>
<td>RCSATT</td>
<td>FC-2380</td>
<td>Entry to Phase 1</td>
<td>Sh. 2, 3</td>
</tr>
<tr>
<td>SMALLMP</td>
<td>FC-2370</td>
<td>One and one-half precision multiplication</td>
<td>Sh. 10</td>
</tr>
<tr>
<td>STICKCHK</td>
<td>FC-2370</td>
<td>Decode RHC commands</td>
<td>Sh. 3, 5</td>
</tr>
</tbody>
</table>

### FLAG

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>STKFLAG flagword 1 bit 14</td>
<td>RHC control</td>
<td>CMC control</td>
<td>Sh. 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RCS-DAP JET SELECTION LOGIC

ENTRY FROM TS RUPT - FC0380 SH1

JETSLECT

SAVE L IN BANKRUPT

TIMES ← 60MS - TTIME

TS RUPT IN 60MS MINUS DELAYS

OVERFLOW?

YES

TIMES ← 20MS

TO INSURE TS RUPT (IN CASE OF EXCESSIVE DELAYS)

NO

TS START SCHEDULE
JET TURN ON IN 14MS
VIA TS RUPT
SH.17

SET BIT 15 OF CHAN13

SAVE Q IN TS RUPT

ENABLE TS RUPT

TSTEMP ← COMPROF
BIT 12 - 7

CHAN13

PICK UP TRANSLATION COMMANDS

ANY COMMANDS?

NO

TSTEMP #0?

YES

NOXLNCMD

+0 = NO TRANS.

XNDX1 = 0

1+ = TRANS.

YNDX = Y TRANS. COMMANDS

2+ = TRANS.

ZNDX = Z TRANS. COMMANDS

3+ = NO TRANS.

ZNOX ← 0

NEXT PAGE

PWORD

SH.9

ZERO COMMANDS

+0 = NO TRANS.

XNDX1 = 0

1+ = TRANS.

YNDX = Y TRANS. COMMANDS

2+ = TRANS.

ZNDX = Z TRANS. COMMANDS

3+ = NO TRANS.

ZNOX ← 0

NEXT PAGE

PWORD

SH.9

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NEXT PAGE

PWORD

SH.9

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NEXT PAGE

PWORD

SH.9

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2+ = TRANS.

ZNDX = Z TRANS. COMMANDS

3+ = NO TRANS.
FROM PRECEDING PAGE

PWORD

- SIGN TAU1 ?
  \[ \pm 0 \]

- PINDEX → 2
- PINDEX → +0
- PINDEX → +1

PITCH COMMANDS

+0 → NO PITCH
1 → + PITCH
2 → - PITCH

QUAD C FAIL

- SIGN RACFAIL ?
  \[ \pm 0 \]

0 OR +3

CMAG + P

QUAD A FAIL

+2 VALUE OF XNDX1 ?

A → +12
A → +0
A → +3
A → +6
A → +9

AFAILP

FAILP

SELECT PWORDS FROM LOCATION (A + PINDEX) OF PYTABLE BITS 10,9 AND 4-1

NUMBER OF PITCH JETS

TO NEXT PAGE

<table>
<thead>
<tr>
<th>A PINDEX</th>
<th>BIT1 BIT2 BIT3 BIT4</th>
<th>BIT5 BIT6 BIT7</th>
<th>ROT.</th>
<th>TRANS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>0</td>
<td>5</td>
<td>1</td>
<td>1</td>
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</tr>
<tr>
<td>0</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>7</td>
<td>1</td>
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<tr>
<td>0</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* IN THE CASE OF A OR C FAILS, THESE 1-JET ROTATIONS WILL CAUSE TRANSLATIONS WHICH MAY OR MAY NOT COINCIDE WITH THE ACTUAL TRANSLATION COMMANDS, WHICH ARE IGNORED.
FROM PRECEDING PAGE

**Yz Table**

<table>
<thead>
<tr>
<th>LOC</th>
<th>BIT5</th>
<th>BIT4</th>
<th>BIT3</th>
<th>BIT2</th>
<th>BIT1</th>
<th>QUAD</th>
<th>Z-TRANS</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-9</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-1 *</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>+1 *</td>
<td>0</td>
<td>1</td>
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</tr>
<tr>
<td></td>
<td>6</td>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>+1 *</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>-1 *</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*These possibly unwanted torques are handled below.

Add in Z translations:

Bits 9-11 = Net Roll Torque +4.

A = (Quad B-0 Z translation code) from location A of YZ Table, Bits 11-9 and 4-1

TSTEMP = A + RWORO1

Bits 3-1 of NRJETS = (Bits11-9 of TSTEMP) - 4

IF NRJETS = 0 AND TAU IS NOT +10, Z TRANSLATIONS IN THE PRESENCE OF QUADfails WILL CANCEL THE DESIRED ROLL, SO Z TRANSLATIONS MUST BE REJECTED

IF THIS HAPPENS, ASTRONAUT SHOULD CHANGE TO B-D ROLL SO THAT Z TRANSLATIONS CAN BE ACCOMMODATED IN THE PRESENCE OF QUAD FAILS
CALCULATION OF ROLL USING QUADS B AND D

E TRANSLATION COMMANDS

SAME LOGIC AS ABOVE EXCEPT THAT E COMMANDS ARE COMBINED WITH THE ROLL COMMANDS.
BIT 11-9 = NET ROLL + 2.
BIT 4-1 INDICATE JETS SELECTED AS FOLLOWS
BIT 4 → JET 10
BIT 3 → JET 11
BIT 2 → JET 12
BIT 1 → JET 9
FROM PRECEDING PAGE

NO Y TRANS. OR 2

VALUE YNDX?

+Y TRANS

A = A

A = A + 1

SAME LOGIC AS ABOVE, BITS 14-11 = NET ROLL TORQUE +2, BITS 9-5 INDICATE JET COMMANDS AS FOLLOWS:

BIT 8 = JET 14
BIT 7 = JET 15
BIT 6 = JET 16
BIT 5 = JET 13

ADD IN Y TRANS. COMMANDS NET ROLL TORQUE

TSTEMP += A + RWORD1
BITS 3-1 OF NRJETS += (BITS 14-12 OF TSTEMP) * 4

A = AC QUADS Y TRANSLATION CODE FROM LOCATION A OF YZTABLE BITS 14-12 AND 8-5

IS NRJETS > 0?

NO

TAUCHECK

SIGN TAU?

±

±0

BDRAC2

ACCEPT Y TRANSLATION COMMANDS

ROLLTIME SH 9

IF THIS HAPPENS ASTRONAUT SHOULD CHANGE TO AC ROLL SO THAT Y TRANSLATIONS CAN BE ACCOMMODATED IN THE PRESENCE OF QUAD FAILS.

IF NOY Y relax translation end

IF NO Y relax translation end

IF NO Y relax translation end

N0AC Y

ignore Y translations REVISE NUMBER OF JETS.

BET3-1 OF NRJETS += (BITS 14-12 OF RWORD1) - 2

BET3-1 OF NRJETS
FROM PRECEDING PAGE

RWORD 2 IS CALCULATED FOR TRANSLATIONS WITHOUT ROTATIONS. IT WILL REPLACE WORD 1 (WHICH INCLUDES ROTATION COMMANDS) AT THE END OF THE TIME CALCULATED FOR ROTATIONS (BLAST), SO THAT TRANSLATIONS WILL CONTINUE FOR THE FULL .5 SEC.

ACB 02 Y

SIGN ACRBD ?

\[ \leq 0 \] AC ROLL

\[ \geq 0 \] BD ROLL

AC 2 Y

QUAD C FAIL?

QUAD A FAIL?

SIGN RACFAIL ?

A \rightarrow 6

A \rightarrow 10

A \rightarrow 3

ANY AC FAILS?

YES

\[ \text{NO} \]

RWORD 2 \rightarrow +0

NO Y XLNS. WITH AC ROLL AND AC FAILS

A \rightarrow A

A \rightarrow A+1

A \rightarrow A+2

GET RWORD 2 FROM LOCATION A OF Y TABLE BITS 14-12 AND 8-5

LOGIC AS BEFORE, NO ROTATIONS.

NO XLNS

VALUE YNDX ?

LOGIC AS BEFORE, NO ROTATIONS.

2 XLNS

1 XLNS

A \rightarrow A

A \rightarrow A+1

A \rightarrow A+2

VALUE YNDX ?

3, 0

NO XLNS

1 XLNS

A \rightarrow A

A \rightarrow A+1

A \rightarrow A+2

ADD IN ROTATIONS CAUSED BY XLNS. WITH FAILS

NRJETS \rightarrow (BITS 14-12 OF RWORD 2) - 2

DFT \leftarrow DFT + NRJETS(1 - BLAST)

ANY Z TRANSLATION COMMANDS?

YES

ACB 02 Z

Z \rightarrow 0 BD ROLL

SIGN ACRBD ?

\[ \leq 0 \] AC ROLL

BDF 2 Z

\[ \text{NO} \]

SH 11

SH 11

TO NEXT PAGE
FROM PRECEDING PAGE

FOR EXPLANATION OF THIS SECTION, SEE COMMENTS IN PRECEDING SECTION - PITCHTIM.

YAWTIME

20

\( \text{SIGN} \ \text{Tau2?} \)

- \( \rightarrow \)

DFT2+10

YBYPASS

YWORD2+YWORD1

BLAST2=0

T6 SETUP

6H15

NYJETS=NYJETS

YTAUNEG

YTAUPOS

SELECT VALUE OF NJET FROM LOCATION NYJETS OF NJET TABLE

BLAST2=TAU2(NJET)

IS BLAST2<1.5SEC?

NO

ADJ.NMSY

IS BLAST2<1MS?

YES

BLAST2=14MS

YES

YBLASTOK

DFT2=BLAST2(NYJETS)

TAU2=+0

TO NEXT PAGE
BLAST[1] ← 0
BLAST[11] ← 4
BLAST[21] ← 11

THEN
DXCHT 12
ELSE
EXIT

THEN
YES
ELSE
NO
DXCHT 23

THEN
YES
ELSE
NO

EXCHANGE IS DP SO THAT BRANCH INDEX REMAINS WITH APPROPRIATE TIME VALUE AND SERVES AS AN IDENTIFYING LABEL.

BLASTS ARE NOW IN ORDER OF INCREASING MAGNITUDE: BLAST[2], BLAST[1], BLAST[11].
TIME 5 SET TO 60MS AT BEGINNING OF JETSLECT AND HAS BEEN RUNNING SINCE THEN.

ENDJETS
CLEAR BIT 1 OF RCSFLAGS
TS-PHASE <- 0
RESUME

INITIALIZE T6 PROGRAM
RESET FOR PHASE 1.
INITIATED BY UNDERFLOW OF TIME & REGISTER WHENEVER AUTOPILOT IS ON

IF TSTOP COMES DURING TSTOP, TIME6 MAY BE RESET IN TSTOP PROGRAM, IN WHICH CASE WAIT FOR NEW TSTOP

TSTOP START

SAVE IN
BANKRUPT
SAVED IN
QSTOP

TIME6/0 ?

YES

RETURN

IS THIS THE FIRST PASS OF THIS CYCLE?

NO

SET BIT 1 OF RC6-FLAGS CLEARED

YES

NEXT TIME TAKE OTHER BRANCH

CHAN-&
RWD1

CHAN-&
PWD+1

TSTOP

SIGN
BLAST ?

T61
5818

TO

REPLACE

VALUE OF BLAST+?

0

4

T61
5818

REPLACE RWD1 WITH RWD2 IN CHAN 6

REPLACE PWD1 WITH PWD2 IN CHAN 6

REPLACE YWD1 WITH YWD2 IN CHAN 5

PLAY

TO NEXT PAGE

PASS &
EXIT

ZBLAST

A=+ BLAST BLAST++0

TAKE BRANCH THROUGH REPLACE NEXT TIME

TO NEXT PAGE
FROM PRECEDING PAGE

BLAST = 1

T611

SIGN BLAST1

- 10

REPLACE1

WHAT BRANCH INDEX?

VALUE OF BLAST1+1?

0

REPLACER
TURN OFF ROLL JETS (CHAN 6) SH19

REPLACE P
TURN OFF PITCH JETS (CHAN 6) SH19

REPLACE Y
TURN OFF YAW JETS (CHAN 2) SH19

II

CEASE APPROPRIATE ROTATIONS, TRANSLATIONS CONTINUE

BLAST1+1

T612

UNLIKELY BRANCH

- RESUME

(PASS 5 EXIT)

+ SIGN BLAST2

PASS 3 EXIT

REPLACE2

WHAT BRANCH INDEX?

VALUE OF BLAST2+1?

0

REPLACER
TURN OFF ROLL JETS SH19

REPLACE P
TURN OFF PITCH JETS SH19

REPLACE Y
TURN OFF YAW JETS SH19

II

CEASE APPROPRIATE ROTATIONS, TRANSLATIONS CONTINUE

BLAST2+1

RESUME

PASS 4 EXIT

SINCE TERM V PORT IS NOT ENABLED, THIS IS NOMINALLY THE LAST PASS, BUT IF ANOTHER TERMINAL SHOULD OCCUR, THIS WILL ENSURE THAT NOTHING IS DISTURBED.

ALL ROTATIONS CEASED, ONLY TRANSLATIONS CONTINUE.

FROM PRECEDING PAGE

BLAST = 1

T611

SIGN BLAST1?

10

REPLACE1

WHAT BRANCH INDEX?

VALUE OF BLAST1+1?

4

REPLACER
TURN OFF ROLL JETS (CHAN 6) SH19

REPLACE P
TURN OFF PITCH JETS (CHAN 6) SH19

REPLACE Y
TURN OFF YAW JETS (CHAN 2) SH19

II

CEASE APPROPRIATE ROTATIONS, TRANSLATIONS CONTINUE

BLAST1+1

T612

UNLIKELY BRANCH

- RESUME

(PASS 5 EXIT)

+ SIGN BLAST2

PASS 3 EXIT

REPLACE2

WHAT BRANCH INDEX?

VALUE OF BLAST2+1?

0

REPLACER
TURN OFF ROLL JETS SH19

REPLACE P
TURN OFF PITCH JETS SH19

REPLACE Y
TURN OFF YAW JETS SH19

II

CEASE APPROPRIATE ROTATIONS, TRANSLATIONS CONTINUE

BLAST2+1

RESUME

PASS 4 EXIT

SINCE TERM V PORT IS NOT ENABLED, THIS IS NOMINALLY THE LAST PASS, BUT IF ANOTHER TERMINAL SHOULD OCCUR, THIS WILL ENSURE THAT NOTHING IS DISTURBED.

ALL ROTATIONS CEASED, ONLY TRANSLATIONS CONTINUE.
SUBROUTINES FOR T6START

REPLACER

CHANGE RW0RD2

RETURN VIA Q

REPLACE RW0RD1 WITH RW0RD2,
which in effect stops the roll
jets, while Y and Z translations continue.

REPLACE PW0RD1 WITH PW0RD2
( stops pitch jets, X translations continue )

RETURN VIA Q

REPLACE YW0RD1 WITH YW0RD2
( stops yaw jets, X translations continue )

RETURN VIA Q
TVC START-UP AND EXECUTIVE ROUTINES

TVCDAPON  Sh. 2
TVCINIT1  Sh. 2
DAPINIT  Sh. 9
TVCEXEC  Sh. 10
REDOTVC  Sh. 18
ENABL2  Sh. 20
CMDSOUT  Sh. 21
EXRSTRT  Sh. 22
MASSPROP  Sh. 23
PRESWTCH  Sh. 28
SWICHOVR  Sh. 28
LOADCOEF  Sh. 31
Called by T5RUPT from SPSON Allows at least .42 sec for SPS thrust buildup.
Inputs set by SPSON
TVCPHASE=1
TVCEXPHS=0
Flagword 6 bits 15, 14 =10

Save return values for RESUME

Reset 52 temporary DAP variables:
- OMEGAYC\_D - OMEGAZ\_C\_D
- OMEGAX\_B\_D - OMEGAZ\_B\_D
- PTMP1-PTMP6
- YTMP1-YTMP6
- ROLLFIRE-ROLLWORD
- TEMREG-STROKER
- PERRB-YERRB
- DELPBAR-DELYBAR
- PDELOFF-YDELOFF

Next Sheet
From Preceding Sheet

MASSPROP
  Update TVC Mass Parameters
  Sh. 23

\[ \text{TENMDOT} \leftarrow 1000 \cdot \text{EMDOT} \]
\[ \text{MASSTMP} \leftarrow \text{CSMMASS} - \text{TENMDOT} \]

Is bit 14 DAPDATRI set?

No, LM off

CNTR \leftarrow 0
COEFFADR \leftarrow \text{GENADR(CSMN10)}

Load filter coefficients
Sh. 31

KTLX/I \leftarrow \text{EKTLX/I}

Next Sheet

Yes, LM on

Switch for LM-on/LM-off

CNTR \leftarrow 1
COEFFADR \leftarrow \text{GENADR(HBN10)}

Load filter coefficients
Sh. 31

KTLX/I \leftarrow \text{EKTLX/I} +1

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<tr>
<th>DRAWN</th>
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<th>APOLLO GUIDANCE AND NAVIGATION</th>
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</table>

Mass decrement for 1st 10 secs
= 1000 x SPS
fuel flow rate in kg/sec @2+3
TENMDOT in kg/216

Expected vehicle mass after first 10 secs of burn in kg @216.
From Preceding Sheet

S40.15
Update gain parameters
FC-2370

TVCINIT2

Inputs: IXX (from MASSPROP Routine) in kg·m²/s²
KTLX (above); IAVG/LHX (from MASSPROP Routine) in sec²

Output: 1/CONACC = 1/ACC in sec²/rev
VARK = DAP filter gain factor @ 2+²·10⁸

0, LM off
CNTR

1, LM on
CNTR in sec @ 2+13

KPRIMEDT ← 00002
T5TVCUT ← 37777-KPRIMEDT+00001

KPRIMEDT in csec @ 2+14
(used as intermediate quantity here)

Clear SWTOVER

KPRIMEDT_D ← KPRIMEDT·EKPRIME
REPFRAC ← EREPFRAC
CNTR ← 00005
STRKTIME ← 1
VCNTR ← 19D
V97VCNTR ← 19D

KPRIMEDT_D ← KPRIMEDT·EKPRIME +1
REPFRAC ← EREPFRAC + 1
CNTR ← 00000
STRKTIME ← 1
VCNTR ← 19D
V97VCNTR ← 18D

KPRIMEDT_D: Steering gain parameter at T/8
REPFRAC: Gain for TMC loop @ 2+²
CNTR: Time of one-shot TMC correction in sec @ 2+13

STRKTIME: Inhibit stroke test
VCNTR: Update counter in sec @ 2+13
V97VCNTR: in sec @ 2+13

Next Sheet
From Preceding Sheet

**TVCINIT3**

**PDELOFF**
**FCMD**
**DELPBAR** ← **PACTOFF**

Store initial pitch trim value in revs @ 2° x 1.07975

**YDELOFF**
**YCMD**
**DELYBAR** ← **YACTOFF**

Store initial YAW trim value in revs @ 2° x 1.07975

**ATTINIT**

Next Sheet
Bypass error needle initialization if LM is attached.

From Preceding Sheet

- Is bit 13 DAPDATTR1 set?
  - Yes, CSM Alone
    - Is \(|\text{ERRBTMP} + 1| < 1.5\,\text{deg}\)?
      - Yes
        - \(\text{ERRBTMP} + 1 \leftarrow -1.5\,\text{deg}\)
    - \(\text{ERRBTMP} + 1 \leftarrow +1.5\,\text{deg}\)
    - \(\text{ERRBTMP} \leftarrow -1.5\,\text{deg}\)
    - \(\text{ERRBTMP} \leftarrow +1.5\,\text{deg}\)
  - No
    - Is \(|\text{ERRBTMP}| < 1.5\,\text{deg}\)?
      - Yes
        - \(\text{PERRB} \leftarrow \text{ERRBTMP}\)
        - \(\text{YERRB} \leftarrow \text{ERRBTMP} + 1\)
      - No
        - \(\text{ERRBTMP} \leftarrow -1.5\,\text{deg}\)
        - \(\text{ERRBTMP} \leftarrow +1.5\,\text{deg}\)

ERRBTMP contains (-ERRORY) in revs @ 2⁻¹
ERRBTMP +1 contains (-ERRORZ) in revs @ 2⁻¹
from P40 at SPSON

Next Sheet
From Preceding Sheet

NEEDLEIN

Set bit 3 of RCSFLAGS via IBNKCALL

NEEDLER

Attitude error display

FC-2370

TVCINIT4

TVCYPHASE

OGANOW ← CDUX

Set for initialization pass of NEEDLER

Initialize attitude-error display

Set up TVC restart to return to TVCINIT4

Initial roll angle for roll autopilot in revs @ 2

Next Sheet
From Preceding Sheet

Test
bit 13
channel 11
Set, engine is on, update mass
Clear, engine off

CSMMASS[MASSTMP

in kg @2^16

TVCEXEC
WAITLIST
Task in 0.5 sec
Sh. 10
Schedule TVCEXC in 0.5 sec

DAPINIT
T5RUPT
Task in 40 or 80 msec
Sh. 9
Schedule DAPINIT in one DAP sample period
40 msec for CSM
80 msec for CSM/LM

ENDTVCIN

RESUME
DAPINIT

BANKRUPT ← L

\[
\text{TIME5} ← 2 \cdot T5TVDT - 37777_8 - 00001_8
\]

Set TIME5 clock (in csec @ 2^{14}) to overflow in
40 msec LM-off,
80 msec LM-on

PITCHDAP

Schedule via T5RUPT

NOQRM

\[
\text{PCDUYPST} ← \text{CDUY}
\]

\[
\text{PCDUZPST} ← \text{CDUZ}
\]

Get past CDUY and CDUZ values for
PITCHDAP in revs @ 2^{-1}
TVCEXEC

TVC DAP on? (FLAGWRD6 bits 15, 14)

Yes

TVCEXEC

WAITLIST Task in 0.5 sec

Sh. 10

ROLLPREP

OGAPAST ← OGANOW
OGANOW ← CDUX

AK ← OGAD - OGANOW
OGAERR ← -1/2 AK

Next Sheet

TVCEXECUTION scheduled as WAITLIST task every 0.5 seconds

Terminate

Schedule self-perpetuating task every 0.5 sec

Update present & past outer gimbal angle values for ROLLDAP in revs @ 2-1

Roll error in revs @ 2^-1
"Fly from" roll error in revs @ 2^0
Schedule ROLLDAP, allowing time for completion of TVCEXECUTIVE, processing of other interrupts, etc.

Inputs: AK, AK1, AK2 - roll, pitch, and yaw error in revs @ 2^-1
Output: FDAO error needle motion
From Preceding Sheet

TVCEXPHS 2

End of phase 1

1 SHOTCHK

Test update counter

Do repetitive e.g. corrector (one-shot already done)

< 0

Test CNTR

Do one-shot correction = 0

CNTRMP

CNTR - 1

Decrement update counter (in sec @ 2^13)

Set up TVCEXECUTIVE restart entry point to return to CNTRCOPY

No

Is REFRAC > 0?

Yes

RECPCHK

TVCEXFIN

Sh. 17

@2^0

TEMPDAP +1 ← REFRAC

TVCEXPHS 4

CORSETUP

Sh. 15

Next Sheet

Set up TVCEXECUTIVE restart entry point to return to CORSETUP

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<table>
<thead>
<tr>
<th>DRAWN</th>
<th>PRGMR</th>
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APOLLO GUIDANCE AND NAVIGATION

TVC Start-up and Executive Routines

COLOSSUS 2D

DOCUMENT NO. FC-2430

REV 1

SHEET 13 OF 36
From Preceding Sheet

1SHOTOK

Is bit 13 of channel 11 on? No SPS engine-off terminate

Yes

Do not allow switchover during engine shutdown tailoff

TVCEXPHS ← 3

Set up TVCEXECUTIVE restart entry point to return to TEMPSET (TVCEXPHS=3)

TEMPSET

TEMPDAP +1 ← FCORFRAC

Load c.g. correction factor

@2 +2 for CSM/LM

@2 +3 for CSM (deg/deg)

TVCEXPHS ← 4

Set up TVCEXECUTIVE entry point to return to CORSETUP (TVCEXPHS=4)

Next Sheet
From Preceding Sheet

\[ \text{CORSETUP} \]

\[ \text{Is bit 13 of DAPDATR1 set?} \]

\[ \begin{align*}
\text{No, LM-on:} & \quad \text{TEMPDAP} \leftarrow \text{TEMPDAP +1} \\
\text{Yes, LM-off:} & \quad \text{TEMPDAP} \leftarrow 2(\text{TEMPDAP +1})
\end{align*} \]

\[ \text{CNTRTMP} \leftarrow -1 \quad \text{One-shot TMC correction finished} \]

\[ \text{CG, CORR} \]

\[ \begin{align*}
PACTTMP_D & \leftarrow \text{PDELOFF + } 4 \left[ \text{TEMPDAP (DELDPBAR-PDELOFF)} \right] \\
YACTTMP_D & \leftarrow \text{YDELOFF + } 4 \left[ \text{TEMPDAP (DELYBAR-YDELOFF)} \right]
\end{align*} \]

\[ \begin{align*}
P\text{ Pitch TMC loop correction in revs at } & \quad @^20 \times 1.07975 \\
Y\text{ Yaw TMC loop correction in revs at } & \quad @^20 \times 1.07975
\end{align*} \]

Next Sheet

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APOLLO GUIDANCE AND NAVIGATION

TVC Start-up and Executive Routines

COLOSSUS 2D

FC-2430

REV 1

SHEET 15 OF 36
Set up TVCEXECUTIVE restart entry point to return to CORCOPY +1 (TVCEXPHS = 5)

Store new values for pitch TMC loop correction in revs @ 2^0 x 1.07975

Store new values for yaw TMC loop correction in revs @ 2^0 x 1.07975

Set up TVCEXECUTIVE restart entry point to return to CNTRCOPY (TVCEXPHS = 6)
From Preceding Sheet

\[ \text{CNTRCOPY} \]

\[ \text{CNTR} \leftarrow \text{CNTRTMP} \quad \text{Update TMC loop counter in sec@ } 2^{413} \]

\[ \text{TVCEXFIN} \]

\[ \text{TVCEXPFS} \leftarrow 0 \quad \text{Reset TVCEXECUTIVE restart entry point - TVCEXECUTIVE finished} \]

\[ \text{TASKOVER} \quad \text{End of TVCEXECUTIVE} \]
TVC Restart Package

REDOTVC

Called by T5RUPT from RESTART

BANKRUPT

Save return values for RESUME

QUIRUPT

EXECPHS

Is TVCEXPHS = 0 ?

Yes

No

TVCEXECUTIVE task

Schedule EXRSTRT to waitlist task in 90 msec.

Sh. 22

Next Sheet

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APOLLO GUIDANCE AND NAVIGATION

TVC Start-up and Executive Routines

COLOSSUS 2D

DOCUMENT NO.
FC-2430

REV 1

SHEET 18 OF 36
Restart occurred during non-critical DAP computation

Are bits 15, 1 of TVCPhase set?

0, 0: TVCPhase = +2 or +0

Restart occurred during TVC DAP initialization

1, 0 or 1, 1: TVCPhase = -1 or -2

Is bit 2 of TVCPhase set?

Yes, = -2: Restart was in V46 switchover logic

TRIM/CMD

PCMD ← PACTOFF

YCMD ← YACTOFF

PCOPY +1: Complete pitch copy cycle

FC 2440

FINCOPY

Test TVCPhase

+1

+3

Complete yaw copy cycle

FC 2440

Next Sh
From Preceding Sheet

ENABL1

Set bits 8 and 11 of channel 12. TVC enable and optics-DAC enable (connects output of CDU optics error counters to SPS Gimbal Servo Amplifiers)

ENABL2

T5RUPT task in 60 msec. Sh. 20

Schedule ENABL2 task

RESUME

ENABL2

Called by T5RUPT from ENABL1

BANKRUPT ← L

Save return value for NOQRSM

Set bit 2 of channel 12. Enable CDU optics error counters

CMDSOUT

T5RUPT task in 20 msec. Sh. 21

Schedule CMDSOUT task

NOQRSM

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APOLLO GUIDANCE AND NAVIGATION

TVC Start-up and Executive Routines

COLUSSUS 217

DOCUMENT NO. FC-2430

REV 1

SHEET 20 OF 36

DRAWN

PRGMR

ANALYST

DOCMR

APPR'D

12/05/78

1/5/78

1/5/78

1/5/78
Called by T5RUPT from ENABL2

Save return values for RESUME

Load output counters with most recent actuator commands (adding -0 insures that the command will never be +0) in revs \(2^0 \times 1.07975\)

Release output counters

-2, repeat switch-over

-1, do a complete restart

TVC pitch: \(-0 + PCMD\)

TVC yaw: \(-0 + YCMD\)

Set bits 11, 12 in channel 14

PHSCHK2

Next Sheet

Start of TVC initialization sequence
From Preceding Sheet

**CHKSTRK**

Is STROKER = 0?

No, stroke test in progress

Yes

TSTINITJ

via POSTJUMP

STROKER ← +0

Disable stroke test. New verb 68 entry is required to repeat stroke test.

**TVCINIT4**

Final part of TVC initialization sequence

**EXRSTRT**

Go to location whose address is contained in location TVCEXPHS of TVCEXADR table

<table>
<thead>
<tr>
<th>TVCEXPHS Value</th>
<th>Entry Point</th>
<th>Sheet No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EXECCOPY +1</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>lSHOTCHK</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>TEMPSET</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>CORSETUP</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>CORCOPY +1</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>CNTRCOPY</td>
<td>17</td>
</tr>
</tbody>
</table>
Update vehicle mass properties IX X, IAVG, and IAVG/TLX as functions of new mass estimates.

Set up ten passes, using PHI333 as a counter @ 2 +14.

MASSPROP

PHI333 ← +9D

LEMTEST

LM attached
No

LM not attached
Yes

Is bit 13 of DAPDATR1 set?

LEMYES

VARSTO(#PHI333)
INTVAL(#PHI333) + 
\[ \frac{1}{4} \cdot [\text{LEMMASS} \cdot \text{SLOPEVAL} (#PHI333)] \]

LEMNO

VARSTO(#PHI333)
NOLEMVAL(#PHI333)

STOINST

Is PHI333 = 0?

No

Yes

Initialization done?

Next Sheet

PHI333 ← PHI333 - 1
From Preceding Sheet

DXTEST

Is bit 15 DAPDATR1 set?

No

LM is attached, with ascent and descent stages

Yes, LM is attached with ascent stage only (no descent stage)

VARSTO +1 ← [VARSTO +1] + [VARSTO +8D]

VARSTO +2 ← [VARSTO +2] + [VARSTO +9D]

VARSTO +7 ← DXITFIX + [VARSTO +7]

Decrement IAVG breakpoint value in kg m²/240
Decrement IAVG/TLX breakpoint value
Change IAVG/TLX slope for CSMMASS less than breakpoint weight in sec²/kg@2-12

FIXCW

PHI333 ← 2
PSI333 ← 2

CSM breakpoint mass (NEGBPW=-33956 lbs)

TEMP333 ← 2 [CSMMASS + NEGBPW]

Is TEMP333 ≤ 0?

Yes

Modify index to pick up slopes for case where CSMMASS > breakpoint mass (33956 lbs)

No

Next Sheet

---

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TVC Start-up and Executive Routines

COLOSSUS2D

DOCUMENT NO.
FC-2430

DRAWN
10/30/79

PRGMR

ANALST

DOCMR

APPR'D

REV 1

SHEET 24 OF 36`
From Preceding Sheet

PEGGY

IXX(#PSI333) ← VARSTO(#PSI333) + 2 · TEMP333 · VARST5(#PHI333)

Is PSI333 = 0?

No

BOKKEP2

PSI333 ← PSI333 - 1
PHI333 ← PHI333 - 1 sign (PHI333)

Decrement Index PSI333
Decrement magnitude of Index PHI333

Yes

Have all 3 parameters been computed?

Is bit 14 of DAPDA TR1 set?

No, CSM alone

Yes, include LM mass in weight update

WEIGHT/G ← CSMMASS

WEIGHT/G ← CSMMASS + LEMMASS

in kg @ 2^16

ENDMASSP

Return via Q

The actual computation (see next sheet for explanation)
### MASSPROP COMPUTATION:

**Step 1:** Compute coefficients on basis of LM mass \( m_{LM} \)

<table>
<thead>
<tr>
<th>NO LM</th>
<th>LM ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_0 = 25445 \text{ (kg} \cdot \text{m}^2) )</td>
<td>( v_0 = 26850 \text{ (kg} \cdot \text{m}^2) + 1.96307 \text{ (m}^2) \cdot m_{LM} \text{ (kg)} )</td>
</tr>
<tr>
<td>( v_1 = 87450 \text{ (kg} \cdot \text{m}^2) )</td>
<td>( v_1 = 127518 \text{ (kg} \cdot \text{m}^2) + 27.5774 \text{ (m}^2) \cdot m_{LM} \text{ (kg)} )</td>
</tr>
<tr>
<td>( v_2 = 30715 \text{ (sec}^2 )</td>
<td>( v_2 = 54059 \text{ (sec}^2 ) + 2.3548 \cdot 10^{-5} \text{ (sec}^2 \text{kg} ) \cdot m_{LM} \text{ (kg)} )</td>
</tr>
<tr>
<td>( v_3 = 1.22877 \cdot 10^{-5} \text{ (sec}^2 \text{ kg}) )</td>
<td>( v_3 = 1.53964 \cdot 10^{-4} \text{ (sec}^2 \text{ kg}) + 2.1777 \cdot 10^{-9} \text{ (sec}^2 \text{ kg}^2 ) \cdot m_{LM} \text{ (kg)} )</td>
</tr>
<tr>
<td>( v_4 = 1.6096 \text{ (m}^2 )</td>
<td>( v_4 = -742923 \text{ (m}^2 + 1.044 \cdot 10^{-3} \text{ (m}^2 \text{ kg}) \cdot m_{LM} \text{ (kg)} )</td>
</tr>
<tr>
<td>( v_5 = 1.54 \text{ (m}^2 )</td>
<td>( v_5 = 1.5398 \text{ (m}^2 ) + 0 )</td>
</tr>
<tr>
<td>( v_6 = 7.77177 \text{ (m}^2 )</td>
<td>( v_6 = 9.68 \text{ (m}^2) + 2.21068 \cdot 10^{-3} \text{ (m}^2 \text{ kg}) \cdot m_{LM} \text{ (kg)} )</td>
</tr>
<tr>
<td>( v_7 = 3.46458 \cdot 10^{-5} \text{ (sec}^2 \text{ kg}) )</td>
<td>( v_7 = 6.47625 \cdot 10^{-4} \text{ (sec}^2 \text{ kg}) + 1.5166 \cdot 10^{-9} \text{ (sec}^2 \text{ kg}^2 ) \cdot m_{LM} \text{ (kg)} )</td>
</tr>
<tr>
<td>( v_8 ) computed, but not meaningful and not used</td>
<td>( v_8 = -27228 \text{ (kg} \cdot \text{m}^2) - 1.284 \text{ (m}^2 \text{ kg}) \cdot m_{LM} \text{ (kg)} )</td>
</tr>
<tr>
<td>( v_9 = -206476 \text{ (sec}^2 \text{ kg}) + 2.10 \cdot 10^{-5} \text{ (sec}^2 \text{ kg}^2 ) \cdot m_{LM} \text{ (kg)} )</td>
<td></td>
</tr>
</tbody>
</table>

**Step 2:** If LM ascent stage only attached, modify \( v_1, v_2, \) and \( v_7 \):

\[
\begin{align*}
 v_1 &= v_1 \text{ (kg} \cdot \text{m}^2) + v_8 \text{ (kg} \cdot \text{m}^2) \\
 v_2 &= v_2 \text{ (sec}^2 \) + v_9 \text{ (sec}^2 \) \\
 v_7 &= v_7 \text{ (sec}^2 \text{ kg}) - 1.88275 \cdot 10^{-5} \text{ (sec}^2 \text{ kg})
\end{align*}
\]
Step 3: Compute $\text{IXX (kg} \cdot \text{m}^2)$, $\text{IAVG (kg} \cdot \text{m}^2)$, and $\text{IAVG/TLX (sec}^2)$:

<table>
<thead>
<tr>
<th>CSM weight $\approx$ 33956 lbs (15402.17 kg)</th>
<th>CSM weight $\approx$ 33956 lbs (15402.17 kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{IXX} = v_0 (\text{kg} \cdot \text{m}^2) + v_5 (\text{m}^2) (m_{\text{CSM}} - 15402.17) (\text{kg})$</td>
<td>$\text{IXX} = v_0 (\text{kg} \cdot \text{m}^2) + v_5 (\text{m}^2) (m_{\text{CSM}} - 15402.17) (\text{kg})$</td>
</tr>
<tr>
<td>$\text{IAVG} = v_1 (\text{kg} \cdot \text{m}^2) + v_6 (\text{m}^2) (m_{\text{CSM}} - 15402.17) (\text{kg})$</td>
<td>$\text{IAVG} = v_1 (\text{kg} \cdot \text{m}^2) + v_4 (\text{m}^2) (m_{\text{CSM}} - 15402.17) (\text{kg})$</td>
</tr>
<tr>
<td>$\text{IAVG/TLX} = v_2 (\text{sec}^2) + v_7 (\text{sec}^2 / \text{kg}) (m_{\text{CSM}} - 15402.17) (\text{kg})$</td>
<td>$\text{IAVG/TLX} = v_2 (\text{sec}^2) + v_3 (\text{sec}^2 / \text{kg}) (m_{\text{CSM}} - 15402.17) (\text{kg})$</td>
</tr>
</tbody>
</table>

In the above equations:

- $\text{IXX}$ = Moment of inertia about vehicle X-axis in kg $\cdot$ m$^2$ @ 2$^{20}$
- $\text{IAVG}$ = Average moment of inertia about Y and Z axes in kg $\cdot$ m$^2$ @ 2$^{20}$
- $\text{IAVG/TLX}$ = IAVG/(vehicle gain) in sec$^2$ @ 2
- $m_{\text{CSM}}$ = CSM mass in kg @ 2$^{16}$
- $m_{\text{LM}}$ = LM mass in kg @ 2$^{16}$

Note: vehicle mass is keyed in in pounds, but internally, mass is stored in kg.
CSM/LM V46 Switchover from high-bandwidth filter to low-bandwidth filter.

Switch to low-bandwidth CSM/LM DAP Sh. 28 via POSTJUMP

Allow interrupts, and terminate verb 46

Inhibit interrupts

Save current phase number for restart

Set up to restart SWICHOVR at the next location

Restart entry point

Save Q in RTRNLOC

Next Sheet
Zero:
\( \text{PTMP1}_D - \text{PTMP6}_D \)
\( \text{YTMP1}_D - \text{YTMP6}_D \)

Zero temporaries for pitch and yaw filters.

Indicate switchover has occurred

Set bit 15
\( \text{FLAGWRD 9} \)

Set gain to low-bandwidth pad loaded value in \( \text{sec}^{-2} \times 1.07975 \) for CSM/LM

Input:
\( \text{KTLX/1} \) in \( \text{sec}^{-2} \times 1.07975 \) for CSM/LM

Compute variable gain (VARK)
\( \text{FC-2370} \)

Output:
VARK \( \times 1.07975 \) for CSM/LM

\( \text{S40.15 +7} \)

Input:
KTLX/1 in \( \text{sec}^{-2} \times 1.07975 \) for CSM/LM

I_avg/TLX in \( \text{sec}^2 \times 2^{+2} \)

Output:
VARK \( \times 2^{+2} \times 1.07975 \) for CSM/LM

Next Sheet
From Preceding Sheet

KPRIMDT ← FKPRIMDT
REPFRAC ← REPFRAC
PDELOFF_D ← DELPBAR
YDELOFF_D ← DELYBAR
COEFFADR ← GENADR(LBN10)

Steering gain @ π/8
TMC loop gain @ 2^{+2}
Trim estimates are set to defilter values in revs @ 2^0 x 1.07975
Input to LOADCOEF routine to select low bandwidth coefficients

LOADCOEF
Load filter coefficients
Sh. 31

TVC PHASE ← PHASE TMF

Return via RTRNLOC

Load N10 thru N10 +14D for low-bandwidth DAP filter

Restore phase number

Return to caller
Load TVC DAP filter coefficients

- GENADR (LBN10)
  CSM/LM low bandwidth

COEFFADR

- GENADR (CSMN10)
  (CSM only)

=GENADR (HBN10)
  CSM/LM high bandwidth
  (COEFFS in ERASABLE)

N10 ← .99999
N10 +1 ← - .3285
N10 +2 ← - .3301
N10 +3 ← - .9101
N10 +4 ← + .8460
N10 +5 ← + .03125
N10 +6 ← 0
N10 +7 ← 0
N10 +8 ← - .9101
N10 +9 ← + .8460
N10 +10 ← + .5000
N10 +11 ← - .47115
N10 +12 ← + .4749
N10 +13 ← - .9558
N10 +14 ← + .9372

N10 ← HBN10
N10 +1 ← HBN10 +1
N10 +2 ← HBN10 +2
N10 +3 ← HBN10 +3
N10 +4 ← HBN10 +4
N10 +5 ← HBN10 +5
N10 +6 ← HBN10 +6
N10 +7 ← HBN10 +7
N10 +8 ← HBN10 +8
N10 +9 ← HBN10 +9
N10 +10 ← HBN10 +10
N10 +11 ← HBN10 +11
N10 +12 ← HBN10 +12
N10 +13 ← HBN10 +13
N10 +14 ← HBN10 +14

Note: In the CSM only case, the 3\textsuperscript{rd} cascade of the filter is not used. The coefficients are in fact initialized but to meaningless values which are not used. As of the released version of COLOSSUS 2, these values are as follows:

N10 +10 ← + .99999
N10 +11 ← - .3285
N10 +12 ← - .3301
N10 +13 ← - .9101
N10 +14 ← + .8460

MIT INSTRUMENTATION LAB
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APOLLO GUIDANCE AND NAVIGATION

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TVC Start-up and Executive Routines

DOCUMENT NO.

COLOSSUS 2D

FC-2430

REV 1

SHEET 31 OF 36
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
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</thead>
<tbody>
<tr>
<td>S40.15</td>
<td>2370</td>
<td>Updates gain parameters</td>
<td>Sh. 4, 12, 29</td>
</tr>
<tr>
<td>NEEDLER</td>
<td>2370</td>
<td>Attitude error display</td>
<td>Sh. 7, 11</td>
</tr>
<tr>
<td>ROLLDAP</td>
<td>2460</td>
<td>TVC roll control</td>
<td>Sh. 11</td>
</tr>
<tr>
<td>PCOPY</td>
<td>2440</td>
<td>Pitch copy</td>
<td>Sh. 19</td>
</tr>
<tr>
<td>YCOPY</td>
<td>2440</td>
<td>Yaw copy</td>
<td>Sh. 19</td>
</tr>
</tbody>
</table>

### FLAGS

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<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWTOVER Flagword 9 bit 15</td>
<td>Switchover has occurred</td>
<td>Switchover has not occurred</td>
<td>Sh. 29</td>
<td>Sh. 3</td>
<td></td>
</tr>
<tr>
<td>RCSFLAGS bit 3</td>
<td>Initialize needle drive</td>
<td>Needle drive initialized</td>
<td>Sh. 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAPBIT1 Flagword 6 bit 15</td>
<td>Both set: Saturn DAP controls vehicle attitude. DAPBIT1=1\ TVC DAPBIT2=0 DAP controls vehicle attitude</td>
<td>DAPBIT1=0 TVC DAPBIT2=1 DAP controls vehicle attitude</td>
<td>Sh. 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAPBIT2 Flagword 6 bit 14</td>
<td>Both clear: no DAP control of vehicle attitude</td>
<td></td>
<td></td>
<td></td>
<td>Sh. 10</td>
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<tr>
<td>AGC TAG</td>
<td>GSOP Symbol</td>
<td>Meaning</td>
<td>Engineering Units</td>
<td>AGC Units</td>
<td>AGC Scaling</td>
</tr>
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<td>-------------</td>
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<td>-------------------</td>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>AK</td>
<td></td>
<td>Roll attitude error</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>CSMMASS</td>
<td>m_CSM</td>
<td>CSM mass (updated version of MASSTMP)</td>
<td>kg</td>
<td>kg</td>
<td>2⁺16</td>
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<tr>
<td>DLPBAR</td>
<td></td>
<td>∫rate error used for offset (pitch)</td>
<td>deg</td>
<td>rev</td>
<td>2⁰ x 1.07975</td>
</tr>
<tr>
<td>DELYBAR</td>
<td></td>
<td>∫rate error used for offset (yaw)</td>
<td>deg</td>
<td>rev</td>
<td>2⁰ x 1.07975</td>
</tr>
<tr>
<td>DXITFIX</td>
<td></td>
<td>Increments VARSTO +7 if LM-on APS-only configuration is specified</td>
<td>sec²/kg</td>
<td>sec²/kg</td>
<td>2⁻¹²</td>
</tr>
<tr>
<td>EMDOT</td>
<td></td>
<td>SPS propellant flow rate</td>
<td>kg/sec</td>
<td>kg/sec</td>
<td>2⁺³</td>
</tr>
<tr>
<td>ERRBTMP ⊥</td>
<td>θ_e</td>
<td>Updated version of PERRB ⊥ and YERRB ⊥ (body attitude error)</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>IAVG</td>
<td></td>
<td>Average moment of inertia about Y-and Z-axes</td>
<td>kg·m²</td>
<td>kg·m²</td>
<td>2⁺²⁰</td>
</tr>
<tr>
<td>IAVG/TLX</td>
<td></td>
<td>IAVG/&quot;thrust moment&quot;</td>
<td>sec²</td>
<td>sec²</td>
<td>2⁺²</td>
</tr>
<tr>
<td>IXX</td>
<td></td>
<td>Moment of inertia about vehicle X-axis</td>
<td>kg·m²</td>
<td>kg·m²</td>
<td>2⁺²⁰</td>
</tr>
<tr>
<td>KPRIMEDT</td>
<td></td>
<td>Steering gain parameter</td>
<td>(rev/DAP cycle)/rad</td>
<td>sec⁻²</td>
<td>π/8</td>
</tr>
<tr>
<td>KTLX/I</td>
<td></td>
<td>Updated version of EKTLX/I (see payloads)</td>
<td>sec⁻²</td>
<td>sec⁻²</td>
<td>2⁺² x 1.07975 for CSM/LM 2⁺⁴ x 1.07975 for CSM</td>
</tr>
<tr>
<td>LEMMASS</td>
<td>m_LM</td>
<td>LM mass</td>
<td>kg</td>
<td>kg</td>
<td>2⁺¹⁶</td>
</tr>
<tr>
<td>MASSTMP</td>
<td></td>
<td>Expected or estimated vehicle mass</td>
<td>kg</td>
<td>kg</td>
<td>2⁺¹⁶</td>
</tr>
<tr>
<td>OGAD</td>
<td></td>
<td>Value of desired outer gimbal angle (CDUX)</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>OGERR</td>
<td></td>
<td>&quot;Fly from&quot; roll error</td>
<td>deg</td>
<td>rev</td>
<td>2⁰</td>
</tr>
</tbody>
</table>

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**MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.**

**APOLLO GUIDANCE AND NAVIGATION**

<table>
<thead>
<tr>
<th>DRAWN</th>
<th>D. E. Stoloff</th>
<th>1/4/70</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRGMR</td>
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<td>ANALYST</td>
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<tr>
<td>DOCMR</td>
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<tr>
<td>APPR'D</td>
<td>REV 1</td>
<td>SHEET 33 OF 36</td>
</tr>
<tr>
<td>COLOSSUS 2D</td>
<td>DOCUMENT NO. FC-2430</td>
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</tr>
<tr>
<td>AGC TAG</td>
<td>GSOP Symbol</td>
<td>Meaning</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>---------</td>
</tr>
<tr>
<td>OGANOW</td>
<td></td>
<td>Roll angle for roll autopilot; updated version of CDUX</td>
</tr>
<tr>
<td>OGPAST</td>
<td></td>
<td>previous value of OGANOW (past CDUX value)</td>
</tr>
<tr>
<td>PACTTMPD</td>
<td></td>
<td>Pitch trim-correction (temporary storage)</td>
</tr>
<tr>
<td>PCDUYPST</td>
<td></td>
<td>Past CDUY value (pitch)</td>
</tr>
<tr>
<td>PCDUZPST</td>
<td></td>
<td>Past CDUZ value (pitch)</td>
</tr>
<tr>
<td>PCMD</td>
<td></td>
<td>Incremental pitch actuator command</td>
</tr>
<tr>
<td>PDELOFFD</td>
<td></td>
<td>Trim correction (pitch)</td>
</tr>
<tr>
<td>PERRBD</td>
<td></td>
<td>Body attitude error (pitch)</td>
</tr>
<tr>
<td>REPFRAC</td>
<td>$K_{cg}$</td>
<td>Updated version of EREPFRAC (see pad-loads)</td>
</tr>
<tr>
<td>TEMP333</td>
<td></td>
<td>Mass (temporary)</td>
</tr>
<tr>
<td>TENMDOT</td>
<td></td>
<td>Amount of mass lost due to 10 seconds of SPS firing</td>
</tr>
<tr>
<td>TVCPITCH</td>
<td></td>
<td>Actuator command (pitch)</td>
</tr>
<tr>
<td>TVCYAW</td>
<td></td>
<td>Actuator command (yaw)</td>
</tr>
<tr>
<td>VARK</td>
<td>VARK or $K_{z}$</td>
<td>Gain for pitch and yaw channels</td>
</tr>
<tr>
<td>VARSTO +1</td>
<td></td>
<td>IAVG breakpoint value</td>
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<td>AGC TAG</td>
<td>GSOP Symbol</td>
<td>Meaning</td>
</tr>
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<td>---------</td>
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<tr>
<td>VARSTO +2</td>
<td></td>
<td>IAVG/TLX breakpoint value</td>
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<tr>
<td>VARSTO +7</td>
<td></td>
<td>IAVG/TLX slope for CSMMASS less than breakpoint value</td>
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<td>VCNTR</td>
<td></td>
<td>Updated version of VCNTRTMP</td>
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<td>VCNTRTMP</td>
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<td>Counter</td>
</tr>
<tr>
<td>V97VCNTR</td>
<td></td>
<td>Updated version of VCNTRTMP</td>
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<tr>
<td>WEIGHT/G</td>
<td></td>
<td>Updated version of CSMMASS and LMMASS</td>
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<tr>
<td>YACTTMP_D</td>
<td></td>
<td>Yaw trim-correction (temporary storage)</td>
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<tr>
<td>YCMD</td>
<td></td>
<td>Incremental yaw actuator command</td>
</tr>
<tr>
<td>YDELOFF_D</td>
<td></td>
<td>Trim correction (yaw)</td>
</tr>
<tr>
<td>YERRB_D</td>
<td></td>
<td>Body attitude error (yaw)</td>
</tr>
</tbody>
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**FIXED LOCATION USED**

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCORFRAC</td>
<td></td>
<td>c.g. correction factor</td>
<td>dimension-less</td>
<td>dimension-less</td>
<td>CSM/LM 2^+2</td>
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</tbody>
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**APOLLO GUIDANCE AND NAVIGATION**

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TVC Start-up and Executive Routines

COLOSSUS 2D

DOCUMENT NO. FC-2430

REV 1

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<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
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<tbody>
<tr>
<td>EKPRIME</td>
<td></td>
<td>&quot;Steer law gain&quot; for LM-off</td>
<td>deg/sec/deg</td>
<td>revs/csec/rad</td>
<td>$\pi/8$</td>
</tr>
<tr>
<td>EKTLX/I_D</td>
<td></td>
<td>K: DAP gain factor</td>
<td>sec$^{-2}$</td>
<td>sec$^{-2}$</td>
<td>CSM/LM: $2^{+2} \times 1.07975$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T: thrust</td>
<td></td>
<td></td>
<td>CSM: $2^{+4} \times 1.07975$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LX: distance from engine gimbal point to c.g. of vehicle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>I: average of moments of inertia about pitch and yaw axes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EREPFRAC</td>
<td></td>
<td>Gain for TMC loop (LM-off)</td>
<td></td>
<td>2$^{+2}$</td>
<td></td>
</tr>
<tr>
<td>EREPFRAC</td>
<td>+1</td>
<td>Gain for TMC loop (LM-on)</td>
<td></td>
<td>2$^{+2}$</td>
<td></td>
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<tr>
<td>PACTOFF</td>
<td></td>
<td>Actuator trim value (pitch)</td>
<td>deg</td>
<td>rev</td>
<td>$2^{0} \times 1.07975$</td>
</tr>
<tr>
<td>YACTOFF</td>
<td></td>
<td>Actuator trim value (yaw)</td>
<td>deg</td>
<td>rev</td>
<td>$2^{0} \times 1.07975$</td>
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TVC DAP

PITCHDAP  Sh. 2
FWDFLTR  Sh. 4
PRECOMP  Sh. 7
PCOPY  Sh. 8
YAWDAP  Sh. 9
YCOPY  Sh. 13
ERRORLIM  Sh. 15
RLIMTEST  Sh. 15
ACTLIM  Sh. 16

Special convention:

\[ TVCDT = \begin{cases} 
80 \text{ msec for CSM/LM} \\
40 \text{ msec for CSM}
\end{cases} \]
**PITCHDAP**

Entered via T5RUPT with BBANK contents in L

**BANKRUPT** ← L

**QRUPT** ← Q

Save BBANK and Q of interrupted program

---

**YAWDAP**

Schedule in T5TVCDA

ms via T5RUPT

Sh. 9

Schedule YAWDAP to run:

- In 40 ms for CSM/LM
- In 20 ms for CSM

---

**PSTROKER**

Is STROKER ≠ 0?

Yes, start/continue stroke test

No

**HACK**

FC-2450

---

**PCDUADOTS**

A ← PCDUYPST - CDUY

PCDUYPST ← CDUY

Past CDUY value - present CDUY value
All in revs @ 2⁻¹

---

**RLIMTEST**

Limit Rate

Sh. 15

Input: A, Δ CDU in revs @ 2⁻¹

Output: A, unchanged if ≤ 2.33 deg
0 otherwise

---

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APOLLO GUIDANCE AND NAVIGATION

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<td>APPR'D</td>
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DOCUMENT NO.
From Preceding Sheet

\[ \text{MCDUYDOT} \leftarrow A \]

\[ A \leftarrow \text{PCDUZPST} - \text{CDUZ} \]

\[ \text{PCDUZPST} \leftarrow \text{CDUZ} \]

RLIMTEST
Limit Rate
Sh. 15

\[ \text{MCDUZDOT} \leftarrow A \]

\[ \text{Store } \frac{1}{2^{-1} \times \text{TVCDO}} \]

\[ \text{CDUZ in revs/sec } \]

\[ \frac{1}{2^{-1} \times \text{TVCDO}} \]

\[ \text{Store } \frac{1}{2^{-1} \times \text{TVCDO}} \]

\[ \text{CDUZ in revs/sec } \]

\[ \frac{1}{2^{-1} \times \text{TVCDO}} \]

\[ \text{PINTEGRLE} \]

\[ \frac{\omega_y}{-\frac{\cos \phi \cdot \cos \gamma \cdot \dot{\theta} + \sin \phi \cdot \dot{\gamma}}{2 \left( \sin \text{CDUX} \cdot \text{MCDUZDOT} \right) + \text{OMEGAYC}} - \frac{1}{4 \left( \text{COSCDUX} \cdot \text{COSCDUZ} \cdot \text{MCDUYDOT} \right) - 2 \left( \sin \text{CDUX} \cdot \text{MCDUZDOT} \right)} \]

\[ \text{OMEGAYD} \]

\[ \text{Measured rate in revs/sec } \]

\[ \frac{1}{2^{-1} \times \text{TVCDO}} \]

\[ \text{COSCDUX, COSCDUZ,} \]

\[ \sin \text{CDUX } 2^{+1} \]

\[ \text{ERRBTMPD} \leftarrow \text{PERRB} + \text{OMEGAYC} - \text{OMEGAYD} \]

\[ \text{Attitude error = rate error (} \omega \text{yc = command rate) in revs } 2^{-1} \]

Next Sheet

\[ \text{MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.} \]

\[ \text{APOLLO GUIDANCE AND NAVIGATION} \]

\[ \text{TVC DAP} \]

\[ \text{COLOSSUS 2D} \]

\[ \text{FC-2440} \]

\[ \text{DRAWN} \]

\[ \text{PRGMR} \]

\[ \text{ANALYST} \]

\[ \text{DOCMT} \]

\[ \text{APPRD} \]

\[ \text{REV 1} \]

\[ \text{SHEET 3 OF 19} \]
To avoid overflow, attitude error is limited to ±45°.

Set up storage locations for forward filter in revs $\leq 2^{-1}$.

DAP1 D ← N10 - ERRBTMP D + TMP1 D

Next Sheet
From Preceding Sheet

2DAPCAS

\[ \text{DAP}_2^D \leftarrow [\text{N10} + 5] \cdot \text{DAP}_1^D + \text{TMP}_3^D \] \hspace{1cm} \text{in revs}\@ \ 2^{-1}

\[ \text{Is Bit 14 of DAPDATR1 set?} \]

No, LM off

\[ \text{DAP}_3^D \leftarrow 4 \cdot \text{DAP}_2^D \] \hspace{1cm} \text{multiply by 4 for scaling. In revs } \ 2^{-3}

Yes, LM on

\[ \text{DAP}_3^D \leftarrow [\text{N10} + 10D] \cdot \text{DAP}_2^D + \text{TMP}_5^D \]

3DAPCAS

Apply the variable gain \text{VARK}, and change sign of output.

\[ \text{CMDTMP}_D \leftarrow 2 \cdot \text{VARK} \cdot (-\text{DAP}_3^D) \] \hspace{1cm} \text{multiply by 2 for scaling. In revs } \ 2^0 \times 1.07975

\[ \text{VARK} \hspace{1cm} \ 2^{-4} \times 1.07975 \text{ for CSM} \]

\[ \ 2^{-2} \times 1.07975 \text{ for CSM/LM} \]

Return via Q

Next Sheet
From Preceding Sheet

OFFSET

CMDTEMP_D ← CMDTEMP_D + PDELOFF_D

Add in trim correction in revs $2^0 \times 1.07975$

PACLIM

ACTLIM
Limit CMDTEMP to ±6 deg
Sh. 16

POUT

TVCPITCH ← TVCPITCH + CMDTEMP - PCMD

(Add incremental pitch command) in revs @ $2^0 \times 1.07975$

Set bit 11
Ch. 14

Release TVCPITCH counts to actuators

PPRECOMP

\[
\begin{align*}
\text{TMP2}_D & \leftarrow \text{PTMP2}_D \\
\text{TMP4}_D & \leftarrow \text{PTMP4}_D \\
\text{TMP6}_D & \leftarrow \text{PTMP6}_D
\end{align*}
\]

Set up filter storage for precomputation in revs @ $2^{-1}$

Next Sheet

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

TVC DAP

<table>
<thead>
<tr>
<th>DRAWN</th>
<th>2/1965</th>
<th>COLOSSUS 2D</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRGMR</td>
<td>2/1965</td>
<td>FC-2440</td>
</tr>
<tr>
<td>ANALST</td>
<td>2/1965</td>
<td></td>
</tr>
<tr>
<td>DOCMTR</td>
<td>2/1965</td>
<td></td>
</tr>
<tr>
<td>APPROD</td>
<td>2/1965</td>
<td></td>
</tr>
<tr>
<td>REV</td>
<td>1</td>
<td>SHEET 6 OF 10</td>
</tr>
<tr>
<td>DOCUMENT NO.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
From Preceding Sheet

PRECOMBP

\[
\begin{align*}
\text{TMP}_1 &\leftarrow 2([N10 +1] \cdot \text{ERRB}_D - [N10 +3] \cdot \text{DAP}_D) + \text{TMP}_2_D \\
\text{TMP}_2_D &\leftarrow [N10 +2] \cdot \text{ERRB}_D - [N10 +4] \cdot \text{DAP}_1_D \\
\end{align*}
\]

2CASFLTR

\[
\begin{align*}
\text{TMP}_3 &\leftarrow 2([N10 +6] \cdot \text{DAP}_1_D - [N10 +8] \cdot \text{DAP}_2_D) + \text{TMP}_4_D \\
\text{TMP}_4_D &\leftarrow [N10 +7] \cdot \text{DAP}_1_D - [N10 +9] \cdot \text{DAP}_2_D \\
\end{align*}
\]

Is bit 13 of DAPDTR1 set?

Yes, LM off

3CASFLTR

\[
\begin{align*}
\text{TMP}_5 &\leftarrow 2([N10 +11] \cdot \text{DAP}_2_D - [N10 +13] \cdot \text{DAP}_3_D) + \text{TMP}_6_D \\
\text{TMP}_5_D &\leftarrow [N10 +12] \cdot \text{DAP}_2_D - [N10 +14] \cdot \text{DAP}_3_D \\
\end{align*}
\]

No, LM on

Return via Q

Next Sheet

Filter computation for the next pass

1st Cascade

in revs @ 2^{-1}

2nd Cascade

in revs @ 2^{-1}

3rd Cascade

(omitted if LM is off)

in revs @ 2^{-1}
From Preceding Sheet

DELBARP

\[ \text{DELBRTMP}_D \leftarrow E(-AT) \cdot \text{DELPBAR}_D + [1 - E(-AT)] \cdot \text{CMDTMP} \]

in revs \( @ 2^{-1} \)

PCOPYCYC

PCOPY

TVCPHASE \( \leftarrow 1 \)

TVC restarts to redo PCOPY on restart

PTMP\(_1\)_D \leftarrow TMP\(_1\)_D

PTMP\(_2\)_D \leftarrow TMP\(_2\)_D

PTMP\(_3\)_D \leftarrow TMP\(_3\)_D

PTMP\(_4\)_D \leftarrow TMP\(_4\)_D

PTMP\(_5\)_D \leftarrow TMP\(_5\)_D

PTMP\(_6\)_D \leftarrow TMP\(_6\)_D

PMISC

AK\(_1\)_S \leftarrow ERRBTMP\(_S\)

PERRD\(_D\) \leftarrow ERRBTMP\(_D\)

PCMD\(_S\) \leftarrow CMDTMP\(_S\)

DELPBAR\(_D\) \leftarrow DELBRTMP\(_D\)

Next Sheet
From Preceding Sheet

TVCPHASE

PCOPY no longer needs
restart protection

Return via Q

PDAPEND

RESUME

YAWDAP

Entered via TSRUPT with BBANK contents in L

BANKRUPT

Save BBANK and Q of
interrupted program

L

QRUPT

Q

PITCHDAP

Schedule YAWDAP to run:
In 40 ms for CSM/LM
In 20 ms for CSM

Schedule in
TSTVCDT
ms via
TSRUPT
Sh. 2

Next Sheet
From Preceding Sheet

YSTROKER

Is STROKER ≠ ±0?

Yes, start/continue stroke test

YCDUDOTS

A ← YCDUYPST - CDUY
YCDUYPST ← CDUY

In revs @ 2⁻¹

RLIMTEST

Limit rate
Sh. 15

Input:
A, ΔCDU in revs @ 2⁻¹

Output:
A, unchanged if < 2.33 deg.
0 otherwise

MCDUYPDOT ← A

Store ΔCDUY in revs/sec @ 2⁻¹ × TVCDT

A ← YCDUZPST - CDUZ
YCDUZPST ← CDUZ

In revs @ 2⁻¹

RLIMTEST

Limit rate
Sh. 15

MCDUZDOT ← A

Store ΔCDUZ in revs/sec @ 2⁻¹ × TVCDT

Next Sheet

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

TVC DAP

COLOSSUS 2D

DOCUMENT NO.
FC-2440

REV 1
\[ \omega_z = -\cos \psi \cdot \sin \phi \cdot \dot{\theta} + \cos \phi \cdot \dot{\psi} \]

\[ \Omega_{\text{DE}} = 4(\cos \phi \cdot \sin \psi \cdot \dot{\phi} \cdot \dot{\psi}) - 2(\cos \phi \cdot \dot{\phi} \cdot \dot{\theta}) \]

Measured rate in revs/sec @ 2^{-1} TVC \dot{c}T

\[ \theta_e = \theta_e \cdot z^{-1} + \omega_{2C} - \omega_z \]

\[ \text{ERRB}_{\text{DE}} = \text{YERRB} + \Omega_{\text{DE}} - \Omega_{\text{DE}} \]

Attitude error = rate error; \( \omega_{2C} \) = command rate in revs @ 2^{-1}

YERRORLIM

ERRORLIM

Limit attitude error

Sh. 15

YFORWARD

\[ \text{TMP1}_{\text{D}} \leftarrow \text{YTMP1}_{\text{D}} \]
\[ \text{TMP3}_{\text{D}} \leftarrow \text{YTMP3}_{\text{D}} \]
\[ \text{TMP5}_{\text{D}} \leftarrow \text{YTMP5}_{\text{D}} \]

Set up storage locations for forward filter in revs@ 2^{-1}

Next Sheet
From Preceding Sheet:

**FWDFLTR**

Filter computation for present output

- ERRBTMP\(_D\) in revs/sec @ \(2^{-1} \times TVCTR\)
- TMP1\(_D\), TMP3\(_D\), TMP5\(_D\) in revs @ \(2^{-1}\)
- (TMP5\(_D\) not used if LM off)

Output:
- CMDTMP\(_D\) (actuator command) = present output including variable gain package (VARK) @ \(2^0 \times 1.07975\)
  - DAP\(_1\)_\(_D\) (1st cascade)
  - DAP\(_2\)_\(_D\) (2nd cascade)
  - DAP\(_3\)_\(_D\) (3rd cascade, omitted if LM off)

Add in trim correction in revs @ \(2^0 \times 1.07975\)

**YOFFSET**

**YACLIM**

**ACTLIM**

Limit CMDTMP\(_D\) to +6 deg

**YOUT**

**TVCYAW**

\[ TVCYAW \leftarrow TVCYAW + CMDTMP - YCMD \]

Add incremental yaw command in revs @ \(2^0 \times 1.07975\)

Set Bit 12 Ch. 14

Release TVCYAW counts to actuator

Next Sheet
From Preceding Sheet

YPRECOMP

\[
\begin{align*}
\text{Set up filter storage for precomputation in revs @ } 2^{-1}
\end{align*}
\]

\[
\begin{align*}
\text{Input:} & \quad \text{ERRBTMP}_D \text{ in revs/sec @ } 2^{-1} x \frac{1}{TVCDT} \\
& \quad \text{DAP1}_D, \text{ DAP2}_D, \text{ DAP3}_D \text{ in revs @ } 2^{-1} \\
& \quad \text{(DAP3}_D \text{ not used if LM off)} \\
\text{Output:} & \quad \text{TMP1}_D, \text{ TMP2}_D, \text{ TMP3}_D, \text{ TMP4}_D, \text{ TMP5}_D. \\
& \quad \text{TMP6}_D \text{ in revs @ } 2^{-1} \\
& \quad \text{(TMP5}_D \text{ and TMP6}_D \text{ omitted if LM off)}
\end{align*}
\]

PRECOMP

Filter computation for the next pass
Sh. 7

DELBARY

\[
\text{DELBRTMP}_D \leftarrow E(-AT) \cdot \text{DELYBAR}_D + \left[ 1 - E(-AT) \right] \cdot \text{CMDTMP}
\]

In revs @ \(2^{-1}\)

YCOPYCYC

YCOPY

TVCPHASE

\[
\text{TVC restarts to redo YCOPY on restart}
\]

Next Sheet

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APOLLO GUIDANCE AND NAVIGATION

TVC DAP

| DRAWN | (dirty) |
|-------|
| PROGR | (dirty) |
| ANALST | |
| DOCMR | (dirty) |
| APPR'D | (dirty) |

COLOSSUS 2D

DOCUMENT NO.
FC-2440

REV 1

SHEET 13 OF 19
From Preceding Sheet

YTMP1D ← TMP1D
YTMP2D ← TMP2D
YTMP3D ← TMP3D
YTMP4D ← TMP4D
YTMP5D ← TMP5D
YTMP6D ← TMP6D

YMISC

AK2S ← ERRBTMP S
YERRB D ← ERRBTMP D
YCMPS ← CMDTMP S
DELYBARD ← DELBRTMP D

TVC > PHASE

← 0

Return via

Q

YDAPEND

RESUME

In revs @ 2⁻¹

In revs @ 2⁻¹

In revs @ 2⁰ x 1.07975

In revs @ 2⁻¹

YCOPY no longer needs restart protection
ERRORLIM

Limit ERRBTEMP to ±45°

Is

\[ |\text{ERRBTEMP}| < 45° \] ?

- Yes, return

\[ \text{Sign ERRBTEMP} \]

\[ \text{ERRBTEMP} \leftarrow -45° \]

\[ \text{ERRBTEMP} \leftarrow +45° \]

Return via Q

RLIMTEST

Is

\[ |A| < 2.33 \text{ deg} \] ?

- No

\[ A \leftarrow +0 \]

Yes

Return via Q

If \(|A| > 2.33 \text{ deg}\), set to zero. This filters out spurious pulses in the more significant bits of the CDU.
ACTLIM

Is \(|\text{CMDTMP} + 1| > 1/2\)?

Yes

Round CMDTMP to single precision

No

CMDTMP ← CMDTMP + (1 bit) SGN(CMDTMP)

Is \(|\text{CMDTMP}| < 6 \text{ deg}\)?

No

Yes, O.K.

Sign CMDTMP?

- CMDTMP ← $-6^\circ$

+ CMDTMP ← $+6^\circ$

Return via Q
SUBROUTINE CALLED WHICH IS FLOWED ON OTHER FLOW CHART

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>HACK</td>
<td>FC-2450</td>
<td>Stroke test</td>
<td>Sh. 2, 10</td>
</tr>
</tbody>
</table>

ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
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<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>AK₁S</td>
<td></td>
<td>Attitude error for pitch needles</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>AK₂S</td>
<td></td>
<td>Attitude error for yaw needles</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>CMDTMP&lt;sub&gt;D&lt;/sub&gt;</td>
<td></td>
<td>Actuator command; updated version of PCMD&lt;sub&gt;S&lt;/sub&gt; and of YCMD&lt;sub&gt;S&lt;/sub&gt;</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹ × 1.07975</td>
</tr>
<tr>
<td>DELBRTMP&lt;sub&gt;D&lt;/sub&gt;</td>
<td></td>
<td>Updated version of DELPBAR&lt;sub&gt;D&lt;/sub&gt; and of DELYBAR&lt;sub&gt;D&lt;/sub&gt; (below)</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>DELPBAR&lt;sub&gt;D&lt;/sub&gt;</td>
<td></td>
<td>Output of pitch DELFILTER (filtered engine command signal)</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>DELYBAR&lt;sub&gt;D&lt;/sub&gt;</td>
<td></td>
<td>Output of yaw DELFILTER (filtered engine command signal)</td>
<td>deg</td>
<td>rev</td>
<td>2⁻¹</td>
</tr>
</tbody>
</table>
### ERASABLE LOCATIONS USED (CONTINUED)

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<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
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</thead>
<tbody>
<tr>
<td>ERRBTMP_D</td>
<td>θe</td>
<td>Updated version of AK1_S and AK2_S (above) and of PERRB_D and YERRB_D (below)</td>
<td>deg</td>
<td>rev</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>MCDU DOT</td>
<td></td>
<td>Past CDU value - present CDU value</td>
<td>deg/sec</td>
<td>rev/sec</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt; × TVCDT</td>
</tr>
<tr>
<td>MCDUZDOT</td>
<td></td>
<td>Past CDUZ value - present CDUZ value</td>
<td>deg/sec</td>
<td>rev/sec</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt; × TVCDT</td>
</tr>
<tr>
<td>OMEGAYB_D</td>
<td>ω_y</td>
<td>Measured body - axis pitch rate</td>
<td>rad/sec</td>
<td>rev/sec</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt; × TVCDT</td>
</tr>
<tr>
<td>OMEGAYC</td>
<td></td>
<td>Pitch body rate command</td>
<td>rad/sec</td>
<td>rev/sec</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt; × TVCDT</td>
</tr>
<tr>
<td>OMEGAZB_D</td>
<td>ω_z</td>
<td>Measured body - axis yaw rate</td>
<td>rad/sec</td>
<td>rev/sec</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt; × TVCDT</td>
</tr>
<tr>
<td>OMEGAZC</td>
<td></td>
<td>Yaw body rate command</td>
<td>rad/sec</td>
<td>rev/sec</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt; × TVCDT</td>
</tr>
<tr>
<td>PCDU YPST</td>
<td>PDELOFF</td>
<td>Past CDU value (pitch)</td>
<td>deg</td>
<td>rev</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>PCDUZPST</td>
<td></td>
<td>Past CDUZ value (pitch)</td>
<td>deg</td>
<td>rev</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>PCMD</td>
<td></td>
<td>Incremental pitch engine command</td>
<td>deg</td>
<td>rev</td>
<td>2&lt;sup&gt;0&lt;/sup&gt; × 1.07975</td>
</tr>
<tr>
<td>PDELOFF_D</td>
<td></td>
<td>Engine trim correction (pitch)</td>
<td>deg</td>
<td>rev</td>
<td>2&lt;sup&gt;0&lt;/sup&gt; × 1.07975</td>
</tr>
<tr>
<td>PERRB_D</td>
<td></td>
<td>Body attitude error (pitch)</td>
<td>deg</td>
<td>rev</td>
<td>2&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>TVCPITCH</td>
<td></td>
<td>Pitch engine command error counter</td>
<td>deg</td>
<td>rev</td>
<td>2&lt;sup&gt;0&lt;/sup&gt; × 1.07975</td>
</tr>
</tbody>
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<tbody>
<tr>
<td>TVCYAW</td>
<td>VARK</td>
<td>Yaw engine command error counter</td>
<td>deg/deg</td>
<td>rev/rev</td>
<td>$2^0 \times 1.07975$</td>
</tr>
<tr>
<td>VARK</td>
<td>VARK</td>
<td>Gain for pitch and yaw channels</td>
<td>deg/deg</td>
<td>rev/rev</td>
<td></td>
</tr>
<tr>
<td>YCDUYPST</td>
<td>YCDUZPST</td>
<td>Past CDUY value (yaw)</td>
<td>deg</td>
<td>rev</td>
<td>For CSM $2^4 \times 1.07975$</td>
</tr>
<tr>
<td>YCMD</td>
<td>YDELOFF_D</td>
<td>Past CDUZ value (yaw)</td>
<td>deg</td>
<td>rev</td>
<td>For CSM/LM $2^2 \times 1.07975$</td>
</tr>
<tr>
<td>YDELOFF</td>
<td></td>
<td>Incremental yaw engine command</td>
<td>deg</td>
<td>rev</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>YERRB_D</td>
<td></td>
<td>Engine trim correction (yaw)</td>
<td>deg</td>
<td>rev</td>
<td>$2^0 \times 1.07975$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Body attitude error (yaw)</td>
<td>deg</td>
<td>rev</td>
<td>$2^{-1}$</td>
</tr>
</tbody>
</table>
VERB 68 STROKE TEST SETUP ENABLE

ARE BIT 15,14 FLAG = 0.0
YES
NO: TVC NOT ON, CAN'T DO STROKE TEST

STRTSTI
NOVAC JOB PRIORITY 50
SCHEDULE STRTSTI TO INITIALIZE STROKE TEST
8.1

ENDEX
RELEASE EXT VERB DISPLAY

GOFIN

STRTSTI

TSTINIT
LOAD PARAMETERS TO DEFINE 1ST WAVEFORM.

CADDY ← 10D
N ← 10D
REVS ← 5
ORD ← 4

RETURN VIA G

INHIBIT INTERRUPTS

IS BIT 14 DAPDATI SET?

YES: CSM/LM

BEGIN STROKE TEST ON NEXT PASS THROUGH TWCDAP.
(STROKER is the PULSE SIZE, NOMINAL VALUE IS LOADING AS ESTROKER)

NO

STROKER ← ESTROKER

ENDOFJOB
ROLLDAP

GORATE

(OGANOW - Ogapast) 2 +

DURATION

ROLL OAP SWITCHING AND JET SELECT LOGIC

JETS ARE STILL ON

NO

IS ROLLFIRE = 0?

YES

JETS ARE NOW OFF

IS TEMREG = 0?

NO

TEMPREG ← 0

YES

JETS HAVE BEEN OFF AT LEAST 1/2 SECOND (OK TO FIRE AGAIN)

ROLLOGIC

TEMPREG ← DB - OGRATE²(1/CONACC)

IS OGRATE > 0?

NO

SGNRT ← -1

YES

SGNRT ← +1

SIGN OF OGRATE

NEXT SHEET

RATE ESTIMATER. SIMPLE FIRST-ORDER BACK-DIFFERENCE SCALED AT 2⁻⁶ REV/SEC. (SAMPLE INTERVAL IS 1/2 SEC.)

JETS MUST BE OFF AT LEAST 1/2 SECOND BEFORE A NEW FIRING

WAIT 1/2

TASKOVER

END OF ROLLDAP TASK

RIGHT HAND SWITCH PARABOLA, X INTERCEPT IN REV'S @ 2° OGRATE IN REV/SEC @ 2⁻⁶ 1/CONACC IN SEC²/REV @ 2⁻⁹
CALCULATE DISTANCE FROM SWITCH PARABOLA (SGNRT PICKS UP RIGHT OR LEFT HAND SWITCH PARABOLA)

DELOGA IN REV @ 2°

FROM PRECEDING SHEET

DELOGA ← OGA - (SGNRT)(TEMREG)

IS OEOGA > 0?

YES

I ← (CA)

NO

I ← (CS)

IS SGNRT ≥ 0?

YES

(-E, +DELOGA)

YES, (+E, -DELOGA)

NOT REGIONS I, (I')

(OARATE ← OARATE SGN(OEOGA)

NO

(-E, -DELOGA)

REGIONS I, (I')

SIGNS OF OARATE AND DELOGA ARE DIFFERENT - [OARATE] HERE

SIGNS OF OARATE AND OEOGA AGREE (BOTH + OR -)

ROLL ON "ABOVE" THE SWITCH LINES (OUTSIDE OF COAST REGION)

NEXT SHEET

CONSTANT FOR INDEXING;
(CS) = 400000; (CA) = 30000
WILL BE USED TO GENERATE EITHER CLEAR-AND-SUBTRACT OR CLEAR-AND-ADD INSTRUCTION

NOTE:
1. PHASE PLANE REGIONS REFER TO FIGURE 3.3.14 OF FORTHCOMING COLOSSUS II GP SECTION 3 R-577 (REV 4 OR 5)

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

DRAWN
A. J. Fogg
APPROVED
J. B. McManus
FROM PRECEDING SHEET

SAME POLARITY, SO CONTINUE FIRING +
MOREROLL

DIFFERENT POLARITY, SO TERMINATE THE CURRENT FIRING, WAITING 1/2 SECOND AT LEAST BEFORE NEXT FIRING.

A
±O

NEWROLL
NO PAST TORQUE, SO MUST START NEW FIRING NOW.
CHECK FOR MINIMUM IMPULSE (0.14 SEC.)

IS /TEMREG/ ≥ TMAXFIRE ?
YES

NO TOO SHORT, DON'T FIRE

MAXTFIRE
CHECK FOR FIRING LONGER THAN TMAXFIRE (2.5 SEC.) AND APPLY LIMIT.

A

ATTEMPT TO TEMREG (1/TMAXFIRE) \( (1/TMAXFIRE = D/14(TMAXFIRE)^{-1}) \) (BITS LOST BY SCALING, CHANGE THE ACTUAL VALUE TESTED AGAINST TO 2.5 SEC. THIS DOES NOT MATERIALLY AFFECT THE OPERATION OF THE PROGRAM.

USE = MAXIMUM

A
±O

USE + MAXIMUM

TEMREG ← -TMAXFIRE

TEMREG ← TMAXFIRE

LESS THAN TMAXFIRE, OK.

NEXT SHEET
Jet firing times for operating points in regions I (x') and II (x'') are computed for the intersection of the control parabola and the straight-line switch boundary, regardless of whether or not the minimum boundary is intersected. This may cause up to 1/2 second of firing into the coast region. Fuel expenditure is small, and performance is still stable and convergent (no extra passes across the deadband are required), so the simplification is reasonable.

ROLL AUTOPILOT
FC-2460

John A. Davis  April 61
## Major Subroutines and External Entry Points

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**ENCLOSED ARE REPLACEMENT SHEETS TO UPDATE THE COLOSSUS II A FLOW-CHART FC-2530, REV. 1, TO THE COLOSSUS II C FLOWCHART FC-2530, REV. 2. CHANGED SHEETS ARE: 2, 31, 34.**
PO1 - PO2
PRELAUNCH SERVICE INITIALIZATION PROGRAM

IMU PERFORMANCE TESTS

GTSCPSS1
OPTIMUM GYROCOMPASSING, SYSTEM TEST ENTRY POINT CALLED HERE VIA VERB STE01E

GTSCPSS

FLAGW001, BIT12 P00 ALLOWED?
YES

POOD001
FC-14D

NO

POODOO

NOEOPOI SET?

GTSCPSSA

GEQODPI ← 1
LEAD IN FOR COMPASS

1/PIPADT ← 1/PIPADT
IMU COMPENSATION (.5 SEC)

NXXTBNW

NEXT SHEET

TURN ON prog. ALARM Light,
STORE ALARM CODE 21521 IN A
FAILREG REGISTER, TERMINATE
CURRENT MAJOR MODE, AND
DO POO.
LENGTH OF HORIZ. GYRO DRIFT TEST = 640 SEC
COMPASS IS A 5 SEC LOOP
NAVIG. BASE ORIENTATION CODE = +0
(NORMAL SPACECRAFT ORIENTATION)

INSTALL NEW AND OLD LAUNCH AZIMUTH

SET UP GYROCOMPASSING

SET UP ROUTINE ZEROING TO SET
THE 18 REGISTERS STARTING AT XSM
TO 0

INPUT: ZERONX1 = (NO. OF REGISTERS TO
BE ZEROED) - 1
A = ADDRESS OF FIRST REGISTER TO
BE ZEROED

OUTPUT: XSMV = 0V
YSMV = 0V
ZSMV = 0V

OUTPUT: XSMV = 0, COS(NEWAZ1), SIN(NEWAZ1)
YSMV = 0, SIN(NEWAZ1), COS(NEWAZ1)
ZSMV = -1, +0
ALL UNIT VECTORS @ 2°.

GYROCOMPASSING

SWITCH TO IMU ZERO MODE
SET UP JOB TO DRIVE STABLE
MEMBER TO ZERO GIMBAL ANGLES;
INITIALIZE IMU-COU COUNTERS CDUX,
CDUY AND CDUZ.
FROM PRECEDING SHEET

IMU_SSLG
WAIT UNTIL IMU HAS FINISHED DRIVING TO ZERO
SH26

IMUBACK

NXCTR ← +0
TORQDNS ← +0
TORQDNSX+1 ← +0

NBPOSPL

ZERODNX ← DEC17
A ← GENADR(XNB)

ZEROING

ZERO NAV BASE COORDS
SH26

XNB ← 1
YNB + 2_o ← SIN(ARYMUTH) / 0
ZNB + 4_o ← COS(ARYMUTH) / 0
ZNBO + 2_o ← -COS(ARYMUTH) / 0

CHECKMM

MM = 03?
SH27

FC-2030

CALCGBA

CALCULATE FINAL
GIMBAL ANGLES
FOR DESIRED ALIGNMENT
FC-2260

IMU/COARDS

COARSE ALIGN
IMU TO
THETA/D'S
FC-2210

NEXT SHEET

PUT THIS JOB TO SLEEP UNTIL IMU MODIFYING FINISHED

COARSE ALIGN THE IMU TO ZERO GIMBAL ANGLES

INITIALIZE DISPLAY TEMPS
TORQDNS = HORIZONTAL DRIFT TEST

SET UP AZIMUTH AND VERTICAL IN NAVIGATION BASE COORDINATES

SET UP INPUTS TO ZEROING

INPUTS: ZERODNX = (NO. OF REGISTERS TO BE ZEROED) - 1.
A = ADDRESS OF FIRST REGISTER
OUTPUT: XNB = 0; YNB = 0; ZNB = 0

SET NAV BASE COORDS TO LAUNCH ALIGNMENT:

XNB = 1, 0, 0
YNB = 0, SIN(ARYMUTH), COS(ARYMUTH)
ZNB = 0, -COS(ARYMUTH), SIN(ARYMUTH)
ALL UNIT VECTORS @ 2°.

INPUT: XNB, YNB, ZNB, N.B. COORDS
OUTPUT: THETA0, THETA0+1, THETA0+2, DESIRED GIMBAL ANGLES.
TORQUE PLATFORM TO CORRECT LEVELING ERROR IN PREPARATION FOR MEASURING VERTICAL PIPA OUTPUT PULSE RATE

COURSE ALIGN MODE

NO

EARTH

TORQUE GYROB
BY EARTH RATE ANGLES

SH39

INITIALIZE
ZERO VERTICAL PIPA COUNTER

DTAPL = DATA STORAGE COUNTER

DTAPL + 4 = OVERFLOW IN PIPA COUNTER

CHECK

OBTAIN CONTENTS OF VERTICAL PIPA COUNTER AND TIME

SH39

INHIBIT INTERUPTS

PIPASASK

TWIGOLE IN 2 CSEC

SH 7

SCHEDULE PIPASASK TO RUN IN .02 SEC

ENDJOB

NEXT SHEET
PIPATASK runs 12 times at 5.12 sec intervals, so that PIPJOB runs for about 15 minutes.

RESCHEDULE PIPATASK IN 5.12 SEC.

FROM PRECEDING SHEET

PIPATASK

LENGTHOTH

LENGTHOTH - 1

YES

LENGTHOTH = 0?

NO

PIPATASK

SCHEDULE AS TASK IN 5.12 SEC

SH72

STARTPIP

PIPJDB

FINDVAC JOB WITH PRIORTY 20

SH32

TASKOVER
```
PIPGJOB

IS NOXCTR ≥ 0 ?

YES

EARTHROT
TORQUE GYROS
BY EARTH RATE ANGLES
SH 38

EXCEPT FOR THE LAST PASS, THIS IS THE END OF PIPJOB

IS LENGTHOT ≥ 0 ?

YES

RESULTCT ← FIVE

YES

WAIT FOR A PIPA PULSE IN X PIP, THEN CATCH TIME AND RETURN

CHECKS
OBTAIN CONTENTS
OF VERTICAL PIPA
COUNTER AND TIME
SH 39

DATAPL + 40 ← DATAPL + 40 - DATAPL

LAST PIPA READING - FIRST PIPA READING = NUMBER OF PIPA PULSES OVER ELAPSED TIME

YES

DATEPL + 60 ≥ DATEPL + 60 ?

NO

OVERFFFFX
FIX UP OVERFLOW
SH 36

NEXT SHEET
```
FROM PRECEDING SHEET

PONG

EARTH RATE
COMPENSATION

EARTHR

ERVECTOR ← +0
ERVECTOR+1 ← +0

ALLOW ONLY SOUTH GYRO
EARTH RATE COMPENSATION

GUESS

CALCULATES THE VERTICAL COMPONENT OF EARTH RATE

TORQNDX ← POSMAX
TORQNDX+1 ← POSMAX

STORE POSMAX TO INDICATE VERTICAL ORIFIT TEST

LOSVEG ← COUX

SAVES INITIAL CDU ANGLE

ESTIMS

SHΩ
ESTIM

GROUP 5.7
SET UP RESTARTS TO SCHEDULE RSTGTS1 AS A FINDAC 706 WITH PRIORITY 20

GROUP 4.0
DISABLE GROUP 4 RESTARTS

RSTGTS1

ENTRY POINT FOR RESTART

INHIBIT INTERRUPTS

CURRENT TIME ZERO THE PIPAS

GSTSWIT1 ← TIME1
PIPAX ← +0
PIPAY ← +0
PIPAZ ← +0

ALLOW INTERRUPTS

SET PARAMETERS FOR ZEROING SUBROUTINES

ZEROING CLEAR SELECTED REGISTERS RH38

ZERO LOCATIONS ALX15 - 4 TO ALX15 + 76

IMU COMPENSATION INITIALIZATION

ALX15 USED AS INDEX AT ALKCG IN LOADING SLOPES AND TIME CONSTANTS

NEXT SHEET
SETGWLIST

MPAC ← Q

INHIBIT INTERRUPTS

A ← GTSWFTL2 - TIME1

A > 0?

NO

YES

A ← A + NEMAX

A ← A + 1SECXTL

A > 0?

NO

RIGHTGTS

YES

A ← 4

4C. SECS.

WTBTSWML

ALLOOP

WAITLIST TASK IN A. SECS.

CALLED AS "TWIDDLE" SINCE E AND F BANKS DON'T HAVE TO BE CHANGED.

RETURN VIA MPAC

ENDIFJOB
ALLOOP

READS AND CLEARS THE PIPA COUNTERS EVERY SECOND

GTSWLT1 ← TIME1
STORE TIME TO SET UP NEXT WAITLIST

ALLOOP3

GEOSAVE1 ← ALTIM
SAVE ALTIM IN CASE OF RESTART

GROUPS.11
SET UP RESTARTS TO SCHEDULE ALLOOP1 AS A WAITLIST Task IMMEDIATELY

ALLOOP4

ALTIM ← GEOSAVE1
RESTORE ALTIM

ALTIM ?

ALTIM ← 0

ALTIM ← ALTIM + 1

DELVX ← PIPAX
PIPAK ← 0
DELVY ← PIPAY
PIPAY ← 0
DELVZ ← PIPAZ
PIPAZ ← 0

GROUPS.23
SET UP RESTARTS TO SCHEDULE SPECSTS AS A WAITLIST Task IMMEDIATELY

SPECSTS

ALFLT

FINDVAC JOB
PRIORITY
22
SH16

TASKOVER

SAVE PIPA COUNTS ACCUMULATED OVER ONE-SECOND PERIOD
FROM PRECEDING SHEET

LOOGE

EXTRAPOLATES THE UPDATED WIND EFFECTS FOR NEXT MEASUREMENT TIME

MPAC\textsubscript{V} \leftarrow (\text{T}\text{R}\text{A}\text{N}\text{S} \text{ M}_{\text{D}}) (\text{PO}\text{S}\text{N} \text{V}_{\text{D}}, \text{VLAU}_{\text{D}}, \text{ACCW}_{\text{D}})

X \text{ COMPONENT}

Y \text{ COMPONENT}

Z \text{ COMPONENT}

BOOP

CALCULATES THE SINES AND COSINES OF THE GIMBAL ANGLES

PL40D \leftarrow 2 \sin \left(\frac{1}{4} \text{ GEORGE J. ANGX} \right)

PL16D \leftarrow \cos \left(\frac{1}{4} \text{ GEORGE J. ANGX} \right)

PL12D \leftarrow 2 \sin \left(\frac{1}{4} \text{ GEORGE J. ANGY} \right)

PL18D \leftarrow \cos \left(\frac{1}{4} \text{ GEORGE J. ANGY} \right)

PL14D \leftarrow 2 \sin \left(\frac{1}{4} \text{ GEORGE J. ANGZ} \right)

PL90D \leftarrow \cos \left(\frac{1}{4} \text{ GEORGE J. ANGZ} \right)

PERFERAS

EBANK \leftarrow 70

SET EBANK TO 7

ERASCALC

CALL ERASABLE PROGRAM STARTING AT LOCATION 1400 OF EBANK 7

ONCMORE

LENGTHOT > 0?

YES, TEST NOT OVER YET

SLEEPIE

NO

YES

TORQNOS > 0?

NO

Saves final CDU angle

LSVE+1 = CDUX

NEXT SHEET
SETS UP EARTH RATE TORQUING FOR COMPASS

OGC

XSM

GEORGEJ [ANX, ANY, ANO3]

TORQINCH

GROUPS.O

DISABLE
GROUPS
RESTARTS

A ← OGCPL

I/MUPULSE
PULSE TORQUE
THE GYROS
FC-2210

I/MUSTLIG
DELAY JOB UNTIL
I/O DONE
SH-35

TORQNDX

YEA

VALMIS

SH-24

NO

YES

EARTHRevSE
CALCULATES EARTH
RATE VECTOR

SH-41

TORQUE

SH-25
FROM PRECEDING SHEET

LASTGTS

THETA1<->ERCOMPI
ALK<->TMARK0

RESTATER

GROUPS.27
SET UP RESTARTS TO SCHEDULE RESTATER AS A FINDAC JOB WITH PRIORITY 20

ERCOMPI<->THETA1+(XSM)(THETAH1)

TMARK<->ALK

EARTH.
CALCULATE AMOUNT OF EARTH RATE COMPENSATION

GEOSAVE<->ERCTIM1

GROUPS.15
SET UP RESTARTS TO SCHEDULE RESTEST1 AS A FINDAC JOB WITH PRIORITY 20

NEXT SHEET

ADD COMPASS COMMANDS INTO ERATE AFTER CONVERTING TO STABLE MEMBER COORDS.
FROM PRECEDING SHEET

RESCHNG

OLOAZMTHA → NEWAZMTHA
LENGTHOTH ⩞ BI7

GROUP5.7
SET UP RESTARTS
TO SCHEDULE RSTRT51
AS A FINDRAC JOB WITH
PRIORITY 20

SPITGYRO

A ⩞ ERCOMPPL
ERCOMPPL = ECAOR ERCOMP

IMPULSE
PULSE TORQUE
THE GYROS
FC-2210

TORQUE THE IRIG'S ACCORDING TO
O.P. INPUTS BEGINNING AT ERCOMP

IMUSTALL
DELAY TO COMPLETION
OF PULSE TORQUING
FC-2210

WAIT UNTIL TORQUING DONE
BAD RETURN

NORMAL RETURN

EST1MS
SH11

SOMERRS
SH37

SPEND 320 SEC. ERECTING
**DISPLAY VERTICAL DRIFT**

1. **VAMLIS**
   - DSPTEM2 +1 → DRIFT0
   - DSPTEM2 ← ZERO

2. **SHOW**
   - DISPLAY VERTICAL GYRO DRIFT
   - VO6: N66

3. **END TEST 4**

4. **CLEAR IMUSE**

5. **A ← 0**

6. **NEW MOD EX**
   - CHANGE MODE REGISTER (Q)
   - FC-2030

7. **MK RELEASES**
   - RELEASE MARK SYSTEM
   - FC-2240

8. **END EXT**

**TERMINATE THE MAJOR MODE**

**SAVE OUTER GIMBAL ANGLE**

**DISPLAY ESTIMATE OF VERTICAL DRIFT**

- **R1 = 0**
- **R2 = DRIFT0 (INSERT ORIFT)**
- **R3 = POSITION**

**INDICATES IMU NO LONGER IN USE**

**FLAGS W00 BIT 8**

**RESETS MOD REG = 0**

**CHANGE MAJOR MODE DISPLAY TO POO**

**RELEASE MARK SYSTEM TO MAKE IT AVAILABLE TO OTHER INTERNAL SYSTEM Routines**
CALCULATES THE EARTH'S ROTATION RATE IN GYRO PULSES

SAVE SOUTH GYRO DRIFT FOR DISPLAY

DISPLAY VERTICAL GYRO DRIFT

QPLACE

SHOW

QPLACE

Q

_SHOW:

DSPT=EM2

DSPT=EM2+1

DRIFT1

SOUTH-R1 # POSITION

DRIFT1

DSPT=EM2+2

POSITION

A

VB06NS6

ENTER

GOFLASH

VOSNS6

RH,R2=GRAVITY

R3=POSITION

PROCEED

RETURN VIA QPLACE

PIPECHECK

SH 6

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

GUIDANCE AND NAVIGATION

PO1, PO2, PO3, PO7,

PRELAUNCH INITIALIZATION & GYRO CALIBRATION

COLOSSUS II

FC-2530

REV 1
OPTICAL VERIFICATION OF GYROCOMPASSING

CKOPTVP

CALLED VIA EXTENDED VERB 65

CHECKMM

IS MAJOR MODE NUMBER = 2 ?

NO, PRELAUNCH NOT OPERATING

FC-2030

YES, PRELAUNCH OPERATING

ALM/END

INHIBIT INTERRUPTS

COMPVER

FINOVAC JOB PRIORIT Y 46

GOPEN

PINBRANCH FC-2130

SCOMPVER

GROUP 4.15

SET UP RESTARTS TO SCHEDULE COMPVER AS A FINOVAC JOB WITH PRIORIT Y 46

NEWMODEX

CHANGE MM TO 03

FC-2030

CHANGE MAJOR MODE TO 003

NEXT SHEET
FROM PRECEDING SHEET

SET UP TO DISPLAY
TARGET NUMBER IN R3

GFLASH PASTES AZIMUTH AND ELEVATION
OVER THE NORMAL R1, R2 CONTENTS OF N30,
BUT LEAVES THE TARGET NUMBER IN R3 ALONE.

TARGET DATA
R1 = TARGET AZIMUTH XXX.XX DEG
R2 = TARGET ELEVATION XXX.XX DEG
R3 = TARGET NUMBER XXXXX. (DECIMAL)

TAZEL1#RUN ← DSPTEM4
TAZEL1+1#RUN ← DSPTEM4+1

TARGET AZIMUTH
TARGET ELEVATION

NO

RUN > 0?

YES

RUN ← 2

OPTDATA +2
SH27

CONTIN33

INPUTS TO TARGDRIVE:
STARCODE : 1 ← AZIMUTH AND ELEVATION
ARE INPUT RATHER THEN CATALOGUE
A = 0 ← TARGET # 1

TARGDRIVE
DRIVE OPTICS TO TARGET 1
SH43

TAZELN REF.
T1, T2 WITH RESPECT TO REF.
SH45

INPUT : TARGET AZIMUTH, ELEVATION TAZELL
OUTPUT : SIN OF ELEVATION OF TARGETS 1 AND 2
AZIMUTH, AND TARGET VECTORS IN
PL06, AND PL12

NEXT SHEET
FROM PRECEDING SHEET

NEXTBNKS

STARAD_y <- XSM_y X PLOG_y
STARAD+6_y <- XSM_y X PL18_y

CONVERT LOG VECTORS TO SM COORDS AND SAVE IN STARAD_y AND STARAD+6_y.

LITTLSUB

CONV. SHAFT AND TRUNNION ANGLES INTO VECTOR REFS.
SH46

LDSVEC <- MPAC_y

MKRELEAS

RELEASE MARK SYSTEM
FC-2240

NEXBNKSS

STARGOE <- 2
A <- 6

TARGDVE

DRIVE TO T2
SH43

LITTLSUB

CONV. SHAFT AND TRUNNION ANGLES INTO VECTOR REFS.
SH46

PDL18_y <- MPAC_y
PDL6_y <- LOSVEC_y

AXIGGEN

COMPUTE COORDS OF ONE COORD SYSTEM REF'D TO ANOTHER SYSTEM
FC-2260

STABLE MEMBER DESIRED WITH RESPECT TO STABLE MEMBER PRESENT

CALCSTA

COMPUTES SYRO TORQUE ANGLES FOR S.M. ORIENTATION
FC-2260

NEXT SHEET
CALLED FROM DSKY VIA EXTENDED VERB 92

NO-TEST ILLEGAL IF MAJOR MODE HAS BEEN SELECTED

PO7 ALLOWED AT THIS TIME?

INPUT: ALARM CODE 21521

PO0000
PO0000

POO000
POE000

TURN OFF AUTOPILOT
(WILL SHUT DOWN AND DAP THAT HAPPENS TO BE RUNNING)

SET TS TO IDLE

CLEAR DAPBIT1 AND DAPBIT2

DAPBIT1 = BIT 15 FLAG 6
DAPBIT2 = BIT 14 FLAG 6
DAP CONFIGURATION
FO40; I.E. "NO CAP"

ENTERED ON V92 CONDITION POO RUNNING

IRIG COEFFICIENT AND PIPA SCALE FACTOR TEST

DRITTT = EAST SM AXIS DRIFT USED IN OPTIMUM ESTIMATOR
GEOCOMP0 = INDEX USED IN THIS TEST

NEXT SHEET
FROM PRECEDING SHEET

COALIGN

TAKE PLATFORM OUT OF GIMBAL LOCK
SH 38

1 SECX1 ← SECX
1 PIPADT ← OCT1400

GUESS

LATAZCHK

LOAD NAVN BASE AZIMUTH AND TEST SITE LATITUDE
SH 47

WANG10 ← COS(LATITUDE)
WANO20 ← SIN(LATITUDE)

GEOIMUTT
SH 3

TAKE CARE OF DRIFT FLAG

CALC.: COS. LAT. AND SIN. LAT.

INPUT: STORED N.B. LATITUDE AND AZIMUTH TEST SITE LATITUDE
OUTPUT: LATITUDE AND AZIMUTH KEYED IN BY ASTRONAUT. MPAC ALSO CONTAINS LATITUDE
CONVERT NEWAZMTH FROM DOUBLE PRECISION 1'S COMPLEMENT TO SINGLE PRECISION 2'S COMPLEMENT IN MPAC₆.
INPUT: MPAC₀

NEWAZMTH (SINGLE PRECISION 2'S COMPLEMENT).

CLEAR OUT NORMAL DISPLAY THAT IS CURRENTLY ACTIVE OR ONE THAT IS SET UP TO BE STARTED OR RESTARTED.

R₁ = XSM LAUNCH AZIMUTH
R₂, R₃ = BLANK.

CONVERT O3PETM₁ FROM SINGLE PRECISIONS 2'S COMPLEMENT TO DOUBLE PRECISION 1'S COMPLEMENT.
INPUT: MPAC₆
OUTPUT: MPAC₀
ROUTINE TO ZERO A SET OF REGISTERS. A CONTAINS ADDRESS OF REGISTER TO BE ZEROED; ZERONDX1 CONTAINS ONE LESS THAN NUMBER TO BE zeroed.

ADDRESS OF FIRST REGISTER TO BE ZEROED

\[ L \leftarrow A \]

\[ C(C(L)) \leftarrow 0 \]

\[ C(C(L)) = \text{CONTENTS OF REGISTER WHERE ADDRESS IS IN } L \]

\[ L \leftarrow L + 1 \]

MOVE DOWN TO NEXT REGISTER

IS ZERONDX1 = 0?

YES, WE ARE DONE

\[ \text{RETURN VIA Q} \]

NO

DECREMENT COUNTER AND GO BACK AGAIN.
SET STABLE MEMBER COORDS. TO LAUNCH ALIGNMENT: ZSM = DOWN;
Y SM = DOWN RANGE; Y SM COMPLETES THE TRIAD.
ALARM 1600: "OVERFLOW IN DRIFT TEST"
ALARM 1601: "BAD IMU TORQUE, ABORT"
EARTH

SAVE QPRET IN S2

LOAD TIME 1 AND 2 INTO MPACO

TIME 2 - MOST SIGNIFICANT HALF OF COMPUTER TIME CLOCK
TIME 1 - LEAST SIGNIFICANT HALF OF COMPUTER TIME CLOCK

(EARTH+3)

TEMP TIME0 = MPACO

SAVE TIME

YES

MPACO ≥ TMARK0?

NO, CLOCK HAS OVERFLOWED SINCE LAST READING

OVERFFIX

FIX-UP OVERFLOW

SH36

ERTHR

ERVECTOR = [\sin(LAT) - \cos(LAT)] \cdot OMEG/MS0

ERCOMPL = ERCOMPL + XSMO \cdot [ERVECTOR(MPACO - TMARK0)]

(XSMO TO CONVERT TO STABLE MEMBER CO-ORDINATES)

TMARK0 = TEM TIME0

SAVE TEM TIME AS REAL TIME OF CALCULATION

X1 = ECADR(ERCOMPL)

INPUT TO PULSEIMU ROUTINE

PULSEIMU

EMIT GYRO TORQUING PULSES

FC-2100

STABLE MEMBER WILL NOW KEEP PACE WITH EARTH

RETURN VIA S2
MONITOR PIPA FOR DATA PULSE

ALLOW INTERRUPTS

NEWJOB > 0?

YES

CHANGE1

SUSPEND THIS JOB IF NEW JOB OF HIGHER PRIORITY IS WAITING
FC-2050

INHIBIT INTERRUPTS

ZERONDX ← PIPAX#PIPINDEX

INHIBIT INTERRUPTS

PIPAX#PIPINDEX+ ZERONDX > 0?

NO

QATAPL#RESULTCT ← PIPAX#PIPINDEX

FINETIME

GET TIME OF PIPA PULSE
SH40

QATAPL#RESULTCT ← A
QATAPL#RESULTCT ← L

ALLOW INTERRUPTS

ENDCHKS

RETURN VIA GPLACE

MONITORS THE VERTICAL PIPA TO DETERMINE WHEN PIPA DATA PULSE OCCURS

LOOP UNTIL A PULSE OCCURS

ZERO PIPA COUNTER JUST EXAMINED TOTAL NUMBER OF PULSES

OUTPUT: DOUBLE PRECISION TIME (HISCALAR, LOSCALAR)
IN A, L CSEC @ 2^28

TIME OF PULSE, DOUBLE PRECISION
READS THE CLOCK AND SCALERS (CHANNELS 3, 4 INTO A, I)

INHIBIT INTERRUPTS

(FINETIME + 1)

LOSCLAR IN CHANNEL 4 AND CONTAINS THE LOWER HALF OF THE CLOCK READING

SAVE

A ← A XOR LOSCLAR

READ LOSCLAR AGAIN, "EXCLUSIVE OR" IT WITH PREVIOUS READING

A = 0 ?

WILL BE 0 IF BOTH READINGS AGREE

YES

NO

IF CLOCK INCREMENTED BETWEEN READINGS, READ IT AGAIN

L ← LOSCLAR

IF LOWER HALF OF CLOCK CONTAINS SOMETHING LESS THAN POSMAX THE HIGHER HALF OF THE CLOCK CAN BE READ SAFELY OTHERWISE, LOOP BACK AND READ AGAIN (I.E., WAIT, UNTIL LOSCLAR OVERFLOW BEFORE READING)

L = 37777??

HISCALAR IS CHANNEL 3 AND CONTAINS HIGHER HALF OF THE CLOCK READING

A ← HISCALAR

RETURN VIA Q
INITIALIZES EARTH RATE VECTOR AT THE LAUNCH SITE LATITUDE

\[ \text{ERVECTOR} \leftarrow \Omega_{E}/8 \left( \sin(\text{LATITUDE}) - \cos(\text{LATITUDE}) \right) \]

EARTH RATE = .1504 ARC/40 USEC
1.618 GYROPULSES = 1 ARCSEC
\[ \Omega_{E}/8 = .243 \text{ GYROPULSES/} 10 \text{ MSEC} \]

LOAD TIME 2 AND 4 INTO MPAC_0

LOAD TIME

FC-2100

TMARK_0 \leftarrow MPAC_0

CURRENT TIME

ERCOMPL \leftarrow D_Y

RETURN VIA GPRET
THESE LOCATIONS ARE LOADED IMMEDIATELY BEFORE THE SUBROUTINE IS CALLED.

<table>
<thead>
<tr>
<th>PUSH LIST LOCATION</th>
<th>CONTENTS OF LOCATION</th>
<th>DOCUMENT SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>PL10p</td>
<td>2 sin(246 GEORGE7-ANGY)</td>
<td>2.SANGYp</td>
</tr>
<tr>
<td>PL11p</td>
<td>2 sin(246 GEORGE7-ANGY)</td>
<td>2.SANGYp</td>
</tr>
<tr>
<td>PL12p</td>
<td>2 sin(246 GEORGE7-ANGY)</td>
<td>2.SANGYp</td>
</tr>
<tr>
<td>PL13p</td>
<td>COS(246 GEORGE7-ANGY)</td>
<td>CANYYp</td>
</tr>
<tr>
<td>PL14p</td>
<td>COS(246 GEORGE7-ANGY)</td>
<td>CANYZp</td>
</tr>
<tr>
<td>PL15p</td>
<td>COS(246 GEORGE7-ANGY)</td>
<td>CANYZp</td>
</tr>
</tbody>
</table>

THE DOCUMENT SYMBOLS ARE ONLY USED FOR CONVENIENCE IN REPRESENTING THIS SUBROUTINE.
THEY ARE NEITHER GSPV SYMBOLS NOR AGC TAGS AND ARE ONLY ON THIS PAGE.

```
INT1p ← INT2p + 2: SANGYp  
INT2p ← INT0p + 2: SANGZp, CANYZp
```

```
WPLAT0p ← DRIFTp - 4: CANYYp + CANYZp 
         - WANGp - (3/4: SANGZp) SANGYp + CANYYp 
         - CANYp - SANGZp) WANGp, 
```

```
WPLAT1p ← WANGp - WANGp + 3/4: SANGZp 
WANGp + DRIFTp - 4: CANYYp + CANYZp 
WANGp 
```

```
ANGYp ← ANGy + GEORGETp (WPLAT0p - CANYYp 
- CANYZp - SANGZp) WANGp, ICANGZp 
```

```
ANGYp ← ANGy + GEORGETp + 3/4: SANGYp 
(WPLAT0p - CANYYp + 3/4: SANGYp) DRIFTp - 3/4: SANGYp 
- WANGp - (3/4: CANYYp - 2 SANGZp) WANGp 
```

```
ANGZp ← ANGz + GEORGETp (2 - CANYYp 
(DRIFTp - 3/4: SANGYp + CANYZp + WANGp + 
(2 SANGZp) WANGp) - 3/4: SANGZp - CANYZp) WANGp) 
```

OVERFLOW IN ABOVE CALCULATIONS?

YES

```
SOMEERRR SH.37
```

NO

RETURN

MIT INSTITUTE RESEARCH LAB CAMBRIDGE, MASS.
A.C. WILLIAMS
C.A. HASS \2\1\17
P.O. POZ, POS, POT, \2\1\17
COLOSSUS II C FC-2530
DRIVES THE OPTICS TO THE SPECIFIED TARGET

TRANSFORMS TARGET AZIMUTH AND ELEVATION ANGLES INTO TARGET VECTORS IN EARTH REFERENCE COORDINATES

A FROM ABOVE: 0 FOR 1ST TARGET
1 FOR SECOND
PLO6 OR PLO12

INPUT: XNB, YNB, ZNB
OUTPUT: SAC (SHAFT ANGLE), PAC (TRUNNION ANGLE)

SHAFT ANGLE
TRUNNION ANGLE

NEXT SHEET
FROM PRECEDING SHEET

RETARG

OPTIND ← 0

ENABLE OPTICS DRAWING

SXTMARK
MARK ON TARGET1
FC-2240

OPTSTALL
INSURE SUCCESSFUL MARK
FC-2210

FAILURE: WAITS UNTIL INPUT-OUTPUT FUNCTION COMPLETED
GTSDPTCS
SH30

HAS PO3 TERMINATION BEEN REQUESTED?
YES, RETURN

TRM03FLG SET?
NO
FLAGWD1, BIT4

GCOMP5
SH30

QPRET#MARKSTAT = 0?
NO
YES, RETARGET

QPLAC

RETARG1

PUT(MARKSTAT-1) INTO THE LOCATION PRECEDING THAT WHOSE ADDRESS IS IN MARKSTAT MARKSTAT = 0

, RELEASE VAC AREA USED BY SXTMARK (MARKSTAT POINTS TO LOCATION O OF SOME VAC AREA.
BY CONVENTION, LOCATION-1 OF A VAC AREA CONTAINS ITS OWN ADDRESS IF THE VAC AREA IS AVAILABLE)

RETARG
SH49

MIT INSTRUMENTATION LAB
LABRIDGE MASS

P1, P2, P3, P4, P5, PRE-LAUNCH INITIALIZATION & SYD COMPASSING

COLOSSUS II FC-2530
TRANSFORMS THE TARGET AZIMUTH AND ELEVATION ANGLES INTO TARGET VECTORS IN EARTH REFERENCE COORDINATES.

1ST PASS USES FIRST TARGET
2ND PASS USES SECOND TARGET

PDL0 = TAZEL1+1
PDL0 = TAZEL1+3
PDL6 = SIN(TAZEL1+1)
PDL12 = SIN(TAZEL1+3)
PDL0 = COS(PDL0)
PDL0 = COS(PDL0)
MPAC = TAZEL1
MPAC = TAZEL1+2

1ST PASS - TARGET'S ELEVATION
2ND PASS - TARGET'S ELEVATION
1ST PASS - SIN TARGET'S ELEVATION
2ND PASS - SIN TARGET'S ELEVATION
1ST PASS - COS TARGET'S ELEVATION
2ND PASS - COS TARGET'S ELEVATION
1ST PASS - TARGET'S ELEVATION
2ND PASS - TARGET'S ELEVATION

CONVERTS SINGLE PRECISION 2's COMPLEMENT NUMBER IN MPAC, SCALED IN HALF REVOLUTION TO DOUBLE PRECISION 1's COMPLEMENT, SCALED IN REVOLUTIONS IN MPAC

PDL 2 = MPAC
PDL 10 = SIN(PDL2) COS(PDL0)
PDL 16 = SIN(PDL2) COS(PDL0)
PDL 8 = COS(PDL2) COS(PDL0)
PDL 14 = COS(PDL2) COS(PDL0)

1ST PASS - SIN(AZIMUTH) COS(ELEVATION)
2ND PASS - SIN(AZIMUTH) COS(ELEVATION)
1ST PASS - COS(AZIMUTH) COS(ELEVATION)
2ND PASS - COS(AZIMUTH) COS(ELEVATION)

Both Passes - Azimuth

ND

x2=0?

Yes

RETURN VIA QPRET

LOOP THRU 2 TIMES/ONCE FOR EACH TARGET
LITLUS

Q PLACE ← Q

CDUSPOT ← PLO2 #(MARKSAT)

SXTNB
CONVERT TO N.B. COORDS
FC-2250

INPUT: CDUSPOT

TRGWNSM
CONVERT TO STABLE MEMBER COORDS
FC-2270

OUTPUT: MPAC

RETURN VIA Q PLACE
DISPLAYS THE STABLE MEMBERS AZIMUTH AND LATITUDE FOR OPERATOR APPROVAL

LATAZCHK

OSPFEM1+1_1 <—— LATITUDE0

MPAC0 <—— AZIMUTH0

18028

CONVERT FROM 1'S TO 2'S

FC-2100

OSPFEM1+1_1 <—— MPAC0

CLEANDSP

CLEAR OUT NORMAL DISPLAY

FC-2130

CLEAR OUT NORMAL DISPLAY THAT IS CURRENTLY ACTIVE OR ONE THAT IS SET UP TO BE STARTED OR RESTARTED

ENTER

TERMINATE

GOFLASH

V06=41

R1 = DSPTEM1 - TARGET AZIMUTH

R2 = DSPTEM1+1 - TARGET ELEVATION

PROCEED

MPAC0 <—— DSPTEM1+1_1

CDULOGIC

CONVERT 2'S TO 1'S

FC-2100

CONVERTS SINGLE PRECISION 2'S COMPLEMENT NUMBER IN MPAC IN HALF REvolutions TO A DOUBLE PRECISION IS COMPLEMENT NUMBER SCALLED IN REVOLUTIONS AND LEFT IN MPAC

AZIMUTH0 <—— MPAC0

LATITUDE0 <—— DSPTEM1+1_1

STORE NEW AZIMUTH AND ELEVATION

RETURN VIA Q
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

P11: READS LIFTOFF TIME, RESETS TIME COUNTER, SETS UP STATE, ATTITUDE ERROR, AND DISPLAY SUBROUTINES. SH. 3

REP11: POSSIBLE RESTART ENTRY TO P11 IF RESTART OCCURS DURING THE TIME SUBROUTINE. SH. 6

MATRIXJOB: STATE SUBROUTINE: COMPUTES INITIAL STATE VECTOR AND STABLE MEMBER ORIENTATION, STARTS STATE VECTOR UPDATING. SH. 7

ATERJOB: COMPUTES AND DISPLAYS ERROR BETWEEN DESIRED AND ACTUAL ATTITUDE DURING BOOST, AND, IF CMC TAKEOVER OF SATURN IS ENABLED, ISSUES CORRECTIVE STEERING SIGNALS TO SATURN INSTRUMENTATION UNIT. SH. 10

VIIIIDOT: COMPUTES AND DISPLAYS NOUN 62: VELOCITY, ALTITUDE, ALTITUDE CHANGE RATE. SH. 18

S11.1: COMPUTES VALUES FOR NOUN 62 DISPLAY. SH. 18

SATSTKON: ORIGINAL ENTRY TO SATURN STICK ROUTINE; SCHEDULES REDOSAT. SH. 19

REDOSAT: INITIALIZES SATURN CREW TAKEOVER FUNCTION, SCHEDULES SATSTICK; RESTART ENTRY FOR SATSTICK. SH. 20

SATSTICK: TRANSMITS ATTITUDE COMMANDS FROM ASTRONAUT (RHC) TO SATURN INSTRUMENTATION UNIT. SH. 21

ENCLOSED ARE REPLACEMENT SHEETS TO UPDATE THE COLOSSUS II FLOWCHART FC-2540, REV. 0 TO THE COLOSSUS IIA FLOWCHART FC-2540, REV. 1

EFFECTIVE SHEETS FOR COLOSSUS IIA ARE:

SH. 1 REV. 0
SH. 2 REV. 1
SH. 3, 4 REV. 0
SH. 5 REV. 1
SH. 6 REV. 0
SH. 7 REV. 1
SH. 8-27 REV. 0
MONITOR EARTH ORBIT INSERTION CONTROLLED BY SATURN
ENTERED FROM POL (GYRO COMPASSING)
(WHEN LIFTOFF DETECTED OR DUE TO VTSE (BACKUP))
WITH PRIORITY 22

GROUP 311
SET UP RESTARTS TO
SCHEDULE REP11 A AS
A FINDVAC JOB WITH
PRIORITY 22

LIFTTEMP ← 0

GROUPS0
KILL
GROUP 5
RESTARTS

P11 + 7

T4LIFTOFF ← -18

LIFTTEMP ← TIME2D

(REP11A ← 5)

A4L ← TIME2O

TIME2O ← +0

REP11A ← 2

T4LIFTOFF ← A4L

REAO LIFTOFF TIME TWICE
IN CASE OF RESTART

INITIALIZE MISSION TIME
TO BEGIN AT LIFTOFF

FINAL STORAGE OF LIFTOFF TIME
(COUNTED FROM ORIGINAL TIME2O SYNCHRONIZATION)

GROUP 313
SET UP RESTARTS TO
SCHEDULE REP11A AS
A FINDVAC JOB WITH
PRIORITY 22

REP11A

INHIBIT INTER-
RUPTS

NEXT SHEET
FROM PRECEDING SHEET

TEPHEM₁, T + TEPHEM₂, O, T NEWD, T

CORRECT REFERENCE EPHEMERIS TIME TO ACCOUNT FOR ACTUAL LIFTOFF TIME IN CSEC @ 2₄₂

GROUP 3
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINOVAC JOB WITH PRIORITY 22

INHIBIT INTERRUPTS

STORE UPDATED REFERENCE EPHEMERIS TIME

PREREAD 01 CLEAR PIPAS AND INITIALIZE SERVICER

GROUP 3
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINOVAC JOB WITH PRIORITY 22

ATERIAL TASK WAIT LIST TASK IN D.S SECOND 5.4

NEWMODEX CHANGE (AND DISPLAY) MAJOR MODE TO 11 FC 22050

AERIAL TASK

AERIAL JOB FINOVAC JOB WITH PRIORITY 1 SH 10

DOES ATTITUDE ERROR COMPUTATION AND DISPLAY LOW PRIORITY; RUNS AFTER P11, SERVICER

INDICATE FIRST PASS THROUGH NEEDLER

SET RCSFLAGS BIT 3

NEEDLER DD INITIALIZATION FOR ATTITUDE ERROR DISPLAY FC 2370

IF P11 ENTERED NORMALLY, ASTRONAUT'S INCOMPLETE ACTION ('V75' WITHOUT 'ENT') STILL USING DSKY AND DISPLAY INTERFACE SYSTEM

SELECT POWERED FLIGHT DOWNLIST

ASATNO ENTERED NO LONGER SELECT MAJOR MODE P01

INITIALIZE SATSW > 0 TO INDICATE CMC NOT IN CONTROL OF SATURN.
GROUP 4.51

SET UP RESTARTS TO SCHEDULE A TASK AS A WAITLIST TASK IMMEDIATELY.

GROUP 3.1

SET UP RESTARTS TO SCHEDULE MATRIX JOB AS A FIND-MAT JOB WITH PRIORITY 22.

QPLACES ← GENADR(P1OUT) SET EXIT FROM PROUT TO P1OUT

CORRECT EARTH ROTATION RATE TO BE COMPENSATED FOR
BY ADDING DRIFT NOT CORRECTED DURING PRELAUNCH
IN REVS/CSEC @ 221 IN STABLE MEMBER COORDINATES
WHERE:

\[
\text{ERCOMP}_v = \text{ERCOMP}_v + x3M_{v} \times \text{THETAN}_v \times 2^4
\]

\[\text{ERCOMP}_v\] = ORIGINAL ERCOMP_v EFFECT OF EARTH ROTATION RATE ON IMU IN REVS/CSEC @ 221,
IN S.A.L. COORDINATES.

\[x3M_{v}\] = DRIFT NOT CORRECTED DURING PRELAUNCH IN REVS/CSEC @ 221 IN EARTH-FIXED
COORDINATES.

\[\text{THETAN}_v\] = DRIFT NOT CORRECTED DURING PRELAUNCH IN REVS/CSEC @ 221 IN EARTH-FIXED
COORDINATES.

\[x3M_{v}\] = MATRIX FOR CONVERSION BETWEEN EARTH-FIXED AND STABLE MEMBER
COORDINATE SYSTEMS @ 221.

2^4 FACTOR IS FOR SCALING.

MPAC_D ← TLIFFOFF_D
S2 ← FCADR(PROUT)

SET EXIT FROM
EARTH+3 TO PROUT

INPUT:
MPAC_D = TIME OF LIFTOFF IN CSEC @ 228
ERCOMP_v = RATE OF EARTH ROTATION TO BE COMPENSATED FOR

ERCOMP_v ← ERCOMP_v + x3M_v \times \text{THETAN}_v \times 2^4
Possible restart entry to P11
(if restart occurs during initial time readings)

Inhibits interrupts

Pre-launch routines restart protected?

Yes: Pre-launch routine will start
P11 again from the beginning

No: End of job

Lifttemp ≠ 0

Yes: Time readings not yet begun —
start now

No: Lifttemp = Liftoff time

Has liftoff time been stored?

Yes: Time readings finished

No: Do it now

Liftoff ≥ 0

Yes: Store liftoff time

No: Lifttemp = Lifttemp old

Time2 = 0

Yes: Has mission time counter been initialized?

No: Do it now

A_L = Lifttemp old

Rep11a-2

Rep11a-1

P11+7

Sh.3

Sh.3

Sh.3

Sh.3
INITIALIZE DESIRED (OUTER, INNER, MIDDLE) IMU GIMBAL ANGLES TO ACTUAL ANGLES (SO NO "ERROR") IN REV'S (2^12 COMPLEMENT) @ 2^-1

CHANGE SCALING TO 2^6

INDICATE THAT VEHICLE IS IN EARTH'S SPHERE OF INFLUENCE

STORE VECTOR GIVING ORIGINAL VEHICLE POSITION IN TERMS OF:
LATITUDE OF LAUNCH PAD IN REV'S @ 2^6
LONGITUDE OF LAUNCH PAD IN REV'S @ 2^6
ALTITUDE OF IMU IN M @ 2^12

USE CONSTANT EARTH RADIUS

INPUT: MPAC_D = TIME CORRESPONDING TO SPECIFIED POSITION IN CSEC @ 2^12
LAT_V = (LAT_D) LATITUDE IN REV'S @ 2^6
LONG_D = LONGITUDE IN REV'S @ 2^6
ALT_D = ALTITUDE IN M @ 2^12
ERADFLAG = CLEAR: USE FIXED (AS OPPOSED TO COMPUTED) EARTH RADIUS

OUTPUT: MPAC_V = ALPHAV = CORRESPONDING POSITION VECTOR R IN REFERENCE COORDINATES IN M @ 2^12

STORE POSITION VECTOR

TIME IN CSEC @ 2^12
PARAMETER 7 @ 2^1

INPUT: PL6_D = TIME CORRESPONDING TO SPECIFIED POSITION IN CSEC @ 2^12
PL8_D = 7 = WEIGHTING PARAMETER FOR COMputation @ 2^1
LAT_V = AS ABOVE

OUTPUT: MPAC_V = ALPHAV = POSITION VECTOR R Relative TO CENTER OF GRAVITY RATHER THAN TO ACTUAL CENTER OF EARTH, AS ABOVE
FROM PRECEEDING SHEET

\[ \text{REFSMAT}_0 = \text{UNIT}(v_2 - \text{UNIT}(v_2 \times \text{UNIT}(v_2 \times \text{UNIT}(v_2 \times v_2))) \]

\[ v_2 = -\omega \times v_2 \]

\[ v_1 = \text{UNIT}(v_2 \times \text{UNIT}(v_2 \times v_2)) \times \text{UNIT}(v_2 \times v_2) \]

\[ E = \text{UNIT}(\text{REFSMAT}_0 \times v_2) \]

\[ \text{PLO}_0 = -\text{UNIT}((\text{REFSMAT}_0 + \text{ID}) \times \text{UNIT}(v_2)) \]

\[ S = \text{UNIT}(E \times \text{REFSMAT}_0) \]

\[ \text{PL}_0 = \text{UNIT}(\text{PLO}_0 \times (\text{REFSMAT}_0 + \text{ID})) \]

\[ \text{REFSMAT}_0 = \sin(A_2)E + \cos(A_2)S \]

\[ \text{REFSMAT}_v = -\text{ UNIT}(\text{LAUNCH} x, \ldots) \times \text{UNIT}(\text{LAUNCH} x, \ldots) \]

\[ \text{REFSMAT}_v = \text{UNIT}(\text{REFSMAT}_0 \times \text{REFSMAT}_v) \]

\[ \text{REFSMAT}_x = \text{UNIT}(\text{REFSMAT}_0 \times \text{REFSMAT}_v) \]

\[ \text{SET} \text{REFSMAT}_v \]

\[ \text{REFSMAT}_v \text{ IS VALID IF GIVES KNOWN STABLE MEMBER ORIENTATION} \]

\[ \text{JUST BEFORE LIFTOFF IN REFERENCE COORDINATES IN MY/CSEC @ 2^1} \]

WHERE:

\[ \text{UNIT}_1 = \text{UNIT}(v_2) = \text{UNIT}(v_2) \times \text{UNIT}(v_2) \]

\[ -\text{EARTH} \times v_2 = -\text{EARTH} \times \text{UNIT}(v_2) \times \text{UNIT}(v_2) \]

\[ -\text{EARTH} \times v_2 = -\text{RATE OF EARTH ROTATION} \times \text{UNIT}(v_2) \]

\[ = -7.292115136 \times 10^{-7} \text{ RAD/CSEC @ 2^1} \]

\[ \text{LAUNCH} = \text{LAUNCH AZIMUTH FROM NORTH TO STABLE MEMBER} \]

\[ +X\text{- AXIS IN REVS @ 2^1} \]

\[ \text{COMPUTE} \text{REFSMAT}_v = \text{REFSMAT}_0 - \text{REFSMAT}_0 \times \text{REFSMAT}_v \]

\[ \text{TRANSFORMATION MATRIX BETWEEN REFERENCE AND STABLE MEMBER COORDINATE SYSTEMS @ 2^1} \]

\[ \text{USING KNOWN INITIAL STABLE MEMBER ORIENTATION} \]

\[ \text{COMPUTE} \text{K}_z = \text{TOTAL ROLL ANGLE NECESSARY TO ALIGN SPACECRAFT} \]

\[ -X\text{- AXIS WITH STABLE MEMBER} \]

\[ +Z\text{- AXIS IN REVS @ 2^1} \]

\[ \text{WHERE:} \text{LAUNCH} = \text{LAUNCH AZIMUTH FROM NORTH TO STABLE MEMBER} \]

\[ +X\text{- AXIS IN REVS @ 2^1} \]

\[ \text{AZIMUTH} = \text{AZIMUTH AT LAUNCH FROM NORTH TO SPACECRAFT} \]

\[ +Z\text{- AXIS IN REVS @ 2^1} \]

\[ \text{INSURE THAT SIGN OF ROLL RATE IS OPPOSITE TO THAT OF K}_z \]

\[ \text{WHERE ORIGINAL SATURATE} = \text{ABSOLUTE VALUE OF SATURN ROLL RATE} \]

\[ \text{IN REVS/CSEC @ 2^1} \]

\[ \text{NEXT SHEET} \]
FROM PRECEEDING SHEET

GROUP 3
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINDVAC JOB WITH PRIORITY 22

AVGEXITD ← 2ADDR(VHHDOT)

SET EXIT FROM SERVICER TO VHHDOT (SH.15)

1/PIPADT ← 200 CSEC

SET AT BETWEEN PIPA READINGS IN CSEC @ 2

GROUP 5
TBASES ← 0

TIMES FOR GROUP 5 WAITLIST TASK RESTARTS WILL BE MEASURED FROM LIFTOFF

YES

HAS IT BEEN AT LEAST 2 SECONDS SINCE LIFTOFF?

NO

TIME1 = LOW-ORDER HALF OF

TIME2 = PRESENT TIME (FROM LIFTOFF)

IN CSEC @ 2

AT THIS POINT, CAN ASSUME

HIGH-ORDER HALF STILL = 0,

SO TIME1 = PRESENT TIME FROM LIFTOFF

IN CSEC @ 2

WANT READACCS TO START 2 SECONDS (AT LEAST) AFTER LIFTOFF

READACCS
WAITLIST TASK IN A CSEC
FC 2683

READS ACCELEROMETERS, SETS UP SERVICER (STATE VECTOR UPDATING)
WITH PRIORITY 20 (RUNS AFTER P11, NORMALIZE)
RESCHEDULES ITSELF EVERY 2 SECONDS UNTIL TURNED OFF

GROUP 5.0
KILL GROUP 5 RESTARTS

GROUP 5.2
SET UP RESTARTS TO SCHEDULE NORMALIZE AS A FINDVAC JOB WITH PRIORITY 32 AND REREADAC AS A WAITLIST TASK IN 2 SECONDS

NORMALIZE
FC 2683

DO INITIAL STATE VECTOR UPDATE AND END JOB
ATERTDB

COMPUTES AND DISPLAYS DIFFERENCE BETWEEN NOMINAL AND ACTUAL ATTITUDE PROFILE DURING SATURN LAUNCH.
INITIALLY SET UP BY ATERTASK (SH-4) AS A JOB WITH PRIORITY 1; RECYCLES APPROXIMATELY EVERY HALF-SECOND.

ATTITUDE UNDER (SATURN) RMCC CONTROL?

YES: END ATTITUDE ERROR DISPLAY

NO: OK TO CONTINUE ATTITUDE ERROR DISPLAY

END OF JOB

BIT 5 OF CHANNEL 3 CLEAR

COMPUTER NOW IN CONTROL OF SATURN STAGE?

YES (LV GUIDANCE SWITCH IN "CMC" POSITION)

STRTAT

WAS COMPUTER IN CONTROL AT LAST PASS?

SATSWL 0?

NO

YES

ATRESET SH-15

ENTERED if STATUS OF CMH CONTROL OF SATURN HAS NOT CHANGED SINCE LAST PASS.

ATTDISP

YES

T > T1 = TIME TO START COMPUTING NOMINAL ATTITUDE?

(RPSTART = T1 IN CSEC @ 214)

NO

T = T - T1

MPAC ← TIME1 - RPSTART

POLARG ← TIME1 - RPSTART

SET UP PARAMETER FOR POLYNOMIAL COMPUTATION:

TIME IN CSEC @ 214

T > T1 + T1 = TIME TO HAVE FIXED ATTITUDE AGAIN?

(POLYSTOP = -T1 IN CSEC @ 214)

NO

THIS TEST NOT VALID IF > 163.85 SECONDS FROM LIFTOFF (TIME 1 ONLY LOW-ORDER HALF OF TIME)

SO CHECK:

TIME2 > 0?

NO

NOPOLY

YES

NOMPOLY SH-15

NEXT SHEET
FROM PRECEDING SHEET

SET PARAMETERS FOR POWRSERS

INPUT:
L = POLYNOM
A = ADRES(POLYLOC)

POWRSERS EVALUATE POLYNOMIAL OF DEGREE N
PC 2090

MPACD = MPACD x 2.5

PLD = MPACD

-CPD = COS(θp)
PL14D = COS(MPACD)

SPD = SIN(θp)
PL10D = SIN(PLD)

PL12D = 0

TRIGONOMETRIC FUNCTIONS @ 21

COMPUTE REMAINING ROLL ANGLE IN REVS @ 2°

θr = K2 x SIGN(K2) x K1 x θp

MPACD = LAUNCHAZD + 1/2 x AZIMUTHD + SATRLTD x SPOLYARG x 214

WHERE:
LAUNCHAZD = A2
= LAUNCH AZIMUTH FROM NORTH TO STABLE MEMBER + X-AXIS IN REVS @ 2°

AZIMUTHD = A2p
= AZIMUTH (AT LAUNCH) FROM NORTH TO SPACECRAFT + Z-AXIS IN REVS @ 2°

K2 = A2 - 180° - A2p
= TOTAL ROLL ANGLE AT LAUNCH TIME

SATRLTD = -SIGN(K2) x K1
= ROLL RATE WITH SIGN OPPOSITE TO K2 IN REVS/CSEC @ 2°

SPOLYARG = θp
= TIME SINCE NOMINAL START OF ROLL IN CSEC @ 214
214 FACTOR IS FOR SCALING

NEXT SHEET
FROM PRECEDING SHEET

\[ X_{DC}^V \leftarrow \text{UNIT}(\text{PL}_{10}) \]
\[ Y_{DC}^V \leftarrow \text{UNIT}(\text{PL}_{16}) \]
\[ Z_{DC}^V \leftarrow \text{UNIT}(\text{PL}_{22}) \]

STORE MATRIX FOR CALGCTA
\@ 2^4

CALGCTA
COMPUTE
EULER ANGLES
CORRESPONDING
TO TRANSFORMATION
FC 22560

INPUT: \[ X_{DC}^V \]
\[ Y_{DC}^V \]
\[ Z_{DC}^V \]

DESIRED STABLE MEMBER AXES
RELATIVE TO
ORIGINAL STABLE MEMBER COORDINATES
\@ 2^4

OUTPUT: \[ \Omega_{GD} \]
\[ \Theta_{GD} \]
\[ \Phi_{GD} \]

EULER ANGLES OF CORRESPONDING
TRANSFORMATION
= DESIRED IMU GIMBAL ANGLES
IN REVS \@ 2^6 (1'S COMPLEMENT)

N-POLYM
COULD ALSO ENTER HERE (WHEN T < T_{E3})
WITH \[ \Omega_{GD} \]
\[ \Theta_{GD} \]
\[ \Phi_{GD} \]

PRESET TO ORIGINAL IMU GIMBAL ANGLES
IN REVS (2'S COMPLEMENT) \@ 2^6

OR WHEN T > T_{E3} + T_{E3}
WITH LAST COMPUTED NOMINAL IMU GIMBAL ANGLES

\[ PL_{2}^V \leftarrow (\Omega_{GD}, \Theta_{GD}, \Phi_{GD}) \]
SAVE EULER ANGLES IN Y, Z, X ORDER

CDUITRG
GET ACTUAL
IMU GIMBAL ANGLES
AND THEIR TRIGONOMETRIC FUNCTIONS
FC 2270

OUTPUT: \[ \text{CSUP}^V \]
\[ \text{CSUP}^X \]
\[ \text{CSUP}^Z \]

ACTUAL
IMU GIMBAL ANGLES
IN REVS \@ 2^6
(1'S COMPLEMENT)

\[ \text{SINC}^V, \text{COSD}^V \]
\[ \text{SINC}^Z, \text{COSD}^Z \]
\[ \text{SINC}^X, \text{COSD}^X \]

SINES, COSINES
OF IMU GIMBAL ANGLES
\@ 2^4

MPAC^V \leftarrow PL_{2}^V
LOAD DESIRED IMU GIMBAL ANGLES

NEXT SHEET
FROM PRECEDING SHEET

VISTO25
CONVERT ANGLES FROM 1'S TO 2'S COMPLEMENT REPRESENTATION
FC-2100

INPUT: MPA0
MPAC0+30
MPAC0+50

OUTPUT: MPA0
MPAC0+1
MPAC0+2

3 ANGLES IN 1'S COMPLEMENT IN REV @ 2°
SAME 3 ANGLES IN 2'S COMPLEMENT IN REV @ 2°

SAVE DESIRED IMU GIMBAL ANGLES
2'S COMPLEMENT @ 2°

CLEAR VECTOR-HIGH-ORDER WORDS ONLY TO BE STORED LATER

LOAD ACTUAL IMU GIMBAL ANGLES

VISTO25
CONVERT ANGLES FROM 1'S TO 2'S COMPLEMENT REPRESENTATION
FC-2100

INPUT: MPA0
MPAC0+30
MPAC0+50

OUTPUT: MPA0
MPAC0+1
MPAC0+2

3 ANGLES IN 1'S COMPLEMENT IN REV @ 2°
SAME 3 ANGLES IN 2'S COMPLEMENT IN REV @ 2°

DELSTOR

ΔCDU = CDU - DGA
ΔCDU = CDU - DGA
ΔCDU = CDU - DGA

PLO ← BOOSTEMP + MPAC
PL2 ← (BOOSTEMP+1) + (MPAC+1)
PL4 ← (BOOSTEMP+2) + (MPAC+2)

COMPUTE DIFFERENCE BETWEEN ACTUAL AND DESIRED IMU GIMBAL ANGLES (2'S COMPLEMENT @ 2°)

TAKING 1'S COMPLEMENT DIFFERENCE OF 2'S COMPLEMENT NUMBERS

GOES TO NEXT INTERPRETIVE LANGUAGE INSTRUCTION (AFTER CALL TO DELSTOR)

RETURN VIA DANZIG

NEXT SHEET
FROM PRECEDING SHEET

AK ← $2^3 \times$ SATSCALE x AK
AK1 ← $2^3 \times$ SATSCALE x AK1
AKZ ← $2^3 \times$ SATSCALE x AKZ

SCALE ATTITUDE CORRECTION
COMMANDS APPROPRIATELY
FOR SATURN HARDWARE.

SATOUT

NEEDLER
DISPLAY
ATTITUDE ERROR
ON
FDAI NEEDLES
FC-2370

INPUT: $\begin{pmatrix} \phi \times 10^{-3} \\ \psi \times 10^{-3} \\ \chi \times 10^{-3} \end{pmatrix}$
ATTITUDE ERROR ANGLES (IN DEG)
IN SPACECRAFT
COORDINATES.

ALSO GIVES STEERING COMMANDS
(TO CORRECT ERROR) TO SATURN
IF CMC IS IN CONTROL.

ATERSET

DELAY JOB

WAIT .25 SECOND
FC-2070

DELAY TO INSURE SUFFICIENT
TIME BETWEEN CALLS TO
NEEDLER.

ATERJOB 54.10

START CYCLE OVER.
**VHMDOT**

- **COMPUTE AND DISPLAY NOUN G2**
  - **ENTERED FROM SERVICER WITH PRIORITY 20**
  - **EVERY 2 SECONDS**

**S1.1**

- **COMPUTE VALUES FOR NOUN G2 DISPLAY**
  - **ALSO CALLED BY CALCNS (FC-2700)**

**V = |x(t)|**

**VMAG1** = |VN |

**V** = MAGNITUDE OF VELOCITY IN M/SEC @ 2^7

**\[ \dot{h} = \frac{y(t) \cdot \text{UNIT}(E(t))}{\text{HOT}_2} \]**

**HOT** = VN UNIT(RN) x 2^1

**\[ \dot{p} = |R_N| \]**

**PL300** = RN UNIT(RN) x 2^7

**MPAC** = RPAD

**R** = LOAD RADIUS CORRESPONDING TO POSITION OF LAUNCH PAD:

**RLP** = 6,373,336 M @ 2^17

**STATE VECTOR IN EARTH SPHERE OF INFLUENCE**

**AMCONFLG**

- **CLEAR**
- **NO: MOON**

**MPAC** = |PL5| x 2^7

**EARTHALT**

**ALTI** = PL300 - MPAC

**RETURN VIA QPRET**

**GROUP S53**

**SET UP RESTARTS TO SCHEDULE REREADAC AS A WAITLIST TASK IN 2 SECONDS**

**DISPLAY NOUN G2:**

- **ENTRY:**
  - **R1:** XXXXX. FT/SEC (VMAG1)
  - **R2:** XXXXX. FT/SEC (HOT)
  - **R3:** XXXXX. NM (ALTI)

**REGDSP**

**ENDOFJOB**

**REGDSP GOES DIRECTLY TO ENDOFJOB.**

---

**NOTE:** "2 SECONDS" IS MEASURED FROM LAST TIME READACCS WAS SCHEDULED.
SATURN TAKEOVER FUNCTION: ALLOWS ASTRONAUT TO
CONTROL ATTITUDE USING SATURN AUTOPILOT
ENTERED VIA V46 IF DAPBIT1 BITS 13,14 HAVE BEEN SET
(BY PREVIOUS USE OF V48)

SATURN UNDER STICK CONTROL
(WILL DISCONTINUE AFTER)

ZEROJET CLEAR RCS JET CHANNELS
FC 2380

TIME6 COUNTER LEFT DISABLED

ALLOW INTERRUPTS

GOPIN

TERMINATES EXTENDED VERB 46
INITIALIZATION FOR SATURN TAKEOVER
ENTERED FROM TSRRUPT, ALSO ENTERED IN
CASE OF RESTART.
(FROM AUTOPILOT RESTART LOGIC - SEE FC-2020)

SAVE REGISTERS FOR INTERRUPTED PROGRAM
L = MEMORY BANK INFORMATION
Q = USUAL CONTENTS

SET RCSFLAGS
UNIT 3

INDICATE INITIALIZATION PASS THROUGH NEEDLER

NEEDLER
DO
INITIALIZATION
FOR SATURN INTERFACE
FC 2370

SET BITS
OF
CHANNEL 12

CONNECT IMU GDU ERROR COUNTERS TO SATURN INSTRUMENTATION
UNIT — PERMITS ATTITUDE CONTROL OF SATURN, BY CLOSING
S I I B TAKEOVER RELAY.
(Causes Needler inputs to be transmitted to
Saturn as well as to FDAI Needles)

SATSTACK
TSRRUPT
TASK IN
0.1 SECOND
SH 21

RESUME
WILL RETURN TO INTERRUPTED PROGRAM

P11- EARTH ORBIT
INSERTION MONITOR

COLOSSUS II A
FC-2540
TRANSMIT ATTITUDE COMMANDS FROM ASTRONAUT TO SATURN
ENTERED FROM TSRUPT EVERY 100 MS UNTIL TSRUPT CONTROL IS TAKEN OVER BY ANOTHER USER
(ASSTRONAUT WILL CAUSE SUCH TERMINATION)

SAVE REGISTERS FOR INTERRUPTED PROGRAM
(L = MEMORY BANK INFORMATION)
(Q = USUAL CONTENTS)

SET UP INPUT TO STICKCHK SIGNALS FROM ASTRONAUT VIA ROTATIONAL NANO CONTROLLER

INPUT: BITS 6-1 OF A = COMPLEMENT OF SOME CHANNEL INPUTS

OUTPUT:
PMANNOX: BITS 15-3 = 0
BITS 2-1 = BITS 2-1 OF A
YMANNHX: BITS 15-3 = 0
BITS 2-1 = BITS 4-3 OF A
RMANNOX: BITS 15-3 = 0
BITS 2-1 = BITS 6-5 OF A

RESULT:
PMANNOX OR 0 — INDICATES NO ROTATION
YMANNOX OR 1 — INDICATES POSITIVE ROTATION
RMANNOX OR 2 — INDICATES NEGATIVE ROTATION

IN PITCH, YAW, ROLL DIRECTIONS, RESPECTIVELY

SATRATE +0 = ZERO ROTATION
SATRATE +1 = POSITIVE ROTATION
SATRATE +2 = NEGATIVE ROTATION

MAGNITUDE OF POSITIVE OR NEGATIVE ROTATION IS EXPRESSED AS FRACTION OF MAXIMUM ROTATION RATE EFFECTED BY RGS CONTROL, WHICH IS:
.5 006/SEC FOR ROLL
.3 006/SEC FOR PITCH, YAW.

INPUT:
AK = ROLL RATE COMMAND
AK1 = PITCH RATE COMMAND
AK2 = YAW RATE COMMAND

NEEDLER DISPLAY AND TRANSMIT TO SATURN ROTATIONAL RATE COMMANDS
FC 2370

RESUME

WILL RETURN TO INTERRUPTED PROGRAM
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALCSTA</td>
<td>2260</td>
<td>COMPUTES EULER ANGLES NECESSARY TO ACHIEVE DESIRED ATTITUDE</td>
<td>SH. 13</td>
</tr>
<tr>
<td>COUTRIG</td>
<td>2270</td>
<td>READS PRESENT IMU GIMBAL ANGLES AND COMPUTES THEIR TRIGONOMETRIC FUNCTIONS</td>
<td>SH. 13</td>
</tr>
<tr>
<td>EARTHIR+3</td>
<td>2530</td>
<td>COMPUTES AND COMPENSATES FOR EFFECT OF EARTH'S ROTATION ON STABLE MEMBER ORIENTATION</td>
<td>SH. 5</td>
</tr>
<tr>
<td>LALOTORY</td>
<td>2280</td>
<td>COMPUTES POSITION VECTOR IN REFERENCE COORDINATES GIVEN LATITUDE, LONGITUDE, ALTITUDE</td>
<td>SH. 7</td>
</tr>
<tr>
<td>LALOTORY+4</td>
<td>2280</td>
<td>COMPUTES POSITION VECTOR GIVEN LATITUDE, LONGITUDE, ALTITUDE, AND GAMMA (WEIGHTING PARAMETER)</td>
<td>SH. 7</td>
</tr>
<tr>
<td>NEEDLER</td>
<td>2370</td>
<td>DISPLAYS (ON FD11 NEEDLES) ATTITUDE ERRORS OR STEERING COMMANDS AND, IF ENABLED, TRANSmits STEERING COMMANDS TO SATURN II</td>
<td>SH. 4, 16, 17, 20, 21</td>
</tr>
<tr>
<td>NEWMODE</td>
<td>2310</td>
<td>CHANGES MAJOR MODE AND DISPLAYS IT</td>
<td>SH. 4</td>
</tr>
<tr>
<td>NORMALIZE</td>
<td>2683</td>
<td>DOES INITIAL STATE VECTOR UPDATE</td>
<td>SH. 9</td>
</tr>
<tr>
<td>POWERSERS</td>
<td>2090</td>
<td>EVALUATES POLYNOMIAL</td>
<td>SH. 11</td>
</tr>
<tr>
<td>PREREADJ</td>
<td>2683</td>
<td>CLEARS PIPAS AND INITIALIZES SERVICER</td>
<td>SH. 4</td>
</tr>
<tr>
<td>PROUT</td>
<td>2530</td>
<td>CAUSES DELAY UNTIL GYRO TORQUING FINISHED</td>
<td>SH. 5</td>
</tr>
<tr>
<td>READACCS</td>
<td>2683</td>
<td>READS ACCELEROMETERS, SETS UP SERVICER; NESC'HEDULES ITSELF EVERY 2 SECONDS UNTIL STOPPED</td>
<td>SH. 9</td>
</tr>
<tr>
<td>STICKCHK</td>
<td>2370</td>
<td>DECODES RC COMMANDS INTO PITCH, ROLL, YAW COMMANDS</td>
<td>SH. 21</td>
</tr>
<tr>
<td>VISTO2S</td>
<td>2100</td>
<td>CONVERTS ANGLES FROM 1'S COMPLEMENT TO 2'S COMPLEMENT REPRESENTATION</td>
<td>SH. 14</td>
</tr>
<tr>
<td>ZEROJET</td>
<td>2380</td>
<td>CLEARS RCS JET CHANNELS</td>
<td>SH. 19</td>
</tr>
</tbody>
</table>

### FLAGS

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMOONFLG</td>
<td>STATE VECTOR IS IN LUNAR SPHERE OF INFLUENCE</td>
<td>STATE VECTOR IS IN EARTH SPHERE OF INFLUENCE</td>
<td>SH. 18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAPBIT1</td>
<td>BOTH SET - SATURN DAPBIT1 = 1 DAPBIT2 = 0 UNDER TVC</td>
<td>DAPBIT1 = 0 BOTH CLEAR DAPBIT2 = 1 RCS DAP IN DAP IN CONTROL CONTROL</td>
<td>SH. 19</td>
<td>SH. 10</td>
<td></td>
</tr>
<tr>
<td>DAPBIT2</td>
<td>STICK DAP IN CONTROL</td>
<td>DAP IN DAP IN CONTROL</td>
<td>SH. 19</td>
<td></td>
<td>SH. 10</td>
</tr>
<tr>
<td>ERAFLG</td>
<td>COMPUTE EARTH RADIUS, ASSUME FIXED MOON RADIUS</td>
<td>ASSUME CONSTANT EARTH RADIUS, USE RLS FOR MOON RADIUS</td>
<td>SH. 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOONPO1</td>
<td>MAJOR MODE PO1 MAY NOT BE SELECTED</td>
<td>MAJOR MODE PO1 MAY BE SELECTED</td>
<td>SH. 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCSFLG</td>
<td>FIRST PASS THROUGH NEEDLER</td>
<td>LATER THAN FIRST PASS THROUGH NEEDLER</td>
<td>SH. 4, 17, 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>REFMSFLG</td>
<td>REFSMMAT IS VALID GIVES KNOWN ORIENTATION OF STABLE MEMBER</td>
<td>STABLE MEMBER ORIENTATION UNKNOWN</td>
<td>SH. 8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Displays

<table>
<thead>
<tr>
<th>VERB-NOUN</th>
<th>TYPE OF DISPLAY</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>V06N82</td>
<td>NORMAL SNAPSHOT</td>
<td>R1 XXXXX, FT/SEC VMAG = (MAGNITUDE OF VELOCITY)</td>
<td>SH. 18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2 XXXXX, FT/SEC HDOT = (RATE OF CHANGE OF ALTITUDE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3 XXXX, X NM ALT I = ALTITUDE ABOVE EARTH OR MOON SURFACE, AS APPROPRIATE</td>
<td></td>
</tr>
</tbody>
</table>

## Erasable Locations Used

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>AK</td>
<td>(E_A)₁</td>
<td>ROLL ATTITUDE ERROR (OR ROLL RATE COMMAND)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>AK1</td>
<td>(E_A)₂</td>
<td>PITCH ATTITUDE ERROR (OR PITCH RATE COMMAND)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>AK2</td>
<td>(E_A)₃</td>
<td>YAW ATTITUDE ERROR (OR YAW RATE COMMAND)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>ALT₁D</td>
<td>H</td>
<td>ALTITUDE OF VEHICLE ABOVE EARTH OR MOON SURFACE, AS APPROPRIATE</td>
<td>M</td>
<td>M</td>
<td>2²⁸</td>
</tr>
<tr>
<td>AVEGEXITD</td>
<td></td>
<td>VARIABLE LOCATION OF SUBROUTINE ENTERED AT END OF SERVICER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BANKRUPT</td>
<td></td>
<td>USED TO SAVE BANK REGISTER OF INTERRUPTED PROGRAM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIASAK</td>
<td></td>
<td>ROLL ATTITUDE ERROR AT TIME CMC IS PUT IN CONTROL OF SATURN</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>BIASAK+1</td>
<td></td>
<td>PITCH ATTITUDE ERROR AT TIME CMC IS PUT IN CONTROL OF SATURN</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>BIASAK+2</td>
<td></td>
<td>YAW ATTITUDE ERROR AT TIME CMC IS PUT IN CONTROL OF SATURN</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>CDUSPOTX</td>
<td></td>
<td>IMU OUTER GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁰</td>
</tr>
<tr>
<td>CDUSPOTY</td>
<td></td>
<td>IMU INNER GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁰</td>
</tr>
<tr>
<td>CDUSPOTZ</td>
<td></td>
<td>IMU MIDDLE GIMBAL ANGLE (SNAPSHOT) (1'S COMPLEMENT)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁰</td>
</tr>
<tr>
<td>CDUX</td>
<td></td>
<td>IMU OUTER GIMBAL ANGLE (2'S COMPLEMENT)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>CDUY</td>
<td></td>
<td>IMU INNER GIMBAL ANGLE (2'S COMPLEMENT)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>CDUZ</td>
<td></td>
<td>IMU MIDDLE GIMBAL ANGLE (2'S COMPLEMENT)</td>
<td>DEGREES</td>
<td>REV 5</td>
<td>2⁻¹</td>
</tr>
<tr>
<td>COSCDFUX</td>
<td></td>
<td>COSINE OF IMU OUTER GIMBAL ANGLE</td>
<td>2¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COSCDUY</td>
<td></td>
<td>COSINE OF IMU INNER GIMBAL ANGLE</td>
<td>2¹</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION
P11 - EARTH ORBIT INSERTION MONITOR

DRAWN: PROOF: ANALYS: DRAWN: APPR: COLOSSUS 2 A

FC-2540 SHEET 23 OF 27
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSCJDZ</td>
<td>COSINE OF IMU MIDDLE GIMBAL ANGLE</td>
<td></td>
<td></td>
<td></td>
<td>$2^1$</td>
</tr>
<tr>
<td>DNLSTCOD</td>
<td>INDICATES WHICH LIST OF INFORMATION IS TO BE TRANSMITTED BY DOWNLINK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECOMPV</td>
<td>ROTATION RATE AFFECTING IMU IN STABLE MEMBER COORDINATES</td>
<td>DEG/SEC</td>
<td>REV/CSEC</td>
<td></td>
<td>$2^1$</td>
</tr>
<tr>
<td>HDOTD</td>
<td>RATE OF CHANGE OF ALTITUDE</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td></td>
<td>$2^7$</td>
</tr>
<tr>
<td>IGCD</td>
<td>INNER IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE</td>
<td>DEGREES</td>
<td>REV</td>
<td></td>
<td>$2^0$</td>
</tr>
<tr>
<td>LATD</td>
<td>POSITION SPECIFIED IN TERMS OF LATITUDE, LONGITUDE, ALTITUDE</td>
<td>DEGREES</td>
<td>REV</td>
<td></td>
<td>$2^0$</td>
</tr>
<tr>
<td>LIFTTEMPD</td>
<td>TEMPORARY STORAGE FOR LIFTOFF TIME</td>
<td>SEC</td>
<td>CSEC</td>
<td></td>
<td>$2^{28}$</td>
</tr>
<tr>
<td>MGCD</td>
<td>MIDDLE IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE</td>
<td>DEGREES</td>
<td>REV</td>
<td></td>
<td>$2^0$</td>
</tr>
<tr>
<td>OGC</td>
<td>OUTER IMU GIMBAL ANGLE CORRESPONDING TO DESIRED ATTITUDE</td>
<td>DEGREES</td>
<td>REV</td>
<td></td>
<td>$2^0$</td>
</tr>
<tr>
<td>PMANNIX</td>
<td>INDICATES ZERO, POSITIVE OR NEGATIVE PITCH COMMAND BY VALUE OF 0, 1 OR 2, RESPECTIVELY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QPLACES</td>
<td>VARIABLE EXIT FROM PRUOT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QRUPT</td>
<td>USED TO SAVE Q REGISTER OF INTERRUPTED PROGRAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REFSMMA, M</td>
<td>TRANSFORMATION MATRIX RELATING STABLE MEMBER AND REFERENCE COORDINATE SYSTEMS</td>
<td></td>
<td></td>
<td></td>
<td>$2^1$</td>
</tr>
<tr>
<td>RLSV</td>
<td>LUNAR LANDING SITE VECTOR IN REFERENCE COORDINATES</td>
<td>M</td>
<td>M</td>
<td></td>
<td>$2^{27}$</td>
</tr>
<tr>
<td>RMANNIX</td>
<td>INDICATES ZERO, POSITIVE OR NEGATIVE ROLL COMMAND, BY VALUE OF 0, 1 OR 2, RESPECTIVELY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RXV</td>
<td>POSITION VECTOR IN REFERENCE COORDINATES</td>
<td>M</td>
<td>M</td>
<td></td>
<td>$2^{20}$</td>
</tr>
<tr>
<td>RNIV</td>
<td>TEMPORARY UPDATED VERSION OF RNV (ABOVE)</td>
<td>M</td>
<td>M</td>
<td></td>
<td>$2^{20}$</td>
</tr>
<tr>
<td>RTX2</td>
<td>INDICATES WHETHER IN EARTH OR MOON SPHERE OF INFLUENCE, BY VALUE OF 0 OR 2, RESPECTIVELY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGC TAG</td>
<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING UNITS</td>
<td>AGC UNITS</td>
<td>AGC SCALING</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>---------</td>
<td>------------------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>SATRLRT</td>
<td>(\text{SIGN}K_2K_R)</td>
<td>NOMINAL SATURN ROLL RATE (SEE PAD LOAD SECTION)</td>
<td>DEG/SEC</td>
<td>REV/CSEC</td>
<td>2^0</td>
</tr>
<tr>
<td>SATSW</td>
<td></td>
<td>INDICATES WHETHER CMC IS IN CONTROL OF SATURN STAGE AND, IF SO, WHETHER THIS IS FIRST OR LATER PASS THROUGH ATERJOB IN THIS SITUATION, BY VALUE &gt;0, &lt;0, OR &gt;0, RESPECTIVELY</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>SINCDUX</td>
<td></td>
<td>SINE OF OUTER IMU GIMBAL ANGLE</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>SINCDUY</td>
<td></td>
<td>SINE OF INNER IMU GIMBAL ANGLE</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>SINCDUZ</td>
<td></td>
<td>SINE OF MIDDLE IMU GIMBAL ANGLE</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>SPOLYARG</td>
<td>(T_p)</td>
<td>TIME SINCE NOMINAL START OF ROLL</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^14</td>
</tr>
<tr>
<td>TRASE5</td>
<td></td>
<td>LOW-ORDER HALF OF TIME FROM WHICH A TIMES FOR GROUP 5 WAITLIST TASK RESTARTS ARE TO BE COUNTED</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^28</td>
</tr>
<tr>
<td>TEPHEM_T</td>
<td>(T_{OK})</td>
<td>REFERENCE EPHemeris TIME</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^42</td>
</tr>
<tr>
<td>TEPHEM1_T</td>
<td>(T_{OK})</td>
<td>TEMPORARY UPDATED VERSION OF TEPHEM_T (ABOVE)</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^42</td>
</tr>
<tr>
<td>THETANV</td>
<td></td>
<td>STABLE MEMBER DRIFT, ETC. NOT CORRECTED DURING PRELAUNCH IN EARTH-FIXED COORDINATES</td>
<td>DEG/SEC</td>
<td>REV/CSEC</td>
<td>2^21</td>
</tr>
<tr>
<td>TIME2_D</td>
<td>(\left(\frac{\text{TIME2}}{\text{TIME1}}\right))</td>
<td>PRESENT TIME [AFTER LIFTOFF; PRESENT (\Delta) TIME FROM LIFTOFF]</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^28</td>
</tr>
<tr>
<td>TLTIPOFFD</td>
<td>(T')</td>
<td>TIME OF LIFTOFF</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^28</td>
</tr>
<tr>
<td>VMAGI_D</td>
<td>(V)</td>
<td>MAGNITUDE OF VELOCITY</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^7</td>
</tr>
<tr>
<td>VN_V</td>
<td>(V(T))</td>
<td>VELOCITY VECTOR, IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^7</td>
</tr>
<tr>
<td>VNI_V</td>
<td>(V(T+\Delta T))</td>
<td>TEMPORARY UPDATED VERSION OF VN_V (ABOVE)</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^7</td>
</tr>
<tr>
<td>XDC_V</td>
<td></td>
<td>DESIRED STABLE MEMBER X-AXIS IN TERMS OF ORIGINAL STABLE MEMBER ORIENTATION</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>XSM_M</td>
<td></td>
<td>MATRIX FOR CONVERSION FROM EARTH-FIXED TO STABLE MEMBER COORDINATE SYSTEM</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>YDC_V</td>
<td></td>
<td>DESIRED STABLE MEMBER Y-AXIS IN TERMS OF ORIGINAL STABLE MEMBER ORIENTATION</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>YMANNIX</td>
<td></td>
<td>INDICATES ZERO, POSITIVE OR NEGATIVE YAW COMMAND, BY VALUE OF 0, 1 OR 2, RESPECTIVELY</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>ZDC_V</td>
<td></td>
<td>DESIRED STABLE MEMBER Z-AXIS IN TERMS OF ORIGINAL STABLE MEMBER ORIENTATION</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>1/PIPAUT</td>
<td></td>
<td>(\Delta) TIME BETWEEN PIPA READINGS</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^8</td>
</tr>
</tbody>
</table>
### PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>-ERTHRAT</td>
<td>&quot;E&quot;</td>
<td>RATE OF EARTH ROTATION</td>
<td>-7.292115138 x 10^-5 RAD/SEC</td>
<td>-7.292115138 x 10^-7 RAD/CSEC</td>
<td>2^-18</td>
</tr>
<tr>
<td>RPAD</td>
<td>RL_P</td>
<td>MAGNITUDE OF POSITION VECTOR FOR LAUNCH PAD</td>
<td>6,373,338 M</td>
<td>6,373,338 M</td>
<td>2^29</td>
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</table>

### PAD LOADS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP TAG</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
<th>OCTAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AZIMUTH</td>
<td>AZP</td>
<td>AZIMUTH (AT LAUNCH) FROM NORTH TO SPACECRAFT +Z-AXIS</td>
<td>DEGREES</td>
<td>DEGREES</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>LATITUDE</td>
<td>LATP</td>
<td>LATITUDE OF LAUNCH PAD</td>
<td>DEGREES</td>
<td>DEGREES</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>LAUNCHAZ</td>
<td>AZ</td>
<td>AZIMUTH (AT LAUNCH) FROM NORTH TO STABLE MEMBER +X-AXIS</td>
<td>DEGREES</td>
<td>DEGREES</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>PADLONG</td>
<td>LONP</td>
<td>LONGITUDE OF LAUNCH PAD</td>
<td>DEGREES</td>
<td>DEGREES</td>
<td>2^0</td>
<td></td>
</tr>
<tr>
<td>GNCSALT</td>
<td>ALT N-1</td>
<td>ALTITUDE OF IMU 1 LESS THAN DEGREE OF POLYNOMIAL FOR COMPUTATION OF NOMINAL PITCH ANGLE</td>
<td>M</td>
<td>M</td>
<td>2^26</td>
<td></td>
</tr>
<tr>
<td>POLYNUM</td>
<td>POLY</td>
<td>POLYNOM</td>
<td>SEC</td>
<td>SEC</td>
<td>2^14</td>
<td></td>
</tr>
<tr>
<td>POLY</td>
<td>POLY</td>
<td>POLYNOM</td>
<td>SEC</td>
<td>SEC</td>
<td>2^14</td>
<td></td>
</tr>
</tbody>
</table>

### SATRATE

<table>
<thead>
<tr>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSSIBLE ROTATION RATE COMMAND TO SATURN- NO ROTATION</td>
<td>0</td>
</tr>
</tbody>
</table>

### SATRATE+1

<table>
<thead>
<tr>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSSIBLE ROTATION RATE COMMAND TO SATURN FRACTION OF MAXIMUM POSITIVE ROTATION RATE, WHICH IS: .5 DEG/SEC FOR ROLL, .3 DEG/SEC FOR PITCH, YAW</td>
<td></td>
</tr>
</tbody>
</table>

### SATRATE+2

<table>
<thead>
<tr>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>POSSIBLE ROTATION RATE COMMAND TO SATURN FRACTION OF MAXIMUM NEGATIVE ROTATION RATE, WHICH IS: -.5 DEG/SEC FOR ROLL, -.3 DEG/SEC FOR PITCH, YAW</td>
<td></td>
</tr>
</tbody>
</table>

---

**MIT INSTRUMENTATION LAB**
**Cambridge, Mass.**
**P11 - EARTH ORBIT INSERTION MONITOR**

**COLOSSUS III**
**FC-2540**
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP TAG</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
<th>OCTAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SATRLRTD</td>
<td>KR</td>
<td>ABSOLUTE VALUE OF NOMINAL SATURN ROLL RATE SIGN ATTACHED DURING THIS PROGRAM (SEE ERASABLE SECTION)</td>
<td>1 DEG/SEC</td>
<td>1/56000 REV/ CSECOND</td>
<td>2^0</td>
<td>00000 18441</td>
</tr>
<tr>
<td>SATSCALE</td>
<td></td>
<td>SCALING FACTOR FOR ATTITUDE CORRECTION COMMANDS TO SATURN HARDWARE</td>
<td>SAME</td>
<td>SAME</td>
<td>2^0</td>
<td>SAME</td>
</tr>
</tbody>
</table>
| UNITW V  | UZ       | UNIT VECTOR IN DIRECTION OF EARTH ROTATION VECTOR (Z) IN REFERENCE COORDINATES | \[
\begin{align*}
3.32402568949 \\
4.18407084553 \\
0.999999998 \\
\times 10^{-5} \\
\times 10^{-5} \\
\times 10^{-1}
\end{align*}
\] | SAME | 2^0         | 7777772 725031 |
|          |          |          | 000001 257407          |          |          | 777771 377771 |
THE MAJOR SUBROUTINES IN THE TPI SEARCH PROGRAM ARE
P17, P77, P17.1, P17.2, P17.3, S17.1, S17.2, S17.3

SPECIAL CONVENTIONS

P17/P77 IS A COLOSSUS AND LUMINARY PROGRAM. THE TERMS PERIGEE (EARTH), PERILUNE (MOON), AND PERICENTER, APOGEE, APOLUNE, APOCENTER, ARE USED INTERCHANGEABLY WITHOUT DISTINGUISHING EXPLICITLY THE PROPER SPHERE OF INFLUENCE.

THE NOTATION USED FollowS THE CONVENTIONS ESTABLISHED IN SECTION 5.4.4.4 OF R577, IN PARTICULAR FIG. 4.4.4.
IF KFLAG IS SET (K = 1), OPTION 2 IS LOADED WITH 1. INDICATING PREFERRED SEARCH SECTOR < 180°. OTHERWISE OPTION 2 = 2, SEARCH SECTOR > 180°.

ASTRONAUT HAS THE FOLLOWING OPTIONS:
1. PROCEED IF SATISFIED WITH \( \beta, \Delta h, \) K DISPLAYED V35E.
2. TERMINATE TO END MAJOR MODE BY V34E.
3. RECYCLE V33E WHICH WILL CAUSE PROGRAM TO RETURN TO PIT1 ABOVE AND REQUEST NEW TPI TIME.

IF ASTRONAUT CHANGED SEARCH SECTOR, ALTER KFLAG ACCORDINGLY.

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CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

TPC SEARCH PROGRAMS

PIT 6, PIT 7

COLOSSUS II

FC-2545
FROM PRECEDING SHEET

SITZ

SAVE QPRET IN QTEMP

IT = √((UNIT(x2) + m0) + 0.002)

WPIAC = (UNIT(RACO) - 62 + DP - 0.002)

UNITS ARE RADIANS @ 2°

YES

KFLAG SET

NO

SIGN OF IT+ IF SEARCH SECTOR < 180°
SIGN OF IT- IF SEARCH SECTOR > 180°
CONVERT IT IN RADIANS TO IT IN REV

K1IT(REV) = IT/π (RAO)
MPAC = MPAC + PIINVERS

K1IT(REV) = IT/π (RAD)
MPAC = COMPC MPAC PIINVERS

w1t = T + ϕ + K1IT

IT = THETZERO - MPAC

SIGN OF ϕ WILL BE + (-ϕ) IF ACTIVE VEHICLE LAGS

SINUTo = SIN(T + ϕ + K1IT)
SNTH = SIN(-THETZERO - MPAC)

COSUTo = COS(T + ϕ + K1IT)
COSII = COS(-THETZERO - MPAC)

COMPLEMENT IF +

SET RVSW

INDICATES FINAL STATE VECTOR NOT TO BE COMPUTED IN TIME-THETA ROUTINE, BELOW

X1 = XPS

RE-ESTABLISH X1 IN CASE OF RE-START

ADJUST SCALING OF RPA53, VPA53 TO COMPENSATE EARTH/MOON

X2 CONTAINS O IN EARTH SPHERE OF INFLUENCE 2.25 RADIUS OF EARTH, VPA53 ARE SCALED 2.25/2.25. THEY ARE SHIFTED RIGHT ON X2 (2° IF EARTH, 2°-2 IF MOON) OBTAINING INPUTS TO TIME-THETA SCALING 2.25/2.25 FOR EARTH INFLUENCE, 2.25/2.25 FOR MOON.
FROM PREcedING SHEET

TIMETHET

Given \( t_p \), \( \nu_0 \) at TP1 time and \( \sin \omega_0 \), \( \cos \omega_0 \),

TIME THET RETURNS TIME OF FLIGHT \( t_f \)

IN GSEC @ 2.18

Time of flight returned by TIMETHET stored as both \( t_f \), intermediate flight time subject to iterative optimization, and \( t_{fp} \), first approximation \( t_f \)

\[
\text{Sin}\omega_f = \sin(T_f + \phi + k2\pi)
\]

\[
\text{SNTH} = \sin(IT)
\]

\[
\text{Cos}\omega_f = \cos(T_f + \phi + k2\pi)
\]

\[
\text{CSI} = \cos(IT)
\]

Complement if +

\[
X_1 = X_{RB}
\]

Re-establish indices

TIMETHET

Given \( t_f \) and \( \nu_0 \) at TP1 and \( \sin \omega_f \), \( \cos \omega_f \)

TIMETHET returns the time of flight \( t_{fp} \)

Store time calculated by TIMETHET as \( t_{fp} \)

Causes values of perigee height \( h_p \) obtained below to be tested when \( \text{CLEAR ITSWITCH} \) is set when acceptable \( h_p \) is found by test, causing \( h_p \) to bypass test on next iteration

\[
\Delta V = 125 \text{ m/sec}
\]

\[
\begin{align*}
\Delta V &= 125 \text{ m/sec} \\
\Delta V &= \frac{-2\pi h_p}{h_p} \\
\Delta V &= \text{DEPMSX} \\
\Delta V &= \text{MANYFLUT}
\end{align*}
\]

Largest possible value of velocity increment \( \Delta V = 125 \text{ m/sec} \) and lowest perigee height \( h_p = -2\pi h_p \) are stored for first perigee iteration, to ensure that \( h_p \) of first approximation \( \Delta V \) does not pass test on first iteration without further optimization.

NO

KFLAG SET

\[
\theta_1 = \frac{360}{360}
\]

\[
\text{THETL} \rightarrow \text{SECETH}
\]

CONCAUL

NEXT SHEET

YES

\[
\theta_1 = \frac{70}{360}
\]

\[
\text{THETL} \rightarrow \text{SECETH}
\]

SET \( \alpha \), outer limit angle according to search sector in REV @ 2°

NEXT SHEET
FROM PRECEDING SHEET

SCALE \( V_1, I_x \) (\( t = 0 \))
\( 2^6 \) FOR \( 2^{29/2} \) (EARTH)
\( 2^8 \) FOR \( 2^{31/2} \) (MOON)

ADJUST SCALING OF TRANSFER TRAJECTORY INITIAL POS., VEL. ON X2 INDEX REGISTER TO OBTAIN CORRECT \( 2^{33}/2^7 \) OR \( 2^{33}/2^8 \) EARTH-MOON SCALING USING X2.

PERIAPO
CALCULATE \( h_p \)
PERIGEE HEIGHT FOR TRANSFER TRAJECTORY
FC-2630

COMPUTES THE PERIGEE HEIGHT \( h_p \) BASED ON \( I_x, V_x \)
FOR THE TRAJECTORY RETURNED BY INITVEL.

\( X_2 \leftarrow X_R + 1 \)
MPAC \( \rightarrow h_p \)
RESTORE \( h_p \) TO
\( 2^{19} \) SCALINGS IF LUNAR MISSION

\( h_p \) MUST BE SCALED \( 2^{29} \) IN BOTH EARTH AND MOON SPHERES OF INFLUENCE SO ITS SCALING WILL MATCH THE \( 2^{19} \) VALUE OF THE THRESHOLD VALUE \( h_p \) LIMIT IN THE TESTS THAT FOLLOW.

\( h_p \leftarrow h_p \)
STORE SCALING \( h_p \) @ \( 2^{19} \) FOR LIMIT TEST.

NEXT SHEET
ALARMS

SET UPDATELG

ALARMS
00124
NO SAFE PERICENTER

MPAC VOSNO9

VNCOMPIT

VINCOMPIT IS A DISPLAY ROUTINE (SEE SHEET 3) THAT INTERFACES WITH DISPLAYS FOR DIFFERENT VERB-NOUS.

REDISPLAY

V84E

ALARM CODE
124

V52E

GOFLASH

ALARM LIGHT AND CAUSES VOSNO9 AND ALARM CODE 00124 (NO SAFE PERICENTER) TO APPEAR IN A FLASHING DISPLAY.

V84E CAUSES THE DISPLAY TO CONTINUE.

V52E WILL CAUSE THE PROGRAM TO TERMINATE.

V52E WILL CAUSE THE PROGRAM TO RECYCLE AND BEGIN AGAIN AT THE BEGINNING WITH A REQUEST THAT A NEW TPI TIME BE SELECTED.

FER CHS

RECYCLE WITH NEW TPI TIME AND/OR SEARCH OPTION.

GOTOOPRIN

INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE NAVIGATION

TPI SEARCH PROGRAMS
R7 & R77

COLOSUS II
FC-2545

DOCUMENT NO.

AUTHOR

DATE

REV

PAGE

WIT
TRANSANG computes the central angle of transfer by calculating \( \omega_f \), the angular velocity of the passive vehicle (using \( \omega_p \) and \( \omega_f \) at intercept) and multiplying by \( \frac{T_f}{T_r} \), the time of flight.

X1 and X2 loaded with addressing and scaling indices for Earth or Moon

\[
\begin{array}{c|c|c}
\text{Earth} & \text{Moon} \\
\hline
X1 & X2 & \hline
-2 & 10 & \\
\end{array}
\]

\[ v_f \text{ at intercept scaled on } X_e \]
\( (0,2) \) to obtain \( 2^5/2^7 \) scaling

\[ \alpha = 1.39650495 \times 10^5 \times 2^{18} \text{ if Earth} \]
\[ = 2.21422176 \times 10^4 \times 2^{15} \text{ if Moon} \]

\[ \mu = 2.25087606 \times 10^{-10} \times 2^{34} \text{ if Earth} \]
\[ = 2.03946 \times 10^{-8} \times 2^{28} \text{ if Moon} \]

\[ \alpha_p \text{ is the semi-major axis of the ellipse} \]

\[ \omega_r = \frac{T_r \cdot v_f}{2 \pi} \]

\[ \omega = \frac{\mu^2}{(D^2 - MPAC)} \]

\[ \text{MPAC} = \frac{\omega}{2 \pi} \text{ (on radians)} \]

\[ \text{MPAC} = \frac{TF \cdot PLO0 \cdot PLO2 \cdot PLO6}{2 \pi} \]

Output: \( \omega \) (Rev) \nSemitaxis: MPAC

Return via SUBEXIT
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVFLAGA</td>
<td>2830</td>
<td>Clears AVFLAG, sets ECSTEER bit 13</td>
<td>SH. 3</td>
</tr>
<tr>
<td>AVFLAGP</td>
<td>2850</td>
<td>Sets AVFLAG</td>
<td>SH. 3</td>
</tr>
<tr>
<td>P20FLGON</td>
<td>2290</td>
<td>Advances LM ( \xi, \psi ) to specified time ( \omega ) or orbital integration</td>
<td>SH. 3</td>
</tr>
<tr>
<td>LEMCONIC</td>
<td>2290</td>
<td>Stores LEM CONIC output in active locs if AVFLAG set, passive locs if AVFLAG clear</td>
<td>SH. 3, 8</td>
</tr>
<tr>
<td>LEMSTORE</td>
<td>2290</td>
<td>Advances LEM CONIC ( \psi ) to specified time ( t_{TP} )</td>
<td>SH. 4, 5</td>
</tr>
<tr>
<td>CSMCONIC</td>
<td>2290</td>
<td>Stores CSM output in active/passive locs if AVFLAG CLEAR/SET</td>
<td>SH. 4</td>
</tr>
<tr>
<td>CSMSTORE</td>
<td>2310</td>
<td>Computes CSM time of flight given initial ( \xi_A, \psi_A ) and terminal ( \xi_p, \psi_p ) of transfer trajectory</td>
<td>SH. 7(2)</td>
</tr>
<tr>
<td>TIMETHEL</td>
<td>2310</td>
<td>Computes time of flight given initial ( \xi_A, \psi_A ) and terminal ( \xi_p, \psi_p ) of transfer trajectory</td>
<td>SH. 7(2)</td>
</tr>
<tr>
<td>INITVEL</td>
<td>2830</td>
<td>Computes ( \xi_A, \psi_A ) at ( t_{TP} ) and ( \xi_p, \psi_p ) at ( t_{TP} ) ( t_{TP} ) INITVEL computes ( \xi_1, \psi_1 ). Active vehicle velocity at beginning and end of transfer trajectory</td>
<td>SH. 8</td>
</tr>
<tr>
<td>PERIAPO</td>
<td>2830</td>
<td>Computes ( \xi_p ) for the trajectory computed by INITVEL</td>
<td>SH. 9</td>
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### FLAGS

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<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
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<tr>
<td>AVFLAG</td>
<td>LM ACTIVE</td>
<td>CSM ACTIVE</td>
<td>SH. 4</td>
<td>SH. 4</td>
<td>SH. 3, 4, 8</td>
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<td>TRACKFLG</td>
<td>MARK TRACKING ALLOWED</td>
<td>MARK TRACKING INHIBITED</td>
<td>SH. 3</td>
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<tr>
<td>UPDATFLG</td>
<td>STATE VECTOR UPDATE ALLOWED</td>
<td>STATE VECTOR UPDATE ALLOWED</td>
<td>SH. 3, 4, 12, 13</td>
<td>SH. 3, 5</td>
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<td>KFLAG</td>
<td>(-\Delta h ) (ACTIVE ABOVE) SEARCH SECTOR (-180^\circ)</td>
<td>(+\Delta h ) (PASSIVE VEHICLE ABOVE) SEARCH SECTOR (+180^\circ)</td>
<td>SH. 4, 5</td>
<td>SH. 4, 5</td>
<td>SH. 5, 6, 7, 10, 11</td>
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<tr>
<td>RVSW</td>
<td>FINAL STATE VECTOR NOT TO BE COMPUTED IN TIMETHEL</td>
<td>COMPUTE FINAL STATE VECTOR IN TIMETHEL</td>
<td>SH. 6</td>
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<tr>
<td>ITSWITCH</td>
<td>ACCEPT NEXT ( \xi_p ) AS SOLUTION</td>
<td>TEST NEXT ( \xi_p ) REITERATE</td>
<td>SH. 10</td>
<td>SH. 7</td>
<td>SH. 10</td>
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## DISPLAYS

<table>
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<tr>
<th>VERB-NOUN</th>
<th>TYPE OF DISPLAY</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
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<tbody>
<tr>
<td>V08N37</td>
<td>GOFLASH</td>
<td>TPI TIME IN R1 O0XXX HOURS</td>
<td>SH, 3</td>
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<tr>
<td></td>
<td></td>
<td>R2 O0XXX MINUTES</td>
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<td></td>
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<td>R3 OXX XX SECONDS</td>
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<tr>
<td>V08N72</td>
<td>GOFLASH</td>
<td>R1 PHI XXX XX DEG ACTIVE VEHICLE LEAD ANGLE</td>
<td>SH, 5</td>
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<td></td>
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<td>R2 BELHIT4 XXXXX X NM PASSIVE VEHICLE ALT.</td>
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<tr>
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<td>R3 OPTION2 XXXXXX. RELATIVE ACTIVE (H. ABOVE)</td>
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<td></td>
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<td>SEARCH SECTOR 1&lt;180°, 2&gt;80°</td>
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<tr>
<td>V08N58</td>
<td>GOFLASH</td>
<td>R1 hp XXXX X NM PERIGEE HEIGHT</td>
<td>SH, 12</td>
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<td></td>
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<td>R2 ΔVₜ₂ₚхи XXXX X FT/SEC VELOCITY INCREMENT IMPARTED AT TPI</td>
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<tr>
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<td></td>
<td>R3 ΔVₜ₂ₚхи XXXX X FT/SEC VELOCITY DIFFERENTIAL AT INTERCEPT</td>
<td></td>
</tr>
<tr>
<td>V08N55</td>
<td>GOFLASHR</td>
<td>R1 XXXXX. P (PERCENT PERICENTER) P = 1 TRANSFER COMPLETED</td>
<td>SH, 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2 BLANK CODE TRANSFER TRAJECTORY</td>
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<td></td>
<td></td>
<td>R3 XXX XX DEGREES SPANS PERICENTER</td>
<td></td>
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<tr>
<td>V05N09</td>
<td>ALARM</td>
<td>R1 00124 DISPLAYS 124 ALARM CODE IN R1 INDICATING</td>
<td>SH, 13</td>
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<td></td>
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<td>R2 BLANK NO SAFE PERICENTER THE SECTOR</td>
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## ERASABLE LOCATIONS USED'

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<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>TTP1</td>
<td>tTTP</td>
<td>STORAGE LOC FOR TPI TIME</td>
<td>SEC</td>
<td>CSEC</td>
<td>2²⁸</td>
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<tr>
<td>TDEC1</td>
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<td>STORAGE LOC FOR TIME INPUT TO CONICS</td>
<td>SEC</td>
<td>CSEC</td>
<td>2²⁸</td>
</tr>
<tr>
<td>RPASS3</td>
<td>r(pTTP)</td>
<td>PASSIVE VEHICLE POSITION AT TPI (TIG)</td>
<td>NM</td>
<td>M</td>
<td>2²⁹/²²⁷</td>
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<tr>
<td>VPASS3</td>
<td>v(pTTP)</td>
<td>PASSIVE VEHICLE VELOCITY AT TPI (TIG)</td>
<td>NM</td>
<td>M/CSEC</td>
<td>2⁷/²⁵</td>
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<tr>
<td>RACT3</td>
<td>tA(pTTP)</td>
<td>ACTIVE VEHICLE POSITION AT TPI (TIG)</td>
<td>NM</td>
<td>M</td>
<td>2²⁰/²²⁷</td>
</tr>
<tr>
<td>VACT3</td>
<td>vA(pTTP)</td>
<td>ACTIVE VEHICLE VELOCITY AT TPI (TIG)</td>
<td>NM</td>
<td>M/CSEC</td>
<td>2⁷/²⁵</td>
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<tr>
<td>DELHIT1</td>
<td>Δh</td>
<td>ACTIVE-TO-PASSIVE VEHICLE ALTITUDE</td>
<td>NM</td>
<td>M</td>
<td>2²⁰/²²⁷</td>
</tr>
<tr>
<td>E2</td>
<td>µIIp</td>
<td>UNIT VECTOR OF PASSIVE VEHICLE ORBITAL PLANE</td>
<td>UNITLESS FRACTION</td>
<td></td>
<td>2¹</td>
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<tr>
<td>THETZERO</td>
<td>φ</td>
<td>LEAD ANGLE OF PASSIVE VEHICLE RELATIVE TO ACTIVE VEHICLE AT TPI</td>
<td>DEG (TO NEAREST .01)</td>
<td>REV</td>
<td>2⁰</td>
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<tr>
<td>OPTION2</td>
<td></td>
<td>LOC CONTAINING SEARCH SECTOR k</td>
<td>DECIMAL 1 OR 2</td>
<td>NO UNITS</td>
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<tr>
<td>HIPERMIN</td>
<td>hiplim</td>
<td>TEMP LOC FOR HPL/HPE MOON/EARTH MINIMUM PERICENTER ALTITUDE</td>
<td>HPL 35,000 FT</td>
<td>M</td>
<td>2²⁰</td>
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<tr>
<td>IT</td>
<td>IT</td>
<td>LOC WHERE &quot;OUT OF PLANE&quot; FACTOR IS STORED FOR USE IN θ₁ &amp; θ₀ COMPUTATION</td>
<td>RAD</td>
<td></td>
<td>2⁰</td>
</tr>
</tbody>
</table>

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*MIT INSTRUMENTATION LAB CARY, MARYLAND*

TPI SEARCH PROGRAMS
P17 & P77

COLOSSUS II FC-2545
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>SNTII</td>
<td></td>
<td>STORAGE LOCATIONS: COS FORM REQUIRED FOR $\phi_{0}(\omega_{1})$ AND $\Phi_{1}(\omega_{1})$ INPUT TO TIMETHET</td>
<td>CSEC</td>
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<td>$2^{1}$</td>
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<tr>
<td>CSTH</td>
<td></td>
<td>FLIGHT TIME FOR INTERCEPT TRAJECTORY</td>
<td>CSEC</td>
<td>$2^{28}$</td>
<td>$2^{28}$</td>
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<tr>
<td>TF</td>
<td>$t_{F}$</td>
<td>FLIGHT TIME FOR FIRST APPROXIMATION</td>
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<td>$2^{28}$</td>
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<tr>
<td>TF0</td>
<td>$t_{F0}$</td>
<td>FLIGHT TIME FOR INTERCEPT LIMIT ($\omega_{1}$, $t_{p}$)</td>
<td>CSEC</td>
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<td>$2^{28}$</td>
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<tr>
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<td>$t_{F1}$</td>
<td>FLIGHT TIME FOR INNER LIMIT ($\omega_{1}$, $t_{p}$)</td>
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<td>$2^{28}$</td>
<td>$2^{28}$</td>
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<tr>
<td>DELVEE</td>
<td>$\Delta v$</td>
<td>VELOCITY INCREMENT REQUIRED FOR TRANSFER</td>
<td>M/SEC</td>
<td>M/CSEC</td>
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<tr>
<td>HP</td>
<td>$h_{p}$</td>
<td>PERICENTER HEIGHT</td>
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<td>VPASS4</td>
<td>$v_{p}(t_{TP1},t_{p})$</td>
<td>PASSIVE VEHICLE VELOCITY VECTOR AT INTERCEPT</td>
<td>M/SEC</td>
<td>M/CSEC</td>
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<tr>
<td>RPASS4</td>
<td>$v_{p}(t_{TP1},t_{p})$</td>
<td>PASSIVE VEHICLE VELOCITY VECTOR AT INTERCEPT</td>
<td>NM</td>
<td>M</td>
<td>$2^{29}$</td>
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<tr>
<td>HTARG</td>
<td>$r_{T}$</td>
<td>PASSIVE VEHICLE POSITION VECTOR AT INTERCEPT</td>
<td>M</td>
<td>$2^{29}$</td>
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<tr>
<td>HPO</td>
<td>$h_{p0}$</td>
<td>MINIMUM SAFE $h_{p}$ (HISTRY, SEE ABOVE)</td>
<td>FT(MOON)/NM(EARTH)</td>
<td>M</td>
<td>$2^{24}/2^{27}$</td>
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<tr>
<td>OHELVEO</td>
<td>$\Delta v_{o}$</td>
<td>VELOCITY INCREMENT TO ACHIEVE $v_{o}$ TRAJECTORY</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>$2^{7}$</td>
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<tr>
<td>INTIME</td>
<td>$t_{TP1}$</td>
<td>TEMP LOC FOR $t_{TP1}$ INPUT TO INITVEL</td>
<td>SEC</td>
<td>CSEC</td>
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<tr>
<td>XRS</td>
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<td>RINIT</td>
<td>$\delta_{A}(t_{TP1},t_{p})$</td>
<td>STORAGE FOR ACTIVE VEHICLE POSITION (INITVEL)</td>
<td>M</td>
<td>M</td>
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<td>VINIT</td>
<td>$\delta_{A}(t_{TP1},t_{p})$</td>
<td>STORAGE FOR ACTIVE VEHICLE VELOCITY (INITVEL)</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>$2^{7}$</td>
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<td>RELDELV</td>
<td>$\Delta v_{TPF}$</td>
<td>ACTIVE-PASSIVE VELOCITY DIFFERENTIAL AT INTERCEPT</td>
<td>FT/SEC</td>
<td>M/CSEC</td>
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<tr>
<td>MAGVTP1</td>
<td>$\Delta v_{TP1}$</td>
<td>ACTIVE-PASSIVE VELOCITY DIFFERENTIAL AT $t_{TP1}$</td>
<td>FT/SEC</td>
<td>M/CSEC</td>
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<tr>
<td>NN1</td>
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<td>STORAGE LOC FOR PERIGEE CODE</td>
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<tr>
<td>POSTTP1</td>
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<td>LOC FOR OUTPUT $h_{p}$ (TO BE DISPLAYED)</td>
<td>FT</td>
<td>—</td>
<td>$2^{29}$</td>
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<tr>
<td>RVEC</td>
<td>$r_{p}(t_{TP1},t_{p})$</td>
<td>STORAGE LOC FOR PASSIVE VEHICLE POSITION VECTOR INTERCEPT</td>
<td>—</td>
<td>M</td>
<td>$2^{28}/2^{27}$</td>
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<tr>
<td>VVEV</td>
<td>$v_{p}(t_{TP1},t_{p})$</td>
<td>STORAGE LOC FOR PASSIVE INTERCEPT VEHICLE VELOCITY</td>
<td>—</td>
<td>M/CSEC</td>
<td>$2^{7}/2^{5}$</td>
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<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING VALUE AND UNITS</td>
<td>AGC VALUE AND UNITS</td>
<td>AGC SCALING</td>
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<td>HPE</td>
<td>hpo</td>
<td>EARTH MINIMUM PERICENTER ALTITUDE</td>
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<td>157420.6 M</td>
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<td>Δt</td>
<td>1 INCREMENTS FOR SAFE h_p TEST</td>
<td>400 SEC</td>
<td>40000 CSEC</td>
<td>2^28</td>
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<tr>
<td>CLSEC</td>
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<td>MIN ΔV TEST</td>
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<td>SEC1THET</td>
<td>θ_1</td>
<td>OUTER SEARCH LIMIT 70° IF K&lt;1, 330° IF K&gt;1</td>
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<td>1944444444</td>
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<td>SEC2THET</td>
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<td>9166666667</td>
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<td>MANYFEET</td>
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<td>LARGE VALUE OF h_p CHOSEN FOR h_p TEST</td>
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<td>-2^27 M</td>
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<tr>
<td>LIMVEL</td>
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<td>THRESHOLD FOR ΔV−ΔV_0 MINIMUM TEST</td>
<td>500 FT</td>
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<td>DFTMOON</td>
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<td>MARGIN TO ALLOW FOR UNCERTAINTY IN MOON POSITION</td>
<td>6.28318530</td>
<td>6.28318530</td>
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<td>2PISC</td>
<td>2π</td>
<td>CONSTANT FOR RADIANS-TO-DEGREES SCALING</td>
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<td>2^18</td>
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<td>MOON: 2.2422176 x 10^5</td>
<td>2^15</td>
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<td>MUTABLE</td>
<td>√μ</td>
<td>SQUARE ROOT OF UNIVERSAL GRAVITY CONSTANT</td>
<td>EARTH: 25087600 x 10^-10</td>
<td>2^34</td>
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<td>+2, 1</td>
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<td>MOON: 203966 x 10^-9</td>
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<td>MUTABLE, 1</td>
<td>1/μ</td>
<td>RECIPROCAL OF UNIVERSAL GRAVITY CONSTANT</td>
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</table>
**RENDEZVOUS NAVIGATION PACKAGE**

The following programs and their related subroutines will be found in this flow chart:

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<tr>
<th>Program</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
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<td>PROG20</td>
<td>Rendezvous Navigation Program (P20)</td>
<td>SH. 3</td>
</tr>
<tr>
<td>V56E</td>
<td>Terminates P20</td>
<td>SH. 8</td>
</tr>
<tr>
<td>R61CSM</td>
<td>Attitude Maneuver Routine</td>
<td>SH. 11</td>
</tr>
<tr>
<td>CRS01, 1</td>
<td>Calculates DAP Inputs</td>
<td>SH. 10</td>
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<tr>
<td>V54E</td>
<td>COS Rendezvous Sighting Mark Routine (R23)</td>
<td>SH. 17</td>
</tr>
<tr>
<td>R23CSM</td>
<td>COS Mark Taking</td>
<td>SH. 18</td>
</tr>
<tr>
<td>V57E</td>
<td>SXT Rendezvous Sighting Mark Routine (R21)</td>
<td>SH. 17</td>
</tr>
<tr>
<td>R21CSM</td>
<td>SXT Mark Taking</td>
<td>SH. 18</td>
</tr>
<tr>
<td>H22</td>
<td>Rendezvous Mark Processing Routine</td>
<td>SH. 19</td>
</tr>
<tr>
<td>RANGERD</td>
<td>Reads VHF Radar Range Data</td>
<td>SH. 32</td>
</tr>
<tr>
<td>INITIAL</td>
<td>Initializes W-Matrix</td>
<td>SH. 36</td>
</tr>
<tr>
<td>GETUM</td>
<td>Calculates LOS Vector</td>
<td>SH. 38</td>
</tr>
<tr>
<td>BVECTORS</td>
<td>Computes AQ and BVECTOR</td>
<td>SH. 39</td>
</tr>
</tbody>
</table>

**Special Conventions:**

1) Scaling indicated as $2^{X/2}$ means $2^X$ is the scaling in Earth sphere of influence, and $2^X$ is the scaling in Moon sphere of influence.

2) 'Variable' in the scaling field of the summary sheets indicates that the erasable location is either a matrix whose components have different scalings or a temporary register with many different scalings.

3) The symbol '#' indicates indirect addressing, i.e., $A#X1$ means $A$ is indirectly addressed by $X1$.

**Note:** If the quantity to the right of the '#' sign is $X1$ or $X2$, then these are subtracted from the quantity on the left of the '#' sign to form the address. If the quantity to the right of the '#' sign is not $X1$ or $X2$, the reader should refer to the coding to determine if it must be added or subtracted from the quantity on the left to form the address.

Enclosed are replacement sheets to correct the Colossus IIa flow chart FC-2550, Rev. 1, to the Colossus IIc flow chart FC-2550, Rev. 2. The following sheets have been changed: 3, 10, 16, 41, 45.
PROG20
RENDZEVOUS NAVIGATION
VIA BANKCALL

ROECBH
IMU STATUS TEST
FC-22370

REQUESTS SELECTION OF APPROPRIATE PROGRAMS
IF IMU IS NOT ON AND ALIGNED (VIA ALARM)

NUMBER OF TRACKING (OPTICS) MARKS INCORPORATED
COUNTER
NUMBER OF VHF RANGING MARKS INCORPORATED
COUNTER

SET PRTTRAT
CLRVRDSRS
SETTTAKFLG
SET UPDATFLG
SET RNDVFLG
SET VSFONRBL

USE PREFERRED TRACKING ATTITUDE
LEM STATE VECTOR TO BE UPDATED
ALLOW TRACKING
ALLOW UPDATING BY MARKS
INDICATE P20 IS OPERATING
ENABLE R60 ATTITUDE MANEUVER

GROUP 4.0
KILL
GROUP 4
RESTARTS

GROUP 2
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINOVA
JOB WITH PRIORITY 26

LOAD TIME
GET PRESENT TIME FROM
COMPUTER FC-2200

OUTPUT: MPACO = TIME2 - TIME1

NEXT SHEET
FROM PRECEDING SHEET

MARKTIME = MPACD

SAVE TIME FOR INPUT TO INTEGRV

SETINTG
INITIALIZE FOR INTEGRATION GIT

SETS FLAGS CALLS INTSTALL

IS W-MATRIX VALID FOR RENDEZVOUS NAVIGATION?

NO

YES

IS RENDWFLG SET?

SET DIMOFLG

INDICATE THAT W-MATRIX IS TO BE INTEGRATED

P20.1

YES

IS VEHUFLG SET?

CLEAR VINTFLAG

NO

INDICATE LEM STATE VECTOR TO BE UPDATED

P20.2

INTEGRV
EXTRAPOLATE LEM/OSM STATE VECTOR TOTAL
FC-2350

INPUT:
TDEC1 = PRESENT TIME SCALED 2^{26} CSEC
OUTPUT:
UPDATED STATE VECTOR

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

NEXT SHEET
FROM PRECEDING SHEET

SET INTO
INITIALIZE FOR INTEGRATION
SH7

SET INTO
SETS FLAGS
CALLS INSTALL

IS CSM STATE VECTOR TO BE UPDATED?

NO

IS VEHUPFLG SET?

YES

CLEAR VINTFLAG

P00.3

INPUT:
TDEC1 = PRESENT TIME SCALED 2^{25} CSEC

OUTPUT:
UPDATING STATE VECTOR

THIS IS THE RENDEZVOUS MARK PROCESSING ROUTINE. IT CHECKS FOR OPTICS MARKS OR VHF RANGE DATA EVERY 4 SEC. IT WILL TERMINATE ONLY IF TRACKFLG AND UPDATFLG ARE CLEARED.

NOTE:
THese TWO RESTARTS WILL CAUSE R22 AND R52 (VIA PKUP20) TO START RUNNING (IF THEY HAVE BEEN TEMPORARILy TERMINATED) WHEN A V57E XJX IS KEyED IN AND IF RNDOVFLG IS SET, IF THE MAJOR MODE (XX) ENTERED SETS TRACKFLG AND UPDATFLG; R22 AND R52 WILL CONTINUE TO RUN OTHERWISE THEY WILL TERMINATE AGAIN AS SOON AS THEY FIND TRACKFLG AND UPDATFLG CLEARED. THESE FLG SETTING MAJOR MODES ARE THE TARGETING PROGRAMS (P50.5 AND P50.3), A LIST CAN BE FOUND IN G5OP SECTION A UNDER P20.

GROUP 2.7
SET UP RESTARTS TO SCHEDULE R22 AS A FINDVAC JOB WITH PRIORITY 10

GROUP 1.11
SET UP RESTARTS TO SCHEDULE PKUP20 AS A FINDVAC JOB WITH PRIORITY 10

PIKUP20

NEXT SHEET
FROM PRECEDING SHEET

PRIORCN
CHANGE
PIKUP20 PRIORITY TO 14
FC-2550

IS TRACKING ALLOWED?
NO
IS TRACKFLG SET?
YES
IS IMU ON AND ALIGNED?
NO
IS RPMMPLG SET?
YES
ENDOFJOB
TEMPORARY END OF P20

F61CNTR ← ZERO

F61CSM
COMPUTE THE
PREFERRED OR
+X AXIS OF S/C
SH10

INPUT:
F61CNTR (SEE SH.10)
OUTPUT:
DESIGNED VEHICLE ATTITUDE

SET TARI1FLG
INDICATE TARGET IS LEM

PROSE18

NEXT SHEET
THIS ROUTINE CYCLES EVERY 2 SECS TO POINT THE CSM OPTICS AT THE LEM. EVERY 4TH CYCLE IT WILL ALSO CALL R52 TO COMPUTE THE PREFERRED (+X AXIS) ATTITUDE AND ALIGN THE CSM ALONG THIS ATTITUDE. ITS OPERATION WILL BE TERMINATED ONLY WHEN IT FINDS TRACKFLG CLEARED (SEE SH3) AND CONTROL WILL BE RETURNED TO P20 AT THE POINT FOLLOWING THE CALL TO R52.

HOLDFLAG ← ONE
INDICATES TO DIGITAL AUTOPILOT (DAP) TO HOLD PRESENT ATTITUDE
ENDJOB
TEMPORARY END OF P20

SETINTG
SUBROUTINE TO SET FLAGS AND CALL INSTALL

EGRESS ← QPRET
SAVE RETURN

INSTALL
RESERVE INTEGRATION ROUTINE FC-2250

TDEC1D ← MARKTIME
TIME INPUT TO INTEGRV

SET STATEFLG
CLEAR INTYPEFLG
CLEAR D1MON
SET VINTFLG
CLEAR D2MON

UPDATE PERMANENT STATE VECTOR
USE ENCKE INTEGRATION
DO NOT INTEGRATE W-MATRIX
INTEGRATE CSM STATE VECTOR
USE 6 DIMENSIONAL W-MATRIX

RETURN VIA EGRESS
RETURN TO P20
**FLOWCHART**

**V56E**

**TERMINATE**

**RENDEZVOUS NAVIGATION**

**PROGRAM PEO**

**TRACK TRM**

**IS PEO RUNNING?**

- **NO**
  - **IS RNDVZFLG SET?**
  - **YES**
    - **CLEAR RNDVZFLG**
    - **INDICATE PEO NOT RUNNING**

- **YES**
  - **ARE R22 AND R52 RUNNING (OR ALLOWED)?**
  - **NO**
    - **GOPIN**
    - **PINBRINCH FC-2130**
  - **YES**
    - **CLEAR TRACKFLG**
    - **CLEAR UPDATFLG**
    - **CLEAR IMUSE**
    - **INDICATE OPTICS TRACKING NOT ALLOWED**
    - **INDICATE UPDATING STATE VECTOR BY MARKS NOT ALLOWED**
    - **INDICATE IMU NOT BEING USED**

**INHIBIT INTERRUPTS**

**NEXT SHEET**
FROM PRECEDING SHEET

STOPRATE
ZERO INPUT TO
DIGITAL AUTOPILOT
FC-2550

OPTIND ~ NE Gone

INHIBIT OPTICS DRIVING BY T4RUPT
(DRIVEN IN R52)

INSTALL
RESERVE
INTEGRATION
ROUTINE
FC-2550

THIS WILL ALLOW INTEGRATION TO BE
COMPLETED IF IT IS IN PROGRESS

GROUP 2.0
KILL GROUP 2
RESTARTS

THIS WILL NOT ALLOW THE R22 JOB
OF P20 TO RESTART

GROUP 1.0
KILL GROUP 1
RESTARTS

THIS WILL NOT ALLOW THE R52 JOB
OF P20 TO RESTART

CLEANOUT

INHINT

A RESTART OCCURS
IN ENEMA WHICH
TERMINATES THE
OPERATION OF P20

ENEMA
FC-2550
Called by PRG or RSE to compute proper PRG or RSE tracking attitude for the CSU if maneuver is less than 10 deg. Performs the maneuver (via the CAP) otherwise calls PRG to perform maneuver.

**Input:**
- RSGCNTR (SEE NOTE BELOW)

**Output:**
- DESIRED VEHICLE ATTITUDE

**MGWAP**
- FROM RETURN ADDRESS
- FC2080

**SWITCH EBNK**

**STORE RETURN ADDRESS OF CALLING PROGRAM IN A**

**GENGET**
- A
- RSGCNTR

**SAVE CALLER'S RETURN ADDRESS (SEE NOTE)**

**CGBAL**
- COMPUTE ATTITUDE AND DIGITAL AUTOPILOT INPUTS
- SIN1

**CLEAR YR11FLS**

**INHIBIT FURTHER RGO ATTITUDE MANEUVERS**

**MPAC**
- = 0

**RSGCNTR**

**A**

**SET RSGCNTR TO 1**

**RSG11**

**CLEAR PDMFLAGS**

**INPUT TO RGO WHICH INDICATES THAT THE MANEUVER WILL BE SPECIFIED BY ONE AXIS (SEE NOTE) RSE IS CHECKING RSGCNTR EVERY FOUR SECONDS AND CANNOT CONTINUE TO OPERATE UNTIL RSE HAS BEEN COMPLETED (RSGCNTR=0)**

**DO NOT ALLOW PRIORITY DISPLAYS IN RGO TO BE INTERRUPTED**

**INRCLM**
- ATTITUDE MANEUVER ROUTINE
- FC3542

**CLEAR PDMFLAGS**

**GROUP 111**
- SET UP NEXT SEND TO SCHEDULE MRTED FINDING JOB PRIORITY 10

**SET RSGCNTR TO 0**

**NOTES:**
- RSGCNTR CAN TAKE ON THE VALUES -1, 0, 1, 2, 3, 4, OR 5
- RSGCNTR = 0 INDICATES TO RSE THAT RGO IS OPERATING
- RSGCNTR = 0 CALCULATES ATTITUDE AND DIGITAL AUTOPILOT INPUTS
- RSE SETS RSGCNTR TO 0
- RSE DOES NOT MODIFY RSGCNTR SO WHILE RSE CALLS RSE EVERY TIME IT IS ACTIVE, RSE WILL CALCULATE ATTITUDE (via CRSSLS) ONLY ONCE FOR EVERY 4 RSE CALLS.
FROM PRECEDING SHEET

TEMPO INDEX REGISTER

DTHETASM ← 2

COULOOP

THIS LOOP CYCLED 3 TIMES TO CHECK X, Y, AND Z COORDINATES

DO THE PRESENT AND DESIRED ATTITUDES DIFFER BY 10° FOR THIS COORDINATE?

GDOU = DTHETASM

THETAU = DTHETASM

DIFFER =

> 0

YES

STKTEST

NO

CHECK NEXT COORDINATE

DTHETASM ← DTHETASM + 1

DECREMENT INDEX

DTHETASM = 0

NO

YES

THIRD TIME THROUGH?

AUTOC

IS THE COMPUTER MODE SWITCH IN "AUTO" (COMPUTER IN CONTROL OF S/C)?

CHAN3

(BITS 15, 14, 13)

= 011

NO

AYE

ASET

SM16

DAPCK

AUTOMATIC MANEUVER TO BE BYPASSED (SEE NOTE)

STKFLAG SET ?

YES - MANUAL

NO - AUTOMATIC

NEXT SHEET

NOTE:

IF THE ROTATIONAL HAND CONTROL HAS MOVED FROM REST POSITION STKFLAG IS SET, INDICATING AUTOMATIC MANEUVER TO BE BYPASSED.
FROM PRECEDING SHEET

STEP BACK

PUSH LIST POINTER SET TO 0

CR561.E

\[ \text{PDLO} = \text{UNIT} \left( R_L - R_C \right) \times \text{UNIT} \left( B_L - B_C \right) \]

\[ \text{PDLO}_v = \text{UNIT} \left( \text{DCDU}_v - \text{SAVEVEL}_v \right) \times \text{SAVEPOS}_v \times \text{RVCS/RDS}_v \]

RVCS/RDS IS A CONVERSION FACTOR TO CONVERT RAD/CSEC TO REV/SEC

\[ \text{PDLO}_6 = \left| B_L - B_C \right| \times \text{PI2TIME} \]

ABSOLUTE VALUE OF LOS VECTOR

\[ \text{PDLO}_20_v = \left[ \text{REFSUMMAT} \left( \text{DCDU}_v - \text{SAVEVEL}_v / \text{PDLO}_6 \right) \times \text{PDLO}_v \right] \]

\[ \text{DTHEASM}_v = \text{TENTH} \left( \text{PDLO}_20_v \right) \]

\[ -1 \times \text{LOS} \] USED BY SMC DURES TO CALCULATE \( \Delta \text{GA} \).

CDUX, CDUY, CDUZ = IMU GIMBAL ANGLES SCALED 2° REVS

INPUT:

COMPUTE SINES AND COSINES OF IMU GIMBAL ANGLES FC = 2270

OUTPUT:

SINCDUX = SINES OF IMU GIMBAL ANGLES SCALED 2°
COSCDUX = COSINES OF IMU GIMBAL ANGLES SCALED 2°

SMC DURES

INPUT:

DTHEASM = INCREMENTAL STABLE MEMBER ANGULAR CHANGES (1.0 LOS) SCALED 2° REVS

OUTPUT:

SINCDUX, COSCDUX (SEE COUTRICG OUTPUT ABOVE)

DCTDUX = INCREMENTAL IMU GIMBAL ANGLE CHANGES (GA) SCALED 2° REVS

SAVE \( \Delta \text{GA} \) FOR DAP

PDL14\_v \rightarrow \text{DCDU}_v

NEXT SHEET
FROM PRECEDING SHEET

INPUT:
CDUX, CDUY, CDUZ = IMU GIMBAL ANGLES SCALED 2° REVS

OUTPUT:
SIN CDUX = SINES OF IMU GIMBAL ANGLES SCALED 2°
COS CDUX = COSINES OF IMU GIMBAL ANGLES SCALED 2°

MPACV ← PDLOV

W LOS INPUT TO = S MNB

*SMNB*

INPUT:
MPACV = VECTOR IN STABLE MEMBER COORDINATES

OUTPUT:
MPACV = VECTOR IN NAVIGATION BASE COORDINATES

\[ \omega_{CA} = [\omega_{CA} [5\text{NB}] \omega_{LOS}] \]
MPACV \[= [\text{BODY TCLW (MPACV)}] \text{POINT B} \]

CR5612A

INHINT

CDUXD1 ← ZERO
CDUYD1 ← ZERO
CDUZD1 ← ZERO

NEXT SHEET

DESIRED LOS RATE IN CONTROL AXIS COORDINATES GSOP EQU. PG. 5.2-67
POINT B IS A SCALE FACTOR TO CONVERT 360° REVS TO 450° REVS
FROM PRECEDING SHEET

CDUO ← SAVEDCDU
CDUYO ← SAVEDCDU+1
CDUZO ← SAVEDCDU+2

TRANSFER DESIRED GIMBAL ANGLES
\((\gamma A,\alpha GA,\phi GA)\) FOR INPUT TO DAP

WBODYO ← MPACD
WBODY1O ← \((MPAC+3)D\)
WBODY2O ← \((MPAC+3)D\)

TRANSFER 4GA FOR INPUT TO DAP

DELCDUO ← PDL1A D
DELCDUYO ← PDL1B D
DELCDUZO ← PDL1C D

TRANSFER 4GA FOR INPUT TO DAP

HOLDFLAG ← -1

SIGNS TO DAP TO PERFORM MANEUVER

NOTE:
The DAP INTERRUPTS EVERY 1.5 SEC TO CHECK
HOLDFLAG. WHEN THE DAP FINDS HOLDFLAG = -1,
IT WILL PERFORM AN ATTITUDE MANEUVER
USING THE ABOVE INFORMATION.
STKTEST

IS RGO ATTITUDE MANEUVER ALLOWED?

CMC WILL PERFORM MANEUVER

SET BIT 3 OF CHANNEL 11

ABET

TURN ON UPLINK ACTIVITY LIGHT TO INDICATE THAT THE RHC IS NOT IN ITS CENTER POSITION

 IF R80 HAS CALLED R61, R60 WILL BE CALLED.
 IF R82 HAS CALLED R61, R60 WILL BE CALLED ONLY IF PRESENT ATTITUDE AND DESIRED ATTITUDE DIFFER BY 10°

MPAC ← 0

RETURN VIA Q611

MANCEXIS

MANCEXIT

INPUT DESIRED IMU GIMBAL ANGLES TO R60

MPAC ← LOONE

MPAC ← 1 INDICATES TO R61 TO CALL R60 TO PERFORM AUTOMATIC MANEUVER

RETURN VIA Q611

RETURN TO R61
THIS ROUTINE CYCLES EVERY FOUR SECONDS TO CHECK FOR OPTICS MARK DATA OR VHF RADAR RANGE DATA. WHEN IT FINDS DATA PRESENT, IT THEN PROCEEDS TO INCORPORATE IT INTO THE APPROPRIATE VEHICLE'S STATE VECTOR. AFTER THE INCORPORATION, THE ROUTINE CONTINUES TO CYCLE CHECKING FOR DATA.

SET RESTART PRIORITY OF R22 TO 26

CHANGE PRIORITY OF R22 TO 6
FC=2050

INDICATES NO OPTICS MARK DATA IN BUFFER2

LOADTIME
GET PRESENT TIME FROM COMPUTER CLOCK
FC=2100

OUTPUT:

MPAC0 = TIMER2.TIME1

SET TVHP TO PRESENT TIME

REND1

GROUP2
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINDVAC JOB WITH SAME PRIORITY

WAITONE
WAIT 4,8,12,...,SEC
SH-31

NEXT SHEET

PROGRAM WILL WAIT HERE 4,8,12,..., SEC UNTIL R60 FINISHES RUNNING AND UPDATFLG IS SET (IF TRACKFLG SET). R22 WILL TERMINATE TEMPORARILY AT THIS POINT IF IMU NOT ON AND ALIGNED OR UPDATFLG AND TRACKFLG BOTH CLEARED.
FROM PRECEDING SHEET

NOTE:
NORMAL CASE: THE LEM'S STATE VECTOR IS
UPDATED BECAUSE OF PZO CLEARING
VEHUPFLG (SH3). IF CSM STATE VECTOR UPDATE
WANTED, VALUE MUST BE ENTERED AFTER PZO
HAS BETHAN.

THIS PART WILL EXTRAPOLATE THE
NON-UPDATING VEHICLE STATE
VECTOR. SEE GSP FIG B.5-4 (PG. 1 OF 3)

CSM STATE VECTOR
BEING UPDATING?

IS
YES
NO

VEHUPFLG
SET?

T
CSMUPP
CLEAR
VINTFLAG
INPUT:
TDEC1 = TIME
OUTPUT:
ESTIMATED CSM
STATE VECTOR

GROUP 1
SET UP RESTARTS TO
SCHEDULE NEXT
LOCATION AS A FIND
VAC JOB WITH SAME
PRIORITY

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

INPUT:
TDEC1 = TIME
OUTPUT:
ESTIMATED LEM
STATE VECTOR

EXTRAPOLATE, INPUT:
LEM STATE VECTOR
TO TDEC1

FC-2290

IS W-MATRIX VALID FOR
RENNZVOUS NAVIGATION?

NO

REND5

YES

RENDWFLG
SET?

SET
DIMOFLAG

INDICATE LEM STATE VECTOR
TO BE EXTRAPOLATED TO TDEC1

INDICATE LEM STATE VECTOR TO BE EXTRAPOLATED TO TDEC1

RENDBA

NEXT SHEET

REND5

INDICATE 6X6 W-MATRIX CAN BE INTEGRATED

RENDWFLG

SET

NEXT SHEET

5.15 NAVIGATION LAB
CAMBRIDGE, MASS.

5.13 GUIDANCE AND NAVIGATION
RENNZVOUS
NAVIGATION R22
COLOSSUS INC
PC-2550

DOCUMENT NO.

REV 8

1977 11 21 64
FROM PRECEDING SHEET

INPUT:
TDEC1 = TIME

OUTPUT:
UPDATED PERMANENT STATE VECTOR

SHIFTNDX
SET SCALING INDEX FOR EARTH OR MOON
SH3B

OUTPUT:
XSCALE ADJUSTING FACTOR FOR EARTH OR MOON SPHERE OF INFLUENCE

SUBROUTINE

CMPOS

\[ r = \hat{r} + r_c \]

CMPOS = DELTACSM + RCOSSM

RETURN VIA QPRET

SET INCORFLAG

FLAG = 1
INDICATES FIRST INCORPORATION PASS
(USED FOR OPTICS MARK DATA ONLY)

SUBROUTINE

LMPOS

\[ r = \hat{r} + r_c \]

LMPOS = DELTALEM + RCULEM

RETURN VIA QPRET

CLEAR ORBFLAG

INDICATE THAT W-MATRIX IS INVALID FOR ORBITAL NAVIGATION

NEXT SHEET
FROM PRECEDING SHEET

IS W-MATRIX VALID FOR RENDEZVOUS NAVIGATION?

YES

IS RENDWFLG SET?

NO

POLO₀ ← WRENDPOS₀

THIS PLACES POLO₀ = Wᵣᵣ
PDL₁₀ = Wᵣᵥ

INPUT:
POLO₀ = POSITION INITIALIZATION VALUE (Wᵣᵣ)
PDL₁₀ = VELOCITY INITIALIZATION VALUE (Wᵣᵥ)

OUTPUT:
INITIALIZED W-MATRIX

CLEAR'S VHF MARKS INCORPORATED COUNTER (VHFcnt₀) AND OPTICS TRACKING MARKS INCORPORATED COUNTER (TRMKcnt₀)

VHFcnt₀ ← ZEROVECS₀

REND6

SET RENDWFLG

INDICATE W-MATRIX VALID FOR RENDEZVOUS NAVIGATION

Fₒ₀ = Fₒ - Fₒ
RCLPᵥ ← LEMPOSᵥ = CSMPOS

CALCULATE LEM TO CSM
LINE OF SIGHT VECTOR

REND7

NEXT SHEET
FROM PRECEDING SHEET

MPAC_D ← RCLP_D + VARIANCE_D

SHIFT INDEX
SET SCALING INDEX FOR EARTH OR MOON
SHIPS

VARIANCE_T ← MPAC_T

VARIANCE_T ← INTVAR_S + VARIANCE_T

IS SC=1 TEST
IS THIS VHF RADAR RANGE DATA?

USE PRESENT
VARIANCE \( \omega^2 \)

NO

USE PRESENT \( \omega^2 \) + VARIANCE

Determine MAX ( \( \omega^2 \) \) VARIANCE_MIN + \( \omega^2 \)

YES: VARIANCE_MIN

\( \omega^2 \) = VARIANCE_MIN

VARIANCE_T ← VARIANCE_MIN

RENEGA

CLEAR DIMFLAG

INDICATE DIMENSION OF W-MATRIX
6x6 FOR INCORPORATION

INPUT:
DELTAQ = MEASUREMENT DEVIATION \( \omega \) SCALED \( 2^{20} / 2^{27} \) M
VARIANCE = MEASUREMENT VARIANCE \( \omega^2 \) SCALED \( 2^{20} \) M^2
BVECTOR = MEASUREMENT GEOMETRY VECTOR (x, y, z)
DMENFLAG = W-MATRIX

COMPUTE STATE VECTOR DEVIATIONS \( \Delta X \)
FC-6510

OUTPUT:
DELTA_X = POSITION DEVIATIONS \( \Delta X \) SCALED \( 2^{20} / 2^{27} \) M
DELTA_Y = VELOCITY DEVIATION \( \Delta X \) SCALED \( 2^{7} / 2^{5} \) M/SEC

NEXT SHEET
FROM PRECEDING SHEET

IS THIS THE SECOND INCORPORATION PASS?

INCREMENTS OPTICS

INCORRFLG CLEAR?

NO

SHIFTNDX

SET SCALING INDEX FOR EARTH/MOON

SH58

OUTPUT:

X2 = SCALE ADJUSTING FACTOR FOR EARTH

OR MOON SPHERE OF INFLUENCE

IS THIS A CSW STATE VECTOR UPDATE?

NO

VEHUPFLG SET?

YES

REVLM

COMPUTE ESTIMATED

CSW POSITION

RETURN VIA

QPRET

SUBROUTINE

LMPOS

RCLP = LEMPOS + DELTALEM + REVLM

RETURN VIA

QPRET

SUBROUTINE

CSWPOS

RCLP = LEMPOS + CSWPOS

RETURN VIA

QPRET

REN13

GROUP2

SET UP RESTARTS

TO SCHEDULE NEXT

LOCATION AS A

DIFFICULT JOB WITH

SAME PRIORITY

RCLP = LEMPOS - CSWPOS

CALCULATE NEW

ESTIMATED LOS

CLEAR

INCORRFLG

INDICATE SECOND

INCORPORATION PASS

REN17

SH23

THIS PATH LEADS TO SECOND

INCORPORATION OF OPTICS

MARK DATA
RENDISP

ENTRERED FROM SH27 TO DISPLAY STATE VECTOR DEVIATIONS.

IS SOURCECONFIG SET?

SC = 1:

TEST IS THIS VHF RADAR RANGE DATA?

NO

A ← BIT 1

SET RB OF VOGN49 DISPLAY TO 1 FOR OPTICS DATA

YES

A ← BIT 2

SET RB OF VOGN49 DISPLAY TO 2 FOR VHF RADAR RANGE DATA

STORE SOURCE CODE FOR RB OF VOGN49 DISPLAY

N490ISP + 4 ← A

TEMPOR1 ← ZERO

TEMPOR1 IS USED TO INDICATE THE RESPONSE TO THE VOGN49 DISPLAY IN THE RENDISP2 JOB.

GROUP 2

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

RENDISP2

NOVAC

PRIORITY 27

RENDISP7

MPAC ← MPAC

SINCE THIS IS AN INTERPRETIVE INSTRUCTION, NEWJOB WILL BE CHECKED. THIS WILL CAUSE RENDISP2 TO BE STARTED BECAUSE ITS PRIORITY IS HIGHER THAN R22.

NEXT SHEET

RENDISP2

PRIOISP

VOGN49 DISPLAY STATE VECTOR DEVIATIONS

TERMINATE

GOTO V56

R1 = XXXX.X POS. DEVIATION
R2 = XXXX.X VEL. DEVIATION
RB = 0000X SOURCE CODE

RECYCLE

PROCEED

A ← ONE

RENDISP2

TEMPOR1 ← A

END OF JOB

THIS PATH LEADS TO PERMANENT TERMINATION OF P20

INSTRUMENT

LAB

CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

RENDZvous

NAVIGATION R22

COLOSSUS II

FC 2550

DRAWN}

ANALYST

DESIGNER

APPROVED

REV 2

SHF 59-10-46
FROM PRECEDING SHEET

VGSN49 DISPLAY NOT ANSWERED YET

VGSN49 DISPLAY ANSWERED WITH PROCEED

TEMPOR1 = 0

= 0

REND12 SH27

> 0

VGSN49 DISPLAY ANSWERED WITH RECYCLE

THIS PATH INCORPORATES STATE VECTOR DEVIATIONS

RENDISP3

SC-1 TEST IS THIS VHF RADAR RANGE DATA

YES

RENDS1 SH19

IS SOURCECFG SET?

NO

INHINT

PLACE ADDRESS OF RENDISP3 IN BBANK

BBANK ← BUF BANK

MRKBUF1 ← NEGONE

MRKBUF2 ← NEGONE

ERASE MARKS TAKEN BECAUSE DEVIATIONS COMPUTED FROM THE LAST OPTICS MARK INDICATE THAT THE OPTICS ARE PROBABLY NOT TRACKING LEM.

RELINT

RENDISP4

RENDISP3

SH20

THIS PATH RECYCLES AND CHECKS FOR VHF RADAR RANGE DATA

INSTRUMENTATION LAB
AMHERST, MASS.

REND (Rendezvous Navigation R28)

COLOSSUS II FC-2550

12/12/11

John Doe
WAITONE

POINTEX ← QPRET

WAITONE2

DELAYJOB

WAIT 4 SECONDS

FC-2070

CONTCHK

IS THE IMU ON AND ALIGNED?

YES

IS REFSCFLG SET?

YES

IS R60 RUNNING?

YES

RESCNTR < 0?

YES

RETURN VIA POINTEX

IS UPDATFLG SET?

YES

IS TRACKFLG SET?

YES

REDOR22

GROUP 2.19

SET UP RESTARTS TO SCHEDULE REDOR22 AS A FINDVAC JOB WITH PRIORITY 10

ENDPLAC

ENDOFJOB TEMPORARY END OF R60

NOT USED IN COLOSSUS II

SAVE RETURN

POINTEX ← QPRET
This subroutine reads VHF radar range data. There are two returns, depending upon status of the VHF range data I/O operation.

1. I/O Good: return is to location calling RANGERD with:
   - VHFRANGE = distance (m) from 5050 m at 25°T
   - MARKTIME = time VHF range data taken

2. I/O Bad: return is to location in R22 which recycles to check for mark data with:
   - VHFTIME = time VHF range data was read
   - Set bits 3-1 to 001 to specify VHF range information to be provided to the computer.
   - Set bits 4 to 1 to initiate transmission of VHF range data to the computer.

Save time VHF range data taken.

Proceed normally with radar read.

I/O Complete and Good

Wait for VHF range data FC 2310

VHFRD

GET VHF RANGE DATA

SH. 34

NEXT SHEET

I/O Complete but Bad

LIGHTQON

YES

NO

VHFRANGE ≠ 0 ?

FAILON

TURN ON TRACKER FAIL LIGHT

FC 2070

LIGHTOFF

STORE TIME VHF RANGE DATA READ

REND1

SH. 34

THIS PATH RETURNS TO R22 TO RECYCLE AND CHECK FOR OPTICS MARK OF VHF RANGE DATA.
FROM PRECEDING SHEET

TRAFOIL OF TRACKER FAIL LIGHT
FC-2070

INDICATES DATA TRANSMITTED

RANGER01

+0

RM

>0

≤0

RANGER3

CONVERT COUNTER READING TO M.

MPAC₀ = RM(BITS 14 - 1) x CONVRANGE₀ + RANGEB14₀

MPAC₀ = RM₂ x CONVRANGE₀

RANGERD4

RANGERD5

LIGHTON +4
5H.32

SAVE RANGE DATA

VHF RANGE DATA

SET SOURCFLG

RETURN VIA GPRET

RETURN TO R22

NOTE: VHF RANGE DATA IS STORED IN A 15-BIT COUNTER WITH ALL BITS BEING MAGNITUDE BITS. THEREFORE A CHECK OF BIT 15 IS NECESSARY TO CONVERT CORRECTLY.
Bits 8-1 of Channel 15 set to 001 signal the computer to read out VHF range data. The readout process begins when bits 14 of Channel 15 are set to 1. At the end of the readout process (55-95 ms after the start), program interrupt 9 is generated, causing control to transfer to location 40446 which calls VHFREAD.

BANKRUPT → SUPERBANKVA
                   SAVE RETURN ADDRESS
                   WHEN INTERRUPT IS OVER
                   CONTINUE WITH RANGERD
                   SAVE Q
                   RADAR READ TO BE DISREGARDED?
                   (DUE TO RESTART)
                   YES
                   TASKOVER
                   UPDATING OF STATE VECTOR
                   BY VHF MARKS ALLOWED?
                   NO
                   TRANSFER 15 BITS OF VHF
                   RANGE DATA TO COMPUTER
                   STORAGE
                   RM → RNRAO
                   IS VHF RANGE DATA CONSIDERED
                   BAD?
                   NO
                   VHFGOOD
                   A ← TWO
                   GO2END
                   I/O COMPLETE AND GOOD
                   FC-2210
                   INDICATES RANGERD
                   IS WAITING FOR VHF
                   RANGE DATA (VIA
                   RADSTALL)
                   YES
                   A ← TWO
                   BADEND
                   I/O COMPLETE BUT BAD
                   FC-2210
                   THESE TWO SUBROUTINES RETURN
                   CONTROL TO RADSTALL WHICH RETURNS
                   CONTROL TO RANGERD DEPENDENT
                   UPON STATUS OF I/O OPERATION
THIS SUBROUTINE ADJUSTS AN INDEX REGISTER FOR THE PROPER SPHERE OF INFLUENCE FOR EITHER CSM OR LEM COMPUTATIONS.

OUTPUT:
X2 = INDEX ADJUSTED FOR EITHER EARTH OR MOON SPHERE OF INFLUENCE

1. **SHIFTNDX**
   - **X2** ← 0
   - **INITIALIZE INDEX**

2. **CSM STATE VECTOR BEING UPDATED?**
   - **NO-LEM**
     - **PERMANENT LEM STATE VECTOR IN LUNAR SPHERE?**
       - **NO-EARTH**
         - **RETURN VIA QPRET**
         - **RETURN TO R22**
       - **ADJUST INDEX FOR LUNAR SPHERE**
         - **X2 ← X2 - 2**
         - **RETURN VIA QPRET**

3. **CMOONFLG SET?**
   - **YES**
     - **ADJUST INDEX FOR LUNAR SPHERE**
       - **X2 ← X2 - 2**
       - **RETURN VIA QPRET**

4. **VENUPFLG SET?**
   - **YES**
     - **TEMPORARY CSM STATE VECTOR IN LUNAR SPHERE?**
       - **NO-EARTH**
         - **RETURN VIA QPRET**
         - **RETURN TO R22**
       - **ADJUST INDEX FOR LUNAR SPHERE**
         - **X2 ← X2 - 2**
         - **RETURN VIA QPRET**
This subroutine initializes the W-matrix for either P25-CISLunar Midcourse Navigation or R22-Rendezvous Mark processing.

**Input:**
- PDLO = position initialization value (WFR or WMP)
- PDV1 = velocity initialization value (WFR or WMP)

**Output:**
- Initialized 6x6 W-matrix

**Initialize Index and Clearing Value**

This loop cycled 6 times.

```
\[
\begin{bmatrix}
W_0 & W_1 \\
W_2 & W_3 \\
W_4 & W_5 \\
W_6 & W_7 \\
W_8 & W_9 \\
W_{10} & W_{11}
\end{bmatrix}
```

**Note:**
- \( W_{xy} \) and \( W_{yx} \) represent either \( W_{FR} \) and \( W_{MV} \) or \( W_{FR} \) and \( W_{MV} \) depending upon which program called INITIALW.
- Sets \( W_0 = 0 \)
- \( W_1 = 0 \)

**Flowchart:**

1. ***INITIALW***
2. \( X1 \rightarrow 36 \)
3. \( MPACV \rightarrow ZEROW \)
4. **INITIALW**
5. \( W_2 = 0 \)
6. \( I \) is one less than loop number
7. \( X1 \rightarrow X1 - 6 \)
8. **NO**
9. \( X1 = 0 \)
10. **YES**
11. \( X1 \rightarrow 36 \)
12. Initialize Index
13. Next Sheet
FROM PRECEDING SHEET

THIS LOOP CYCLED 6 TIMES

INIT8

(W+90-X1)_v → MPA(v)

W53+i = 0

I EQUALS THE LOOP NUMBER

X1 ← X1 - 6

DECREMENT INDEX

NO

X1 = 0

6TH TIME THROUGH?

YES

W5 = Wx5

W4 = Wx4

W3 = Wx3

(W + 90) s

(W + 16) s

→ PDLO_5

→ PDLO_5

(W + 72) s

(W + 60) s

(W + 80) s

→ PDL1_5

W36 = Wx6

W46 = Wx7

W44 = Wx6

RETURN VIA QPRET

RETURN TO P23 OR R22

SETS W3 = 5

AND W4 = 5
THIS SUBROUTINE IS CALLED BY PEE AND R22 TO CALCULATE THE LOS VECTOR (IN BASIC REFERENCE COORDINATES)

INPUT:
MARKDATA = ADDRESS OF MARK DATA

OUTPUT:
MPAC_V = LOS UNIT VECTOR IN BASIC REFERENCE COORDINATES

EGRESS ← QPRET

SAVE RETURN

(MARKDOWN+1)_V ← (1)_V#MARKDATA

THIS MOVES THE CONTENTS OF THE 7 LOCATIONS STARTING WITH THE ADDRESS IN MARKDATA TO THE MARKDOWN ARRAY FOR USE BY DOWNLINK

MARKDOWN_CP ← (0)_CP#MARKDATA

X1 ← MARKDATA
S1 ← MARKDATA+2

ADDRESS OF MARKDATA FOR INPUT TO SXTNB
ADDRESS OF SXT AND IMU ANGLES FOR INPUT TO NSBM

SXTNB

ANGULAR MARK DATA TO NAV BASE COOR.
FC-2250

INPUT:
X1 = ADDRESS OF MARK DATA

OUTPUT:
POL92_V = MPAC_V = LOS VECTOR IN NAVIGATION BASE COORDINATES

NSBM

NAV BASE TO STABLE MEMBER COOR.
FC-2270

INPUT:
POL92_V = VECTOR TO BE TRANSFORMED
S1 = BEGINNING ADDRESS OF SXT AND IMU ANGLES

OUTPUT:
MPAC_V = VECTOR IN STABLE MEMBER COORDS.

CONVERT FROM STABLE MEMBER TO BASIC REFERENCE COORDINATES

MPAC_V ← MPAC_V × REPSSMAT

RETURN VIA EGRESS

RETURN TO PEE OR R22.
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<th>WHERE CALLED</th>
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<tr>
<td>TRPFAILON</td>
<td>2070</td>
<td>TURN ON TRACKER FAIL LIGHT</td>
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<td>2210</td>
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<tr>
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<td>2210</td>
<td>I/O COMPLETE BUT BAD</td>
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<td>WHERE SET</td>
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<td>TRACKING NOT ALLOWED</td>
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<td>ALLOWED</td>
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<td>UPDATING STATE VECTOR BY MARKS</td>
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<td>ALLOWED</td>
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<td>W-MATRIX NOT TO BE INTEGRATED</td>
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<td>LEM STATE VECTOR TO BE INTEGRATED</td>
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<td>FLAGWRD3 BIT 3</td>
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<td>REFSSMAT IS NOT GOOD</td>
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<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
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<tr>
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### Displays

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<th>Where Executed</th>
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<tr>
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<td>R1 = BLANK Request for astronaut to perform alternate LOS</td>
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<td>Flasing</td>
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<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING UNITS</td>
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<td>TRKMKCNT</td>
<td></td>
<td>COUNTER FOR NO. OF OPTICS MARKS INCORPORATED</td>
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<td>LOCATION USED TO CONTROL OPERATION OF OPTICS</td>
<td>(INTEGER)</td>
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<tr>
<td>SAVBnk</td>
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<td>Q811</td>
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<td>P2ITIME</td>
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<td>TIME INPUT TO R63 (ALSO USED AS TEMPORARY STORAGE BY R63)</td>
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<tr>
<td>THETAD</td>
<td>IGA, MGA, OGA</td>
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<td>DEGREES</td>
</tr>
<tr>
<td>SAVEDCDU</td>
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<td>CPII</td>
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<td>DTHETASM</td>
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<td>DEGREES</td>
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<tr>
<td>CDUX</td>
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<td>PRESENT IMU GIMBAL ANGLES</td>
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<td>CDUY</td>
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<td>CDUZ</td>
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<td>DSALMOUT</td>
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<td>INPUT/OUTPUT CHANNEL 11</td>
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<td>DCDU</td>
<td>V. L. OGA</td>
<td>LEM VELOCITY FROM R63 (ALSO USED FOR DESIRED INCREMENTAL CHANGES IN IMU ANGLES)</td>
<td>FT/SEC</td>
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<td>SAVEVEL</td>
<td>V. C</td>
<td>CSM VELOCITY FROM R63</td>
<td>FT/SEC</td>
</tr>
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<td>SAVEPOS</td>
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<td>LOS UNIT VECTOR TO LEM</td>
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<tr>
<td>WBODY</td>
<td>$\theta$CA</td>
<td>DESIRED LOS RATE FOR DAP (1 REV + 450$^\circ$)</td>
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<td>$\Delta$GA</td>
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<td>DEGREES</td>
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<td>MKBUF1</td>
<td>-</td>
<td>7-LOCATION MARK DATA BUFFER 1</td>
<td>(VARIABLE)</td>
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<tr>
<td>MKBUF2</td>
<td>-</td>
<td>7-LOCATION MARK DATA BUFFER 2</td>
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<td>PHSRRT2</td>
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<td>RESTART PRIORITY REGISTER</td>
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<td>VIPTIME</td>
<td>-</td>
<td>TIME VHF RADAR RANGE DATA READ</td>
<td>SEC</td>
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<tr>
<td>MKSTAT</td>
<td>-</td>
<td>ADDRESS FOR MARK DATA VAC AREA IN CASE OF RESTART</td>
<td>(INTEGER)</td>
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<td>MKBUFA</td>
<td>-</td>
<td>ADDRESS OF MARK DATA VAC AREA</td>
<td>(INTEGER)</td>
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<tr>
<td>MARKDATA</td>
<td>-</td>
<td>ADDRESS OF TIME MARK TAKEN</td>
<td>(INTEGER)</td>
</tr>
<tr>
<td>VTEMP</td>
<td>-</td>
<td>ADDRESS OF MARK ANGLES</td>
<td>(INTEGER)</td>
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<td>CSMPOS</td>
<td>$\xi$C</td>
<td>CSM PRECISION POSITION VECTOR</td>
<td>NAUT. MI.</td>
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<td>$\xi$C</td>
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<td>NAUT. MI.</td>
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<td>$\Delta$L</td>
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<td>NAUT. MI.</td>
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<td>$\xi$CL</td>
<td>LEM TO CSM LOS VECTOR</td>
<td>NAUT. MI.</td>
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<td>UCL</td>
<td>$\xi$CL</td>
<td>ESTIMATED LEM TO CSM LOS DIRECTION</td>
<td>NAUT. MI.</td>
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<tr>
<td>UM</td>
<td>$\xi$M</td>
<td>MEASURED LEM TO CSM LOS DIRECTION</td>
<td>NAUT. MI.</td>
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<tr>
<td>USTAR</td>
<td>$\xi$S</td>
<td>FICTITIOUS STAR DIRECTION ALSO USED BY BVECTOR SUBROUTINE FOR ARTIFICIAL STAR DIRECTION</td>
<td>NAUT. MI.</td>
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<tr>
<td>BVECTOR</td>
<td>$(\xi_0, \xi_1, \xi_2)$</td>
<td>GEOMETRY OF MEASUREMENT VECTOR</td>
<td>((2^1, \ldots, 2^1))</td>
</tr>
<tr>
<td>DELTAQ</td>
<td>$\delta Q$</td>
<td>MEASUREMENT DEVIATION</td>
<td>NAUT. MI.</td>
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<tr>
<td>VIHRANGE</td>
<td>$R_M$</td>
<td>VHF RANGE READING</td>
<td>NAUT. MI.</td>
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<td>VARIANCE</td>
<td>$\xi^{2}$</td>
<td>MEASUREMENT ERROR VARIANCE ALSO USED AS A TEMPORARY LOCATION DURING VARIANCE CALCULATION</td>
<td>METERS$^2$</td>
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<td>DELTAX</td>
<td>$\Delta x_0$</td>
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<td>NAUT. MI.</td>
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<tr>
<td>DELTAX+6</td>
<td>$\Delta x_1$</td>
<td>STATE VECTOR VELOCITY DEVIATION</td>
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### Erasable Locations Used (continued)

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<th>AGC Tag</th>
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<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
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<td>N49DISP</td>
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<td>METERS</td>
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<td>N49DISP+2</td>
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<td>FT/SEC</td>
<td>METERS/CSEC</td>
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<td>TEMPOR1</td>
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<td>LOCATION USED TO DETERMINE RESPONSE TO VO6(49) PRIORITY DISPLAY ALSO FSRD AS TEMPORARY REGISTER BY BVVECTOR</td>
<td>(INTEGER)</td>
<td></td>
<td>2^{14}</td>
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<tr>
<td>BUFANK</td>
<td></td>
<td>ADDRESS OF RENDISP3</td>
<td>(INTEGER)</td>
<td></td>
<td>2^{14}</td>
</tr>
<tr>
<td>CHAN13</td>
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<td>INPUT/OUTPUT CHANNEL 13</td>
<td>SEC</td>
<td>CSEC</td>
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<td>TIME2</td>
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<td>PRESENT TIME FROM COMPUTER CLOCK</td>
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<td>NAUT. MI.</td>
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<td>RM</td>
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<td>VHF RADAR RANGE COUNTER</td>
<td>REV</td>
<td></td>
<td></td>
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<td>RNRAID</td>
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<td>REGISTER 46g USED TO RECEIVE RADAR RANGE DATA</td>
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<td>2^{14}</td>
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<td>CHAN33</td>
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<td>INPUT/OUTPUT CHANNEL 33</td>
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<td>MARKDOWN</td>
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<td>DOWNLINK MARK DATA REGISTERS (7)</td>
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<td>VARIABLE</td>
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### Program Constants

<table>
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<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Value and Units</th>
<th>AGC Value and Units</th>
<th>AGC Scaling</th>
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<td>REGISTER CONTAINING OCTAL ZERO</td>
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<td>REGISTER CONTAINING DECIMAL -1</td>
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<td>DEGREE10</td>
<td></td>
<td>10 DEGREES</td>
<td>10°</td>
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<tr>
<td>RVCS/RDS</td>
<td></td>
<td>CONVERSION FACTOR RAD/CSEC TO REV/SEC</td>
<td>100/2π REV-CSEC RAD-SEC</td>
<td>15,915494 (SAME UNITS)</td>
<td>2</td>
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<tr>
<td>TENTH</td>
<td>.1</td>
<td>DECIMAL .1</td>
<td>.1</td>
<td>.1</td>
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</table>
| MBDYCTLM | [NBCA]      | NAVIGATION BASE TO CONTROL AXES TRANSFORMATION MATRIX | \[
\begin{bmatrix}
  .5 & 0 & 0 \\
  0 & \cos 7.5, \sin 7.5 & 0 \\
  0 & \sin 7.5, \cos 7.5 & 0
\end{bmatrix}
\] | \[
\begin{bmatrix}
  .5 \\
  0 \\
  0
\end{bmatrix}
\] | 2^{11} |
| POINT8  | .8          | SCALE FACTOR 1 REV = 360° TO 1 REV = 450° | .8 | .8 | 2^{0} |
| SIX     | 6           | DECIMAL 6 | 6 | 6 | 2^{14} |
| PRIQ16  | 26000       | OCTAL 26000 | 26000B |  | 2^{14} |
| NEG3    | -3          | DECIMAL -3 | -3 | -3 | 2^{14} |
### PROGRAM CONSTANTS (CONTINUED)

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<tr>
<th>AGC TAG</th>
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<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>60SECCDP</td>
<td></td>
<td>60 SECONDS IN DOUBLE PRECISION</td>
<td>60 SEC</td>
<td>8000 CSEC</td>
<td>2^8</td>
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<td>ZEROVECS</td>
<td></td>
<td>THE BEGINNING ADDRESS OF 6 LOCATIONS CONTAINING ZEROS</td>
<td>0</td>
<td>0</td>
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<tr>
<td>SXTVAR</td>
<td>var_SXT</td>
<td>SXT ERROR VARIANCE</td>
<td>.04 x 10^-6 RAD^2</td>
<td>.04 (MR)^2</td>
<td>2^18</td>
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<tr>
<td>IMUVAR</td>
<td>var_IMU</td>
<td>IMU ERROR VARIANCE</td>
<td>.04 x 10^-6 RAD^2</td>
<td>.04 (MR)^2</td>
<td>2^16</td>
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<td>BIT1</td>
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<td>00001</td>
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<tr>
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<td>OCTAL 2</td>
<td>2</td>
<td>00002</td>
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<td>DECIMAL 1</td>
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<td>00001</td>
<td>2^14</td>
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<tr>
<td>CONVRNGE</td>
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<td>CONVERSION FACTOR FROM .01 N.M. TO METERS</td>
<td>18.52 METERS/ NM</td>
<td>303431.7 METERS</td>
<td>2^7</td>
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<td>RANGE14</td>
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<td>VALUE OF 15TH BIT OF VHF RANGE COUNTER</td>
<td>163.84 NAUT. MI.</td>
<td>303431.7 METERS</td>
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<td>DECIMAL 1/4</td>
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<td>PI/4.0</td>
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### PAD LOADS

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<th>AGC TAG</th>
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<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
<th>OCTAL VALUE</th>
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<td>WRENDPOS</td>
<td>w_r</td>
<td>INITIAL W-MATRIX POSITION VALUES</td>
<td>-16,384</td>
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<td>2^40</td>
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<td>WRENDVEL</td>
<td>u_v</td>
<td>INITIAL W-MATRIX VELOCITY VALUES</td>
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<td>-16,384</td>
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<td>RVAR</td>
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<td>δ_rMAX</td>
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<td>-16,384</td>
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GROUND TRACK DETERMINATION - P21

MAJOR ROUTINES ON THIS CHART

PGO 21 GROUND TRACK DETERMINATION}

SH 2
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
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<tr>
<td>INSTALL</td>
<td>FC-1850</td>
<td>TEST AVAILABILITY OF INTEGRATION</td>
<td>SH 3</td>
</tr>
<tr>
<td>INTEGRV</td>
<td>FC-2350</td>
<td>INTEGRATE INPUT STATE VECTOR</td>
<td>SH 4</td>
</tr>
<tr>
<td>INTEGRV</td>
<td>FC-2350</td>
<td>INTEGRATE PERMANENT STATE VECTOR</td>
<td>SH 4</td>
</tr>
<tr>
<td>LAT-LONG</td>
<td>FC-2290</td>
<td>RADIUS VECTOR TO LAT., LONG. AND ALT.</td>
<td>SH 5</td>
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<tr>
<td>LOADTIME</td>
<td>FC-2100</td>
<td>LOAD PRESENT TIME INTO MPAC&lt;sub&gt;0&lt;/sub&gt;</td>
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<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
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<tr>
<td>DIMOFVAL</td>
<td>W MATRIX IS TO BE USED</td>
<td>W MATRIX IS NOT TO BE USED</td>
<td>SH 3, 4</td>
<td>SH 3, 4</td>
<td>SH 3, 4</td>
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<tr>
<td>FLAG3 BIT5</td>
<td>EARTH COMPLETE EARTH RADIUS</td>
<td>MOON USE FIXED RADIUS</td>
<td>SH 3, 4</td>
<td>SH 3, 4</td>
<td>SH 3, 4</td>
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<td>FLAG8 BIT13</td>
<td>MOON USE FIXED RADIUS</td>
<td>ENCKE INTEGRATION</td>
<td>SH 4, 4</td>
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<td>LUNAFLAG FLAG3 BIT12</td>
<td>LUNAFLAG FLAG3 BIT12</td>
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<table>
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<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
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<tr>
<td>V04N06</td>
<td>OPTION CODE</td>
<td>R1 = XXXXX = OPTION CODE</td>
<td>SH 2, 4</td>
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<td>V04N06</td>
<td>OPTION CODE</td>
<td>R2 = XXXX = VEHICLE</td>
<td>SH 2, 4</td>
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<tr>
<td>V06N34</td>
<td>FLASHING</td>
<td>R1 = 00XXX, HR</td>
<td>SH 2, 4</td>
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<tr>
<td>V06N34</td>
<td>FLASHING</td>
<td>R2 = 000XX, MIN</td>
<td>SH 2, 4</td>
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<td>R3 = 0XX, XX SEC</td>
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<td>R1 = XXX, XX DEG</td>
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<td>V06N34</td>
<td>FLASHING</td>
<td>R2 = XXX, XX DEG</td>
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<tr>
<td>V06N34</td>
<td>FLASHING</td>
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<table>
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<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
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</thead>
<tbody>
<tr>
<td>OPTION 2</td>
<td>DSTEML1</td>
<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>VEHICLE CODE</td>
<td>(INTEGER)</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>DP2TETIME</td>
<td>TCON</td>
<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>DISPLAY NOUN FOR TIME</td>
<td>CSEC</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>TOECL1</td>
<td>TCON</td>
<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>TIME FOR LAT-LONG</td>
<td>CSEC</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>RATT</td>
<td>TCON</td>
<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>TIME FOR INTEGRATION</td>
<td>CSEC</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>TAT</td>
<td>TCON</td>
<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>CONIC POSITION VECTOR</td>
<td>CSEC</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
<td></td>
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<td>TCON</td>
<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>TIME OF POSITION</td>
<td>METERS</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
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<td>LAT</td>
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<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>LATITUDE</td>
<td>DEG</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
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<tr>
<td>LONG</td>
<td>TCON</td>
<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>LONGITUDE</td>
<td>DEG</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>ALT</td>
<td>TCON</td>
<td>t&lt;sub&gt;time&lt;/sub&gt;</td>
<td>ALTITUDE</td>
<td>NAUT, MI</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
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</table>

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GROUND TRACK DETERMINATION
P21
COLOSSUS II
FC-2580
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>P21048006</td>
<td></td>
<td>VEHICLE TEST VALUE 10 MINUTES</td>
<td>10 MINUTES</td>
<td>0.00001</td>
<td>(2^{14})</td>
</tr>
<tr>
<td>600 SEC</td>
<td></td>
<td></td>
<td></td>
<td>60000 CSEC</td>
<td>(2^{28})</td>
</tr>
</tbody>
</table>
P22. ORBITAL NAVIGATION

MAJOR SUBROUTINES:
S22.1 - PROCESSES MARK DATA TO UPDATE CSM STATE VECTOR.
S21TOGDN - CONVERTS X-MATRIX FROM 9 TO 6 DIMENSIONS.

SPECIAL CONVENTIONS:
1) "W" IS USED TO REPRESENT A MATRIX.
   I.e. B IS MATRIX B.

2) "VARIABLE" IN THE SCALING FIELD OF THE SUMMARY SHEETS INDICATES
   THAT THE ERASABLE LOCATION IS USED EITHER TO STORE A MATRIX WHOSE
   COMPONENTS HAVE DIFFERENT SCALING OR AS A TEMPORARY LOCATION HAVING
   MANY DIFFERENT SCALINGS.

3) 2^x/2^y IN THE SCALING FIELD OF THE SUMMARY SHEETS IS USED FOR EARTH/MOON
   SPHERE OF INFLUENCE.
   I.e. 2^x IS THE SCALING IN EARTH SPHERE.
   2^y IS THE SCALING IN MOON SPHERE.

THE ENCLOSED REPLACEMENT SHEETS WILL UPDATE THE COLOSSUS I (REV 237) FLOWCHART
FC-2590, REV 0, TO COLOSSUS II FC-2590, REV 1.

THE EFFECTIVE SHEETS FOR COLOSSUS II ARE:

1   REV 0
2   REV 1
3   REV 0
4-8  REV 1
9   REV 0
10  REV 1
11  REV 0
12-14 REV 1
15-16 REV 0
17-19 REV 1
20  REV 0
21  REV 1
22  REV 0
23  REV 1
24  REV 0
25  REV 1
26-27 REV 0
28-31 REV 1
32-40 REV 0
41-42 REV 1
43-44 REV 0

P22. ORBITAL NAVIGATION
FROM PRECEDING SHEET

CLEAR PR2 WFFLGS SET ERADFLG

PR2 DOWNLINKED MARK DATA WAS NOT JUST TAKEN. COMPUTE EARTH RADIUS OR USE FIXED MOON RADIUS DEPENDING UPON SPHERE OF INFLUENCE.

MOON SPHERE OF INFLUENCE?
YES-MOON

IS CMDNPLGS SET?

NO-EARTH

SET LUNAFLG

MOON LAT-LONG

INPUT FOR NTQ DISPLAY

MFAC → VOSNTO2.0

RETURN FOR MOON LANDMARK

RETURN FOR ADVANCED GROUND TRACK

REQUEST LAT, LONS, AND ALT FROM ASTRONAUT

SUB

CALL R52

GROUP AD

KILL GROUP 4

RESTARTS

GROUP E

SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINDING JOB WITH PRIORITY 13

MARKNO ← 5

SET NUMBER (5) OF MARKS WANTED (USED BY R53)

SET TARG2FLGS CLEAR TARG1FLG

SIGHTING LMK

NOT SIGHTING LMK

R52 AUTOMATIC OPTICS ROUTINE FC=ET50

INPUT LAT, LONG, ALT OPTICS DRIVEN AUTOMATICALLY TO SIGHT ON DESIRED LANDMARK.

OUTPUT MARK DATA (VIA R53)

DDVSN71

NEXT SHEET

NOTE: IF OPTICS SWITCH IS IN MANUAL, OPTICS WILL NOT BE DRIVEN. R53 WILL BE ENTERED TO TAKE MARKS.
FROM PRECEDING SHEET

MPAC ← V0341222

INPUT FOR NEXT DISPLAY

SPEETOP

DISPLAY AND DECIDE LANDMARK DATA

MARK = ADDRESS OF MARK DATA VAC AREA
SET BNN = QPRT OF MARK DATA VAC AREA
(NO. OF MARKS TAKEN)

PROGRESS

COMPRESS STATES VECTOR CHANGES, INCORPORATES CHANGES INTO STATE VECTOR.
NOTE: P22 CAN BE TERMINATED IN 322.1.

SECOND

INCORPORATE MARK DATA

PREVIEW

GROUP 2.
SET UP BLOCK TO
SCHEDULE NEXT LOCATION
AS A RNDVAC JOB
WITH SAME PRIORITY

PROGRAM WILL RECYCLE TO MARK ON ANOTHER
LANDMARK FOR INCORPORATION, CAN BE
TERMINATED AT ANY DISPLAY.
This subroutine requests astronaut to enter LAT, LONG and ALT.
Output: LAT, LONG, ALT.

P22SUBRB

522TOFF+1 → QPRET

SAVE RETURN

P22SUBRB+2

RS = LAT. XX.XXX DEG.
RE = LANDLONG XX.XXX DEG.
RS = LANDALT XXX.XX HAUT.MI. (CONVERTED TO METERS BY DISPLAY ROUTINE)

NOTE: ASTRONAUT ENTERS ONLY HALF DESIRED LONGITUDE SINCE REGISTER ONLY GOES TO 90° (SEE LLASRDA).

GOFLASH

LOAD LAT. LONG/ ALT.
DISPLAY LAT. LONG, ALT.
PROCEED

GOTOP00H

FALTON

TURN ON OPERATOR ERROR LIGHT
EC-E180

IS /LANDLAT/ > 90 DEG ?
YES

/ LANDLAT/ > 90 DEG ?
NO

YES

SUBROUTINE TO SET LONG AND ALT FROM THEIR DISPLAY NOUNS.

IS /LANDLONG/ > 90 DEG ?
NO

LONG = LANDLONG X 2
ALT = LANDALT

RETURN VIA QPRET

RETURN TO P22SUBRB

LONG SET TO TWICE VALUE ENTERED SINCE IT CAN GO FROM 0°-180° WHILE ENTERED VALUE CAN ONLY GO FROM 0°-90°.

RETURN VIA 522TOFF+1

SUBROUTINE TO SET LONG AND ALT FROM THEIR DISPLAY NOUNS.

RETURN TO P22

LLASRDA

ALT → LANDALT
LONG → LANDLONG X 2

RETURN VIA QPRET

RETURN TO P22SUBRB

RETURN VIA 522TOFF+1

RETURN TO P22

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

P22 - ORBITAL NAVIGATION

DRAWN: A.C. WILLIAMS
DRAWN: E.M. HOWARD
ANALYST: D.W. WILSON
ROOM: 154
APPRO'd: W.M. RICHARDS

COLOSSUS II
FC-2590

REV 1
SHL 8 OF 44
This subroutine performs major calculations of PZZ. It computes state vector changes for a set of marks and incorporates them into the state vector.

(RGS, referenced in R-57: COLOSUS GSDP Section 5 Rev.1, PSS 5.2-41 to 5.2-42)

```plaintext
522.4
522RTHEX  QPRET

OK ← 1
522LOC ← ECAODR(SVMKDAT)

X2 ← MARKSTAT
X1 ← 36

Initialize indices to move mark data

This loop cycled 6 times

Vac area indexed by X2,
SVMKDAT area indexed by X1,

LOOP 1
LOOP 2

LOOP 3

LOOP 4

LOOP 5

LOOP 6

Mark data is transferred from vac area used to record marks to SVMKDAT area in downlist.

X2 ← X2 - 6
X1 ← X1 - 6

Decrement indices

NO

X1 ≤ 0?

YES

6th time through loop

SET P22MKFLG

PZZ downlinked mark data was just taken

MARKRELEASE
RELEASE MARK SYSTEM
FC 5240

NEXT SHEET

Output: OPTMODES (BIT'S) = 0
OPTIND = -1
MARKSTAT = 0
```

Pre-Orbital Navigation
FROM PRECEDING SHEET

**GROUP4**
KILL GROUP 4 RESTARTS

**GROUP2.1**
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A FINDVAC JOB WITH PRIORITY 13

X1 ← 0
X1 USED AS A SHIFT INDICATOR

NO-EARTH

10 CMOWNFLG SET ?

MOON SPHERE OF INFLUENCE ?

YES

X1 ← −2
SET SHIFT FOR MOON SPHERE OF INFLUENCE

SIZESHIFT

SIZEORM ← X1

FIGEXIT

INSTALL
RESERVE INTEGRATION ROUTINE
FC: 2290

---

**SIZEFLGS**

SUBROUTINE WHICH Initializes Flags FOR INTEGRATION ROUTINE

SET DINOFLG
SET GEOGORSFLG
SET VINTFLG
SET STATEFLG
CLEAR INYFLG

RETURN VIA QPRET

NEXT SHEET

---

P22-ORBITAL NAVIGATION

DEMN: A.C. WILLIAMS
BIOG: MT. P., 24MT

COLOSSEUS II

FC-2590

10/44
FROM PRECEDING SHEET

IS W-MATRIX VALID FOR ORBITAL NAVIGATION?

(START GSNP FIG. 2.4-1)

YES - VALID W-MATRIX

IS ORBIFLAG SET?

NO - INVALID W-MATRIX

GETWWD

THIS SECTION INITIALIZES 6 DIMENSION
W-MATRIX FOR ORBITAL NAVIGATION

NOTE: D15 THE W-MATRIX INDICATOR DETERMINED
BY ORBFLAG AND GDRSFILG.

D15 W-MATRIX O.DIM, ORBFILG CLEARED

D16 W-MATRIX 6.DIM, ORBFILG SET AND
GDRSFILG CLEARED

D19 W-MATRIX 9.DIM, ORBFILG SET AND
GDRSFILG SET

CLEAR ORBFILG

RENEWFLAG

X1 = 108

INITIALIZE INDEX
FOR LOOP CONTROL

CLEARWW5

N IS ONE LESS
THAN LOOP NO.

Wn = 0

LOOP 1

W1 = ZEROVEC3

W2 = (W1+0) = ZEROVEC3

...

W11 = ZEROVEC3

LOOP 18

X1 = X1 - 6

DECREMENT INDEX

X1 ≤ 0?

NO

FINISHED 18 TIMES?

YES

W0 = W4+1

INITIALIZE POSITION ELEMENT (W0)
OF W-MATRIX FOR ORBITAL
NAVIGATION

W = W0POS

(W0) = W0POS

W6 = W0POS

W4 = W0POS

INITIALIZE VELOCITY ELEMENT (W4)
OF W-MATRIX FOR ORBITAL
NAVIGATION

NOTE: I = \begin{bmatrix} 100 \\ 001 \end{bmatrix} = IDENTITY MATRIX

W17 AND W19 ARE PRE-LOADED CONSTANTS

SETWAND

NEXT SHEET

PEZ-ORBITAL NAVIGATION

A.C. WILLIAMS

N. M. R. W. W.

D. COX

COLOSSUS II FC-2590
W-MATRIX IS 6 DIMENSIONAL
(FLAG USED BY MEASUREMENT INCORPORATION ROUTINE)

AFTER EACH MARK HAS BEEN PROCESSED, THE PROGRAM RETURNS HERE TO PROCESS THE NEXT MARK. (START OF GOOP FIG. 2.4-2)

GETFF

MPAC_y ← OFSEELOC

RETURN VIA QPRET

TOECL_y ← MPAC_y

TRANSFER TIME FOR INPUT TO INTEGRY.

INTEGRY

EXTRAPOLATE CSM STATE VECTOR TO TOECL
FC-2250

SUBROUTINE

SEECCALRC

DETERMINE CSM POSITION VECTOR

\[
\begin{align*}
\mathbf{C}_y &= \mathbf{C}_0 + \mathbf{C}_v \\
\mathbf{CSMPOS}_y &= \mathbf{DELTACSM}_y + \mathbf{ROVCSM}_y
\end{align*}
\]

RETURN VIA QPRET

MARKDATA ← SEELOC

TRANSFER ADDRESS OF MARK DATA FOR INPUT TO GETUM

GETUM

GET CONVERT SYT ANGLES TO LOS VECTOR
FC-2570

INPUT: MARKDATA = ADDRESS OF MARK ANGLES OUTPUT: MPAC_y = LINE OF SIGHT VECTOR IN BASIC REFERENCE COORDINATES

\[
\begin{align*}
\mathbf{W}_y &= MPAC_y \\
\mathbf{U}_y &= MPAC_y
\end{align*}
\]

STORE LOS VECTOR FOR FUTURE USE

NEXT SHEET
FROM PRECEDING SHEET

DMFINITEG

C/OFF=0,0K

XOFF=0

NO

YES

S22OFF=1

GETTF

SUBROUTINE

GET TIME FOR
THIS MARK (t_P)

SAVE TIME AND POSITION
FOR
OFFSET LANDING SITE PROCESSING

S22DEFF = MPAC

S22DEFF = UM

S22X = N

SHIT

THIS PATH CHECKS
FOR LAST MARK

IS W-MATRIX 2 DIMENSIONAL?

NOW: INITIALIZE W-MATRIX FOR LANDING SITE PROCESSING

S22D=5

FOR INPUT
TO R-TO-RP

PDLO = X

PDLO = X789

PDLO = t

PDLO = SETPROM

INPUT TO
R-TO-RP

MPAC = S22FORM

INPUT TO
R-TO-RP

R-TO-RP

CONVERT FROM
BASIC TO
PLANETARY
COORDINATE
SYSTEM

FC 2283

NEXT SHEET

GROUPS

SET UP RESTORE TO
SCHEDULE NEXT LOCATION
AS A FINDUCAC JOB
WITH SAME PRIORITY

W-MATRIX VALID FOR ORD. NAV
D=5 W-MATRIX 3 DIM.
D5P=1 DISPLAY AR + AX FLG
WHAT RADIUS FLAG?

SET ORBFLGS
SET DIMEFLGS
SET Z2DSPFLGS
SET ERDFLGS

SET

IS

KNOWNFLGS

SET

NO

S22B0X=22

SHIT

THIS PATH INITIALIZES
W-MATRIX FOR KNOWN
LANDMARK.

THIS PATH INITIALIZES
W-MATRIX FOR UNKNOWN LANDMARK.
NOTE: AAA IS A FLOWCHART
NOT PROGRAM MNEONIC.
FROM PRECEDING SHEET

RP VECTOR FROM P-TO-RP ROUTINE
USED AS INPUT TO RP-TO-R ROUTINE

GETFP

MPAC = OMP52ELOC

RETURN VIA QPRET

PDLO_1 → MPAC

GET TIME FOR NEXT MARK (t_F)

INPUT TO RP-TO-R

PDLO_1 = t_F

PDLO_2 → MPAC_2

INPUT TO RP-TO-R

MPAC → S2E2ORM

INPUT: OQ_1 = RADIUS VECTOR IN PLANETARY COORDINATES
GPO = TIME
MPAC = PLANET INDICATOR
0 = EARTH, NOT 0 = MOON
OUTPUT: MPAC_2 = RADIUS VECTOR IN BASIC COORDINATES
NOTE: THE CALLS TO RP-TO-R AND RP-TO-R ROUTINES
HAVE UPDATED THE LANDMARK POSITION
VECTOR FROM TIME (t_i) TO TIME (t_f).

S2E2BOX32

II = MPAC

XT63_1 ← MPAC

SAVE LANDMARK POSITION

SET INCORPLG

FIRST INCORPORATION PASS
FLAG = 1

CLEAR QFIND

IC = II - IC

RPC_1 ← MPAC - CSMP08

CALCULATE ESTIMATED CSM TO
LANDMARK LINE OF SIGHT
GSOP EQU. 2.4.3

NEXT SHEET
FROM PRECEDING SHEET

\[ U_0 = \text{UNIT} \left[ \frac{U_{CL} \times U_{CM}}{\text{UNIT} \left( \text{UNIT} (RCLP) \times U_{CM} \right)} \right] \]

MPAC = \text{UNIT} \left( \text{UNIT} (RCLP) \times U_{CM} \right)

\text{INITIALIZE FICITIOUS STAR DIRECTION} \quad \text{GSO P EQU. 2.4.4}

IF OVERFLOW, THEN ANGLE LESS THAN \( \epsilon_{15} \) AND STATE VECTOR CHANGES WILL BE NEGLIGIBLE. 
THUS THIS SET OF MEASUREMENT DATA WILL BE DISCARDED AND NEXT MARK WILL BE PROCESSED.

\text{SAVE FICITIOUS STAR DIRECTION FOR USE BY IVECTORS TO COMPUTE ARTIFICIAL STAR DIRECTION}

\text{NOTE: THIS IS THE ENTRY FOR SECOND INCORPORATION PASS.}

\[ \text{W-MATRIX} \quad \text{9 DIMENSIONAL VEHICLE IS CSM} \]

\[ \alpha^2 = \frac{e^2}{\text{RCLP}} (\text{VAR}_{\alpha^2} + \text{VAR}_{\beta^2}) \]

\[ \text{VARIANCE} = \frac{(\text{RCLP})^2}{\text{SCVAR}_{\alpha^2} + \text{SCVAR}_{\beta^2}} \]

\[ \text{COMPUTE INSTRUMENT ERROR VARIANCE} \quad \text{GSO P EQU. 2.4.13} \]

\text{BVECTORS} \quad \text{COMPUTE DELTAQ AND IVECTORS} \quad \text{FC-2590}

\[ b_2 = \frac{-b_2}{(\text{BVECTOR} + 12)} \]

\text{INITIALIZE} \ b_2

\text{INCORP.} \text{COMPUTE STATE VECTOR CHANGE} \quad \text{FC-EL10}

\text{NEXT SHEET}

\text{COMPUTE GSO P EQU. 2.4.12}

\text{INPUT:} \ U_{CM} = \text{MEASURED LOS VECTOR (U_{CM})} \quad \text{USTAR\_n = FICTIOUS STAR DIRECTION (U_{CM})} \quad \text{RCLP\_n = COMPUTE LOS VECTOR (RCLP)}

\text{OUTPUT:} \ U_{STAR} = \text{ARTIFICIAL STAR DIRECTION (U_{CM})} \quad \text{BVECTOR\_n = 9 DIM. GEOMETRY VECTOR (b_0, b_1, b_2)} \quad \text{DELTAQ = MEASURED DEVIATION (\delta Q)}

\text{INPUT:} \ \text{DELTAQ = ESTIMATED AND MEASURED POSITION DEVIATION (\delta Q)} \quad \text{VARIANCE = INSTRUMENT ERROR VARIANCE (\alpha^2)} \quad \text{BVECTOR = 9 DIM. GEOMETRY VECTOR (b_0, b_1, b_2)} \quad \text{DMENFSL = DIMENSION OF W-MATRIX} \quad \text{SET-9 DIM.}

\text{OUTPUT:} \ \text{DELTAQ = STATE VECTOR DEVIATIONS (\delta X)}
FROM PRECEDING SHEET

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

10
22DSFPLG
SET

NOTE: STATE VECTOR DEVIATIONS WILL BE DISPLAYED FOR APPROVAL ONLY FOR THE FIRST MARK. IF THESE ARE ACCEPTED, ALL OTHER DEVIATIONS (FOR THIS SET OF MARKS) WILL BE INCORPORATED WITHOUT BEING DISPLAYED.

WILL DEVIATIONS BE DISPLAYED?

YES - DISPLAY STATE VECTOR DEVIATIONS
CLEAR 22DSFPLG
DO NOT DISPLAY DEVIATIONS

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

N4090ISP, (N4090ISP + δ) / (DELTAX + δ)

PLACE POSITION (δx) AND VELOCITY (δv) DEVIATIONS IN THEIR DISPLAY NOUNS.

GOFLASH
VOMAG
DISPLAY δx AND δv FOR APPROVAL

REJECT DEVIATIONS (ENTER DATA)

PROCEDURE
SE28OVA2

INCORP2
INTEGRATE STATE VECTOR DEVIATIONS
FC-2640

INCORP2
INTEGRATE STATE VECTOR DEVIATIONS
FC-2640

INPUT: DELTAX = STATE VECTOR DEVIATIONS (δx)
DIMENFLG = DIMENSION OF W-MATRIX
OUTPUT: UPDATED STATE VECTOR

SE2EXEX
RETURN VIA SE2ERTNEX

SUBROUTINE
SE3CALRC

DETERMINE CSM POSITION VECTOR

RETURN VIA QPRET

NEXT SHEET

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CAMBRIDGE, MASS.

DRAWN A.C.WILLIAMS
PROBIE M.P. SMITH
ANALYST
DOOR: A.C. WHITE

F22-ORBITAL NAVIGATION
COLOSSUS II
FC-2590
FROM PRECEDING SHEET

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

INSTALL
RESERVE INTEGRATION
ROUTINE
FC-2590

SUBROUTINE

S22FLGS
SET OMENFLG
SET DCMOTFLG
SET VINTFLG
SET STATEFLG
CLEAR INTYPFLG
RETURN VIA
QPRET

ISOMFLG
SET
NO=6
DIMENSIONAL
0=0
(W-MATRIX NOT
INITIALIZED)

NOTE: THIS BRANCH TAKEN ONLY IF
THE FIRST MARK IS A OFFSET
LANDING SITE.

IS W-MATRIX 9 DIMENSIONAL
(LANDMARK PORTION INITIALIZED) ?

YES=9 DIMENSIONAL
THIS PATH TAKEN IF FIRST
MARK NOT AN OFFSET
LANDING SITE.

IS W-MATRIX 6 DIMENSIONAL
(W-MATRIX INTEGRATION
BECAUSE IT HAS NOT BEEN
INITIALIZED FOR ORBITAL
NAVIGATION.

NO=6
DIM (W-MATRIX)

SET DIMOFLAG
CLEAR DCMOTFLG
SELECT
9102

THIS PATH ALLOWS 6-DIMENSIONAL
W-MATRIX INTEGRATION

SET DCMOFLAG
CLEAR DCMOTFLG

IS W-MATRIX VALID FOR
ORBITAL NAVIGATION ?

YES

THIS BRANCH PROCESSES
NEXT MARK.
FROM PRECEDING SHEET

CLEAR LUNAFLAG

BARTH LAT-LONG

MPAC = Fe

MPACv = X78v

MOVE Fe TO
ADJUST SCALING

IS CMOONFLG SET?

NO

IN MOON SPHERE
OF INFLUENCE?

YES

MONTH LAT-LONG

LUNAFLAG

ADJUST
SCALING

Fe (FOR MOON) SCALING ADJUSTED
TO 2E FROM 25 FOR INPUT TO
LAT-LONG

<22BX44B

Fe = MPAC

SOLVE FOR INPUT
TO LAT-LONG

MPAC = E60

MPACv = <22TXOFF

STORE TIME FOR
INPUT TO LAT-LONG

LAT-LONG

CONVERT POSITION
VECTOR TO LAT,
LONG AND ALT.

ALPHA = MPAC

FC-2280

SUBROUTINE

LLASRD

PLACE LONG AND ALT IN THEIR
RESPECTIVE DISPLAY NOUNS.

NOTE: LAT ALREADY IN ITS DISPLAY
NOUN. ALSO, LANDLONG SCALED
2^ (SEE DISPLAY BELOW)

NEXT SHEET

MCP

INSTRUMETATION LAB
CAMBRIDGE, MASS.

PRINTED BY R.E. WILLIAMS
DATE 10/20/72
ANALYSE 11/23/72
DRAWN 11/20/72
FINISHED 1/21/73

PEZ-ORBITAL NAVIGATION

COLOSSUS II

FC-2590
FROM PRECEDING SHEET

PROCEED

TERMINATE

R1 = LANDLAT XX.XXX DEG.
R2 = LANDLONG XX.XXX DEG.
R3 = LANDALT XXX.XX NAUT.MI.
NOTE: LANDLONG IS 1/6 ACTUAL LONGITUDE BECAUSE REGISTER CAN DISPLAY ONLY TD 30°

TIME FOR LAST MARK

FINAL LANDMARK POSITION
NON-ZERO IN MPAC

INPUT: Q = POSITION VECTOR IN
BASIC REF. COOR.

T = TIME

MPAC = PLANET INDICATOR

O = EARTH NON-ZERO+MOON

OUTPUT: MPAC = POSITION VECTOR IN
PLANETARY COOR.

STORE NEW LANDING SITE VECTOR

GOTOPOOH

522GTP

5D WTFQGW

CONVERT W-MATRIX FROM 9 TO 6 DIM.

6H33

S22.985X

9D WFTOGDW

CONVERT W-MATRIX FROM 9 TO 6 DIM.

GOTOPOOH

RETURN VIA S22RNE

THIS IS A RETURN WHICH WILL RECYCLE P22 TO TAKE MARK DATA ON ANOTHER LANDMARK (OR THE SAME ONE AGAIN) OR TO TERMINATE P22 AT ANY DISPLAY.

P22-ORBITAL NAVIGATION

COLOSSUS II FC-2590
THIS BRANCH INITIALIZES LANDMARK SECTION OF W-MATRIX FOR KNOWN LANDMARK.

THIS LOOP CYCLES 9 TIMES TO CLEAR W₁₁, W₁₉, W₉₉

WITH W₁₈ = 0

W₁₉
W₁₈

(W + 100)₂₉ ← ZEROVECS₂₉
(W + 114)₂₉ ← ZEROVECS₂₉

· · ·

(W + 156)₂₉ ← ZEROVECS₂₉
LOOP 9

X₁ ← X₁ - 6

LOOP COMPLETED 9 TIMES?

YES

W₁₂ = W₁₉
(W + 144) ← 562WSUBL
W₁₇ = W₁₉
(W + 150) ← 562WSUBL
W₁₉ = W₁₉
(W + 156) ← 562WSUBL

INITIALIZE DIAGONAL ELEMENTS OF W₉₉ = W₁₁

CLEAR LUNAFLAG EARTH LAT-LONG

MOON SPHERE OF INFLUENCE?

YES

SET LUNAFLAG MOON LAT-LONG

SET LUNAFLAG

562BY22A

NEXT SHEET
FROM PRECEEDING SHEET

GETTP

MPACQ → ON#82ELOC

RETURN VIA QPRET

GET TIME FOR THIS MARK

LALOTOVR

CONVERT LAT, LONG AND ALT TO RADIUS VECTOR

PC-2280

MPAC = FE

MPAC1 = ALPHA

MOVE LANDMARK VECTOR TO ADJUST SCALING

IS CWVEDFLG SET?

NO

MOON SPHERE OF INFLUENCE?

YES

ADJUST SCALING

2E7 METERS MOON LANDMARK

522BOX2EB

522BOX32

SM14

THIS BRANCH LEADS TO INCORPORATION OF THIS MARK.
THIS BRANCH INITIALIZES LANDMARK SECTION OF W-MATRIX FOR UNKNOWN LANDMARK.

\[ \text{ALPHAV}_v = (\text{ALPHAV}_v, \text{ALPHAV}_v + 2, \text{ALPHAV}_v + 4) \]
\[ \text{ALPHAV}_v + 4 = \text{MIN} \] \text{L} \text{USED BY SETRE}

CLEAR LUNAFLAG

EARTH LAT-LONG

\text{IS} \text{CMOONFLG \ SET ?}

\text{NO- \text{EARTH}}

\text{MOON SPHERE OF INFLUENCE ?}

\text{YES- \MOON}

SET LUNAFLAG

MOON LAT-LONG

\text{S2EC = 1}

SET \text{ERAD} \text{FLG}, \text{ALPHAV}_v + 4, \text{LUNAFLAG}

\text{INPUT: \text{ERADFLG, ALPHAV}_v + 4, LUNAFLAG}

\text{OUTPUT: \text{ERADM = RADIUS OF EARTH OR MOON}}

\text{G5OP \ EQU. 2.4.10}

\text{INPUT: \text{CSMP} \text{POS} (\text{r}_c) = CSM \text{POSITION SCALED 2}^{25/24} \text{METERS.}}
\text{UM (\text{u}c) = LOS \text{VECTOR SCALED 2}^{1/2} \text{METERS.}}
\text{ERAD} \text{M (\text{r}c) = \text{RADIUS OF EARTH OR MOON SCALED 2}^{1/2} \text{METERS.}}

\text{OUTPUT: \text{MPAC}_v = X780 (\text{c}) = \text{LANDING SITE VECTOR SCALED 2}^{25/24} \text{METERS.}}

\text{COMPUTE LANDMARK LOCATION}

\text{NO- \text{EARTH}}

\text{IS \text{CMOONFLG \ SET ?}}

\text{NO- \text{MOON}}

\text{MOON SPHERE OF INFLUENCE ?}

\text{YES- \MOON}

\text{MPAC IS SCALED 2}^{25/24} \text{FOR EARTH/MOON BY S22F2410. HERE MPAC SCALE ADJUSTED TO 2}^{25} \text{IF MOON SPHERE OF INFLUENCE.}}

\text{ADJUST SCALING}

\text{SAVE LANDMARK LOCATION}

\text{NOTE: THIS STARTS G5OP FIG. 2.4-3.}

\text{NEXT SHEET}
FROM PRECEDING SHEET

\[ d = u_m \cdot \frac{\phi}{\theta} \]

\[ 522D \rightarrow u_m \cdot MPAC_v \]

EVALUATE SCALAR USED TO INITIALIZE \( W_L \) AND \( W_T \)

SET CO TO 17D
EQUAL TO 0

PD81, PD82 \rightarrow HIGHTHALF
PD83 \rightarrow HIGHTHALF

CLEAR FIRST 18 LOCATIONS
OF PUSHLIST

SET PUSHLIST EQUAL TO IDENTITY MATRIX \( (I) \)
(USED IN LOOP BELOW)

[0 0 1]
[0 1 0]
[0 0 1]

0D TO 5D
6D TO 11D
12D TO 17G

\[ 5225X1 \rightarrow u_m \]

\[ MPAC_v \rightarrow 522RL_v \]

\( V_m \) AND \( I_e \) MOVED FOR INPUT TO \( 52231 \times 13 \)

\[ 52231X13 \]
DO 3X1 BY
1X3 MATRIX
MULTIPLICATION
5552

INPUT: \( 5223X1_v = 3 \times 1 \) MATRIX
\( MPAC_v = 1 \times 3 \) MATRIX

OUTPUT: \( 522UMRL = 3 \times 3 \) MATRIX \( \left( u_m^* \phi e^T \right) \)

\[ x_1 \rightarrow 15 \]

INITIALIZE FOR LOOP CONTROL

522HXTU

THIS LOOP CYCLED
3 TIMES

\[ y_1 = x_1 - \frac{d}{u_m \cdot \phi} \]

\[ 522UMRL \rightarrow 522RL \left( \frac{522UMRL \times 522D}{522D} \right) \]

\[ w_e = x_1 - \frac{d}{u_m \cdot \phi} \left( \frac{522UMRL \times 6_e}{522D} \right) \]

\[ \left( \frac{522UMRL \times 6_e}{522D} \right) \]

\[ 522HXTU \]

\[ u = x_1 - \frac{1}{d} u_m \frac{\phi}{\theta} e^T \]

LOOP 1

\[ u = x_1 - \frac{1}{d} u_m \frac{\phi}{\theta} e^T \]

LOOP 2

\[ u = x_1 - \frac{1}{d} u_m \frac{\phi}{\theta} e^T \]

LOOP 3

\[ u = x_1 - \frac{1}{d} u_m \frac{\phi}{\theta} e^T \]

\[ x_1 \rightarrow x_1 - 6 \]

DECREMENT INDEX

NO

\[ x_1 < 0 \]

THIRD PASS

YES

NEXT SHEET

PRE-ORBITAL NAVIGATION

COLOSUS II

FC-2590
SUBROUTINE TO MULTIPLY A 3 BY 1 MATRIX BY A 1X3 MATRIX YIELDING A 3 BY 3 MATRIX.
INPUT: S2231 = 3 BY 1 MATRIX
MPAC = 1 BY 3 MATRIX
OUTPUT: S22UMRL = 3 BY 3 MATRIX

62231X15

6221X3 ← MPAC
SAVE 1X3 MATRIX

X2 ← 6
X1 ← 18
SET UP INDICES FOR LOOP CONTROL

62231NXT

THIS LOOP CYCLED 3 TIMES

X1 ← X1 - 6
DECREMENT INDEX

X2 ≤ 2
IS THIS THE THIRD PASS?

RETURN VIA OPRET
RETURN TO 6221
THIS SUBROUTINE CONVERTS W-MATRIX FROM
9Dx6 DIMENSIONS.

NOTE: W-MATRIX CONVERSION ROUTINE IS
DESCRIBED IN SPACE GUIDANCE SYSTEM
MEMO #20-66.

GAVE RETURN

WORKN
XTEMP1

INITIALIZE: 9DWP
9DWI
9DWN
9DWO

NOTE: COMPUTER VALUES FOR COUNTERS (IJ AND P)
ARE TWICE GSOP VALUES BECAUSE VARIABLES
ARE DOUBLE PRECISION.

THIS BEGINS GSOP FIG. 2-4-3.

I = 29
9DWO = 58

9DWI = J

SPWEPICAL

ROWDOT
CALCULATE
ROW DOT
PRODUCT

KEO

OUTPUT:

\[ \sum_{k=0}^{\infty} W_{j+k} = MPAC_D \]

\( (E_{MATRICE + 40})^T \cdot 9DWP \rightarrow MPAC_D \)

NOTE: P IS GOING FROM
0 TO 20 INSTEAD
OF GSOP 20 TO 0.

NEXT SHEET
FROM PRECEDING SHEET

START OF GSOP FIG. 2.4-6

GROUP

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

J = 29
S0WJ = 55

S0WPv = HIGZEROSv

P = 0
I = 0
N = 0

INITIALIZE COUNTERS

X1 = 108

INITIALIZE INDEX FOR LOOP CONTROL

CLEAR WS4

THIS LOOP CYCLED 18 TIMES.

WH = 0

LOOP 1: W0 = 0
LOOP 2: W1 = 0

LOOP 19: W19 = 0

X1 = X1 - 6

DECUMENT INDEX

X1 ≤ 0

IS THIS THE 18TH PASS?

Yes

GO TO JA

I = 1

GO TO S0WJ

ROWOUT

CALCULATE ROW OUT PRODUCT

WH = 0

W0 = c0 - 2
W1 = W3 + 2k
W2 = 2k

MPAC0 = (SUM) x [54] x 90WP - MPAC2

NEXT SHEET

INPUT: S0WI = I
S0WJ = 10
W - MATRIX

OUTPUT: MPAC0 = \frac{2}{\mu0} W2 + 2k W2 + 2k

PE2 - ORBITAL NAVIGATION

COLUMBUS II FC-2590
THIS PART CALCULATES THE SOLUTION (EQUI. 2.4-16) TO GSOP EQUI. 2.4-17.

\[
\begin{pmatrix}
W_0^T & W_1^T \\
W_2^T & W_3^T
\end{pmatrix}
\]

EQUI. 2.4-16

TST2I = 0

I = 0 TEST

SDWI = 0

NO

AJUST COUNTERS

YES

SDWI = SDWI - SDWID

NO

I = I - 1

SDWI = SDWI - 500

I = 26 TEST

YES

SDWIAC

NEXT SHEET

SDWJ = SDWJ - SDWID

NO

SDWJ - SDWJ > 0

I = 26 TEST

YES

SETJ = 2A

SDJ = SDJ - 4

SDWI = JA

5H54

THIS PATH COMPUTES ANOTHER ELEMENT OF SOLUTION TO GSOP EQUI. 2.4-17.

MPAC = \frac{((E\text{MATRIX} + 40) \times SDWP)}{WORKW

SEE GSOP EQUI. 2.4-17

P = P + 1

9DWP = 9DWP - 2
FROM PRECEEDING SHEET

NO

OVFIND

SET?

YES

SETWIN=0

MPAC2 --- HIGZEROS

W2±N = 0

SOWSETW

W2±N = MPAC2

W6 (3DIW - 3DIN) --- MPAC2

TST2± = 0

SHIT

THIS PATH RECYCLES TO
COMPUTE ANOTHER ELEMENT
OF SOLUTION TO EQU. 2.4 - 27.
THIS SUBROUTINE CALCULATES \( c_p = \sum_{k=0}^{2^6-1} \frac{1}{k+1} W_{2k+3} W_{2k+3} \)

**INPUT:**
- \( SOWI = I \)
- \( SOWJ = J \)
- \( W\)-MATRIX

**OUTPUT:**
- \( MPAC_{c} = \sum_{k=0}^{2^6-1} W_{2k+3} W_{2k+3} \)

\( 3 \times 2^6 = 2^7 - 1 \) THIS IS THE \( k \)-INDEX IT IS DIVIDED BY 2 \((5 \text{ TIMES})\) UNTIL IT IS ZERO.

---

**Initialize I and J indices for indirect addressing**

**Rowdott**

\[ X_{MP1} = 37^B \]

**Clear ovfino**

**Rowdott1**

\[ X_{1} = -SOWI \]
\[ X_{2} = -SOWJ \]
\[ IOB = 0 \]

**This loop cycled 3 times. \( k=0,1,2,\ldots,6 \)**

**Rowdott2**

\[ 18_B \rightarrow 18_B + (W_{2k+3})(W_{2k+3}) \]
\[ 18_B \rightarrow 18_B + (W_{2k+3})(W_{2k+3}) \]

**If computational overflow, then W-MATRIX will be invalid for orbital navigation.**

**Rowdott3**

**Yes**

**Is ovfino set?**

\[ X_{MP1} = X_{MP1} / 2 \]

**No**

**This forms I+3k and J+3k indices**

**Rowdott4**

\[ X_{1} = X_{1} + 6 \]
\[ X_{2} = X_{2} - 6 \]

**Rowdott5**

**MPAC \rightarrow X_{MP1}**

**K = 6 test**

**Yes**

**Rowdott6**

**MPAC \rightarrow 18_B**

RESULT OF \( \sum_{k=0}^{2^6-1} \frac{1}{k+1} W_{2k+3} W_{2k+3} \) WILL BE OUTPUT IN MPAC.

**RETURN VIA GRET**

**RETURN TO SOWDOW**
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>RO3BOT9</td>
<td>2210</td>
<td>CHECKS STATUS OF IMU</td>
<td>SH3</td>
</tr>
<tr>
<td>LOADTIME</td>
<td>2100</td>
<td>GETS PRESENT TIME FROM COMPUTER</td>
<td>SH3, 7</td>
</tr>
<tr>
<td>CSMCONIC</td>
<td>2290</td>
<td>EXTRAPOLATES CSM STATE VECTOR TO TIME TDEC1 (CONIC)</td>
<td>SH3</td>
</tr>
<tr>
<td>BLANKET</td>
<td>2130</td>
<td>BLANKS OUT CERTAIN DISPLAY REGISTERS</td>
<td>SH3, 8, 16</td>
</tr>
<tr>
<td>RT2</td>
<td>2730</td>
<td>AUTOMATIC OPTICS DRIVING ROUTINE</td>
<td>SH4</td>
</tr>
<tr>
<td>ADVORB</td>
<td>2730</td>
<td>ADVANCED GROUND TRACK ENTRY POINT OF RT2</td>
<td>SH7</td>
</tr>
<tr>
<td>RP-TO-R</td>
<td>2283</td>
<td>CONVERT FROM PLANETARY TO BASIC REFERENCE COORDINATES</td>
<td>SH7, 14</td>
</tr>
<tr>
<td>LAT-LONG</td>
<td>2280</td>
<td>CONVERT RADIUS VECTOR TO LAT, LONG, AND ALT, RELEASE MARK SYSTEM</td>
<td>SH7, 20</td>
</tr>
<tr>
<td>MGKRELEAS</td>
<td>2240</td>
<td>RESERVE INTEGRATION ROUTINE</td>
<td>SH9</td>
</tr>
<tr>
<td>INSTALL</td>
<td>2290</td>
<td>EXTRAPOLATE CSM STATE VECTOR TO TIME TDEC1</td>
<td>SH10, 18</td>
</tr>
<tr>
<td>INTEGY</td>
<td>2290</td>
<td>CONVERT SIGHTING ANGLES TO LINE OF SIGHT VECTOR</td>
<td>SH12</td>
</tr>
<tr>
<td>GETUM</td>
<td>2270</td>
<td>CONVERT FROM BASIC REFERENCE TO PLANETARY COORDINATES</td>
<td>SH12</td>
</tr>
<tr>
<td>R-TO-RP</td>
<td>2283</td>
<td>COMPUTE MEASURED TO ESTIMATED POSITION DEVIATION AND MEASUREMENT GEOMETRY VECTOR</td>
<td>SH13, 21</td>
</tr>
<tr>
<td>BVECTORS</td>
<td>2250</td>
<td>COMPUTE STATE VECTOR CHANGE</td>
<td>SH15</td>
</tr>
<tr>
<td>INCORP1</td>
<td>2210</td>
<td>INTEGRATE CSM STATE VECTOR TO TIME TDEC1</td>
<td>SH15</td>
</tr>
<tr>
<td>INCORP2</td>
<td>2210</td>
<td>EXTRAPOLATE CSM STATE VECTOR TO TIME TDEC1 (PRECISION)</td>
<td>SH16, SH19</td>
</tr>
<tr>
<td>CSMPREC</td>
<td>2290</td>
<td>CONVERT LAT, LONG, AND ALT TO RADIUS VECTOR</td>
<td>SH23</td>
</tr>
<tr>
<td>LALATORV</td>
<td>2280</td>
<td>COMPUTE EARTH OR MOON RADIUS</td>
<td>SH24</td>
</tr>
</tbody>
</table>

### FLAGS

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNDVZFLG</td>
<td>P20 IS RUNNING</td>
<td>P20 IS NOT RUNNING</td>
<td>SH3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 0 BIT</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>RENDWFLG</td>
<td>W-MATRIX IS VALID FOR RENDEZVOUS NAVIGATION</td>
<td>W-MATRIX IS INVALID FOR RENDEZVOUS NAVIGATION</td>
<td>SH3, 11</td>
<td>SH3, 11</td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 5 BIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P22MKFLG</td>
<td>P22 DOWNLINK MARK DATA WAS JUST TAKEN</td>
<td>P22 DOWNLINK MARK DATA WAS NOT JUST TAKEN</td>
<td>SH5</td>
<td>SH4</td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 3 BIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERADFIL</td>
<td>EARTH: COMPUTE FISHER ELLIPSOID RADIUS</td>
<td>EARTH: USE FIXED RADIUS</td>
<td>SH4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 1 BIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CMONNFLG</td>
<td>CSM STATE VECTOR IS IN LUNAR SPHERE OF INFLUENCE</td>
<td>CSM STATE VECTOR IS IN EARTH SPHERE OF INFLUENCE</td>
<td>SH4, 19, 20, 22, 23, 24</td>
<td>SH4, 19, 20, 22, 23, 24</td>
<td>SH4, 19, 20, 22, 23, 24</td>
</tr>
<tr>
<td>FLAGWORD 8 BIT</td>
<td></td>
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</tr>
<tr>
<td>LUNAFLG</td>
<td>LAT-LONG IS FOR MOON</td>
<td>LAT-LONG IS FOR EARTH</td>
<td>SH4, 20, 22, 24</td>
<td>SH4, 20, 22, 24</td>
<td>SH4, 20, 22, 24</td>
</tr>
<tr>
<td>FLAGWORD 12 BIT</td>
<td></td>
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<tr>
<td>KNOWNFLG</td>
<td>LANDMARK IS KNOWN</td>
<td>LANDMARK IS UNKNOWN</td>
<td>SH6</td>
<td>SH6</td>
<td>SH7, 13</td>
</tr>
<tr>
<td>FLAGWORD 6 BIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TARG2FLG</td>
<td>SIGHTING LANDMARK</td>
<td>SIGHTING STAR</td>
<td>SH7</td>
<td></td>
<td></td>
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<tr>
<td>FLAGWORD 9 BIT</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>TARG1FLG</td>
<td>SIGHTING LEM</td>
<td>NOT SIGHTING LEM</td>
<td>SH7</td>
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<tr>
<td>FLAGWORD 10 BIT</td>
<td></td>
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</tbody>
</table>

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P22-ORBITAL NAVIGATION

COLOSSUS II FC-2590

DRAUGHT

APPROVED

ANALYST

DRAWN

CHECKED

APPROVED

DATE

REV

41 44
### Flags (Cont'd)

<table>
<thead>
<tr>
<th>NAME</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIMOFLAG</td>
<td>W-Matrix is to be used</td>
<td>W-Matrix is not to be used</td>
<td>SH10,18</td>
<td>SH11,18</td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 3 BIT 1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>D608FLG</td>
<td>W-Matrix is 9 dimensional for integration</td>
<td>W-Matrix is 6 dimensional for integration</td>
<td>SH10,18</td>
<td>SH11,18</td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 3 BIT 2</td>
<td></td>
<td>Integrate CSM state vector</td>
<td>SH10,18</td>
<td></td>
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</tr>
<tr>
<td>VINTFFLAG</td>
<td>Permanent state vector to be updated</td>
<td>Permanent state vector not to be updated</td>
<td>SH10,18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 3 BIT 3</td>
<td></td>
<td></td>
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<tr>
<td>STATEFLG</td>
<td>Conic integration</td>
<td>Eccne integration</td>
<td>SH10,18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 3 BIT 5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>INTYPFLG</td>
<td>W-MATRIX IS 8 for orbital navigation</td>
<td>W-MATRIX IS 8 for orbital navigation</td>
<td>SH10,18</td>
<td>SH11,18</td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 3 BIT 4</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>ORBWEFLG</td>
<td>W-MATRIX IS 9 for orbital navigation</td>
<td>W-MATRIX IS 9 for orbital navigation</td>
<td>SH15</td>
<td>SH12</td>
<td>SH13,18</td>
</tr>
<tr>
<td>FLAGWORD 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DMNFLG</td>
<td>W-MATRIX IS 9 dimensional for incorporation</td>
<td>W-MATRIX IS 9 dimensional for incorporation</td>
<td>SH15</td>
<td>SH14</td>
<td>SH17</td>
</tr>
<tr>
<td>FLAGWORD 5 BIT 9</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>INCORFLG</td>
<td>First incorporation pass</td>
<td>Second incorporation pass</td>
<td>SH15</td>
<td>SH17</td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 5 BIT 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>VEHUPFLG</td>
<td>CSM state vector is being updated</td>
<td>LEM state vector is being updated</td>
<td>SH15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAGWORD 1 BIT 8</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>22DSPFLG</td>
<td>Display Δr and Δv</td>
<td>Do not display Δr and Δv</td>
<td>SH16</td>
<td>SH16</td>
<td></td>
</tr>
<tr>
<td>FLAGWORD BIT 8</td>
<td></td>
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</tbody>
</table>

### Displays

<table>
<thead>
<tr>
<th>Verb-Noun</th>
<th>Type of Displays</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
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</thead>
<tbody>
<tr>
<td>V06N45</td>
<td>Flashing</td>
<td>R1 = BLANK</td>
<td>SH3</td>
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<td>R2 = BLANK</td>
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<tr>
<td></td>
<td></td>
<td>R3 = xxx, xx DEG</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>Middle</td>
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<td></td>
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<td>Gimbal angle</td>
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<td>V05N70</td>
<td>Flashing</td>
<td>R1 = BLANK</td>
<td>SH6</td>
</tr>
<tr>
<td></td>
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<td>R2 = xxx, xxx ABCDE = MARKS</td>
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<td>R3 = BLANK</td>
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<td>R2 = xxx, xxx ABCDE = MARKS</td>
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<td>V06N89</td>
<td>Flashing</td>
<td>R1 = BLANK</td>
<td>SH8, 21</td>
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<td>R2 = xx, xx DEG</td>
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<td>R3 = xx, xx NAUT. DEG</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Latitude</td>
<td></td>
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<tr>
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<td>Longitude</td>
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<td>Altitude</td>
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<td>V06N49</td>
<td>Flashing</td>
<td>R1 = xxx, x</td>
<td>SH16</td>
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</tr>
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<td>R3 = BLANK</td>
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</tr>
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<td></td>
<td>Naut. Ml</td>
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</tr>
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<td>Velocity change</td>
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<td>SEC</td>
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<td>CONIC VELOCITY VECTOR</td>
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<td>ADDRESS OF MARK DATA VAC AREA</td>
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<td>DE</td>
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<td>OFFSET MARK INDICATOR</td>
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<td>(2(^{1}/2^{1}/2^{1}))</td>
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<td>RADIUS OF EARTH/MOON</td>
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<td>W</td>
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<td>W-MATRIX</td>
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<td>METERS</td>
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<tr>
<td>S22D</td>
<td>d</td>
<td>INTERMEDIATE SCALAR</td>
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**MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.**
### ERASABLE LOCATIONS USED (CONT'D)

<table>
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<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
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<tr>
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<td>U</td>
<td>WORK MATRIX</td>
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<td>S22RHO</td>
<td>p</td>
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<td>E</td>
<td>1ST PART OF SOLUTION MATRIX</td>
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### PROGRAM CONSTANTS

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<td>(INTEGER)</td>
<td>2&lt;sup&gt;-18&lt;/sup&gt;</td>
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### PAD LOADS

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<td>w&lt;sub&gt;lf&lt;/sub&gt;</td>
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<td>METERS</td>
<td>METERS</td>
<td>2&lt;sup&gt;18&lt;/sup&gt;</td>
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<td>METERS/CSSEC</td>
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<td>S22WSUBL</td>
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<td>ORBITAL NAVIGATION W-MATRIX LANDMARK INITIALIZATION VALUE</td>
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<td>VARIANCE OF PRIMARY BODY RADIUS ERROR</td>
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<td>METERS&lt;sup&gt;2&lt;/sup&gt;</td>
<td>2&lt;sup&gt;28&lt;/sup&gt;</td>
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</table>
P23 - Cislunar Midcourse Navigation
Called from Osky

Pointaxs - Computes the CSM to landmark/horizon pointing vector
Horiz - Computes horizon location vector

SPECIAL CONVENTIONS

1) Scaling indicated as \(2^* / 2^*\) means \(2^*\) is the scaling in earth sphere of influence and \(2^*\) 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., \#A 1 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. NTO, 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 "NTO"
P23

Called via O5K

CLEAR RND/2FLG

Indicates P20 is not running

GROUP 4.0

Will group 4 restarts

GROUP 2.1

Set up restarts to return to last display

PBSRDT2 ← PRID15

Set restart priority to 15.

MARKINDX ← 1

Set number of marks to be taken in R53 to 1.

CLEAR TARG1FLG/
CLEAR TARG2FLG

Indicate that the target is a star
used by R52.

STARIND ← 0

BESTI ← 0

Initialize star index to besti
Indicates sighting first star
Input to R53

CLEAR RESTIFLAG/
CLEAR VB4FLAG

Indicates optics need to be calibrated.
Do not allow V54 (see note on sheet 8)

PE23.00

NEXT SHEET
FROM PRECEDING SHEET

P23.152

A = A (BITS 9-7) MASK "C" OIGIT

IS "C" = 1 ?

NO

YES

P23.16

CLEAR LUNAFLAG EARTH LAT-LONG

IS "C" = 2 ?

NO

YES

R23.10

SET LUNAFLAG LUNAR LAT-LONG

FALTON

Turn on operator error flag FC-2180

A = STARCODE

TEST STARCODE

< 0

NO

P23.17

BEST = STARCODE (SPSIX)

SUBROUTINE TO PICK UP STAR VECTOR FROM LOW MEMORY

LOWMEMORY

MPAC \textsubscript{V} \rightarrow \text{CATLOG} \textsubscript{V} \neq \text{BEST} \text{I}

RETURN VIA QRET

STARSAY2 \textsubscript{V} \rightarrow MPAC \textsubscript{V}

SAVE STAR VECTOR

NEXT SHEET
FROM PRECEDING SHEET

P23.176

IS HORIZON = 0?

YES

P23.20

A ← HORIZON (BITS 6-4) MASK "D" DIGIT

NO

R22SUBRD REQUEST LAT., LONG. AND ALT FROM ASTRONAUT PD-5053 SH6

IS "D" = 1?

YES

P23.18

NO

IS "D" = 2?

YES

CLEAR NORFHR

NO

SET NORFHR

FAR HORIZON

P23.30

IS STARCODE = ?

YES

P23.31

A ← 0588

NO

A ← 0588

RECYLE

GOFLASH V0088

DISPLAY VECTOR TO PLANET

PROCEED

TERMINATE

GOTOPOOH

P23.85

CLEAR RENDWFLG

W MATRIX INVALID FOR RENDEZVOUS NAVIGATION

P23.55

SH3

INPUT: LANDMARK = LMK DISPLAY NOUN IDOFLMK = LMK ID. NO.
MARKTIME = TIME MARK TAKEN
OUTPUT: MPC0 = POINTING VECTOR VZC0 = CSM VELOCITY VECTOR

POINTAXS

COMPUTE POINTING VECTOR FROM CSM TO LANDMARK HORIZON

SH13
FROM PRECEDING SHEET
R1=002028 = CHECKLIST CODE (INDICATING
PERFORM GNCS AUTOMATIC MANEUVER)
ENTER - ATTITUDE MANEUVER
WILL BE PERFORMED MANUALLY

GOTOPOOL

PROCEED - LET
COMPUTER PERFORM
ATTITUDE MANEUVER

VS4ENTER

LOADTIME
GET PRESENT
TIME FROM
COMPUTER CLOCK
FC-2100

MARKTIME< = MPAC_P

INPUT TO POINTAXES

POINTAXES
COMPUTE POINTING
VECTOR FROM CSM
TO LANDMARK / HORIZON
S152

INPUT TO RGOCSM

INPUT:
LANDMARK = LMK DISPLAY NOUN
ID0FLMK = LMK ID NO.
MARKTIME = PRESENT TIME SCALED 2^32 SEC
OUTPUT:
MPAC[10] = POINTING VECTOR SCALED
2^32 METERS
VZC[23] = CSM VELOCITY VECTOR
SCALED 2^32 METERS/SEC

POINTVSM_v = UNIT[REFSMAT](MPAC)_v

COMPUTE CSM TO LANDMARK/ HORIZON VECTOR IN STABLE MEMBER
COORDINATES.

SET SPACE CRAFT AXES WHICH WILL BE
ALIGNED TO LANDMARK/ HORIZON LINE OF SIGHT EQUAL TO 32 M.

SCAXIS_v = JCAXIS_v

CLEAR
3AX15. FLG

INDICATES MANEUVER IS
SPECIFIED BY ONE AXIS.

TEMPFLG = RGOCALL

SETS UP CONTROL TO RETURN TO
"RGOCALL" IF A RESTART OCCURS
AFTER THIS POINT (SHE 8).

GROUP 2.1
SET UP RESTARTS TO RETURN TO LAST DISPLAY

NEXT SHEET
FROM PRECEDING SHEET

R6OCALL

R6OCSM

ATTITUDE MANEUVER ROUTINE
FC-2240

INPUT: POINTSM = DIRECTION OF ALIGNMENT
SCAXIS = SPACRAFT BODY VECTOR TO BE ALIGNED
SAXISFLG = SET = 3 AXIS MANEUVER
CLEAR = 1 AXIS MANEUVER
OUTPUT: SCAXIS WILL BE ALIGNED TO POINTSM

GROUP 2

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

ISHave optics been calibrated?

YES

RSTFLAG
SET F

NO

P23.56

RST

OPTICS CALIBRATION ROUTINE
FC-2242

OUTPUT: TRJNBIAS = TRUNNION BIASS ANGLE
i.e., ANGLE DETERMINED WHEN SHAFT AND LMK LINE OF SIGHTS ARE SUPERIMPOSED (NOT NECESSARILY ZERO BECAUSE OF UNEVEN HEATING BY SUN)

P23.57

ALLOW V54 TO BE ENTERED WHILE IN R52 (P53).
NOTE: IF THE ASTRONAUT WISHES TO RECYCLE AND RE-MANEUVER THE VEHICLE HE WILL ENTER V54 BEFORE ACCEPTING THE MARK (VIA R53) AND THE PROGRAM RETURNS TO "VASENT" (5N7). INDICATES THAT OPTICS HAVE BEEN CALIBRATED.

R52

V54FLAG
SET RSTFLAG

INPUT: STARSVE = STAR VECTOR OPTICS DRIVEN AUTOMATICALLY TO SIGHT ON GIVEN STAR.
OUTPUT: MARKSTAT = ADDRESS OF MARK DATA TAKEN IN R53
NOTE: R53 WILL CONTINUE TO POINT SXT LOSS AT THE GIVEN STAR UNTIL THE OPTICS SWITCH IS PLACED IN MANUAL (FROM AUTOMATIC) WHICH AUTOMATICALLY CALLS R53 TO TAKE MARKS.

NEXT SHEET
FROM PRECEDING SHEET

CLEAR V34FLG
CLEAR RSTFLG

DO NOT ALLOW V34 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 R33

MARKTIME ← O6 # MARKDATA

GET TIME OF MARK

TRUNION ← 54 # MARKDATA

GET TRUNION ANGLE

RELEASE INTER-
RUPTS

MARKDOWN ← MARKDATA
MARKDOWN+6 ← MARKDATA+6

MARKOFA ← MARKOFA+6

G0FLASH

V0SHT1 REQUEST AND
DISPLAY MEASUREMENT DATA

PROCEED

P23.65

SET SAVEFLG

P23.15

SH4

GOTOPOOH

INDICATES THAT MARK HAS BEEN TAKEN AND IT SHOULD
BE INCORPORATED INTO STATE VECTOR AFTER ABOVE
MEASUREMENT DATA IS PROCESSED.

MARKSTAT LOCATIONS
0,1 = TIME
2,4,6 = IMU ANGLES
5 = TRUNION ANGLE
3 = SHAFT ANGLE

LOAD MEASUREMENT DATA

THIS BRANCH LEADS TO
PROCESSING OF ABOVE
MEASUREMENT DATA.

SEE NOTE ON SHEET 4
FOR CODES.
- **COMPUTE UNIT POINTING VECTOR FROM CSM TO LANDMARK/HORIZON.**
  - GSOP EQU. 2.6.2

- **SAVE \( \mathbf{v}_{G} \) FOR USE IN COMPUTING THE VARIANCE, \( \mathbf{v}_{G} \).**
  - \( \mathbf{v}_{G} \) (\( \mathbf{a}_{G} \) \( \mathbf{c}_{G} \)) IN POL32 ARE FORMED BY THE ABOVE UNIT INSTRUCTION.

- **CORRECT POINTING VECTOR FOR ABERRATION.**
  - GSOP EQU. 2.6.4

- **CORRECT STAR VECTOR FOR ABERRATION.**
  - GSOP EQU. 2.6.3

- **\( \mathbf{v}_{SS} \) VELOCITY OF SUN RELATIVE TO THE EARTH.**

- **COMPUTE COSINE OF ESTIMATED ANGLE BETWEEN STAR AND POINTING VECTOR.**
  - GSOP EQU. 2.6.21

- **COMPUTE GEOMETRY OF MEASUREMENT VECTOR \( (b_0, b_1, b_2) \).**
  - GSOP EQU. 2.6.21

- **SAVE STAR TO POINTING VECTOR ANGLE.**

- **CLEAR MPAC.**
  - CONVERT TRUNNION ANGLE FROM 15 TO 2% COMPLEMENT.
  - (BY SPECIAL SUBTRACT INSTRUCTION)
  - STORE TRUNNION ANGLE FOR LATER USE.

- **NOTE: VARSUBL IS DEFINED TO BE 3 WORDS, THE FIRST WORD OF WHICH IS ZERO.**

---

**MIT INSTRUMENTATION LAB**
**CAMBRIDGE, MASS.**

**SPS-CLSNS, RCMD: COARSE NAVIGATION**
**NAVIGATION**

**COLOSSUS 300**
**FC-2600**

**M. M. D. H. A. N. O.**
**10-11-15**

**REV. 1. 1916 10 27**
FROM PRECEDING SHEET

\[
\text{MPAC} = \left[ (A - \text{TRUNION}_{\text{MAX}}) - \cos^{-1}(\text{GSO}) + 19.77 \right] (r_d)
\]

\[
\text{MPAC}_s \left( \left[ \left( \text{PDLS}_d - \text{TRUNIAS}_d \right) + \text{PDLS}_o + \text{TRUNIB}_d \right] + \text{PDLS}_e \right) (\pi/4.0)_o
\]

COMPUTE MEASUREMENT DEVIATION
GSO EQU. 2.1.21

IS MOON SPHERE OF INFLUENCE?

NO

CMOONFLG
SET?

YES

ADJUST SCALING

MPAC SCALED 2.97 METERS FROM 2.99 METERS IF IN MOON SPHERE OF INFLUENCE.

R23.51

\[ DQ = \text{MPAC} \]

\[ \text{DEVIATION BETWEEN MEASURED ANGLE AND ESTIMATED ANGLE.} \]

\[ \alpha^2 = \frac{\text{VAR}_{\text{TRUN}} + \text{VAR}}{\text{VARIANCE}_{\text{TD}}} \]

\[ \text{VARIANCE}_{\text{TD}} = \left( \text{PDLS}_d - \text{TRUNIAS}_d \right) + \text{VAR}_{\text{TD}} \]

VARIANCE OF MEASUREMENT ERRORS
GSO EQU. 2.1.22

CLEAR DHENFLG

INDICATES W-MATRIX IS 6 X 6 FOR INCORPORATION

INCRBP

COMPUTE STATE VECTOR DEVIATIONS
\[ \Delta X = (A - \Delta Y) \]

GSO 2.1.20

GROUPS

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

MPAC = \[ \left[ \Delta X \right] \]

\[ \text{MPAC}_s = \text{ADVAL}(\Delta X \times 6) \]

NEXT SHEET

\[ \Delta X = (A - \Delta Y) \]

\[ \text{MPAC}_s = \text{ADVAL}(\Delta X \times 6) \]
SUBROUTINE WHICH COMPUTES THE CSM TO LANDMARK/HORIZON POINTING VECTOR

INPUT:
- LANDMARK = LMK
- DISPLAY NOUN
- MARKTIME = TIME MARK TAKEN

OUTPUT:
- POLO = MPAC(\(\vec{r}_{cl}\)) = POINTING VECTOR
  SCALED 2^8 METERS
- VZC(VZC) = CSM VELOCITY VECTOR
  SCALE 2^7 METERS/CSEC

SAVE RETURN

[Diagram with flowchart]

NEXT SHEET
IS THE W-MATRIX INITIALIZED FOR MIDCOURSE NAVIGATION?

PLACE PDL0 LOADED W-MATRIX POSITION \((w_{mx}, w_{my})\) AND VELOCITY \((w_{mx}, w_{my})\) INITIALIZATION ELEMENTS IN THE PDLIST FOR INPUT TO INITW

INPUT: PDL0(WMIDPOS) = W-MATRIX POSITION INITIALIZATION VALUE PDL1(WMIDVEL) = W-MATRIX VELOCITY INITIALIZATION VALUE

OUTPUT: INITIALIZED W-MATRIX

\[
\begin{bmatrix}
W_0 & W_1 \\
W_2 & W_3
\end{bmatrix}
\]

SUB-Routine

SET TIMS

EGRESS ← QPRET SAVE RETURN

INSTALL RESERVE INTEGRATION ROUTINE

FC-2280

\(\text{TDCl}_{3} \rightarrow \text{MARKTIME}_{3}\) SET TIME FOR INPUT TO INTEGRATE

UPDATE PERMANENT STATE VECTOR

ENCKE INTEGRATION

DO NOT USE W-MATRIX

INTEGRATE CSM STATE VECTOR

6 DIMENSION W-MATRIX

RETURN VIA EGRESS
ISO-MATRIX VALID FOR MIDCOURSE NAVIGATION?

NO

DRBMFLAG

SET

YES

INDICATE M-MATRIX IS TO BE INTEGRATED

R23.2

SET DRBMFLAG

INDICATE M-MATRIX VALID FOR MIDCOURSE NAVIGATION

INPUT: TDEC1 = TIME

OUTPUT: UPDATED CSM PERMANENT STATE VECTOR

RQVY(F2C) = CSM POSITION VECTOR RELATIVE TO SECONDARY BODY (NON-SPHERE OF INFLUENCE BODY)

GROUP E

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

RECT.1

Determine

Z1, F2C AND V2C

INPUT: CSM PERMANENT STATE VECTOR

CMONFLG, LUNAFLAG

OUTPUT: R2C (F2C) = CSM POSITION VECTOR SCALED 2^9 METERS,

V2C (V2C) = CSM VELOCITY VECTOR SCALED 2^6 METERS/SEC.

ZMEASURE = 1 - MEASUREMENT AND PRIMARY PLANET DIFFERENT,

0 - MEASUREMENT AND PRIMARY PLANET SAME

ARE MEASUREMENT AND PRIMARY PLANET DIFFERENT?

R23.3

ZMEASURE

SET

YES

MPACv = MARITIMEv

LUNAPOS

OUTPUT: MPACv = SIGMA = POSITION OF MOON

POSITION OF MOON (F2C)

FC-2282

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE MASS.

A.G.WILLIAMS

5/9/81

COLDUSUS 2D FC-2600
SUBROUTINE TO COMPUTE Z, \( \vec{r}_E \) AND \( \vec{v}_E \)

INPUT: CSM PERMANENT STATE VECTOR
CMOONFLG, LUNAFLG

OUTPUT: \( \vec{r}_E (x_2) \) = CSM POSITION VECTOR SCALED 200 Meters
\( \vec{v}_E (x_2) \) = CSM VELOCITY VECTOR SCALED 27 Meters/CSEC
ZMEASURE = 1-MEASUREMENT AND PRIMARY PLANET DIFFERENT
0-MEASUREMENT AND PRIMARY PLANET SAME

MOON SPHERE OF INFLUENCE?

\begin{align*}
\text{YES} & \quad \text{SET } x_2 \text{ FOR SCALING} \\
\text{NO} & \quad \text{EARTH} \\
\text{LUNAR MEASUREMENT?} & \\
\text{NO} & \quad \text{EARTH} \\
\text{YES} & \quad \text{LUNAFLG SET?} \\
\text{NO} & \quad \text{RECT. 2}
\end{align*}

\begin{align*}
\text{YES} & \quad \text{LUNAFLG SET?} \\
\text{NO} & \quad \text{RECT. 4}
\end{align*}

\begin{align*}
\text{YES} & \quad \text{CLEAR ZMEASURE} \\
\text{NO} & \quad \text{MEASUREMENT PLANET AND PRIMARY PLANET SAME} \\
\text{Z = 0}
\end{align*}

\begin{align*}
\vec{r}_E & = \vec{r}_E + \vec{DeltaCSM} + \vec{RovCSM} \\
\vec{v}_E & = \vec{v}_E + \vec{NuvCSM} + \vec{YuvCSM}
\end{align*}

RETURN VIA QPRET

RETURN TO POINT AX5
SUBROUTINE WHICH COMPUTES HORIZON LOCATION VECTOR

INPUT: R2C(\(\mathbf{r}_2\)) = OBSERVER POSITION VECTOR RELATIVE TO MEASUREMENT PLANET
        SCALED 2^12 METERS,
        US(\(\mathbf{u}_3\)) = STAR UNIT VECTOR
        LUNAPLAGE,NORIYOR
OUTPUT: MPAC(\(\mathbf{x}\)) = HORIZON LOCATION VECTOR SCALED 2^12 METERS.

SRRETURN -> QPRET

SAVE RETURN

DEFINE \(\mathbf{u}_2 = \left(-\frac{\mathbf{a}_y}{\mathbf{a}_x}\right)\)
WHERE
\(\mathbf{a}_y = EARTH\ MUTATION\ ANGLE\)
\(\mathbf{a}_x = EARTH\ PRECESSION\ ANGLE\)

GSOP EQU 2.6.6
DEFINE ORTHOGONAL COORDINATE SYSTEM WITH:
\(\mathbf{u}_2\) ALONG SEMI MAJOR AXIS OF HORIZON ELLIPSE.
\(\mathbf{u}_1\) ALONG SEMI MINOR AXIS OF HORIZON ELLIPSE.
\(\mathbf{u}_2\) PERPENDICULAR TO HORIZON ELLIPSE.

\(\mathbf{u}_2 = \text{UNIT}(\mathbf{u}_2 \times \mathbf{r}_2)\)
\(\text{UNIT}(\mathbf{u}_2 \times \mathbf{r}_2)\)

\(\mathbf{u}_1 = \mathbf{u}_2 \times \mathbf{u}_3\)
\(\text{UNIT}((\mathbf{u}_2 \times \mathbf{u}_3) \times \mathbf{u}_2)\)

IS LUNAPLAGE SET?

MOON HORIZON?

NO - EARTH

GSOP EQU 2.6.8
\(\sin L = \mathbf{u}_1 \cdot \mathbf{u}_2\)
\(\mathbf{u}_1 \cdot \mathbf{u}_2\)
\(\text{ALPHA} + \mathbf{A} = \mathbf{u}_1 \cdot \mathbf{u}_2 \cdot \mathbf{P}_{OL}\)

GETERAD
COMPUTE EARTH RADIUS
FC = 2650

\(\mathbf{b}_0 = \mathbf{r}_2 + h\)
\(\text{MPAC}_0 = \text{MPAC} + \text{HORIZALT}_0\)

DETERMINE SEMI MINOR AXIS OF HORIZON ELLIPSE
GSOP EQU 2.6.9
\(\delta_0 = \mathbf{d} + h\)
\(\mathbf{P}_{OL} = \text{AEARTH} + \text{HORIZALT}_0\)

DETERMINE SEMI MAJOR AXIS OF HORIZON ELLIPSE
GSOP EQU 2.6.10

HORIZ, 4

NEXT SHEET
FROM PRECEDING SHEET

Transform pointing vector to the horizon coordinate system.
GSOE 2.6.12

\[ \mathbf{s}_v = M \mathbf{s}_{16} \]

PDL4_v \leftarrow (UBAROM)(PZC_v) \]

\[ \mathbf{u}_{3h} = M \mathbf{u}_3 \]

PDL0_v \leftarrow (UBAROM)(U5_v) \]

Transform star vector to the horizon coordinate system.
GSOE 2.6.12

\[ \mathbf{M} = \begin{pmatrix} u_0^T \\ u_1^T \\ u_2^T \end{pmatrix} \]

PDL34_v \leftarrow PDL2_v

MPAC0 \leftarrow PDL4_v

Pick up \( a_w \) \n
Pick up \( x_h \)

DIVIDE

MPAC0 \leftarrow MPAC0 / PDL34_v

SH22

PDL30_v \leftarrow MPAC0 - MPAC0

FORM \( x_h / a_w \)

PDL34_v \leftarrow PDL34_v

MPAC0 \leftarrow MPAC0

Pick up \( b_w \)

Pick up \( y_x \)

DIVIDE

MPAC0 \leftarrow MPAC0 / PDL34_v

SH22

A = \( x_h^2 / a_w^2 + y_x^2 / b_w^2 \)

PDL16_v \leftarrow PDL30_v - MPAC*MPAC

GSOE 2.6.17

PDL16_v \leftarrow \sqrt{A - I}

PDL18_v \leftarrow \text{SQRT}(PDL16_v - 1.0*15)

PDL34_v \leftarrow PDL18_v

MPAC0 \leftarrow MPAC0

Next sheet

Pick up \( x_h \)

Pick up \( a_w \)
## SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>R57</td>
<td>2242</td>
<td>OPTICS CALIBRATION ROUTINE</td>
<td>SH 4, 8</td>
</tr>
<tr>
<td>FALTON</td>
<td>2180</td>
<td>TURN ON OPERATOR ERROR LIGHT</td>
<td>SH 4</td>
</tr>
<tr>
<td>R53</td>
<td>2730</td>
<td>SIGHTING MARK ROUTINE</td>
<td>SH 4</td>
</tr>
<tr>
<td>P22SUBRB</td>
<td>2520</td>
<td>REQUEST LAT., LONG AND ALT FROM ASTRONAUT</td>
<td>SH 6</td>
</tr>
<tr>
<td>LOADTIME</td>
<td>2100</td>
<td>GET PRESENT TIME FROM COMPUTER C LOCK</td>
<td>SH 7</td>
</tr>
<tr>
<td>R60CSM</td>
<td>2340</td>
<td>ATTITUDE MANEUVER ROUTINE</td>
<td>SH 8</td>
</tr>
<tr>
<td>R52</td>
<td>2730</td>
<td>AUTOMATIC OPTICS ROUTINE</td>
<td>SH 8</td>
</tr>
<tr>
<td>INCORPI</td>
<td>2610</td>
<td>COMPUTE STATE VECTOR DEVIATIONS</td>
<td>SH 11</td>
</tr>
<tr>
<td>INCORP2</td>
<td>2610</td>
<td>INCORPORATE STATE VECTOR DEVIATIONS</td>
<td>SH 12</td>
</tr>
<tr>
<td>BLANKET</td>
<td>2130</td>
<td>BLANK OUT CERTAIN DISPLAY REGISTERS</td>
<td>SH 12</td>
</tr>
<tr>
<td>INSTALL</td>
<td>2290</td>
<td>RESERVE INTEGRATION ROUTINE</td>
<td>SH 14</td>
</tr>
<tr>
<td>INTEGR8</td>
<td>2290</td>
<td>EXTRAPOLATE CSV STATE VECTOR TO TDECI</td>
<td>SH 15</td>
</tr>
<tr>
<td>LUNPOS</td>
<td>2266</td>
<td>COMPUTE POSITION OF MOON</td>
<td>SH 15</td>
</tr>
<tr>
<td>LALORTV</td>
<td>2280</td>
<td>CONVERT LAT., LONG., ALT TO RADIUS VECTOR</td>
<td>SH 16</td>
</tr>
<tr>
<td>GETERAD</td>
<td>2280</td>
<td>COMPUTE EARTH RADIUS</td>
<td>SH 18</td>
</tr>
</tbody>
</table>

### FLAGS

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>RNDYFGLG</td>
<td>P20 IS RUNNING</td>
<td>P20 IS NOT RUNNING</td>
<td>SH 3</td>
<td></td>
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<tr>
<td>TARGETFGLG</td>
<td>SIGHTING ON LEM</td>
<td>NOT SIGHTING ON LEM</td>
<td>SH 3</td>
<td></td>
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<tr>
<td>TARGET2FGLG</td>
<td>SIGHTING LANDMARK</td>
<td>SIGHTING STAR</td>
<td>SH 3</td>
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<tr>
<td>R57FGLG</td>
<td>DO NOT DO R57, TRU NION BIAS HAS BEEN OBTAINED</td>
<td>DO R57, TRU NION BIAS NEEDED</td>
<td>SH 8</td>
<td>SH 3, 9</td>
<td>SH 8</td>
</tr>
<tr>
<td>V94FGLG</td>
<td>V94 ALLOWED DURING P23</td>
<td>V94 NOT ALLOWED DURING P23</td>
<td>SH 8</td>
<td>SH 3, 9</td>
<td>SH 8</td>
</tr>
<tr>
<td>IMUFGLG</td>
<td>IMU ON AND ALIGNED</td>
<td>IMU NOT ALIGNED</td>
<td>SH 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAAECLFGLG</td>
<td>P23 DISPLAY AND DATA STORAGE AFTER MARK IS TAKEN</td>
<td>P23 DISPLAY AND DATA STORAGE BEFORE MARK IS TAKEN</td>
<td>SH 3</td>
<td>SH 4</td>
<td>SH 5</td>
</tr>
<tr>
<td>LI NAFGLG</td>
<td>LUNAR LAT-LONG</td>
<td>EARTH LAT-LONG</td>
<td>SH 5</td>
<td>SH 5</td>
<td>SH 17</td>
</tr>
<tr>
<td>NORTFGLG</td>
<td>SIGHTING ON FAR HORIZON</td>
<td>SIGHTING ON NEAR NORIZON</td>
<td>SH 6</td>
<td>SH 6</td>
<td>SH 22</td>
</tr>
<tr>
<td>RENDERFGLG</td>
<td>W = MATRICES VALID FOR RENDEZVOUS NAVIGATION</td>
<td>W = MATRICES INVALID FOR RENDEZVOUS NAVIGATION</td>
<td>SH 6</td>
<td></td>
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<tr>
<td>3AXISFGLG</td>
<td>MANEUVER SPECIFIED BY 3 AXES</td>
<td>MANEUVER SPECIFIED BY 1 AXIS</td>
<td>SH 7</td>
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### Flags (Continued)

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
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</thead>
<tbody>
<tr>
<td>CMOONFLG</td>
<td>Permanent CSM state vector in lunar sphere</td>
<td>Permanent CSM state vector in earth sphere</td>
<td></td>
<td></td>
<td>SH 11, 12, 17</td>
</tr>
<tr>
<td>FLAGWORD 8</td>
<td>Dimension of W-Matrix is 9 for incorporation</td>
<td>Dimension of W-Matrix is 6 for incorporation</td>
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<td>SH 11</td>
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<tr>
<td>BIT 12</td>
<td>CM STATE VECTOR IS BEING UPDATED</td>
<td>LEM STATE VECTOR IS BEING UPDATED</td>
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<td>SH 12</td>
</tr>
<tr>
<td>DMENFLG</td>
<td>W-MATRIX VALID FOR MIDCOURSE NAVIGATION</td>
<td>W-MATRIX INVALID FOR MIDCOURSE NAVIGATION</td>
<td></td>
<td></td>
<td>SH 15, 14, 15</td>
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<tr>
<td>FLAGWORD 5</td>
<td>Permanent state vector to be updated</td>
<td>Permanent state vector not to be updated</td>
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<td>SH 14</td>
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<tr>
<td>BIT 9</td>
<td>CONIC INTEGRATION</td>
<td>ENCKE INTEGRATION</td>
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<td>SH 14</td>
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<td>VEHUPFLG</td>
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<td>ORBFLG</td>
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<td>FLAGWORD 3</td>
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<tr>
<td>BIT 5</td>
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<td>STATEFLG</td>
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<td>BIT 4</td>
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<td>INTYPFLG</td>
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<tr>
<td>FLAGWORD 3</td>
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<tr>
<td>BIT 4</td>
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</tr>
<tr>
<td>DIMOFLAG</td>
<td>W-MATRIX IS TO BE USED</td>
<td>W-MATRIX NOT TO BE USED</td>
<td></td>
<td></td>
<td>SH 15, 14</td>
</tr>
<tr>
<td>FLAGWORD 3</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>BIT 1</td>
<td>CM STATE VECTOR TO BE INTEGRATED</td>
<td>LEM STATE VECTOR TO BE INTEGRATED</td>
<td></td>
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<td>SH 14</td>
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<tr>
<td>VINTFLG</td>
<td>CM STATE VECTOR TO BE INTEGRATED</td>
<td>LEM STATE VECTOR TO BE INTEGRATED</td>
<td></td>
<td></td>
<td>SH 14</td>
</tr>
<tr>
<td>FLAGWORD 3</td>
<td>DIMENSION OF W-MATRIX IS 9 FOR INTEGRATION</td>
<td>DIMENSION OF W-MATRIX IS 6 FOR INTEGRATION</td>
<td></td>
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<td>SH 14</td>
</tr>
<tr>
<td>BIT 3</td>
<td>MEASUREMENT PLANET AND PRIMARY PLANET DIFFERENT</td>
<td>MEASUREMENT PLANET AND PRIMARY PLANET SAME</td>
<td></td>
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<td>SH 17, 15</td>
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<tr>
<td>D60R5FLG</td>
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<td>FLAGWORD 3</td>
<td></td>
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<tr>
<td>BIT 2</td>
<td>EARTH: COMPUTE FISCHER ELLIPSOID RADII</td>
<td>EARTH: USE FIXED RADIUS</td>
<td></td>
<td></td>
<td>SH 16</td>
</tr>
<tr>
<td>RMFLAG</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>FLAGWORD 1</td>
<td></td>
<td></td>
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<tr>
<td>BIT 13</td>
<td>MOON: USE FIXED RADIUS</td>
<td>MOON: USE RLS FOR RADIUS</td>
<td></td>
<td></td>
<td>SH 12</td>
</tr>
</tbody>
</table>

### Displays

<table>
<thead>
<tr>
<th>Verb-Noun</th>
<th>Type of Display</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
</tr>
</thead>
</table>
| V05N70    | FLASHING        | R1 = 00DE = STAR ID NO
R2 = ABCDE = LMK DATA
R3 = 00CD0 = HORIZON DATA
REQUEST MEASURE-MENT DATA BEFORE MARK IS TAKEN | SH 4           |
| V06N88    | FLASHING        | R1 = STAR0 - XXXXX
R2 = STAR2D - XXXXX
R3 = STAR4D - XXXXX
VECTOR TO PLANET                                                                                           | SH 16          |
| V50N25    | FLASHING        | R1 = 00202
PLEASE PERFORM AUTOMATIC MANEUVER                                                                        | SH 17          |
| V05N71    | FLASHING        | R1 = 00DE = STAR ID NO
R2 = ABCDE = LMK DATA
R3 = 000CD0 = HORIZON DATA
REQUEST MEASURE-MENT DATA AFTER MARK IS TAKEN                                                              | SH 19          |
| V06N49    | FLASHING        | R1 = XXXX.X NART MI. POSITION DEVIATION
R2 = XXXX.X FEET/SEC VELOCITY DEVIATION
R3 = BLANK                                                                                                   | SH 12          |
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNIT</th>
<th>AGC UNIT</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>PIBSPRT2</td>
<td></td>
<td>RESTART PRIORITY REGISTER</td>
<td>(INTEGER)</td>
<td>2^14</td>
<td></td>
</tr>
<tr>
<td>MARKINDEX</td>
<td></td>
<td>NUMBER OF MARKS WANTED REGISTER</td>
<td>(INTEGER)</td>
<td>2^14</td>
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</tr>
<tr>
<td>STARIND</td>
<td></td>
<td>STAR INDEX TO BESTI OR BESTJ</td>
<td>(INTEGER)</td>
<td>2^14</td>
<td></td>
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<tr>
<td>BESTI</td>
<td></td>
<td>RELATIVE ADDRESS OF DESIRED IN STAR TABLES</td>
<td>(INTEGER)</td>
<td>2^14</td>
<td></td>
</tr>
<tr>
<td>LANDMARK</td>
<td></td>
<td>LANDMARK DATA DISPLAY NOUN</td>
<td>(INTEGER)</td>
<td>2^14</td>
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<tr>
<td>HORIZON</td>
<td></td>
<td>HORIZON DATA DISPLAY NOUN</td>
<td>(INTEGER)</td>
<td>2^14</td>
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<tr>
<td>STARCDE</td>
<td></td>
<td>STAR ID NO DISPLAY NOUN</td>
<td>(INTEGER)</td>
<td>2^14</td>
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<tr>
<td>STARSAV2 (ALSO TAGGED US)</td>
<td></td>
<td>TEMPORARY STORAGE OF STAR I UNIT VECTOR</td>
<td>(INTEGER)</td>
<td>2^{1, 2^1, 2^1}</td>
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<tr>
<td>IDDFLMK</td>
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<td>LANDMARK ID NUMBER</td>
<td>(INTEGER)</td>
<td>2^14</td>
<td></td>
</tr>
<tr>
<td>MARKTIME</td>
<td></td>
<td>TIME OF MARK</td>
<td>SEC</td>
<td>2^28</td>
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<tr>
<td>REFSMAT</td>
<td></td>
<td>TRANSFORMATION MATRIX: BASIC REFERENCE TO STABLE MEMBER COORDINATES</td>
<td>(INTEGER)</td>
<td>2^1</td>
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</tr>
<tr>
<td>POINTVSM</td>
<td></td>
<td>DESIRED TRACK AXIS</td>
<td>(INTEGER)</td>
<td>2^{1, 2^1, 2^1}</td>
<td></td>
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<tr>
<td>SCIAXIS</td>
<td></td>
<td>SPACE CRAFT AXIS TO BE ALIGNED WITH POINTVSM</td>
<td>(INTEGER)</td>
<td>2^{1, 2^1, 2^1}</td>
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<tr>
<td>R60ADS</td>
<td></td>
<td>DESIRED ADDRESS OF ‘R60 CALL’</td>
<td>(INTEGER)</td>
<td>2^{14}</td>
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<tr>
<td>TEMPELISH</td>
<td></td>
<td>RESTART RETURN ADDRESS</td>
<td>(INTEGER)</td>
<td>2^{14}</td>
<td></td>
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<tr>
<td>MARKDATA</td>
<td></td>
<td>ADDRESS OF MARK DATA STORAGE LOCATIONS</td>
<td>(INTEGER)</td>
<td>2^{14}</td>
<td></td>
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<tr>
<td>MARKSTAT</td>
<td></td>
<td>MARK DATA INFORMATION REGISTER FROM R63</td>
<td>(INTEGER)</td>
<td>2^{14}</td>
<td></td>
</tr>
<tr>
<td>TRUNNION</td>
<td></td>
<td>MEASURED TRUNNION ANGLE</td>
<td>DEG</td>
<td>2^3</td>
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<tr>
<td>UCLSTAR</td>
<td>L^CL</td>
<td>CSM TO LANDMARK/HORIZON UNIT VECTOR CORRECTED FOR ABBERRATION</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>2^{7, 2^7}</td>
</tr>
<tr>
<td>VZC</td>
<td>L^C</td>
<td>CSM VELOCITY VECTOR</td>
<td>FEET/SEC</td>
<td>METERS/ CSEC</td>
<td>2^{7, 2^7}</td>
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<tr>
<td>USSTAR</td>
<td>L^S</td>
<td>STAR UNIT VECTOR CORRECTED FOR ABBERRATION</td>
<td>(INTEGER)</td>
<td>2^{1, 2^1, 2^1}</td>
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<tr>
<td>US</td>
<td>L^S</td>
<td>STAR UNIT VECTOR</td>
<td>(INTEGER)</td>
<td>2^{1, 2^1, 2^1}</td>
<td></td>
</tr>
<tr>
<td>BVECTOR</td>
<td>(b_0, b_1, b_2)</td>
<td>GEOMETRY OF MEASUREMENT MATRIX</td>
<td>DEG</td>
<td>2^3</td>
<td></td>
</tr>
<tr>
<td>TRUNBIAS</td>
<td></td>
<td>CALIBRATION ANGLE FOR SEXTANT</td>
<td>NAUT. MI.</td>
<td>METERS</td>
<td>2^{29, 2^27}</td>
</tr>
<tr>
<td>DELTAQ</td>
<td></td>
<td>MEASURED AND ESTIMATED DEVIATION</td>
<td>NAUT. MI.</td>
<td>METERS</td>
<td>2^{29, 2^27}</td>
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<tr>
<td>VARIANCE</td>
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<td>VARIANCE OF MEASUREMENT ERRORS</td>
<td>NAUT. MI.</td>
<td>METERS</td>
<td>2^{29, 2^27}</td>
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<tr>
<td>DELTAX</td>
<td></td>
<td>STATE VECTOR POSITION DEVIATIONS</td>
<td>NAUT. MI.</td>
<td>METERS</td>
<td>2^{29, 2^27}</td>
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<tr>
<td>DELTAX^6</td>
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<td>STATE VECTOR VELOCITY DEVIATIONS</td>
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<td>N49DISP</td>
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<td>DISPLAY NOUN FOR DELTAX</td>
<td>(INTEGER)</td>
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<td>N49DISP+6</td>
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<td>DISPLAY NOUN FOR DELTAX+6</td>
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<tr>
<td>POINTEX</td>
<td></td>
<td>RETURN ADDRESS FROM POINTAXS</td>
<td>(INTEGER)</td>
<td>2^14</td>
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</tr>
</tbody>
</table>

---

**ERASABLE LOCATIONS USED**

- **PIBSPRT2**
- **MARKINDEX**
- **STARIND**
- **BESTI**
- **LANDMARK**
- **HORIZON**
- **STARCDE**
- **STARSAV2** (ALSO TAGGED US)
- **IDDFLMK**
- **MARKTIME**
- **REFSMAT**
- **POINTVSM**
- **SCIAXIS**
- **R60ADS**
- **TEMPELISH**
- **MARKDATA**
- **MARKSTAT**
- **TRUNNION**
- **UCLSTAR**
- **VZC**
- **USSTAR**
- **US**
- **BVECTOR**
- **TRUNBIAS**
- **DELTAQ**
- **VARIANCE**
- **DELTAX**
- **DELTAX^6**
- **N49DISP**
- **N49DISP+6**
- **POINTEX**

---

**Midcourse Navigation**

- Coelostus 2D
- FC-2600
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNIT</th>
<th>AGC UNIT</th>
<th>AGC SCALING</th>
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<td>ALT</td>
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<td>ALTITUDE</td>
<td>NAUT. MI.</td>
<td>METERS</td>
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<td>DEG</td>
<td>REV</td>
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<tr>
<td>LONG</td>
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<td>DEG</td>
<td>REV</td>
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<td>REV</td>
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<td>EGRESS</td>
<td></td>
<td>SUBROUTINE RETURN ADDRESS</td>
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<td>(INTEGER)</td>
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<td>TDECI</td>
<td></td>
<td>TIME FOR INTEGRATION</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^28</td>
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<tr>
<td>RZC</td>
<td>R ZC</td>
<td>CSM POSITION VECTOR RELATIVE TO MEASUREMENT PLANET</td>
<td>METERS</td>
<td>METERS</td>
<td>3^29</td>
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<tr>
<td>RQVV</td>
<td>R QC</td>
<td>CSM POSITION VECTOR RELATIVE TO SECONDARY PLANET</td>
<td>METERS</td>
<td>METERS</td>
<td>2^39</td>
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<td>RL</td>
<td>R f</td>
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<td>METERS</td>
<td>METERS</td>
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<td>RCLL</td>
<td>R CL</td>
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<td>METERS</td>
<td>METERS</td>
<td>2^39</td>
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<td>DELTACSM</td>
<td>d</td>
<td>CSM CONIC POSITION DEVIATION</td>
<td>METERS</td>
<td>METERS</td>
<td>2^22/2^18</td>
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<tr>
<td>RCVCSM</td>
<td>v c</td>
<td>CSM CONIC VELOCITY DEVIATION</td>
<td>METERS</td>
<td>METERS</td>
<td>2^7/2^5</td>
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<tr>
<td>NUVCSM</td>
<td>v</td>
<td>CSM REFERENCE CONIC POSITION</td>
<td>METERS/CSEC</td>
<td>METERS/CSEC</td>
<td>2^9/2^7</td>
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<tr>
<td>VCVCSM</td>
<td>v c</td>
<td>CSM REFERENCE CONIC VELOCITY</td>
<td>METERS/CSEC</td>
<td>METERS/CSEC</td>
<td>2^3/2^-1</td>
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<tr>
<td>SRRETURN</td>
<td></td>
<td>RETURN ADDRESS FROM HORIZ</td>
<td></td>
<td></td>
<td>(2^1, 2^1, 2^1)</td>
</tr>
<tr>
<td>UBAR0</td>
<td>u_0</td>
<td>DEFINE HORIZON COORDINATE SYSTEM</td>
<td></td>
<td></td>
<td>(2^1, 2^1, 2^1)</td>
</tr>
<tr>
<td>UBAR1</td>
<td>u_1</td>
<td></td>
<td></td>
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<tr>
<td>UBAR2</td>
<td>u_2</td>
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<tr>
<td>ALPHA</td>
<td></td>
<td>SINE OF LATITUDE (FOR GETERAD)</td>
<td></td>
<td></td>
<td>2^1</td>
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### PROGRAM CONSTANTS

<table>
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<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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<tr>
<td>PRI013</td>
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<td>PRIORITY 13 REGISTER</td>
<td>13</td>
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<td>SPSIX</td>
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<td>SINGLE PRECISION 6</td>
<td>6</td>
<td>00006</td>
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<tr>
<td>CATLOG</td>
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<td>BEGINNING ADDRESS OF STORED STAR VECTORS</td>
<td></td>
<td>(INTEGER)</td>
<td>2^14</td>
</tr>
</tbody>
</table>
| JCAXIS  |             | TRACK AXIS VECTOR | \[
\begin{align*}
551/2^0 \\
90^0 \\
321/2^0
\end{align*}
\] | \[
\begin{align*}
268649805 \\
421685725
\end{align*}
\] | 2^1 |
| ONE/C   |             | RECIPROCAL OF SPEED OF LIGHT | \[
1/8.835712 \times 10^{-8}
\] FT/SEC | \[
0.333564040 \times 10^{-6}
\] CSEC/METERS | 2^-21 |
| ZEROVECS |             | BEGINNING ADDRESS OF 6 REGISTERS OF 0 | 0 | 0 | 2^14 |
| VARSUBL |             | LANDMARK/HORIZON ERROR VARIANCE | | 3.4299040 \times 10^6 | 2^40 |
| TRUN19  |             | TRUNNION BIAS ANGLE | 19.77 DEG | .055 REV | 2^0 |
| PI/4.0  |             | CONVERSION FACTOR REV TO RADIANS | 2\# | .1802 RAD REV | 2^-3 |
| TRUNVAR |             | TRUNNION ERROR VARIANCE | | 2.5 \times 10^-9 | 2^-18 |
| 9DWDID  |             | DECIMAL 2 | | (INTEGER) | 2^14 |
| LATTAB  |             | BEGINNING ADDRESSES OF STORED LANDMARK LATITUDE, LONGITUDE, AND ALTITUDE TABLES | | (INTEGER) | 2^14 |
| LONGTAB |             | | | | |
| ALTAB   |             | | | | |
| DPPOSMax |             | DOUBLE PRECISION REGISTER CONTAINING MAXIMUM VALUE | \[
.999999996
\] | 37777 | 2^0 |
| PADMOON | r_m         | RADIUS OF MOON | | 1738090 METERS | 2^29 |
| AEARTH  | a           | A - AXIS OF EARTH | | 6378166 METERS | 2^29 |

### PAD LOADS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP TAG</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMIDPOS</td>
<td>w_{mr}</td>
<td>W - MATRIX POSITION INITIALIZATION VALUE</td>
</tr>
<tr>
<td>WMIDVEL</td>
<td>w_{vt}</td>
<td>W - MATRIX VELOCITY INITIALIZATION VALUE</td>
</tr>
<tr>
<td>VESO</td>
<td>v_{es}</td>
<td>VELOCITY OF SUN RELATIVE TO EARTH</td>
</tr>
<tr>
<td>-AYO</td>
<td>A_{Y}</td>
<td>EARTH NUTATION ANGLE</td>
</tr>
<tr>
<td>AXO</td>
<td>A_{X}</td>
<td>EARTH PRECESSION ANGLE</td>
</tr>
<tr>
<td>HORIZALT</td>
<td>r</td>
<td>EARTH HORIZON ALTITUDE</td>
</tr>
</tbody>
</table>
NAVIGATION EXTENDED VERBS

V67 - W-MATRIX MONITOR  SH2
V82 - INDICATE OFFSET LANDING SITE  SH6
V86 - R25 VARK REJECT  SH7
V97 - ALLOW VHF RADAR RANGE DATA  SH7
V88 - DO NOT ALLOW VHF RADAR RANGE DATA  SH7
V93 - INDICATE W-MATRIX INVALID FOR RENDEZVOUS NAVIGATION  SH7

ENCLOSED ARE REPLACEMENT SHEETS TO UPDATE THE COLOSSUS II FLOWCHART FC-2605, REV. 0, TO THE COLOSSUS IIA FLOWCHART FC-2605, REV. 1.

EFFECTIVE SHEETS FOR FC-2605, REV. 1:

SH. 1–3  REV. 0
SH. 4–5  REV. 1
SH. 6–7  REV. 0
KEYED IN BY ASTRONAUT

V67E
W-MATRIX MONITOR AND INITIALIZATION

V67

TESTXACT
TEST/SET EXTVPACT (BITS 3, 8)
FC-2180

AN EXTENDED VERB IS RUNNING, TURN ON ERROR LIGHT

NO EXTENDED VERB RUNNING
SET EXTVPACT (BITS 3, 8)

V67 CALL
FINDING JOB
PRIORITY 5
5H3

END OF JOB

ALM/END

FALTON
TURN ON OPERATOR ERROR LIGHT
FC-2180

PINBRUNCH
FC-2180

NAVIGATION EXTENDED VERBS
COLOSSUS III FC-2605
SUBROUTINE

V67WW

SZ ← QPRT
SAVE RETURN

CLEAR OVFIND

INSTALL RESERVE INTEGRATION ROUTINE FC-225D

WWPOS₀ ← ZEROVEC₀
WWVEL₀ ← ZEROVEC₀
WWOPT₀ ← ZEROVEC₀

CLEAR NOUN 99 DISPLAY LOCATIONS

X₁ ← 360
INITIALIZE INDEX REGISTRY FOR LOOP CONTROL

NXPOSVEL

LOOP 1
WWPOS₀ ← (W₁)² + WWPOS₀
WWVEL₀ ← (W₁)³ + WWVEL₀

LOOP 2
WWPOS₀ ← (W₁ + 2)² + WWPOS₀
WWVEL₀ ← (W₁ + 2)³ + WWVEL₀

LOOP 6
WWPOS₀ ← (W₁ + 6)² + WWPOS₀
WWVEL₀ ← (W₁ + 6)³ + WWVEL₀

X₁ ← X₁ - 6

NO

X₁ = 6

YES
6TH PASS

NEXT SHEET

THESE LOOP CYCLED 8 TIMES TO SUM POSITION AND VELOCITY ERRORS
FROM PRECEDING SHEET

`wwvel_0 = (wwvel_0)`

`wwpos_0 = (wwpos_0)`

**COMPUTE RMS OF POSITION AND VELOCITY ERRORS**

**IF COMPUTATION OF EITHER RMS ERROR OVERFLOWS, SET BOTH TO MAXIMUM POSITIVE VALUE (OCT 37777, 37777).**

**SITE OVFAIL SET?**

**NO**

- CLEAR OVFAIL

- WWPOS = OPPOS

- WWVEL = OPPOS

**YES**

- VT6XXX

**IF**

- `wwpos_0 = FT99993`

**SET UP RETURN**

- INTWAKE

- RELEASE INTEGRATION ROUTINE FC-263D

**THE RETURN IS VIA QPRET IN INTWAKE**

NEXT SHEET
After taking a mark in P22, the astronaut has the option of designating it as being an offset landing site by keying in VSE. This causes the mark to be noted as being an offset landing site by setting the offset indicator in the landmark register to the mark number landmark = ABCDE

A = TYPE OF LMK
B = INDEX OF OFFSET LMK
C = (NOT USED)
DE = LMK ID NO.

KEYED IN BY ASTRONAUT

Indicate Offset Landing Site

VSE

Indicate Offset Landing Site

CHECKMM

Determine if P22 is running

FC-2080

ALM/END

FALTON

Turn on operator error light

FC-2180

STORE MARK NUMBER IN APPROPRIATE BITS

LANDMARK(BITS 12,11,10) = 5 - MARKSTAT(BITS 14,13,12)

MARKSTAT (BITS 14,13,12) = 5 - MARK NUMBER

GOPIN

PINBRANCH

FC-2180

INSTRUMENTATION LAB
CAMBRIDGE MASS.

NAVIGATION EXTENDED VERBS

COLOSSUS IIIA FC-2605

APPROVED

[Signatures]

[Date]
VERB94
Test Flag 9 bit 11

Is V94FLAG set?
Yes, V94 allowed via DOWNFLAG (FC-2070)
Clear V94 FLAG

CHECKMM
Check no. of major mode program in progress FC-2030

MM ≠ 23
Operator error

ALM/END FC-2190
Turn on operator error light.

Group 2, 11
Restarts V94ENTER, as a job with priority 14

Set Group 2 to do R64
V94ENTER in FC-2600

CLEANOUT FC-2190
Cause restart via ENEMA (Do R64)
## SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Where Flowed</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALM/END</td>
<td>FC-2190</td>
<td>Turns on operator error light</td>
<td>Sh. 2</td>
</tr>
<tr>
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<td>Sh. 2</td>
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<tr>
<td>CLEANOUT</td>
<td>FC-2190</td>
<td>Causes restart</td>
<td>Sh. 2</td>
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<td>DOWNFLAG</td>
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## FLAGS

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<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
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<td>V94 allowed</td>
<td>V94 not allowed</td>
<td>Sh. 2</td>
<td>Sh. 2</td>
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</tbody>
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MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

V94 (R54)

COLOSSUS 2D

DOCUMENT NO. FC-2606

REV SHEET 3 OF 3
MEASUREMENT INCORPORATION

MAJOR SUBROUTINES:
INCRP1 - COMPUTES STATE VECTOR DEVIATIONS
INCRP2 - INCORPORATES STATE VECTOR DEVIATIONS INTO STATE VECTOR

SPECIAL CONVENTIONS:
1. 2' / 2' IN THE SCALING FIELD OF THE SUMMARY SHEETS IS USED TO DENOTE EARTH/MOON SPHERE OF INFLUENCE
2. THE WORD VARIABLE IN THE SCALING FIELD INDICATES EITHER THE VARIABLE IS USED AS A TEMPORARY LOCATION WITH MANY DIFFERENT SCALINGS, OR THE CALLING PROGRAM SETS THE SCALE. (SEE NOTE SH14)
**GENERAL FLOW**
**MEASUREMENT INCORPORATION**

**CALLED BY**
P22 RENDEZVOUS NAVIGATION FOR OSM
P23 RENDEZVOUS NAVIGATION FOR OSM
P2B COLUMAR NAVIGATION FOR OSM
P20 RENDEZVOUS NAVIGATION FOR LEM
P22 COLUMAR SURFACE NAVIGATION FOR LEM

**AFTER INITIALIZING**

- **DMENFLG** - DIMENSION OF STATE VECTOR
- **σ²** - VARIANCE OF MEASUREMENT ERRORS
- **ΔQ** - DEVIATION OF MEASURED AND ESTIMATED POSITION
- **B** - VECTOR OF MEASUREMENT GEOMETRY

**INCORP1**

- COMPUTE STATE VECTOR DEVIATIONS OF POSITION, VELOCITY, AND
  (IF NINE DIMENSIONAL) LANDMARK
  POSITION OR RADAR BIAS.

**RETURN TO CALLING PROGRAM**

**VALID DEVIATIONS?**

- **NO**
  - **RETURN FOR NEW MARK**
- **YES**
  - **INCORP2**
    - **UPDATE W MATRIX**
    - **UPDATE APPROPRIATE STATE VECTOR**
  - **RETURN TO CALLING PROGRAM**
SUBROUTINE WHICH CALCULATES THE SIX DIMENSIONAL STATE VECTOR DEVIATIONS FOR POSITION AND VELOCITY OR THE NINE DIMENSIONAL DEVIATION OF POSITION, VELOCITY, AND LANDMARK POSITION OR RADAR BIAS.

**INPUT**

- \( W = \) ERROR TRANSITION MATRIX
  - 6x6 OR 9x9
- \( \Delta q = \) DEVIATION BETWEEN ESTIMATED AND ACTUAL TRACKING MEASUREMENT (SCALAR)
- \( \sigma^2 = \) VARIANCE INHERENT IN MEASUREMENT AND STATE VECTOR UNCERTAINTIES (SCALAR)
- \( B = \) 6 OR 9 DIMENSIONAL GEOMETRY OF MEASUREMENT VECTOR
- \( D = \) DIMENSION OF \( W \)
  - \( 0 = 6 \times 6 \)
  - \( 1 = 9 \times 9 \)

**OUTPUT**

- \( \Delta x = \) 6 OR 9 DIMENSIONAL STATE VECTOR DEVIATIONS
- \( \Omega = \) 6 OR 9 DIMENSIONAL VECTOR USED FOR THE INCORPORATION
- \( \gamma = \) SCALAR USED FOR INCORPORATION

**Variables Defined**

- \( Z \)
- \( \tilde{Z} \)
- \( \mathbf{W} \)
- \( \mathbf{B} \)
- \( \mathbf{O} \)
- \( \mathbf{S} \)
- \( \mathbf{p} \)
- \( \mathbf{q} \)
- \( \mathbf{r} \)
- \( \mathbf{v} \)
- \( \mathbf{w} \)
- \( \mathbf{z} \)

**Equation 2.3-9**

\[ \mathbf{Z} = \mathbf{W}^T \mathbf{B} \]

**Loop**

- Loop 1
  - \( Z_0 = W_0 \mathbf{Z}_0 + W_3 \mathbf{Z}_3 + W_6 \mathbf{Z}_6 \)
  - \( Z_1 = W_3 \mathbf{Z}_1 + W_4 \mathbf{Z}_4 + W_7 \mathbf{Z}_7 \)
  - \( Z_{1+6} = (W_{1+6}) \mathbf{Z}_{1+6} + (W_{1+7}) \mathbf{Z}_{1+7} + (W_{1+12}) \mathbf{Z}_{1+12} \)
  - \( Z_{1+12} = (W_{1+12}) \mathbf{Z}_{1+12} + (W_{1+14}) \mathbf{Z}_{1+14} \)

- Loop 2
  - \( X_1 = X_1 - 10 \)

- Loop 3
  - \( X_2 = X_2 - 6 \)

**Flow Chart**

- **Initial Index Registers**
  - \( X_1 \rightarrow 54 \)
  - \( X_2 \rightarrow 18 \)

- **Compute Z Vector**

- **Decrement Index Registers**
  - \( X_1 \rightarrow X_1 - 10 \)
  - \( X_2 \rightarrow X_2 - 6 \)

- **Test for End of Z Calculation**
  - **Yes**
    - \( 15 \) Dimensional
    - \( \tilde{Z} \) is only 6 Dimensional
    - \( \tilde{Z} = 0 \)
    - \( (Z_{1+12}) \vec{v} \) ZERO FLOP

- **Incor 1**

- **Find 2nd and 3rd Components of Z**

- **Incor 1a**

- **Egress**

- **Save Return**
A = \mathbf{Z}^2 + \alpha^2

A is an intermediate value used in calculating \( \Delta X \). Equation 2.3.9

\[ \mathbf{A} = \frac{1}{\mathbf{1}^2} \mathbf{Z}^2 + \frac{1}{\mathbf{1}^2} \alpha^2 \]

TRIPAT \left( \frac{1}{\mathbf{1}^2} \right) \mathbf{Z}^2 \left( \frac{1}{\mathbf{1}^2} \right) \alpha^2 \left( \frac{1}{\mathbf{1}^2} \right) \text{ VARIANCE}

\[ \mathbf{X}^2 \rightarrow O \]

MPAC \rightarrow \text{ VARIANCE} \rightarrow O

TEMPVAR \rightarrow MPAC

\( \alpha^2 \) is placed in a temporary location

\[ \text{IS MPAC = O ?} \]

YES

THIS LOOP PERFORMS NORMALIZATION

INCOR1B

NORMALIZE \( \alpha^2 \) IN PREPARATION FOR USE IN SQUARE ROOT.

SHIFT MPAC LEFT 2 PLACES

X2 \rightarrow X2+2

TEMPVAR \rightarrow MPAC

\( X_2 \) CONTAINS THE NORMALIZING COUNT

TEMPVAR CONTAINS THE NORMALIZED VARIANCE

NO

OVERFLOW?

YES

\[ \text{INCOR1C} \]

\[ \text{MPAC } = \mathbf{A} + \sqrt{\mathbf{A} \alpha^2} \]

\[ \text{MPAC}_D \leftarrow \text{TRIPAC}_D + \sqrt{\text{TRIPAC}_D \text{ (TEMPVAR)}_D} \]

\( X_2 \) CONTAINS NORMALIZING COUNT.

NORMGAM = \( X_2 - 2 \)

\( X_2 \rightarrow 162 \)

\[ \gamma = \frac{1}{\mathbf{1}^2} \left( A + \sqrt{A \alpha^2} \right) \]

\[ \text{GAMMA}_D \rightarrow \text{OP1/TH/(MPAC)}_D \]

GAMMA IS USED IN INCORP2.

EQUATION 2.3.10

\[ \text{NORMALIZE TRIPAT} \]

\[ \text{NORMALIZE DELTAG} \]

\[ X_1 \rightarrow X_1 - \text{S1} \]

X1 CONTAINS NORMALIZING COUNT OF A.

S1 CONTAINS NORMALIZING COUNT OF \( \Delta Q \)

\[ \text{POLO } = \frac{\Delta Q}{A} \]

\[ \text{POLO}_D \rightarrow \text{DELTAQ} / \text{TRIPAC}_D \]

SCALING ADJUSTED VIA X1

TO NEXT SHEET
FROM PRECEDING SHEET

NEWZCOMP

\[ 36D = \frac{|Z_0|}{\text{NORMZI}_0} \]

PDLC_D \[ \frac{|Z_1|}{PDLC_D} \]

\[ \frac{|Z_1| - |Z_0|}{\text{MPAC}_D} \]

MPAC \[ \text{MPAC} - \text{NORMZI}_D \]

\[ \text{YES} \]

\[ |Z_1| > |Z_0|? \]

\[ \text{NO} \]

\[ 36D = \frac{|Z_1|}{\text{NORMZI}_D} \]

PDLC_D \[ \frac{|Z_1|}{PDLC_D} \]

\[ \frac{|Z_2| - |Z_0| - |Z_1|}{\text{MPAC}} \]

MPAC \[ \text{MPAC} - \text{NORMZI}_D \]

\[ \text{YES} \]

\[ (+) \]

\[ |Z_4| > |Z_0| \text{OR} |Z_1| \]

\[ (-) \]

\[ \text{NO} : |Z_0| \text{OR} |Z_1| > |Z_2| \]

\[ \text{NORMZI} \]

NEWZCOMP

MPAC \[ \text{NORMZI} \]

\[ \text{NORMZI} \rightarrow X1 \]

\[ \text{NORMALIZE MPAC (CONTAINS MAX|Z|)} \]

\[ \text{NORMALIZE LARGEST Z COMPONENT, SAVE COUNT} \]

NEXT SHEET

SUCCESSIVE WEIGHTED MEASUREMENTS DECREASE ZI WEIGHTING VECTOR.
NEWZCOMP NORMALIZES COMPONENTS OF ZI ON LARGEST Z COMPONENT
PREVENTING LOSS OF SIGNIFICANCE.
FROM PRECEDING SHEET

\[ Z_0 = Z_0 \times 2^{x1} \]
\[ Z_{II} = VSL \# 0,1 Z_{II} \]
SHIFT \( Z_0 \) LEFT BY \( x1 \)
(NORM COUNT +2)

\[ Z_1 = Z_1 \times 2^{x1} \]
\[ Z_{II} + 6 = VSL \# 0,1 Z_{II} + 6 \]
SHIFT \( Z_1 \) LEFT BY \( x1 \)
(NORM COUNT +2)

SAVE \# SHIFTS FROM \( x1 \)
(NORM COUNT +2)

\[ NORM_{II} + 1 = SXA_{1} \]

\[ Z_2 = Z_2 \times 2^{x1} \]
\[ Z_{II} + 12D = VSL \# 0,1 Z_{II} + 12D \]

NORMALIZING COUNT MINUS 2.
NORMAM CONTAINS GAMMA
NORMALIZING COUNT MINUS 2.

\[ x1 = \frac{\text{NORMCOUNT - 2}}{NORMAM} \]
\[ x1 = \frac{\text{NORMCOUNT - 2 - (MATRIX NORMCOUNT)}}{NORMAM - \text{NORMAM - 2 (NORMII + 1)}} \]
NORMALIZING COUNT FOR \( y \) MINUS 2 RETURNED TO \( x1 \) WHERE TWICE NUMBER OF SHIFTS REQUIRED FOR MATRIX NORMALIZATION (NORMII + 1) ARE SUBTRACTED.

\[ x1 = \text{COMPLEMENT OF MATRIX NORMCOUNT} \]
\[ LXC_{1} \text{ NORMII + 1} \]
STORE NORMAM COMPLEMENT IN \( x1 \).

\[ \text{NEW NORMCOUNT} = (\text{COMPLEMENT OF MATRIX SHIFTS}) / (\text{NORMCOUNT - NORMCOUNT} \times 2) \]
\[ x1 = x1 + \text{NORMII} \]
OLD NORMALIZING COUNT (\( x1 - 51 \)) FOR \( \Delta Q/A \) MODIFIED BY SHIFTS NEEDED TO NORMALIZE ZVECTOR.

\[ PDL = 2D \]

NEXT SHEET
FROM PRECEDING SHEET

52 → 54

INCR2

COMPUTE $w$ VECTOR

\[ w_2 = Z_0 w_0 + Z_1 w_1 + Z_2 w_2 \]

PDL2V \[ \rightarrow 2(v(W)(m+1)(v+g)(v+1)(v+12)(v+36)(m) \]

\[ w_1 = Z_0 w_3 + Z_1 w_4 + Z_2 w_5 \]

PDLBV \[ \rightarrow 2(v(W+5)(m+1)(v+g)(v+12)(v+90)(m) \]

\[ w_0 = Z_0 w_6 + Z_1 w_7 + Z_2 w_8 \]

PDL14V \[ \rightarrow 2(v(W+108)(m+1)(v+g)(v+12)(v+144)(m) \]

X2 → X2 = 54

FIND 2ND AND 3RD COMPONENTS OF W

NO

X2 = 0

YES

(W + \( \text{OMEGA} + 12 \))V = PDL14V

(W + \( \text{OMEGA} + 6 \))V = PDLBV

(W + \( \text{OMEGA} \))V = PDL2V

IS

DIMENFLG

SET P

NO

YES

INCR3AB

X2 → X2 = 18

S2 → 6

TO NEXT SHEET

MOVE \( \mathbf{w} \) FROM PUSH LIST TO STORAGE.

IF W-MATRIX IS 6 DIMENSIONAL \( \mathbf{w} \) IS ONLY 6 DIMENSIONAL

\[ w_0 = 0 \]

\( \text{OMEGA} + 12 \)V = ZEROVECS

MEASUREMENT INCORPORATION

FC-2610
\[ \Delta \mathbf{x} = \Delta \mathbf{q} \left( \frac{\Delta \mathbf{q}}{\mathbf{r}} \right) \]

This loop cycled 3 times for \( \Delta \mathbf{x}_0, \Delta \mathbf{x}_1, \Delta \mathbf{x}_2 \)

\( \Delta \mathbf{x} \) is the state vector deviation

Equation 2.3.3

**Flowchart:**

1. **Compute \( \Delta \mathbf{x} \) Vector**
   - \( \Delta \mathbf{x}_0 = \mathbf{q}_0 \Delta \mathbf{q}/\mathbf{r} \)
   - \( \Delta \mathbf{x}_1 = \mathbf{q}_1 \Delta \mathbf{q}/\mathbf{r} \)
   - \( \Delta \mathbf{x}_2 = \mathbf{q}_2 \Delta \mathbf{q}/\mathbf{r} \)

2. **Loop 1**
   - \( \Delta \mathbf{x}_0 = \mathbf{q}_0 \Delta \mathbf{q}/\mathbf{r} \)
   - \( \Delta \mathbf{x}_1 = \mathbf{q}_1 \Delta \mathbf{q}/\mathbf{r} \)
   - \( \Delta \mathbf{x}_2 = \mathbf{q}_2 \Delta \mathbf{q}/\mathbf{r} \)

3. **Loop 2**
   - \( \Delta \mathbf{x}_0 = \mathbf{q}_0 \Delta \mathbf{q}/\mathbf{r} \)
   - \( \Delta \mathbf{x}_1 = \mathbf{q}_1 \Delta \mathbf{q}/\mathbf{r} \)
   - \( \Delta \mathbf{x}_2 = \mathbf{q}_2 \Delta \mathbf{q}/\mathbf{r} \)

4. **Loop 3**
   - \( \Delta \mathbf{x}_0 = \mathbf{q}_0 \Delta \mathbf{q}/\mathbf{r} \)
   - \( \Delta \mathbf{x}_1 = \mathbf{q}_1 \Delta \mathbf{q}/\mathbf{r} \)
   - \( \Delta \mathbf{x}_2 = \mathbf{q}_2 \Delta \mathbf{q}/\mathbf{r} \)

5. **Find 2nd and 3rd components of \( \Delta \mathbf{x} \)**
   - **No**
   - **Yes**

6. **Change \( \Delta \mathbf{x}_2 \) to correct scale**

7. **Return via Egress**

8. **Return to calling program**
SUBROUTINE WHICH INCORPORATES THE COMPUTED STATE VECTOR DEVIATIONS INTO THE ESTIMATED STATE VECTOR FOR EITHER THE CSM OR LEM. CALLED AFTER STATE VECTOR DEVIATIONS CALCULATED BY INCORP1 HAVE BEEN ACCEPTED EITHER BY ASTRONAUT OR BY CALLING PROGRAM.

INPUT:
VEHUPFLG - UPDATE VEHICLE
1 = CSM, 0 = LEM
W = ERROR TRANSITION MATRIX
DELTA = ΔX = G OR 9 DIMENSIONAL STATE VECTOR DEVIATIONS
DMENFLG = DIMENSION OF W
1 = 9x9, 0 = 6x6
OMEGA = Ω = G OR 9 DIMENSIONAL OMEGA WEIGHTING VECTOR USED TO MINIMIZE STATISTICAL ERRORS
GAMMA = Y = SCALAR USED IN THE INCORPORATION
ZI = G OR 9 DIMENSIONAL VECTOR USED IN THE INCORPORATION
PERMANENT STATE VECTOR FOR EITHER LEM OR CSM
NORMGAM = NORMALIZATION COUNT FOR RESTORING W MATRIX UPDATE

OUTPUT:
UPDATED PERMANENT STATE VECTOR
UPDATED W MATRIX

INCRPR2
EGRESS - QPRET
SAVE RETURN

INSTALL
PROHIBITS INTERRUPTION OF INTEGRATION PROGRAM
FC-2290

OMEGA1 = OMEGAV(GAMMA)
OMEGA2 = (OMEGA + Y)(GAMMA)
OMEGA3 = (OMEGA + 12Y)(GAMMA)

WIXA = 54
WIXB = 54
ZIXA = 0
ZIXB = 0

INITIALIZE LOCATIONS FOR USE BY INDEX REGISTERS

FA2A

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

FA2A1

PRIORITY IS THAT OF CALLING PROGRAM. FIRST PHASE OF INCORP2, UPDATE 6 OR 9 DIMENSIONAL W-MATRIX IN TEMPORARY STORAGE.

TO NEXT SHEET
FROM PRECEDING SHEET

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

**3RD PHASE OF INCORPZ.**
UPDATE OF VEHICLE STATE VECTOR IN TEMPORARY REGISTERS.

$\Delta x_z + 3$RD COMPONENT OF VEHICLE STATE VECTOR IS SAVED IN TEMPORARY REGISTER FOR FUTURE USE

YES-CSM

**VEHUPFLG SET?**

NO-LEM

WHICH VEHICLE STATE VECTOR IS BEING UPDATED?

**STATE VECTOR QUANTITIES**

$RCV = R_z = \text{CONIC POSITION}$

$VCV = V_z = \text{CONIC VELOCITY}$

$TDELTAV = T\text{-POSITION DEVIATION FROM CONIC}$

$TNUV = U = \text{VELOCITY DEVIATION FROM CONIC}$

**MOVEPGM CSM STATE VECTOR TRANSFERRED FROM PERMANENT CORE TO TEMPORARY WORK AREA FC-2290**

**FAZAB**

**CLEAR OVFIND**

X2 $\rightarrow 0$

**NO-EARTH**

**IS MOONTHIS SET?**

YES-MOON

X2 $\rightarrow 2$

**MPACV = $x + \Delta x_z$**

**MPACV $\rightarrow TDELTAV + \Delta x_z$**

MPAC IS SCALLED $2^{27}$ FOR MOON, $2^{29}$ FOR EARTH ORBIT
ADD UPDATING STATE VECTOR DEVIATIONS ($\Delta x_z$)
TO POSITION DEVIATION FROM CONIC ($\delta$)

$\text{OVFIND = 1 ?}$

YES $\delta$ HAS BECOME 'TOO LARGE'

FAZAB1

TO NEXT SHEET

**MOVEMEM LEM STATE VECTOR TRANSFERRED FROM PERMANENT CORE TO TEMPORARY WORK AREA FC-2290**

LEM AND CSM STATE VECTORS ARE NOT WORKED WITH DIRECTLY. A WORK AREA, COMMON TO BOTH, IS USED TO PREVENT LOSS OF STATE VECTOR DURING MANIPULATIONS.

TO NEXT SHEET
5th phase of INCORP2
Update 3rd component (landmark position or radar bias) of state vector if W-matrix is 9 dimensional.

Dimension of W-matrix

Move updated 3rd component calculated previously from temporary registers to state vector.

Restore return value

Wakes up jobs waiting for integration and performs them according to priority.

Return is in INTWAKE
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

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<td>RESERVES INTEGRATION ROUTINE</td>
<td>SH7</td>
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<tr>
<td>MOVECPSM</td>
<td>2290</td>
<td>MOVE CSM STATE VECTOR FROM PERMANENT TO TEMPORARY REGISTERS</td>
<td>SH10</td>
</tr>
<tr>
<td>MOVEPLEM</td>
<td>2290</td>
<td>MOVE LEM STATE VECTOR FROM PERMANENT TO TEMPORARY REGISTERS</td>
<td>SH10</td>
</tr>
<tr>
<td>RECTIFY</td>
<td>2290</td>
<td>ADDS DEVIATIONS TO CONIC POSITION AND VELOCITY</td>
<td>SH11</td>
</tr>
<tr>
<td>MOVEACSM</td>
<td>2290</td>
<td>MOVE CSM STATE VECTOR FROM TEMPORARY TO PERMANENT REGISTERS</td>
<td>SH11</td>
</tr>
<tr>
<td>MOVEALEM</td>
<td>2290</td>
<td>MOVE LEM STATE VECTORS FROM TEMPORARY TO PERMANENT REGISTERS</td>
<td>SH11</td>
</tr>
<tr>
<td>SVDW1</td>
<td>2250</td>
<td>STORES CSM STATE VECTOR IN DOWNLINK REGISTERS</td>
<td>SH11</td>
</tr>
<tr>
<td>SVDW2</td>
<td>2250</td>
<td>STORES LEM STATE VECTOR IN DOWNLINK REGISTERS</td>
<td>SH11</td>
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<tr>
<td>INTWAKE</td>
<td>2290</td>
<td>RELEASES INTEGRATION ROUTINE</td>
<td>SH12</td>
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### FLAGS

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
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<tbody>
<tr>
<td>DMENFLG FLAGWORD 5 BIT 9</td>
<td>W-MATRIX IS 9 DIMENSIONAL</td>
<td>W-MATRIX IS 6 DIMENSIONAL</td>
<td>SH3,5,8,9,12</td>
<td>SH7</td>
<td></td>
</tr>
<tr>
<td>REINFLG FLAGWORD 10 BIT 7</td>
<td>INTEGRATION ROUTINE TO BE RESTARTED</td>
<td>INTEGRATION ROUTINE NOT TO BE RESTARTED</td>
<td>SH7</td>
<td>SH10,11</td>
<td></td>
</tr>
<tr>
<td>VEHUFLG FLAGWORD 1 BIT 8</td>
<td>CSM STATE VECTOR BEING UPDATED</td>
<td>LEM STATE VECTOR BEING UPDATED</td>
<td>SH10</td>
<td>SH10</td>
<td></td>
</tr>
<tr>
<td>MOONTHS FLAGWORD 8 BIT 11</td>
<td>PERMANENT LM STATE VECTOR IN LUNAR SPHERE</td>
<td>PERMANENT LM STATE VECTOR IN EARTH SPHERE</td>
<td>SH10</td>
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### ERASABLE LOCATIONS USED

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<thead>
<tr>
<th>ACU TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>ACU UNITS</th>
<th>ACU SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGRESS</td>
<td></td>
<td>RETURN FOR CALLING PROGRAM</td>
<td>(INTEGER)</td>
<td>2^{14}</td>
<td>VARIABLE</td>
</tr>
<tr>
<td>W</td>
<td>Z</td>
<td>W-MATRIX</td>
<td>VARIABLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZI</td>
<td>A</td>
<td>VECTOR USED IN THE INCORPORATION</td>
<td>VARIABLE</td>
<td></td>
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</tr>
<tr>
<td>TRIPA</td>
<td></td>
<td>SCALAR USED IN THE INCORPORATION</td>
<td>VARIABLE</td>
<td></td>
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<tr>
<td>VARIANCE</td>
<td>A</td>
<td>INSTRUMENT ERROR VARIANCE</td>
<td>VARIABLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BVVECTOR</td>
<td>(b1,b2,b3)</td>
<td>GEOMETRY OF MEASUREMENT VECTOR</td>
<td>VARIABLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEMPPAR</td>
<td></td>
<td>TEMPORARY STORAGE FOR VARIANCE</td>
<td>VARIABLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORMGAM</td>
<td></td>
<td>NORMALIZING COUNT FOR GAMMA</td>
<td>VARIABLE</td>
<td></td>
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<tr>
<td>GAMMA</td>
<td></td>
<td>SCALAR USED IN THE INCORPORATION</td>
<td>VARIABLE</td>
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<tr>
<td>DELTAQ</td>
<td></td>
<td>MEASUREMENT TRACKING DEVIATIONS</td>
<td>VARIABLE</td>
<td></td>
<td></td>
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<tr>
<td>OMEGA</td>
<td></td>
<td>STATISTICAL WEIGHTING VECTOR</td>
<td>VARIABLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELTAX</td>
<td></td>
<td>STATE VECTOR DEVIATIONS</td>
<td>VARIABLE</td>
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<td>OMEGAM1,2,3</td>
<td></td>
<td>VECTOR USED IN THE INCORPORATION</td>
<td>VARIABLE</td>
<td></td>
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<tr>
<td>WIXA, WIXB</td>
<td></td>
<td>SCALARS USED FOR INDEXING</td>
<td>VARIABLE</td>
<td></td>
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<tr>
<td>ZIXA, ZIXS</td>
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<td>SCALARS USED FOR INDEXING</td>
<td>VARIABLE</td>
<td></td>
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<td>HOLDW</td>
<td></td>
<td>TEMPORARY STORAGE FOR W-MATRIX</td>
<td>VARIABLE</td>
<td></td>
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### DOCUMENT INFORMATION

- **MIT INSTRUMENTATION LAB, CAMBRIDGE, MASS.**
- **APOLLO CONTRACT AND MANUFACTURING**
- **MEASUREMENT INCORPORATION**
- **DRAWN BY:** [Signature]
- **CHECKED BY:** [Signature]
- **ANALYST:** [Signature]
- **REVISION:** 15/36
### ERASABLE LOCATIONS USED (CONT'D)

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
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<tr>
<td>TX789</td>
<td></td>
<td>TEMPORARY STORAGE FOR THIRD COMPONENT OF STATE VECTOR</td>
<td></td>
<td></td>
<td>VARIABLE</td>
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<tr>
<td>X789</td>
<td>δ</td>
<td>THIRD COMPONENT OF STATE VECTOR</td>
<td>METERS/SEC</td>
<td>METERS</td>
<td>VARIABLE</td>
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<tr>
<td>TDELTAV</td>
<td>v</td>
<td>POSITION DEVIATION FROM CONIC</td>
<td>METERS/SEC</td>
<td>METERS/SEC</td>
<td>2^27/2^25</td>
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<tr>
<td>TNUV</td>
<td>v</td>
<td>VELOCITY DEVIATION FROM CONIC</td>
<td>METERS/SEC</td>
<td>METERS/SEC</td>
<td>2^27/2^25</td>
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<tr>
<td>RCV</td>
<td>r_c</td>
<td>CONIC POSITION</td>
<td>METERS/SEC</td>
<td>METERS/SEC</td>
<td>2^27/2^25</td>
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<tr>
<td>VCV</td>
<td>v_c</td>
<td>CONIC VELOCITY</td>
<td>(INTEGER)</td>
<td>2^14</td>
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<td>PSODY</td>
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<td>SCALE ADJUSTING VARIABLE</td>
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</table>

*NOTE: VARIABLE INDICATES SCALING AND UNITS DEPEND ON CALLING PROGRAM. SEE FIG. 1 TEST PACKAGE LEVEL II #72 FOR COLOSSUS, SUNDANCE, AND LUMINARY*

### PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC TAG</th>
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<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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<tr>
<td>ZEROVECS</td>
<td></td>
<td>A VECTOR OF ZEROS</td>
<td>1/4 (INTEGER)</td>
<td>.25</td>
<td>(2^28, 2^28, 2^28)</td>
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<tr>
<td>DPI/4TH</td>
<td></td>
<td>DOUBLE PRECISION ONE FOURTH</td>
<td></td>
<td></td>
<td>2^0</td>
</tr>
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</table>
P30 EXTERNAL AV MANEUVER AND
P31 LAMBERT AIM POINT MANEUVER
PRE-THRUST COMPUTATIONS

MAJOR SUBROUTINES
P30/P31 (USED BY P30 AND P31)
S30.1 (P30 ONLY)
S31.1 (P31 ONLY)

EXTERNAL ENTRY POINTS:
DISPMGA(SH5), CNTNUP30(SH6)
ENTER WITH
VOTESOE

P30

SAVE Q
IN
P30/31RT

SET
UPDATEFLG

BIT 7, FLAG 1
ALLOW P20 UPDATING

SET
TRACKFLG

BIT 5, FLAG 1
ALLOW TRACKING

GOFLASHER
V66N33
DISPLAY TIG

TERMINATE
V34E

GOTOPOOH

TIG, OV VALUES UPLINKED VIA P21T
FROM RTCC OR COMPUTED VIA
CMC OR LGC.
SEE TABLE P.5.2-22 R-577

RECYCLE NEW DATA
V25E

5.1
SET UP RESTART
RETURN TO
LAST DISPLAY

ENDOFJOB

RETURN VIA
P30/31RT

CONTINUE
V66N50
DISPLAY
\( \Delta x, y, z, (LV) \)

FC-2620

TERMINATE
V34E

GOTOPOOH

R1 = DELTA X (LV)
WHERE: X IS COMPONENT ALONG X-AXIS
R2 = DELTA Y (LV)
Y IS COMPONENT ALONG Y-AXIS
R3 = DELTA Z (LV)
Z IS COMPONENT ALONG R
R IS GEOCENTRIC/SELENOCENTRIC
RADIUS VECTOR, V IS CM
VELOCITY VECTOR.

RECYCLE NEW DATA
V25E

V33E
PROCEED

SET
XDELVFLG

CLEAR
UPDATEFLG

INHIBIT P20 UPDATING

630.1

NEXT SHEET
BEGIN

1. SAVE Q IN PROPINT
2. SET UP ATTLG
3. BIT 7, FLAG 1 ALLOW PRO UPDATING
4. SET TRACKFLG
5. BIT 5, FLAG 1 ALLOW TRACKING
6. RECYCLE NEW DATA
7. V8SE E
8. SET UP RESTART RETURN TO LAST DISPLAY
9. ENDUOFJOB
10. RETURN VIA P30/P31
11. CLEAR UPATTLG & NORMSN
12. S31:
13. SAVE Q Điểm on QTEMP
14. TDCLn — TIGp
15. AGAIN
16. INTEGRATE CSM TO TIG, USE INPUT TO COMPUTE TRANSFER PARAMETERS
17. FC-7600 SH.35
18. NEXT SHEET

INPUT: TIG, INTERC TIN CLSC @ 2^18ette: INTERC DR M @ 2^6, DELT4 = s @ 2^6, SEC @ 2^6
OUTPUT: SMOOTHED TRANSFER TRAJECTORY VELOCITY, ALL IN METERS/SECOND
VPTRM, TERMINAL TRANSFER TRAJECTORY VELOCITY @ 2^7
DELVTS, INITIAL VELOCITY INCREMENT AT TIG TO ACHIEVE TRANSFER
RTIGp CONTAINS RATT, OP TIG IN M @ 2^5
VTTGp CONTAINS VATT, OP TIG IN M @ 2^7
VINITp CONTAINS VATT, OP TIG IN M @ 2^7
ALSO RTIG & RTX2 (-2^10 & 8^12 FOR EARTH/MOON SCALING)
DELTA = TIME OF FLIGHT (INTERCEPT TIG) IN SECOND

END

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APPROVED
GUIDANCE AND NAVIGATION

P30/P31
EXTERNAL DELTA VELOCITY

FC-2620

DRAWN A. S. WILLIAMS
PROPOSE

REVIEW

ARTWORK

REV 4

Sheet 7 of 12
SCHEDULE COMPUTATION OF TFI TIME AT ONE SECOND INTERVALS (-BEFORE TIG, +AFTER). SET TIMERFLAG.

R3 = MARKCOUNT = ND MARKS PROCESSED BY PEG.
R2 = TFI TIME FROM IGNITION IN MIN @ SEC (MIN 50@55, MAX 50@55), -BEFORE TIG, +AFTER
R5 = PGA = MIDDLE GIMBAL ANGLE AT TIG.
SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>THISPRCC</td>
<td>FC-1350</td>
<td>UPDATES CSM TO TDECI TIME</td>
<td>SH. 3</td>
</tr>
<tr>
<td>LOMAT</td>
<td>FC-1740</td>
<td>CONVERTS REF TO LV COORDINATES</td>
<td>SH. 3</td>
</tr>
<tr>
<td>PERIAPO1</td>
<td>FC-1780</td>
<td>COMPUTES H_p, H_A OF ACTIVE VEHICLE</td>
<td>SH. 4, 8</td>
</tr>
<tr>
<td>MAXCHK</td>
<td>FC-2325</td>
<td>LIMITS H_p/H_A AT DSKY REGISTER CAPACITY 0000, 9 NM</td>
<td>SH. 4, 8</td>
</tr>
<tr>
<td>GET+MGA</td>
<td>FC-1760</td>
<td>COMPUTES MIDDLE GIMBAL ANGLE</td>
<td>SH. 5, 9</td>
</tr>
<tr>
<td>COMPTGO</td>
<td>FC-1710</td>
<td>COMPUTES TFI (VIA CLOCKTASK) AT ONE SEC. INTERVALS</td>
<td>SH. 5, 10</td>
</tr>
<tr>
<td>AGAIN</td>
<td>FC-2680</td>
<td>INTEGRATES CSM TO TIG AND USES (\dot{t}<em>{\text{m}}), (\dot{v}</em>{\text{m}}) IN INITVEL TO COMPUTE</td>
<td>SH. 7</td>
</tr>
<tr>
<td>MIDGIM</td>
<td>FC-1760</td>
<td>CONVERTS (\Delta v) FROM INERTIAL TO LV COORDINATES</td>
<td>SH. 8</td>
</tr>
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FLAGS

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
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<tbody>
<tr>
<td>UPDATFLG</td>
<td>ALLOW P20 UPDATING</td>
<td>DISALLOW P20 UPDATING</td>
<td>SH. 2, 7</td>
<td>SH. 2, 7</td>
<td>SH. 5, 9</td>
</tr>
<tr>
<td>TRACKFLG</td>
<td>ALLOW TRACKING</td>
<td>DISALLOW TRACKING</td>
<td>SH. 2, 7</td>
<td>SH. 2, 7</td>
<td>SH. 5, 9</td>
</tr>
<tr>
<td>REPSMFLG</td>
<td>REFSMAT GOOD</td>
<td>REFSMAT NOT AVAILABLE</td>
<td>SH. 6, 10</td>
<td>SH. 6, 10</td>
<td>SH. 5, 9</td>
</tr>
<tr>
<td>TIMERFLG</td>
<td>CONTINUE 1 SEC. TFI CLOCKTASK</td>
<td>STOP COMPUTING TFI</td>
<td>SH. 6, 10</td>
<td>SH. 6, 10</td>
<td>SH. 5, 9</td>
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<tr>
<td>XDELVFLG</td>
<td>EXTERNAL (\Delta v) MANEUVER</td>
<td>LAMBERT STEERING MANEUVER</td>
<td>SH. 7</td>
<td>SH. 7</td>
<td>SH. 5, 9</td>
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<tr>
<td>NORMW</td>
<td>UNIT NORMAL COMPUTED</td>
<td>LAMBERT MUST COMPUTE UNIT NORMAL</td>
<td>SH. 7</td>
<td>SH. 7</td>
<td>SH. 5, 9</td>
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<tr>
<td>AVFLG</td>
<td>LM ACTIVE IN THIS CASE USED TO SELECT LV CONVERSION OPTION IN MIDGIM</td>
<td>CSM ACTIVE</td>
<td>SH. 8</td>
<td>SH. 8</td>
<td>SH. 5, 9</td>
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DISPLAYS

<table>
<thead>
<tr>
<th>VERB-</th>
<th>TYPE OF DISPLAY</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
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<tbody>
<tr>
<td>V06N53</td>
<td>FLASHING</td>
<td>R1, R2, R3 CONTAIN TIG IN HRS, MIN &amp; SEC, RESPECTIVELY</td>
<td>SH. 2, 7</td>
</tr>
<tr>
<td>V06N81</td>
<td>FLASHING</td>
<td>R1, R2, R3 CONTAIN DELTA V X, Y &amp; Z COMPONENTS IN LOCAL VERTICAL COORDINATES</td>
<td>SH. 2, 9</td>
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<tr>
<td>V06N42</td>
<td>FLASHING</td>
<td>DISPLAYS H_A, H_p, (\Delta v) FOR TRANSFER TRAJECTORY</td>
<td>SH. 4, 9</td>
</tr>
<tr>
<td>V16N45</td>
<td>FLASHING</td>
<td>DISPLAYS MARKCOUNT, TFI &amp; +MGA</td>
<td>SH. 5, 10</td>
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### ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
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<td>RETURN ADDRESS FOR P30</td>
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<tr>
<td>TDEC1</td>
<td>t_i</td>
<td>STORAGE LOC FOR TIME INTEGRATED TO TIG</td>
<td>HRS, MIN, SEC</td>
<td>CSEC</td>
<td>2^28</td>
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<tr>
<td>VTIG</td>
<td></td>
<td>ACTIVE VEHICLE VELOCITY AT TIG</td>
<td>FPS</td>
<td>M/CSEC</td>
<td>2^7</td>
</tr>
<tr>
<td>RTIG</td>
<td></td>
<td>ACTIVE VEHICLE POSITION AT TIG</td>
<td>NAUTICAL MILES</td>
<td>METERS</td>
<td>2^29</td>
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<tr>
<td>HACT3</td>
<td></td>
<td>SAME AS RTIG</td>
<td>NAUTICAL MILES</td>
<td>METERS</td>
<td>2^7/2^29</td>
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<tr>
<td>UNRM</td>
<td>u_TD</td>
<td>UNIT VECTOR OF ACTIVE VEHICLE</td>
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<tr>
<td>DELVSN</td>
<td>ΔVL</td>
<td>STORAGE LOC FOR ΔVL</td>
<td>FPS</td>
<td>M/CSEC</td>
<td>2^7</td>
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<td>VGDISP</td>
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<td>STORAGE LOC FOR</td>
<td>FPS</td>
<td>M/CSEC</td>
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<tr>
<td>HIPER</td>
<td>H_p</td>
<td>PERIGEE HEIGHT STORAGE LOC</td>
<td>NM</td>
<td>METERS</td>
<td>2^29</td>
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<tr>
<td>HAP0</td>
<td>H_A</td>
<td>APOGEE HEIGHT STORAGE LOC</td>
<td>NM</td>
<td>METERS</td>
<td>2^29</td>
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<tr>
<td>RTARG</td>
<td>t(T_T)</td>
<td>AIM POINT TARGET VECTOR FOR INITVEL (CALLED BY AGAIN)</td>
<td>NM</td>
<td>M</td>
<td>2^29</td>
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<tr>
<td>TDELL4</td>
<td>t_F</td>
<td>TIME OF FLIGHT FROM RINT TO RTARG</td>
<td>M</td>
<td>CSEC</td>
<td>2^28</td>
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<tr>
<td>VIPRIME</td>
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<td>INITIAL TRANSFER VELOCITY</td>
<td>FPS</td>
<td>M/CSEC</td>
<td>2^7</td>
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<tr>
<td>VTPRIME</td>
<td></td>
<td>TERMINAL TRANSFER VELOCITY</td>
<td>FPS</td>
<td>M/CSEC</td>
<td>2^7</td>
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<tr>
<td>HINT</td>
<td></td>
<td>SAME AS RTIG, VTIG ABOVE EXCEPT EARTH SCALING</td>
<td>NM</td>
<td>M</td>
<td>2^29</td>
</tr>
<tr>
<td>VINT</td>
<td></td>
<td></td>
<td>NM</td>
<td>M/SEC</td>
<td>2^7</td>
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### PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC TAG</th>
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<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>MARSDDP</td>
<td>-000.02°</td>
<td>IMU/REFMSMAT NOT READY FOR MGA COMP.</td>
<td>DEGREES</td>
<td>REV</td>
<td>2^0</td>
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THE ENCLOSED REPLACEMENT SHEET WILL UPDATE THE COLOSSUS II FLOW CHART FC-2626 REV. 0 TO THE COLOSSUS II A FLOW CHART FC-2626 REV. 1

THE EFFECTIVE SHEETS FOR COLOSSUS II A FC-2626 REV. 1

<table>
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<tr>
<th>Sheet</th>
<th>Revision</th>
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<tbody>
<tr>
<td>1 - 22</td>
<td>REV. 0</td>
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<tr>
<td>23</td>
<td>REV. 1</td>
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<td>24 - 26</td>
<td>REV. 0</td>
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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

P32 AND P72 CO-ELLIPTIC SEQUENCE INITIATION

DOCNO. COLOSSUS II-A FC-2626

DRAWN: 2/28/74
MOD: 03/09/74
CHECKED: 03/09/74
APPROVED: 05/15/74

SHEET 1 OF 2
FROM PRECEDING PAGE

P32/P72E

T1TOT2_Dp

\( \text{MPAC}_Dp \times (\text{T1TOT2}_Dp - 60\text{MIN}_Dp) \)

\( \text{MPAC}_Dp \times (\text{T2TOT3}_Dp - 60\text{MIN}_Dp) \)

\( \text{MPAC}_Dp \times (\text{DELVEETL}) \)

\( \text{MPAC}_Dp \times (\text{DELVEETL}) \)

\( \text{DELVEETL} \)

\( \text{SET TIME FROM CSI TO CDH < 60 MIN} \)

\( \Delta T_3 \) TIME FROM CDH TO TPI

\( \text{SET TIME FROM CDH TO TPI < 60 MIN} \)

\( R_1 = \text{DIFFALT}_Dp = \text{ALTITUDE BETWEEN ACTIVE AND PASSIVE VEHICLES AT CDH IN NM} \)

\( R_2 = \text{T1TOT2}_Dp = \Delta \angle \text{BETWEEN CSI AND CDH MANEUVERS IN MIN AND SEC} \)

\( R_3 = \text{T2TOT3}_Dp = \Delta \angle \text{BETWEEN CDH AND TPI MANEUVERS IN MIN AND SEC} \)

REQUIRED \( \Delta \gamma \) FOR CSI MANEUVER

TO NEXT PAGE
FROM PRECEDING PAGE

S32/33-1

SUREXIT ← QPRET

SAVE RETURN ADDRESS

SET UP VERB-NOUN FOR DISPLAY

VGNB1

DISPLAY ΔV AT CSI IN LOCAL VERTICAL COORDINATES
(CREW MAY CHANGE ΔV TO CORRECT FOR OUT-OF-PLANE COMPONENTS)

VGNB1

INPUT: MPAC = ΔV AT CSI

R1 = X COMPONENT OF ΔV

R2 = Y COMPONENT OF ΔV

R3 = Z COMPONENT OF ΔV

ΔV = VGNB1 FOR DISPLAY

OUTPUT: DELVNC = ΔV IN LOCAL VERTICAL COORDINATES (ΔV / )

INPUT: RAC1, UPL

OUTPUT: DELVNC = REFERENCE TO LOCAL VERTICAL TRANSFORMATION (MREF)

DELVNC = DELVNC

ΔV = MAGNITUDE OF ΔV

DELVNC = DELVNC

ΔV = NEW VALUE OF ΔV IF MODIFIED BY CREW TO CHANGE OUT-OF-PLANE COMPONENTS

DELVEET1 = MPAC

ΔV = POSITION OF ACTIVE VEHICLE AT CDH

RAC1 = RAC2

MPAC = DELVEET1

ΔV = REQUIRED ΔV AT CDH

VERB-NOUN FOR DISPLAY

DISPLAY ΔV AT CDH IN LOCAL VERTICAL COORDINATES

VGNB2

INPUT: MPAC = ΔV AT CDH

R1 = X COMPONENT OF ΔV

R2 = Y COMPONENT OF ΔV

R3 = Z COMPONENT OF ΔV

ΔV = VGNB1 FOR DISPLAY

TO NEXT PAGE

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

PD2 AND PTE
CO-ELLIPIC SEQUENCE INITIATION

DRAWN: A.C. WILLIAMS
PROD: E. E. E. D.
ANAL: K. W. K.
DOC: T. D. F. F.
APPROVED: J. T. T.

COLOSSUS II FC-2626

REVISION 1 SHEET 4 OF 25
ADVANCE

STORE RETURN ADDRESS

TIME OF IGNITION (INPUT TO PRESET)

INPUT: H, U, L, MPAC, AVGLAG
OUTPUT: RACT3, VACT3 - STATE VECTOR OF ACTIVE VEHICLE AT TIG
        RPASS2, VPASS2 - STATE VECTOR OF PASSIVE VEHICLE AT TIG

EXTERNAL DELTA-V MANEUVER
(NOT LAMBERT AMOUNT)

VELOCITY VECTOR OF PASSIVE VEHICLE AT TIG

POSITION VECTOR OF PASSIVE VEHICLE AT TIG

U = UNIT \{ \mathbf{p}_a \times \mathbf{p}_p \}

\mathbf{u}_p = UNIT \left\{ \mathbf{UNIT} \{ \mathbf{RPASS}_1 \times \mathbf{VPASS}_1 \} \right\}

RTIG = RACT3

POSITION OF ACTIVE VEHICLE AT IGNITION

ROTATES THE VECTOR INTO THE PLANE OF THE PASSIVE VEHICLE

\mathbf{F}_{p_3} = \mathbf{F}_{p_3} \left\{ \mathbf{UNIT} \left\{ \mathbf{UNIT} \left\{ \begin{array}{c}
\mathbf{F}_{p_3} \\
\mathbf{F}_{p_3} \times (\mathbf{F}_{p_3} \times \mathbf{U}_p) \end{array} \right\} \right\} \right\}

MPAC = [RTIG \times UNIT \{ RTIG \times \mathbf{U}_p \} \times \mathbf{U}_p]

RETURN VIA QPRET

POSITION VECTOR OF ACTIVE VEHICLE WHEN ROTATED INTO PLANE OF PASSIVE VEHICLE

TO NEXT PAGE
FROM PRECEDING PAGE

\[ V_{TIG} \rightarrow VACT_2 \]

VELOCITY OF ACTIVE VEHICLE AT IGNITION

\[ Y_{TIG} = Y_{TIG} \text{ UNIT} [V_{TIG} \cdot (V_{TIG} \cdot U)] \]

\[ MPAC \leftarrow |V_{TIG} \text{ UNIT} [V_{TIG} \cdot (V_{TIG} \cdot UPL) \cdot UPL] \]

RETURN VIA \text{ QRET}

\[ VACT_2 \rightarrow MPAC \]

\[ VACT_1 \rightarrow MPAC \]

VELOCITY VECTOR OF ACTIVE VEHICLE ROTATED INTO PLANE OF PASSIVE VEHICLE

RETURN VIA \text{ SURET}

\[ VACT_2 \rightarrow \]

\[ VACT_1 \rightarrow \]
CSI/A

CLEAR S32.IP1
SET S32.IP2

CLEAR S32.IP3A
SET S32.IP3B

LOOPT1 = D
CSIALRM = D

CLEAR CSI. NEWTON ITERATION COUNTER
CLEAR ALARM INDICATOR

START OF SECOND SEARCH
IN OPPOSITE DIRECTION
(FROM SH1)

CSI/B

FIRST GUESS AT MAGNITUDE OF TOTAL VELOCITY
REQUIRED AFTER CSI
(VELOCITY REQUIRED TO ACHIEVE A RADIUS
EQUAL TO TPA IN 1/8 ORBIT FROM CSI POINT)

\[ \sqrt{\frac{2}{(\tau_1/\tau_3)} + 1} \]

RTMU"R = \frac{2}{\sqrt{\frac{1}{\text{RAC1}^2_1} + 1} \text{RAC1}_1}

\[ \text{MPAC}_1 = \text{UNIT} \left( u \times \text{RAC1} \right) \]

\[ b_1 = \text{UNIT} \left( u \times \text{RAC1} \right) \]

\[ V_1 = \sqrt{\frac{2}{(\tau_1/\tau_3)} + 1} \tau_1 - (\tau_1 \cdot b_1) \]

\[ \Delta V_1 = 10 \text{ cm/sec} \]

DELVCR = INITST

NEWTON RAPSON
ITERATION LOOP
(FROM SH17 15.13)

CSI/B1

INCREMENT ITERATION COUNTER

LOOPT1 = LOOPT1 + 1

INDEX TO ALARM CODE TABLE. #5 REFER TO ALARM
CODE .00405 # OF ITERATIONS EXCEEDS LOOP MAXIMUM

NO

TO NEXT PAGE

\[ \text{NO SOLUTION AFTER 15 ITERATIONS} \]
ALARM CONDITIONS THAT CAUSE ENTRY OF SCONSOL ARE:
1. NO SOLUTION AFTER 15 ITERATIONS
2. $V_1 > 1000$ ft/sec and 2 SUCCESSIVE ITERATIONS
   $t_s < t_e$
   $h_p < 55$ NM OR 35,000 FT
   $h_s < 55$ NM OR 35,000 FT
   $\Delta t_e < 10$ MIN
   $\Delta t_s < 10$ MIN

STORE ALARM FROM FIRST SEARCH TO BE DISPLAYED IF SCONSOL IS ENTERED FROM THE SECOND SEARCH

SCONSOL

**S32.1F3A**

**SET**?

**YES**($S3 = 0$ OR $S$)

**NO**($S3 = 0$)

**S32.1F3B**

**SET**?

**YES**($S3 = 1$)

**ALMVT**

**SH 21**

**CSILRM** ← $X2$

**MPAC** ← ZEROVGS

**VH DO NOT EXCEED MAXIMUM VALUE**

**CLEAR S32.1F1**

**GO FIRST PASS**

**SET S32.1F1**

**S2 = 0**

**START SEARCH IN OPPOSITE DIRECTION**

**CLEAR S32.1F3A**

**CLEAR S32.1F3B**

**LOOP CT → 0**

**CLEAR ITERATION COUNTER**

**CS1/0**

**SH 10**

**LOOP TO START SEARCH IN OPPOSITE DIRECTION**
ALMIXITA

CSIALRM ←→ X2

ALMIXIT

00000 IF CSIALRM = 1
00001 = 2 PERCENT ALTITUDE AFTER CS1 LESS THAN 35NM (EARTH) OR 35,000FT (MOON)
00002 = 3 PERCENT ALTITUDE AFTER CS2 LESS THAN 35NM (EARTH) OR 35,000FT (MOON)
00003 = 4 TIME FROM CST TO COM LESS THAN 10 MIN
00004 = 5 TIME FROM COM TO TPE LESS THAN 10 MIN
00005 = 6 NO SOLUTION AFTER 16 ITERATIONS
00006 = 7 REQUIRED NP AT OST GREATER THAN 1000 FPS ON 2 SUCCESSIVE ITERATIONS

VARALARM

TURN ON ALARM LIGHT AND STORE ALARM CODE FOR DISPLAY

GOFLASH

VOSNOB DISPLAY ALARM CODE

PROCEED

TERMINATE

RECYCLE YNPE

RETURN TO BEGINNING OF PROGRAM TO CHANGE INPUT PARAMETERS

RETURN TO BEGINNING OF PROGRAM TO CHANGE INPUT PARAMETERS

GOPOOM
Routine computes time to go to ignition (TT0GO)

Enable CLOKTask

CLOKTask continues running once each second to update TT0GO for V1G48E display

GROUP 6.3
Set up restarts to schedule CLOKTask as a task in 1 sec.

GROUP 4
Set up restarts to schedule the next location as a job with priority

RETURN VIA RTRN

P3X or P7X

IF P3X RETURN TO NEXT LOC.
IF P7X RETURN TO NEXT LOC + 1

NO P7X

BIT 6 = 0 ?

P3X YES

Q ← Q + 1

RETURN

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ROUTINE COMPUTES TIME TO GO TO IGNITION (TTOGO)

ENABLE CLOKTASK

CLOKTASK CONTINUES RUNNING ONCE EACH SECOND TO UPDATE TTOGO FOR VIGN45 DISPLAY

GROUP 6.3
SET UP RESTARTS TO SCHEDULE CLOKTASK AS A TASK IN 1 sec.

GROUP 4
SET UP RESTARTS TO SCHEDULE THE NEXT LOCATION AS A JOB WITH PRIORITY.

RETURN VIA RTRN

P3XOR7X
IF P3X RETURN TO NEXT LOC.
IF P7X RETURN TO NEXT LOC + 1.
NO
P7X
YES
P3X

BIT 6 = 0
Q ← Q + 1

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### P32 - Coelliptic Sequence Initiation

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<td>M &amp; TABLE</td>
<td>$\mu_e$ GRAVITATIONAL CONSTANT OF EARTH</td>
<td>$3.986023 \times 10^{10}$</td>
<td>M$^3$/CSFC$^2$</td>
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<td>$\sqrt{\mu_e}$</td>
<td>$0.5008752 \times 10^{-5}$</td>
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<td>$\frac{1}{\sqrt{\mu_m}}$</td>
<td>$0.45162595 \times 10^{-4}$</td>
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MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

P32 AND P72 COELLIPTIC SEQUENCE INITIATION

COLOSSUS II

FC-2626

SHEET 25 OF 25
SET ITSWM

\( \Delta t_s \) INITIALIZE RELATIVE TPI TIME (INPUT TO S33/S34.1)

INPUT: RACT3, VACT3, RPAS53, VPA553, ELEV, NOMTPI, ITSWM

OUTPUT: NOMTPI = \( \Delta t_s \) FROM INITIALLY ASSUMED TPI TIME

TO COMPUTED TPI TIME

MPAC = 0 IF THERE IS A SOLUTION
NO IF THERE IS NO SOLUTION

MPAC = 0

NO (NO SOLUTION)

YES (SOLUTION)

ALARM

TURN ON ALARM
LIGHT AND STORE
ALARM CODE 411
FOR DISPLAY

G0FLASH

VOSNOS DISPLAY ALARM CODE

PROCEED

NOMTPI = 0

GOTO P002

P31/P30

FINALSFLS

SET P

NO

ALLOW P2O

UPDATING

P31/P30

\[ t_s = t_3 + \Delta t_s \]

TPI TIME = TPI TIME CALCULATED BY P20
+ \( \Delta t_s \) REQUIRED TO ACHIEVE THE
REQUIRED ELEVATION ANGLE

TO NEXT PAGE
**Cos of the Transfer Angle (θ) from the Passive Vehicle to the Active Vehicle**

\[
\cos \theta = \frac{\gamma_p - \gamma_e}{\gamma_p + \gamma_e}
\]

**Sine of the Transfer Angle (θ) from the Passive Vehicle to the Active Vehicle**

\[
\sin \theta = \text{SGN} \left[ \left( 1 - \frac{\gamma_p}{\gamma_e} \right) \sqrt{1 - \cos^2 \theta} \right]
\]

\[
\text{SGN}(\cdot) = \begin{cases} 1 & \text{if positive} \\ 0 & \text{if zero} \\ -1 & \text{if negative} \end{cases}
\]

**X1 = RTX1**

\[
V_{ve} = \gamma_e
\]

**Clear RVSW**

**Calculate State Vector during Timethet Routine**

- Input: CSTM, SNTH, VVEC, RVEXT, RVEEX, RVSW, X1
- Output: MPAC, YPVE, VVEC, RVEXT, RVSW

**Timethet**

- Plan Passive Vehicle to Radial Position at Active Vehicle Position at Time
- FC-2310

\[
\text{TD}_{op} = \text{MTAC}
\]

\[
V_p = \gamma_e - \gamma_e - \gamma_e
\]

**Vertical Velocity of Passive Vehicle at Radial Position of Active Vehicle at CDH**

\[
\text{DO}_{op} = \text{MPAC} \cdot \text{UNIT}(\gamma_e)
\]

\[
\text{ED}_{op} = \text{RACF} \cdot \gamma_e
\]

**Difference in Altitude Between Passive Vehicle and Active Vehicle at Radial Position of Active Vehicle at CDH (DOp is from Timethet, it was saved before writing Vp)**

\[
\text{DO}_{op} = \frac{\text{RACF}}{\text{RI}_{op}} \cdot \text{DIFFALT}_{op}
\]

\[
\text{DO}_{op} = \frac{\text{RI}_{op} \cdot \text{DIFFALT}_{op}}{\text{RI}_{op}}
\]

**Required Semi-Major Axis of Active Vehicle Orbit at CDH**

\[
\text{AD}_{op} = \frac{\text{RI}_{op} \cdot \text{DIFFALT}_{op}}{\text{RI}_{op}}
\]

**To Next Page**
### MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

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P34

CSM ACTIVE VEHICLE

AVFLAGA
CLEAR AVFLAG
SET EOSTEP=4
FO-2426

P34/P44A

P20FLGON
SET
UPDATFLG
TRACKFLG
FC-2626

NEXT SHEET

P4

LEM IS ACTIVE VEHICLE

AVFLAGP
SET AVFLAG
FO-2426

ALLOW P20 UPDATING,
ENABLE TRACKING

MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN: A.C. WILLIAMS  DATED: 9/13/73
PREPARED: O.W. BROWN  CHECKED: G.R. COLLINS
ANALYST: J.R. HARDY  DESIGNED: R.J. MCCONNELL
CHECKED: J.J. HUMPHREYS  DRAFTED: M.R. STINSON
APPROVED: John A. How  REV: 1
FROM PRECEDING SHEET

R4 = TIME OF TPI IGNITION
R2 = TTPD = (00XX, -HRG)
R3 = 00XX, -MIN
OXX, XX - SEC

E - ELEV, ANGLE BETWEEN CSM/LEM LINE OF SIGHT AND LOCAL HORIZONTAL PLANE OF ACTIVE VEHICLE REFERENCED TO THE DIRECTION OF FLIGHT.
CENTANG = ORBITAL CENTRAL ANGLE OF PASSIVE VEHICLE DURING TRANSFER FROM TPI TO TIME OF INTERCEPT.
R1 = NN = NUMBER OF OFFSETS
R2 = ELEV = ELEVATION ANGLE IN DEGREES
R3 = CENTANG = ORBITAL CENTRAL ANGLE OF THE PASSIVE VEHICLE DURING TRANSFER FROM TPI IGNITION TO TIME OF INTERCEPT.

INDICATES TPI TIME SUPPLIED FOR P34.

TTPD = INPUT TPI TIME

INDICATES ELEV ANGLE IS SUPPLIED FOR P34

SELECTMNU
SELECT PROPERnie ACCORDING TO SPHERE OF INFLUENCE ON ACTIVE VEHICLE

R1 = TRIMKCPNT = NO. OF MARKS SINCE LAST MAKEUP OR INITIATION OF P20
R2 = T TO GO = TIME TILL TPI MANEUVER
R3 + MGA = MIDDLE GIMBAL ANGLE AT THRUSTING ATTITUDE

ITERATE FOR TIG WHEN SET

IF ETPIFLAG CLEAR, TIG IS INPUT AND ITERATION TO COMPUTE TIG FROM AN INPUT E-ANGLE IS UNNECESSARY

P34, P74 TRANSFER PHASE
INITIATION TARGETING
FROM PRECEDING SHEET

INTLOOP

TDEC1 = TTPI + NONTP10.

NOMTP1 = COMPUTED AT FROM S33/341
0 FIRST PASS.

INPUT: TDEC1, LM AND CSM STATE VECTORS
OUTPUT: RACT, YACT, RPASS, VPASS

INPUT: RACT, YACT, RPASS, VPASS, TTPI,
NOMTP1, ELEV, SWITCH
OUTPUT: ELEV OR NOMTP1

CLEAR SWITCH

IF SWCHCLR

E COMputation
FOR TPI NOT
REQUIRED

CPU

DISPLAY Alarm 0061
NO TIG FOR GIVEN
ELEV ANGLE

PROCEED

SWITCH SET

ITERATION COMPLETE,
DISPLAY RESULT

DISPLAY E

DISPLAY E AND CENTANG

R1=BLANK
R2=ELEV -XXX.XX DEG.- ELEVATION ANGLE
R3=CENTANG -XXX.XX DEG.- ORBITAL CENTRAL ANGLE
OF THE PASSIVE VEHICLE
DURING TRANSFER
FROM TPI TO TIME OF
INTERCEPT.

P34/P74D

WNPOOH

V5653 DISPLAY TPI
TIME

SH10

PROCEED

P34/P74E

SET PUSHLIST TO ZERO

X10 = RTXI0
O0 = CENTANG0
CSTH0 = COS(CENTANG0)
SNTH0 = SIN(CENTANG0)
RVEC0 = RPASS0 V
VVEC0 = VPASS0 V

SET RVSW

DO NOT COMPUTE FINAL STATE VECTOR IN TIME-THETA.
(ONLY TIME IS TO BE OUTPUT OF TIMETHETA ROUTINE)

NEXT SHEET
INPUT: \( \vec{R}_V, \vec{V}_V, \vec{S}_T, \vec{S}_V, \vec{C}_{103} (CENTANG) \)

OUTPUT: \( T_0 \) = TIME FOR THE PASSIVE VEHICLE TO TRAVERSE THE ANGLE (CENTANG) BETWEEN THE TPI AND INTERCEPT POINTS.

FOR INIT VEL

\( T_0 = \) TIME FROM TPI TO INTERCEPT TIME

INPUT: \( \vec{R}_{PA}, \vec{V}_{PA}, \vec{R}_{TIP}, \vec{V}_{TIP} \), UNRM, RACT, VACT

OUTPUT: RTAR, VPA, DELVLC, DELVEET, VPRIME

\( VPRIME = \) VELOCITY AT TARGET AFTER RENDEZVOUS MANEUVER

\( VIPRIME = \) VELOCITY REQUIRED TO EFFECT RENDEZVOUS

INPUT: OD (POSITION VECTOR OF ACTIVE VEH)

OUTPUT: MPAC (VELOCITY VECTOR OF ACTIVE VEH)

\( POSTTPI = H_p = \) PERIGEE ALTITUDE DISPLAYED TO INSURE ACTIVE VEHICLE IS A SAFE DISTANCE FROM EARTH.

\( R_1 = POSTTPI = \) PERIGEE ALTITUDE

\( R_2 = DELVLC = \Delta V_{tip} = \) REQUIRED VELOCITY FOR TPI MANEUVER

\( R_3 = DELVLC = \Delta V_{tip} = \) REQUIRED VELOCITY FOR FINAL INTERCEPT MANEUVER

INPUT: \( \vec{V}_{O}, \vec{V}_{N}, \vec{S}_B, \) DISPLAY PARAMETERS

\( SH = 10 \)

\( S34/35.5 \)

DISPLAY \( \Delta V \) COMPONENTS FOR ASTRONAUT APPROVAL IN LOCAL VERT. COORDS

\( SH = 16 \)

\( R_1 = TRIMCNT = \) NO. OF MARKS MADE SINCE THE LAST THRUSTING MANEUVER OR INITIATION OF \( P_20 \)

\( R_2 = TT090 = \) TIME TO OR FROM TPI

\( R_3 = MGA = \) MIDDLE GIMBAL ANGLE
COMPUTES ONE OF TWO QUANTITIES: 1. ELEVATION ANGLE \( \theta \) BETWEEN CSM/LM LINE OF SIGHT AND LOCAL HORIZONTAL OF THE ACTIVE VEHICLE, OR 2. THE TIME CORRECTION \( \Delta t \) TO THE TPI TIME AT WHICH THE ELEVATION ANGLE \( \theta \) IS ATTAINED.

INPUT: RACT, VACT, VPASS, RPASS, TTP, NMT, ITP, ELEV

OUTPUT: ELEV OR NMT (\( \Delta t \))

\[ \text{TITER} \leftarrow 40000 \]
\[ \text{SEGM} \leftarrow \text{MAX} \times \text{SEGM} \]
\[ \text{RAT} \leftarrow \text{RAT3} \]
\[ \text{VAP} \leftarrow \text{VACT3} \]
\[ \text{PPR} \leftarrow \text{RPA33} \]
\[ \text{VPP} \leftarrow \text{VPASS3} \]

\[ \text{ELC} \leftarrow \text{CALC} \]

\[ \text{CALCULATES THE UNIT LOS VECTOR AND THE UNIT NORMAL VECTOR TO THE LOS VECTOR} \]

\[ \text{ULOS} \leftarrow \text{UNIT} (\text{RPA33} - \text{RAT3}) \]

\[ \text{VL} \leftarrow \text{UNIT} (\text{RAT} \times \text{VACT}) \]

\[ \text{UNRM} \leftarrow \text{UNIT} (\text{RAT3} \times \text{VACT3}) \]

\[ \text{RETURN VIA} \]
\[ \text{QPRET} \]

\[ \text{OO} \leftarrow \text{ULOS} \times \text{VL} \]
\[ \text{OO} \leftarrow \text{UNRM} \times \text{VL} \]

\[ \text{OO} \leftarrow \text{ULOS} - (\text{ULOS} \times \text{OO}) \times \text{OO} \]

\[ \text{COMPUTED ELEVATION ANGLE} \]

\[ \theta \leftarrow \text{COS}^{-1} \left( \frac{\text{VL} \cdot \text{ULOS} \cdot \text{SGN}(\text{VL} \cdot \text{ULOS})}{\text{OO} \cdot \text{OO} - \text{ULOS} \cdot \text{ULOS} \cdot \text{SGN}(\text{OO})} \right) \]

\[ \text{OO} \leftarrow \text{COS} \left( \frac{\text{ULOS} \cdot \text{VAP} \cdot \text{SGN}(\text{OO})}{\text{OO} \cdot \text{OO} - \text{ULOS} \cdot \text{ULOS} \cdot \text{SGN}(\text{OO})} \right) \]

\[ \text{OO} \leftarrow \text{COS} \left( \frac{\text{ULOS} \cdot \text{VAP} \cdot \text{SGN}(\text{OO})}{\text{OO} \cdot \text{OO} - \text{ULOS} \cdot \text{ULOS} \cdot \text{SGN}(\text{OO})} \right) \]
MAKE $E_A > 180^\circ$ WHEN THE LOG LIES BELOW THE HORIZONTAL PLANE.

COMPUTING ELEVATION ANGLE THIS PASS

ITERATE FOR TPI TIME

$\Delta E = E_A - E_D$

$DELEL = DELEL_0 = 0$

ITERATION IS SUCCESSFUL, AN ACCEPTABLE $E_A$ AND THE CORRESPONDING TPI TIME HAS BEEN COMPUTED

RETURN VIA NORMEX

DECREDMENT COUNTER

TOO MANY ITERATIONS $MPAC \neq 0$ WHICH WILL SIGNAL ALARM CALL IN MAIN PROGRAM

$\gamma = \frac{E_A}{E_D}$

$\gamma = \frac{E_A}{R_A}$

$\gamma = \frac{E_A}{R_P}$

$\gamma = \frac{E_A}{R_P - E_A}$

OPHALF = $\frac{1}{2}$ REV

$O_D = \text{UNIT} (R \times \text{PASS3}_y)$

$6D_y = \text{UNIT} (R \times \text{ACT3}_y)$

$12D_w / \text{PASS3}_y$

$14D_w / \text{ACT3}_y$

$30D_w = 120 - 140$

$16D_w = \text{OPHALF}_D = E_D$

$\text{TP1}_D = \text{TP1}_P + \text{NOM}_P$

$\text{TP1}_D = \text{TP1}_P$

$\text{MPAC}_D = \text{DELEL}_0$

$\text{TPI TIME SUPPLIED FOR P34_74}$

$ELEV = \text{COMPUTED ELEV ANGLE, } E_A$

$\text{TP1FLAG}$

$\text{SET}$

$\text{ELEV} = \text{MPAC}_D$

$\text{ELEV} = \text{ZEROVEC}_D$

$\text{INDICATES A TIP IN}$
THE ELEVATION ANGLE \( E \) IS INCONSISTENT WITH THE RELATIVE ALTITUDES OF THE TWO VEHICLES: RETURN AND DISPLAY ALARM 00611.

\[ 2BD = \frac{-\cos(16D_0)14D_0}{12D_0} \]

USED LATER IN CALCULATION OF \( \Delta t \)

\[ -\cos(16D_0) = \cos E \]

THE LOS FROM THE ACTIVE VEHICLE DOES NOT INTERSECT THE CIRCULAR ORBIT WITH RADIUS EQUAL TO THAT OF PASSIVE VEHICLE: RETURN AND DISPLAY ALARM 00611.

\[ \omega_A = \frac{\text{UNIT}(u_1 x T_A) \cdot v_1}{16D_0} \]

\[ \omega_p = \frac{\text{UNIT}(r_p x v_p) \cdot x T_A}{16D_0} \]

\[ 16D_0 = \omega_A - \omega_p \]

\[ 16D_0 - 16D_0 = \text{MPAC}_0 \]

\[ 16D_0 = \omega_A - \omega_p \]

\[ 16D_0 = \left( \frac{r_A \times p}{16D_0 \times v_p} \right) \cdot 11 \]

\[ 16D_0 = \text{MPAC}_0 \]

\[ \text{MPAC} = \text{SGN} \left( r_A \times p \right) \cdot \cos \left( r_A \times p / r_A \right) \]

\[ \text{MPAC}_0 = \text{SGN} \left( 16D_0 \cdot \cos \left( 6D_0 \times v_p \right) \right) \]

\[ \Delta \tau = \text{MPAC} + E - \text{MPAC}_0 \]

\[ \Delta t = \frac{\left( 16D_0 \cdot \cos^{-1} \left( r_A \cos E / r_p \right) \right) \cdot \text{SGN} \left( r_p - r_A \right) + \left( -\tau \right)}{16D_0 \cdot \left( \text{MPAC}_0 \cdot \cos^{-1} \left( 16D_0 \right) \right)} \cdot \text{SGN} \left( 16D_0 \cdot \cos^{-1} \left( 16D_0 \right) \right) \cdot \text{TWCP} \]

\[ 2\pi \text{ CANCELS REV. UNITS SO THAT THE UNITS OF THE FINAL EXPRESSION WILL BE CSEC.} \]

NEXT SHEET

---

**P34, P74 TRANSFER PHASE INITIATION TARGETING**

**COLLOSUS II A FC-2630**
FROM PRECEDING SHEET

If $\Delta t > 250$ sec, reduce $\Delta t$ to 250 sec to help assure convergence in quest of TPI time.

1. NO
2. YES

TITER > 0 ?

FIRST PASS

TITER = $3777\Delta t$

LOAD $\Delta t$

$\Delta t = \Delta t \cdot \text{sgn} (\Delta t)$

$\Delta t = \text{sgn} (\Delta t)$

SOLUTION POINT HAS BEEN BYPASSED. REVERSE DIRECTION OF ITERATION BY $1/2$ OF CALCULATED STEP SIZE.

REVERS

REDUCING SECMAX HELPS PREVENT AN OSCILLATION DURING ITERATION

1. NO
2. YES

PROCEEDING IN WRONG DIRECTION

REVERSE DIRECTION OF ITERATION BY SUBTRACTING 1.5$\Delta t$ FROM NONTP1

LOAD $\Delta t$

$\Delta t = \text{sgn} (\Delta t)$

NO

STOP DELT

$\Delta t = \Delta t$

DELTEE0 = $\Delta t$

AD TIME

$\Sigma \Delta t = \Sigma \Delta t + \Delta t$

LOAD ACTIVE VEHICLE STATE VECTOR FOR GHOST ROUTINE

14. VAPREC

MPAC = RAPREC

NEXT SHEET

NOMTP1 = $\Sigma \Delta t / \Delta t$ = DIFFERENCE BETWEEN INPUTTED TPI TIME AND COMPUTED TPI TIME

$\Sigma \Delta t = t - t_c$ WHERE: $t_c$ IS INPUT TIME

$\Delta t$ IS COMPUTED TPI TIME

$\Sigma \Delta t$ IS COMPUTED TPI TIME

PS4, PS4 TRANSFER PHASE INITIATION TARGETING
FROM PRECEDING SHEET

GO INT

UPDATE ACTIVE VEHICLE TO TIME NONMPL VIA CONIC INTEGRATION

ACTIVE, RACT,v, RATT,v, VACT,v, VATT,v

FOC-2641

STORE UPDATED ACTIVE VEHICLE STATE VECTOR VALUES

GO INT

UPDATE PASSIVE VEHICLE TO TIME NONMPL VIA CONIC INTEGRATION

PASSIVE, RPASS,v, RATT,v, VPASS,v, VATT,v

FOC-2641

STORE UPDATED PASSIVE VEHICLE STATE VECTOR VALUES

EL CALC

RECYLE FOR NEXT ITERATION

VNPOON

SOLVE RETURN IN RTRN

RTRN = Q

SAVE RETURN IN RTRN

VERB NOUN -> A

STORE REQUESTED VERB/NOUN TO BE USED ON DISK

SAVE CALLER'S FRANK IN LOC TRASES

A -> VERB NOUN

VN BANK

KEY IN NEW PARAMETERS

GO FLASH

DISPLAY REQUESTED VERB/NOUN

TERMINATE

R1 R2 R3 DEPENDS ON REQUEST

PROCEED

GOTOPOON

RESTORE CALLING ROUTINE FRANK FROM TRASES

RETURN VIA RTRN
ADVANCES PASSIVE VEHICLE TO INTERCEPT TIME AND CALCULATES VELOCITY REQUIRED FOR ACTIVE TO ACHIEVE INTERCEPT POINT.

INPUT: VPASS3, RPASS3, INTIME, TPA554, UNRM, RACT3, VACT3

OUTPUT: RTARG, VPASS4, OELVLC

PREPARE VAC AREA WITH INPUTS FOR INTEGRATION ROUTINE INDICATES CONIC INTEGRATION IF NN IS ZERO, USE CONIC INTEGRATION OTHERWISE USE PRECISION

INPUT: O0(VPASS3), O0(RPASS3), 120(INTIME), 340(TPA554), 160(ZEROVECS OR TW0PI)

OUTPUT: VATT, MPAC(RATT)

POSITION VECTOR OF PASSIVE VEHICLE AT INTERCEPT TIME VELOCITY VECTOR OF PASSIVE VEHICLE AT INTERCEPT TIME

RTARG, MPAC, VPASS4, VATT

O0, UNIT(RTARG), 6D, UNIT(RACT3)

G0 = x, x, y
6D = O0 X 6D, UNRM

MPAC = UNIT(RACT3)

\[ \theta = \cos^{-1}\left(\frac{\mathbf{r} \cdot \mathbf{f}}{r f}\right) \]
\[ \frac{\mathbf{r} \cdot \mathbf{f}}{r f} = \cos^{-1}\left(\frac{\mathbf{MPAC} \cdot \mathbf{O0}}{\mathbf{MPAC} \cdot \mathbf{UNRM}}\right) \]

\[ \theta > 0 \] NO

\[ \theta = \theta + 2\pi \]
\[ \mathbf{MPAC} \rightarrow \mathbf{MPAC} + \mathbf{DPOSMAX} \]

MAKE \( \theta \) POSITIVE IN THIRD OR FOURTH QUADRANT

\[ \theta = 0 \]

OELT4 = TIME FROM TPI TO TPF, NN INDICATES NUMBER OF LOOPS IN LAMBERT/INTEGRAL ITERATION PROCESS

NPIE

ACTCENT = \( \theta \)

OELT4 = TIME FROM TPI TO TPF, NN INDICATES NUMBER OF LOOPS IN LAMBERT/INTEGRAL ITERATION PROCESS

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

P34, P74 TRANSFER PHASE INITIATION TARGETING

COLOSSUS III P34  P74

NOV 1

APPROVED 11/20
INPUT: \( \Delta V \) IN LOCAL VERTICAL COORDINATES

RETURN VIA SUBEXIT

INITVEL

COMPUTE MANEUVER PARAMETERS

INPUT: RINIT, VINIT, ATARG, DELTA, INTIME

\( \Delta x \) : OF MERTONS OF LAMBERT ANGLE TO ECLIPSE

\( \Delta y \) : EARTH - SO LUNAR, \( \Delta z \) : (0 EARTH, 2 LUNAR)

OUTPUT: \( \Delta V \) (OFFSET TARGET POSITION VECTOR), VPRIM (VELOCITY REQUIRED FROM TPI POINT FOR ACTIVE VEHICLE TO ACHIEVE TPF POINT), VTPRIM (ACTIVE VEHICLE VELOCITY AFTER TPF POINT), DELVEET (\( \Delta V \) FOR TPI MANEUVER)

INITVEL COMPUTES THE REQUIRED MANEUVER AND DELTA VELOCITIES TO TRANSFER THE ACTIVE VEHICLE FROM ITS INITIAL POSITION (TPI) TO TARGET POSITION (TPF) IN A PRESCRIBE TIME OF FLIGHT.

DELVLVC, (OD, \( \Delta V \), DELVEET, \( \Delta V \))

COMPUTES MATRIX TO CONVERT \( \Delta V \) FROM REFERENCE TO LOCAL VERTICAL COORDINATES

INPUT: UNRM, PACT, OUTPUT: TRANSFORMATION MATRIX IN OD, \( \Delta V \)
CALCULATES NEW TARGET VECTOR IF \( \Delta V \) OVERWRITE AND LINE OF SIGHT \( \Delta Y \)

**Input:** DELVLVC, VACT3, RACT3, TIG, TPASS4, UNRM, ULOS
**Output:** DVLOS, RTARG

**Input:** UNRM, RACT3
**Output:** TRANSFORMATION MATRIX IN ODM

PUSH LIST COUNTER IS 18 UPON RETURN FROM LOMAT
DELVECT3 \( = \Delta Y_{\text{TPF}} \) IN REFERENCE COORDS.
DELVLVC \( = \text{NEW} \Delta Y_{\text{TPF}} \) INPUTTED BY ASTRONAUT OVERWRITE.

SET UP VAC AREA FOR INTEGRATION ROUTINE
INDICATES PRECISION INTEGRATION

**Input:** SEE PREVIOUS BOX
**Output:** RATT

NEW OFFSET TARGET VECTOR

\[
\begin{align*}
\mathbf{R} & = \left[ \begin{array}{c}
\mathbf{U}_{\text{LOS}} \\
\mathbf{U}_{\text{LOS}} \\
\mathbf{U}_{\text{LOS}} \\
\mathbf{U}_{\text{LOS}} \\
\mathbf{U}_{\text{LOS}}
\end{array} \right] \\
\mathbf{d} & = \mathbf{R} \cdot \mathbf{d}_{\text{LOS}} \\
\mathbf{d}_{\text{LOS}} & = \text{UNIT} \times \mathbf{U}_{\text{LOS}}
\end{align*}
\]

This matrix is used to convert \( \Delta V \) from reference coordinates to line of sight coordinates.

**Line of Sight Delta Velocity**

RETURN
ROUTINE TO PREPARE USER FOR CONIC OR PRECISION INTEGRATION.
INPUT: VELOCITY VECTOR IN PUSH LIST, MPACV;
POSITION VECTOR
OUTPUT: UPDATED STATE VECTOR IN RATTv, VATTv

STORE POSITION VECTOR
SET TET TO ZERO
TIME INCREMENT FOR INTEGRATION
DO CONIC INTEGRATION

G0INT

RTRN

INT

INSTALL

TEST FOR
AVAILABILITY
OF INTEGRATION
FC: 2230

CLEAR
INTYPFLG

MPAC = LAST ITEM IN VAC AREA

MPAC = 0

SET

INTYPFLG

INDICATES CONIC INTEGRATION IS TO BE USED.

LAST ITEM IN PUSH LIST IF SET INDICATES CONIC INTEGRATION SHOULD BE USED.

MPAC = 0

PUSHLISTD

TOECD

SET

MOONFLG

INDICATES SPHERE OF INFLUENCE IS LUNAR

X2 = RTX2

CMOONFLG = 0 MEANS PERMANENT CSM STATE VECTOR IS IN THE LUNAR SPHERE

CMOONFLG = SET

INDICATES SPHERE OF INFLUENCE IS EARTH.

NEXT SHEET

SET = 0 IF EARTH CENTERED ORBIT
SET = 2 IF MOON CENTERED ORBIT

CMOONFLG = SET

INDICATES SPHERE OF INFLUENCE IS EARTH.

CMOONFLG = SET

INDICATES SPHERE OF INFLUENCE IS EARTH.

CMOONFLG = SET

INDICATES SPHERE OF INFLUENCE IS EARTH.
FROM PRECEDING SHEET

**ALLSET**

- **TE** → MPCA

- **RCV** → PUSHLIST
- **VCP** → PUSHLIST

**INTEGRVS**

UPDATE INDICATED VEHICLE TO
**TDEC = 90**

**MPAC** → RATT

RETURN VIA RTRN

**TIME OF STATE VECTOR**

PRESENT POSITION IN LAST PUSHLIST AREA USED
PRESENT VELOCITY IN NEXT TO LAST PUSHLIST AREA USED

**INPUT**: RCV, VCV, TDIC1, TET
**OUTPUT**: VAT, MPAC (RATT)

**POSITION AT TDIC1**

**LOMAT**

\[
\begin{align*}
Z &= \text{UNIT(D)} \\
\text{UNIT(D)} &= \text{UNIT(D)} \\
\text{UNIT(D)RATC} &= \text{UNIT(D)RATC} \\
\text{UNIT(D)RATC} &= \text{UNIT(D)RATC}
\end{align*}
\]

- **SET**
- **PUSHLIST** TO 16D

RETURN VIA QPRET

**DISPLAYE**

**NORMEX** → Q

- **ENTER**
- **NEW DATA**

**GOFLASH**

**V50N55**
**DISPLAY E**
AND CENTANG

**RETURN VIA**
**NORMEX**

**R1 - NN** XXXXX - NUMBER OF OFFSETS
**R2 - ELEV** - XXX.X DEG - ELEV. ANGLE
**R3 - CENTANG** - XXX.XX DEG - ORBITAL CENTRAL ANGLE OF THE PASSIVE VEHICLE DURING TRANSFER FROM TPI TO TIME OF INTERCEPT

**TERMINATE**

**PROCEED**

**GOTOPOOH**
FROM PRECEDING SHEET

ARE6 ← V06N99

VNP00H
DISPLAY ΔV
IN LOS
COORDINATES
SHIG

R1 - R2 - R3 -
DVLOS, = XXXX.X FT/SEC
ΔVX (LOS) ΔYY (LOS) ΔVZ (LOS)

PROCEED

RETURN VIA SUBEXIT
## P34 Transfer Phase Initiation (TPI)

### Subroutines

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### Other Charts

- AVFLAGA: Clear AVFLAG, set ECSTEER = 1, set UPDATFLG and TRACKFLG
- AVFLAGP: SET AVFLAG
- TIMEHET: Calculates delta time of flight
- INTEGHS: Update vehicle to specified time
- COMPTGO: Computes time to or from maneuver time
- LEMPRECS: Updates LEM to specified time via integration
- CSMPREC: Updates CSM to specified time via integration
- PRECLS: Executes precision update of both vehicles
- INITVEL: Computes required maneuver and delta velocities
- PHA1P01: Calculates perigee altitude to active vehicle
- V1645: Displays M, TFLMA
- P20FLGON: SETS TRACKFLG, UPDATFLG

### Flags

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<tr>
<td>FINAFLG</td>
<td>SET: Last pass thru rendezvous program computations</td>
<td>SH16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLEARED: Interim pass thru rendezvous program computations</td>
<td>SH15</td>
<td></td>
<td></td>
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<tr>
<td>UPDATFLG</td>
<td>SET: Updating via marks allowed</td>
<td>SH15</td>
<td></td>
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</tr>
<tr>
<td>CLEARED: Updating via marks disabled</td>
<td>SH15</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>AVFLAG</td>
<td>SET: LM active vehicle</td>
<td>SH15</td>
<td></td>
<td></td>
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<tr>
<td>CLEARED: CSM active vehicle</td>
<td>SH15</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>XDELVFLG</td>
<td>SET: Use external AV computation for maneuver velocity</td>
<td>SH15</td>
<td></td>
<td></td>
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<tr>
<td>CLEARED: Use Lambert computation to determine maneuver velocity</td>
<td>SH15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRACKFLG</td>
<td>SET: Tracking allowed</td>
<td>SH15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLEARED: Tracking disabled</td>
<td>SH15</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
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### Alarms

<table>
<thead>
<tr>
<th>Alarm</th>
<th>Meaning</th>
<th>Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>00611</td>
<td>No time of ignition for given elev. angle</td>
<td>SH3</td>
</tr>
</tbody>
</table>
| Variable | Description                                                                 | Units  
|----------|-----------------------------------------------------------------------------|--------
<p>| TTP1     | Time of TPI maneuver                                                       | Centiseconds |
| TIG      | Ignition time of maneuver                                                  | Centiseconds |
| ELEV     | Desired LOS angle at TPI                                                  | Revolutions |
| NN       | Number of integration offsets: 0 = conic, 2 = precision                   | Centiseconds |
| NONTPI   | Delta time between assigned and computed TPI time                         | Centiseconds |
| TDECI    | Input time to integration                                                  | M/CSC |
| DELEETS3 | Delta for TPI maneuver                                                    | Revolutions |
| CENTANG  | Angle traversed by passive vehicle from TPI to TPF                        | Revolutions |
| GTHI     | Cos of centangle                                                          | Revolutions |
| SNTH     | Sin of centangle                                                          | Revolutions |
| RVEC     | State vector position value                                               | Meters |
| RPASS3   | Passive vehicle position vector at TPI time                               | Meters |
| VPASS3   | Passive vehicle velocity vector at TPI time                               | M/CSC |
| VVEC     | State vector velocity value                                               | M/CSC |
| INTIME   | Input time to INTVEL routine                                              | Centiseconds |
| T        | Time from TPI to TPF                                                      | Centiseconds |
| TPASS4   | Rendezvous time                                                           | M/CSC |
| DELATPI  | Magnitude of delta at TPI                                                  | M/CSC |
| DELATPF  | Magnitude of delta at TPF                                                  | M/CSC |
| RPASS4   | Passive vehicle position vector at TPF time                               | Meters |
| VPASS4   | Passive vehicle velocity vector at TPF time                               | M/CSC |
| VTPTME   | Velocity at target after maneuver                                         | M/CSC |
| VTPRME   | Maneuver velocity required                                                | Meters |
| RTARG    | Offset target position vector                                             | Meters |
| RTXI     | Shift counter, -2 for Earth orbit, -10 for Lunar orbit                    | Revolutions |
| RTX2     | Shift counter, 0 for Earth orbit, 2 for Lunar orbit                       | Revolutions |
| +MGA     | Middle gimbal angle                                                       | Centiseconds |
| TTOGO    | Time to ignition                                                          | Centiseconds |
| TRKMKCNT | No. of optics marks incorporated since last maneuver                       | Revolutions |
| TITER    | Iteration counter for 533/341                                            | B14 |
| SECMAX   | Delta upper limit for current iteration                                   | Meters |
| HACT3/BINIT | Position vector of active vehicle at TPI                                  | Meters |
| VACT3/VINIT | Velocity vector of active vehicle at TPI                                  | Meters |
| LOS      | Unit line of sight vector                                                 | Meters |
| UNRM     | Unit normal vector to active vehicle's plane                              | Revolutions |
| DEEL     | Difference between desired and computed elevation angle                   | Revolutions |
| DEEL0    | Temp. storage for Deel                                                    | Centiseconds |
| DELTELO  | Current iteration's value of delta                                        | Centiseconds |
| RAPREC   | Position vector of active at TPI temp. storage                            | Meters |
| VAPREC   | Velocity vector of active at TPI temp. storage                            | Meters |
| RIPREC   | Position vector of passive at TPI temp. storage                           | Meters |
| VIPREC   | Velocity vector of passive at TPI temp. storage                           | Meters |
| ATT      | Position vector after integration update                                   | Revolutions |
| RAT      | Velocity vector after integration update                                   | Revolutions |
| ACTCSENT | Central angle traversed by active from TPI to TPF                         | Revolutions |
| TET      | Time input to integration routine                                         | Centiseconds |
| AVG      | Present velocity input to integration routine                            | M/CSC |
| BCV      | Present position input to integration routine                             | Meters |</p>
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<tr>
<th>VERB- NOUN</th>
<th>TYPE OF DISPLAYS</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
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<tr>
<td>V06N37</td>
<td>FLASHING</td>
<td>R1 - TTPID, 0000, HRS., 0000, MIN., 0000, SEC</td>
<td>TIME OF TPI IGNITION</td>
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<tr>
<td>V06N55</td>
<td>FLASHING</td>
<td>R1 - NN NUMBER OF OFFSETS, 0 = CONIC, 2 = PRECISION</td>
<td>ELEVATION ANGLE</td>
</tr>
<tr>
<td>V06N58</td>
<td>FLASHING</td>
<td>R1 - POSTTPI, XXX, A, NUT, ML, PERIGEE ALTITUDE</td>
<td>DELTA V REQUIRED FOR TPI MANEUVER</td>
</tr>
<tr>
<td>V06N81</td>
<td>FLASHING</td>
<td>R1 - DELVLVC, XXX, 0 FT/SEC DELTA V REQUIRED FOR TPI MANEUVER</td>
<td>DELTA V REQUIRED FOR TPI MANEUVER IN LOCAL VERTICAL COORDINATES</td>
</tr>
<tr>
<td>V06N59</td>
<td>FLASHING</td>
<td>R1 - DVLOS, XXX, 0 FT/SEC DELTA V REQUIRED FOR TPI MANEUVER</td>
<td>DELTA V REQUIRED FOR TPI MANEUVER IN LINE OF SIGHT COORDINATES</td>
</tr>
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</table>
LOAD VEHICLE & OPTION (ACTIVE/PASSIVE) CODE

MPAC → OPTIONX

ENTER NEW OPTION CODE IF LM ACTIVE

GOFLASH

VO412
DISPLAY VEHICLE OPTION CODES IN R1, R2

PROCED

OPTIONX+1 → OPTIONX

Save option code

R36A

DSPLMXYD → T1G

Initial time

GOFLASH

VO416N
Request time for which Y, Y, Y desired

Terminate

ENDEXT

Proceed

MPACD → DSPLMXYD

Is DSPLMXYD = 0 ?

Yes, load present time

ENTTIM2

LOADTIME

Load present time into MPACD

FC-2100

ASTROTIM

TDECI → MPACD

Store time in csec $2^{28}$

PRELIMINARY
FROM PRECEDING SHEET

R36INT

MPAC ← OPTIONY + 1 × 2⁻¹

OPTIONY CONTAINS OPTIONX +1
(option code)

CSM ACTIVE

OPTIONY + 1

NO (1)

THISPREC

PRECISION UPDATE CSM TO TDECI
PC-2230

LM ACTIVE

YES (2)

P36PROG2

OTHERPRE

PRECISION UPDATE LM TO TDECI
PC-2230

UPDATE PASSIVE VEHICLE

INPUT: EVENT TIG IN CSM @ 2³⁶
OUTPUT: RATT, VATT IN M, M(CSM)
@ 2⁹, 2⁷ RESPECTIVELY

STORE PASSIVE VEHICLE PARAMETERS
FROM PRECISION INTEGRATION

R36PROG3

R4PASSG4 → RATT
OD ← UNIT(VATT)
UNP36 ← UNIT[\sqrt{\mu} \times UNIT(\mu)]
TDECI ← TAT
MPAC ← OPTIONX × 2⁻¹

CSM

NO (1)

OPTIONY > 1

YES (2)

P36PROG4

THISPREC

PRECISION UPDATE CSM TO TDECI
PC-2230

UPDATE ACTIVE VEHICLE
(inputs outputs same as above)

OTHERPRE

PRECISION UPDATE LM TO TDECI
PC-2230

PRELIMINARY
$\psi = \cos^{-1}\left(\frac{V_{ax} - V_{ah}}{V_{ah} \cdot V_{ah}}\right)$

$\theta = \arccos\left(\frac{V_{ax} \cdot V_{ah} + V_{ay} \cdot V_{ay} + V_{az} \cdot V_{az}}{V_{ax} \cdot V_{ax} + V_{ay} \cdot V_{ay} + V_{az} \cdot V_{az}}\right)$

UNIT HORIZONTAL OF ACTIVE VEHICLE CROSSED INTO LOS PROTECTION ON HORIZONTAL;
RESULT COMPARED WITH VERTICAL FOR SENSE (PARALLEL UP MEANS PASSIVE VEHICLE IS LEFT OF ACTIVE VEHICLE PLANE; FORWARD HORIZONTAL.)

SIGN MPAC + $\psi$

IF $\psi$, SUBTRACT FROM 360° TO GIVE POS ANGLE.

R3GTC2

MPAC $\rightarrow$ 360

RETRIEVE EVENT TIME

SIGNAGREE

FORCE SIGN AGREEMENT TP

FC-1200

DISPMAX $\rightarrow$ MPACD

GOFLASH

VoG&SO3 DISPLAY Y, Y, $\psi$

PROCEED

RECYCLE FOR NEW EVENT TIME

R3GTP3 SH 3

INDEX

PRELIMINARY
### Subroutines

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<th>Where</th>
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<td><code>LQAOB</code> PRESENT TIME INTO MPAC</td>
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<tr>
<td>THSPREC</td>
<td><code>ENKE</code> UPDATE OF CSM</td>
<td>SH 4</td>
</tr>
<tr>
<td>OTHPREC</td>
<td><code>ENKE</code> UPDATE OF LM</td>
<td>SH 4</td>
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<tr>
<td>SGNAAGREL</td>
<td><code>FORCE SIGN AGREEMENT (TRIPLE PRECISION)</code></td>
<td>SH 6</td>
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<tr>
<td>TESTXACT</td>
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<td>SH 2</td>
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### Displays

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<tbody>
<tr>
<td>VO4N12</td>
<td>DISPLAY VEHICLE CODE (1 = LM, 2 = CSM) IN R1 AND OPTION CODE (1 = THIS VEHICLE ACTIVE, 2 = PASSIVE) IN R2</td>
<td>SH 3</td>
</tr>
<tr>
<td>VO4N16N</td>
<td>REQUEST TIME FOR WHICH (Y, \dot{Y}, \dot{\phi}) DESIRED</td>
<td>SH 3</td>
</tr>
<tr>
<td>VO4N19N</td>
<td>DISPLAY (Y, \dot{Y}, \dot{\phi})</td>
<td>SH 6</td>
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### Erasables

<table>
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<th>Subroutine</th>
<th>Description</th>
<th>Units</th>
<th>Scaling</th>
</tr>
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<tbody>
<tr>
<td>OPTIONX</td>
<td>VEHICLE OPTION CODE (LM = 1, CSM = 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPTIONX +1</td>
<td>(EQUALS OPTIONY) VEHICLE CODE (1 = CSM ACTIVE, 2 = LM ACTIVE)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSPTEMX</td>
<td>DISPLAY BUFFER AREA (SAME AS OPTIONX)</td>
<td>CSEC</td>
<td>(2^{28})</td>
</tr>
<tr>
<td>TDEC1</td>
<td>TIME STORAGE LOS</td>
<td></td>
<td>(2^{25})</td>
</tr>
<tr>
<td>RPAS36</td>
<td>STORAGE FOR PASSIVE VEHICLE POSITION VECTOR</td>
<td>METERS</td>
<td></td>
</tr>
<tr>
<td>UNP36</td>
<td>UNIT VECTOR OF PASSIVE VEHICLE MOMENTUM/PLANE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RANGE</td>
<td>(Y, ) ACTIVE VEHICLE DISTANCE FROM PASSIVE VEHICLE PLANE</td>
<td>METERS</td>
<td></td>
</tr>
<tr>
<td>RRATE</td>
<td>(Y, ) ACTIVE VEHICLE VELOCITY COMPONENT NORMAL TO PASSIVE PLANE</td>
<td>M/CSEC</td>
<td></td>
</tr>
<tr>
<td>RTHETA</td>
<td>(\phi,) ANGLE BETWEEN ACTIVE VEHICLE UNIT FORWARD HORIZONTAL &amp; LOS PROJECTED INTO HORIZONTAL PLANE</td>
<td></td>
<td></td>
</tr>
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</table>

---

**PRELIMINARY**
FROM PREVIOUS SHEET

INPUT: $R_{PASS}$, $V_{PASS}$, $INTIME$, $TPASS$
OUTPUT: $RTARG$, $V_{PASS}$, $DELVLVC$

INPUT: $DELVLVC$
OUTPUT: $DELVSN$

R1 = TRKMCNT = NO. MARKS MADE SINCE THE LAST THRUSTING MANEUVER OR INITIATION OF P.20
R2 = TTOGO = TIME TO OR FROM TIG
R3 = T MGA = MIDDLE GIMBAL ANGLE

TERMINATE

DISPLAY $\theta$, $M_{TIG}$ AND MGA

PROCEED/ENTER

P34/PTCB
SH 1
P35 TRANSFER PHASE MIDCOURSE

ON OTHER CHARTS

- AVFLAGA: CLEAR AVFLAG, SETS ECSTEER = 1
- AVFLAGP: SETS AVFLAG
- LOADTIME: SETS MPA/C TO PRESENT TIME
- SELECTMU: SELECT MU VALUE ACCORDING TO LUNAR OR EARTH SPHERE OF INFLUENCE
- PRECSET: EXECUTES PRECISION UPDATE OF BOTH VEHICLES
- 534/35:1: COMPUTES LOS AND UNIT NORMAL VECTORS
- 534/35:2: UPDATES PASSIVE VEHICLE TO INTERCEPT TIME
- 534/35:5: DISPLAY GV COMPONENTS
- VN1645: DISPLAY M1, TFI AND MGA
- P20FLOON: SET UDATFLG, TRACHFLG

FLAGS

- AVFLAG
- TRACKFLG
- FINALFLG
- UDATFLG
- AVFLAG

DISPLAYS

- R1-TRKMCNT-XXXX: NO OF MARKS
- V16N45: RR-TTOGO-XXX MIN.-SEC.-TIME TO/ FROM TIG
- R3-MGA-XXX: DEG. MIDDLE GIMBAL ANGLE

ALARMS

NONE

ERASABLES

- KT: TIME DELAY STORAGE
- TSTRT: PRESENT TIME STORAGE
- TIG: TIME OF MANEUVER
- ATIGINC: PAD LOADED TIME DELAY FOR P35
- PTIGINC: PAD LOADED TIME DELAY FOR P75
- INTIME: INPUT TIME TO INTVEL
- TDEC1: INPUT TIME TO INTEGRATION

UNITS

- CENTISECS
- 2

SCALING

- 2
- 1
- 8
- 2
- 2
COMMON TARGETING SUBROUTINES

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

INITVEL Sh. 4
HAVEGUES Sh. 4
VECSHIFT Sh. 10
SHIFTR1 Sh. 10
GET+MGA Sh. 11
GET. LVC Sh. 12
PERIAPO Sh. 13
PERIAPO1 Sh. 13
SELECTMU Sh. 14
PRECSET Sh. 15
LEMSTORE Sh. 15
CSMSTORE Sh. 15
GIVEN THE INITIAL TIME t₀, THE INITIAL POSITION X₀(t₀), THE FINAL POSITION X₁(t₁) AND THE CORRESPONDING TRANSFER TIME t₂, THIS SUBROUTINE CALCULATES THE FOLLOWING VECTORS:

1) THE INITIAL VELOCITY VECTOR X₀'(t₀) WHICH WILL TAKE ONE IN A PRECISION INTEGRATION FROM X₀(t₀) TO X₁(t₀), AND
2) THE FINAL POSITION VECTOR X₁(t₁) WHICH ONE WOULD ARRIVE AT IF ONE USED THE ABOVE INITIAL VELOCITY VECTOR X₀'(t₀) AND UPDATED USING ONLY A CONIC CALCULATION. THIS VECTOR IS REFERRED TO AS THE OFFSET TARGET VECTOR.

INITVEL IS CALLED BY:
\( \text{P1F \ OR \ P11} \), \( \text{CALLIVEL} \), S44.1, MANUPARM
HAVEGUES IS CALLED BY:
S44.9.

INPUT:
1) \( \text{INITv} = X₀(t₀) \), INITIAL POSITION VECTOR, IN METERS, AT \( t₀ \).
2) \( \text{VINITv} = X₀'(t₀) \), INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT \( t₀ \). IT IS USED TO DETERMINE WHETHER THE TRANSFER ANGLE FROM THE INITIAL POSITION VECTOR TO THE TARGET VECTOR IS LESS THAN OR GREATER THAN 180°. IT IS ALSO USED TO SPECIFY THE TRANSFER PLANE. IF ONLY IF THE TARGET VECTOR LIES WITHIN THE CONE.
3) \( \text{RTARGv} = X₁(t₁) \), THE TARGET VECTOR, IN METERS, AT \( t₁ \). IF \( N₁ = 0 \) IT IS THE TRUE TARGET VECTOR. IF \( N₁ = 1 \) IT IS THE OFFSET TARGET VECTOR.
4) \( \text{DELTt} = t₂ \), DESIRED TRANSFER TIME FROM \( X₀(t₀) \) TO \( X₁(t₁) \), IN CSEC, AT \( t₀ \).
5) \( \text{INTIME} = t₁ \), THE TIME OF VALIDITY OF \( X₁(t₁) \), IN CSEC, AT \( t₀ \).
6) \( \text{PLS} = N₁ \), THE NUMBER OF OFFSETS TO BE USED IN CALCULATING THE OFFSET TARGET VECTOR. IT IS ALSO EQUAL TO THE NUMBER OF ITERATIONS MINUS 1. \( N₁ \neq 0 \) IMPLIES A SINGLE CONIC CALCULATION BUT NO INTEGRATION OR OFFSET CALCULATION. IN THIS CASE \( \text{RTARGv} \) IS ASSUMED TO BE THE OFFSET VECTOR.
7) \( \text{PL2} = \theta \), THE CONE ANGLE OF A CONE MEASURED ABOUT \( X₀(t₀) \), IN REVOLUTIONS, AT \( t₀ \).
8) \( \text{GUESSW} = F₁ \), A FLAG, IS CLEAR IF AN INITIAL GUESS OF \( \cot \gamma \) IS TO BE INPUT TO LAMBERT, IS SET IF \( \cot \gamma \) IS NOT INPUT BUT MUST BE CALCULATED BY LAMBERT.
9) \( \text{COTA} = \cot \gamma \), THE INITIAL GUESS OF \( \cot \gamma \) IF \( F₁ \) IS CLEAR.
10) \( \text{B2BFLAG} = F₂ \), A FLAG, IS CLEAR IF EARTH IS CENTRAL BODY AND SUBROUTINE SHOULD CALCULATE WITH NOMINAL SCALING. IT IS SET IF MOON IS CENTRAL BODY AND \( \text{OFF} = \) NOMINAL SCALING IS REQUIRED.
11) \( \text{XI} = \) INDEX REGISTER CONTAINING VALUE USED BY LAMBERT TO SET UP PROPER TABLE, IS -2 FOR EARTH, 15-102 FOR MOON.
12) \( \text{AVEFLAG} = F₃ \), IF SET \( \text{ITERCTR} \) IS SET EQUAL TO 1, IF CLEAR \( \text{ITERCTR} \) IS SET EQUAL TO 200.
13) \( \text{PUSH LIST POINTER} = \) AT THE GENERAL VALUE \( P₁ \), WHERE \( \phi \leq \phi \leq 360° \).

OUTPUT:
1) \( \text{VPRIME} = Y₁(t₁) \), THE VELOCITY REQUIRED AT TIME \( t₁ \) IN ORDER TO REACH \( X₁(t₁) \) IN A PRECISION MANNER IN TIME INTERVAL \( t₂ \), IN METERS/CSEC, AT \( t₀ \). THIS IS THE FINAL VELOCITY OUTPUT FROM LAMBERT AND IS THE VELOCITY USED IN THE VELOCITY-TO-BE-GAINED EQUATIONS.
2) \( \text{RTARGv} = X₁(t₁) \), THE COMPUTED OFFSET TARGET VECTOR, IN METERS, AT \( t₂ \).
3) \( \text{VPRIMEv} = Y₁'(t₁) \), THE FINAL PRECISION VELOCITY VECTOR RESULTING FROM A PRECISION UPDATE OF THE INITIAL POSITION VECTOR \( X₀(t₀) \) AND THE REQUIRED INITIAL VELOCITY VECTOR \( X₀'(t₀) \) IF \( N₁ = 0 \). IT IS THE FINAL CONIC VELOCITY VECTOR RESULTING FROM A CONIC UPDATE OF \( X₀(t₀) \) AND \( Y₁(t₁) \) IN METERS/CSEC AT \( t₀ \).
4) \( \text{DELVEET} = \Delta Y \), THE VELOCITY TO BE GAINED, IN METERS/CSEC, AT \( t₀ \).
5) \( \text{RATTW} = Y₁'(t₁) \), THE POSITION VECTOR RESULTING FROM A PRECISION INTEGRATION FROM \( X₀(t₀) \) USING \( Y₁(t₁) \) AS THE INITIAL VELOCITY, IN METERS, AT \( t₂ \).
6) \( \text{COTA} = \cot \gamma \), COTANGENT OF FLIGHT PATH ANGLE OF THE VECTORS \( Y₁(t₁) \) AND \( Y₁'(t₁) \) MEASURED FROM THE VERTICAL, AT \( t₂ \).
7) \( \text{NORMSW} = N₂ \), A FLAG, IF CLEAR IF \( \text{RTARGv} \) LIES OUTSIDE OF THE CONE, IS SET IF \( \text{RTARGv} \) LIES INSIDE THE CONE.
8) \( \text{ITERCTR} = \) ITERATION COUNT USED IN LAMBERT.
9) \( \text{PUSH LIST POINTER} = \) AT \( \phi \).
FROM PRECEDING SHEET

\[ \begin{align*}
\phi_d &= |zvec| \\
2d_v &= mpac_v - r2vec_v \\
\text{both scaled at } 2^{1/2} \end{align*} \]

\[ e(t_1) = \{e(t_1) \cdot e\}_{\text{MPAC}} \]

\[ e(t_1) \text{ is the vector projection of } e(t_1) \text{ on to } e. \]

\[ \text{FORM } e(t_1) - e(t_2) \]

\[ \text{FORM THE COMPONENT OF } e(t_2) \text{ ORTHOGONAL TO } e. \]

\[ e(t_3) = r(t_1) \cdot (e(t_1) - e(t_2))_{\text{UNIT}} \]

\[ r2vec_v = \phi_d \cdot mpac_v \]

\[ \text{scaled by } 2^{1/2} \]

\[ \text{SINCE } e(t_4) \text{ IS INITIALLY SET EQUAL TO } e(t_1), \text{ THIS OPERATION (PERFORMED ON THE FIRST PASS ONLY) IS EQUIVALENT TO ROTATING } e(t_2) \text{ IN THE SAME MANNER AS } e(t_3) \text{ WAS ROTATED.} \]

\[ s_0 = d \left( e(t_4) \cdot \left\{ e(t_4) \times e(t_1) \right\} \right) \]

\[ \text{GEOMSIGN} = \text{SIGN}(r2vec_v \cdot \text{UNIT}(r2vec_v)) \]

\[ e(t_4) = e(t_3) \]

\[ \text{ITNTVEL ASSUMES THAT IN THE CALCULATION OF } s_0 \text{ THE PLANE CHANGE IS NEVER MORE THAN } 90^\circ. \]
LAMBERT INPUT:
1) RIVECv = \( \mathbf{c}(t_i) \), THE INITIAL POSITION VECTOR.
2) R2VECv = \( \mathbf{c}(t_s) \), INTERMEDIATE VALUE OF THE OFFSET VECTOR.
3) TDESIRED = \( t_s \), DESIRED TRANSFER TIME.
4) GEOMSGN = S>0, A FLAG, IF POSITIVE \( \theta < 180^\circ \), IF NEGATIVE \( \theta > 180^\circ \).
5) VTARGTAG = N>0, A FLAG, IF NON-ZERO \( \mathbf{v}_x(t_i) \) IS NOT Calculated.
6) GUESSW = f_3, A FLAG, IF SET \( \gamma \) IS NOT INPUT.
7) GOGA = \( \cot \gamma \), AN INITIAL GUESS IF \( f_1 \) IS CLEAR.
8) NORMSW = f_2, A FLAG, IF CLEAR \( \gamma \) IS CLEAR.
9) UNV = f_3, UNIT VECTOR, NORMAL TO \( \mathbf{c}(t_i) \) AND \( \mathbf{y}(t_i) \).
10) X1 = INDEX REGISTER CONTAINING VALUE TO SELECT \( \mathbf{c}(t_i) \).

LAMBERT OUTPUT:
1) \( \mathbf{v}_x(t_i) \), VELOCITY REQUIRED AT TIME \( t_i \) IN ORDER TO ARRIVE AT THE OFFSET POSITION \( \mathbf{c}(t_s) \) IN A CONIC MANNER AT TIME \( t_s \).
2) \( \mathbf{v}_{\text{TARGET}} = \mathbf{v}_x(t_i) \), VELOCITY AT THE OFFSET POSITION. IF \( N_1 = 0 \) THIS VALUE IS CALCULATED BY LAMBERT AND USED. IF \( N_1 \neq 0 \) THIS VALUE IS NOT CALCULATED BY LAMBERT AND THE VALUE SUBSEQUENTLY USED IS THE OUTPUT OF INTEGRV.
3) \( \mathbf{v}_x \), VALUE CONVERGED TO BY LAMBERT.
4) SOLNSW = f_3, A FLAG, IF CLEAR THE SOLUTION IS VALID.

\( f_1 \) IS CLEARd BECAUSE A VALUE OF \( \cot \gamma \) IS AVAILABLE NOW AS AN INITIAL GUESS TO LAMBERT ON THE NEXT PASS THRU THE LOOP.

STORE THE VELOCITY \( \mathbf{v}(t_i) \) IN ITS OUTPUT LOCATION. FOLLOWING THE LAST PASS THRU THE LOOP THIS VALUE WILL BE USED IN THE VELOCITY-TO-BE-GAINED EQUATION.
FROM PRECEDING SHEET

CLEAR MOONFLAG EARTH IS CENTRAL BODY.

INITVELS
RCV = RVEC, RINIT
VCV = VPRIME V
TET = INTIME

TDEC1 = THE TIME TO INTEGRATE TO, AND IS REQUIRED BY INTEGRVS.
IS CLEARED TO INDICATE TO INTEGRVS THAT PRECISION INTEGRATION BY THE ENCKE METHOD IS DESIRED, NOT CONIC INTEGRATION.

INTEGRVS INPUT:
1) RCV = X(t1), INITIAL POSITION VECTOR
2) VCV = Y(t1), VELOCITY VECTOR THAT IS OUTPUT FROM THE LAMBERT SUBROUTINE.
3) TET = t1, TIME OF VALIDITY OF STATE VECTOR.
4) TDEC1 = t2, TIME TO INTEGRATE TO.

INTEGRVS OUTPUT:
1) RATT1 = X(t2)
2) VATT1 = Y(t2), THE TARGET STATE VECTOR RESULTING FROM A PRECISION INTEGRATION.
SAVE THE INTERMEDIATE VALUE OF \( t(t_2) \).

INCREMENT THE ITERATION COUNTER.

N2 = N1 + 1

HAVE ITERATED A TOTAL OF N1+1 TIMES, USING N1 OFFSETS, NOW PREPARE TO EXIT.

CONTINUE ITERATING

\[ e(t_2) = e(t_1) - \left( e_1(t_2) - e_2(t_2) \right) \]
R2VEC = R2VEC - (RATT1 - RTARG1)
SCALED AT 2^{4/2}.

COMPUTE A NEW INTERMEDIATE VALUE OF THE OFFSET TARGET VECTOR \( e(t_2) \), WHERE \( e_1(t_2) \) IS AN INTERMEDIATE VALUE RESULTING FROM A PRECISION INTEGRATION AND \( e_2(t_2) \) IS THE TRUE TARGET VECTOR.

GO BACK TO THE BEGINNING OF THE LOOP.

COMMON TARGETING SUBROUTINE
INITVEL, MIDGIM
PBCAT, PERTIAO, SELEGPMV, PREDSET
COLOSSUS 2D FC-2611

3. kann 
7. kann
WOULD COME HERE DIRECTLY IF \( N_1 = \phi \). IN THIS CASE RTARG_y STILL CONTAINS THE INPUT VALUE WHICH IS, FOR \( N_1 = \phi \), THE OFFSET VECTOR.

\[ \Delta v = \gamma(t) - \gamma(t_i) \]

\[ \Delta v = \gamma(t) - \gamma(t_i) \]

VPRIME_y, VTARGET_y

STORE \( \gamma(t) \), THE FINAL VALUE OF THE FINAL PRECISION VELOCITY VECTOR, IN ITS OUTPUT LOCATION.

FOR EARTH CENTERED SYSTEM OR NOMINAL MOON CENTERED SYSTEM.

SCALE RTARG_y AT \( 2^{15} \) AND VPRIME_y, VPRIME_y, DELVEET_y AT \( 2^x \).

COMMON TARGETING SUBROUTINES

INITVEL, MIDCMA

PERIPPO, SELECTMLI, PRECSET

COLOSSUS 2D FC-2641
THE FOLLOWING IS A GEOMETRICAL REPRESENTATION OF WHAT OCCURS WHEN THREE PASSES ARE MADE THROUGH THE MAIN LOOP IN INITVEI. IT USES 2 OFFSETS AND 3 ITERATIONS (N2 = 3). THE SUBSCRIPTS OF (1), (2) AND (3) FOLLOWING THE VARIABLES REFER TO THE ITERATION NUMBER.

\[ \vec{x}(t_1) \] is the given position vector, \( \dot{\vec{x}}(t_1) \) is the given velocity vector.

\[ \vec{e}_1(t_2) \] is the given target vector. For completeness and consistency in use of subscripts the target vector \( e_1(t_2) \) can be considered to be the zeroth offset vector \( \vec{e}(t_2) \).

**Iteration 1**

1. \( y_1(t_1) \) is calculated by Lambert using \( \vec{e}(t_1) \) from 1 and \( \vec{e}(t_2)(0) = \vec{e}(t_1) \) from 2.
2. \( \vec{e}_1(t_2)(1) \) is calculated by precision integration using \( \vec{e}(t_1) \) from 1 and \( y_1(t_1) \) from 3.
3. \( y_1(t_2)(1) \) is the offset vector resulting from subtracting the miss vector between \( \vec{e}(t_2)(0) \) from 1 and \( \vec{e}_1(t_2)(1) \) from 2 from the offset vector \( e(t_2) = \vec{e}(t_2) \) from 2.

**Iteration 2**

4. \( y_2(t_1)(1) \) is calculated by Lambert using \( \vec{e}(t_1) \) from 1 and \( \vec{e}(t_2)(1) \) from 3.
5. \( \vec{e}_1(t_2)(2) \) is calculated by precision integration using \( \vec{e}(t_1) \) from 1 and \( y_1(t_1) \) from 4.
6. \( y_2(t_2)(2) \) is the offset vector resulting from subtracting the miss vector between \( \vec{e}(t_2)(2) \) from 1 and \( \vec{e}_1(t_2)(2) \) from 2 from the offset vector \( e(t_2) = \vec{e}(t_2) \) from 2.

**Iteration 3**

7. \( y_3(t_1)(2) \) is calculated by Lambert using \( \vec{e}(t_1) \) from 1 and \( \vec{e}(t_2)(2) \) from 3.
8. \( \vec{e}_1(t_2)(3) \) is calculated by precision integration using \( \vec{e}(t_1) \) from 1 and \( y_2(t_1) \) from 6.
9. The routine now prepares to exit. It calculates the velocity-to-be-gained as the difference \( y_3(t_1)(2) - y(t_1) \).
10. There is no calculation of the offset vector \( e(t_2)(3) \) corresponding to \( \vec{e}_1(t_2)(3) \).
11. The final output vectors are:

   - \( y_1(t_2)(1) \) from 3
   - \( \vec{e}_1(t_2)(2) \) from 4
   - \( \vec{e}_1(t_2)(3) \) from 5
**PURPOSE:** Subroutine to scale input vectors to proper sphere of influence

**Input:** MPAC \_n = Input velocity vector

**Output:** MPAC \_n = Velocity vector

**Input:** PLOD \_n = Input position vector

**Output:** PLOD \_n = Position vector

**LOAD INDEX REGISTERS**

**SCALE INPUT VECTORS FOR PROPER SPHERE OF INFLUENCE**

**RETURN VIA Q**

---

**PURPOSE:** Subroutine to scale input double precision word to sphere value in index RTX2

**LOAD INDEX REGISTER**

**SCALE INPUT VALUE TO PROPER SPHERE OF INFLUENCE**

**RETURN VIA Q**
IF THE ACTIVE VEHICLE IS PERFORMING THIS COMPUTATION THIS ROUTINE COMPUTES THE POSITIVE MIDDLE GIMBAL ANGLE FOR THE ACTIVE VEHICLE, ACCORDING THE X-AXIS AND IS ALIGNED WITH THE AX IMPULSE THRUST DIRECTION. IF THE PASSIVE VEHICLE IS PERFORMING THIS COMPUTATION THIS ROUTINE TRANSFORMS THE INPUT VELOCITY VECTOR FROM INERTIAL COORDINATES TO LOCAL VERTICAL COORDINATES OF THE ACTIVE VEHICLE.

INPUT:
1) AVFLAG-A flag, is clear if CSM is active vehicle, is set if LM is active vehicle.
2) COMPUTER-A flag, is clear if LM is doing the computing, is set if CSM is doing the computing.
3) VINIT = \( \vec{V}_I \), RADIUS VECTOR OF ACTIVE VEHICLE, IN METERS, AT 27°.
4) VINIT = \( \vec{V}_I \), VELOCITY VECTOR OF ACTIVE VEHICLE, IN METERS/CSEC AT 27°.
5) ODV = \( \Delta \vec{V} \), DELTA VELOCITY VECTOR OF ACTIVE VEHICLE IN INERTIAL COORDINATES, IN METERS/CSEC, AT 27°.

OUTPUT:
MGLVFLAG = A FLAG, IS CLEAR IF MIDDLE GIMBAL ANGLE WAS COMPUTED, IS SET IF DELTA VELOCITY VECTOR TRANSFORMED.
2) +MGA = MIDDLE GIMBAL ANGLE, IN REVOLUTIONS IN RANGE 0 TO 1, AT 27°.
3) DELVLC = \( \Delta \vec{V} \), DELTA VELOCITY VECTOR OF ACTIVE VEHICLE IN LOCAL VERTICAL COORDINATES, IN METERS/CSEC, AT 27°.

COME HERE IF THE ACTIVE VEHICLE IS PERFORMING THIS COMPUTATION.

\[ \sin^{-1}\left(\Delta y_{\text{UNIT}} \cdot \mathbf{y}_{\text{SN}}\right) \]

\[ MPAC_1 = \sin^{-1}\left[\text{UNIT} \cdot \left(\text{UNIT} \cdot \text{GEFSMMAT} + 6\right)\right] \]

SCALED AT 2°

TEST SIGN OF ANGLE.

POSITIVE

\[ MPAC_2 = MPAC_1 + \text{HALFREV}_1 + \text{HALFREV}_2 \]

NEGATIVE

\[ +\text{MGA} = MPAC_2 \]

STORE MIDDLE GIMBAL ANGLE.

SCALED AT 2°

CLEAR MGLVFLAG

INDICATE MIDDLE GIMBAL ANGLE WAS COMPUTED.

RETURN VIA QPRET

\[ y_{\text{SN}} \] IS THE UNIT VECTOR IN DIRECTION OF THE Y STABLE MEMBER AXIS.

CONVERT A NEGATIVE ANGLE TO A CORRESPONDING POSITIVE ANGLE BY ADDING ONE REVOLUTION.

COMMON TARGETING SUBROUTINES

INITVL, INITPL
PERIAD, SELECT
CONTSS 20 10
COME HERE IF THE PASSIVE VEHICLE IS PERFORMING THIS CALCULATION.

GET_LVC

\[ \mathbf{u}_x = - \mathbf{e}_{\text{UNIT}} \]

ROW 3 OF MATRIX \( \mathbf{u}_{yz} \).

\[ 16v \leftarrow \text{MPAC}_v \rightleftharpoons \text{UNIT}(\text{RINIT}_v) \]

\[ \mathbf{u}_y = (-\mathbf{e} \times \mathbf{y}) \text{UNIT} \]

ROW 2 OF MATRIX \( \mathbf{u}_{zy} \). THIS IS EQUIVALENT TO \( (\mathbf{y} \times \mathbf{e}) \text{UNIT} \).

\[ 12v \leftarrow \text{MPAC}_v \rightleftharpoons \text{UNIT}(\text{MPAC}_v \times \text{VINIT}_v) \]

\[ \mathbf{u}_z = (\mathbf{u}_y \times \mathbf{u}_z) \text{UNIT} \]

ROW 1 OF MATRIX \( \mathbf{u}_{zy} \).

\[ 6v \leftarrow \text{UNIT}(\text{MPAC}_v \times 18\mathbf{d}_v) \]

\[ \Delta v_{uv} = \mathbf{u}_{zy} \Delta x \]

DELVLCV \( \leftarrow 6 \mathbf{d}_x \times \mathbf{d}_v \) SCALED AT 2°

INDICATES COORDINATE TRANSFORMATION OF \( \Delta x \) PERFORMED.

SET MLSVFLAG

RETURN VIA OPREX

COMMON TARGETING SUBROUTINES

INITVEL, MBOGIM
PERIAPO, SELECTHU, PRECSET
COLOSSUS 2D FC-2611
THIS ROUTINE SETS UP VALUES OF \( \mu \) AND \( \frac{1}{\sqrt{\mu}} \) APPROPRIATE FOR EITHER EARTH OR MOON AS PRIMARY BODY AND DEPENDS ON CONDITION OF CMOONFLG.

CALLED BY: P32, P33, P34, P35, P38, P39, P72, P73, P74, P75, P76, P79

INPUT:
1) CMOONFLG = PERMANENT CSM STATE FLAG, IS CLEAR FOR EARTH PRIMARY BODY, IS SET FOR MOON.

OUTPUT:
1) RTMU = \( \mu \), AT 2^{16}.
2) RTSRI/\mu = \frac{1}{\sqrt{\mu}}, AT 2^{31}/2^{14}.
3) RTX1 = PRIMARY BODY INDICATOR, IS 2 FOR EARTH, 10D FOR MOON.
4) RTX2 = SCALING FACTOR FOR NOMINAL/OFF-NOMINAL DATA, IS 0 FOR NOMINAL, IS 2 FOR OFF-NOMINAL.

\[ \frac{\mu}{\mu} = \frac{\frac{\mu}{\mu}}{\mu} \]

MPAC = MUTABLE + 6 SCALED AT 2^{16}

\[ \frac{\mu}{\mu} = \frac{\mu}{\mu} \]

MPAC = MUTABLE + 140 SCALED AT 2^{16}

\[ \frac{\mu}{\mu} = \frac{\mu}{\mu} \]

MPAC = MUTABLE + 80 SCALED AT 2^{30}

CMMONFLG = CLEAR

SHIFT MPAC TO SCALE \( \mu \) AT 2^{16}

STORE \( \mu \).

STORE INDEX REGISTER 2, THE SCALING FACTOR.

INTERIM PASS THROUGH RENDEZVOUS PROGRAM COMPUTATIONS.

GO TO VNI445

COMMON TARGETING SUBROUTINES
INITVEL, H104
PEPIAPL, SELECTMU, P1353
COLOSSUS 2D FC-2641

\[ \frac{\mu}{\mu} = \frac{\mu}{\mu} \]
This routine performs a precision update of the active and passive vehicles to a specified time.

Input:
1) $TDEC1 = \text{TDEC}_1, \text{time to integrate to } T0_1, \text{in csec at } T2_1$.

Output:
1) $\text{RACT}_3 = \mathbf{r}(T3)$, position vector of active vehicle at $T2_2$, in meters, at $T2_1$.
2) $\text{VACT}_3 = \mathbf{v}(T3)$, velocity vector of active vehicle at $T2_2$, in meters/csec, at $T2_1$.
3) $\text{RPASS}_3 = \mathbf{r}(T3)$, position vector of passive vehicle at $T2_3$, in meters, at $T2_1$.
4) $\text{VPASS}_3 = \mathbf{v}(T3)$, velocity vector of passive vehicle at $T2_3$, in meters/csec, at $T2_1$.

Set up $T2_1$ from temporary storage.

Common Targeting Subroutine:
- IHTVEL, MINCV
- MINV, PERTA, SELECT, PRESET
- COLOSSUS 2D FC-2641

L J. Ellis, 17 Nov 1974
### Subroutines Called on Other Charts

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### Flags Used

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<tr>
<td>HALFREV&lt;sub&gt;D&lt;/sub&gt;</td>
<td>0.5 REVOLUTIONS</td>
<td>2&lt;sup&gt;0&lt;/sup&gt;</td>
<td>1.0 B-1</td>
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<tr>
<td>EPSFOUR&lt;sub&gt;D&lt;/sub&gt;</td>
<td>15/360 REVOLUTIONS (EQUALS 15°)</td>
<td>2&lt;sup&gt;0&lt;/sup&gt;</td>
<td>0.04166666666</td>
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<td>RPAD&lt;sub&gt;D&lt;/sub&gt;</td>
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<td>3.986032 E10 B-36</td>
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<td>$1/\sqrt{\mu_E'}$ IN $\text{CSEC}/\text{M}^{3/2}$</td>
<td>2&lt;sup&gt;-17&lt;/sup&gt;</td>
<td>0.50087529 E-5 B17</td>
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<td>4.902778 E8 B-30</td>
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<td>MUTABLE + 14D&lt;sub&gt;D&lt;/sub&gt;</td>
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<td>2&lt;sup&gt;-14&lt;/sup&gt;</td>
<td>0.45122595 E-4 B14</td>
<td></td>
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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.
ENTRANCE FROM RTE390

VET100
CALLS: GAMDV10
XTILIM
DVACLC

INPUT:
1) R(T1) = MAGNITUDE OF INITIAL POSITION VECTOR IN METERS @ 2³
2) RCON = MAGNITUDE OF FINAL POSITION VECTOR IN METERS @ 2³
3) V(T1) = INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2³
4) PTDV0 = DELTA VELOCITY DESIRED IN METERS/CSEC @ 2³
5) URL/C = UNIT INITIAL POSITION VECTOR @ 2³
6) URL/C = UNIT HORIZONTAL VECTOR @ 2³
7) X(T2) = COT OF FINAL FLIGHT PATH ANGLE @ 2³
8) CPPA = COS OF INITIAL FLIGHT PATH ANGLE @ 2³
9) MMAXH (TEMPORARY LOWER) BOUND ON GAMDV IN METERS @ 2³
10) MMAXL (TEMPORARY UPPER) BOUND ON GAMDV IN METERS @ 2³
11) NNLX = CONIC ITERATION COUNTER. (NNLX < 0 IMPLIES THIS IS CONIC PHASE.)

OUTPUT:
1) VE(T1) = POST-IMPULSE INITIAL VELOCITY VECTOR IN METERS/CSEC @ 2³
2) DV = INITIAL DELTA V IN METERS/CSEC @ 2³
3) X(T1) = COTAN OF INITIAL FPA (POST-IMPULSE)@ 2³
4) ROCN = SEMI-LATUS Rectum IN METERS @ 2³
5) BETAL = 1 - X(T2)²
6) MPAC = 0, NORMAL EXIT
MPAC #0, ALARM CODE OCT 605 - EXCESSIVE ITERATIONS IN GAMDV10
7) ABORT EXIT TO POOG000: OCT 610

FROM PRECEDING SHEET
FROM PRECEDING SHEET

IS MPAC > D?

YES

RTE347

RVEC = R(T1) / V(T1)
RECON = RC0N / V(T1)

PUT RTS VARIABLES INTO LOCATIONS EXPECTED BY TIMEAR, THE CONIC SUBROUTINE CALLED BY TMRAID00.

INPUT: RVEC, INITIAL POSITION VECTOR IN METERS @ 2^13
VECC, INITIAL VELOCITY VECTOR IN METERS/SEC @ 2^14
RECON, RECONAL FINAL RAD, FOR WHICH TRANSFER TIME IS TO BE COMPUTED IN METERS @ 2^29
OUTPUT: R(T2)/FINAL POSITION VECTOR IN METERS @ 2^29
V(T2)/FINAL VELOCITY VECTOR IN METERS/SEC @ 2^29
T2/TRANSFER TIME TO FINAL RAD IN SEC @ 2^29

T2 = FINAL TIME

IS TAKE ASTRONAUT ENTRY ANGLE?

NO

COMPUTE FPA DESIRED (CENTER OF CORRIDOR)

USE ASTRONAUT'S ENTRY ANGLE

INPUT: X = |V(T2)|

POLY

COMPUTE D1 + 2X + 3X^2 + 4X^3

FC-7100

MPAC = 2^7 (RTE01 + MPAC)

NEXT SHEET
FROM PRECEDING SHEET

RTE350

PL16D ← DX(tz)
RCON = RCONL
PL16D ← MPAC
RCON ← PLO20

IS THERE OVERFLOW?

YES

PLORED = ORCON
(x(tz)err = x(tz)err)
IN THAT CASE X(tz), X(tz)ERR, AND X(tz)', ARE
NOT UPDATED

NO

RTE3680

SH5

x(tz) ← x(tz)err
x(tz) ← x(tz)
X(tz) ← DX(tz) + X(tz)
RREX ← X(tz)
RPRE ← X(tz)
X(tz) ← PL16D + X(tz)

SAVE LATEST FIGURES

RTE3600

SH5

P37 - RETURN TO EARTH
MAIN PROGRAM
INPUT: $v(t_1)/v_i$, $r(t_1)/r_i$, $v_2(t_1)/v(t_1)$, $u(t_1)/u_i$, $sprop$, $t_e$.
OUTPUT: Display
LATITUDE LONGITUDE AT 400,000 FT.
DELTA TIME TO 400,000 FT
$V_PREC$: MAGNITUDE OF VELOCITY AT 400,000 FT
$GAMMAP$: FLIGHT PATH ANGLE AT 400,000 FT
$DELTV$: IMPULSIVE DELTA V
ASTRONAUT MAY APPROVE THESE CALCULATIONS AND PROCEED, OR DISAPPROVE AND EITHER TERMINATE OR RECYCLE.

$RECON = \text{RADIUS OF CONIC TRAJECTORY.}$
$RCON$ IS CALCULATED IN IVCALC.

$\phi_2 = 1$ = SEMI LATUS RECTUM
$\beta_1 = 1 + x(t_2)^2$ CALCULATED IN VETO

$RCON > (\text{MON})/(\text{BETA})$ = ENTRY NEAR PERIGEE

$\phi_2 = 1$ = ENTRY NEAR APOGEE

(PRECISION INTEGRATION SUBROUTINE)

CALLS: RTEIN, RTE03, RTE04, RTE05, RTE06, RTE07, RTE08, RTE09, RTE10

INPUT:
1) $RCON = RCON$ = FINAL RAD. OF CONIC TRAJECTORY IN METERS @ 20
2) $R(t_1)/r_i = (t_1)$ = PRE-RETURN POS. VECTOR IN METERS @ 20
3) $V(t_1)/v_i = (t_1)$ = PRE-RETURN VELOCITY VECTOR IN M/S/CSEC @ 20
4) $t_1 = t_1$ = TIME OF PRE-RETURN STATE VECTOR IN CSEC @ 20
5) $T_2 = T_2$ = TRANSFER TIME TO THE FINAL POSITION TIME IN CSEC @ 20
6) $R(t_2)$ = MAGNITUDE OF $R(t_2)$ IN METERS @ 20
7) $X(t_2)$ = COTAN OF FINAL FLIGHT PATH ANGLE @ 20
8) $X(t_1)$ = COTAN OF INITIAL FLIGHT PATH ANGLE @ 20
9) $KTD$ = DELTA VELOCITY DESIRED IN M/S/CSEC @ 20
10) $MAMAX 1 = MA_1 = \text{MAJOR AXIS LIMIT ON LOWER BOUND OF}$
     $GAMMA ITERATOR IN METERS @ 20$
11) $MAMAX 2 = MA_2 = \text{MAJOR AXIS LIMIT ON UPPER BOUND OF}$
     $GAMMA ITERATOR IN METERS @ 20$
12) $URL = U_{L_2} = \text{UNIT PRE-RETURN POSITION VECTOR @ 20}$
13) $URL = U_{L_2} = \text{UNIT HORIZONTAL VECTOR @ 20}$
14) $BETA_1 = \beta_1 + x(t_2)^2$ @ 20
15) $\phi_2 = 1 = \text{PERIGEE OR APOGEE @ 20}$

$1 = \text{APOGEE} - 1 = \text{PERIGEE}$

OUTPUT:
1) $v_2(t_2)/v(t_2) = \text{POST IMPULSE INITIAL VELOCITY VECTOR}$
   IN M/S/CSEC @ 20
2) $R(t_2)/r_i = (t_2)$ = FINAL POSITION VECTOR IN METERS @ 20
3) $V(t_2)/v_i = (t_2)$ = FINAL VELOCITY VECTOR IN M/S/CSEC @ 20
4) $T_2 = t_2$ = FINAL TIME IN CSEC @ 20
5) $MPAC = 0$ FOR NORMAL EXIT
   $MPAC = 0$ FOR ALARM EXIT.

NEXT SHEET

(THIS OCCURS ONLY FOR NEARLY CIRCULAR ORBITS.)

P37 - RETURN TO EARTH
(MAIN PROGRAM)

A.C. WILLIAMS
4/19/70
F.C. 2642

[Signature]

[Date]
FROM PRECEDING SHEET

\[ T_{IG} = T_1 - C_T \Delta T_0 \]

\[ T_{IG} = T_1 - \frac{W_{o-2} \cdot C_{SUO} \cdot M_{MAC}}{E^{3-2D} \cdot X_1} \]

BIASED TIG

PSTOGOF

STORE \( Q_3 \) IN SPRTX

FLASH IS CONTINUED

RECYCLE

GOFLESH

VERDBG: NOUN33

DISPLAY BIASED TIG

PROCEED

GOTOPOOH

RETURN VIA SPRTX

\[ \begin{align*}
N33 & \quad \text{FL: 00XX, DEC = KPS} \\
R2 & \quad 00XX, DEC = \text{MIN} \\
R3 & \quad 0XX.XX, DEC = \text{SEC}
\end{align*} \]

CLEAR MARK COUNTERS (INITIALIZE FOR NEW USE OF RADAR)

NUMBER OF VHF MARKS INCORPORATED.

NUMBER OF RENDEZVOUS MARKS TAKEN.

RTENCK1: SETS INTYPFLG, MAKING THE INTEGRATION ROUTINE, INTEGRVS, DO CONIC INTEGRATION CLEARS MOONFLG, INDICATING EARTH SPHERE OF INFLUENCE LOADS THE INPUT INTO THE VARIABLES EXPECTED BY INTEGRVS, AND LOADS THE OUTPUT INTO VARIABLES EXPECTED BY PST.

INPUT: \( R(T_1), v(T_1), T_1, T_2 \)

OUTPUT: \( R(T_2), v(T_2), T_2 \)

\[ \begin{align*}
V(T_2) & = \text{VELOCITY VECTOR} \\
T_2 & = \text{TIME IN SEC O} \cdot \text{2} \text{.9} \\
X_1 & = \text{-CONIC X1 FOR PROPER A-TABLE VALUES}
\end{align*} \]

NEXT SHEET

P37 - RETURN TO EARTH

(MAIN PROGRAM)

A.C.WILLIAMS

COLOSSUS 2D

FC-2642
FROM PRECEDING SHEET

\[
\begin{align*}
K & = \text{UNIT} \left[ f(t) \right] = -\text{UNIT} \left[ f(t) \right] \cdot \left( \frac{u_{R} \cos 7.5^\circ + u_{W} \sin 7.5^\circ}{\text{MPAC}} \right) \\
\text{MPAC} & = \text{UNIT} \left( R(t) \right) \cdot \left( \frac{\cos 7.5^\circ \text{UR}_W + \sin 7.5^\circ \text{UR}_R}{\text{MCOS} 7.5^\circ \text{UR}_W + \text{MSIN} 7.5^\circ \text{UR}_R} \right)
\end{align*}
\]

MCOS 7.5° = 0.99144486 = MINUS COS 7.5°
MSIN 7.5° = -1.30680922 = MINUS SIN 7.5°

IS TARGET FOR LAMBERT STEERING
SUFFICIENTLY FAR (22.5°) FROM 180°
TO KEEP LAMBERT STEERING
FROM GUIDING SHIP OUT OF PLANE?

YES

IS PSEUDO-TARGET AFTER 180°?

NO

NEW TARGET NEEDED: OBTAIN PROPER INPUTS FOR
TIMETHET

NO

\[
\begin{align*}
\text{UN}_W \cdot R(t) \cdot \langle 0 \rangle \Rightarrow \text{P3TW}
\end{align*}
\]

P3TW

P3TV

\[
\begin{align*}
\text{SNTH} & = \sin(\text{THETA} 165) \\
\text{CSTH} & = \cos(\text{THETA} 165)
\end{align*}
\]

\[
\begin{align*}
\text{THETA} 165, 45, 33, 333 \text{ DEC} \\
165^\circ \text{ in REVS}
\end{align*}
\]

PUSH PSEUDO-TARGET BACK TO 165°

\[
\begin{align*}
\text{SNTH} & = \sin(\text{THETA} 210) \\
\text{CSTH} & = \cos(\text{THETA} 210)
\end{align*}
\]

\[
\begin{align*}
\text{THETA} 210, 33, 333, 333 \text{ DEC} \\
210^\circ \text{ in REVS}
\end{align*}
\]

PUSH PSEUDO-TARGET FORWARD TO 210°

\[
\begin{align*}
\text{SNTH} & = \sin(\theta) @ 2^\circ, \text{ WHERE } \theta \text{ IS THE TRUE ANOMALY DIFFERENCE.} \\
\text{CSTH} & = \cos(\theta) @ 2^\circ
\end{align*}
\]

CLEAR RVSW

RVSW IS CLEARED TO ALLOW TIMETHET TO COMPUTE: Z(t₂)
AND ¥(t₂).

\[
\begin{align*}
\text{RVEC}_x & = [t(t)], \text{ INITIAL POSITION VECTOR IN METERS @ } 2^\circ \\
\text{VVEC}_x & = [y(t)], \text{ INITIAL VELOCITY VECTOR IN METERS @ } 2^\circ
\end{align*}
\]

INPUTS TO TIMETHET:

\[
\begin{align*}
\text{RVEC}_x, \text{ VVEC}_x, \text{ XI}_x = -2, \text{ INDEX VALUE FOR A - TABLE;} \\
\text{SNTH}, \text{ CSTH}, \text{ RVSW, CLEARED.}
\end{align*}
\]

OUTPUTS: TIMETHET COMPUTES TRANSFER TIME GIVEN THE INITIAL STATE VECTOR, AND THE DESIRED TRUE ANOMALY DIFFERENCE, ε; AND, IN THIS CASE, THE FINAL STATE VECTOR, Z(t₂), AND ¥(t₂), FOR LAMBERT STEERING:

\[
\begin{align*}
\text{t}_2 & = \text{TRANSFER TIME IN CESG, @ 2^\circ} \\
\text{FLOO} & = [Z(t₂)] = \text{FINAL POSITION VECTOR IN METERS @ } 2^\circ \\
\text{MPAC} & = [¥(t₂)] = \text{FINAL VELOCITY VECTOR}
\end{align*}
\]

NEXT SHEET

P37 - RETURN TO EARTH (MAIN PROGRAM)

COLOSSUS = 2D

FC-2642
FROM PRECEDING SHEET

CLEAR XDELYFLG CLEAR NORMSW SET FINALFLG

INPUT TO P40,41 XDELYFLG LAMBERT (AIMPOINT) COMPUTATION NORMSW LAMBERT MUST COMPUTE ITS OWN NORM.
THIS FLAG ALLOWS PROPER COMPUTATION OF MGA AND TERMINATION OF VN1645 BY V32 ENTER.

\[
t_4 = t_{3a} + t_{3b}
\]
\[
I(t_3) \quad t_3
\]

STARG \rightarrow FLOOD TASSA \rightarrow T + 71
DELVSN_3 \rightarrow V_2(T_3) - V(T_1)\_3

INPUT FOR VN1645

P37WW

KEYBOARD ENTRIES:

VF3 ENTER TERMINATE V34 ENTER P37
V32 ENTER TRANSFERS TO P37WW.

INPUT: DELVSN

Flag: FINALFLG SET

OUTPUT: MGA + MIDDLE GIMBAL ANGLES

DISPLAY:

VERB16
NOUN 45
R1: MARKS: NOT MEANINGFUL
R2: T1: TIME TO T1 (BUILDER)
R3: MIDDLE GIMBAL ANGLE XXX.XX DEG.
IF REFRESHMNT FLAG IS CLEAR
R3 = -.00002.
IF REFRESHMNT FLAG IS SET,
R3 WILL BE COMPUTED.

V32 recycles VN1645, asking for terminate or proceed response.
CALL BY MAINLINE PROGRAM AFTER RTE290

SAVE QPRET IN SPRTTEX

STORE TIG IN LOCATION EXPECTED BY CSMPREC

CSMPREC COMPUTES THE PRECISION STATE VECTOR FOR THE CSM AT TIG.

INPUT:
  TDEC = TIG IN CSEC @ \(2\times10^3\)
  CURRENT CSM STATE VECTOR AND CURRENT TIME

OUTPUT:
  RATT = \(r(t_1)\): POSITION VECTOR AT TIG IN METERS @ \(2\times10^3\)
  VATT = \(v(t_1)\): VELOCITY VECTOR AT TIG
  IN METERS/CSEC @ \(2\times10^3\)
  TAT = TIG: TIME T1 IN CSEC @ \(2\times10^3\)
  P(T1): COORDINATE SYSTEM ORIGIN: EARTH: \(P(T1) = 0\)
  MOON: \(P(T1) = 2\)

PUT CSMPREC OUTPUT INTO P37 LOCATIONS.

DOES TIG PUT CRAFT INTO EARTH'S SPHERE OF INFLUENCE?

IS \(P(t_1) = 0\) ?

NO

MOON'S SPHERE

YES

MPAC ← OCT612

TNVC109

RTEALRM CALLS PSTDARLM WHICH DISPLAYS ALARM
SHOW TIG PUTS CRAFT IN MOON'S SPHERE, RECYCLE OR TERMINATE

CFAA = \(U_{R1} \cdot U_{V2}\)

\(U_{R1} = \text{UNIT}(R(T1))\)

\(U_{V2} = \text{UNIT}(v(t_1))\)

\(R(T1) = \text{UNIT}(r(t_1))\)

\(CFAA = \cos(\text{INITIAL FLIGHT PATH ANGLE})\)

NEXT SHEET

P37 ← RETURN TO EARTH (INVC100)
From preceding sheet

\[ \text{\textbf{EPCLMPTE}} = \text{DEC.} \pm 90 \pm 0.5 \pm 2 \pm 1 \]

\( \text{\textbf{EPCLMPTE}} \) is equal to \( \text{\textbf{LST}} \). Question asks: if the angle between \( \text{\textbf{EPCLMPTE}} \) and \( \text{\textbf{XCLMPTE}} \) is less than 1.0°, this test will fail only near the moon.

\[ \eta = (0, 0, 1) \]

\[ \text{MPAC} = (0, 0, 1) \]

\[ \text{IF} [\eta] \text{\textbf{EPCLMPTE}} \text{\textbf{YES}} \]

\[ \text{INVC115} \]

Angle too small. Define \( \eta \) such that \( \text{MPAC} \) will have the same angle with the equatorial as \( \text{\textbf{XCLMPTE}} \).

\[ \eta = \text{MPAC} \times \text{UNIT} \]

\[ \text{INVC100} \]

\[ \text{CLEAR RETROFLG} \]

\[ \text{IS THE Z COMPONENT OF } \eta > 0? \]

\[ \\]

\[ \text{NO} \]

\[ \text{RETOGRADE TRAJECTORY} \]

\[ \eta = -\eta \]

\[ \text{MPAC} = -\text{MPAC} \]

\[ \text{SET RETROFLG} \]

\[ \text{INVC125} \]

\[ \text{RETURN VIA SPFRTX} \]

\[ \text{UNIT} (\eta \times \text{UNIT}) \]

\[ \text{UNIT} (\text{MPAC} \times \text{UNIT}) \]

\[ \text{FORM UNIT HORIZONTAL VECTOR} \]
CALLED BY: MAINLINE AT RTE360, SH 5
PREC100 AT PREC210, SH 40

ALARM CODE
20610
(λ < 1)

PO0000
FC-2140

STORE QPRET
PL33D

λ = r(τi)/RCON
A1 = 1 + k(τi)²
β = -(λ)A1
β = \sqrt{2}(λ-1)
λ = \sqrt{2}/(τi)

PLOD
\[ \text{INPUT FOR XTILIM} \]

PLOD \rightarrow \text{MAX}1
PLOD \rightarrow \text{MAX}1

XTILIM COMPUTES GSOP VARIABLE A10, TESTS IT, AND COMPUTES X(τi) LIMITS, DEPENDING ON WHICH MAX IS INPUT.

INPUT:
PL10D = MAX1
PL10D = MAX1
PL10D = MAX1
PUSHLIST POINTER AT 140
PLOD = A5
κ = X1
X(τi) = [X(τi)] RADIUS OF CONIC TRAJECTORY & 29
R(τi) = RADIUS OF CONIC TRAJECTORY & 29

OUTPUT:
MPAC = -X(τi) MIN: LOWER BOUND ON THE COTANGENT OF THE POST-RETURN FLIGHTPATH ANGLE & 29
PUSHLIST POINTER AT 100

NEXT SHEET
GAM0VIO CALLS OVLALS. By iteration, it calculates \( V(t_1)/\dot{\gamma} = Y_\dot{\gamma}(t_1) \), \( \Delta V = \Delta V(t) \), \( x(t_1) = x(t_1) \) and \( PCON = PCON \).

**Input:**
- \( \theta_1 = A_s \lambda - 1 \)
- \( \theta_2 = \theta(t_1)(\lambda - 1) \)
- \( \theta_3 = x(t_1)/r(t_1) \)
- \( x(t_1)_{MIN} = \text{LOWER BOUND ON INDEPENDENT VAR.} X(t_1) \)
- \( \Delta x(t_1)_{MIN} = \text{MINIMUM \( \Delta x(t_1) \)} \)
- \( x(t_1)_{MAX} = \text{UPPER BOUND ON IN. VAR.} X(t_1) \)
- \( \Delta x(t_1)_{MAX} = \text{CHANGE IN} X(t_1) \)

**Output:**
- \( V(t_1)/\dot{\gamma} = Y_\dot{\gamma}(t_1) = \text{INITIAL, PRE-IGNITION VELOCITY} \) \( \text{VECTOR IN METERS/CSEC @} 2^T \)
- \( \text{RTEDVD} = \Delta V = \text{KEYED-IN \( \Delta \) VELOCITY DESIRED IN METERS/CSEC @} 2^T \)
- \( U(t_1)/\dot{\gamma} = U_{RT} = \text{UNIT POSITION VECTOR AT} T_0 \)
- \( \dot{U}_H = U_{HRT} = \text{UNIT HORIZONTAL VECTOR} \)
- \( \text{X}(t_1) = \cot \text{OF INITIAL FLIGHT PATH ANGLE FROM THE VERTICAL.} \)
- \( \text{FERTE} = \text{FLAG ON MEANS TIME CRITICAL MODE.} \) \( \text{FLAG OFF MEANS NOT IN TIME CRITICAL MODE} \)

**Output:**
- \( V(t_1)/\dot{\gamma} = Y_\dot{\gamma}(t_1) = \text{POST-IMPULSE VELOCITY VECTOR IN METERS/CSEC @} 2^T \)
- \( \Delta V = \text{CHANGE IN VELOCITY} \)
- \( x(t_1) = \cot \text{OF INITIAL POST-RETURN FLIGHT PATH ANGLE FROM VERTICAL.} \)
- \( PCON = PCON = \text{SEMI-LATUS RECIPM IN METERS @} 2^T \)

**Flowchart:**
- From preceding sheet.
- **V21100**
- **GAM0VIO**
- **COMPUTE**
  - \( V(t_1)/\dot{\gamma} = Y_\dot{\gamma}(t_1) \)
  - \( \Delta V = \Delta V(t) \)
  - \( x(t_1) = x(t_1) \)
  - \( PCON = PCON \)
- **RETURN VIA 335G**
- **IS THIS FUEL CRITICAL MODE?**
- **YES**
  - **RTEDVD = 0**
  - **VCTIX**
- **NO**
- **NEXT SHEET**
A_{10} = \frac{\text{MA} - f(t)}{\text{MA} - \text{RCON}} - 1

\text{MPAC} = \frac{(R^{2} + 43 - R(t)) - z^{2}}{\text{NORM} \times (4L - 23 - \text{RCON} - z^{2})} - z^{2} - x_{1} - x_{2} - (4 \times z^{2})

\text{OVERFLOW} = \text{YES}

\text{IS MPAC} < 0 \rightarrow \text{YES}

\text{X(1) LIMIT} = 0

\text{MPAC} \rightarrow \text{ZERORTE}

\text{X(1) LIMIT} = \sqrt{A_{10}}

\text{MPAC} \rightarrow \sqrt{\text{MPAC}}

\text{OVERFLOW} = \text{IF YES}

\text{XTILIMX}

\text{RETURN VIA PL20D}

\text{XTILIM} IS USED TWICE: ONCE USING \text{MAMAX1} AND ONCE USING \text{MAMAX2}.

\text{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.}

\text{WHEN MAMAX2 IS USED, XTILIM DETERMINES WHETHER R(T), THE ABSOLUTE VALUE OF THE POSITION VECTOR, IS GREATER THAN MAMAX2. IN THAT CASE, THE MAXIMUM RADIUS IS TAKEN TO BE R(T) ITSELF. THE POST-IMPULSE FPA IS THEREFORE NOT PERMITTED TO HAVE A POSITIVE RADIAL COMPONENT.}
\[ P_{\text{con}} = \frac{\theta_2}{\theta_1 - R(t_1)} \]

\[ V_2(t_1) = \frac{\theta_3}{\sqrt{P_{\text{con}}} R(t_1)} \left( x(t_1) \right) \left( u_x + u_y \right) \]

\[ \Delta v = \left| V_2(t_1) - V_1(t_1) \right| \]

\[ P_{\text{con}} \rightarrow \left[ \frac{\text{norm}_{\text{pl}} \left( \text{plod}_{\text{pl}} \right)}{\text{norm}_{\text{pl}} \left( \text{plod}_{\text{pl}} - x(t_1)^2 \right)} \right] \left( x(t_1)^2 + y(t_1)^2 \right) \]

\[ V_2(t_1)/_y = \text{norm}_{\text{pl}} \left( \text{plod}_{\text{pl}} \right) \left( \text{norm}_{\text{pl}} \left( x(t_1) \right) \left( u_x + u_y \right) \left( x(t_1)^2 + y(t_1)^2 \right) \left( x(t_1)^2 + y(t_1)^2 \right) \right) \]

\[ \Delta v \rightarrow \left| V_2(t_1)/_y - V_1(t_1)/_y \right| \]

**RETURN VIA PL32D**

**PON**

PON Satisfies the Equation:

\[ P_{\text{con}} = \frac{2 \tau(t_1)}{R_{\text{con}} \left( R_{\text{con}} - 1 \right)} \]

WHERE

\[ \theta_4 = 2 \tau(t_1) \left( \frac{R(t_1)}{R_{\text{con}}} - 1 \right) \]

AND

\[ \theta_5 = \left( \frac{R(t_1)}{R_{\text{con}}} \right) \left( 1 + \left( x(t_1)^2 \right)^{-1} \right) \]

WHERE \( R(t_1) \) = RADIUS

AT \( T_{\text{fin}} \), \( R_{\text{con}} = \) FINAL RADIUS 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.
FROM PRECEDING SHEET

13 $a_k < \Delta x(t_1)_{\text{max}}$?

WILL THE NEW $\Delta x(t_1)$ KEEP $x(t_1)$ WITHIN PRESCRIBED LIMITS? IF NOT, MODIFY $\Delta x(t_1)$.

NO

$\Delta x(t_1)_{\text{may put } x(t_1) \text{ over } x(t_1)_{\text{max}} \text{ on next iteration.}}$

YES

$\text{PL24D < PL14D ?}$

$\Delta x(t_1) = \frac{1}{2}(x(t_1)_{\text{max}} - x(t_1))$

$\text{PL14D } = \frac{1}{2}(x(t_1)_{\text{max}} - x(t_1))$

RESTRICT $\Delta x(t_1)$

GAMDV50

YES

$\Delta x(t_1)_{\text{may put } x(t_2) \text{ under } x(t_2)_{\text{min}}}$

NO

GAMDV60

$\Delta x(t_1)_{\text{may put } x(t_2) \text{ under } x(t_2)_{\text{min}}}$

RESTRICT $\Delta x(t_1)$

GAMDV60

IS $\Delta x(t_1)$ SMALL ENOUGH?

NO

$\Delta x(t_1)$ NOT SMALL ENOUGH.

CYCLE LOOP AGAIN.

GAMDV25

YES

$|\text{PL14D}| \leq \text{EPSRTE}$

RETURN VIA PL31D

GAMDV25

GAMDV60

GAMDV60

RETURN VIA PL31D

GAMDV25

GAMDV60

GAMDV60

RETURN VIA PL31D
TIME RADIUS CALLING SUBROUTINE

INPUT:
- RVREC
- VVEC
- RDESIRED
  - INITIAL POSITION VECTOR
  - INITIAL VELOCITY VECTOR
  - FINAL RADIUS FOR WHICH TRANSFER TIME IS TO BE COMPUTED

OUTPUT:
- R(T2)/
- V(T2)/
- T12
  - FINAL POSITION VECTOR
  - FINAL VELOCITY VECTOR
  - TRANSFER TIME TO FINAL RADIUS

ABORT EXIT FOR NO SOLUTION: POOD000, WITH OCT 607

CALLED BY RTE367, SH 6
RTEDISP, SH 31

STORE QPRT in RTENCKEX

CLEAR RVSW

RVSW is cleared to allow TIMERAD to compute R(T2)/ and V(T2)/

S GRNDUTs = - OCT 2000002
X1s = CONIX1s

f(t2) is assumed to have negative radial velocity
mutable index value for μe

INPUT:
1) RVREC = I(t1)
2) VVEC = Y(t1)
3) X1 = INDEX VALUE USED BY PARAM TO SET UP PROPER A- TABLE
4) RDESIRED = T(t2), TERMINAL RADIAL DISTANCE ON TRAJECTORY FOR WHICH TRANSFER TIME IS COMPUTED.
5) SGRNDO = S, IS POSITIVE IF f(t1) IS ASSUMED TO HAVE POSITIVE RADIAL VELOCITY, NEGATIVE FOR NEGATIVE RADIAL VELOCITY.

OUTPUT:
1) T = T12 = TRANSFER TIME IN CSECS @ 2.18
2) FPLODD = I(t2) = TERMINAL POSITION VECTOR
3) MPAC = Y(t2) = TERMINAL VELOCITY VECTOR
4) ABORT: POOD000 WITH OCT 607

PUT TIMERAD OUTPUT INTO P37 LOCATIONS

RETURN VIA RTENCKEX

P37 - RETURN TO EARTH (TIMERAD100)
CALLED BY: P37E
P37E

STORE QPRET IN VSTORE

RTEDISP CALLS: TRAODDO, AUSEKUGL AND LAT-LONG
INPUT: V(T1) = Y(t2) FINAL VELOCITY VECTOR IN METERS/CSEC @ 27
R(T1) = E(t2) FINAL POSITION VECTOR IN METERS @ 27
Y(T1) = Y(t1) POST-IMPULSE INITIAL VELOCITY VECTOR
IN METERS/CSEC @ 27
V(T1) = O(t1) PRE-IMPULSE INITIAL VELOCITY VECTOR
IN METERS/CSEC @ 27
URL1 = U11 = UNIT INITIAL POSITION VECTOR @ 27
URLH = U1H = UNIT HORIZONTAL VECTOR AT T16
SPRTENG = KEYED-IN T16 IN CSEC @ 27
T16 = FINAL TIME IN CSEC @ 27
OUTPUT: LAT(SPL) = LATITUDE AT T2, IN DECS @ 27
LNG(SPL) = LONGITUDE AT T2, IN DECS @ 27
VPRED = MAGNITUDE OF VELOCITY AT 400,000 FT
IN METERS/CSEC @ 27
GAMMAE1 = FLIGHT PATH ANGLE @ 400,000 FT
IN DECS AND ABOVE HORIZON @ 27
TSTOT = TRANSIT TIME TO 400,000 FT, IN CSEC @ 27
DELYVC = INITIAL VELOCITY CHANGE VECTOR IN LOCAL
VERTICAL COORDINATES IN METERS/CSEC @ 27

P37OGOFR

SAVE Q IN RTENCHEK

GOFLASH

QUESTION

GOTOQOGF

PROCEDURE

RETURN VIA RTENCCHEK

ROUTE

HP

ENDOFJOB

NEXT SHEET

DISPLAY
RL: LATITUDE DEC
RD: LONGITUDE DEC
RD: DEC
RD: BLANKED OUT

P37 - RETURN TO EARTH
FROM PRECEDING SHEET

PS/STOP

SAVE Q IN SPRTEX

GOFLASH

V0 NO1
DISPLAY DELVUC

ENTER
TERMINATE

PROCEED

GOTDPOOH

RETURN VIA SPRTEX

RETURN VIA VSTORE

DELAV (LV) = DELVUC * ORG.XXX.X
FT/SEC EACH COMPONENT
FROM PRECEDING SHEET

TLS = t_e + t_x + t_e

PLOD1 ← MPAC + T2 + T2

TIME TO SPLASH-DOWN

CHANGE IN RANGE?

PSTRANGE6

#0 NO

#0 YES

USE P37 RANGE FOR DISPLAY

RTD22

PLOD3 ← PSTRANGE6

S_g x ← SIN(g_x)
S_g y ← COS(g_y)

LNG(SPL) ← SIN(RK-40)
LAT(SPL) ← COS(RK-40)

Ux = UNIT([x(t_e) + x(t_x)] x t(t_e)]
U_y = Ux_S_g_x + Ux_S_g_y

PLOD4 ← UNIT([UNIT(RK-40) x UNIT(VK-40)] x UNIT(RK-40) x LNG(SPL)]
ALPHA ← PLOD4 + LAT(SPL) x UNIT(RK-40)

MPAC ← PLOD6

T_L = t_e + t_x + t_e
S_g x ← SIN(g_x)
C_g x ← COS(g_x)

Uy = UNIT([y(t_e) + y(t_x)] x t(t_e)]
U_z = Uy_S_g_y + Uy_S_g_x

PLOD2 ← MPAC + T2 + T2

LNG(SPL) ← SIN(PLOD4)
LAT(SPL) ← COS(PLOD4)
PLOD4 ← UNIT([UNIT(RK-40) x UNIT(VK-40)] x UNIT(RK-40) x LNG(SPL)]
ALPHA ← PLOD4 + LAT(SPL) x UNIT(RK-40)

MPAC ← T_E + T2 + T2

CLEAR ERDFLAG

LAT-LONG USES FIXED RADIUS

CLEAR LUNAFLAG

LAT-LONG COMPUTES FOR EARTH

NEXT SHEET

P37- RETURN TO EARTH (RTEDISP)
FROM PRECEDING SHEET

LAT=LONG

INPUT: MIRC=TIME, OSSC @ 27
ERADFLAG = 0 MEANS FIXED EARTH RAD
LUNAFLAG = 0 MEANS FOR EARTH
ALPHA= POSITION VECTOR IN METERS @ 29

OUTPUT: LAT = LATITUDE IN REVS @ 29
LONG = LONGITUDE IN REVS @ 29

LNG(SPL) --- LONG
LAT(SPL) --- LAT

RETURN VIA SPRTPK
Called by mainline flow at RTE21

STORE GPRM in SPKTEX

\[ T_1 = 10 \]
\[ R = \text{RCON} \]
\[ f_1 = 1 \]

NM1 = SORT R
RD = RCON

In this program, INIA positive is equivalent to \( f_1 \) set. \( f_1 \) set means this is the precision phase. \( \text{RCON} \) computed by CONC phase is now held constant.

Next sheet

\[ \Delta^2 T_t = \text{RSMAX} \]
\[ N_2 = 0 \]
\[ DTZ1PR = ERTE1 \]
\[ N2 = 256 \]

iteration entry for new \( V_2 (T_1) \)

IN2 is incremented toward 0.

RTENCK3

This routine takes the vectors \( V(t_1) \) produced by VD100 and RT100 and PRECISION integrates to \( T_e \). RTENCK enters the integration routine with INTYPFLS and MOONFLS cleared. First calling INSTALL to ensure that the integration routine is not being used. It loads P1 variables into input locations used by the integration routine and loads the output of the integration routine into locations used by P17.

Input:
1. \( R(T_1) \) = Initial position vector in meters @ 219
2. \( V(T_1) \) = Initial velocity vector in meters/sec @ 219
3. \( T_1 = \) Initial time in CDC @ 219
4. \( T_e = \) Final time in CDC @ 219

Output:
1. \( R(T_e) \) = Final position vector in meters @ 219
2. \( V(T_e) \) = Final velocity vector in meters/sec @ 219
3. \( T_e = \) Final time in CDC @ 219
4. \( X_1 = \text{CONC} \times X_T = \) Table index for Earth.
5. \( P_2000 = R(T_e) \)

Sub - iteration loop entry (for "time - gamma" iteration routine)
FROM PRECEDING SHEET

IF \( R_F \) CLOSE TO \( R_{PRE} \)?

- \( R_F = A \cdot R_{PRE} \)
  - \( N_{PRE} = N_{PRE} + 1 \)
  - \( PLOED = 2(\text{PLOED}) \cdot R_{PRE} \)
  - \( N_{PRE} = N_{PRE} + 1 \cdot \text{IRTEB1} \)

FLOOD CONTAINS REQUIRED INCREMENT TO \( R_F \)

SET RVSW

RVSW IS SET TO PREVENT TIMERAD FROM COMPUTING A NEW STATE VECTOR.

LOAD PST VARIABLES INTO LOCATIONS EXPECTED BY TIMERAD.

- \( A \)-TABLE INDEX
- \( R_F \)

TIMERAD CALCULATES THE TRANSFER TIME, \( T \), FROM \( I \) TO A DESIRED RADIUS ON THE TRAJECTORY.

TIMERAD CALLS PARAM, LAMBERT, OR PARAM, GET \( X \), AND TIME.,

INPUT:
1) \( RVEC = R(T) \) = POSITION VECTOR FROM WHICH TRANSFER TIME TO THE RADIUS DESIRED WILL BE CALCULATED IN METERS @ 2^29
2) \( VVEC = V(T) \) = VELOCITY VECTOR CORRESPONDING TO \( R(T) \) IN METERS/SEC @ 2^29
3) \( X1 = \text{CONIC1} \), FOR PROPER \( A \)-TABLE REFERENCE
4) \( R_{DESIRED} = RADIUS \) OF POINT ON THE TRAJECTORY IN METERS @ 2^29
5) \( \text{SIGNDOT} = -\text{OCT99999} \), IMPLIES THAT \( R_{DESIRED} \) HAS A NEGATIVE RADIAL VELOCITY.
6) RVSW IS SET SO THAT THE NEW STATE VECTOR WILL NOT BE CALCULATED.

OUTPUT:
- \( T \) = TRANSFER TIME IN SEC @ 2^29
- \( ABORT \) \( EXIT \): POODOO: OCT 607

\[ \Delta r = \frac{\Delta r_1}{\Delta r_2} \]
\[ A_3 = A_1 \cdot \frac{\Delta t_2}{\Delta t_1} \]
\[ PLOED = \frac{[\text{PLOED}/\text{NORM}_{\text{TVPS}}]}{2^{-7 \cdot 22}} \]

NEXT SHEET

P37 - RETURN TO EARTH (PRE100)

A. A. WILLIAMS

COLDSSUS 2D FC-2642

2 37 53
IF \( \Delta t_i \) is positive, then the last iteration used \( \Delta t_{i-1} \) with identical sign. If \( \Delta t_i \) is negative, then there is danger of oscillation around the optimum value; therefore it is necessary to set up a limit for the \( \Delta t_i \) and to change its sign.

\[
\Delta t_i = \begin{cases} 
1.0 & \text{MPAC} \rightarrow \text{PLOED} \\
\text{PLOED} \rightarrow \text{EXIT} & \end{cases}
\]

\[
\Delta t_{i+1} = \Delta t_i \cdot 0.6 \quad \text{DEC} \quad \text{MPAC} \rightarrow \text{PLOED} \\
\text{PLOED} \rightarrow \text{M.I.RTE} \quad \text{M.I.RTE} = 0.6
\]

\[
\Delta t_{i+1} = \Delta t_i \quad \text{PLOED} \rightarrow \text{PLOED} \cdot \text{DT2IPR}
\]

**SAVE PREVIOUS \( \Delta t_i \)**

**RTENCK2 CALLS**
- INSTALL, CLEAR INTPFLG AND MOONFLAG
- LOADS PBT VARIABLES INTO INTEGRVS LOCATIONS, CALLS INTEGRVS AND LOADS INTEGRVS INTO PBT LOCATIONS.
- INPUT: \( R(T_0), V(T_0), T_0, \text{PLOED} = \Delta t_{i-1} \) (PUSHLOC
- OUTPUT:
  1. \( R(T_2) \rightarrow \text{POSITION VECTOR AT } T_2 + \Delta t_i \) in Meters or \( 2^3 \)
  2. \( T_2 \rightarrow \text{TAT* UPDATED } T_2 \text{ IN OSSEC @ } 2^4 \)
  3. \( \text{MPAC}, V(T_2) \rightarrow \text{VELOCITY VECTOR AT TAT} \) in Meters/Sec @ \( 2^4 \)

**GO BACK FOR NEXT SUB-ITERATION.**

**PBT - RETURN TO EARTH (PREC100)**

**COLOSSUS 2D FC-2642**
ENTRY IS FROM PREC 165

\[ R_{err} = R_{pre} - R_d \]

\[ PLOAD = R_{pre} - R_d \]

PLOAD CONTAINS \( \gamma_4 \)

IS \( R_{pre} \) CLOSE TO \( R_d \) ?

YES

IS PLOAD < EPCTRDE ?

\[ \gamma_1 = 10 ? \]

YES

IS NNLK = LMTEN ?

NO

TOM ANY ITERATIONS

YES

IS THIS THE FIRST ITERATION ?

NO

IS NNLK = LMTEN ?

NO - NOT FIRST

\[ S = \frac{DA_{con}}{R_{pre} - R_{pre}} \]

\[ PLOAD = R_{con} + 2 \times 2 \times 2 \times \text{NORM}_{\gamma_4}(R_{pre} - R_{pre}) \]

SLOPE ITERATION ON ALL CYCLES EXCEPT FIRST.

MPAC → PLOAD + IRTEBL

\( S + 2 \)

IS THERE OVERFLOW ?

NO

\[ R_{pre} = R_{pre} \]

YES

IS \( |S_{E}| < 2 \) ?

YES

\[ |PLOAD + IRTEBL| < IRTE01 \]

NO

\[ |S_{E}| \) TOO LARGE, SET SLOPE = -4

\[ S = -4 \]

\[ PLOAD = -2 \times IRTE02 \]

NEXT SHEET

PREVIOUS SHEET

PREVIOUS SHEET

RETURN TO EARTH

(PREC100)
CALLED BY P37F

STORE QPRET IN RTENCKX

INSTALL
STALL THIS JOB IF INTEGRATION IS BEING USED
FC-2290

\[ P(t) \]
MPAC \( \rightarrow R(t) \)\/_

SET INTYPFLG

RTENCK3B SH43

RTENCK2

CALLED BY PREC174

STORE G IN RTENCKX

INSTALL
STALL THIS PROGRAM IF INTEGRATION IS BEING USED
FC-2290

CLEAR INTYPFLG

DO PRECISION INTEGRATION.

\[ R(t) \] \( \rightarrow \) MPAC
\[ V(t) \] \( \rightarrow \) VCV
\[ T(t) \] \( \rightarrow \) TET

PUT P37V VARIABLES INTO LOCATIONS EXPECTED BY INTEGRVS
MPAC \( \rightarrow \) T2 + LAST QUANTITY IN PUSHLST
ADVANCES T2 BY \( \Delta T_2 \)
RATHER THAN EXTRAPOLATE A NEW FINAL STATE VECTOR FROM \( R(t) \) AND \( V(t) \)
TIME IS SAVED BY EXTRAPOLATING THE NEW FINAL STATE VECTOR FROM THE OLD,
USING ONLY A SMALL CHANGE IN T2, I.E., STATE VECTOR AT T2 + \( \Delta T_2 \) IS EXTRAPOLATED FROM STATE VECTOR AT T2.
FROM PRECEDING SHEET

INTEGRVS
ENTER INTEGRATION
WITH FLAGS CLEARED
AND SET AS ABOVE.
CALCULATE RATE, VATT, TAT
FC-2290

INTEGRVS
INPUT:
R0: POSITION VECTOR AT TET @ 27
V0: VELOCITY VECTOR AT TET @ 27
TET: TIME TO BE INTEGRATED FROM
TDECL: TIME OF NEW STATE VECTOR @ 228

OUTPUT:
RATT: POSITION VECTOR AT TDECL
IN METERS @ 229
VATT: VELOCITY VECTOR AT TDECL
IN METERS/SEC @ 27
TAT: TDECL IN SEC @ 220

CONIK1 = # TABLE INDEX VALUE

RETURN VIA RTENCKEX
CALLED BY: RTEALRM
RTE360: EXCESSIVE ITERATIONS IN \( \theta_2 \) OR \( \theta_3 \); OCT605 OR FINAL FLIGHT PATH ANGLE NOT ACHIEVED OCT615.

STORE QP RET IN SPRINTX_a

A_a \rightarrow MPAC_0

PUT ALARM CODE INTO ACCUMULATOR

VARALARM
PUT ALARM CODE INTO ALMCADR, ALMCADR+3 OR \( \theta_3 \), OR SET SUPERBIT

FC-2140

INPUT: \( A = \) ALARM CODE
OUTPUT: FAILREG, OR FAILREG+1 OR FAILREG+2 OR SET SUPERBIT

A

DISPLAY ALARM FAILREG REGISTERS

PROCEED NOT AN OPTION

V33

TERMINATE

RECYCLE

GOFLASH

VERB 5 NOUH 9

RETURN VIA SPRINTX

CALLING SEQUENCE IS FOLLOWED BY TE P37

CALLED BY INVCD0 = MOON'S SPHERE OF INFLUENCE; OCT612.
RTE360 = EXCESSIVE ITERATIONS FOR \( \theta_2 \); OCT605
RTE378 = EXCESSIVE ITERATIONS FOR \( \theta_3 \)
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALPHA V</td>
<td>[t]_2</td>
<td>INPUT TO GETERAD (UNIT (RT(2)V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BETA1D</td>
<td>β1</td>
<td>1 + t_2^2</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>BETA2D</td>
<td>θ4</td>
<td>SIGN INDICATOR FOR TIMERAD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPFA D</td>
<td>CFPA</td>
<td>COSINE OF PRE-RETURN FPA</td>
<td></td>
<td></td>
<td>2^1</td>
</tr>
<tr>
<td>COGA D</td>
<td>x^2(t_2) PRE</td>
<td>OUTPUT OF PARAM. COT OF PRECISION ORBIT AT T2</td>
<td></td>
<td></td>
<td>2^5</td>
</tr>
<tr>
<td>CSTR D</td>
<td></td>
<td>INPUT TO TIMETHET: COS OF 165° OR 210°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CONICX D</td>
<td></td>
<td>CONIC TABLE INDEX</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELVSIN D</td>
<td>x^2(t_1)</td>
<td>V_2(t_1) - V_1(t_1) INPUT TO VNS1245</td>
<td>FT/SEC</td>
<td>M/CSEC</td>
<td></td>
</tr>
<tr>
<td>DRCON D</td>
<td>ΔR CON</td>
<td>RCON SLOPE ITERATOR</td>
<td>METERS</td>
<td>METERS</td>
<td>2^9</td>
</tr>
<tr>
<td>DT21PR D</td>
<td>Δt_21</td>
<td>PREVIOUS Δt_21</td>
<td>SECONDS</td>
<td>CSEC</td>
<td></td>
</tr>
<tr>
<td>DV D</td>
<td>ΔV</td>
<td>TEMPERATURE ABOLUTE VALUE OF ΔVLOCITY AT TIG</td>
<td>FT/SECOND</td>
<td>M/CSEC</td>
<td>2^7</td>
</tr>
<tr>
<td>ECSTEER D</td>
<td></td>
<td>STEERING CONSTANT FOR LAMBERT STEERING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERAD D</td>
<td></td>
<td>RADIUS OF FISCHER ELLIPSOID FOR T2</td>
<td>METERS</td>
<td>METERS</td>
<td>2^9</td>
</tr>
<tr>
<td>GAMMA1 D</td>
<td>MA_1</td>
<td>MAJOR AXIS CLOSE TO PARABOLIC TRAJECTORY USED TO COMPUTE LOWER BOUND ON RT1, COT OF POST IMPULSE FPA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAMA D</td>
<td>MA_2</td>
<td>MAXIMUM MAJOR AXIS USED FOR COMPUTING UPPER BOUND ON RT1</td>
<td>METERS</td>
<td>METERS</td>
<td>2^9</td>
</tr>
<tr>
<td>NN1A D</td>
<td>n_1</td>
<td>COUNTER #1 FOR ITERATION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIGN(NN1A)</td>
<td>f_1</td>
<td>POSITIVE = PRECISION PHASE; NEGATIVE = CONIC PHASE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NN2 D</td>
<td>n_2</td>
<td>COUNTER #2 FOR ITERATION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/RREP D</td>
<td>P/RPRE</td>
<td>RATIO OF SEMI-LATUS RECTUM TO</td>
<td>RT(2)V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCON D</td>
<td>P CON</td>
<td>TEMPORARY SEMI-LATUS RECTUM</td>
<td>METERS</td>
<td>METERS</td>
<td>2^9</td>
</tr>
<tr>
<td>PHIF D</td>
<td>ΦE</td>
<td>RANGE FROM 400,000 FT ENTRY ALTITUDE TO SPLASHDOWN</td>
<td>NAUTICAL MILES</td>
<td>METERS</td>
<td>2^9</td>
</tr>
<tr>
<td>PHI2 D</td>
<td>φ2</td>
<td>PERIGEE-APOGEE INDICATOR: -1 = APOGEE -1 = PERIGEE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#EMDOT</td>
<td>M</td>
<td>MASS DECELERATION FACTOR FOR CSM</td>
<td>LB/SEC</td>
<td>KG/CSEC</td>
<td>2^3</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P3.Range</td>
<td>RANGE FROM 300 K FT TO SPLASH IF # 0. IF = 0, USE AUGERKUL COMPUTATION.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(T1)D</td>
<td>PRIMARY BODY AT T1: 1 = MOON, 0 = EARTH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R/αPRE</td>
<td>RATIO OF R(T1)/V TO SEMI-MAJOR AXIS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R(RAT)</td>
<td>RADIUS VECTOR OUTPUT OF INTEGRATION ROUTINES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCON</td>
<td>TEMP FINAL RADIUS OF CONIC TRAJECTORY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCV</td>
<td>RADIUS VECTOR INPUT TO INTEGRALS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R(d)</td>
<td>FINAL RADIUS DESIRED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R(desired)</td>
<td>TEMPORARY FINAL RADIUS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPRE</td>
<td>TEMP FINAL RADIUS OF A PRECISION TRAJECTORY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPRE(D)</td>
<td>LAST x(t₂) COT (FINAL FPA) (FOR CONIC) LAST R PRE (FOR PRECISION)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTARG</td>
<td>INPUT TO UNITS RADIUS VECTOR AT FINAL TIME</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RTEVD</td>
<td>ΔV</td>
<td>Δ VELOCITY DESIRED</td>
<td></td>
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</tr>
<tr>
<td>RTEGAM2</td>
<td>τ(t₂)D</td>
<td>FINAL FPA DESIRED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REX</td>
<td>RETURN ADDRESS STORAGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RVEC</td>
<td>INPUT TO CONIC SUBROUTINES (RADIUS VECTOR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R(T1)</td>
<td>RADIUS MAGNITUDE AT T1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R(T1)D</td>
<td>RADIUSVECTOR AT T1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R(T2)</td>
<td>RADIUSVECTOR AT T2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SGNROOT</td>
<td>INPUT TO TIMERAD POSITIVE FOR POSITIVE RADICAL VELOCITY, NEGATIVE FOR NEGATIVE RADICAL VELOCITY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SNT1</td>
<td>INPUT TO TIME/EVENT SINE OF 165° OR 210°</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>SPRTTIG</td>
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<td>TAT</td>
<td>TIME OF OUTPUT VECTORS OF CONIC SUBROUTINES</td>
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**Nautical Miles**

**Revs**

2

2.29
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
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<tr>
<td>POLY</td>
<td>2100</td>
<td>DOUBLE PRECISION POLYNOMIAL EVALUATOR</td>
<td>SH. 4, 6, 11</td>
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<tr>
<td>GETERAD</td>
<td>2280</td>
<td>COMPUTE EARTH RADIUS</td>
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<tr>
<td>TIMETHET</td>
<td>2360</td>
<td>COMPUTE TIME AND, IF RVSW IS CLEAR, STATE VECTOR TO A PARTICULAR ANGLE, THETA.</td>
<td>SH. 13</td>
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<tr>
<td>VN1645</td>
<td>2720</td>
<td>COMPUTE AND DISPLAY MIDDLE GIMBAL ANGLE</td>
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<tr>
<td>CSMPREC</td>
<td>2290</td>
<td>EXTRAPOLATE PRECISION STATE VECTOR TO TIME (IN THIS CASE, TIG)</td>
<td>SH. 15</td>
</tr>
<tr>
<td>TIMERAD</td>
<td>2360</td>
<td>COMPUTE TIME TO A PARTICULAR RADIUS</td>
<td>SH. 27, 37</td>
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<tr>
<td>AUGEKUGL</td>
<td>2650</td>
<td>COMPUTE RANGE FROM 400,000 FT ENTRY TO SPLASHDOWN</td>
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<td>LAT-LONG</td>
<td>2280</td>
<td>GIVEN TIME AND STATE VECTOR AT THAT TIME</td>
<td>SH. 33</td>
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<tr>
<td>PARAM</td>
<td>2360</td>
<td>COMPUTE ORBITAL PARAMETERS FOR A GIVEN STATE VECTOR</td>
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<td>INSTALL</td>
<td>2290</td>
<td>STALL P37 IF INTEGRVS IS BEING USED</td>
<td>SH. 42, 43</td>
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<td>INTEGRVS</td>
<td>2290</td>
<td>EXTRAPOLATE BY CONIC OR ENCKE METHOD FROM A STATE VECTOR TO A GIVEN TIME</td>
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<td>VARALARM</td>
<td>2140</td>
<td>PUT ALARM CODE INTO A FAILREG REGISTER, OR SET SUPERBIT</td>
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**FLAGS**

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<tr>
<th>NAME</th>
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<tr>
<td>RVSW</td>
<td>DO NOT COMPUTE FINAL STATE VECTOR IN TIME-TIETA, TIMERAD</td>
<td>COMPUTE FINAL STATE VECTOR IN TIME-TIETA, TIMERAD</td>
<td>SH. 37</td>
<td>SH. 13, 27</td>
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<td>XDELVFLG</td>
<td>EXTERNAL DELTA VG COMPUTATION</td>
<td>LAMBERT (AIM POINT) VG COMPUTATIONS</td>
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<td>NORMSW</td>
<td>UNIT NORMAL INPUT TO LAMBERT</td>
<td>LAMBERT COMPUTES ITS OWN UNIT NORMAL</td>
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<td>FINALFLG</td>
<td>LAST PASS THROUGH RENDEZVOUS PROGRAM COMPUTATIONS</td>
<td>INTERIM PASS THROUGH RENDEZVOUS PROGRAM COMPUTATIONS</td>
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<td>F2RTG</td>
<td>IN TIME CRITICAL MODE</td>
<td>IN FUEL CRITICAL MODE</td>
<td>SH. 20</td>
<td>SH. 17</td>
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<td>ERADFLAG</td>
<td>COMPUTE USING FISCHER ELLIPSOID</td>
<td>COMPUTE USING FIXED RADIUS</td>
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<td>LUNAFLAG</td>
<td>LUNAR LAT-LONG</td>
<td>EARTH LAT-LONG</td>
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<td>INTYFLG</td>
<td>CONIC INTEGRATION</td>
<td>ENCKE INTEGRATION</td>
<td>SH. 42</td>
<td>SH. 42, 43</td>
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<td>MOONFLAG</td>
<td>MOON IS SPHERE OF INFLUENCE</td>
<td>EARTH IS SPHERE OF INFLUENCE</td>
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<td>NJETSFGLG</td>
<td>2 JET RCS BURN</td>
<td>4 JET RCS BURN</td>
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<td>RETROFLG</td>
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<td>SLOWFLG</td>
<td>COAST SLOWDOWN IS DESIRED</td>
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<td>SH. 4</td>
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<td>TDEC1_D</td>
<td>t_e</td>
<td>INPUT TO INTEGRATE TIME TO BE INTEGRATED TO</td>
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<td>T12_D</td>
<td>t_1</td>
<td>TRANSFER TIME TO FINAL RADIUS</td>
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<td>T2_D</td>
<td>t_2</td>
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<td>SECONDS</td>
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<td>U_H</td>
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<td>UNIT HORIZONTAL VECTOR</td>
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<td>V(T1)</td>
<td>v(T1)</td>
<td>VELOCITY VECTOR AT t_1 (PRE-IMPULSE)</td>
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<td>M/CSEC</td>
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<td>V2(T1)</td>
<td>v(T1)</td>
<td>VELOCITY VECTOR AT t_1 (POST-IMPULSE)</td>
<td>FT/SEC</td>
<td>M/CSEC</td>
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<td>V(T2)</td>
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<td>VELOCITY VECTOR AT t_2</td>
<td>FT/SEC</td>
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<td>V_PRED_D</td>
<td>v(t_f)</td>
<td>VELOCITY IN AN INITIAL TO DESIRED VELOCITY</td>
<td>FT/SEC</td>
<td>M/CSEC</td>
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<td>V_VEC</td>
<td>v(t_f)</td>
<td>INPUT TO CONIC ROUTINES (V(T1))</td>
<td>FT/SEC</td>
<td>M/CSEC</td>
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<td>WEIGHT_G</td>
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<td>MASS OF VEHICLE</td>
<td>POUNDS</td>
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<td>X(T1)</td>
<td>x(t_f)</td>
<td>COTAN INITIAL POST-IMPULSE FPA</td>
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<td>X(T2)</td>
<td>x(t_f)</td>
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<td>X(T2)PRE</td>
<td>x(t_f)</td>
<td>COTAN OF FINAL FPA OF PRECISION TRAJECTORY</td>
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### DISPLAYS

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<tr>
<td>V06N33</td>
<td>GOFLASH</td>
<td>R1 00 XXX, HRS</td>
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<td></td>
<td></td>
<td>R2 00 XXX, MIN</td>
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<td>R3 00 XX, XX SEC</td>
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<td>V06N60</td>
<td>GOFLASH</td>
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<td>R2 VPRD XXXX, FT/SEC</td>
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<td>R3 GAMMAEi (FLIGHT PATH ANGLE)</td>
<td>ΔV DESIRED</td>
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<td>R3 FPA</td>
<td>DFP DESIRED</td>
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<td>V04N06</td>
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<td>R1 OPTION CODE</td>
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<td>R2 ASSUMED OPTION</td>
<td>OCTAL: RCS-SPS OPTION</td>
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<td>R1 00 XXX, HRS</td>
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<td>R2 00 XXX, MIN</td>
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<td>R3 00 XX, XX SEC</td>
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<td>SH. 28</td>
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<td>R2 XXX, XX</td>
<td>LATITUDE</td>
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<td>DEGREES</td>
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<td>R2 00 XXX, MIN</td>
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<td>GOFLASH</td>
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<td>R3 GAMMAEi XXX, XX DEGREES</td>
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<td>V06N81</td>
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<td>R2 XXX, X FT/SEC</td>
<td>ΔV VECTOR</td>
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<td>R3 XXX, X FT/SEC</td>
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<td>V05N09</td>
<td>GOFLASH</td>
<td>R1 OCTAL ALARM CODE FROM MPAC, 00 XXX, IN ONE</td>
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### PAD LOADS

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<td>RTED1D</td>
<td>D1</td>
<td>X0 COEFFICIENT IN COMPUTATION OF R(t)</td>
<td>.2075330</td>
<td>1.6602637</td>
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### PROGRAM CONSTANTS

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<td>CSUBT_P</td>
<td>C T</td>
<td>VALUE USED IN CALCULATING BIASED TIG</td>
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<td>C4RTE_D</td>
<td>MAI</td>
<td>MAXIMUM MAJOR AXIS FOR R(t)/V WITH NEGATIVE RADIAL COMPONENT</td>
<td>8. x 10^8 METERS</td>
<td>8 x 10^8 Meters</td>
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<td>EP4RTE_D</td>
<td>E1</td>
<td>VALUE USED TO TEST WHETHER RADIUS AND VELOCITY VECTORS ARE NEARLY COLINEAR</td>
<td>COSH(1.5)</td>
<td>.999966</td>
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<td>MEANING</td>
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<tr>
<td>EPC2RTE_D</td>
<td>ε₂</td>
<td>CRITERION USED TO DETERMINE WHETHER CONIC PORTION HAS CONVERGED TO A SUITABLE REENTRY RADIUS</td>
<td>100 METERS</td>
<td>100 METERS</td>
<td>$2^{20}$</td>
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<tr>
<td>EPC3RTE_D</td>
<td>ε₂</td>
<td>CRITERION USED TO DETERMINE WHETHER CONIC PORTION HAS CONVERGED TO A SUITABLE REENTRY ANGLE (AL THOUGH THE TEST IS MADE ON THE COTANGENT OF THE ANGLE, IT IS EQUIVALENT TO 0.58°)</td>
<td>0.001</td>
<td>0.001</td>
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<tr>
<td>EPC4RTE_D</td>
<td>ε₄</td>
<td>CRITERION USED TO DETERMINE WHETHER PRECISION PORTION OF FINAL STATE VECTOR COMPUTATION HAS REACHED THE DESIRED REENTRY ANGLE (TEST MADE ON COTANGENT EQUIVALENT TO 0.00058°)</td>
<td>0.00001</td>
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<td>EPC6RTE_D</td>
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<td>CRITERION USED TO DETERMINE WHETHER FINAL STATE VECTOR COMPUTATION HAS ALREADY REACHED THE DESIRED REENTRY ANGLE</td>
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<td>EPC7RTE_D</td>
<td>ε₇</td>
<td>CRITERION USED TO DETERMINE WHETHER PRECISION SECTION HAS CONVERGED UPON THE REENTRY RADIUS SELECTED IN CONIC PORTION</td>
<td>1000 METERS</td>
<td>1000 METERS</td>
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<tr>
<td>EPC8RTE_D</td>
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<td>CRITERION USED TO MAKE FINAL CHECK ON REENTRY ANGLE REACHED IN PRECISION PORTION (TEST ON COTANGENT EQUIVALENT TO 0.116°)</td>
<td>0.02</td>
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<tr>
<td>EPC9RTE_D</td>
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<td>CRITERION USED TO DETERMINE IF GAMDV10 ITERATOR HAS REACHED A MINIMUM</td>
<td>$2^{-20}$</td>
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<td>$2^{3}$</td>
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<tr>
<td>EPC10RTE_D</td>
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<td>CRITERION USED TO DETERMINE WHETHER GAMDV10 ITERATOR HAS REACHED A MINIMUM</td>
<td>0.01 M SEC</td>
<td>0.0001 M SEC</td>
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<td>E3RTE_D</td>
<td>ε₃</td>
<td>REENTRY ALTITUDE ABOVE FISCHER ELLIPSOID</td>
<td>121920 M</td>
<td>121420 M</td>
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<td>K1RTE_D</td>
<td>K₁</td>
<td>RADIUS USED TO DETERMINE WHICH ESTIMATE OF REENTRY ANGLE TO BE USED</td>
<td>$7.0 \times 10^6$ M</td>
<td>$7.0 \times 10^6$ M</td>
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<td>K2RTE_D</td>
<td>K₂</td>
<td>INITIAL ESTIMATE OF REENTRY RADIUS</td>
<td>$6.495 \times 10^6$ M</td>
<td>6495000 M</td>
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<td>K3RTE_D</td>
<td>K₃</td>
<td>INITIAL ESTIMATE OF COTANGENT OF REENTRY ANGLE USED WHEN [RTI, V] $&lt; K_1$ (EQUIVALENT TO $-3^°20$, 5°)</td>
<td>$-0.06105$</td>
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### Program Constants (Continued)

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<th>Meaning</th>
<th>Engineering Value and Units</th>
<th>AGC Value and Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>KARTE_D_D</td>
<td>K4</td>
<td>Initial estimate of cotangent of reentry angle used when ( \sqrt{R(T)/V} &gt; K1 ) (equivalent to (-5.58°))</td>
<td>0.7944485</td>
<td>0.7944485</td>
<td>2.0</td>
</tr>
<tr>
<td>MCOS7.5_D_D</td>
<td>-COS 7.5°</td>
<td>Used in determining GSOP quantity K</td>
<td>0.9237053</td>
<td>0.9237053</td>
<td>2.0</td>
</tr>
<tr>
<td>MCOS22.5_D_D</td>
<td>-COS 22.5°</td>
<td>Criterion used to determine whether target for Lambert steering is too close to (180°)</td>
<td>0.6375 kg/sec</td>
<td>0.0016375</td>
<td>2.0</td>
</tr>
<tr>
<td>MDOTIII_D</td>
<td>m(SPS)</td>
<td>Mass deceleration factor for SPS burn</td>
<td>63.8 lb/sec</td>
<td>28939132 kg/csec</td>
<td>2.3</td>
</tr>
<tr>
<td>MDOTRCS_D</td>
<td>m(RCS)</td>
<td>Mass deceleration factor for RCS burn</td>
<td>1.13052619 kg/sec</td>
<td>1.13052619 kg/csec</td>
<td>2.0</td>
</tr>
<tr>
<td>MSIN7.5_D</td>
<td>-SIN 7.5°</td>
<td>Used in determining GSOP quantity K</td>
<td>1.3052619</td>
<td>1.3052619</td>
<td>2.0</td>
</tr>
<tr>
<td>RTMURTE_D</td>
<td>( \sqrt{E} )</td>
<td>Square root of Earth gravitational constant</td>
<td>19965050.1 m(^{3/2})/sec</td>
<td>199650.501 m(^{3/2})/csec</td>
<td>2.16</td>
</tr>
<tr>
<td>THETA16D_D</td>
<td>165°</td>
<td>165° = Position of new target for Lambert steering</td>
<td>165°</td>
<td>45833333.33 revs</td>
<td>2.0</td>
</tr>
<tr>
<td>THETA210_D</td>
<td>210°</td>
<td>210° = Position of alternate new target for Lambert steering</td>
<td>210°</td>
<td>58333333.33 revs</td>
<td>2.0</td>
</tr>
<tr>
<td>VCRS_D</td>
<td>V_C(RCS)</td>
<td>Thrust velocity of RCS jets</td>
<td>2706.64 meters/sec</td>
<td>27.0644 meters/csec</td>
<td>2.5</td>
</tr>
<tr>
<td>VCSPS_D</td>
<td>V_C(SPS)</td>
<td>Thrust velocity of SPS engine</td>
<td>3088.11 meters/sec</td>
<td>30.8811 meters/csec</td>
<td>2.5</td>
</tr>
<tr>
<td>2RTEB1_D</td>
<td>POSMAX</td>
<td>Initial setting of ( \Delta t_{21} )</td>
<td>7777737777 oct</td>
<td>7777737777 oct</td>
<td>2.0</td>
</tr>
<tr>
<td>30480RTET_D</td>
<td>30480</td>
<td>Input to timerad = ( R(T2)/V - 30480 )</td>
<td>30480 meters</td>
<td>30480 meters</td>
<td>2.20</td>
</tr>
</tbody>
</table>

The following are inputs to the Poly subroutine, called to compute \( \text{MAXM}, \text{XH21}, \) and \( -\Delta \text{V}/\text{V} \); in the order they appear. (All values dp; no AGC tags - Poly uses indexed addressing.)

\[
\begin{align*}
C_0 &= 1.810000043 \times 10^8 M \\
C_1 &= 1.50785145 \\
C_2 &= -6.49993057 \times 10^{-9} M^{-1} \\
C_3 &= 0.76938926 \times 10^{-18} M^{-2} \\
\end{align*}
\]

\( \text{Coefficients used to compute } MA_2 \)
<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>D₁</td>
<td></td>
<td></td>
<td>-4.8760771 x 10⁻⁴ S/M</td>
<td>-4.8760771 x 10⁻² CSEC/M</td>
<td>2⁻⁴</td>
</tr>
<tr>
<td>D₂</td>
<td></td>
<td></td>
<td>4.5418476 x 10⁻⁸ S²/M²</td>
<td>4.5418476 x 10⁻⁴ CSEC²/M²</td>
<td>2¹¹</td>
</tr>
<tr>
<td>D₃</td>
<td></td>
<td>COEFFICIENTS USED TO COMPUTE X²(T²)</td>
<td>-1.4317675 x 10⁻¹² S²/M³</td>
<td>-1.4317675 x 10⁻⁸ CSEC³/M³</td>
<td>2⁻¹⁶</td>
</tr>
<tr>
<td>D₄</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₀</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₁</td>
<td></td>
<td>COEFFICIENTS USED TO COMPUTE (1-e⁻⁹Av/ρ)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
P38 - P78 STABLE ORBIT RENDEZVOUS

(PHASE 1 SOI STABLE ORBIT INITIATION (SOI)
AND PHASE 2 STABLE ORBIT RENDEZVOUS (SOI))

P39 - P79 STABLE ORBIT MIDCOURSE (SOM)

EXTERNAL ENTRY POINT: PREC/TT (SH. 11)
PROGLGN
SET TRACKFLG
AND UPDATFLG
FC-2626
A ← VNO633
VUJDSPL
GOFLASHR
VGAH33SR
REQUEST TIG
SH12
RELOAD V25E
A ← VNO655
GOFLASHR
VGAH555SR
REQUEST CENTANG
PROCEED
GOTOPHOOK
TERMINATE
OPTION1= 5
OPTION2= 1
GOFLASHR
VGAH555SR
DISPLAY REENDEEV PHASE
REND GEV PHASE
OPTIONS
PROCEED
GOTOPHOOK
TERMINATE
NN ← 2
A ← OPTION2
NEXT SHEET

REQUEST TIG FOR
501/502 MANEUVER
TO NEAREST .01 SEC

Astronaut Inputs:
R1 000XX HRS
R2 000XX MIN
R3 0XX.XX SEC

Output: TIG in CSEC @ 2^E

Astronaut Inputs:
R1 BLANK
R2 BLANK
R3 CENTANG-
6 BETWEEN
TPI AND
INTERCEPT
FROM PRE-TPI
COMPUTATION

Central Angle
IN LOC CENTANG
IN REV @ 2^E

Program loads R1 w/5
Astronaut Inputs R2

Stable Orbit: R1 00005 @ 2^E
1=S01 PHASE
2=S02 PHASE

Output: 1 or 2 in LOC OPTION 2

1=S01 PHASE
2=S02 PHASE

Stable Orbit R3 BLANK
MAINRTME

TDECI — TARGETIME

INTPUP

UPDATE PASSIVE
VEHICLE TO TARGET
TIME t1,
SH12

INTIME0 — TIG0

SUBEXIT — TEST3979

MPACv — RATT

53435.25

COMPUTE ΔV
FOR TRANSFER
TRAJECTORY, ALSO
LV TRANSFORM
FC-2640 SH4

TEST3979

YES P38/P78

NO P39/P79

P38/P78

DISPLAY81

NEXT SHEET

P39/P79

IF NOT FINAL PASS (RECYCLE @ PRIOR
VN1645), SET UPATFLG, PERMITTING
STATE VECTOR UPDATE

OUTPUTS:
RATT = \( I_p(t_1), VATT = \gamma_p(t_1) \)

STORE TIG IN CSEC @ 216

EXIT FROM 53435.25

\( \gamma_T = \gamma_p(t_T) \)

INPUT: \( I_p, \gamma_p \) AT \( t_T \) IN MPAC; VATT RESPECTIVELY;
TIG0 IN INTIME; \( t_T \) IN TARGETIME; \( \gamma_T \) AT
TIG IN RPASS30, VRASS30 [FROM FIRST (SH4)
PRECDTT CALC]

INTLEVEL IS CALLED (WITH \( n_l = 2, e = 15^\circ \)) BY 53435.25
TO COMPUTE A TRANSFER TRAJECTORY BETWEEN
THE INITIAL AND TERMINAL POINTS, THE INITIAL
AND TERMINAL VELOCITIES AND THE TOTAL ΔV
REQUIRED. CENTANG IS RETURNED IN ACTCENTG,
AND \( t_T = t_T - t_{IG0} \) IS RETURNED IN DELT4G. ΔV AT
SOI TIG IS RETURNED IN DELVEE3, IN REFERENCE
X,Y,Z COMPONENTS, THEN CONVERTED
INTO LOCAL VERTICAL COORDINATES. OUTPUT IN
DELVLC(N, STD. ASC POSITION, VELOCITY, TIME
SCALING THROUGHOUT)

OUTPUT: RTARG(\( I_p @ t_T \), VIPRIME(\( \gamma_p @ 501 \));
VTIPRIME(\( \gamma_p @ 501 \)); DELVEE3(ΔV @ 501);
VPASS30(\( \gamma_p @ 501 \)); ACTCENT (\( \gamma_p \));
DELT4G,
(\( t_T \)); DELVLC(\( \gamma_p @ 501 \)))

MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.
P38-P78

N/A

STABLE ORBIT RENDEZVOUS
COLOSSUS II

FC-2644

REV 1

SH: 6 OF 15
From preceding sheet:

\[ \Delta V_{\text{FINAL}} = \sqrt{ \Delta V_{\text{FINAL}}^2 + \Delta V_{\text{FINAL}}^2 } \]

\[ \Delta V_{\text{FINAL}} = \sqrt{ V_{\text{FINAL}}^2 - V_{\text{FINAL}}^2 } \]

\[ \text{DELYTP1} = \text{ABVAL} (\text{DELYTP1}) \]

\[ \text{DELYTP1} = \text{ABVAL} (\text{VPASS4-VPRIME}) \]

\[ \text{OD}_v = \text{RACT3} \]

\[ \text{MP}_a = \text{VIPRIME} \]

\[ \text{PERIGEO2} \]

\[ \text{OBTAIN } \theta_v \]

\[ \text{USING } T_{\text{FINAL}} \]

\[ \text{FC-2644} \]

\[ \text{POSTP12} = H_p \]

\[ \text{FINALFLG} = 1 \]

\[ \text{FINAL PASS} \]

\[ \text{ENABLE STATE VECTOR UPDATE} \]

\[ \text{DISPLY58} \]

\[ \text{VNDSPLY} \]

\[ \text{VOSNBSR} \]

\[ \text{FLASH } H_p, \Delta V \]

\[ \text{AND } \Delta V_{\text{FINAL}} \]

\[ \text{SH1B} \]

R1 XXXX.X PERIGEE ALT IN NM TO NEAREST .1NM

R2 XXXX.X \( \Delta V \) REQUIRED AT TIG

R3 XXXX.X \( \Delta V \) REQUIRED AT INTERCEPT

(R2, R3 to nearest .1FPS)

\[ \text{COMPONENTS OF IMPELLIVE } \Delta V \]

\[ \text{REQUIRED AT TIG} \]

\[ \text{IN LOCAL VERTICAL COORDINATES TO NEAREST .1FPS} \]

\[ \text{LOCAL VERTICAL COORDINATE SYSTEM DEFINED AS:} \]

\[ L_X = (R \times V) \times R \]

\[ L_Y = V \times R \]

\[ L_Z = -R \]

\[ \text{LAMBERT STEERING REQUIRED IN THRUSTING PROGRAM TO FOLLOW} \]

\[ \text{NEXT SHEET} \]

\[ \text{SHIFT CONTENTS } \text{MP}_a (H_p), R1 \text{ AND STORE FOR NOUN 58 DISPLAY BELOW} \]

\[ H_p \text{ IN METERS @ } 2^{17} \text{ IN EARTH COORD,} \]

\[ \text{IN METERS @ } 2^{17} \text{ IN MOON COORD.} \]

\[ \text{COMPUTE TRANSFER TRAJECTORY} \]

\[ \text{PERIGEE HEIGHT USING } T_a, \theta_v \text{ AT TIG.} \]

\[ \text{RETURN PERIGEE HT. IN METERS @ } 2^{17} \text{ EARTH, } 2^{17} \text{ MOON} \]
STORE ΔVTF REF COORD

R1 MARK COUNT XXXXXX

R2 TTGO/TFI XXXXXX MIN/SEC
(=BEFORE TIG, +AFTER TIG)

R3 MIDDLE GIMBAL ANGLE XXX.XX
AT TIG

-00001 IS DISPLAYED IN R3 UNTIL
FINALFLG IS SET (IMPLIED LAST PM05),
THEN

A - R3 WILL DISPLAY -00001 IF THE
CSM IMU POSITIVE X-AXIS IS NOT
ALIGNED WITH THE THRUSTING
DIRECTION

B - R3 WILL DISPLAY THE IMU
POSITIVE MIDDLE ANGLE WHEN
THE IMU IS ALIGNED

NOTE: FOR FULL DETAILS OF VN1645
SEE FC-2626
SELECT PREPARATION TIME
67 FOR THRUST MANEUVER
PAO LOADED OR ASSIGNED
BY ASTRONAUT IN P27

BEGIN MIDCOURSE INITIAL CONDITIONS DISPLAY

ALLOW MARKING IN P20 AND
MARK INCORPORATION

P39/P79

LOADS VALUES OF $\frac{y}{\mu}$ AND $\mu$
INTO RT6R1/MU AND RT6RNU FOR EARTH
OR MOON SPHERE OF INFLUENCE ALSO
CLEAR PFINALFLG AND SETS UPDATFLG
AND TRACKFLG

P20FLGON
SET TRACKFLG
AND UPDATFLG
PC2626 S43

P39/P79 SW

SELECTMU
SELECT $\mu$
FOR SPHERE OF
INFLUENCE
PC2630 S43

GOFLESH
V184AB
DISPLAY TRKMCNT
TTGOG + MGA
PC2626 S43

PROCEED
TERMINATE

RECYCLE

FINALFLG SET?
NO
GOTOPUSH

YES
SET FINALFLG
CLEAR UPDATFLG

R1 XXBXX TRKMCNT
R2 XXBXX TTGOG
R3 XXXXX MGA
-00002 IS DISPLAYED IN R3 UNTIL
FINALFLG IS SET (IMPLIED LAST PASS),
THEN
A - R3 WILL DISPLAY -00002 IF THE
CSM IMU POSITIVE X-AXIS IS NOT
ALIGNED WITH THE THRUSTING
DIRECTION
B - R3 WILL DISPLAY THE IMU
POSITIVE MIDDLE ANGLE WHEN
THE IMU IS ALIGNED

NEXT SHEET
TRANSPORT VN CODE TO DISPLAY LOC VERB/NOUN

INTRPVDP
SAVE GPRET IN RTRN

CSM PASSIVE
CSMPREC PRECISION UPDATE CSM TO TDEC1
FC 2290

LEM PASSIVE
LEMPREC PRECISION UPDATE LM TO TDEC1
FC 2290

RETURN VIA RTRN

INPUT: t_f IN CSEC @ E_{16}
VEHICLES STATE VECTORS FOR LM, CSM
OUTPUT: \( \mathbf{r}_f, \mathbf{v}_f \) IN RATT, VATT AT
t_f OR t_f
STANDARD AGC SCALING
### SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVFLAGA</td>
<td>FC-2626</td>
<td>CLEARS AVFLAG (CSM ACTIVE), SETS ECSTEER</td>
<td>SH. 3, 9</td>
</tr>
<tr>
<td>AVFLAGP</td>
<td>FC-2626</td>
<td>SETS AVFLAG</td>
<td>SH. 3, 9</td>
</tr>
<tr>
<td>P20FLQON</td>
<td>FC-2626</td>
<td>SETTRACK &amp; UPDATFLG</td>
<td>SH. 3, 9</td>
</tr>
<tr>
<td>SELECTM2U</td>
<td>FC-2630</td>
<td>SELECTS PROPER $1/\mu$, $\mu$ FOR EARTH/MOON SPHERE OF INFLUENCE</td>
<td>SH. 4, 9</td>
</tr>
<tr>
<td>S3435.25</td>
<td>FC-2630</td>
<td>PREPARES INPUTS FOR (AND CALLS) INITVEL, WHICH COMPUTES TRANSFER TRAJECTORY AND INITIAL AND TERMINAL VELOCITIES BEFORE, AND AFTER TRANSFER</td>
<td>SH. 6, 10</td>
</tr>
<tr>
<td>PERIAPO1</td>
<td>FC-2641</td>
<td>COMPUTES TRANSFER TRAJECTORY USING $R_A$ &amp; $V_A$ AT TIG AND RETURNS $p$, PERIGEE HEIGHT</td>
<td>SH. 7</td>
</tr>
<tr>
<td>CSMPREF</td>
<td>FC-2220</td>
<td>PRECISION UPDATE CSM TO TDECI</td>
<td>SH. 12</td>
</tr>
<tr>
<td>LMPREC</td>
<td>FC-2220</td>
<td>PRECISION UPDATE LM TO TDECI</td>
<td>SH. 12</td>
</tr>
<tr>
<td>PRESET</td>
<td>FC-2626</td>
<td>UPDATE PASSIVE VEHICLE TO TDECI</td>
<td>SH. 10, 11</td>
</tr>
<tr>
<td>S34/35.1</td>
<td>FC-2610</td>
<td>CALCULATES UNIT LOS AND UNIT NORMAL</td>
<td>SH. 11</td>
</tr>
<tr>
<td>TIMETHET</td>
<td>FC-2630</td>
<td>COMPUTES TIME OF FLIGHT OVER CENTANG</td>
<td>SH. 11</td>
</tr>
</tbody>
</table>

### FLAGS

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVFLAG</td>
<td>LM ACTIVE VEHICLE</td>
<td>CSM ACTIVE VEHICLE</td>
<td>SH. 3</td>
<td>SH. 3</td>
<td>SH. 12</td>
</tr>
<tr>
<td>UPDATFLG</td>
<td>UPDATING ALLOWED</td>
<td>UPDATING DISALLOWED</td>
<td>SH. 3, 6, 7</td>
<td>SH. 7, 9</td>
<td></td>
</tr>
<tr>
<td>TRACKFLG</td>
<td>TRACKING ALLOWED</td>
<td>TRACKING DISALLOWED</td>
<td>SH. 3</td>
<td>SH. 4</td>
<td></td>
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<tr>
<td>OPTNSW</td>
<td>SOI PHASE OF P38</td>
<td>ORIG PHASE OF P38</td>
<td>SH. 4</td>
<td>SH. 4</td>
<td>SH. 5</td>
</tr>
<tr>
<td>FINALFLG</td>
<td>LAST PASS</td>
<td>NOT LAST PASS</td>
<td>SH. 7, 9</td>
<td>SH. 5, 6, 7, 9</td>
<td></td>
</tr>
<tr>
<td>NDELAVFLG</td>
<td>LAMBERT STEERING IN NOT REQUESTED</td>
<td>LAMBERT STEERING NOT TO FOLLOW</td>
<td>SH. 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P38/70TW</td>
<td>MIDCOURSE COMPUTATION</td>
<td>NOT MIDCOURSE</td>
<td>SH. 9</td>
<td></td>
<td>SH. 6, 8</td>
</tr>
</tbody>
</table>

### VERB-NOUN

<table>
<thead>
<tr>
<th>TYPE OF DISPLAY</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>V06N333R</td>
<td>GOFFLASH</td>
<td>SH. 3</td>
</tr>
<tr>
<td>V06N558R</td>
<td>CRASH</td>
<td>SH. 3</td>
</tr>
<tr>
<td>V04N065R</td>
<td>CRASH</td>
<td>SH. 3</td>
</tr>
<tr>
<td>V05N578R</td>
<td>CRASH</td>
<td>SH. 4</td>
</tr>
<tr>
<td>V05N345R</td>
<td>CRASH</td>
<td>SH. 4</td>
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</table>
## Displays (continued)

<table>
<thead>
<tr>
<th>Verbose Noun</th>
<th>Type of Display</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
</tr>
</thead>
<tbody>
<tr>
<td>V16N45 GOFLASH</td>
<td>R1 XXBXX TTOG/TFI</td>
<td>TIME TO IGNITION/TIME FROM IGNITION IN MINUTES, SECONDS (MAXIMUM 60.0)</td>
<td>SH. 5, 8, 9</td>
</tr>
<tr>
<td></td>
<td>R2 XXBXX</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R3 MIDDLE GIMBAL ANGLE</td>
<td>IN DEGREES</td>
<td></td>
</tr>
<tr>
<td>V05N58SR GOFLASH</td>
<td>R1 0000.1 PERIGEE ALT. IN N.M.</td>
<td></td>
<td>SH. 7</td>
</tr>
<tr>
<td></td>
<td>R2 0000.0 ΔTVG IN FPS</td>
<td>IN REFERENCE COORDINATES</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R3 0000.0 ΔTFP IN FPS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V05N61SR GOFLASH</td>
<td>R1 0000.0 ΔX</td>
<td>IN LOCAL VERTICAL COORDINATES</td>
<td>SH. 7</td>
</tr>
<tr>
<td></td>
<td>R2 0000.0 ΔY</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R3 0000.0 ΔZ</td>
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## Erasable Locations Used

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPTION1</td>
<td>5</td>
<td>STABLE ORBIT CODE</td>
<td>MIN B SEC</td>
<td>CSEC</td>
<td>2.14</td>
</tr>
<tr>
<td>OPTION2</td>
<td>1 OR 2</td>
<td>PHASE 1 (SO1) OR PHASE 2 (SOR)</td>
<td>MIN B SEC</td>
<td>CSEC</td>
<td>2.14</td>
</tr>
<tr>
<td>TINT</td>
<td>t₁</td>
<td>TIME OF INTERCEPT FOR SOI</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
</tr>
<tr>
<td>TINTSOI</td>
<td>t₁</td>
<td>SOI INTERCEPT TIME STORED FOR SOR-1G(SOR)</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
</tr>
<tr>
<td>TDEC1</td>
<td>t₁</td>
<td>STORAGE LOC FOR T₁, t₁ FOR INTEGRATION</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
</tr>
<tr>
<td>T</td>
<td>t₁</td>
<td>TIME OF FLIGHT, T₁G TO T₁</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
</tr>
<tr>
<td>DELTAR</td>
<td>δr</td>
<td>OFFSET OF STABLE ORBIT (INTERCEPT) POINT FROM PASSIVE VEHICLE</td>
<td>NM</td>
<td>METERS</td>
<td>2.29</td>
</tr>
<tr>
<td>DELTTIME</td>
<td>δt</td>
<td>TIME TO TRAVERSE δr</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
</tr>
<tr>
<td>TARGTIME</td>
<td>tₜ</td>
<td>TIME ACTIVE VEHICLE REACHES STABLE ORBIT POINT</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
</tr>
<tr>
<td>INTIME</td>
<td>t₁G</td>
<td>IGNITION TIME FOR S345.25 (CALLS INITVEL)</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
</tr>
<tr>
<td>DELVTPF</td>
<td>ΔV FINAL</td>
<td>MAGNITUDE OF ΔV REQUIRED FOR BURN</td>
<td>FPS</td>
<td>M/CSEC</td>
<td>2.7</td>
</tr>
<tr>
<td>POSTTPF</td>
<td>H₀</td>
<td>MIN PERIGEE ALT.</td>
<td>NM</td>
<td>METERS</td>
<td>2.29</td>
</tr>
<tr>
<td>DELVΣIN</td>
<td>ΔV</td>
<td>VALUE OF VELOCITY INCREMENT IN REFERENCE INERTIAL COORDINATES FOR EXTERNAL ΔV BURNS</td>
<td>FPS</td>
<td>M/CSEC</td>
<td>2.7</td>
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<td>KT</td>
<td>δt</td>
<td>STORAGE LOC FOR ATIGINC, PTIGINC (BELOW)</td>
<td>CSEC</td>
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<td>2.28</td>
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<tr>
<td>ATIGINC</td>
<td>δt</td>
<td>ACTIVE</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
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<tr>
<td>PTIGINC</td>
<td>δt</td>
<td>PASSIVE</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
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<tr>
<td>VERBNOUN</td>
<td>VXXNXX</td>
<td>STORE VERBNOUN COMBINATIONS</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
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<tr>
<td>TIG</td>
<td>t₁G</td>
<td>IGNITION TIME FOR MANEUVER</td>
<td>CSEC</td>
<td></td>
<td>2.28</td>
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### PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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</thead>
<tbody>
<tr>
<td>MUTABLE</td>
<td>$\mu_e$ (MUE)</td>
<td>EARTH GRAVITATIONAL CONSTANT</td>
<td>$3.986032 \times 10^{10}$</td>
<td>$M^2/CSEC^2$</td>
<td>$2^{-36}$</td>
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<tr>
<td>MUTABLE+6</td>
<td>$1/\sqrt{\mu_e}$</td>
<td>RECIPROCAL SQRT OF $\mu_e$</td>
<td>$50087529 \times 10^{-5}$</td>
<td>$CSEC/M^{3/2}$</td>
<td>$2^{-17}$</td>
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<tr>
<td>MUTABLE+8</td>
<td>$\mu_M$ (MUM)</td>
<td>MOON GRAVITATIONAL CONSTANT</td>
<td>$4.902778 \times 10^{8}$</td>
<td>$M^3/CSEC^2$</td>
<td>$2^{-30}$</td>
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<tr>
<td>MUTABLE+14</td>
<td>$1/\sqrt{\mu_M}$</td>
<td>RECIPROCAL SQRT OF $\mu_M$</td>
<td>$45182595 \times 10^{-4}$</td>
<td>$CSEC/M^{3/2}$</td>
<td>$2^{-14}$</td>
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</table>

### PAD LOADS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP TAG</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
<th>OCTAL VALUE</th>
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<tr>
<td>ATIGINC</td>
<td>6τ</td>
<td>CSM PREP. TIME FOR MIDCOURSE MANEUVER PREPARATION</td>
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<tr>
<td>PTIGINC</td>
<td>6τ</td>
<td>LM PREP. TIME FOR MIDCOURSE MANEUVER PREPARATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ORBITAL PARAMETERS DISPLAY

Major Subroutines and External Entry Points:

- **V82PERF:** Entry from Verb FAN
- **V82CALL:** Display and calling routine
- **TICKTEST:** TFF countdown mechanism
- **SR30.1:** Subroutine for calculating TFF and TPER
Keyed in by astronaut V82E

V82E Request orbital parameter display

V82PERF

TESTXACT Test for extended verb activity FC-2190

Previous extended verb active. Error exit

No other extended verb active

PRIORGNG

Give this job priority? FC-2050

ALM/END

FALTON

Turn on operator error light FC-2180

PINBRNCH FC-2130

V82CALL Do orbital parameter display Sh. 3

V82CALL is a NOVAC job

ENDEXT

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APOLLO GUIDANCE AND NAVIGATION

Orbital Parameters Display

Colossus IIC

DOCUMENT NO. FC-2650

DRAWN T.Ciccolo 5-5-69
PRGMR T.Ciccolo 5-29-69
ANALST

DOCNR 5-29-69

APPR'D

REV 1

SHEET 2 OF 25
From Preceding Sheet

V82GOF1
FINDVAC job priority 07
Sh. 6

Schedule computations as FINDVAC job

V82STALL holds progress of program until V82GOF1, the state vector update subroutine has had a chance to set one of the flags in V82FLAGS

V82STALL
Delay job 1 sec
FC-2070

Is one of the bits of V82FLAGS set?

Yes, a flag on

No, no flag on

V82STALL
Display: monitor
Apogee : R1 XXXX.X dec naut miles
Perigee: R2 XXXX.X dec naut miles
TFF : R3 XXBXX dec min. sec.

GOXDSPF
V16 N44
R1: Apogee
R2: Perigee
R3: TFF

Recycle

Terminate
Proceed

B5OFFF

Ends extended verb which has called TESTXACT

V82GOF1P
Sh. 3
V82GON AVERAGEG running

V82GON1 FINDVAC PRIOR?
Sh. 11

FINDVAC jobs will be done before NOVAC jobs of the same nominal priority. Therefore the next test on NEWJOB will result in V82GON1 being completed before V82GON

No

Is NEWJOB = 0 ?

Yes

V82REDSP

Does present job still have highest priority?

GoXDSPF

Monitor

R1 Apogee: XXXX.X naut. miles
R2 Perigee: XXXX.X naut. miles
R3 TFF: XXBXX min.-sec.

Recycle

Proceed or terminate

V82GON1

V82GON1 is such a job

CHANG1 FC-2050

There is a job with higher priority

B5OFF

Ends extended verb which has called TESTXACT
Initially displays 0. If astronaut desires conically extrapolated orbital parameters of orbit at current time, key in PRO. Otherwise, key in Ground Elapsed Time and then PRO.

Recycle (Load new time)

GOXDSPF

V06 N16
R1: hours
R2: minutes
R3: csec

Terminate

ISTIMEOK

MPAC_D ← DSPTEMX_D

Was an integration time loaded?

Is MPAC_D ≠ 0 ?

Yes

GETNOW

LOADTIME
Load present time into MPAC_D

FC-2100

Output: MPAC_D = present time in csec @2^28

NO

STRTDECI

TDEC1_D ← MPAC_D
TSTART82_D ← MPAC_D

Store loaded time

Next Sheet
From Preceding Sheet

Does astronaut choose this vehicle?

No

Does OPTION82 = 1?

Yes

LEM

OTHPREC = LEMPREC

Input: permanent LM state vector

TDEC1: time to integrate

Output:

RATT \_ position vector

VATT \_ velocity vector

TATD \_ time of RATT

OTHSHIP

OTHPREC integrate state vector of LM to present time FC-2290

THISSHIP

THISPREC = CSMPREC

Input: permanent CSM state vector

TDEC1 = time to integrate to

Output:

RATT \_ position vector @27

VATT \_ velocity vector @29

TATD \_ time of RATT

VATT

BOTHSHIP

Output of conic routines put into R30

locations:

\[ \frac{1}{\mu} \]

rone = RATT

vone = VATT

tff/rtmued = 1/rtmued x2

hpermind = minpered x2

\[ \frac{1}{\mu} \]

1/rtmue = .50087529 x 10^{-5} m. @2^{-17}

1/rtmum = .45162595 x 10^{-4} m. @2^{-14}

minperm = 10668m. @2^{-27}

minperse = 91440m. @2^{-29}

X2 index register contains zero if spacecraft is in earth's sphere of influence 2 for moon's sphere, so that proper value will be picked up.

Next Sheet

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APOLLO GUIDANCE AND NAVIGATION

Orbital Parameters Display

COLOSSUS IIIC

DOCUMENT NO.
FC-2650

REV 1 SHEET 7 OF 25
From Preceding Sheet

Is spacecraft in earth's sphere?

Yes

Does $x_2 = 0$ ?

Yes

EARTH PAD

Clear V82EMFLG

Indicate to be in earth's sphere

$\text{MPAC}_D - \text{RPAD}_D$

$\text{RPAD}_D = 6,373,338 \text{ m } @ 29$

$= 20,909,901.57 \text{ ft}$

$\text{MPADTEM}_D - \text{MPAC}_D$

No

MOON PAD

Set V82EMFLG

Indicate to be in moon's sphere

$\text{MPAC}_D - |\text{RLS}_V|_D$

$\text{RLS}_V$ = position vector of landing site, m $@ 27$

Next Sheet
VONE\textsuperscript{v} = present velocity vector
V82EMFLG: Flag on \textbullet{} moon's sphere
Flag off \textbullet{} earth's sphere
RPADTEM\textsubscript{D} = radius of pad: meters

\begin{align*}
\text{Output:} & \quad \text{HAPOX}\textsubscript{D} = \text{apogee altitude above pad} \\
& \quad \text{radius: meters} @ 2^{29} \\
& \quad \text{HPERX}\textsubscript{D} = \text{perigee altitude above pad} \\
& \quad \text{radius: meters} @ 2^{29} \\
& \quad \text{TFF}\textsubscript{D} = \text{time of free fall: csec} @ 2^{28} \\
& \quad \text{TPER}\textsubscript{D} = \text{time to perigee: csec} @ 2^{28}
\end{align*}

SR30.1
Input: \quad \text{RONE}_\text{V} = \text{present position vector:} \\
\quad \text{meters} @ 2^{29} \\
\text{VONE}_\text{V} = \text{present velocity vector:} \\
\quad \text{m/csec} @ 2^{7}

\text{V82EMFLG: Flag on \textbullet{} moon's sphere} \\
\text{Flag off \textbullet{} earth's sphere}

\text{Calculation}
\text{HAPOX}_\text{D} \quad \text{HPERX}_\text{D}
\text{TFF}_\text{D} - \text{TPER}_\text{D}

\text{From Preceding Sheet}

\begin{align*}
\text{Is POO running?} \\
\text{MODREG} = 0 \\
\text{Yes} \\
\text{No} \\
\text{CA N D E L} \\
\text{Sh. 13}
\end{align*}

\text{Entrance from SPLRET, with POO running}

\begin{align*}
\text{TSTART82}_\text{D} + \text{TIME2}_\text{D} - \text{TSTART82}_\text{D} \\
\text{Time elapsed since TSTART82}
\end{align*}

\text{Next Sheet}
- TPER is set to zero when pericenter is above minimum. If so, TFF will be displayed as 59 min. 59 sec, and - TPER will be decremented. Note, TFF will also be displayed as 59 min. 59 sec when apocenter is below minimum pericenter, but it will then start decrementing, giving meaningless values.
V82GON scheduled this FINDVAC job of priority 07

\[
\begin{align*}
\text{V82GON1} & \quad \text{Position vector m @}^2_{29} \\
\text{V82GON2} & \quad \text{Velocity vector m/csec @}^2_{27}
\end{align*}
\]

Earth's sphere

Is AMOONFLG on?

No

EARTHGON

Indicate earth sphere for SR30.1

Clear V82EMFLG

\[
\begin{align*}
\text{TFF/RTMU}_D & + \text{1/RTMUE}_D \\
\text{HPERMID}_D & + \text{MINPERE}_D \\
\text{MPACD}_D & + \text{RPAD}_D
\end{align*}
\]

91440 m @^2_{29} (300,000 ft.)

Yes

MOONGON

Indicate moon sphere for SR30.1

Set V82EMFLG

\[
\begin{align*}
\text{TFF/RTMU}_D & + \text{1/RTMUM}_D \\
\text{HPERMID}_D & + \text{MINPERMD}_D \\
\text{MPACD}_D & + |RLS_V|_D
\end{align*}
\]

10668 m @^2_{27} (35,000 ft.)

\[ RLS_V = \text{position vector of moon landing site.} \]
From Preceding Sheet

RPATDEM ← MPAC_D

SR30.1
Calculate
HAPOX_D, HPERX_D
TFF_D, TPER_D
Sh. 15

SR30.1
Input:
RONE_V = position vector in meters @ 2^29
VONE_V = velocity vector in meters/csec @ 2^7
RPADTEM = pad radius in meters @ 2^29
V82EMFLG on = moon.
off = earth

Output:
HPERX_D perigee height above pad radius @ 2^29
HAPOX_D apogee height above pad radius @ 2^29
TFF_D time of freefall csec @ 2^28
-TPER_D time to perigee

Is MODREG = 11 running?
(earth orbit insertion monitor)

No

V82GON3

Is bit 5 of EXTVBACT = 0?

Yes

Does astronaut wish to terminate?

No

ENDEXT

DELAYJOB
Delay job 1 sec
FC-2070

V82GON1
Sh. 11

When AVERAGEG is running, computations are updated after 1 sec

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APOLLO GUIDANCE AND NAVIGATION
Orbital Parameters Display

DRAWN: J. Gossia
PRGMR: T. Girolamo
ANALST:

DOCNR: 8/25/69
APPR'D: 8/25/69

COLOSSUS IIC
DOCUMENT NO. FC-2650

REV 1 SHEET 12 OF 25
From Preceding Sheet

**CANDEL**

**INSTALL**
Stall this program until integration is free
FC-2290

Any integration must be completed before DELRSLPL can run

**DELRSLPL**
Input:
- MPACD = TFF
- TFF/RTMU D', RMAG1 D'
- NRMAG D', TFFVSQ D'
- TFFNPD D', RTERM D'
- NRTERM D', TFFX D'
- TFFTEM D', LAT(SPL) D'
- LNG(SPL) D'

Output:
- SPLERROR_D = range angle in revs @200

**SPLRET**

Is POO running?

- **No**
  - Check for terminate instruction, or DELAYJOB
    - V82GON3
      - Sh. 12
  - SPLRET1
    - Sh. 9

- **Yes**
This is a WAITLIST task which is first scheduled by V82GOFF, and then at the beginning of each cycle for 1 second intervals.

TICKTEST

Is bit 5 of EXTVOBACT off?

- Yes
  - Has astronaut killed this extended verb?
    - No
      - V82 not killed
    - Yes
      - ENDEXT
      - NOVAC
      - priority 25
      - FC-2130
      - An extended verb is a job, and cannot be terminated by a task

- No
  - DOTICK

TICKTEST

WAITLIST

1 sec

Sh. 14

Reschedule TICKTEST for 1 sec

Which, if any, of first 2 bits of V82FLAGS is set?

- Bit 1:
  - None
  - TPERTICK

- Bit 2
  - None
  - TFFTICK

- TPED ← TPED + 1SEC
- Increment TPED by one sec

- TFD ← TFD + 1SEC
- Increment TFD by one sec

TASKOVER

TASKOVER

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APOLLO GUIDANCE AND NAVIGATION

Orbital Parameters Display

COLOSSUS IIC

DOCUMENT NO.
FC-2650

DRAWN: J. Cincaja 1/2/69
PRGMR: J. Cincaja 8/24/69
ANALYST:

DOCMT: 1/27/69
APPR'D: 1/29/69

REV. 1

SHEET 14 OF 25
SR30.1

Set PUSHLIST pointer to 0

Store QPRET in S2

Is V82EMFLG off?

Yes - earth's sphere

No - moon's sphere: rescaling required

No rescaling

RONEV = 2^2 * RONEV
VONEV = 2^2 * VONEV

TFFCALLS

Next Sheet
TFFCONMU:

Input:
- $\mathbf{RONE}_\mathbf{V} = \text{position vector in meters } E@^{29} M@^{27}$
- $\mathbf{VONE}_\mathbf{V} = \text{velocity vector in m/csec } E@^{27} M@^{25}$
- $\mathbf{TFF/RTMU} = 1/V \ E@^{2-17} M@^{2-14}$

Output:
- $\mathbf{RMAG}_D = \text{radius at time of } \mathbf{RONE} \text{ in meters } E@^{29}, M@^{27}$
- $\mathbf{NRMAG}_D = \text{normalized } \mathbf{RMAG}, \text{ norm count in } X_1 \text{ meters } E@^{29-NR} M@^{27-NR}$
- $\mathbf{NR} = -X_1 = -\text{norm count for } \mathbf{NRMAG}$
- $\mathbf{TFFNP}_D = \text{semilatus rectum, weighed by NR: meters } E@^{29-2NR} M@^{26-2NR}$
- $\mathbf{TFFVSQ}_D = \sqrt{\mathbf{V}} \text{ present velocity, normalized 1/meters } E@^{20} M@^{18}$
- $\mathbf{TFFALFA}_D = \text{a weighted by NR, in 1/meters } E@^{26+NR} M@^{24+NR}$
- $\mathbf{TFFRTALF}_D = \sqrt{\mathbf{G}} \text{ normalized } E@^{10-NA} M@^{9-NA}$
- $\mathbf{X2} = -\mathbf{NA} = \text{norm count for } \sqrt{\mathbf{G}}$
- $\mathbf{TFF1/ALF}_D = \text{signed, semi-major axis weighted by NA. In meters } E@^{2.22+2NA} M@^{2.20+2NA}$

$\mathbf{VONE'} = \mathbf{VONE} \cdot \mathbf{TFF/RTMU} \text{ in } 1/(M \ 1/2) @^{10/2^{9}}$

TFFRP/RA:

Input:
- $\mathbf{TFFALFA}_D = \alpha = \text{(semi-major axis)}^{-1} \text{ in meters } E@^{26+NR}/2^{24+NR}$
- $\mathbf{TFFNP}_D = \text{semi-latus rectum in meters } @^{29-2NR}/2^{38-2NR} \text{ set by } \mathbf{TFFCONMU}$

Output:
- $\mathbf{RPER}_D = \text{perigee radius in meters } @^{28}/2^{27}$
- $\mathbf{RAPO}_D = \text{apogee radius in meters } @^{29}/2^{27}$

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Orbital Parameter Display

COLOSSUS IIC DOCUMENT NO.

FC-2550

REV 1 SHEET 16 OF 25
From Preceding Sheet

Yes - earth's sphere

Is V$^2$EMPLG off?

No - moon's sphere

$MPAC_\text{D} \leftarrow MPAC_\text{D} \cdot 2^{-2}$ Scaling necessary for moon

MAXCHK

Is $MPAC \geq MAXNM_\text{D}$?

No

Below MAX

Yes too large for display

$MPAC_\text{D} \leftarrow MAXNM_\text{D}$

Return via QPRET

Next Sheet

If apocenter exceeds the maximum possible for display, program chooses maximum.
From Preceding Sheet

STORHAPC

\[ \text{HAPOX}_D - \text{MPAC}_D \]
\[ \text{MPAC}_D - \text{RPER}_D - \text{RPADTEM}_D \]
\[ \text{MPAC} + 4D - \text{RPER}_D - \text{RPADTEM}_D \]

Store into apocenter location: meters @ \(2^{29}\)
Prepare to store HPERD
Save for comparison with HPERMIN

Yes - earth's sphere
Is V82EMFLG off?
No - moon's sphere

MPACD \(=\) MPAC \(\cdot 2^{-2}\)
Rescaling necessary

MAXCHK
Check for too large value
Sh. 17

If pericenter exceeds the maximum possible for display, program chooses maximum

Next Sheet
From Preceding Sheet

STORHPER

HPERX_D ← (MPAC + 4)

Store into pericenter location meters @2^29

Is orbit pericenter greater than minimum pericenter?

Yes: calculate time to perigee

MPAC_D ← ZERO_D

Make -TPER=0

DOTPER

MPAC_D ← RPER_D

CALCTPER

Input:

RONE_V = position vectors in meters
@2^29/2^27

VONE' V = \sqrt{\mu} csec/m^2 @2^{-10}/2^{-9}

RMAG_1D = RONE_V D meters @2^29/2^27

MPAC_D = RPER_D = terminal radius length, meters @2^29/2^27

TFF/RTMU_D = 1/\sqrt{\mu} csec/m^3/2 @2^{-17}/2^{-14}

NRMAG_D = NORMX1 (RMAG) meters
@2^29 - X1/2^27 - X1

X1 = Norm factor for KMAG

TFFNP_D = semilatus rectum meters
@2^{38} - 2X/2^{36} - 2X

TFFALFA = a meters @2^{-26} + X1/2^{-24} + X1

TFFRTALF = \sqrt{\alpha} meters^{1/2} @2^{10} - X2/2^{-9} - X2

X2 = Norm count for TFFRTALF

TFF1/ALF = signed, semimajor axis, meters
@2^{-22} - 2X2/2^{-20} - 2X2

Output:

MPAC_D = time to perigee in csec @2^28

Next Sheet
From Preceding Sheet

MPAC_D → MPAC

SKIPTPER

-TPER_D ← MPAC_D
MPAC_D ← HPERMIN_D + RPADTEM_D

CALC_TFF
Calculate time of free fall

FC-2320

TFF_D ← -MPAC_D

Return via S2

CALC_TFF
Input:
RONE_V, VONE_V, RMAG1_D, MPAC = RPADTEM + HPERMIN, TFF/RTMU_D
NRMAG_D X1, TFFNP_D, TFFALFA_D' TFFRTALF_D' X2, TFF1/ALF

Output:
MPAC_D = TFF = time of free-fall, in csec @ 22

Note:
If the trajectory fails to reach HPERMIN + RPADTEM (300,000' or 35,000') then TFF will be displayed as 59B59
<table>
<thead>
<tr>
<th>TYPE OF DISPLAY</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>VERB NOUN</th>
<th>WHERE EXECUTED</th>
<th>WHERE TESTED</th>
<th>WHERE CLEARED</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOXDSFF</td>
<td>R1: Option code 2</td>
<td>V04N12</td>
<td>SH. 3</td>
<td>SH. 4</td>
<td>SH. 6</td>
<td>AVERAGEG running</td>
<td>AVERAGEG not running</td>
</tr>
<tr>
<td></td>
<td>R2: Option 1 assumed</td>
<td>V16N44</td>
<td></td>
<td></td>
<td></td>
<td>Bit 5 or EXTVECT</td>
<td>Do not terminate extended verb</td>
</tr>
<tr>
<td></td>
<td>R3: Blanked out</td>
<td>V06N16</td>
<td></td>
<td></td>
<td></td>
<td>AMOONFLAG</td>
<td>In moon's sphere</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>V82EMFLAG</td>
<td>TICKPER operating</td>
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<td></td>
<td></td>
<td>Bit 1 of V82PLAF</td>
<td>In earth's sphere</td>
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<td>Bit 2 of V82PLAF</td>
<td>TICKPER not operating</td>
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<td>TICKTF</td>
<td>TICKTF not operating</td>
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<tr>
<td>SUBROUTINE NAME</td>
<td>FLOW CHART</td>
<td>DESCRIPTION</td>
<td>WHERE CALLED</td>
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<tr>
<td>CALCTFF</td>
<td>2370</td>
<td>Calculates time of free fall to a particular radius</td>
<td>SH. 20</td>
<td></td>
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<tr>
<td>CALCTPER</td>
<td>2320</td>
<td>Calculates time of free fall to pericenter</td>
<td>SH. 19</td>
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<tr>
<td>DELAYJOB</td>
<td>2070</td>
<td>Delays a job for a particular time period</td>
<td>SH. 12</td>
<td></td>
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<tr>
<td>DELRSPL</td>
<td>2320</td>
<td>Calculates error in splashdown between calculated and predicted</td>
<td>SH. 13</td>
<td></td>
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<tr>
<td>ENDEXT</td>
<td>2130</td>
<td>Ends an extended verb</td>
<td>SH. 14</td>
<td></td>
<td></td>
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<tr>
<td>FALTON</td>
<td>2130</td>
<td>Turns on operator error light</td>
<td>SH. 2</td>
<td></td>
<td></td>
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<tr>
<td>LOADTIME</td>
<td>2100</td>
<td>Loads present time into MPACD</td>
<td>SH. 6</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>OTHPREC</td>
<td>2300</td>
<td>Update LM vector to a particular time</td>
<td>SH. 7</td>
<td></td>
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<tr>
<td>PRIOCHNG</td>
<td>2050</td>
<td>Change calling job's priority</td>
<td>SH. 2</td>
<td></td>
<td></td>
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<tr>
<td>TESTXACT</td>
<td>2190</td>
<td>Test for extended verb activity</td>
<td>SH. 2</td>
<td></td>
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<tr>
<td>TFFCONMU</td>
<td>2320</td>
<td>Computes various parameters used in the TFF routines, and establishes them in the push list area</td>
<td>SH. 16</td>
<td></td>
<td></td>
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<tr>
<td>TFFRP/RA</td>
<td>2320</td>
<td>Calculates perigee and apogee radius for a given conic</td>
<td>SH. 16</td>
<td></td>
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<tr>
<td>THISPREC</td>
<td>2300</td>
<td>Update CSM state vector to a particular time</td>
<td>SH. 7</td>
<td></td>
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<tr>
<td>INSTALL</td>
<td>2300</td>
<td>Stall calling program until integration is not in use. Then inhibit any other program from using integration until INTAKE is called</td>
<td>SH. 13</td>
<td></td>
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<tr>
<td>AGC TAG</td>
<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING UNITS</td>
<td>AGC UNITS</td>
<td>AGC SCALING</td>
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<td>-------------</td>
<td>--------------------------------</td>
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<td>-----------</td>
<td>-------------</td>
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<td></td>
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<tr>
<td>-TPER_D</td>
<td>( t_{PER} )</td>
<td>Negative of time from pericenter</td>
<td>min/sec</td>
<td>csec</td>
<td>( 2^{28} )</td>
<td></td>
<td></td>
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<tr>
<td>HAPOX_D</td>
<td>( h_a )</td>
<td>Apocenter altitude</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{29}/2^{27} )</td>
<td></td>
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<tr>
<td>HPERMIN_D</td>
<td>( h_p )</td>
<td>Minimum perigee</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{29}/2^{27} )</td>
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<tr>
<td>HPERX_D</td>
<td>( h_p )</td>
<td>Pericenter altitude</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{29}/2^{27} )</td>
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<tr>
<td>MODREG</td>
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<td>Major mode indication</td>
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<td>NEWJOB</td>
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<td>Points to coreset of active job</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>of highest priority</td>
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<tr>
<td>NRMAG_D</td>
<td></td>
<td>Normalized RMAG</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{27} + x1/2^{24} + x1 )</td>
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<td></td>
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<tr>
<td>RAPO_D</td>
<td></td>
<td>Apogee radius</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{29}/2^{27} )</td>
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<tr>
<td>RATT_D</td>
<td>( r )</td>
<td>Radius vector output of</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{29} )</td>
<td></td>
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</tr>
<tr>
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<td></td>
<td>integration</td>
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</tr>
<tr>
<td>(</td>
<td>R_{LS}V</td>
<td>_D )</td>
<td>( r_{LS} )</td>
<td>Lunar landing site radius</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{27} )</td>
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<tr>
<td>RMAG1_D</td>
<td>( r )</td>
<td>Magnitude of radius vector</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{27}/2^{29} )</td>
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<tr>
<td>RN_D</td>
<td>( r )</td>
<td>Radius vector as given by</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{29} )</td>
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<tr>
<td></td>
<td></td>
<td>AVERAGEG</td>
<td></td>
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<tr>
<td>RONE_D</td>
<td>( r )</td>
<td>Radius vector input to</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{29}/2^{27} )</td>
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</tr>
<tr>
<td></td>
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<td>integration</td>
<td></td>
<td></td>
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<tr>
<td>RPADTEM_D</td>
<td></td>
<td>Location for storing pad radius</td>
<td>feet</td>
<td>meters</td>
<td>( 2^{29}/2^{27} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGC TAG</td>
<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING UNITS</td>
<td>AGC UNITS</td>
<td>AGC SCALING</td>
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<td></td>
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<tr>
<td>RPERD</td>
<td>r_p</td>
<td>Magnitude of pericenter</td>
<td>feet</td>
<td>meters</td>
<td>$2^{27}/2^{29}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TFF_D</td>
<td>t_ff</td>
<td>Time of free fall to a certain altitude</td>
<td>seconds</td>
<td>csec</td>
<td>$2^{28}$</td>
<td></td>
<td></td>
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<tr>
<td>TFF/RTMU_D</td>
<td>$1/\sqrt{\mu}$</td>
<td>Inverse of the square root of mu</td>
<td>sec/feet$^{3/2}$</td>
<td>csec/m$^{3/2}$</td>
<td>$2^{14}/2^{17}$</td>
<td></td>
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<tr>
<td>TFFALFAD</td>
<td>$p$</td>
<td>Inverse of the semimajor axis of a conic</td>
<td>1/feet</td>
<td>1/meters</td>
<td>$2^{-26} - X1$, $2^{-24} - X1$, $2^{28} + X1$, $2^{36} + X1$, $2^{-10} - X1$, $2^{-9} - X1$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TFFNP_D</td>
<td>$\alpha$</td>
<td>Semilatus rectum, normalized</td>
<td>feet</td>
<td>meters</td>
<td>$2^{-20}/2^{-18}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TFFRTALF_D</td>
<td>$\sqrt{\alpha}$</td>
<td>Square root of alpha</td>
<td>1/feet$^{1/2}$</td>
<td>1/m$^{1/2}$</td>
<td>$2^{22} - 2 \cdot X2$, $2^{20} - 2 \cdot X2$, $2^{28}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TFFVSQ_D</td>
<td>$(v)^2$</td>
<td>Velocity/$\sqrt{u}$</td>
<td>1/feet$^{1/2}$</td>
<td>1/m$^{1/2}$</td>
<td>$2^{28}$</td>
<td></td>
<td></td>
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<tr>
<td>TFF1/ALF_D</td>
<td>X2</td>
<td>Signed, semi-major axis, weighted by X2</td>
<td>feet</td>
<td>meters</td>
<td>$2^{28}$</td>
<td></td>
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<tr>
<td>TIME2_D</td>
<td></td>
<td>Timing registers</td>
<td>seconds</td>
<td>csec</td>
<td>$2^{28}$</td>
<td></td>
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<tr>
<td>TSTART82_D</td>
<td></td>
<td>Storage for TIME2 input</td>
<td>seconds</td>
<td>csec</td>
<td>$2^{28}$</td>
<td></td>
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<tr>
<td>TDEC1_D</td>
<td></td>
<td>Time to be integrated to</td>
<td>seconds</td>
<td>csec</td>
<td>$2^{28}$</td>
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### ERASABLE LOCATIONS USED (CONTINUED)

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<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>VATT&lt;sub&gt;V&lt;/sub&gt;</td>
<td>Velocity output of integration routines</td>
<td>feet/sec</td>
<td>meters/csec</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>VN&lt;sub&gt;V&lt;/sub&gt;</td>
<td>Velocity vector, output of AVERAGEG</td>
<td>feet/sec</td>
<td>m/csec</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
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<tr>
<td>VONE&lt;sub&gt;V&lt;/sub&gt;</td>
<td>Velocity vector</td>
<td>feet/sec</td>
<td>m/csec</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
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<tr>
<td>VONE&lt;sup&gt;1/2&lt;/sup&gt;&lt;sub&gt;V&lt;/sub&gt;</td>
<td>VONE</td>
<td>feet&lt;sup&gt;-1/2&lt;/sup&gt;</td>
<td>m&lt;sup&gt;-1/2&lt;/sup&gt;</td>
<td>2&lt;sup&gt;-10/2&lt;/sup&gt;</td>
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### PROGRAM CONSTANTS

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<tr>
<th>AGC TAG</th>
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<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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</thead>
<tbody>
<tr>
<td>MAXNM</td>
<td></td>
<td>Maximum display value possible</td>
<td>9999.9 NM</td>
<td>01065 05603&lt;sub&gt;8&lt;/sub&gt;</td>
<td>2&lt;sup&gt;0&lt;/sup&gt;</td>
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<tr>
<td>MINPERE</td>
<td>r&lt;sub&gt;pMIN&lt;/sub&gt;</td>
<td>300,000 ft reference alt for earth</td>
<td>300,000 ft</td>
<td>91440 meters</td>
<td>2&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
<tr>
<td>MINPERM</td>
<td>r&lt;sub&gt;pMIN&lt;/sub&gt;</td>
<td>35,000 ft reference alt for moon</td>
<td>35,000 ft</td>
<td>1068 meters</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
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<tr>
<td>RPAD</td>
<td></td>
<td>Standard pad radius</td>
<td>20910922 ft</td>
<td>6373338 meters</td>
<td>2&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
<tr>
<td>1/RTMUE</td>
<td>1/&lt;sqrt&gt;µ&lt;sub&gt;e&lt;/sub&gt;</td>
<td>Inverse of the square root of µ for earth</td>
<td>0.0008427916 x&lt;sup&gt;-5&lt;/sup&gt;</td>
<td>50087529 x&lt;sup&gt;-5&lt;/sup&gt;</td>
<td>2&lt;sup&gt;-17&lt;/sup&gt;</td>
</tr>
<tr>
<td>1/RTMU</td>
<td>1/&lt;sqrt&gt;µ&lt;sub&gt;M&lt;/sub&gt;</td>
<td>Inverse of the square root of µ for moon</td>
<td>0.007599228 x&lt;sup&gt;-4&lt;/sup&gt; sec/ft&lt;sup&gt;3/2&lt;/sup&gt;</td>
<td>0.45162595 x&lt;sup&gt;-4&lt;/sup&gt; csec/m&lt;sup&gt;3/2&lt;/sup&gt;</td>
<td>2&lt;sup&gt;-14&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
SET TRACKFLAG

MPAC $\rightarrow$ VOCN84+1

RECYCLE

GOFFLASH

VOCN33

DISPLAY LAST TIG

PROCEED

MPAC $\rightarrow$ VOCN84

RECYCLE

GOFFLASH

VOCN84

DISPLAY LAST $\Delta V$

PROCEED

TOECD1 $\rightarrow$ TIG

Set NO DODFLAG

OTHPRC

PRECISION INTEGRATE LM STATE VECTOR TO TIG
FC-2290

COMPMAT

24D $\rightarrow$ UNIT($-B$)
16D $\rightarrow$ UNIT($YX2$)
12D $\rightarrow$ UNIT($[X(X)]X-B$)

MPAC $\rightarrow$ OELV0V

$\Delta X_{LV} = (\Delta Y_{REF} \times UNIT([X(X)]X-B)) + Y_{TIG}$

$6D_{V} = (MPAC_{V} \times 12D_{V}) + VATT.$

INSTALL

RESERVE ORBITAL INTEGRATION
FC-2290

NEXT SHEET

ENABLE TRACKING

R1 XXXXX HRS
R2 G00XX MIN
R3 G00XX SECS

TIG FOR LM BURN

3-COMPONENT LM $\Delta V$ BASIC REF COORDINATES BEFORE BURN

SAME AS LEMPREC
UPDATE LM TO TIG
INPUT: TIG IN TOECD1
OUTPUT RATT, VATT OF LM AT TIG

DISALLOW V3?

BURN $\Delta V$ TRANSFORMED TO LV COORDINATES AND ADDED TO LM VELOCITY AT TIG

CHECK AVAILABILITY INTEGRATION

TARGET DELTA V

FC-2670
FROM PRECEDING SHEET

P76SUB1

CLEAR
MOONFLAG

X = 0

NO

YES

SET
MOONFLAG

EARTH
SPHERE OF
INFLUENCE

MOON SPHERE
OF INFLUENCE

RVQ

VCV = GD * X + 2
RCV = RATT * X + 2

TET = TIG

MPAC = TETTHIS

CLEAR
INTYFLG

INTOTHIS

TDEC1 = MPAC

INTGRVS

UPDATE
LEM TO TIG
(ENGKE)

FC-2290

INTSTALL
RESERVE
INTEGRATION

FC-2290

NEXT SHEET

SCALE V,R LM ON X2 2/2 EARTH/MOON

STORE TIG, TETTHIS

BIT 4, FLAGWORD 3 ENGKE INTEGRATION

TIG FOR INTGRVS

INPUT: TIG
OUTPUT: RATT, VATT OF CSM @ TIG

P76
TARGET DELTA V

COLOSSUS 2D FC-2670
FROM PRECEDING SHEET

P76SUB1
SET/CLEAR MOONFLAG
SH2

SAVE CSM POSITION, VELOCITY, TIME
INTEGRATED TO

PERRECT ← RATT1
RCV ← RATT1
TET ← TAT
MPAC ← VATT1

INITIALIZE NEW CONIC
FC-2290

GROUP 4
SET UP RESTARTS
TO SCHEDULE
NEXT LOC AS FND-
VAC JOB W/SAME
PRIORITY

SET RENTFLG

ATOPOTH
MOVE PERRECT
OF LM FROM ACTIVE
TO PASSIVE LOC
FC-2290

INTKARK
PERMIT USE OF
ORBITAL
INTEGRATION
FC-2290

CLEAR NORDFLG

ENDP76

MARKCTR ← ZERO
VHF CNT ← ZERO
MRKBUF2 ← NEGONE

GOTOP00H

BIT 7, FLAG 10
INTEGRATION ROUTINE TO BE RESTARTED
(SAME AS ATOPLEM)

RELINQUISH INTEGRATION ROUTINE

ALLOW V37

CLEAR COUNTERS
### SUBROUTINES CALLED

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>WHERE CALLED</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
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<tbody>
<tr>
<td>OTHPREC</td>
<td>FC-2290</td>
<td>(SAME AS LEMPREC) PRECISION INTEGRATION OF LM</td>
<td>Sh. 2</td>
</tr>
<tr>
<td>INSTALL</td>
<td>FC-2290</td>
<td>RESERVES ORBITAL INTEGRATION</td>
<td>2</td>
</tr>
<tr>
<td>INTERGRS</td>
<td>FC-2290</td>
<td>ENKE UPDATE OF LEM TO TIG</td>
<td>3</td>
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<tr>
<td>MINRECT</td>
<td>FC-2290</td>
<td>INITIALIZE NEW CONIC</td>
<td>4</td>
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<tr>
<td>ATOPOTH</td>
<td>FC-2290</td>
<td>MOVES LM STATE VECTOR TO PASSIVE STORAGE LOC</td>
<td>1</td>
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<tr>
<td>INTWAKE 0</td>
<td>FC-2290</td>
<td>RELEASES ORBITAL INTEGRATION ROUTINES</td>
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### FLAGS

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<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
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<tbody>
<tr>
<td>TRACKFLG</td>
<td>ENABLE MARKTAKING</td>
<td>INHIBIT MARKTAKING</td>
<td>Sh. 2</td>
<td>Sh. 3</td>
<td>Sh. 5</td>
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<tr>
<td>MOONFLAG</td>
<td>MOON SPHERE OF INFLUENCE</td>
<td>EARTH SPHERE OF INFLUENCE</td>
<td>Sh. 5</td>
<td>Sh. 3</td>
<td>Sh. 5</td>
</tr>
<tr>
<td>INTYPLAG</td>
<td>ENKE INTEGRATION</td>
<td>CONIC INTEGRATION</td>
<td>Sh. 3</td>
<td>Sh. 3</td>
<td>Sh. 3</td>
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<tr>
<td>REINFLAG</td>
<td>RESTART INTEGRATION</td>
<td>DO NOT RESTART INTEGRATION</td>
<td>Sh. 4</td>
<td>Sh. 4</td>
<td>Sh. 4</td>
</tr>
<tr>
<td>NODOFLG</td>
<td>V=7 NOT PERMITTED</td>
<td>V=7 PERMITTED</td>
<td>Sh. 2</td>
<td>Sh. 4</td>
<td>Sh. 4</td>
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### VARIABLE ERASABLE LOCATIONS (USED)

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<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
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<tr>
<td>TDSEC</td>
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<td>STORAGE LOC FOR INTEGRATION TIME</td>
<td>CSEC</td>
<td>2^28</td>
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<td>CSEC</td>
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<td>ΔV OTHER VEHICLE (LM)</td>
<td>M'CSEC</td>
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<td>V</td>
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<td>CSEC</td>
<td>2^28</td>
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<td>TEMPORARY TIME OF CSM STATE VECTOR</td>
<td>CSEC</td>
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<td>TEMPORARY POSITION AT RECT TIME</td>
<td>M</td>
<td>2^23</td>
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<td>MARK COUNTER (USED BY R31)</td>
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<td>VIIF MARK COUNTER</td>
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<td>DESCRIPTION OF EACH REGISTER</td>
<td>WHERE EXECUTED</td>
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<td>V06N30</td>
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<td>DISPLAY LAST X</td>
<td>Sh. 2</td>
<td></td>
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<tr>
<td>V06N33</td>
<td></td>
<td>DISPLAY LAST TIG</td>
<td>Sh. 2</td>
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</table>
THRUST PROGRAMS (P40 AND P41)

Within this flowchart are the replacement sheets (Sh. 15, 51) to update the COLOSSUS 2C flowchart, FC-2680, Rev. 2, to the COLOSSUS 2D flowchart, FC-2680, Rev. 3.
THRU TRANPS (P40 AND P41)

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS:

P40CSM: HANDLES TIMING OF AN SPS MANEUVER

INPUTS (FROM PRE-THRU TRANPS):

TIG, TIME OF INITIATION OF MANEUVER, IN CSEC @ 16
XDELFVFLG = INDICATES WHETHER EXTERNAL ΔV
OR LAMBERT MANEUVER

IF EXTERNAL ΔV

{ DELDSIN = DESIRED IMPULSIVE VELOCITY CHANGE
  IN REFERENCE COORDINATES,
  IN M/CSEC @ 16
  WEIGHT/G = MASS OF TOTAL VEHICLE (INCLUDING
  LM IF APPROPRIATE), IN KG @ 16
  RTV = POSITION VECTOR AT TIME OF IGNITION
  IN REFERENCE COORDINATES, IN M @ 16
  VTIG = VELOCITY VECTOR AT TIME OF IGNITION
  IN REFERENCE COORDINATES, IN M/CSEC @ 16

OR

IF LAMBERT

ECSTEER = CROSS-PRODUCT STEERING CONSTANT
@ 16
RTARG = AIMPOINT POSITION VECTOR IN REFERENCE COORDINATES, IN M @ 16
TPASS = TIME OF ARRIVAL AT AIMPOINT
IN CSEC @ 16

P41CSM: HANDLES TIMING OF AN RCS MANEUVER

INPUTS (FROM PRE-THRU TRANPS):

ALL THOSE FOR P40 (EXTERNAL ΔV CASE), AS WELL AS
NJETSFLG = INDICATES 2- OR 4-JET BURN

SETMINDB: SETS MINIMUM DEADBAND
SH, 7
TIGBLNK: BLANKS DISPLAY (AT TIG-35)
SH, 14
TIGAVEG: RESUMES DISPLAY; STARTS AVERAGE ROUTINE (AT TIG-30)
SH, 15
TIG-5 SCHEDULES IGNITION (AT TIG-5), CAUSES V99 FLASH (IGNITION
ENABLE REQUEST)
SH, 16
S40.13 DETERMINES WHETHER LONG (STEERING) OR SHORT (IMPULSE)
BURN, IF SHORT, COMPUTES BURN TIME
SH, 17
TIG-0 STARTS IGNITION
SH, 20
IGNITION: TURNS ON SPS ENGINE, SETS UP TVC DAP; IF SHORT BURN,
SCHEDULES ENGINE CUTOFF
SH, 20
ENGINOFF: SETS UP ENGINE CUTOFF AND RETURN TO RCS DAP
SH, 24
SETMAXDB: SETS MAXIMUM DEADBAND
SH, 25
SPSOFF: TURNS OFF SPS ENGINE; DOES TVC UPDATES
SH, 27
TVCZAP: DISABLES THRUST VECTOR CONTROL
SH, 28
POSTBURN: DOES FINAL DISPLAY
SH, 29
P40CS: CLEANS UP AFTER-BURN DETAILS
SH, 30
TIGN: LETS ASTRONAUT DO SMALL VELOCITY CHANGE CORRECTION
SH, 30
POST41: ENDS PROGRAM
SH, 31
TTG/0: ENDS DISPLAY; SETS UP END OF PROGRAM
SH, 31
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS (CONTINUED):

S40.1: CALCULATES INITIAL VELOCITY-TO-BE-GAINED AND INITIAL THRUST DIRECTION  SH.32
AGA2N: CALCULATES REQUIRED VELOCITY AND VELOCITY CHANGE FOR A MANEUVER BEGINNING AT A GIVEN TIME  SH.38
S40.2, 3: COMPUTES PREFERRED SPACECRAFT ATTITUDE  SH.40
S40.6: TESTS (IF REQUIRED) AND TRIMS SPS ENGINE GIMBALS  SH.44
PRE40.6: RESTART ENTRY TO S40.6  SH.44
P40CSM

SET UP SPS BURN
Called from DSKY with YSTE10E
PRIORITY 13

CLEAR ENGEFLAG

SPS BURN

MPAC ← ECSTEER
MPAC + 1 ← 0

INITIALIZE STEER-LAW CONSTANT
FOR LAMBERT CALCULATION

LAMBERT CALCULATION?

YES: MPAC IS CORRECT FOR LAMBERT
NO: EXTERNAL DELTA V CALCULATION

XOVELVFLG CLEAR

MPACp ← 0

CORRECT MPAC FOR EXTERNAL ΔV

P40S/C

CSSTEERp ← MPACp

SET STEERINGS PARAMETER

MPACq ← PENPp

SPS ENGINE THRUST (F_{SPS})
10^{-11} METER
IN C56G (3.224 NEWTONS) @ 2°

P405/F

SHG
SET UP RCS BURN
CALLED FROM OSKY WITH V37E41E
PRIORITY 15

RCS BURN

SET ENERFLAG

CSTEER\rightarrow 0

RC3 THRUFT FOR 2 JETS \( F_{RCS} \)
KiG-M
IN CSECF \( = 10^{-6} \) NEWTONS @ 2°

MPAC\rightarrow FRCS2\rightarrow

YES: 2-JET BURN

NO: 4-JET BURN

NJETSFLG

SET

MPAC\rightarrow MPAC + FRCS2\rightarrow

DOUBLE THRUST
FOR 4 JETS

P405/F

80s
CALLED BY PHOCSM, P14CSM WITH APPROPRIATE THRUST IN MPACD

\[ T_s \rightarrow MPACD \]

SAVE THRUST IN MBM (\(-10^{-4}\) NEWTONS) OF Z

\[ SAVENOMTIGNOM = TIG_2 \]

SAVE NOMINAL TIME OF IGNITION - ACTUAL TIME MAY BE CHANGED IN CSEC @ 2^5

(UPLINKED FROM GROUND OR KEYED IN BY ASTRONAUT)

RETURNS HERE ONLY IF OKAY, OTHERWISE DISPLAYS ALARM AND TERMINATES PROGRAM.

\[ S40.1 \]

CALCULATE INITIAL VELOCITY-TO-BE-GAINED AND INITIAL THRUST DIRECTION

\[ SH32 \]

INPUT:
- \[ \mathbf{V}_{TIG} \] = VELOCITY VECTOR AT TIG IN REFERENCE COORDINATES IN M/CSEC @ 2^5
- \[ \mathbf{R}_{TIG} \] = POSITION VECTOR AT TIG IN REFERENCE COORDINATES IN M @ 2^5
- \[ \Delta V_{USHM} \] = DESIRED IMPSIVE VELOCITY CHANGE IN M/CSEC @ 2^5
- \[ O_{USHM} \] = DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES IN M/CSEC @ 2^5
- \[ \mathbf{R}_{TARG} \] = AIMPOINT POSITION VECTOR IN REFERENCE COORDINATES IN M/CSEC @ 2^5
- \[ T_{TARG} \] = TIME SHOULD ARRIVE AT AIMPOINT IN CSEC @ 2^5

OUTPUT:
- \[ \mathbf{V}_{TIG} \] = VELOCITY-TO-BE-GAINED AT TIG IN REFERENCE COORDINATES IN M/CSEC @ 2^5
- \[ \Delta V_{USHM} \] = VELOCITY-TO-BE-GAINED AT TIG IN L.M. COORDINATES IN M/CSEC @ 2^5
- \[ \mathbf{U}_T \] = UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST IN REFERENCE COORDINATES @ 2^5

\[ S40.2.0 \]

COMPUTE PREFERRED SPACECRAFT ATTITUDE

\[ SH40 \]

INPUT:
- \[ \mathbf{U}_T \], \[ \mathbf{R}_{TIG} \], \[ \mathbf{V}_{TIG} \]
- \[ PACTOFF = PITCH OFFSET ANGLE \] FROM TVC DSP
- \[ YACTOFF = YAW OFFSET ANGLE \]

OUTPUT:
- \[ \mathbf{P}_{TVCSA} \] = UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST IN L.M. COORDINATES @ 2^5
- \[ \mathbf{S}_{TVCSA} \] = UNIT VECTOR IN DIRECTION OF THRUST IN SPACECRAFT COORDINATES @ 2^5
- \[ \times \mathbf{SCREF} \]
- \[ \mathbf{YCSREF} \] = DESIRED SPACECRAFT AXES
- \[ \mathbf{ZCSREF} \] = PREFERRED IMU ORIENTATION (SEE SH. 42)

PREFERRED ATTITUDE HAS BEEN COMPUTED.

NEXT SHEET
FROM PRECEDING SHEET

P40XY

SETMINDB-1

INHIBIT INTERRUPTS

SETMINDB CALLED BY FRESH START, RESTART

THETADX ← CDUX
THETADY ← CDUY
THETADZ ← CDOU

SAVE CURRENT VALUES OF 1MU GIMBAL ANGLES (2's COMPLEMENT) IN REVS @ 2^-1

ADD ← MINDB

CLEAR DAPDATR1 BIT 4

SET ANGULAR DEADBAND TO MINIMUM VALUE
= 4.6D x 2^-10 REVS
(≈ .5 DEG) @ 2^-1

INDICATE MINIMUM ANGULAR DEADBAND FOR ATTITUDE HOLD AND AUTOMATIC MANEUVERS.

RETURN VIA Q

ALLOW INTERRUPTS

NEXT SHEET
FROM PRECEDING SHEET

INPUT SCAXIS = AXIS (IN SPACECRAFT COORDINATES) TO BE ALIGNED @ 2
POINTVCXM = DIRECTION (IN.S.M.COORDINATES) OF DESIRED ALIGNMENT @ 2
BSXIBFLG = 0 (SET BY FRESHSTART AND RESET EVERY TIME RGGCM RUNS)
INDICATES THAT ROUTINE IS TO ALIGN ONE VECTOR RATHER THAN 3 AXES.

INITIALIZE VARIABLE TO BEGIN S40.9 (VELOCITY-TO-BE-GAINED CALCULATION)

SET TIMRFLAG
CLOKTASK OPERATING

P40/P40
DETERMINE WHICH BURN IS BEING DONE
SH.9

P40/SPS
SH.5

P41/SPS
SH.11

P41/SPS
SH.11
INITIALIZE NVWORD1 so that CLOCKJOB will cause display of: TTOG0 = TIME FROM TIG

VGDISP = MAGNITUDE OF VELOCITY-TO-BE-GAINED
DVTOTAL = SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE BEGINNING OF MANEUVER.

VGDISP = VGSTB / 2
DVTOTAL = 0

AVERAGEP = 2CADR(STEERING)

SET UP EXIT FROM SERVICER (EC-2683) TO STEERING (FC-2682)

PROCEED: TEST AND TRIM

TST,TRIM

A ← +1

MRKRTMP ← A

PNTR ← +1

NEXT SHEET

DISPLAY VSOZ5 CHECKLIST 204

TERMINATE

RECYCLE ENTER TRIM ONLY

POST41 PART

ASTRONAUT KEY IN SPS Gimbal Option

R1: 00004
R2: BLANK
R3: BLANK

MRKRTMP INDICATES WHETHER GIMBAL TEST

INDICATE THAT ENTRY TO 540.5 WILL BE A NORMAL (NOT RESTART) ENTRY.
P41/03P

NVWORD1 — VOWN85B

P4CMV85
SET UP VGBODY, (NOUN 85) FOR DISPLAY
FC-2682

AVEGEXIT — ECDR(CALCN85)

GROUP 4.3
SET UP RESTARTS TO SCHEDULE CLOK TASK AS A WAILLIST TASK IN 1 SECOND
TBDG2 — TIME1

GROUP 4.25
SET UP RESTARTS TO SCHEDULE P4M/S/H AS A FINDVAC JOB WITH PRIORITY 12

P4M/S/H
SH12

INITIALIZE NVWORD1 SO THAT CLOCKJOB WILL CAUSE DISPLAY OF VGBODY, = 3-COMPONENT VELOCITY-TO-BE-GAINED IN CONTROL COORDINATES

INPUT: VGPRV, = VGSTG
"VELOCITY-TO-BE-GAINED IN REFERENCE COORDINATES IN M/CSEC @ 2° (FROM SAG01)
OUTPUT: VGBODY, = VELOCITY-TO-BE-GAINED IN CONTROL COORDINATES IN M/CSEC @ 2°

SET UP EXIT FROM SERVICER (FC-2682) TO CALCN85 (FC-2682)
P40S/KS

CLOK TASK
WAIT LIST TASK IN Q.01 SEC.
FC-2681

ALLOW INTERRUPTS

P408/SV

INPUT TO MIDTOAVI IN CSEC @ 225

TDEC1; = TIG; - 29.96 SEC.

MIDTOAVI

EXTRAPOLATE STATE VECTOR TO DESIRED TIME
FC-2250

NORMA L RETURN

INPUT: TDEC1; = DESIRED TIME
OUTPUT: RN1, VN1, PIPEM1; = FINAL STATE VECTOR
MPAC0; = TIME INTEGRATED TO Present TIME, IN CSEC (≥ 2560 CSEC)
NORMAL RETURN: INTEGRATED TO WITHIN 3 CSEC OF ORIGINAL DESIRED TIME
TIG SLIP RETURN: CURRENT TIME WHEN INTEGRATION FINISHED WOULD BE LESS THAN 5.6 SECONDS BEFORE DESIRED TIME, SO INTEGRATED TO A LATER TIME TO SATISFY THIS CONDITION AND SET ALARM 1703 TO INDICATE TIG SLIPPED.

THIS STATE VECTOR UPDATED BY SERVICER STARTING AT TIG - 30.

PA00988VM

TIG; = PIPEM1; + 29.96 SEC.

NEXT SHEET
SCHEDULED BY PINFO (P40,P41) FOR APPROXIMATELY 15-35 SEC.

TIGBLNK

WAITLIST TASK IN 5 SECONDS

NVQO = 0

DON'T DO CLOCK JOB

P4OBLKRR

NOVAC WITH PRIORITY 14

CLEANDSP

BLANK DISPLAY

ENDOFJOB

GROUP 4-37

SET UP RESTARTS TO SCHEDULE TIGAVG AS A WAITLIST TASK IN 5 SECONDS

TEASE --- TIME1

TASKOVER

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ARMINI GUIDANCE AND NAVIGATION

PROG P-1170

DRAWN A.C.WILLIAMS

PASSED

ANALYST

DOCKS

APPROVED
Scheduled by TIGBLNK(P40,P41) for approximately TIG-30 sec.

Preferred attitude not computed.

P40: SPS

Determine which burn is being done

P41: RCS

Resume display of TIGGO, VGOISP, OVTOTAL

NVWORD1 → VGN40

TIG-5

Waitlist task in 24.96 sec.

TTS5HS

GROUP 4.6

Set up restarts to schedule precheck as a waitlist task immediately and TIG-5 as a waitlist task in 24.96 sec.

TBASE4 ← TIME1

Precheck

Has servicer been restart protected?

>0: Yes, don't start it again

=0: No, start it then

Servicer (from PREREAD) is rescheduled every two seconds and exits to routine specified by this program.

Test phase 5

Taskover

PREREAD

FC-2653

NOW MONITOR (CONTINUALLY UPDATING DISPLAY) VGOBDY,

NVWORD1 → VGN858

TTG/O

Waitlist task in 22.93 sec.

TTS8HS

GROUP 4.4

Set up restarts to schedule precheck as a waitlist task immediately and TTG/O as a waitlist task in 22.93 sec.

TBASE4 ← TIME1

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P40,P41-THRUST PROGRAMS

BRAIN: A.J. WILLSM

PREP: A.J. WILLSM

APPLY: A.J. WILLSM

CHECK: A.J. WILLSM

APPROVE: A.J. WILLSM

COLOSSUS II DFC-2650

REV 5
SCHEDULED BY TIGAVES (P40 CASE) FOR APPROXIMATELY TIG-5 SEC.

NVWORDI \rightarrow -BIT9

GROUP 4.7
SET UP RESTARTS TO SCHEDULE TIG-0 AS A WAITLIST TASK IN 5 SECONDS

\[ \text{GROUP 3.3} \]
SET UP RESTARTS TO SCHEDULE S4013 AS A FINDVAC JOB WITH PRIORITY 80

S4013
FINDVAC JOB WITH PRIORITY 80

CALCULATE WHETHER BURN TIME IS LONG ENOUGH TO ALLOW STEERING.

TASKOVER
540.15

CALCULATE WHETHER THERE IS TIME FOR STEERING
SCHEDULED BY TG-3 (P40) WITH PRIORITY 14 OR BY CLOCKDB (VSTB SEQUENCE) WITH PRIORITY 20.

SET IMPULSE
(MINIMUM IMPULSE BURN
(WILL ASSUME THIS FOR NOW AND CHANGE FLAG IF ASSUMPTION PROVES FALSE)

MPAC_2 → VGTIG_1 P

VELOCITY-TO-BE-GAINED AT TG IN M/CSEC @ 2^7

IS BIT 'T' OF CHANNEL 31 CLEAR?

NO

IS ANY +X-TRANSLATION ULLAGE COMMANDED BY HAND CONTROLLER?

YES

PLD_2 → 2 × MPAC_2

CALCULATE AVELOCITY DUE TO 7.96 SECONDS OF 2-JET ULLAGE — IN M/CSEC @ 2^7
WHERE:
WEIGHT/G_2 = M × MASS OF VEHICLE IN KG @ 2^16
540.135_2 = 7.96 × IMPULSE OF 195.6 LBS, FOR 7 SEC + .96 SEC FROM LAST PIPA READING
NEWTONS = 195.6 LBS. × 4.45 LBS = 7.96 SEC × 10^3 SEC
7.96 SEC × 10^3 SEC = VGTIG_1 P

ULLAGE WILL TERMINATE 2 SECONDS AFTER IGNITION = 7.96 SECONDS AFTER LAST PIPA READING
KG; 4-JET BURN

YES: 2-JET BURN

NJETSFLG SET?

MPAC_2 → Z × MPAC_2

DOUBLE EFFECT FOR 4 JETS

540130

VGTIG_1 P

NOW HAVE VGTIG_1 P CORRECTED FOR ULLAGE (FOR BURN TIME COMPUTATION ONLY)

PLD_2 → MPAC_2

V_6 IN M/CSEC @ 2^7

NEXT SHEET
Intermediate result relating \( v_2 \) and velocity due to 1 sec of SPS thrust in m/csec @ 2^7

\( k_{val} = \text{SPS impulse after 1 sec of thrust (\( *k_{val} \)) for a 1 kg vehicle} \)

in kg-m/csec @ 2^8

weight/\( g_0 \) = mass of vehicle in kg @ 2^10

**Flowchart**

1. **T_t = v_2 - v_1**
   - **MPAC** \( \rightarrow \) **PL2** \( \rightarrow \) **KIVAL** \( \rightarrow \) **WEIGHT/\( g_0 \)**

   - **Burn time < 1 second?**
     - **YES**
     - **MPAC = \(-0T\)**
     - **PL2 = MPAC**
     - **SAVE t_1**

   - **NO**

   - **CALCULATE \( \Delta v \) VELOCITY DUE TO 5 SEC OF SPS THRUST IN m/csec @ 2^7**

   \( T_e = \frac{m_{f} - m}{m_{f} - m_{i}} \times \Delta v_{5sec} \times 2^2 \)

   - **FAN** = thrust in kg-m/csec @ 2^7
     - (pad loaded)
   - **weight/\( g_0 \)** = mass of vehicle in kg @ 2^10
   - **\( \Delta v_{5sec} \)** = rate of mass decrease during burn in kg-m/csec @ 2^3

   - **5 seconds** = 500 csec @ 2^14
   - **3.5 seconds** = 350 csec @ 2^13

   - **mean burn time for 1-6 seconds**

   \( 2^{-2} \) factor is for scaling.

2. **Burn time < 6 sec?**
   - **YES**
   - **PL3 < PL4?**
     - **YES**
     - **MPAC = \(-v_{15sec} + PL2 \times 5sec\)**
     - **MPAC = \(-v_{15sec} + PL2 \times 5sec\)**
     - **PL3 = PL4**
     - **SAVE t_1**

   - **NO**

   - **CALCULATE BURN TIME BY EXTRAPOLATION IN csec @ 2^14**

   \( 15sec = 100 csec @ 2^7 \)

---

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**APOLLO TURBINE AND NAVAID TECH.**

**DRAWN **
A.C. Williams

**FACSIMILE**

**ANALYST**
R. Lytle

**CHECKED**

**APPROVED**

**PAGE**
P40-PA1-THRUST PROGRAMS

**DOCUMENT NO.**
COLLOSUS II D

**FC-2680**

**SHELL 10**
ENTRY FROM S40.13 FOR BURN TIME < 1 SECOND

CALCULATE BURN TIME IN CSEC @ 2^4
WHERE:
\[ P_{0} = \text{VELOCITY-TO-BE-GAINED IN M/SEC} @ 2^4 \]
\[ W = \text{WEIGHT IN KG} @ 2^4 \]
\[ K_3 = \text{MINIMUM IMPULSE (ALKVAL3)} IN KG-M/CSEC @ 2^4 \]
\[ K = \text{RATE OF INCREASE OF MINIMUM IMPULSE (ALKVAL1)} IN KG-M/CSEC @ 2^4 \]

ENTRY FROM S40.13 FOR 1 SECOND <= BURN TIME < 6 SECONDS
WITH MPAC = BURN TIME IN CSEC @ 2^4

TPAGREE
FORCE 
SIGN AGREEMENT 
IN 
MPAC

ENTRY FROM S40.13 FOR BURN TIME 2-6 SECONDS
CLEAR
IMPULSE

STEERING BURN

NOTE: BURN TIME COMPUTATIONS (ABOVE) FOLLOW
THE EMPIRICALLY DERIVED EXPRESSION FOR IMPULSE:

FOR 0 SEC. < AT < 1 SEC: MVe = -K_3 \Delta t

FOR 1 SEC. < AT < 6 SEC: MVe = K_3 + F_{imp} (AT-1SEC)

\[ K_1, K_2, K_3, F_{imp} \text{ STORED IN ERASABLE MEMORY} \]
TIG-O

SCHEDULED BY TIG-5 (P40) FOR TIME OF IGNITION

SET IG10FLG

TIG HAS ARRIVED

HAS ASTRONAUT SET IGNITION?
(FLAG SET BY CLOCKJOB WHEN ASTRONAUT RESPONDS TO VIG DISPLAY WITH "PROCEED")

FLAG SET?

NO

TASKOVER

RETURN TO ORIGINAL DISPLAY
(IN CASE OF RESTART DURING VIG SEQUENCE IN CLOCKJOB)

YES

NVWORD1 -> VOGNAD

GROUP 461

SET UP RESTARTS TO SCHEDULE IGNITION AS A WAITLIST TASK IMMEDIATELY

IGNITION

MAY ALSO BE SET UP BY CLOCKJOB (VIGP SEQUENCE)

OGAD -> CDUX

SAVE IMU OUTER GIMBAL ANGLE FOR ROLL DAP

TEVENT, -> TIMER

ACTUAL TIME OF IGNITION — FOR DOWNLINK IN CSEC @ E180

SET ENGINFLG

ENGINE IS ON
(INDIQUE IN CASE OF RESTART)

SPSON

TURN ON SPS ENGINE

SET BIT 15 OF CHANNEL II

NEXT SHEET
FROM PRECEDING SHEET

TSLOC = E2CADR (TS2DLOC)

NO DAP USING TIMES COUNTER—TERRUPT WILL GO TO IDLING ROUTINE

GROUP 4.3
SET UP RESTARTS TO SCHEDULE DOTVC
ON AS A WAITLIST TASK IN 0.4 SECOND
TBASE = TIMES

FITXDELAY
WAIT
0.4 SECOND
FC-2030

DOTVC

TVPHASE = -1
TVEXECPS = +1

RESTART INITIALIZATION PHASE OF TVC DAP
NOT INTO TVEXEC YET

SET DMPBIT CLEAR DMPBIT

TVC DAP IN CONTROL

GROUP 4.3
SET UP RESTARTS TO SCHEDULE CLOKTASK AS A WAITLIST TASK IN 1 SECOND

ERRBTMP = ERRORY
ERRBTMP+1 = ERRORZ

SAVE PITCH, YAW ATTITUDE ERRORS FROM RCS DAP FOR USE IN INITIALIZING TVC DAP IN REV@2^1

GROUP 4.5
SET UP RESTARTS TO SCHEDULE DOSTRULL AS A WAITLIST TASK IN 1.6 SECONDS
TBASE = TIMES

TVCDAPON
TERRUPT TASK WITHIN 0.015 SECOND
FC-2480

NEXT SHEET

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P40, P41—THRUST PROGRAMS

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FROM PRECEDING SHEET

WAIT 2 SECONDS TOTAL BEFORE ULLAGE-OFF, STEERING

FIXDELAY
WAIT 16 SECONDS MORE
FC-2660

DOSTROLL

IS STEERING TO BE DONE (ROUTINE STEERUL?)

YES

STEERUL
STEERING ENABLE AND ULLAGE-OFF
SH23

ULLAGEOFF
ULLAGE-OFF ONLY
SH22

GROUP 4.0
KILL GROUP 4 RESTARTS

ENDIGN

TASKOVER

NO

$STEERUL

SET STEERGW

ULLAGEOFF

CLEAR CHANNEL 5

ZERO X-TRANSLATIONAL RCS JET COMMANDS

RETURN VIA Q
END SPS BURN SCHEDULED BY IMPBURN IF IMPULSE BURN OR BY STEERING IF STEERING BURN MAY ALSO BE SCHEDULED BY CLOCKJOB IF TERMINATION OF BURN IS REQUESTED.

UPDATE MASSTEMP = VEHICLE MASS IN KG OR kg
   FOR SPS OFF

GROUP 3.0
KILL GROUP 3 RESTARTS

GROUP 4.45
SET UP RESTARTS TO SCHEDULE OOSP5OFF
AS A WAITLIST TASK IMMEDIATELY

TBASE4 = TIME1

DOOSP5OFF

SPS5OFF
TURN OFF SPS ENGINE AND UPDATE CSM MASS

SH27

GROUP 4.78
SET UP RESTARTS TO SCHEDULE OUTVCRG AS A WAITLIST TASK IN 2.5 SECONDS

TBASE4 = TIME1

FIXDELAY
WAIT 2.5 SECONDS
FC-2680

NEXT SHEET
FROM PRECEDING SHEET

DOTVCROS

(SETMAXDB-1)

THIS ENTRY TO SETMAXDB NOT USED

INHIBIT INTERRUPTS

SETMAXDB

ALSO CALLED BY FRESH, START, RESTART

ADB ← MAXDB

SET ANGULAR DEADBAND TO MAXIMUM VALUE = 4555 x 2^-15 REVS
(≈ 5 DEG) AT 2^-4

INDICATE MAXIMUM ANGULAR DEADBAND FOR ATTITUDE HOLD AND AUTOMATIC MANEUVERS.

RETURN

VIA Q

RCSDAPON

SET UP RCS DAP
FC-2370

MASSPROP

UPDATE FILTER BANDS
AND WEIGHT/G
FOR RCS DAP
FC-2430

TV32AP

DISABLE TVC
REENABLE OPTICAL
DISABLE CLOFTASK
SKELE

NO MORE TVC DAP CONTROL

NEXT SHEET
FROM PRECEDING SHEET

GROUP 4.35
SET UP RESTARTS TO SCHEDULE POSTBURN AS A NOVAC JOB WITH PRIORITY 12

POSTBURN NOVAC JOB WITH PRIORITY 12

TASKOVER
SPS OFF

TEVENT = TIME?

CLEAR ENGINE FLG.

CLEAR BIT 13 OF CHANNEL II

SET BIT 14 OF CHANNEL 9E

MASS BACK

M(T + N) = M(T) + M(T)

CSMMASS = EMOT x VS7VCRTR x 1SEC x 12^14 x MASS TMP

UPDATE VEHICLE MASS IN KG @ 2^14 WHERE:

MASS TMP = OLD VEHICLE MASS IN KG @ 2^14

EMOT = RATE OF MASS DECREASE DURING BURN IN KG/SEC @ 2^3

VS7VCRTR = NO. OF HALF-SECOND CYCLES @ 2^14

1SEC = 100 USEC @ 2^14

= 50 USEC @ 2^15

2^14 FACTOR IS FOR SCALING

NO TVC DAP STILL IN INITIALIZATION PHASE(IF ANY) ?

NO TVC DAP IN CONTROL ?

DO UPDATES ONLY WHEN IN TVC DAP, PAST INITIALIZATION PHASE—OTHERWISE DELPBAR, DELYBAR DO NOT CONTAIN DESIRED INFORMATION

UPDATE PITCH, YAW OFFSET ANGLES FOR TVC DAP IN REV 1.07975312

RETURN VIA Q

RETURN VIA Q

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P40, P41 THRUST PROGRAMS

COLOSSUS II

F-2680
DISABLE TVC, REENABLE OPTICS
CALLED BY CLOKJOB (V29 OR VST SEQUENCE)

INHIBIT INTERRUPTS

TVZIAP

CALLED BY ENSINOFF(P40)

CLEAR CHANNEL 12
BITS 2,8,11

ZERO AND DISABLE CDU OPTICS ERROR COUNTERS
DISABLE THRUST VECTOR CONTROL
REENGAGE OPTICS DIGITAL/ANALOG CONVERTER

OPTIND -- 1

ENABLE OPTICS MONITOR,
BUT NO COARSE OPTICS DRIVE

INVORDI -- 10

DON'T DO CLOKJOB

CLEAR TIMRFLAG

CLOK TASK WILL STOP RUNNING

RETURN VIA Q
SET UP BY ENGINOFF (P40) AS A NOVAC JOB WITH PRIORITY 12

POSTBURN

REFLASH

DISPLAY FLASHER V1640

TERMINATE

PROCEED

POST41

SH50

P40RCs

MAY ALSO BE ENTERED FROM CLOCK JOB (V999 SEQUENCE)

AVESEXIT2 ← ZCADDR (CALCNOS)

SET UP EXIT FROM SERVICER (FC-2685)

TO CALCNOS (FC-2682)

DELAY JOB

WAIT 2 SECONDS

FC-2670

PROMINDB

SETMINDB-1

SET MINIMUM DEADBAND SH7

INHIBITS INTERRUPTS

ALLOW INTERRUPTS

TIGNOW SH50
ENTERED FROM POSTBURN (P40) WITH PRIORITY 32.
OR SETUP BY TSG/O(P41) AS A NOVAC JOB WITH
PRIORITY 20

GROUP 4
SETUP RESTARTS TO
SCHEDULE NEXT LOCATION
AS A NOVAC JOB
WITH PRIORITY 20

REFLASH
DISPLAY
FLASHING
VIGILS

RECYCLE

MONITOR $V_{BODY, V} = \text{VELOCITY-TO-DE-GAINED IN}
CONTROL COORDINATES}
M/CSEC @ 2°
R1: XXXXX FT/SEC X-COMPONENT
R2: XXXXX FT/SEC Y-COMPONENT
R3: XXXXX FT/SEC Z-COMPONENT

AT THIS POINT ASTRONAUT USES HAND CONTROLLERS
to bring VELOCITY-TO-DE-GAINED DOWN TO ZERO
BEFORE HE ALLOWS CONTINUATION (END) OF THE PROGRAM.

PROCEED,
TERMINATE

POST41
MAY ALSO BE ENTERED FROM CLOCKJOB (V09T SEQUENCE)

AVEGEXIT_B \rightarrow DCAE(SERVEXIT)_B

SET UP EXIT FROM SERVICER (FC-2683)
TO SERVEXIT (FC-2683)

GOTOPOOM
SELECTION OF NEW MAJOR MODE WILL END
RESCHEDULING OF SERVICER.
SCHEDULED BY TIGAVEG (PHI CASE) FOR TIME OF IGNITION

TIGNOW

NOVAC JOB WITH PRIORITY 20

Sh.30

P40CLK

CLEAR TIMEFLAG

CLOKTASK WILL STOP RUNNING

TASKOVER
CALCULATE INITIAL VELOCITY-TO-BE-GAINED AND INITIAL THRUST DIRECTION CALLED BY PAO, PAI (SHG)

FIRST PASS THROUGH S40.3

SET FIRSTPLG

ROT, → (0,0,0) INITIALIZE BAT

SAVE QPRET IN QTEMP

YES: EXTERNAL OR MANEUVER

NO: LAMBERT (AIMPOINT) MANEUVER

S40.1B

SET?

S40.3B

DELVISAD, → [DELVISIN,]

COMPUTE MAGNITUDE OF DESIRED IMPULSIVE VELOCITY CHANGE

STORE INPUT TO MIDSIM

STORE INPUT TO MIDSIM

VELOCITY AT TIG IN M/CSEC@²

UNIT NORMAL TO PLANE OF TRAJECTORY @ ²

WHERE:

RTIG, = POSITION VECTOR AT TIG IN M @ ²

U, = UNIT (V, X B,)

UT, = UNIT (VTIG, X RTIG,)

VL3B, = VTIG, X RTIG, @ ²

RINIT, = RTIG, SET INPUT TO MIDSIM

PL3D, = RTIG,² = RTIG, X RTIG, @ ²

NEXT SHEET
Input: AVFLG (indicating subroutine option)
Computer (always set in Colossus - indicates CGC (not LGC) computer)

FLO0 = vector in reference coordinates
RINITx = position vector for same time as FLO0
in reference coordinates in m @ 20
VINITx = velocity vector for same time as FLO0
in reference coordinates in m/sec @ 20

Output: MGLVF Lag (indicating which subroutine option was used in this case, set)
DELVx = vector in local vertical coordinates
(converted from FLO0)

:. Here, DELVx = velocity to be gained at time of ignition
in m/sec @ 20
SET UP INPUTS TO AGAIN:

\[ \text{TDEC} = \text{two seconds before time of ignition} \]
\[ \text{IN CSEC @ 2}^{28} \]
\[ \text{WHERE TDY} = \text{200 CSEC @ 2}^{28} \]
\[ \text{DELT} = \text{time from TDEC to until time air timepoint} \]
\[ \text{IS TO BE REACHED} \]
\[ \text{IN CSEC @ 2}^{28} \]
\[ \text{WHERE TPA} = \text{time that air timepoint is to be} \]
\[ \text{reached in CSEC @ 2}^{28} \]

INPUT: TDEC, DELTA, RTARG v = air timepoint position vector
IN reference coordinates
IN M @ 2^{29}

OUTPUT: VPRIME v = initial velocity required for
MANEUVER AT TDEC, IN M/SEC @ 2^{29}
RINIT v, RIT v = position vector at TDEC, IN M @ 2^{29}
IN reference coordinates
FINIT v, FITY v = velocity vector at TDEC, IN M/CSEC @ 2^{29}
IN reference coordinates
DELVECT v = change in velocity required for
MANEUVER AT TDEC, IN M/CSEC @ 2^{29}
IN basic reference coordinates

TEMPORARY STORAGE FOR V (T:0-2)
IN M/CSEC @ 2^{29}

SET UP INPUTS TO AGAIN (IN CSEC @ 2^{28})
WHERE TDEC = time of ignition this time.

INPUT: TDEC, DELTA, RTARG v
OUTPUT: VPRIME v,
RINIT v, RIT v,
FINIT v, FIYT v,
DELVECT v

SAVE REQUIRED VELOCITY CHANGE AT T: v
IN PLD, AS INPUT TO MIDSIM
AND IN VIYT v FOR FUTURE REFERENCE
IN reference coordinates IN M/CSEC @ 2^{29}

NEXT SHEET
FROM PRECEDING SHEET

SET AVFLAG

INPUT TO MIDGIM: INDICATING THAT IT IS TO CONVERT A VECTOR FROM REFERENCE TO LOCAL VERTICAL COORDINATES.

INPUT: AVFLAG (INDICATING SUBROUTINE OPTION)
COMPUTER (ALWAYS SET IN COLossus - INDICATES CGC COMPUTER)

PLO_ = VECTOR IN REFERENCE COORDINATES
FINIT_ = POSITION VECTOR FOR SAME TIME AS PLO_ IN REFERENCE COORDINATES IN M/CSEC @ tp
VINIT_ = VELOCITY VECTOR FOR SAME TIME AS PLO_ IN REFERENCE COORDINATES IN M/CSEC @ t

OUTPUT: MGAVFLAG (INDICATING WHICH SUBROUTINE OPTION WAS USED; IN THIS CASE, SET)

DELVLC_ = VECTOR IN LOCAL VERTICAL COORDINATES (CONVERTED FROM PLO_)

HERE: DELVLC_ = VELOCITY-TO-BE-GAINED AT TIME OF IGNITION IN M/CSEC @ 2^7

INPUT TO CALGRAV:
POSITION VECTOR AT DESIRED TIME IN REFERENCE COORDINATES IN M/CSEC @ 2^9

CALCULATE:
MPAC_ = RTIG

CALGRAV
CALCULATE GRAVITATIONAL ACCELERATION
FC-2663

INPUT: MPAC_ = POSITION VECTOR
OUTPUT: MPAC_ = GDT3/E_ = 1/2 THE DIFFERENCE IN VELOCITY DUE TO GRAVITATIONAL ACCELERATION, AT SPECIFIED POSITION, OVER 2 SECONDS IN REFERENCE COORDINATES IN M/CSEC @ 2^7

CALCULATE CD_ = INTERMEDIATE RESULT IN REFERENCE COORDINATES IN M/CSEC @ 2^9

WHERE:
VIPRIME_ = V'T(Tig) = REQUIRED VELOCITY AT TIG IN M/CSEC @ 2^7
UT_ = V'R(Tig+2) = REQUIRED VELOCITY AT TIG+2 IN M/CSEC @ 2^7
Z00CS_ = 200 CSEC @ 2^18
CSTEER = STEER-LAW CONSTANT @ 2^2
(SET BY PA0, PA1)
2^2 FACTOR IS FOR SCALING.
FROM PRECEDING SHEET

\[ Q = \frac{C_B \cdot \text{UNIT} (V_G (T_D) \cdot C_B) \cdot \text{UNIT} (V_G (T_D))}{PL_1 (V_G (T_D) \cdot C_B) \cdot \text{UNIT} (V_G (T_D)) \cdot \text{UNIT} (V_G (T_D)) \times 2^4} \]

CALCULATE \( Q \) = INTERMEDIATE RESULT IN REFERENCE COORDINATES IN M/CSEC @ \( 2^7 \)

WHERE:

- \( V_G (T_D) \) = VELOCITY-TO-BE-GAINED AT T_D IN REFERENCE COORDINATES IN M/CSEC @ \( 2^7 \)
- \( 2^4 \) FACTOR IS FOR SCALING.

\[ \mathbf{v}_{\mathbf{v}_D} = \text{UNIT} \left( \sqrt{\frac{F_e}{M}} - (Q)^2 \cdot \text{UNIT} (V_G (T_D)) + Q \right) \]

\[ \mathbf{u}_{\mathbf{v}_D} = \text{UNIT} \left( \sqrt{\frac{F_e}{\text{WEIGHT}/G_2}} - (PL_2)^2 \cdot \text{UNIT} (V_G (T_D)) \times 2^4 + PL_2 \right) \]

RETURN VIA QTEMP

CALCULATE \( \mathbf{v}_{\mathbf{v}_D} \) = UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST @ \( 2^7 \) (IN REFERENCE COORDINATES)

WHERE:

- \( F_e \) = ENGINE THRUST IN KG-M/CSEC \( 2^7 \) (FROM PAO OR PM1)
- \( \text{WEIGHT}/G_2 = \text{MASS OF VEHICLE IN KG} @ 2^16 \)
- \( 2^4 \), \( 2^7 \) FACTORS ARE FOR SCALING.
 AGAIN

SAVE QRET IN QTEMP.

INPUT: TDEC1 = DESIRED TIME IN CSC @ 2^28
OUTPUT: RAT, = POSITION VECTOR AT DESIRED TIME
IN REFERENCE COORDINATES, IN M @ 2^28
VATT, = VELOCITY VECTOR AT DESIRED TIME
IN REFERENCE COORDINATES, IN M/CSC @ 2^7
TAT, = ACTUAL TIME INTEGRATED TO, IN CSC @ 2^7
(= TDEC1 -
X1 = -2 IF IN EARTH SPHERE OF INFLUENCE,
-10 IF IN MOON SPHERE OF INFLUENCE,
X2 = 0 IF IN EARTH SPHERE OF INFLUENCE,
2 IF IN MOON SPHERE OF INFLUENCE.

THIS PREC.
INTEGRATE
STATE VECTOR
TO DESIRED
TIME
FC-1280

RTX2 = X2
RTX1 = X1

SAVE INDEX REGISTER VALUES FOR INITVEL.

SET UP OUTPUT STATE VECTOR,
INPUTS TO INITVEL
= STATE VECTOR AT TDEC1 -

PLD = 0

MPAC = EP4(45)H_

IS ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS
IN THE RANGE SUCH THAT TARGET VECTOR SHOULD BE
ROTATED INTO THE POSITION-VELOCITY PLANE?

LEAVE THE RANGE
LARGE SO THAT
ANGLE WILL REMAIN
INSIDE IT DURING
THE BURN

YES

NORMSW
SET

IF NOT, CORRECT MPAC TO 10^-
DECREASE THE RANGE SO THAT
ANGLE WILL REMAIN OUTSIDE IT
DURING THE BURN

IF ANGLE BETWEEN INITIAL AND TARGET
POSITION VECTORS IS WITHIN \( \varepsilon \) OF
\( \frac{1}{2} \) REV(180°), INITVEL WILL ROTATE
THE TARGET VECTOR INTO THE
POSITION-VELOCITY PLANE

SET \( \varepsilon \) (IN REVs AT 2^28) SUCH THAT:

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AP-685
SPACECRAFT AND NAVIGATION

PAC-411 - THRUST PROGRAMS

DRAWN A.C.WILLIAMS
CHECKED H. MILLER
ANALYZED R.R. MILLER
DRAFTED T. WILLIAMS
PAC-411 FC-2680

MIT 58 of 58
FROM PRECEDING SHEET

INPUTS:
- \( \mathbf{R}_{\text{INIT}} \): Initial position vector in reference coordinates
  in \( \text{m} \text{ @ } 2^\circ \)
- \( \mathbf{V}_{\text{INIT}} \): Initial velocity vector in reference coordinates
  in \( \text{m/s @ } 2^\circ \)
- \( \mathbf{R}_{\text{TARG}} \): Offset target vector in reference coordinates
  in \( \text{m} \text{ @ } 2^\circ \)
- \( \Delta t_{\text{FLIGHT}} \): Time of flight from \( \mathbf{R}_{\text{INIT}} \) to \( \mathbf{R}_{\text{TARG}} \)
  in \( \text{s} @ 2^\circ \)
- \( \text{PLO}_{\text{\&}} \): No. of iterations \(-1(0 \text{ indicates Lambert})\)
- \( \text{PLR}_{\text{\&}} \): Angle \( \psi \) (in revs @ \( 2^\circ \)) which determines
  situation in which target vector
  must be rotated
- \( \text{RTX}_{\text{\&}} \): -2 if in Earth sphere of influence,
  -10 if in Moon sphere of influence,
  0 if in Earth sphere of influence,
  2 if in Moon sphere of influence.

OUTPUTS:
- \( \mathbf{V}_{\text{PRIME}} \): Initial velocity required for maneuver
  in reference coordinates
  in \( \text{m/s @ } 2^\circ \)
- \( \mathbf{V}_{\text{FINISH}} \): Final velocity (at \( \mathbf{R}_{\text{TARG}} \)) after maneuver
  in reference coordinates
  in \( \text{m/s @ } 2^\circ \)
- \( \Delta \mathbf{V}_{\text{INIT}} \): Initial change in velocity required for
  maneuver
  in reference coordinates
  in \( \text{m/s @ } 2^\circ \)

RETURN VIA \( \text{QTEMP1} \)
COMPUTE PREFERRED SPACECRAFT ATTITUDE CALLED BY P40, P41

\[ U_0 = \text{REFSMAT} U_{TP} \]

WHERE:

- **REFSMAT**: TRANSFORMATION MATRIX BETWEEN REFERENCE AND SIM,COORDINATE SYSTEMS
- **\( U_{TP} \)**: UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST IN REFERENCE COORDINATES

\( \varepsilon \) \( \text{FACTOR IS FOR SCALING.} \)

CONVERT INITIAL THRUST DIRECTION VECTOR TO STABLE MEMBER COORDINATES @ 2^1

SAVE OFFSET IN GTEMP

YES: SPS BURN (P40)
NO: RCS BURN (P41)

CLEAR ?

CALCULATE INTERMEDIATE RESULTS @ 2^1

WHERE:

- **YACTOFF** = YAW OFFSET ANGLE IN REVS @ 1.07375111
- **PACTOFF** = PITCH OFFSET ANGLE IN REVS @ 1.07375111
- **TRIMSCAL** = SCALING CONSTANT FOR YACTOFF, PACTOFF

\[ YBIAS_0 = Y_0 = \text{YAW MECHANICAL BIAS ANGLE} \]
\[ = 0.95^\circ \text{ IN REVS @ } 2^0 \]

\[ PBIAS_0 = P_0 = \text{PITCH MECHANICAL BIAS ANGLE} \]
\[ = -2.15^\circ \text{ IN REVS @ } 2^0 \]

\( \varepsilon \) \( \text{FACTOR IS FOR SCALING} \)

NEXT SHEET
FROM PRECEDING SHEET

\[ x_{x}(\theta) = (\cos(p + \theta) \cos(y + \theta), \cos(p + \theta) \sin(y + \theta), \sin(p + \theta)) \]
\[ y_{y}(\theta) = (\sin(y + \theta), \cos(y + \theta), 0) \]
\[ z_{z}(\theta) = (-\sin(p + \theta) \cos(y + \theta), \sin(p + \theta) \sin(y + \theta), \cos(p + \theta)) \]

\[ x_{x}(\theta) = x_{x}(\theta), y_{y}(\theta) = y_{y}(\theta), z_{z}(\theta) = z_{z}(\theta) \]

Calculate \[ M = \begin{bmatrix} x_{x}(\theta) & y_{y}(\theta) & z_{z}(\theta) \end{bmatrix} \]

Giving spacecraft axes in engine bell coordinates @ \( z_4 \)

Where \( M = \begin{bmatrix} x_{x}(\theta) & y_{y}(\theta) \end{bmatrix} \)

Gives \( x_{e}^{(5)} \)

ENGINE BELL AXES IN SPACECRAFT COORDINATES

Calculate unit vector in direction of engine bell \( x \)-axis of engine bell coordinate system) in spacecraft coordinates @ \( z_4 \)

(for PLCOGM)

\[ x_{e}^{(5)}(\theta) = (\cos(p + \theta) \cos(y + \theta), \cos(p + \theta) \sin(y + \theta), \sin(p + \theta)) \]

SCALES \[ (x_{SC}^{(5)}, y_{SC}^{(5)}, z_{SC}^{(5)}) \]

\[ x_{SC}^{(5)} = (x_{x}(\theta), y_{y}(\theta), z_{z}(\theta)) \]

\[ \hat{X}_{SC}(\theta) = \hat{U}_{TO} \]

\[ \hat{P}_{LO} = \hat{U}_{TO} \]

\[ Y_{OR}(\theta) = \hat{U}_{TO} \times \text{UNIT}(S(T_{4})) \]

\[ \hat{P}_{LO} = \text{UNIT}(P_{LO} \times \text{UNIT}(\text{RTI}_{3})) \]

INPUT TO TSTKUT @ \( z_5 \)

CALCULATE \[ [M_{LO} = \begin{bmatrix} x_{e}^{(5)}(\theta) \end{bmatrix} \]

GIVING DESIRED ENGINE BELL COORDINATE AXES IN REFERENCE COORDINATES @ \( z_4 \)

\[ y_{e}(\theta) = \hat{U}_{TO} \times \text{UNIT}(\text{RTI}_{3}) \]

\[ x_{e}(\theta) = \hat{U}_{TO} \times \text{UNIT}(\text{RTI}_{3}) \]

\[ z_{e}(\theta) = \hat{U}_{TO} \times \text{UNIT}(\text{RTI}_{3}) \]

\[ 2^4 \text{ FACTOR IS FOR SCALING} \]

NEXT SHEET
FROM PRECEDING SHEET

\[ X_{BM(RF)} = X_{SC(RC)} \times [M_i] \]
\[ Y_{BM(RF)} = Y_{SC(RC)} \times [M_i] \]
\[ Z_{BM(RF)} = Z_{SC(RC)} \times [M_i] \]

CALCULATE
\[
\begin{bmatrix}
X_{SC(RF)} \\
Y_{SC(RF)} \\
Z_{SC(RF)}
\end{bmatrix}
= [M]^{T} \times [M_i]
\]

GIVING DESIRED SPACECRAFT AXES IN REFERENCE COORDINATES @ \( \theta \) \( \times \)
WHERE \( \theta \) FACTOR IS FOR SCALING

NOTE: THESE AXES ALSO GIVE THE PREFERRED IMU ALIGNMENT, IN CASE ASTRONAUT CHOOSES TO REALIGN IMU (PS2)

RETURN VIA GTEMP

NOTE: THE COMPUTATION ABOVE IS DERIVABLE FROM THE EQUATION:

\[
[M_{EB(RF)}] = [M_{EB(SC)}] \times [M_{SC(RF)}]
\]

\([M_{EB(RF)}]\) AND \([M_{EB(SC)}]\) ARE KNOWN,

SO \([M_{SC(RF)}] = [M_{SC(SC)}] \times [M_{EB(RF)}] = [M_{SC(SC)}]^{T} \times [M_{EB(RF)}] \)
ENTERS FROM S4O.2,3 FOR RCS BURN (P41)

\( S_{\text{C4}} \rightarrow \text{UNITX} \)

\( Y_{\text{SC}(\text{mp})} = U_{\text{TD}} \times \text{UNIT}(X_{\text{SC}(\text{mp})}) \)

\( X_{\text{SC}(\text{mp})} = \text{UNIT}(X_{\text{TD}} \times R_{(T)}) \)

\( \text{PLG}_x \rightarrow \text{UNIT}(U_{\text{TD}} \times R_{1}(T)) \)

\( \text{PLG}_0 \rightarrow U_{\text{TD}} \times R_{1}(T) \)

INITIALIZE VALUE WHICH MAY BE CHANGED BY TSTRXUT

INPUT TO TSTRXUT @ 2^0

\( \text{TSTRXUT} \)

\( \text{ARE UT, AND RTG, COLLINEAR?} \)

\( \text{NO} \)

\( \text{PL}_3=0? \)

\( \text{BADVECTOR} \)

\( \text{MPAC}_x \leftarrow \text{PLG}_x \)

\( Y_{\text{SC}(\text{mp})} = \text{UNIT}(U_{\text{TD}} \times \left[ \text{UNIT}(R_{1}(T)) + \frac{1}{2} \text{UNIT}(V_{(T_2)}) \right]) \)

\( \text{MPAC}_y \leftarrow \text{UNIT}(U_{\text{TD}} \times \left[ \text{UNIT}(R_{1}(T)) + \frac{1}{2} \text{UNIT}(V_{(T_2)}) \right]) \)

\( \text{PLG}_y \leftarrow \text{UNIT}(U_{\text{TD}} \times \left[ \text{UNIT}(R_{1}(T)) + \frac{1}{2} \text{UNIT}(V_{(T_2)}) \right]) \)

RETURN VIA QPRET

\( Y_{\text{SC}(\text{mp})} \leftarrow \text{MPAC}_x \)

\( Z_{\text{SC}(\text{mp})} \rightarrow Z_{\text{SC}(\text{mp})} \times Y_{\text{SC}(\text{mp})} \)

\( Z_{\text{SC}(\text{mp})} \rightarrow X_{\text{SC}(\text{mp})} \times Y_{\text{SC}(\text{mp})} \)

RETURN VIA QTEMP

\( \text{SET OUTPUT SSCANIX}_x = \text{UNIT VECTOR IN THRUST DIRECTION} \)

\( \text{IN SPACECRAFT COORDINATES} @ 2^1 \)

WHERE UNITx = (1,0,0) @ 2^1

\( \text{CALCULATE} \)

\( \text{SC4}(\text{mp}) \)

\( Y_{\text{SC}(\text{mp})} \)

\( Z_{\text{SC}(\text{mp})} \)

\( \text{GIVING PREFERRED SPACECRAFT AXES} \)

\( \text{IN REFERENCE COORDINATES} \)

\( \text{@ 2}^1 \)

\( \text{SEE NOTE SH42} \)
FROM PRECEDING SHEET

FIXDELAY
WAIT .02 SECOND
RF-202A

WAIT FOR RELAY LATCHING

RESTRTST

IS THIS A RESTART ENTRY?
CNTR > 0 ?

NO

CNTR ← MRKRTMP
SAVE MRKRTMP IN CASE OF RESTART

YES: DO GIMBAL TRIM WITHOUT DELAY

GIMTRIM12
SH47

NO: TEST GIMBALS FIRST
MRKRTMP ≤ 0?

YES: GIMBAL TRIM ONLY

GIMTRIM
SH47

GDTSETUP

CNTR ← -0
SET INDEX TO TEST PITCH DRIVE FIRST

NEXT SHEET
FROM PRECEDING SHEET

GIMTRIM

START HERE IF TRIM ONLY IS DESIRED

FITDELAY

WAIT
4 SECONDS
FC-2060

DELAY BEFORE GIMBAL TRIM

GIMTRIM +2

START HERE IF RESTART ENTRY

TVPITCH → PACTOFF +0

TVCYAW → YACTOFF +0

STORE PITCH,YAW TRIM VALUE IN COUNTERS IN REV > 1.07975111
(PREVENT INPUT OF 10)

SET

CHANNEL 14

BIT 11,1E

RELEASE PULSE TRAINT FROM TVPITCH, TVCYAW TO COU (OPTICS) ERROR COUNTERS TO DRIVE SPS GIMBALS

END40.6

TASKOVER
DRIVE SPECIFIED GIMBAL DESIRED AMOUNT CALLED BY GIMTEST (SH-46)

SAVE Q IN TEMPRGO

Q: PITCH GIMBAL

CNTR?

-1: YAW GIMBAL

TVCPITCH ← A

SET BIT 11 OF CHANNEL 14

RETURN VIA TEMPRGO

TVCYAW ← A

SET BIT 12 OF CHANNEL 14

WAIT WHILE ASTRONAUT VERIFIES GIMBAL MOTION

SET APPROPRIATE COUNTER TO AMOUNT (IN REVS @ 1,000/2411) GIMBAL IS TO BE DRIVEN

RELEASE PULSE TRAIN FROM APPROPRIATE COUNTER TO COU ERROR COUNTER TO DRIVE SPS GIMBAL.

FIXED DELAY

WAIT 2 SECONDS

FC-2050
P41/P40

DETERMINE WHETHER MAJOR
MODE IS P40 OR P41
CALLED FROM SH4, SH15

NO: P40 (S/PB BURN)

15 MODES BIT 1
SET?

YES: P41 (RCS BURN)

INCREMENT
Q

RETURN
VIA Q

RETURN
VIA Q


SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
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<tbody>
<tr>
<td>CALCGRAV</td>
<td>2683</td>
<td>CALCULATE GRAVITATIONAL ACCELERATION</td>
<td>SH. 36</td>
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<tr>
<td>CLOKTASK</td>
<td>2681</td>
<td>UPDATE TTGO, MAINTAIN DISPLAY</td>
<td>SH. 12</td>
</tr>
<tr>
<td>INITVEL</td>
<td>2641</td>
<td>CALCULATE VELOCITY AND Δ VELOCITY REQUIRED FOR MANEUVER</td>
<td>SH. 39</td>
</tr>
<tr>
<td>MASSPROP</td>
<td>2430</td>
<td>UPDATE MASS PROPERTIES FOR DAPS (&amp; FILTER GAIN VALUES FOR TVC DAP)</td>
<td>SH. 25</td>
</tr>
<tr>
<td>MIDGIM</td>
<td>2430</td>
<td>OPTION USED HERE: CONVERT VECTOR FROM REFERENCE COORDINATES TO LOCAL VERTICAL COORDINATES</td>
<td>SH. 34, 36</td>
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<tr>
<td>MIDTOAV1</td>
<td>2290</td>
<td>EXTRAPOLATE STATE VECTOR TO DESIRED TIME</td>
<td>SH. 12</td>
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<tr>
<td>PRERead</td>
<td>2683</td>
<td>SET UP SERVICER, WHICH UPDATES STATE VECTOR DURING BURN</td>
<td>SH. 15</td>
</tr>
<tr>
<td>P40CNV85</td>
<td>2682</td>
<td>SET UP NOUN 85 (VGBODY_v) FOR DISPLAY</td>
<td>SH. 11</td>
</tr>
<tr>
<td>R5CDAPON</td>
<td>2270</td>
<td>SET UP RCS DAP (HENCE DISCONTINUE ANY OTHER-HERE, TVC DAP)</td>
<td>SH. 25</td>
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<tr>
<td>R02BOTH</td>
<td>2210</td>
<td>CHECK IMU STATUS AND TERMINATE PROGRAM IF NOT OK</td>
<td>SH. 6</td>
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<tr>
<td>R50CSM</td>
<td>2240</td>
<td>PERFORM SPACECRAFT ATTITUDE MANEUVER</td>
<td>SH. 8</td>
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<tr>
<td>THSPREC (+ CSMREC)</td>
<td>2290</td>
<td>PRECISION UPDATE OF STATE VECTOR TO DESIRED TIME</td>
<td>SH. 38</td>
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<tr>
<td>TPAGREE</td>
<td>2090</td>
<td>FORCE SIGN AGREEMENT IN TRIPLE-PRECISION MPAC</td>
<td>SH. 19</td>
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<tr>
<td>TVCDAPON</td>
<td>2430</td>
<td>SET UP TVC DAP</td>
<td>SH. 22</td>
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FLAGS

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<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
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<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
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<td>ASTRONAUT HAS OKAYED IGNITION</td>
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<td>FLAGWRD7</td>
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<td>AVFLAG</td>
<td>WHEN USED IN COLOSSUS AS INPUT TO MIDGIM: MIDGIM IS TO CONVERT A VECTOR FROM REFERENCE COORDINATES TO LOCAL VERTICAL COORDINATES</td>
<td>MIDGIM IS TO COMPUTE MIDDLE GIMBAL ANGLE</td>
<td>SH. 33, 36</td>
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<td>FLAGWRD2</td>
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<td>DAPDATR1</td>
<td>ANGULAR DEADBAND IS MAXIMUM</td>
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<td>ENGNFGLG</td>
<td>SPS ENGINE IS ON</td>
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<td>FLAGWRD5</td>
<td>SPS ENGINE IS OFF</td>
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<td>ENGFGLG</td>
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<td>SPS BURN</td>
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<td>FIRST PASS THROUGH ROUTINE S40, 9</td>
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<td>TIME OF IGNITION HAS ARRIVED</td>
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<td>IMPULSW</td>
<td>MINIMUM IMPULSE BURN - CUTOFF TIME IS KNOWN</td>
<td>SH, 17</td>
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<tr>
<td>FLAGWRD2</td>
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<td>SH, 17</td>
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<td>BIT 9</td>
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<td>NETSFGLG</td>
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<td>4-JET RCS BURN</td>
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<td>BIT 15</td>
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<td>NORMSW</td>
<td>ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS IS SUCH THAT TARGET VECTOR MUST BE ROTATED INTO THE POSITION VELOCITY PLANE</td>
<td>SH, 38</td>
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<tr>
<td>FLAGWRD7</td>
<td>ANGLE BETWEEN INITIAL AND TARGET POSITION VECTORS IS SUCH THAT TARGET VECTOR MUST BE ROTATED INTO THE POSITION VELOCITY PLANE</td>
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<td>BIT 10</td>
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<td>PFRATFGLG</td>
<td>PREFERRED ATTITUDE HAS BEEN COMPUTED</td>
<td>SH, 6</td>
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<td>PREFERRED ATTITUDE NOT COMPUTED</td>
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<tr>
<td>BIT 4</td>
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<tr>
<td>STEERSW</td>
<td>STEERING IS TO BE DONE</td>
<td>SH, 23</td>
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<tr>
<td>FLAGWRD2</td>
<td>STEERING WILL NOT BE DONE</td>
<td>SH, 23</td>
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<tr>
<td>BIT 11</td>
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<tr>
<td>STRULLSW</td>
<td>DO ROUTINE STEERULL (STEERING IS TO BE DONE)</td>
<td>SH, 21</td>
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<td>FLAGWRD6</td>
<td>DO ONLY ROUTINE ULAGEOFF (NO STEERING)</td>
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<td>BIT 13</td>
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<td>SH, 23</td>
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<tr>
<td>TIMRFGLG</td>
<td>CLOKTASK OPERATING</td>
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<tr>
<td>FLAGWRD7</td>
<td>CLOKTASK NOT OPERATING</td>
<td></td>
<td>SH, 28</td>
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<tr>
<td>BIT 11</td>
<td></td>
<td></td>
<td>SH, 31</td>
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<td>XDELVFLG</td>
<td>EXTERNAL DELTA V MANEUVER</td>
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<td>SH, 4, 32</td>
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<td>FLAGWRD2</td>
<td>LAMBERT (AIMPOINT) MANEUVER</td>
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<td>SH, 4, 32</td>
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<td>BIT 8</td>
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<tr>
<td>3AXISFGLG</td>
<td>DESIRED MANEUVER SPECIFIED BY 3 AXES</td>
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<td>FLAGWRD8</td>
<td>DESIRED MANEUVER SPECIFIED BY ONE ALIGNMENT AXIS</td>
<td>SH, 8</td>
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<tr>
<td>NAME</td>
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<td>MEANING WHEN CLEAR</td>
<td>WHERE SET</td>
<td>WHERE CLEARED</td>
<td>WHERE TESTED</td>
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<tr>
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<td>---------------------------------------------------------</td>
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<tr>
<td>CHANNEL 5</td>
<td>RCS JETS CONTROLLING X-TRANSLATION, PITCH AND YAW ROTATION ARE FIRING</td>
<td>RCS JETS CONTROLLING X-TRANSLATION, PITCH AND YAW ROTATION ARE NOT FIRING</td>
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<td>SH. 23</td>
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<td>BITS 8-1</td>
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<tr>
<td>CHANNEL 11</td>
<td>SPS ENGINE ON</td>
<td>SPS ENGINE OFF</td>
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<td>SH. 20</td>
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<td>CHANNEL 12</td>
<td>OPTICS CDU ERROR COUNTERS ENABLED</td>
<td>OPTICS CDU ERROR COUNTERS CLEARED AND DISABLED</td>
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<td>SH. 44</td>
<td>SH. 28, SH. 44</td>
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<td>OPTICS CDU ERROR COUNTERS CONNECTED TO SPS GIMBALS</td>
<td>OPTICS CDU ERROR COUNTERS DISCONNECTED FROM SPS GIMBALS</td>
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<td>SH. 44</td>
<td>SH. 28</td>
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<td>OPTICS DIGITAL/ANALOG CONVERTER ENGAGED</td>
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<td>SH. 28</td>
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<td>SIV B CUTOFF NOT COMMANDED</td>
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<td>BIT 14</td>
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<td>PULSE TRAIN RELEASED FROM TVCPITCH</td>
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<td>AUTOMATIC WHEN PULSE TRAIN ENDED</td>
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<td>CHANNEL 14</td>
<td>PULSE TRAIN RELEASED FROM TVCYAW</td>
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<td>AUTOMATIC WHEN PULSE TRAIN ENDED</td>
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<td>X-TRANSLATION IS NOT COMMANDED BY TRANSLATIONAL HAND CONTROLLER</td>
<td>X-TRANSLATION IS COMMANDED BY TRANSLATIONAL HAND CONTROLLER</td>
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## Displays

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<th>Verb-Noun</th>
<th>Type of Displays</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
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<tr>
<td>V5N25</td>
<td>Please perform flashing</td>
<td>R1: 002 04 checklist code - SPS GIMBAL TRIM</td>
<td>SH, 9</td>
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<td>V16N40</td>
<td>Flashing monitor</td>
<td>R1: XXXX, X FT/SEC</td>
<td>SH, 29</td>
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<td>R2: XXXX, X FT/SEC</td>
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<td>R3: XXXX, X FT/SEC</td>
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<td>V16N55</td>
<td>Flashing monitor</td>
<td>R1: XXXX, X FT/SEC</td>
<td>SH, 30</td>
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<td>R2: XXXX, X FT/SEC</td>
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<td>R3: XXXX, X FT/SEC</td>
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### Erasable Locations Used

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<th>AGC Tag</th>
<th>GSP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
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<td>ADB</td>
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<td>Angular deadband for autopilot</td>
<td>Degrees</td>
<td>Revs</td>
<td>$2^{-1}$</td>
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<td>AVEGEXIT</td>
<td></td>
<td>Variable address of exit from servicer (FC6883)</td>
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<td>BDT&lt;sub&gt;V&lt;/sub&gt;</td>
<td>B&lt;sub&gt;T&lt;/sub&gt;</td>
<td>Intermediate quantity in steering computations: equal to $(\gamma - \alpha)$ in reference coordinates</td>
<td>M/SEC&lt;sup&gt;2&lt;/sup&gt;</td>
<td>M/CSEC&lt;sup&gt;2&lt;/sup&gt;</td>
<td>$2^7$</td>
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<tr>
<td>CDUX</td>
<td></td>
<td>Outer IMU gimbalm angle (2's complement)</td>
<td>Degrees</td>
<td>Revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>CDUY</td>
<td></td>
<td>Inner IMU gimbalm angle (2's complement)</td>
<td>Degrees</td>
<td>Revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>CDUZ</td>
<td></td>
<td>Middle IMU gimbalm angle (2's complement)</td>
<td>Degrees</td>
<td>Revs</td>
<td>$2^{-1}$</td>
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<tr>
<td>CNTR</td>
<td></td>
<td>Used here to indicate whether entry to S40.6 is a restart entry and to indicate pass through testing portion of S40.6</td>
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</tr>
<tr>
<td>CSMMASS</td>
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<td>CSM vehicle mass</td>
<td>KG</td>
<td>KG</td>
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</tr>
<tr>
<td>CSTEER&lt;sub&gt;D&lt;/sub&gt;</td>
<td>C</td>
<td>Cross product steering constant</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DELT&lt;sub&gt;4&lt;/sub&gt;&lt;sub&gt;D&lt;/sub&gt;</td>
<td></td>
<td>Length of time to reach target</td>
<td>SEC</td>
<td>CSEC</td>
<td>$2^{38}$</td>
</tr>
<tr>
<td>DELPBRAR</td>
<td></td>
<td>TVC pitch output-tracker-filter output</td>
<td>Degrees</td>
<td>Revs</td>
<td>$1.07075111$</td>
</tr>
<tr>
<td>DELVEEET&lt;sub&gt;3&lt;/sub&gt;&lt;sub&gt;V&lt;/sub&gt;</td>
<td>DELVLC&lt;sub&gt;V&lt;/sub&gt;</td>
<td>Change in velocity required for a maneuver, in reference coordinates</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>$2^7$</td>
</tr>
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### INSTRUMENTATION LAB

- Mission: P42-P41 - Thrust Programs
- Project: FC-2680
- Instrumentation Lab
- Campaign Mass
- Design
- Approval

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<tr>
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<th>Instrumentation Lab</th>
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<tr>
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<td>Colossus 1</td>
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<td>Colossus 2</td>
<td>FC-2680</td>
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<td>Colossus 3</td>
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
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<th>AGC TAG</th>
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<tr>
<td>DELYBAR</td>
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<td>TVC YAW OFFSET-TRACKER-FILTER OUTPUT</td>
<td>DEGREES</td>
<td>REV$^1$</td>
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<tr>
<td>DELVSAB$_D$</td>
<td>V$_LV$</td>
<td>MAGNITUDE OF VELOCITY-TO-BE-GAINED AT TIME OF IGNITION</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2$^7$</td>
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<tr>
<td>DELVSIN$_V$</td>
<td>V</td>
<td>DESIRED IMPULSIVE VELOCITY CHANGE IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2$^7$</td>
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<td>ERRBTMP</td>
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<td>TEMPORARY STORAGE FOR ERRORY (BELOW) - USED BY TVC DAP</td>
<td>DEGREES</td>
<td>REV$^1$</td>
<td>2$^1$</td>
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<td>REV$^1$</td>
<td>2$^1$</td>
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<tr>
<td>ERRORY</td>
<td></td>
<td>PITCH ATTITUDE ERROR (CONTROL COORDS.) - FROM RCS DAP</td>
<td>DEGREES</td>
<td>REV$^1$</td>
<td>2$^1$</td>
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<tr>
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<td>DEGREES</td>
<td>REV$^1$</td>
<td>2$^1$</td>
</tr>
<tr>
<td>F$_D$</td>
<td>F</td>
<td>NOMINAL THRUST (USED IN CENTRAL ANGLE COMPUTATION)</td>
<td>POUNDS OR KG</td>
<td>M/CSEC</td>
<td>2$^7$</td>
</tr>
<tr>
<td>GDT1/2$_V$</td>
<td>(1/2)GAT</td>
<td>1/2 THE DIFFERENCE IN VELOCITY DUE TO GRAVITATIONAL ACCELERATION AT A SPECIFIED POINT OVER A 2-SECOND INTERVAL, IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2$^7$</td>
</tr>
<tr>
<td>MASMTMP</td>
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<td>TEMPORARY STORAGE FOR UPDATED CSM VEHICLE MASS</td>
<td>KG</td>
<td>KG</td>
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<tr>
<td>MODREG</td>
<td></td>
<td>MAJOR MODE, OR PROGRAM NUMBER</td>
<td></td>
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<td>MKRTMP</td>
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<td>USED HERE TO INDICATE TO S40.6 WHETHER ENGINE GIMBALS ARE TO BE TESTED, OR ONLY TRIMMED</td>
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<td>NBRCYCLS</td>
<td>N</td>
<td>USED TO INDICATE WHETHER S40.9 IS TO BEGIN ANEW, AND IF NOT, THE NUMBER OF 2-SECOND CYCLES SINCE S40.9 WAS LAST STARTED</td>
<td></td>
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<tr>
<td>NMTIC$_D$</td>
<td></td>
<td>NOMINAL TIME OF IGNITION (ACTUAL TIME OF IGNITION MAY BE CHANGED)</td>
<td>SEC</td>
<td>CSEC</td>
<td>2$^{28}$</td>
</tr>
<tr>
<td>NVWORDI</td>
<td></td>
<td>USED TO INDICATE TO CLOCK TASK WHETHER ANY DISPLAY IS TO BE DONE (BY CLOCKJOB) AND IF SO, WHICH ONE</td>
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<tr>
<td>OGAD</td>
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<td>OLTER IMU GIMBAL ANGLE FOR ROLL DAP</td>
<td>DEGREES</td>
<td>REV$^1$</td>
<td>2$^1$</td>
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<tr>
<td>OPTIND</td>
<td></td>
<td>INDICATES WHAT, IF ANY, OPTICS ACTIVITY IS TO BE ALLOWED</td>
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<td>PACTOFF</td>
<td></td>
<td>PITCH OFFSET ANGLE</td>
<td>DEGREES</td>
<td>REV$^1$</td>
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<tr>
<td>PHASES</td>
<td></td>
<td>INDICATES WHETHER CERTAIN ROUTINES ARE TO BE RESTARTED AND, IF SO, AT WHAT POINT</td>
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<tr>
<td>PIPTIME$_D$</td>
<td></td>
<td>TIME CORRESPONDING TO SOME UPDATED STATE VECTOR</td>
<td>SECS</td>
<td>CSECS</td>
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### Erasable Locations Used (continued)

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<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
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<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>POINTVCMSM</td>
<td>U_D</td>
<td>Unit vector in direction in which another vector associated with the spacecraft is to be aligned (in this case, in the direction of initial thrust), in stable member coordinates</td>
<td></td>
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<tr>
<td>RATT_V</td>
<td>R(T)</td>
<td>Position vector, in reference coordinates, computed by integration routine for a specified time</td>
<td>M</td>
<td>M</td>
<td>2.29</td>
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<tr>
<td>REFSMMAT_M</td>
<td>[REFSMMAT]</td>
<td>Transformation matrix for conversion between reference and stable member coordinate systems</td>
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<td>2.1</td>
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<tr>
<td>RINIT_V</td>
<td></td>
<td>Position vector at a specified time, in reference coordinates</td>
<td>M</td>
<td>M</td>
<td>2.29</td>
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<tr>
<td>RTARG_V</td>
<td>R(T_2)</td>
<td>Aimpoint position vector, in reference coordinates</td>
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<td>2.29</td>
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<tr>
<td>RTIG_V</td>
<td>R(T_IG)</td>
<td>Position vector at time of ignition, in reference coordinates</td>
<td>M</td>
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<td>RTXI</td>
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<td>Temporary storage for index register 1, indicates whether reference coordinate system is centered at earth or moon, by value of -2 or -10, respectively</td>
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<tr>
<td>RTX2</td>
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<tr>
<td>SCAXIS_V</td>
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<td>Unit vector (in this case, in direction of thrust) in spacecraft coordinates, to be aligned with another vector</td>
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<tr>
<td>TDEC1_D</td>
<td>T</td>
<td>Specified time corresponding to state vector to be computed</td>
<td>SECS</td>
<td>CSECS</td>
<td>2.28</td>
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<tr>
<td>TEVENT_D</td>
<td></td>
<td>Actual time of relevant event, for downlink</td>
<td>SECS</td>
<td>CSECS</td>
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<tr>
<td>TGO_D</td>
<td>T_GO</td>
<td>Time until engine cutoff (if known)</td>
<td>SECS</td>
<td>CSECS</td>
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<tr>
<td>THETADX</td>
<td></td>
<td>Snapshot of outer IMU gimbal angle</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2.1</td>
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<tr>
<td>THETADY</td>
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<td>Snapshot of inner IMU gimbal angle</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2.1</td>
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<td>AGC TAG</td>
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<td>ENGINEERING UNITS</td>
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<tr>
<td>THETA_DZ</td>
<td>T_IG</td>
<td>SNAPSHOOT OF MIDDLE IMU GIMBAL ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
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<tr>
<td>TIG_D</td>
<td>T_IG</td>
<td>TIME OF IGNITION OR OF CUTOFF, WHICHEVER IS RELEVANT</td>
<td>SECS</td>
<td>CSECS</td>
<td>2^28</td>
</tr>
<tr>
<td>TIME1</td>
<td>CURRENT TIME</td>
<td>SECS</td>
<td>CSECS</td>
<td>2^28</td>
<td></td>
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<tr>
<td>TIME2_D</td>
<td>T_2</td>
<td>TIME OF ARRIVAL AT TARGET</td>
<td>SECS</td>
<td>CSECS</td>
<td>2^28</td>
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<td>TVCSEXPHS</td>
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<td>USED TO INDICATE WHICH AREA IN THE TVC EXECUTIVE IS TO BE RESTARTED</td>
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<td>TVCPHASE</td>
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<td>USED TO INDICATE WHICH AREA IN THE TVC DAP IS TO BE RESTARTED</td>
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<tr>
<td>TVCPITCH</td>
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<td>ANGLE THROUGH WHICH SPS ENGINE PITCH GIMBAL IS TO BE DRIVEN</td>
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<td>REVS</td>
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<tr>
<td>TVCYAW</td>
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<td>ANGLE THROUGH WHICH SPS ENGINE YAW GIMBAL IS TO BE DRIVEN</td>
<td>DEGREES</td>
<td>REVS</td>
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<tr>
<td>UT_V</td>
<td>U_TD</td>
<td>UNIT VECTOR IN DIRECTION OF DESIRED INITIAL THRUST, IN REFERENCE COORDINATES</td>
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<tr>
<td>VATT_V</td>
<td>V(T)</td>
<td>VELOCITY VECTOR, IN REFERENCE COORDINATES, COMPUTED BY INTEGRATION ROUTINE FOR A SPECIFIED TIME</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^7</td>
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<tr>
<td>VGBODY_V</td>
<td></td>
<td>VELOCITY-TO-BE-GAINED IN CONTROL COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^7</td>
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<tr>
<td>VGDISP_D</td>
<td></td>
<td>MAGNITUDE OF VELOCITY-TO-BE-GAINED (FOR DISPLAY)</td>
<td>M/SEC</td>
<td>M/CSEC</td>
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<tr>
<td>VGPREV_V</td>
<td>V_0</td>
<td>LAST COMPUTED VELOCITY-TO-BE-GAINED, IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^7</td>
</tr>
<tr>
<td>VGTIG_V</td>
<td>V_0(T_IG)</td>
<td>VELOCITY-TO-BE-GAINED AT TIME OF IGNITION, IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^7</td>
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<tr>
<td>VINIT_V</td>
<td></td>
<td>VELOCITY VECTOR AT A SPECIFIED TIME, IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
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## ERASABLE LOCATIONS USED (CONTINUED)

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<td>VPRIMEV</td>
<td>V <em>R</em></td>
<td>VELOCITY REQUIRED AT BEGINNING OF A MANEUVER, IN REFERENCE COORDINATES</td>
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<td>M/CSEC</td>
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<td>VTIGV</td>
<td>V <em>TIG</em></td>
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<td>M/CSEC</td>
<td>2^7</td>
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<tr>
<td>VSVCNTR</td>
<td>M</td>
<td>USED BY TVC DAP TO COUNT NUMBER OF HALF-SECOND INTERVALS</td>
<td>KG</td>
<td>KG</td>
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<tr>
<td>WEIGHTD</td>
<td>M</td>
<td>MASS OF VEHICLE (INCLUDING LUMMUS IF APPROPRIATE)</td>
<td>KG</td>
<td>KG</td>
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<td>XSSREFV</td>
<td>X_SC(RF)</td>
<td>SPACECRAFT X AXIS IN REFERENCE COORDINATES</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^1</td>
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<tr>
<td>YACTOFF</td>
<td>Y_SC(RF)</td>
<td>YAW OFFSET ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
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<tr>
<td>YSCREFV</td>
<td>Y_SC(RF)</td>
<td>SPACECRAFT Y AXIS IN REFERENCE COORDINATES</td>
<td>DEGREES</td>
<td>REVS</td>
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<tr>
<td>ZSCREFV</td>
<td>Z_SC(RF)</td>
<td>SPACECRAFT Z AXIS IN REFERENCE COORDINATES</td>
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## PROGRAM CONSTANTS

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<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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<tr>
<td>EP4(10)D</td>
<td>10°</td>
<td>POSSIBLE VALUE FOR MINIMUM ANGLE BETWEEN INITIAL AND FINAL POSITION VECTORS, SUFFICIENT TO DEFINE A PLANE OF FLIGHT</td>
<td>10 DEGREES</td>
<td>.027777777 REV</td>
<td>2^0</td>
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<tr>
<td>EP4(45)D</td>
<td>45°</td>
<td>POSSIBLE VALUE FOR MINIMUM ANGLE BETWEEN INITIAL AND FINAL POSITION VECTORS, SUFFICIENT TO DEFINE A PLANE OF FLIGHT</td>
<td>45 DEGREES</td>
<td>.125 REV</td>
<td>2^0</td>
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<tr>
<td>FEKG</td>
<td>F_SPS</td>
<td>SPS ENGINE THRUST (USED IN CENTRAL ANGLE COMPUTATION FOR P40)</td>
<td>90500 LBS</td>
<td>9.1186544 KG-M/CSEC</td>
<td>2^7</td>
</tr>
<tr>
<td>FRCSD</td>
<td>F_RCS</td>
<td>RCS THRUST FOR 2 JETS (USED IN CENTRAL ANGLE COMPUTATION FOR P41)</td>
<td>199.6 (COS 10) LBS</td>
<td>.87437837. KG-M/CSEC</td>
<td>2^7</td>
</tr>
<tr>
<td>MAXDB</td>
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<td>MAXIMUM VALUE FOR ANGULAR DEADBAND (FOR AUTOPILOT)</td>
<td>4.998779 DEGREES</td>
<td>455 x 2^-15 REVS</td>
<td>2^-1</td>
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<tr>
<td>MINDB</td>
<td></td>
<td>MINIMUM VALUE FOR ANGULAR DEADBAND (FOR AUTOPILOT)</td>
<td>.505371 DEGREES</td>
<td>46 x 2^-15 REVS</td>
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## Program Constants (Continued)

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<th>° ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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<tr>
<td>PBIAS_D</td>
<td>P0</td>
<td>BIAS IN PITCH OFFSET ANGLE</td>
<td>-2.15 DEGREES</td>
<td>-0.0059722222 REV</td>
<td>2^0</td>
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<tr>
<td>S40.135_D</td>
<td>7.98FL</td>
<td>IMPULSE OF VEHICLE THRUST DUE TO 2-JET BURN FOR 7.98 SECONDS</td>
<td>1588.818 LB-SEC</td>
<td>89.6005183 KG-M/CSEC</td>
<td>2^3</td>
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<tr>
<td>TRIMSCAL_D</td>
<td>YO</td>
<td>SCALING FACTOR FOR SPS ENGINE GIMBAL OFFSET ANGLES</td>
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<tr>
<td>YBIAS_D</td>
<td>YO</td>
<td>BIAS IN YAW OFFSET ANGLE</td>
<td>+0.95 DEGREES</td>
<td>+0.0283688888 REV</td>
<td>2^0</td>
</tr>
<tr>
<td>+2ACTDEG</td>
<td></td>
<td>AMOUNT OF ROTATION USED IN TESTING ENGINE GIMBALS</td>
<td>+1.9928 DEGS</td>
<td>+0.00553583 REV</td>
<td>1.07975111</td>
</tr>
<tr>
<td>-4ACTDEG</td>
<td></td>
<td>AMOUNT OF ROTATION USED IN TESTING ENGINE GIMBALS (MUST BE -2 x +2ACTDEG (ABOVE))</td>
<td>-3.9856 DEGS</td>
<td>-0.01107166 REV</td>
<td>1.07975111</td>
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## PAD Loads

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP TAG</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
<th>OCTAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECSTEER</td>
<td>EC</td>
<td>CROSS-PRODUCT STEERING CONSTANT, USED FOR LAMBERT MANEUVER – UPDATED BY PRE-THRUST PROGRAMS – USUALLY THE VALUE REMAINS 1.0, BUT MAY BE CHANGED TO .5 OR ANY VALUE FROM -.0 TO +.0</td>
<td>1.0</td>
<td>1.0</td>
<td>2^2</td>
<td>10000</td>
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<tr>
<td>EMDOT</td>
<td>M</td>
<td>RATE OF MASS DECREASE DURING SPS BURN</td>
<td></td>
<td></td>
<td>2^3</td>
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<tr>
<td>K1VAL_D</td>
<td>K1</td>
<td>1-SECOND SPS IMPULSE</td>
<td>LB-SEC</td>
<td>KG-M/CSEC</td>
<td>2^3</td>
<td></td>
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<tr>
<td>FANG_D</td>
<td>FIMP</td>
<td>EFFECTIVE THRUST DURING 1-6 SECOND INTERVAL OF BURN (USED IN IMPULSIVE BURN TIME COMPUTATIONS)</td>
<td>POUNDS OR NEWTONS</td>
<td>KG-M/CSEC</td>
<td>2^7</td>
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<tr>
<td>K2VAL_D</td>
<td>K2</td>
<td>-SPS MINIMUM IMPULSE</td>
<td>LB-SEC</td>
<td>KG-M/CSEC</td>
<td>2^3</td>
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<tr>
<td>K3VAL_D</td>
<td>K3</td>
<td>EFFECTIVE THRUST DURING 0-1 SECOND INTERVAL OF BURN (USED IN IMPULSIVE BURN TIME COMPUTATIONS)</td>
<td>LB-SEC/SEC</td>
<td>KG-M/CSEC</td>
<td>2^9</td>
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<tr>
<td>CLOKTASK</td>
<td>COMPUTES TIME-TO-GO AND, IF DESIRED, SETS UP DISPLAY</td>
<td>SH. 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------------</td>
<td>------</td>
<td></td>
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<tr>
<td>CLOCKJOB</td>
<td>UPDATES TRIGONOMETRIC FUNCTIONS OF IMU GIMBAL ANGLES AND CAUSES DESIRED DISPLAY</td>
<td>SH. 4</td>
<td></td>
<td></td>
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<tr>
<td>DYNDisp</td>
<td>SETS UP VELOCITY-TO-BE-GAINED FOR NOUN 85 DISPLAY AND DISPLAYS IT</td>
<td>SH. 4</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>V99T</td>
<td>TERMINATES PROGRAM (FROM TERMINATE RESPONSE TO V99 FLASH)</td>
<td>SH. 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>V99P</td>
<td>SETS UP IGNITION OF SPS ENGINE (FROM PROCEED RESPONSE TO V99 FLASH)</td>
<td>SH. 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>V99E</td>
<td>BYPASSES SPS BURN, JUMPING TO RCS TRIM PORTION OF PROGRAM (FROM ENTER RESPONSE TO V99 FLASH)</td>
<td>SH. 7</td>
<td></td>
<td></td>
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<tr>
<td>V97T</td>
<td>ENDS SPS BURN, THEN SETS UP TERMINATION OF PROGRAM (FROM TERMINATE RESPONSE TO V97 FLASH)</td>
<td>SH. 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V97P</td>
<td>ALLOWS SPS BURN TO CONTINUE 2 SECONDS MORE BEFORE AGAIN TESTING FOR THRUST FAILURE (FROM PROCEED RESPONSE TO V97 FLASH)</td>
<td>SH. 10</td>
<td></td>
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<tr>
<td>V97E</td>
<td>TURNS OFF SPS ENGINE, SETS UP RE-IGNITION (FROM ENTER RESPONSE TO V97 FLASH)</td>
<td>SH. 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CLOK TASK

TIMFLAG

SET ?

YES

GROUP 6

KILL GROUP 6

RESTARTS

TASKOVER

CLOCKON

TT0G0 = TIME2B - TIG0

SETCLOCK

CLOK TASK

WAITLIST

TASK IN 1

SECOND

SH 6

YES

NVWORD1

= +0 ?

NO

CLOCKJOB (DISPLAY) TO BE BYPASSED?

NO:

SOMETHING ELSE

NVWORD1

NO6N858B

YES

SETUPDYN

CLOCKJOB

NOVAC

JOB WITH

PRIORITY 27

SH 4

DYNDISP

FINDVAC

JOB WITH

PRIORITY 27

SH 4

SET TB6

GROUP 6

TBASE6 = TIME1

TASKOVER

COMPUTE TIME-TO-GO AND, IF DESIRED, SET UP DISPLAY
SET UP AS A WAITLIST TASK BY PS0'S OR PS0'S
RESCHEDULE EVERY SECOND UNTIL TERMINATED

IS CLOK TASK TO CONTINUE OPERATING?

NO

COMPUTE FOR DISPLAY: TIME FROM ENGINE
IGNITION OR CUT-OFF,
IN CSEC @ 228

WHERE: TIME2B PRESENT TIME IN CSEC @ 228
TIG0 = TIME OF IGNITION OR ENGINE CUT-
OFF (WHICHEVER IS CURRENTLY
RELEVANT) IN CSEC @ 228
ENTERED FROM TERMINATE RESPONSE BY ASTRONAUT TO IGNITION ENABLE REQUEST (SH4) OR SET UP BY V39T SEQUENCE (SH9)

GROUP 6.0
KILL GROUP 6
RESTARTS

GROUP 4
SETUP RESTARTS TO SCHEDULE NEXT LOCATION AS A NOVAC JOB WITH PRIORITY 27

V39TJOB

TCVZAP-1
DISABLE TVC3
DISCONTINUE CLOKTASK
FC-2680

POST-41
FC-2680

END PROGRAM
ENTERED FROM PROCEED RESPONSE BY ASTRONAUT TO IGNITION ENABLE REQUEST (SHA)

HAS IGNITION OK ALREADY BEEN SIGNALLED?

ASTNFLAG SET?

NO: THEN SIGNAL IT

ASTNV99P

SET ASTNFLAG

ASTRAVET OK? (BY KEYING IN 'PROCEED' ABOVE)

HAS IGNITION TIME ARRIVED?

IGNFLAG SET?

NO

ENDV99PI

IGNITION
WAITLIST TASK
IN 0.01 SECOND
FC-2680

TURNS ON SPS
ENGINE, SETS UP
TVG, DAP, ETC.

SET UP DISPLAY (FOR NEXT PASS
THROUGH CLOCKJOB) OF:

TT2G0 = TIME FROM T1G
VADISP = MAGNITUDE OF VELOCITY
TO-BE-GAINED

DVTOTAL = SUM OF MAGNITUDES
OF 2-SECOND VELOCITY
CHANGES SINCE BEGINNING
OF MANEUVER
ENTERED FROM ENTER RESPONSE (BY ASTRONAUT) TO IGNITION ENABLE REQUEST (SH4)

GROUP 6.0
KILL GROUP 6
RESTARTS

GROUP 4
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A NOVAC JOB WITH PRIORITY 27

V99EJOB

TVCTAPA
DISABLE TVC
DISCONTINUE CLOKTASK
FC-2680

FC-6680

DO MANUAL (RCS) AX TRIM
ENTERED FROM TERMINATE RESPONSE (BY ASTRONAUT) TO ENGINE FAILURE DISPLAY (SH-4)

GROUP 6.0
KILL GROUP 6 RESTARTS

GROUP 4.67
SET UP RESTARTS TO SCHEDULE V977:JOB AS A NOVAC JOB WITH PRIORITY 27

V977:JOB
NVWORD ← +0

DISCONTINUE CLOCKJOB

V977:TASK
WAITLIST TASK IN 0.01 SECOND

ENDOFJOB

V977:TASK

NEXT SHEET

SET UP INPUT TO SPOFF:
VEHICLE MASS IN KG @ 2^16
WHERE:
CSMASS = LAST VALUE FOR VEHICLE MASS IN KG @ 2^16
3MDOT = 3 x S-SECOND
= 3-SECOND MASS LOSS NOT ALREADY ACCOUNTED FOR (BECAUSE OF ENGINE FAILURE)
= 86,975,596 KG @ 2^16
NOTE:
3 SECONDS IS AVERAGE OF 2-4 SECOND LOW-THRUST DETECTION PERIOD
FROM PRECEDING SHEET

GROUP 4
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A WAITLIST TASK IMMEDIATELY

SPSOFF
TURN OFF SPS ENGINE, DO UPDATES FOR RCS DAP
FC-2680

GROUP 4.71
SET UP RESTARTS TO SCHEDULE V97TRCS AS A WAITLIST TASK IN 2.5 SECONDS
TBASE4 ← ← ← ← TIME1

FIXDELAY
WAIT 2.5 SECONDS
FC-2060

V97TRCS

RCDAPON
SET UP RCS DAP
FC-2370

V97T
NOVAC
JOB WITH PRIORITY 27
SH 5

ENDV97T

TASKOVER

WAIT FOR POSSIBLE SPS THRUST TAIL-OFF

NOW FINISH TERMINATION OF PROGRAM
ENGINED FROM PROCEED RESPONSE (BY ASTRONAUT) TO ENGINE FAILURE DISPLAY (SH 4) — WHEN
ASTRONAUT DECIDES TO CONTINUE BURN; WHEN HE HAS USED MANUAL SPS IGNITION SWITCH, WHEN
MONITORING DPS THRUST, OR WHEN FAILURE INDICATION IS FALSE

RESUME DISPLAY (NEXT PASS THROUGH CLOCKJOB)
OF TTOG = TIME FROM TIG
V_G08P = MAGNITUDE OF VELOCITY-TO-BE-
GAINED
DV_TOTAL = SUM OF MAGNitudes OF 2-SECOND
VELOCITY CHANGES SINCE BEGINNING
OF MANEUVER

TELL TVC CAP TO RESUME MASS UPDATES ($40.8 INHIBITED THEM WHEN ENGINE FAIL
DETECTED)

INHIBIT R40 (ENGINE
FAIL SIGNAL ROUTINE); ALLOW STEERING

SET UP RESTARTS TO
SCHEDULE R40ENABL
AS A WAITLIST TASK
IN 2 SECONDS
TBASE4 = TIME1

INHIBIT ENGINE FAILURE SIGNAL FOR
2 SECONDS TO AVOID PROBLEMS WITH
TIMING OF READACS, MANUAL SPS
IGNITION — DON'T WANT ANOTHER
FAILURE INDICATION RIGHT AWAY

RE-ENABLE R40 (ENGINE FAILURE SIGNAL ROUTINE)
ENTERED FROM ENTER RESPONSE (BY ASTRONAUT) TO ENGINE FAILURE DISPLAY (SH4)

GROUP4.53
SET UP RESTART TO SCHEDULE V97EJOB AS A NOVAC JOB WITH PRIORITY 30

V97EJOB

NVWORD: V96N40

V97ETASK
WAITLIST TASK IN IN 0.01 SECOND

SH11
ENDDFJOB

V97ETASK

TIG ← -20

SET TIME OF IGNITION (TIG2) LESS THAN $-1.9 \times 10^{-3} \text{ SEC (≈ 51.9 MIN)} @ 2^{16}$, THIS VALUE WILL INSURE THAT TIME - FROM TIG COMPUTED BY CLOKTASK WILL BE SO GREAT THAT IT WILL BE DISPLAYED AS THE MAXIMUM:

+59 MIN 59 SEC

SET UP INPUT TO SPOFF: VEHICLE MASS IN KG @ 2^{16} WHERE:

CSMMASS = LAST VALUE FOR VEHICLE MASS IN KG @ 2^{16}

3MDOT = M \times 3 SECONDS

GREATNESS LOSS NOT ALREADY ACCOUNTED FOR (BECAUSE MASS UPDATES STOPPED WHEN ENGINE FAILURE DETECTED)

GROUP4.75
SET UP RESTART TO SCHEDULE SPOFF97 AS A WAITLIST TASK IMMEDIATELY

TBASE4 ← TIME1

NEXT SHEET
FROM PRECEDING SHEET

SP5OFF

SP5OFF
TURN OFF
SPS ENGINE, DO
UPDATES FOR
RCS DAP
FC-2680

GROUP 4.11
SET UP RESTARTS TO
SCHEDULE V97E90.6
AS A WAITLIST TASK
IN 2.5 SECONDS

FIXDELAY
WAIT 2.5
SECONDS
FC-2680

WAIT FOR POSSIBLE SPS THRUST TAILOFF

NEXT SHEET
FROM PRECEDING SHEET

V97E40.6

PRE40.6

WAITLIST TASK IN 0.01 SECOND
FC-2680

RCSDAPON
SET UP RCS DAP
FC-2870

GROUP 6.2
SET UP RESTARTS TO SCHEDULE PRE40.6 AS A WAITLIST TASK IMMEDIATELY AND CLOKTASK AS A WAITLIST TASK IN 1 SECOND

GROUP 4
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A WAITLIST TASK IMMEDIATELY

QUICKIGN

CLEAR ASTNFLAG
SET IGNFLAG

FIXDELAY
WAIT 0.3 SECOND
FC-2680

NEXT SHEET

RESTART ENTRY TO $40.6 WILL DO SPS ENGINE GIMBAL TRIM ONLY

PRE40.6 MUST BE RESTARTED, SINCE TVC DAP IS NOT IN CONTROL, WILL NOT TAKE CARE OF INTERFACE

SET UP SITUATION FOR V99P SEQUENCE TO CAUSE IGNITION (ANOTHER TRY): THE SITUATION IS PARALLEL TO THAT OF A LATE IGNITION

ASTRONAUT HAS NOT YET OK'D (NEW) IGNITION
IGNITION TIME HAS ARRIVED (PROCEED RESPONSE TO V99 FLASH WILL BRING IMMEDIATE IGNITION)

ALLOW TIME FOR $40.6(PRE40.6) TO BE EXECUTED
FROM PRECEDING SHEET

V99FLASH

NVWORD1 ← BIT9

GROUP 4.77
SET UP RESTARTS TO SCHEDULE TIG-0 AS A WAITLIST TASK IMMEDIATELY
TBASE4 ← TIME2

GROUP 5.3
SETUP RESTARTS TO SCHEDULE S40.13 AS A FINDVAC JOB WITH PRIORITY 20

S40.13
FINDVAC JOB WITH PRIORITY TO FC-2680

ENDV97E

TASKOVER

SET INDICATOR NEGATIVE TO CAUSE V99 FLASH (IGNITION ENABLE REQUEST) NEXT TIME THROUGH CLOCKJOB

DETERMINES LENGTH OF IMPULSIVE BURN.
VULAGE ALLOWANCE WILL BE INCORRECT THIS TIME, UNLESS THERE IS NO VULAGE
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGNITION</td>
<td>2680</td>
<td>TURNS ON SPS ENGINE; SETS UP TVC DAP</td>
<td>SH, 8, SH, 4</td>
</tr>
<tr>
<td>POST41</td>
<td>2680</td>
<td>TERMINATES PROGRAM</td>
<td>SH, 5</td>
</tr>
<tr>
<td>PRE40,6</td>
<td>2680</td>
<td>TRIMS SPS ENGINE GIMBALS</td>
<td>SH, 13</td>
</tr>
<tr>
<td>P40CNV85</td>
<td>2682</td>
<td>PREPARES VELOCITY-TO-BE-GAINED FOR NOUN 85 DISPLAY</td>
<td>SH, 4</td>
</tr>
<tr>
<td>P40RCS</td>
<td>2680</td>
<td>RCS TRIM PORTION OF P40</td>
<td>SH, 7</td>
</tr>
<tr>
<td>QUITRIG</td>
<td>2270</td>
<td>COMPUTES TRIGONOMETRIC FUNCTIONS OF THREE ANGLES GIVEN</td>
<td>SH, 4</td>
</tr>
<tr>
<td>RCSDAPON</td>
<td>2370</td>
<td>SETS UP RCS DAP</td>
<td>SH, 9, SH, 13</td>
</tr>
<tr>
<td>SPOFF</td>
<td>2680</td>
<td>TURNS OFF SPS ENGINE, DOES UPDATES FOR RCS DAP</td>
<td>SH, 9, SH, 12</td>
</tr>
<tr>
<td>S40, 13</td>
<td>2680</td>
<td>DETERMINES LENGTH OF IMPULSIVE BURN</td>
<td>SH, 14</td>
</tr>
<tr>
<td>TVCZAP-1</td>
<td>2680</td>
<td>DISABLES THRUST VECTOR CONTROL; DISCONTINUES CLOKTASK</td>
<td>SH, 5, SH, 7</td>
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</tbody>
</table>

### Flags

<table>
<thead>
<tr>
<th>NAME</th>
<th>MEANING WHEN SET</th>
<th>MEANING WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASYNFLAG</td>
<td>ASTRONAUT HAS OKAYED IGNITION</td>
<td>ASTRONAUT HAS NOT OKAYED IGNITION</td>
<td>SH, 6</td>
<td>SH, 13</td>
<td>SH, 6</td>
</tr>
<tr>
<td>FLAGWRD7 BIT 12</td>
<td>INHIBIT R40 ENGINE FAIL SIGNAL ROUTINE</td>
<td>ENABLE R40 ENGINE FAIL SIGNAL ROUTINE</td>
<td>SH, 10</td>
<td>SH, 10</td>
<td>SH, 10</td>
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<tr>
<td>IDLEFAIL</td>
<td>IGNITION TIME HAS ARRIVED</td>
<td>IGNITION TIME HAS NOT ARRIVED</td>
<td>SH, 13</td>
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<td>SH, 5</td>
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<tr>
<td>STEERSSW</td>
<td>CLOKTASK TO CONTINUE</td>
<td>CLOKTASK NOT TO RUN</td>
<td>SH, 10</td>
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<td>SH, 5</td>
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<tr>
<td>TIMFLAG</td>
<td>BIT 11</td>
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<tr>
<td>CLOKTASK NOT TO RUN</td>
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</tbody>
</table>

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

COLOSSUS III FC-2681

CLOKTASK & CLOCKJOB

DRAWN BY:
PROD. MANAGER:
REPORTED:
APPROVED:

SHEET 15 OF 17
## DISPLAYS

<table>
<thead>
<tr>
<th>VERB- NOUN</th>
<th>TYPE OF DISPLAY</th>
<th>DESCRIPTION OF EACH REGISTER</th>
<th>WHERE EXECUTED</th>
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<tbody>
<tr>
<td>V06N40</td>
<td>NORMAL</td>
<td>R1: Xxxxx MIN-SEC TTOGO - TIME FROM TIG</td>
<td>SH. 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2: Xxxxx, X FT/SEC VGBSP - MAGNITUDE OF VELOCITY-TO-BE-GAINED</td>
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<tr>
<td></td>
<td></td>
<td>R3: Xxxx, X FT/SEC DVTOTAL - SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE BEGINNING OF MANEUVER</td>
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</tr>
<tr>
<td>V06N85</td>
<td>NORMAL</td>
<td>R1: Xxxx, X FT/SEC VGBODYv = VELOCITY-TO-BE GAINED IN CONTROL COORDINATES</td>
<td>SH. 4</td>
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<tr>
<td></td>
<td></td>
<td>3 COMPONENTS OF</td>
<td></td>
</tr>
<tr>
<td>V16N85</td>
<td>MONITOR</td>
<td>SAME AS ABOVE</td>
<td>SH. 4</td>
</tr>
<tr>
<td>V90N40</td>
<td>FLASHING, PLEASE PERFORM: IGNITION ENABLE</td>
<td>REGISTERS SAME AS FOR NOUN 40 DISPLAY ABOVE</td>
<td>SH. 4</td>
</tr>
<tr>
<td>V97N40</td>
<td>FLASHING, PLEASE PERFORM: RESPONSE TO THRUST FAILURE</td>
<td>REGISTERS SAME AS FOR NOUN 40 DISPLAY ABOVE</td>
<td>SH. 4</td>
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</tbody>
</table>

### ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>ACC UNITS</th>
<th>ACC SCALING</th>
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</thead>
<tbody>
<tr>
<td>CIOUSPOTX</td>
<td>FIRST ANGLE INPUT TO QUICTRIC - IN 2'S COMPLEMENT</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
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<tr>
<td>CIOUSPOTY</td>
<td>SECOND ANGLE INPUT TO QUICTRIC - IN 2'S COMPLEMENT</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
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<tr>
<td>CIOUSPOTZ</td>
<td>THIRD ANGLE INPUT TO QUICTRIC - IN 2'S COMPLEMENT</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
<td></td>
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<tr>
<td>CIOUSDUX</td>
<td>OUTER IMU GIMBAL ANGLE IN 2'S COMPLEMENT</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
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<tr>
<td>CIOUSDUX</td>
<td>INNER IMU GIMBAL ANGLE IN 2'S COMPLEMENT</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
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<tr>
<td>CIOUSDUX</td>
<td>MIDDLE IMU GIMBAL ANGLE IN 2'S COMPLEMENT</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
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<tr>
<td>CIOUSDUX</td>
<td>COSINE OF FIRST ANGLE INPUT TO QUICTRIC</td>
<td>2^1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CIOUSDUX</td>
<td>COSINE OF SECOND ANGLE INPUT TO QUICTRIC</td>
<td>2^1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CIOUSDUX</td>
<td>COSINE OF THIRD ANGLE INPUT TO QUICTRIC</td>
<td>2^1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CIOUSDUX</td>
<td>MASS OF CSM</td>
<td>KG</td>
<td>KG</td>
<td>2^16</td>
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<tr>
<td>CIOUSDUX</td>
<td>SUM OF MAGNITUDES OF 2-SECOND VELOCITY CHANGES SINCE BEGINNING OF MANEUVER</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^16</td>
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<tr>
<td>CIOUSDUX</td>
<td>TEMPORARY UPDATED VERSION OF CSMMASS (ABOVE)</td>
<td>KG</td>
<td>KG</td>
<td>2^16</td>
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### ERASABLE LINES (SEE CONTINUATION)

<table>
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<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>NWORD1</td>
<td></td>
<td>Indicates whether any display is to be set up by clockjob and, if so, which one</td>
<td></td>
<td></td>
<td>2</td>
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<tr>
<td>SINCDUX</td>
<td></td>
<td>Sine of first angle input to quietrig</td>
<td></td>
<td></td>
<td>2</td>
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<tr>
<td>SINCDUY</td>
<td></td>
<td>Sine of second angle input to quietrig</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>SINCDUZ</td>
<td></td>
<td>Sine of third angle input to quietrig</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>TRASE6</td>
<td></td>
<td>Low order half of time from which group &amp; waitlist task restarts' time is measured</td>
<td>SEC</td>
<td>CSEC</td>
<td>14</td>
</tr>
<tr>
<td>TIGD</td>
<td>TIG</td>
<td>Time of engine ignition or cutoff, whichever is currently relevant</td>
<td>SEC</td>
<td>CSEC</td>
<td>28</td>
</tr>
<tr>
<td>TIMES2D</td>
<td>TIMES1</td>
<td>Present time</td>
<td>SEC</td>
<td>CSEC</td>
<td>28</td>
</tr>
<tr>
<td>TTOGOD</td>
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<td>Time from TIG (above)</td>
<td>SEC</td>
<td>CSEC</td>
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<tr>
<td>VGBODY</td>
<td></td>
<td>Velocity-to-be-gained in control coordinates (displayed as noun 86)</td>
<td>M/SEC</td>
<td>M CSEC</td>
<td>7</td>
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<tr>
<td>VGDISP</td>
<td></td>
<td>Magnitude of velocity-to-be-gained (displayed as part of noun 40)</td>
<td>M/SEC</td>
<td>M CSEC</td>
<td>7</td>
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<tr>
<td>VGPREV</td>
<td>ΔG</td>
<td>Velocity-to-be-gained in reference coordinates</td>
<td>M/SEC</td>
<td>M CSEC</td>
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### PROGRAM CONSTANTS

<table>
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<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>3MUOT</td>
<td>M x 3 SEC</td>
<td>3-second mass loss due to SPS burn</td>
<td>86.8175796 KG</td>
<td>86 8175796 KG</td>
<td>16</td>
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SERVICER

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

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<td>PREREAD1</td>
<td>Zero PIPA's</td>
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<td>NORMALIZE</td>
<td>Does Initial State Vector Update</td>
<td>Sh. 4</td>
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<td>READACCS</td>
<td>Reads Accelerometers, Sets up SERVICER; Reschedules Itself Every 2 Seconds Until Stopped</td>
<td>Sh. 5</td>
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<td>PIPASR</td>
<td>Reads PIPA Counters</td>
<td>Sh. 9</td>
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<td>REREADAC</td>
<td>Possible Restart Entry to READACCS - In Case Accelerometers Must Be Rread</td>
<td>Sh. 12</td>
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<tr>
<td>QUIKREAD</td>
<td>Takes Quick Accelerometer Readings for Downlink Telemetry</td>
<td>Sh. 15</td>
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<tr>
<td>SERVICER</td>
<td>Checks Δ Velocity Values Read In, Does Permanent State Vector Update Using Sensed Δ Velocity</td>
<td>Sh. 16</td>
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<tr>
<td>CALCRVG</td>
<td>Computes New State Vector</td>
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<tr>
<td>CALCGRAV</td>
<td>Calculates Gravitational Acceleration at Specified Position</td>
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<td>AVGEND</td>
<td>Final Exit from SERVICER: Performs Transition to Coasting Flight Routines</td>
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<td>SERVEXIT</td>
<td>Common End of SERVICER Routines</td>
<td>Sh. 27</td>
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MIT INSTRUMENTATION LAB CAMBRIDGE, MASS. APOLO GUIDANCE AND NAVIGATION

RAWN A. Welch 04/19
PRGRM S. Singel
ANALST P. Welch
DOCIR B. Singel
APPR'D F. Welch

COLOSSUS 2D DOCUMENT NO. FC-2683
REV 1 SHEET 1 OF 37
Initialization of SERVICER
Entered from P40, P41, P61 (P61 P62), P47
Powered flight

LASTBIAS
NOVAC job with priority 21
FC 2230

Does last gyro compensation in free-fall (drift) mode;
beginning PIPA-reading mode

Entry from P11

DOADACCS
WAITLIST task in 2 seconds
Sh. 5

Does initial state vector update

Note: LASTBIAS is not restart protected.

TBASE←←TIME1

Taskover

Entry (Powered Right flight monitor)

(2 sec) used by 1/PIPA see Sh. 13

Sets 1/PIPAdT= Δ time between PIPA readings
Also called by P11 (Earth Orbit Insertion Monitor)

Initializes PIPA's for later readings

Indicate PIPA reading finished

Continue running SERVICER
Don't do free fall gyro compensation
(Not in drift portion of flight)
SERVICER is running

Initialize sum of magnitude of 2-second velocity changes since beginning of maneuver (P40)
Do initial state-vector update set up by PREREAD with priority 32; also called by P\textsuperscript{11}

Set parameter for GENTRAN
A + 1 = number of words to be moved

Input: RN\textsubscript{1} = First word to be stored
RN = First word to be stored into
Result: RN\textsubscript{V} = RN\textsubscript{1V}
VN\textsubscript{V} = VN\textsubscript{1V}
PIPTIME\textsubscript{D} = PIPTIME\textsubscript{1D}
(Update powered flight permanent state vector)

GENTRAN inhibits interrupts

Set up input to CALCGRAV

Input: MPAC\textsubscript{V} = Position vector in reference coordinates in M\textsubsymbol{263}
RTX2 Indicates whether in earth or moon sphere of influence, by value of 0 or 2 respectively
Output: MPAC\textsubscript{V} = GDT\textsubscript{1/2} = One-half the velocity change due to gravitational acceleration at the specified position over a two-second interval, in reference coordinates in m/csec \textsubsymbol{27}
And if in earth's sphere of influence:
GOBL\textsubscript{1/2} = correction term for gravitational anomaly due to earth oblateness \textsubsymbol{24}
Store new values from CALCGRAV
**READACCS**
Read accelerometers; Set up SERVICER.
Set up as task every 2 seconds until stopped.
Initiated by PREREAD (Sh. 4) or by P11 (FC-2540)

**PIPASR**
Read and clear PIPA's Sh. 9

**PIPSDONE**

**GROUP 5.5**
Set up restarts to schedule RED05.5 as a WAITLIST task immediately

**RED05.5**

**PIPAGE**
Indicate PIPA reading finished

**PIPCTR4**
Initialize counter for QUIKREAD

**CM/DSTBY set?**
Entry phase of mission?
Yes

**CHEKAVEG**
Sh 8

Output: DELVX, DELVY, DELVZ:
3 components of the $\Delta$ velocity since the last reading in SM coordinates, in m/csec $0.000585 \times 2^{14}$ (nominally)
(zeroes low-order words)

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APOLLO GUIDANCE AND NAVIGATION

SERVICER

<table>
<thead>
<tr>
<th>DRAWN</th>
<th>B. Welke</th>
<th>8/65</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRGMR</td>
<td></td>
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<tr>
<td>ANALST</td>
<td>D. Engel</td>
<td>11/65</td>
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<td>DOCMR</td>
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<tr>
<td>APPR</td>
<td>Roberts; CM, 11/65</td>
<td></td>
</tr>
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</table>

COLOSSUS 2D
DOCUMENT NO.
FC-2883

REV 1
SHET 5 OF 37
From Preceding Sheet

GROUP 6
TBASE6 ← -(PIPTIME1 + 1)

PIPTIME1 + 1 is low-order half of PIPTIME admittedly time of last PIPA reading

AOG/PIP ← AOG
AIG/PIP ← AIG
AMG/PIP ← AMG

Save for entry DAP:
Latest snapshot (taken by entry DAP at 100 ms intervals) of:
IMU gimbal angles (2's complement) in revs @ 2^-1

ROLL/PIP ← ROLL/180
ALFA/PIP ← ALFA/180
BETA/PIP ← BETA/180

Corresponding Euler angles for CM attitude in revs @ 2^-1

No

CMDAPARM set?

Entry firings and calculations allowed?

Yes

QUIKREAD WAITLIST task in 0.5 second Sh. 15

Takes new PIPA reading for Downlink telemetry

XOLDBUF ← XPIPBUFF
YOLDBUF ← YPIPBUFF
ZOLDBUF ← ZPIPBUFF
XPIPBUFF ← DELVX
YPIPBUFF ← DLEVY
ZPIPBUFF ← DELVZ

But first save the current ones from PIPASR

Next Sheet
Update time delay for entry DAP restart to 5 csec \( \Theta \frac{2}{4} \)

Initiates entry ROLLDAP

Next Sheet
From Preceding Sheet

CHEKAVEG

Also entered directly from Sh. 5 if in powered flight maneuver rather than entry

AVEGFLG

Is SERVICER to continue?

AVEGOUT

avaGexit

set?

2CADR(AVGEND)

No: this is the last time

Set up final exit from SERVICER

READACCS

WAITLIST task in 2 seconds

Sh. 5

Repeat this routine every 2 seconds

MAKEServ

SERVICER

FINDVAC job with priority 20

Sh. 16

Updates state vector

GROUP 5,4

Set up restarts to schedule SERVICER as a FINDVAC job with priority 20 and REREADAC as a WAITLIST task in 2 seconds

Note: Δ times for future Group 5 WAITLIST task restarts are measured from the time this instruction is executed

TBASE5 ← TIME1

Set bit 9 of channel 11

Indicate SERVICER active (For hybrid simulator)

TASKOVER
PIPLSR
Read PIPA's

PIPTIME1D ← TIME2D
Save time of PIPA readings in csec @ \(2^{28}\)

TEMX ← 0
TEMY ← 0
TEMZ ← 0
Initialize temporary storage registers
(in case of restart)

DELVY ← +0
DELVZ ← +0
Initialize \(\Delta\) velocity registers
(in case of restart)

DELVX +1 ← +0
DELVY +1 ← +0
DELVZ +1 ← +0
Zero low-order \(\Delta\) velocity registers
to indicate compensation of values has not yet
been done
(for Downlink telemetry)

PIPAGE ← +0
Indicate PIPA reading in progress

REPIPL
Next Sheet
From Preceding Sheet

TEMX ← PIPAX
TEMY ← PIPAY

Temporary storage of X and Y PIPA readings

DELVX ← PIPAX
DELVY ← PIPAY

Final storage of X and Y PIPA readings

PIPAX ← 0
PIPAY ← 0

Clear X and Y PIPA counters

Set \[ \text{DELV} = \frac{1}{\text{D}} \left( \int_{t-2}^{t} A_x \, dt \right) \]

Where \( t = 2 \)

Set \[ \text{DELV} = \frac{1}{\text{D}} \left( \int_{t-2}^{t} A_y \, dt \right) \]

Where \( t = 2 \)

Set \[ \text{DELV} = \frac{1}{\text{D}} \left( \int_{t-2}^{t} A_z \, dt \right) \]

Where \( t = 2 \)

All in SM coordinates

Note: Scaling of \( \text{DELV} \) increments, as measured by PIPA's, is inaccurate due to bias and scale factor errors in the hardware. These errors are compensated for (making scale factor accurate and removing bias) in \( 1/\text{PIPA} \) (See Sh. 17)
From Preceding Sheet

TEMZ ← PIPAZ
Temporary storage of Z PIPA reading

A ← PIPAZ

PIPAZ ← 0
Clear Z PIPA counter

DOLDEVZ

DELVZ ← A
Final storage of Z PIPA reading

Return via Q
Do PIPA reading if necessary
Possible restart entry to READACCS
(Appropriate if restart occurred between
end of one READACCS cycle and an early
point (PIPSDONE) in next cycle) or between
end of PREREAD and first READACCS cycle.

- set \( \frac{1}{\text{PIPADT}} = \Delta \text{time} \) between PIPA
readings \( @2^8 \) in case LASTBIAS wiped out
during restart between PREREAD and first
READACCS cycle.

- Was PIPA reading in progress when restart occurred?
  No: start READACCS at the beginning

- Set up correct return to READACCS

- Z-component reading not finished
  No: PIPA reading finished

- Y-component reading not finished
  No: Z-component reading was in progress
  when restart occurred

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APOLLO GUIDANCE AND NAVIGATION

SERVICER

COLOSSUS 2D

DOCUMENT NO. FC-2883

REV 1 SHEET 12 OF 37
From Preceding Sheet

CHKTEMX

Test TEMX

+0

X and Y PIPA's have been read
(TEMX = -PIPAx)
(TEMY = -PIPAY)

-0: No PIPA's have been read

Final storage of X PIPA reading

DELVX ← +TEMX

Final storage of Y PIPA reading

DELVX ← -TEMX

DELVY ← -TEMY

Final storage of Z PIPA reading

PIPAX ← -0

PIPAY ← +0

Clear X and Y PIPA counters

REPIP3

- Sh. 10

Now take Z PIPA reading
(CHKTEMX -7)

L ← PIPAZ

Get Z PIPA reading

PIPAZ ← +0

Clear Z PIPA counter

Test TEMZ

-0: Z PIPA has not been read - use new reading in L

Z PIPA has been read (TEMZ = -PIPAZ)

A ← -TEMZ

DELVZ ← PIPAZ

(See Sh. 10)

A ← +TEMZ

DELVZ ← L

Return via Q

DO DELVZ

Sh. 11
Store past and present PIPA readings (3 times) for Downlink telemetry. May be scheduled by READACCS when run during entry. PIPCTR preset to 2 by READACCS.

XOLDBUF → XPIPBUF
YOLDBUF → YPIPBUF
ZOLDBUF → ZPIPBUF
XPIPBUF → PIPAX
YPPIPBUF → PIPAY
ZPIPBUF → PIPAZ

Old PIPA readings

New PIPA readings

PIPCTR = 0?
Yes: Last pass

No

ONMNIATOR

PIPCTR ← PIPCTR - 1
Decrement loop counter

FIXDELAY
Wait 0.5 second

1-C-2060
SERVICER

Update state vector using sensed velocity change; set up by READACCS (every 2 seconds) with priority 20

Inhibit Interrupts

Interrupts allowed during restart changes below

RUPTRG1 ← 2

Initialize index value (Also loop counter)

PIPCHECK

Check that each PIPA reading is within proper limits

Yes

DELVZ (Y, X) = +0?

No

Is magnitude of $\Delta V_Z (\Delta V_Y, \Delta V_X)$ maximum that hardware can produce?

Yes

MAXDELV = 6398 pulses = (3200 pulses/sec x 2 sec - 2 pulses)

No

PIPLOOP

Have all components been checked?

Yes

No

RUPTRG1 ← RUPTRG1 - 1

Next Sheet
Input: \( \text{DELVX}, \text{DELVY}, \text{DELVZ} = 3 \) components of \( \Delta \) velocity as read from PIPA's in SM coordinates

Nominally in m/csec: \( 0.000585 \times 2^{14} \)

\( 1/\text{PIPADT} = \Delta \) time between PIPA readings in csec \( 2 \times 2^8 \)

(See Sh. 2, Sh. 12)

Output: \( \text{DELV}_\alpha = (\text{DELVX}_D, \text{DELVY}_D, \text{DELVZ}_D) \)

\( = \) velocity change vector \( (\Delta \gamma) \)
corrected for scale factor, bias errors in PIPA's,

Actually in m/csec: \( 0.000585 \times 2^{14} \)

Note: \( 1/\text{PIPA} \) is not restart protected.

\[ TTE_D = - \text{negative time of free fall from latest PIPA reading} \]
\[ \text{in csec } 2^{28} \]

Where: \( TTE_D = \) negative absolute time of arrival at EMS altitude in csec \( 2^{28} \)

Drag less than .05g?

No

.05GSW clear?

Yes

\[ TTE_D \leftarrow TTE_D + \text{PIPTIME}_D \]

Next Sheet
Update $DVTOTAL_D = \text{sum of the magnitudes of 2-second velocity changes since beginning of the maneuver in m/csec at } 2^7$

Where $KPI1 = 0.000585 \times 2^7$

scaling factor for $DELV_V$

Group 5, 3
Set up restarts to schedule REREADAC as a WAITLIST task in 2 seconds

Group 5
Set up restarts to schedule next location as a FINDVAC job with priority 20

Input:
- $DELV_V = 2\text{-second velocity change in SM coordinates in m/csec at } 2^{14}$
- $RNV = \text{Old position vector in reference coordinates in m at } 2^{29}$
- $VNV = \text{Old velocity vector in reference coordinates in m/csec at } 2^7$
- $GDT/2^V = 1/2 \text{ the change in velocity due to gravitational acceleration at RNV over an interval of 2-secs in reference coordinates, in m/csec at } 2^7$
- $RTX2 = \text{Indicates whether in earth or moon sphere of influence, by value of 0 or 2, respectively}$

Output:
- $DELVREF_V = \text{Sensed velocity change in reference coordinates in m/csec at } 2^7$
- $RN1V = \text{Updated position vector in reference coordinates in m at } 2^{29}$
- $VN1V = \text{Updated velocity vector in reference coordinates in m/csec at } 2^7$
- $GDT1/2^V = 1/2 \text{ the change in velocity due to gravitational acceleration at RN1V over an interval of 2 secs in reference coordinates, in m/csec at } 2^7$

And if in earth's sphere of influence:
- $GOBL1/2^V = \text{Gravitational anomaly due to earth oblateness at } 2^4$
Set up restarts to schedule REREADAC as a WAITLIST task in 2 seconds

Set up restarts to schedule next location as a FINDVAC job with priority 20

Set parameter for GENTRAN:

\[ A + 1 = \text{number of words to be moved} \]

Input: RN1 = First word to be stored
RN = First word to be stored into
Result: RN_V ← RN1_V
VN_V ← VN1_V
PIPTIME_D ← PIPTIME1_D
GDT/2_V ← GDT1/2_V
GOBL/2_V ← GOBL1/2_V

(Update powered flight permanent state vector)
in reference coordinates

GENTRAN inhibits interrupts

Location specified in AVGEXIT_D

AVGEXIT_D Set by program using SERVICER:

STEERING (FC 2682) Set by P40 (SPS Thrust)
CALCN85 (FC 2682) Set by P40, P41 (Thrust)
CM/POSE (FC 2758) Set by P62 (Entry)
CALCN83 (FC 2706) Set by P47 (Thrust Monitor)
VHIDOT (FC 2540) Set by P11 (Earth Orbit)

AVGEN (Sh. 25) Set by READACCS in final pass
SEVEREXIT (Sh. 27) Common end of this routine
CALCRVG

Update state vector

\[ \Delta V_{REF} = \Delta V_{SM} \cdot [\text{REFSMMAT}] \]  
\[ \text{DELVREF}_v = KPI1 \times \text{DELV}_v \times \text{REFSMMAT}_M \times 2^1 \]

Convert \( \Delta V \) sensed into reference coordinates in m/csec 2

Where: DELV\(_v\) = \( \Delta V \) in SM coordinates in m/csec

\( KPI1 = 0.000585 \times 2^7 \) (for scaling DELV\(_v\))

\( \text{REFSMMAT}_M \) = Transformation for conversion between SM and reference coords 2^1

2^1 factor is for scaling

\[ \frac{1}{2} \Delta V \] (in reference coords, in m/csec 2^7)

in reference coords

\[ \frac{1}{2} G (T) \Delta T + \frac{1}{2} \Delta V \] in m/csec 2^7

Save intermediate results:

Compute new position vector in reference coords, in m 2^9

Where: RN\(_v\) = Old position vector in reference coordinates in m 2^9

VN\(_v\) = Old velocity vector in reference coordinates in m/csec 2^7

GDT/2\(_v\) = 1/2 the velocity change due to gravitational acceleration at RN\(_v\) over a 2-second interval in reference coordinates in m/csec 2^7

2SEC(22)\(_D\) = 200 csec 2^22

Save new position vector

Next Sheet
From Preceding Sheet

Input: \( \text{MPAC} = \text{Position vector in reference coordinates in m} \)

\( \text{RTX2} \) - Indicates whether in earth or moon sphere of influence, by value of 0 or 2, respectively

Output: \( \text{MPAC}_v = \text{GDT1/2}_v \) = 1/2 the change in velocity due to gravitational acceleration at the specified position over a 2-second interval in reference coordinates in m/csec

And if in earth's sphere of influence:

\( \text{GOBL1/2}_v \) = Gravitational anomaly due to earth oblateness

\[
\begin{align*}
V (T+\Delta T) &= V(T) + \left( \frac{G(T+\Delta T) + G(T)}{2} \right) \frac{\Delta T + \Delta V}{V_N1} \\
V_N1 &= V_N + \text{MPAC}_v + \text{PL6}_v + \text{PL0}_v \\
\text{PL6}_v &\text{ Intermediate results saved above}
\end{align*}
\]

Compute new velocity vector in reference coords, in m/csec

Where: \( V_N \) = Old velocity vector in reference coordinates in m/csec

\( \text{PL0}_v \)

\( \text{PL6}_v \)

Return via PL31
Calculate gravitational acceleration at position given in MPAC in reference coordinates in m.

Get unit vector in direction of position vector in reference coordinates.

Note: PLX refers to location in pushlist to which pointer (PUSHLOC) refers when this routine is called.

\[ \frac{R}{R} = \text{UNIT}(R) \]

\[ \text{UNITR} \leftarrow \text{UNIT}(\text{MPAC}_V) \]

\[ \text{PLX} \leftarrow \text{UNIT}(\text{MPAC}_V) \]

\[ R^2 = \text{MPAC}_V \cdot \text{MPAC}_V \]

\[ R^2 \text{ is saved (in m}^2 \text{)} \]

\[ \text{PL34D} \leftarrow \text{MPAC}_V \cdot \text{MPAC}_V \]

Save RTX2 = Indicator of earth or moon sphere of influence by value of 0 or 2 respectively.
From Preceding Sheet

No: Moon X1 = 0?

In earth's sphere of influence?

Yes: must make correction for earth oblateness

\[ \cos \phi = \frac{U_R \cdot U_Z}{PLX_D} \]

\[ PLX_D = PLX_V \cdot UNITW_V \]

Compute \( \cos \phi \) at \( 2^\circ \)
Where: \( \phi \) = angle between position vector and earth polar axis
UNITW = Unit vector in direction of Z = Earth rotation vector (Polar axis)
in reference coordinates

\[ R_E^2 G_B = \frac{3}{2} J_{2E} \left( \frac{R_E}{R} \right)^2 \left[ (1 - 5 \cos^2 \phi) U_R + 2 \cos \phi U_Z \right] \]

GOBL \( 1/2 \) \( V \) - 20\( J_D \) \( R_{\text{EQ}} \) \( D \) \( PLX^2 \) \( D \) UNITW \( V \)

Compute gravitational anomaly due to earth oblateness at \( 2^\circ \) (Reference coords)
Where: \( 20 J_D = 20 \times \frac{3}{2} J_{2E} @ 2^\circ \)
Where \( J_{2E} = 1.0823067 \times 10^{-2} \)
= 2nd harmonic of earth's potential function
2\( J_D = 2 \times \frac{3}{2} J_{2E} @ 2^\circ \)
\( R_{\text{EQ}} = R_E^2 \) = Square of equatorial radius of the earth = 40,680,9913 \( m^2 \) @ \( 2^\circ \)
DP1/20 \( D = .05 = 1/20 \)

\[ PLX_V = UNITR_V + GOBL \( 1/2 \) \( V \) \]

When in earth sphere of influence, must correct for earth oblateness by adding in \( G_B \) (@ \( 2^\circ \))

Next Sheet
Compute $\frac{1}{2} G \Delta T$

$= \frac{1}{2}$ the $\Delta$ velocity due to gravitational acceleration (at specified position) over 2 seconds

in reference coordinates in m/csec @ 27

Where:

$- \text{MUDT(M)} = \frac{\mu}{M} \Delta T$

$= \left( \frac{4902778 \times 10^{-9} \text{m}^3 \text{sec}^{-2}}{\text{csec}} \right) \times (200 \text{csec}) \phi \text{244}$

$- \text{MUDT(E)} = \frac{\mu}{E} \Delta T$

$= \left( \frac{398603225 \times 10^{11} \text{m}^3 \text{sec}^{-2}}{\text{csec}^2} \right) \times (200 \text{csec}) \phi \text{244}$

$2^{-21}$ factor is for scaling

GDT1/2_V \rightarrow MPAC_V

Store new value for $\frac{1}{2} G \Delta T$

Return via QPRET
Entered from SERVICER last time through: final exit

Set OLDBT1 = (1/PIPADT) = Time of last PIPA compensation to low-order half of PIPTIME_D

= time of last PIPA reading in csec @ 2^28

Do gyro compensation (resuming drifting flight)

Group 5:0
Kill Group 5 restarts

Group 2
Set up restarts to schedule next location as a FINDVAC job with priority 20

AVETOMID
Perform transition from powered flight to coasting state vector maintenance

Input: \( \mathbf{R}_V, \mathbf{V}_N, \mathbf{PIPTIME}_D = \) Final state vector from AVERAGEG computation

Result: Updates variables used in coasting flight integration, updates state vector of other vehicle (LM) Does W matrix if RENDWFLG or ORBWFLAG is set

Clear mark counters (initialize for new use of radar, optics)
Number of VHF ranging marks incorporated
Number of optics marks incorporated
Common end of SERVICER routines

Group 5.3
Set up restarts to schedule REREADAC as a WAITLIST task in 2 seconds

ENDOFJOB
<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALARM</td>
<td>2140</td>
<td>Turns on alarm light; sets alarm code</td>
<td>Sh. 16</td>
</tr>
<tr>
<td>AVETOMID</td>
<td>2290</td>
<td>Performs transition from powered flight to coasting flight</td>
<td>Sh. 25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>maintenance of state vector; updates state vector of other vehicle (LM);</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>extrapolates W matrix if REND or ORB W flag is set (uses CSM state)</td>
<td></td>
</tr>
<tr>
<td>CALCN83</td>
<td>2700</td>
<td>Updates total ΔV for noun 83 display and inertial V, rate of change of V,</td>
<td>Sh. 19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>altitude above pad for noun 62 display</td>
<td></td>
</tr>
<tr>
<td>CALCN85</td>
<td>2682</td>
<td>Updates velocity-to-be-gained for noun 85</td>
<td>Sh. 19</td>
</tr>
<tr>
<td>CM/POSE</td>
<td>2775</td>
<td>Return point to re-entry control</td>
<td>Sh. 19</td>
</tr>
<tr>
<td>GENTRAN</td>
<td>2070</td>
<td>Transfers a string of data words from one location to another</td>
<td>Sh. 4, 19</td>
</tr>
<tr>
<td>LASTBIAS</td>
<td>2230</td>
<td>Does last gyro compensation in free fall mode</td>
<td>Sh. 2</td>
</tr>
<tr>
<td>PIPFREE</td>
<td>2210</td>
<td>Terminates program use of PIPA'S</td>
<td>Sh. 26</td>
</tr>
<tr>
<td>SETJTAG</td>
<td>2780</td>
<td>Initiates entry ROLLDAP</td>
<td>Sh. 7</td>
</tr>
<tr>
<td>STEERING</td>
<td>2682</td>
<td>Updates velocity-to-be-gained, computes steering rate</td>
<td>Sh. 19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>commands for TVC DAP and time-to-SPS-cutoff</td>
<td></td>
</tr>
<tr>
<td>VHHDOT</td>
<td>2540</td>
<td>Updates and displays inertial V, rate of change of V, altitude above pad</td>
<td>Sh. 19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Noun 62)</td>
<td></td>
</tr>
<tr>
<td>1/PIPA</td>
<td>2230</td>
<td>Does PIPA compensation and powered flight gyro</td>
<td>Sh. 17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>compensation; corrects sensed ΔV values for scale-factor, bias errors</td>
<td></td>
</tr>
</tbody>
</table>
## FLAGS

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVEGFLAG</td>
<td>SERVICER to continue running</td>
<td>SERVICER to stop running</td>
<td>Sh. 3</td>
<td>Sh. 8</td>
<td>Sh. 8</td>
</tr>
<tr>
<td>CMDAPARM</td>
<td>Entry firings and calculations allowed</td>
<td>Entry firings and calculations inhibited</td>
<td>Sh. 6</td>
<td></td>
<td>Sh. 5</td>
</tr>
<tr>
<td>CM/DSTBY</td>
<td>Entry DAP activated</td>
<td>Entry DAP not activated</td>
<td>Sh. 26</td>
<td>Sh. 5</td>
<td>Sh. 5</td>
</tr>
<tr>
<td>DRIFTFLG</td>
<td>Drifting flight: Gyro compensation done</td>
<td>Not drifting: No free fall gyro compensation done</td>
<td>Sh. 25</td>
<td>Sh. 3</td>
<td>Sh. 3</td>
</tr>
<tr>
<td>RNDVZFLG</td>
<td>P20 running</td>
<td>P20 not running</td>
<td>Sh. 25</td>
<td>Sh. 3</td>
<td>Sh. 26</td>
</tr>
<tr>
<td>V37FLAG</td>
<td>SERVICER running</td>
<td>SERVICER not running</td>
<td>Sh. 3</td>
<td>Sh. 26</td>
<td>Sh. 17</td>
</tr>
<tr>
<td>.05GSW</td>
<td>Drag over .05g</td>
<td>Drag under .05g</td>
<td>Sh. 3</td>
<td>Sh. 26</td>
<td>Sh. 17</td>
</tr>
</tbody>
</table>

### CHANNEL BITS

<table>
<thead>
<tr>
<th>CHANNEL BIT</th>
<th>EFFECT WHEN SET</th>
<th>EFFECT WHEN CLEAR</th>
<th>WHERE SET</th>
<th>WHERE CLEARED</th>
<th>WHERE TESTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANNEL 11</td>
<td>SERVICER active (For hybrid simulator)</td>
<td>SERVICER not active (For hybrid simulator)</td>
<td>Sh. 8</td>
<td>Sh. 26</td>
<td></td>
</tr>
</tbody>
</table>
### DISPLAYS

| Verb Nu6th | Type of Display | Description of Each Register | Where Executed |
|------------|-----------------|-------------------------------|----------------|----------------|
| ALARM      | Alarm light on; R1, R2, R3 not affected | Sh. 16                       |                |

### ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIG</td>
<td></td>
<td>Snapshot of inner IMU gimbal angle (2's complement)</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>AIG/PIP</td>
<td></td>
<td>Value of AIG (above) at time of last PIPA reading (used by entry DAP)</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>ALFA/PIP</td>
<td></td>
<td>Value of ALFA/180 (below) at time of last PIPA reading (used by entry DAP)</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>ALFA/180</td>
<td></td>
<td>Third Euler angle for CM attitude</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>AMG</td>
<td></td>
<td>Snapshot of middle IMU gimbal angle (2's complement)</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>AMG/PIP</td>
<td></td>
<td>Value of AMG (above) at time of last PIPA reading (used by entry DAP)</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>AOG</td>
<td></td>
<td>Snapshot of outer IMU gimbal angle (2's complement)</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>AOG/PIP</td>
<td></td>
<td>Value of AOG (above) at time of last PIPA reading (used by entry DAP)</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
</tbody>
</table>
### ERASABLE LOCATIONS USED (CONTINUED)

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVGEXITD</td>
<td>ΔVREF</td>
<td>2CADR of location which begins routine to run after SERVICER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BETA/PIP</td>
<td></td>
<td>Value of BETA/180 (below) at time of last PIPA reading (used by entry DAP)</td>
<td>degrees</td>
<td>revs</td>
<td>2^{-1}</td>
</tr>
<tr>
<td>BETA/180</td>
<td></td>
<td>Second Euler angle for CM attitude</td>
<td>degrees</td>
<td>revs</td>
<td>2^{-1}</td>
</tr>
<tr>
<td>DELVREFV</td>
<td>ΔV</td>
<td>Sensing velocity change in reference coordinates</td>
<td>m/sec</td>
<td>m/csec</td>
<td>2^7</td>
</tr>
<tr>
<td>DELVX</td>
<td>ΔVX</td>
<td>Sensing velocity change in stable member coordinates</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2^{14}</td>
</tr>
<tr>
<td>DELVY</td>
<td>ΔVY</td>
<td>X-component of sensing velocity change in SM coordinates</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2^{14}</td>
</tr>
<tr>
<td>DELVZ</td>
<td>ΔVZ</td>
<td>Y-component of sensing velocity change in SM coordinates</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2^{14}</td>
</tr>
<tr>
<td>DELVZD</td>
<td></td>
<td>Z-component of sensing velocity change in SM coordinates</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2^{14}</td>
</tr>
</tbody>
</table>
### ERASABLE LOCATIONS USED (CONTINUED)

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVTOTAL_D</td>
<td></td>
<td>Sum of the magnitudes of 2-second velocity changes since beginning of the maneuver</td>
<td>m/sec</td>
<td>m/csec</td>
<td>2^7</td>
</tr>
<tr>
<td>GDT/2_V</td>
<td>1/2 Q (T) ΔT</td>
<td>1/2 The change in velocity due to gravitational acceleration over a 2-second interval, in reference coordinates</td>
<td>m/sec</td>
<td>m/csec</td>
<td>2^7</td>
</tr>
<tr>
<td>GDT1/2_V</td>
<td>1/2 Q(T+ΔT)/ΔT</td>
<td>Temporary storage for updated version of GDT/2_V (above)</td>
<td>m/sec</td>
<td>m/csec</td>
<td>2^7</td>
</tr>
<tr>
<td>GOBL/2_V</td>
<td>-R^2 /μ_E G_B (T)</td>
<td>Correction term (in reference coordinates) for gravitational anomaly due to earth oblateness - satisfies the equation: ( G(\text{at } R) = \frac{\mu}{R^2} \text{ UNIT (R)} + G_B )</td>
<td>m/sec</td>
<td>m/csec</td>
<td>2^1</td>
</tr>
<tr>
<td>GOBL1/2_V</td>
<td>-R^2 /μ_E G_B (T+ΔT)</td>
<td>Temporary storage for updated version of GOBL/2_V (above)</td>
<td>m/sec</td>
<td>m/csec</td>
<td>2^1</td>
</tr>
<tr>
<td>MRKBUF2</td>
<td></td>
<td>Temporary storage for marks used in rendezvous tracking; invalid if negative</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OLDBT1 =1/PIPADT</td>
<td></td>
<td>Δ Time between PIPA readings or time of last PIPA compensation</td>
<td>sec</td>
<td>csec</td>
<td>2^8 or 2^14</td>
</tr>
<tr>
<td>PHASE5</td>
<td></td>
<td>Indicates whether certain routines are to be restarted and, if so, at what point</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Erasable Locations Used (Continued)

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIPAGE</td>
<td></td>
<td>Indicate whether or not PIPA reading is in progress, by value of 0 or 1, respectively</td>
<td>m/sec</td>
<td>m/csec</td>
<td>0.000585 x $2^{14}$</td>
</tr>
<tr>
<td>PIPAX</td>
<td></td>
<td>Counter accumulating X-component velocity change (in SM coordinates) since last reading</td>
<td>m/sec</td>
<td>m/csec</td>
<td>0.000585 x $2^{14}$</td>
</tr>
<tr>
<td>PIPAY</td>
<td></td>
<td>Counter accumulating Y-component velocity change (in SM coordinates) since last reading</td>
<td>m/sec</td>
<td>m/csec</td>
<td>0.000585 x $2^{14}$</td>
</tr>
<tr>
<td>PIPAZ</td>
<td></td>
<td>Counter accumulating Z-component velocity change (in SM coordinates) since last reading</td>
<td>m/sec</td>
<td>m/csec</td>
<td>0.000585 x $2^{14}$</td>
</tr>
<tr>
<td>PIPTIME$_D$</td>
<td></td>
<td>Time of last PIPA reading</td>
<td>sec</td>
<td>csec</td>
<td>$2^{28}$</td>
</tr>
<tr>
<td>PIPTIME1$_D$</td>
<td></td>
<td>Temporary updated version of PIPTIME$_D$ (above)</td>
<td>sec</td>
<td>csec</td>
<td>$2^{28}$</td>
</tr>
<tr>
<td>REFSMMAT$_M$</td>
<td>[REFSMMAT]</td>
<td>Transformation matrix for conversion between SM and reference coordinate systems</td>
<td></td>
<td></td>
<td>$2^1$</td>
</tr>
<tr>
<td>RN$_V$</td>
<td>R(T)</td>
<td>Position vector in reference coordinates</td>
<td>m</td>
<td>m</td>
<td>$2^{29}$</td>
</tr>
<tr>
<td>RN1$_V$</td>
<td>R(T+$\Delta$T)</td>
<td>Temporary updated version of RN$_V$ (above)</td>
<td>m</td>
<td>m</td>
<td>$2^{29}$</td>
</tr>
<tr>
<td>AGC Tag</td>
<td>GSOP Symbol</td>
<td>Meaning</td>
<td>Engineering Units</td>
<td>AGC Units</td>
<td>AGC Scaling</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------------------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>ROLL/PIP</td>
<td></td>
<td>Value of ROLL/180 (below) at time of last PIPA reading (used by entry DAP)</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>ROLL/180</td>
<td></td>
<td>First Euler angle for CM attitude</td>
<td>degrees</td>
<td>revs</td>
<td>$2^{-1}$</td>
</tr>
<tr>
<td>RTX2</td>
<td></td>
<td>Indicator of whether vehicle is in earth or moon sphere of influence, by value of 0 or 2, respectively</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEMX</td>
<td></td>
<td>Temporary storage for PIPA reading (PIPAX above)</td>
<td>m/sec</td>
<td>m/csec</td>
<td>$-0.000585 \times 2^{14}$</td>
</tr>
<tr>
<td>TEMY</td>
<td></td>
<td>Temporary storage for PIPA reading (PIPAY above)</td>
<td>m/sec</td>
<td>m/csec</td>
<td>$-0.000585 \times 2^{14}$</td>
</tr>
<tr>
<td>TEMZ</td>
<td></td>
<td>Temporary storage for PIPA reading (PIPAZ above)</td>
<td>m/sec</td>
<td>m/csec</td>
<td>$-0.000585 \times 2^{14}$</td>
</tr>
<tr>
<td>TIME2_D = (TIME2 / TIME1)</td>
<td></td>
<td>Present time</td>
<td>sec</td>
<td>csec</td>
<td>$2^{28}$</td>
</tr>
<tr>
<td>TRMKCNT</td>
<td></td>
<td>Number of optics marks incorporated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TTE_D</td>
<td>-T_FF</td>
<td>Negative of time of free fall from latest PIPA reading</td>
<td>seconds</td>
<td>csec</td>
<td>$2^{28}$</td>
</tr>
<tr>
<td>TTE2_D</td>
<td></td>
<td>Negative of absolute time of arrival at EMS altitude</td>
<td>seconds</td>
<td>csec</td>
<td>$2^{28}$</td>
</tr>
</tbody>
</table>
**ERASABLE LOCATIONS USED (CONTINUED)**

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNITR_V</td>
<td>U_R</td>
<td>Unit vector in direction of position vector (in reference coordinates)</td>
<td></td>
<td></td>
<td>2(^1)</td>
</tr>
<tr>
<td>VHFCNT</td>
<td></td>
<td>Number of VHF ranging marks incorporated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V(N)_V</td>
<td>V((T))</td>
<td>Velocity vector in reference coordinates</td>
<td></td>
<td></td>
<td>2(^7)</td>
</tr>
<tr>
<td>V(N1)_V</td>
<td>V((T+\Delta T))</td>
<td>Temporary updated version of V(N)_V (above)</td>
<td></td>
<td></td>
<td>2(^7)</td>
</tr>
<tr>
<td>XOLDBUF</td>
<td></td>
<td>Old PIPAX (see above) reading for Downlink telemetry</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2(^{14})</td>
</tr>
<tr>
<td>XPIPBUF</td>
<td></td>
<td>New PIPAX (see above) reading for Downlink telemetry</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2(^{14})</td>
</tr>
<tr>
<td>YOLDBUF</td>
<td></td>
<td>Old PIPAY (see above) reading for Downlink telemetry</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2(^{14})</td>
</tr>
<tr>
<td>YPIPBUF</td>
<td></td>
<td>New PIPAY (see above) reading for Downlink telemetry</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2(^{14})</td>
</tr>
<tr>
<td>ZOLDBUF</td>
<td></td>
<td>Old PIPAZ (see above) reading for Downlink telemetry</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2(^{14})</td>
</tr>
<tr>
<td>ZPIPBUF</td>
<td></td>
<td>New PIPAZ (see above) reading for Downlink telemetry</td>
<td>m/sec</td>
<td>m/csec</td>
<td>.000585 x 2(^{14})</td>
</tr>
</tbody>
</table>
## PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Value and Units</th>
<th>AGC Value and Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPI1</td>
<td></td>
<td>Scaling factor for converting ΔV sensed to nominal velocity scaling</td>
<td>0.00585 x 10^7</td>
<td>0.00585 x 10^7</td>
<td>2^0</td>
</tr>
<tr>
<td>-MAXDELV</td>
<td></td>
<td>Maximum ΔV component (hardware can sense - 2)</td>
<td>-6398 Pulses</td>
<td>-6398 Pulses</td>
<td>2^14</td>
</tr>
<tr>
<td>-MUDT(E)D</td>
<td>(μ_EΔT)</td>
<td>(Earth gravitational constant) x (2 seconds)</td>
<td>-7.9720645 x 10^{15} m^3/sec</td>
<td>-7.9720645 x 10^{13} m^3/csec</td>
<td>2^44</td>
</tr>
<tr>
<td>-MUDT(M)D</td>
<td>(μ_MΔT)</td>
<td>(Moon gravitational constant) x (2 seconds)</td>
<td>-9.805556 x 10^{13} m^3/sec</td>
<td>-9.805556 x 10^{11} m^3/csec</td>
<td>2^44</td>
</tr>
<tr>
<td>RESQD</td>
<td>(R_E^2)</td>
<td>Square of equatorial radius of the earth</td>
<td>40.6809913 x 10^{12} m^3</td>
<td>40.6809913 x 10^{12} m^2</td>
<td>2^59</td>
</tr>
<tr>
<td>2(J_D)</td>
<td>2 x (3/2 (J_{2E}))</td>
<td>2 x 3/2 x the 2nd harmonic of earth's potential function</td>
<td>3.2469201 x 10^{-3} x 10^{-3}</td>
<td>3.2469201</td>
<td>2^{-1}</td>
</tr>
<tr>
<td>20(J_D)</td>
<td>20 x (3/2 (J_{2E}))</td>
<td>20 x 3/2 x the 2nd harmonic of earth's potential function</td>
<td>3.2469201 x 10^{-2} x 10^{-2}</td>
<td>3.2469201</td>
<td>2^{-1}</td>
</tr>
<tr>
<td>AGC Tag</td>
<td>GSOP Tag</td>
<td>Meaning</td>
<td>Engineering Value And Units</td>
<td>AGC Value And Units</td>
<td>AGC Scaling</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>---------</td>
<td>----------------------------</td>
<td>---------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>UNITW,</td>
<td>UZ</td>
<td>Unit vector in the direction of earth rotation vector (Z) in reference coordinates</td>
<td>3.32402568949 x 10^-6</td>
<td>4.18407084553 x 10^-5</td>
<td>9.9999998 x 10^-1</td>
</tr>
</tbody>
</table>

PROGRAM CONSTANTS (CONTINUED)
### MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS:

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>P47CSM</td>
<td>Sets up monitor of velocity change. Used during non-GNCS controlled maneuvers</td>
<td>SII.3</td>
</tr>
<tr>
<td>TIGON</td>
<td>Starts average G maintenance of state vector</td>
<td>SII.4</td>
</tr>
<tr>
<td>P47BODY</td>
<td>Initializes and displays velocity change</td>
<td>SII.5</td>
</tr>
<tr>
<td>CALCN83</td>
<td>Updates values for noun 83 (V in control coordinates) and noun 82 (V, H, R) displays</td>
<td>SII.6</td>
</tr>
<tr>
<td>S41.1</td>
<td>Converts vector from reference to control coordinates</td>
<td>SII.8</td>
</tr>
</tbody>
</table>

The enclosed replacement sheets (SII.4, 5) will update the CoLOSSUS II flowchart FC-2700, rev. 1, to CoLOSSUS IIIC, FC-2700, rev. 2.
MONITORS VELOCITY CHANGE DURING MANEUVERS NOT UNDER GNCS CONTROL.
CALLED VIA OSKY BY V37E47E
(FINDVAC JOB WITH PRIORITY 13)

RETURNS HERE ONLY IF OKAY—
OTHERWISE DISPLAYS ALARM AND TERMINATES PROGRAM

OUTPUT: \( \mathbf{r}_N \) = POSITION VECTOR IN REFERENCE
COORDINATES IN M @ 2.29
\( \mathbf{v}_N \) = VELOCITY VECTOR IN REFERENCE
COORDINATES IN M/CSEC @ 2.27
\( \text{PITIME}_D \) = TIME CORRESPONDING TO \( \mathbf{r}_N, \mathbf{v}_N \)
in CSEC @ 2.28
(A LITTLE PAST THE PRESENT TIME)
\( \text{MPAC}_H \) = TIME INTEGRATED TO \( \text{PITIME}_D \)-PRESENT TIME
in CSEC @ 2.28

\( \text{P40TMP} \leftarrow (\text{MPAC} + 1) \)
SAVE THIS \( \Delta t \)

\( \text{TICON} \)
WAITLIST TASK IN (MPAC+1) CSEC
SH.4

GROUP 4.57
SET UP RESTARTS TO SCHEDULE TICON AS
A WAITLIST TASK IN (P40TMP) CSEC
TBASEx = --TIME 1

ENDOFJOB
TIGON

AVERAGED ← RADDR(CALCN83)

SET UP EXIT FROM SERVICER TO CALCN83 (SHEET 6)

P47BODY

NOVAC JOB WITH PRIORITY 30
SH.5

WILL RUN BEFORE SERVICER, WHICH HAS PRIORITY 20

TTGPHS

GROUP 4.2

SET UP RESTARTS TO SCHEDULE PRECHECK AS A WAITLIST TASK IMMEDIATELY AND P47BODY AS A NOVAC JOB WITH PRIORITY 30

TBASE4 ← TIME 1

PRECHECK

TEST PHASE 5

HAS SERVICER BEEN RESTART PROTECTED?

> 0: YES, THIS MUST BE A RESTART ENTRY DON'T START SERVICER AGAIN

0: NO, START IT NOW

TASKOVER

PREREAD FC-2683

PREREAD Initializes SERVICER WITH PRIORITY 20, WHICH IS RESCHEDULED EVERY 2 SECONDS
P47BOD

DELVIMU ← (0,0)
DELVCT ← (0,0)

INITIALIZES AND DISPLAYS NOUN 83
SET UP BY TIGON AS A NOVAC JOB, PRIORITY 30

P47BOD

PRIORING
CHANGE PRIORITY
OF THIS JOB
TO 45
FC-2070

NOW SERVICER (INCLUDING CALCN83), WITH PRIORITY 20, MAY INTERRUPT THIS JOB

GROUP4

SET UP RESTARTS TO
SCHEDULE NEXT LOCATION
AS A NOVAC JOB
WITH PRIORITY 15

P47/DSP

GLOFLASH
FLASHING
MONITOR OF
V46-N83

RC: XXXX.X FT/SEC
R2: XXXX.X FT/SEC
R3: XXXX.X FT/SEC

3 COMPONENTS OF DELVIMU = TOTAL Δ VELOCITY SINCE BEGINNING OF MANEUVER (OR LAST INITIALIZATION) IN CONTROL COORDINATES

PROCEED, TERMINATE

SELECTION OF NEW MAJOR MODE WILL END RESCHEDULING OF SERVICER

GOTOPO0H

RECYCLE
UPDATES VALUES FOR NOUN 83 AND NOUN 62 DISPLAYS
ENTERED DIRECTLY FROM SERVICER EVERY 2 SECONDS WITH PRIORITY 20

UPDATE TOTAL VELOCITY CHANGE IN REFERENCE COORDINATES
IN M/CSEC @ 27 WHERE:
DELVCt = OLD TOTAL ΔV IN REFERENCE COORDINATES
IN M/CSEC @ 27
DELVRF = LAST 2-SECOND VELOCITY CHANGE IN
REFERENCE COORDINATES IN M/CSEC @ 27

INPUT: PLOV = VECTOR IN REFERENCE COORDINATES

OUTPUT: MPAC = VECTOR IN CONTROL COORDINATES
(SAME SCALING)

STORE ΔV IN S.C. COORDINATES, IN M/CSEC @ 27

INPUT: RN = POSITION VECTOR IN REFERENCE COORDINATES
IN M @ 27
VN = VELOCITY VECTOR IN REFERENCE COORDINATES
IN M/CSEC @ 27
OUTPUT: VMAG = MAGNITUDE OF VELOCITY, IN M/CSEC @ 27
HDT = RATE OF CHANGE OF ALTITUDE
(COMPONENT OF VN ALONG RN) IN M/CSEC @ 27
ALT = DISTANCE OF VEHICLE FROM EARTH OR
MOON SURFACE, AS APPROPRIATE
IN M @ 27

NOTE: NOUN 62 DISPLAY WILL NOT BE DONE AUTOMATICALLY,
BUT MAY BE REQUESTED BY ASTRONAUT

NOTE: THIS TIME IS MEASURED FROM THE LAST TIME
READACCS WAS SCHEDULED
SET PARAMETER FOR GENTRAN
A+1 = NUMBER OF WORDS TO BE MOVED

INPUT: DV47TEMP = FIRST WORD TO BE STORED
DELVCTL = FIRST WORD TO BE STORED INTO

RESULT: DELVCTL ← DV47TEMP
(STORE UPDATED VERSION OF TOTAL ΔV IN REFERENCE COORDINATES, IN MV/CSEC @ z^7)

COMMON EXIT FROM SERVER

FROM PRECEDING SHEET

A ← 5
CONVERTS VECTOR FROM REFERENCE TO CONTROL COORDINATES
ENTERED WITH INPUT VECTOR IN PL-X, SCALED AT 2^4
(WHERE PUSHLOC POINTS TO PL’(X+6))

SAVE QP*RET IN QTEMP

CONVERT TO TRIG UPDATING TRIGONOMETRIC FUNCTIONS OF IMU GIMBAL ANGLES
FC-2270

OUTPUT: SINCUX, COSCUX
SINCUY, COSCUDY
SINCUDZ, COSCUDZ

MPACy ← REFSMMATM * PLy |

CONVERT INPUT VECTOR TO S.M. COORDINATES @ 2^4+1
WHERE REFSMMATM = TRANSFORMATION MATRIX FOR CONVERSION BETWEEN REFERENCE AND STABLE MEMBER COORDINATE SYSTEMS @ 2^4

INPUT: SINCUX, COSCUX
SINCUY, COSCUDY
SINCUDZ, COSCUDZ
MPACy = VECTOR IN S.M. COORDINATES

MPACy = VECTOR IN N.B. COORDINATES (SAME SCALING)

MPACy ← 10 x 2^4 * QUADROTM * MPACy |

CONVERT VECTOR TO CONTROL COORDINATES @ 2^4
WHERE: QUADROTM = TRANSFORMATION MATRIX FOR CONVERSION BETWEEN NAV. BASE AND CONTROL COORDINATE SYSTEMS @ 60
10, 2^4 FACTORS ARE FOR SCALING

RETURN VIA QTEMP
### Subroutines Called Which Are Followed on Other Flow Charts

<table>
<thead>
<tr>
<th>Subroutine Name</th>
<th>Flow Chart</th>
<th>Description</th>
<th>Where Called</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDUTRIG</td>
<td>2270</td>
<td>Updates trigonometric functions of IMU gimbal angles</td>
<td>SH.8</td>
</tr>
<tr>
<td>GENTRAN</td>
<td>2070</td>
<td>Move given number of words from one location into another</td>
<td>SH.7</td>
</tr>
<tr>
<td>MIDTOAV2</td>
<td>2200</td>
<td>Update state vector to a little past present time</td>
<td>SH.3</td>
</tr>
<tr>
<td>PREREAD</td>
<td>2683</td>
<td>Starts servicer, which maintains state vector during a maneuver</td>
<td>SH.4</td>
</tr>
<tr>
<td>PRIORCHING</td>
<td>2050</td>
<td>Changes priority of the current job</td>
<td>SH.5</td>
</tr>
<tr>
<td>R22BOTH</td>
<td>2210</td>
<td>Checks that IMU is on, has known orientation (and terminates program if not)</td>
<td>SH.3</td>
</tr>
<tr>
<td>SERVEXIT</td>
<td>2683</td>
<td>Common end of servicer routines</td>
<td>SH.7</td>
</tr>
<tr>
<td>S11.1</td>
<td>2540</td>
<td>Computes magnitude of velocity, altitude and altitude change rate for noun &amp; display</td>
<td>SH.6</td>
</tr>
<tr>
<td>$^<em>$SMNB</em></td>
<td>2270</td>
<td>Converts given vector from stable member to navigation base coordinates</td>
<td>SH.8</td>
</tr>
</tbody>
</table>

### Displays

<table>
<thead>
<tr>
<th>Verb-Noun</th>
<th>Type of Display</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
</tr>
</thead>
<tbody>
<tr>
<td>V18N83</td>
<td>Flashing Monitor</td>
<td>R1: XXXX.X FT/SEC</td>
<td>SH.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2: XXXX.X FT/SEC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3: XXXX.X FT/SEC</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Erasable Locations Used

<table>
<thead>
<tr>
<th>AGC Tag</th>
<th>GSOP Symbol</th>
<th>Meaning</th>
<th>Engineering Units</th>
<th>AGC Units</th>
<th>AGC Scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTI,D</td>
<td>H</td>
<td>Distance of vehicle from earth or moon surface, as appropriate</td>
<td>M</td>
<td>M</td>
<td>$2^{28}$</td>
</tr>
<tr>
<td>AVEG_EXIT,D</td>
<td></td>
<td>Variable 2CADR address of exit from servicer (FC-2683)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COSCDUX</td>
<td></td>
<td>Cosine of outer IMU gimbal angle</td>
<td>2&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COSCDU,</td>
<td></td>
<td>Cosine of inner IMU gimbal angle</td>
<td>2&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COSCDUZ</td>
<td></td>
<td>Cosine of middle IMU gimbal angle</td>
<td>2&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGC TAG</td>
<td>GSOP SYMBOL</td>
<td>MEANING</td>
<td>ENGINEERING UNITS</td>
<td>AGC UNITS</td>
<td>AGC SCALING</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td>---------</td>
<td>-------------------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>DELVCTL&lt;sub&gt;v&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>TOTAL ∆V SENSED SINCE BEGINNING OF MANEUVER (OR SINCE LAST INITIALIZATION) IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>DELVIMU&lt;sub&gt;v&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>TOTAL ∆V SENSED SINCE BEGINNING OF MANEUVER (OR SINCE LAST INITIALIZATION) IN CONTROL COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>DELVREF&lt;sub&gt;v&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>SENSED 2-SECOND VELOCITY CHANGE IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>DV47TEMP&lt;sub&gt;v&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>TEMPORARY UPDATED VERSION OF DELVCTL&lt;sub&gt;v&lt;/sub&gt; (ABOVE) FOR COPY CYCLE</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>HDOT&lt;sub&gt;D&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>RATE OF CHANGE OF ALTITUDE (ABOVE LAUNCH PAID)</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>PHASES</td>
<td></td>
<td>INDICATES WHETHER CERTAIN ROUTINES ARE TO BE RE-STARTED AND, IF SO, AT WHAT POINT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIITIME&lt;sub&gt;D&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>TIME OF LAST ACCELEROMETER READING (CORRESPONDS TO R&lt;sub&gt;N&lt;/sub&gt;&lt;sub&gt;V&lt;/sub&gt;, V&lt;sub&gt;N&lt;/sub&gt;&lt;sub&gt;V&lt;/sub&gt;)</td>
<td>SEC</td>
<td>CSEC</td>
<td>2&lt;sup&gt;28&lt;/sup&gt;</td>
</tr>
<tr>
<td>REFSSMAT&lt;sub&gt;M&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>TRANSFORMATION MATRIX FOR CONVERSION BETWEEN REFERENCE AND STABLE MEMBER COORDINATE SYSTEMS</td>
<td></td>
<td></td>
<td>2&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>R&lt;sub&gt;N&lt;/sub&gt;&lt;sub&gt;V&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>POSITION VECTOR IN REFERENCE COORDINATES</td>
<td>M</td>
<td>M</td>
<td>2&lt;sup&gt;29&lt;/sup&gt;</td>
</tr>
<tr>
<td>RNI&lt;sub&gt;V&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>TEMPORARY UPDATED VERSION OF R&lt;sub&gt;N&lt;/sub&gt;&lt;sub&gt;V&lt;/sub&gt; (ABOVE)</td>
<td>M</td>
<td>M</td>
<td>2&lt;sup&gt;29&lt;/sup&gt;</td>
</tr>
<tr>
<td>SINCOUX</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>SINE OF OUTER IMU GIMBAL ANGLE</td>
<td></td>
<td></td>
<td>2&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>SINCOUY</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>SINE OF INNER IMU GIMBAL ANGLE</td>
<td></td>
<td></td>
<td>2&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>SINCOUZ</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>SINE OF MIDDLE IMU GIMBAL ANGLE</td>
<td></td>
<td></td>
<td>2&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>VMAGL&lt;sub&gt;D&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>INERTIAL VELOCITY (MAGNITUDE)</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>V&lt;sub&gt;N&lt;/sub&gt;&lt;sub&gt;V&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>VELOCITY VECTOR IN REFERENCE COORDINATES</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
<tr>
<td>VNI&lt;sub&gt;V&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>TEMPORARY UPDATED VERSION OF V&lt;sub&gt;N&lt;/sub&gt;&lt;sub&gt;V&lt;/sub&gt; (ABOVE)</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2&lt;sup&gt;7&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**PROGRAM CONSTANTS**

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING AND AGC VALUE</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUADROT&lt;sub&gt;M&lt;/sub&gt;</td>
<td>GSO&lt;sub&gt;p&lt;/sub&gt;</td>
<td>TRANSFORMATION MATRIX FOR CONVERSION BETWEEN NAVIGATION BASE AND CONTROL COORDINATE SYSTEMS (A 7.25 DEGREE ROTATION)</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

```
QUADROT<sub>M</sub> =
[ 1 0 0 ]
[ 0 .9200 -1.2820 ]
[ 0 .12820 .9200 ]
```
P52: IMU REALIGNMENT

ENCLOSED ARE REPLACEMENT SHEETS (SH. 1, 23) TO UPDATE THE COLOSSUS II FLOWCHART FC-2720, REV. 0, TO THE COLOSSUS IIC FLOWCHART FC-2720, REV. 1.
FROM PRECEDING SHEET

PS2T

DSPTEML = 0

NEW TIME - ENTER

GOPLASH

VO6N34

PROCEED

IS T(ALIGN) DEFINED TO BE ZERO?

= 0

YES

DSPTEML - TIME2:

T(ALIGN) = T PRESENT

IS STORRED ORIENTATION CODE EQUAL TO ZERO?

NO - LANDING SITE

INPUT: DSPTEML - TIME OF ALIGNMENT

RLS - LANDING SITE VECTOR

OUTPUT: YSMD, YSMO, ZSMO

YES - NOMINAL

PS2LS

COMPUTE LANDING SITE ORIENTATION

SH7

INPUT: TIME OF EVENT (NDW IN MPAC) FOR

CSM CONIC

OUTPUT: STABLE MEMBER

DESIREO : XSMO = YSMO X ZSMO

ALIGN

YSMD = V X R

ZSMO = R

TO LOCAL VERTICAL

SS2.3

COMPLETE NOMINAL IMU ORIENTATION

SH40

PS2O

SS2.2

COMPLETE DESIRED GIMBAL ANGLE

SH8

READ VEHICLE ATTITUDE AND COMPUTE GIMBAL ANGLES

INPUT: CDUX, CDUY, CDUZ, HARDWARE CDU (COUPLING DATA
UNIT) REGISTERS XSMO, YSMO, ZSMO (MOVED INTO
extracted text continues...
FROM PRECEDING SHEET

IMPULSE
SET UP TORQUING OF SYRO'S BY DESIRED AMOUNT
FC-2510

IMUSTALL
DELAY UNTIL GYRO TORQUING DONE
FC-2510

GROUP 4
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A JOB WITH DLD PRIORITY

INPUT: \( OGC_1, IG_2, MG_3 \)

INPUT: \( ECADR(XSMD) \)

INPUT: \( ECADR(REFSMAT) \)

MATMOVE
TRANSFER MATRIX DATA
SR27

CLEAR PFRATFLG

SET REFSFLG

SET/PDT
SET 1/P/PAT TO TIME 1
FC-2710

\( GC\text{DMP}_v \leftarrow (D,0,0) \)
INITIALIZE PARAMETER FOR GYRO COMPENSATION

SET DRIFTFLG

INPUT: \( X_1 = EC\text{AOR}(\text{MATRIX TO BE TRANSFERRED}) \)

INPUT: \( X_2 = EC\text{AOR}(\text{MATRIX TO BE STORED INTO}) \)

RESULT: \( \text{REFSMAT}_m \)

\[
\begin{bmatrix}
XSM_{Dv} \\
YSMD_{v} \\
ZSM_{Dv}
\end{bmatrix}
\]

NO PREFERRED ATTITUDE COMPUTED

REFSMAT MATRIX IS AGAIN VALID

GYRO COMPENSATION TO BE DONE
INPUT: COUX, COUY, COUZ, THETAD, +1, +2 FOR IMU CARB
OUTPUT: REFSSMAT = (XSMV, YSMV, ZSMV)
REFSSMAT = PRESENT IMU ORIENTATION

REFSSMAT IS GOOD

INPUT: COMPUTER CLOCK
OUTPUT: MPAC₀ - TIME 2, TIME 1

TIME OF SIGHTING

INPUT: MPAC₀ - TIME OF SIGHTING
OUTPUT: V_EARTH, V_SUN, V_MOON

NEXT SHEET
FROM PRECEDING SHEET

2 STARS NOT AVAILABLE

P52E

PICAPAR
STAR PAIR
SELECTION
SH13

INPUT:
VEARTH, VSUN, VMOON
CDOX, COUY, CDOZ-COU REGISTERS
HARDWARE MAINTAINED
STAR CATALOG - STAR POINTING
VECTORS FROM EARTH'S CENTER
OUTPUT:
BESTJ - STAR NO.'S X6

DO FINE ALIGN

2 STARS
AVAILABLE

P52F

DISPLAY ALARM
CODE
R1-
R2-
R3-

ALARM
TWO STARS NOT
AVAILABLE
405

INPUT: BESTJ - STAR 1 X 6
BESTJ - STAR 2 X 6
OUTPUT: TORQUE IRGS AT IMU PULSE
ACCORDING TO DP DELTA GYRO
ANGLES IN OSC, IG1, MG1 AS
COMPUTED IN CALCOTA (CALLED
BY R51 VIA R55)

GOFLASH

FIRE

VOSNOB

PROCEED

RECYCLE

R51
FINE ALIGN
SH18

GO TO POOL

VEHICLE HAS BEEN MANEUVERED
DISPLAY THE LANDING SITE LATITUDE, LONGITUDE AND ALTITUDE COMPUTE THE LANDING SITE ORIENTATION FOR PS2 OR PS4.

INPUT: DSPTEMI - TIME OF ALIGNMENT
RLS - LANDING SITE VECTOR IN MOON FIXED COORDINATES

OUTPUT: XSMD, YSMD, ZSMD

LUNAR LAT AND LONG

TIME IS ALIGNMENT

USE FIXED RADIUS

LANDING SITE VECTOR
TIME OF ALIGNMENT

CONVERT RP (VECTOR IN PLANETARY COORDINATE SYSTEM MOON FIXED) TO R (SAME VECTOR IN BASIC REF. SYSTEM)

INPUT: MPAC - NON ZERO = MOON
0 - RP - RP VECTOR
6-70 - TIME
OUTPUT: MPAC - R VECTOR 829 FOR MOON

R VECTOR 829
TIME OF ALIGNMENT

CONVERT RAD VECTOR AT GIVEN TIME TO LAT, LONG, AND ALT
INPUT: ALPHAV - POSITION VECTOR
MPACDP - TIME
ERADFLG, LUNAFLG
OUTPUT: LAT - LATITUDE
LONG - LONGITUDE
ALT - ALTITUDE

STORE IN LOCATIONS FOR N88 DISPLAY
INPUT: ALTD, LONGD
OUTPUT: LANDALT, LANDLONG
NOTE: LAT AND LANDLAT ARE THE SAME

NEXT SHEET
FROM PRECEDING SHEET

LSDISP

ENTER

GOFLASH

V06N8B

PROCEED

LLASRDA

RESTORE ALT AND LONG

FC-2590

MPAC\[DP\]

TSIGHT

CALCTORV

CONVERT LAT AND LONG TO RADIUS VECTOR

FC-2280

XSMO \rightarrow UNIT [\alpha] = \frac{RALT \times \text{VATT}}{ \text{XSMO} \times \text{XSMO} ]

TDECI\[DP\]

TSIGHT\[DP\]

CSMPREC

PERFORM ORBIT INTEGRATION

FC-2290

YSMO \rightarrow UNIT [ZSMO \times \text{XSMO}]

RETURN VIA QMAJ

DISPLAY STORED LANDING SITE COORDINATES
R1 - LAT - LATITUDE OF LANDING SITE IN DEG TO
NEAREST .001 DEG
R2 - LONG/2 - LONGITUDE OF LANDING SITE
DIVIDED BY 2 IN DEG TO NEAREST
.001 DEG PLUS 15 EAST
R3 - ALT - ALTITUDE ABOVE MEAN LUNAR RADIUS ZERO

INPUT: LANDALT\[DP\], LANDLONG\[DP\]
OUTPUT: ALT, LONG

CONVERT LAT, LONG, ALT AT A GIVEN TIME TO
RADIUS VECTOR
INPUT: LAT, LONG, ALT, (MPAC\[DP\] - TIME)
ERADFLAG, LUNAFLAG
OUTPUT: \alpha_\text{AV}, R

LANDING SITE X UNIT VECTOR

LANDING SITE Y UNIT VECTOR

LANDING SITE Z UNIT VECTOR

INPUT: TDECI
OUTPUT: RATT - POSITION VECTOR
VATT - VELOCITY VECTOR
COMPUTES THE GIMBAL ANGLES FOR DESIRED
STABLE MEMBER AND PRESENT VEHICLE
INPUT: COUX, COUY, COUZ - OUTER, INNER, MIDDLE
GIMBAL ANGLES XSMO, YSMO, ZSMO - STABLE
MEMBER DESIRED IN BASIC COORDS
OUTPUT: THETAD, +1, +2 - 2'S COMP. SP. VALUES
OF THE GIMBAL ANGLES IN DEGREES
SAVE 0 IN QMAT

INPUT: COUX, COUY, COUZ
OUTPUT: SINCDOUX, SINCDOUY, SINCDOUZ
COSCDOUX, COSCDOUY, COSCDOUZ

INPUT: SINCDOUX, SINCDOUY, SINCDOUZ
COSCDOUX, COSCDOUY, COSCDOUZ
OUTPUT: XNB, YNB, ZNB - DIRECTIONS OF THE
X, Y, Z AXES OF THE NAV.
BASE (= SPACE CRAFT) COORDINATE SYSTEM
IN STABLE MEMBER COORDINATE SYSTEM

18 WORD MATRIX
6 WORD VECTORS

DIRECTIONS OF THE X, Y, Z AXES OF THE PRESENT NAV.
BASE COORDINATE SYSTEM IN BASIC REFERENCE
COORDINATE SYSTEM

INPUT TO MATMOVE

INPUT: X1, X2
OUTPUT: MOVE MATRIX FROM X1 LOCATION
TO X2 LOCATION

INPUT: XNB, YNB, ZNB - PRESENT NAV. BASE COORDS-
UNIT VECTOR
XSMO, YSMO, ZSMO - DESIRED IMU ORIENTATION-
UNIT VECTOR
OUTPUT: THETAD, +1, +2 - SINGLE PRECISION 2'S
COMPLEMENT VALUES OF Desired GIMBAL ANGLES

CALC SムС
COMPUTE NAV.
BASE WORDS
SH25

X1 = 180
S1 = 60

SS2.2.A

XNB = UNIT [XNB X REF SMAT]
YNB = UNIT [YNB X REF SMAT]
ZNB = UNIT [ZNB X REF SMAT]

SS2.2.1

X1 = -CADR(XSMO)
X2 = -CADR(XSMO)

MATMOVE

MOVE XSMO, YSMO, ZSMO INTO XSMO,
YSM, ZSM
SH27

CALC SムС
COMPUTE GIMBAL
ANGLES
FC-2260

RETURN VIA QMAT
computes nominal orientation based on \( \bar{\mathbf{r}} \) and \( \mathbf{v} \) (position and velocity vectors)

input: \( \text{TIG} \) (in MPAC) - time of ignition

output: \( x_{\text{SMDO}}, y_{\text{SMDO}}, z_{\text{SMDO}} \) - desired gimbal axes in basic reference coordinates

\[ \text{QMAJ} \rightarrow \text{QPRET} \]

\[ \text{TDEC1} \rightarrow \text{MPAC} \]

\( \text{CSMPREC} \)

\[ \text{INTEGRATE} \]

\[ \text{STATE VECTOR} \]

\[ FC-2290 \]

\[ x_{\text{SMDO}} \rightarrow \text{UNIT} \left[ -x_{\text{ATT}} \right] \]

\[ y_{\text{SMDO}} \rightarrow \text{UNIT} \left[ y_{\text{ATT}} \times x_{\text{ATT}} \right] \]

\[ x_{\text{SMDO}} \rightarrow \text{UNIT} \left[ y_{\text{SMDO}} \times z_{\text{SMDO}} \right] \]

\[ \text{RETURN VIA QMAJ} \]

\[ \text{TIME OF IGNITION (IF KNOWN) OR CURRENT TIME} \]

input: \( \text{TDEC1} \) - time of integration

output: \( x_{\text{ATT}}, y_{\text{ATT}} \) - position and velocity vectors

desired gimbal axes

\[ x_{\text{SMDO}} = \text{UNIT} \cdot r \]

\[ y_{\text{SMDO}} = \text{UNIT} \left( y \times r \right) \]

\[ x_{\text{SMDO}} = \text{UNIT} \left( y_{\text{SMDO}} \times z_{\text{SMDO}} \right) \]
COMPUTES INPUTS FOR PICAPAR AND PLANET
INPUT: TIME IN MPAC_D

MOON

OUTPUT: VSUN = (RES-REM) - 1(REM)
VEARTH = (REM+RATT) - 1(RATT)
VMoon = -1(RATT)
CEARTH = COS 5
CMoon = COS(sin(REM/RATT)+5) = COS 5
CSun = COS 15
VEL/C = VSUN X ECLP + VATT/C = SAME

EARTH

INPUT: TIME IN MPAC_D
OUTPUT: VMoon-MPAC-POSITION VECTOR OF THE MOON
VSUN-2D-POSITION VECTOR OF THE SUN

LOCATE SUN AND MOON
FC-2286

VMOON-MPAC
VSUN-2D
TDEC1-D-TSIGHT-D

POSITION VECTOR OF MOON
POSITION VECTOR OF SUN
TIME OF INTEGRATION

INTEGRATE STATE VECTOR
FC-2290

INPUT: TDEC1 (TIME OF INTEGRATION)
OUTPUT: RATTV-POSITION VECTOR
VATTV-VELOCITY VECTOR

IS EARTH PRIMARY?
YES

MOONCNTR

VSUN-UNIT(VSUN-VMoon)
VEARTH-UNIT(VMoon+RATT)
VMoon-UNIT(RATT)
MPAC_D-RSUN D

R_m (EQUATORIAL RADIUS (1738040 METERS)
OF MOON)

INPUT := MPAC D-Rm
OUTPUT := MPAC = (COS(ARCSIN(R_m/36)-5))

COMPUTE COSINE OF ANGLE OF OCCULTATION
SH18

CMoon-MPAC
CEARTH-C555
MPAC_V-VSUNV

COSINE 5°

NEXT SHEET

PS2
IMU REALIGNMENT

COLOSSUS II
FC-2720
THIS PROGRAM READS THE IMU, CDUS, AND COMPUTES THE VEHICLE ORIENTATION WITH RESPECT TO INERTIAL SPACE. IT THEN COMPUTES THE SHAFT AXIS WITH RESPECT TO REFERENCE INERTIA. EACH STAR IN THECATALOG IS TESTED TO DETERMINE IF IT IS OCCULDED BY EITHER THE EARTH, SUN OR MOON. PAIRS OF STARS THAT ARE NOT OCCULDED ARE TESTED FOR GOOD SEPARATION. PAIRS WITH GOOD SEPARATION ARE TESTED TO SEE IF THEY LIE IN THE CURRENT FIELD OF VIEW. THE PAIR OF MAXIMUM SEPARATION IS CHOSEN.

INPUT: \[ V_{\text{earth}} = -\text{UNIT}(r) \] WHERE \( r \) HAS BEEN UPDATED TO APPROX. TIME OF SIGHTING.

OUTPUT: BESTJ, BESTJ - STAR NO. 5 X G

VFLAG = SET IMPLIES NO. OF STARS IN FIELD OF VIEW

CDUTRIG

COMPUTE SINES AND COSINES OF CDUX, Y, Z

FC = 2270

CALCSCMC

LOCATE NAV BASE AXES

SH = 28

SET VFLAG

BESTI = DZERO

STORAGE FOR STAR NUMBERS

\[ \text{SAV}_v = \text{UNIT} \left[ \left( \text{XNB}_v \times \sin \phi \right) + \left( \text{ZNB}_v \times \cos \phi \right) \right] (\text{REFSMAT}) \]

SHAFT AXIS IS DEFINED IN THE BASIC REFERENCE SYSTEM. IT HAS NOW BEEN TRANSLATED TO THE CENTER OF THE EARTH

\[ x_1 = 6(37 \text{ STARS}) + g = 228 = \text{PRIMARY STAR} \]

\[ \text{STAR VECTORS ARE 6 WORDS APART} \]

\[ x_1 = 228 \]

\[ g \]

\[ 0 \]

NEXT SHEET
FROM PRECEDING SHEET

PIC4

MPAC \rightarrow \text{CATLOG,2}

OCCULT
DETERMINE OCCULTATION \$W17\$

INPUT: MPACV - STAR VECTOR CATALOG
VEARTH, VSUN, VMOONV
OUTPUT: CULTFLAG

\begin{align*}
\text{IS CULTFLAG SET?} & \quad \text{NO} \\
\text{MPAC} \rightarrow \text{(CATLOG,1+CATLOG,2)} - \text{CS5G6} & \quad \text{CS5G6} = \left(\cos 70^\circ\right)/4 \\
\text{IS SEPARATION LESS THAN } 70^\circ? & \quad \text{NO} \\
\text{MPAC} < 0 & \quad \text{YES}
\end{align*}

\begin{align*}
\text{MPAC} \rightarrow \text{MPAC} + \text{CS5G640} & \quad \text{CS5G640} = \left(\cos 30^\circ\right)/4 \\
\text{IS SEPARATION GREATER THAN } 30^\circ? & \quad \text{NO} \\
\text{IS MPAC} > 0? & \quad \text{YES}
\end{align*}

\begin{align*}
\text{MPAC} \rightarrow \text{(CATLOG,1-6AX)} - \text{CS533} & \quad \text{CS533} = \left(\cos 38^\circ\right)/4 \\
\text{IS STAR 1 BEYOND } 38^\circ \text{ OF SHAFT AXIS?} & \quad \text{NO} \\
\text{MPAC} < 0 & \quad \text{YES}
\end{align*}

\begin{align*}
\text{MPAC} \rightarrow \text{(CATLOG,2-6AX)} - \text{CS533} & \quad \text{IS STAR 2 WITHIN } 38^\circ \text{ OF SHAFT AXIS?} \\
\text{NO} & \quad \text{GET ANOTHER STAR} \\
\text{MPAC} > 0 & \quad \text{YES}
\end{align*}

\begin{align*}
\text{PIC3} & \quad \text{SH14} \\
\text{GET ANOTHER 2ND STAR} & \quad \text{NEXT SHEET}
\end{align*}
FROM PRECEDING SHEET

STRATEGY

CLEAR VFLAG

WAS VFLAG SET?
  YES
  NO

X1 ← BESTI
X2 ← BESTJ

STRAT

PUSH ← (CATLOG X1, CATLOG X2)

DETERMINE SEPARATION OF PAIR OF STARS

INVERT VFLAG

WAS VFLAG SET?
  YES
  NO

DOES PRESENT PAIR HAVE A LARGER SEPARATION?
  YES (GO)
  NO (> 0)

PIC 3
SH 14

BESTI ← C(X1)
BESTJ ← C(X2)

THIS IS THE BEST PAIR OF STARS

PIC 3
SH 14
INPUT: STAR VECTOR (CATLOG) FROM LOC:AM: CULTRIX, V EARTH, V SUN, V MOON @ 21

OCCULT

MPAC, = CSS, - CULTRIX, + CATLOG

YES

IS STAR OCCULTED BY EARTH?

NO

MPAC < 0?

MPAC + 3 < 0?

YES

IS STAR OCCULTED BY SUN?

NO

IS STAR OCCULTED BY MOON?

YES

CULFLED

NO

SET CULFLED

CLEAR CULFLED

INDICATE WHETHER STAR IS OCCULTED

RETURN VIA QPRET
ALIGN THE STABLE MEMBER TO REFMMAT
INPUT: BESTI, BESTJ
OUTPUT: GYRO TORQUE PULSES

RS1
FINE ALIGN

RS1+1

SET STARIND MARKINDEX

STAR NO. INDEX
ONE STAR

RS1.3

CLEAR TARGETFLG
TARG4FLG

SIGHTING FLAG
NOT SIGHTING LEM

GROUP4

SET UP RESTARTS
TO SCHEDULE THE
NEXT LOCATION AS
A FINDVAC JOB
WITH PRIORITY 13

STARCODE ← 1/6 BESTI STARIND

STARCODE

RS1DSP

DISPLAY STARCODE
R1 = STARCODE

GOFLASHR

VO1N70

IMMEDIATE RETURN

ENTER

PROCEED

CHKSCODE

0 ≤ STARCODE ≤ 50
YES

FC-2730

NO

LOADTIME

LOAD COMPUTER CLOCK
FC-2100

FALTON

TURN ON OPERATOR ERROR LIGHT

RS1DSP

6H18

BLANKET

BLANK R1, R3
FC-2130

ENDOFJOB

INPUT: MPAC₀ - TSIGHT
OUTPUT: MPACᵥ - STORED REFERENCE POSITION OF SIGHTED BODY

PLANET PROVIDE REFERENCE VECTOR
FC-2710

NEXT SHEET

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

APPLIED TACTICS AND NAVIGATION

PS2 IMU REALIGNMENT

COLOSSUS III FC-2720

G.S. WAIN M.E. MAE

MISSILE ANALYST

APPROD 3104 1970 32 18
FROM PRECEDING SHEET

IS STARIND SET? NO - SECOND STAR

YES - FIRST STAR

R51ST

STORED DIRECTION OF 1ST BODY (INPUT FOR R52)

STORED DIRECTION OF SECOND BODY (INPUT FOR R52)

IS THIS P54?

NO (P52) R51B

R56 BACKUP SIGHTING ROUTINE

FC-2730

INPUT: TARG1FLG - NOT SIGHTING LEM
TARG2FLG - SIGHTING LEM
MARKINDEX - ONE STAR
STARIND - INDEX TO BESTI OR BESTJ
OUTPUT: DRIVE SHAFT AND TRUNNION CDUS

R52 AUTO OPTICS POSITIONING ROUTINE

FC-2730

R51A

SXTSM

INPUT: DRIVE SHAFT AND TRUNNION CDUS

OUTPUT: MPACV - DIRECTION VECTOR

COMPUTE LOS VECTOR

FC-2730

STARSAV2 - MPACV

OBSERVED DIRECTION OF STAR

MKRELAS

RERO MARKSTAT

FC-2240

MPACR - TSIGHT

PLANET PROVIDE REFERENCE VECTOR

FC-2710

INPUT: MPAC0 - TSIGHT

OUTPUT: MPACV - STORED REFERENCE POSITION OF SIGHTED BODY

NEXT SHEET
FROM PRECEDING SHEET

IS STARIND SET?

YES - FIRST STAR

NO - SECOND STAR

STARADV = \text{UNIT(REFSMAT X MPAC)}}

STORED DIRECTION OF SECOND STAR

STORED DIRECTION OF FIRST STAR

PLANVEC = \text{UNIT(REFSMAT X MPAC)}}

STARSAV1 = STARSAV2

STARIND = D

R51.4

R51.3

SH18

G0V = STARSAV2

12DV = STARSAV1

STARADG = PLANVEC

SECOND OBSERVED STAR

FIRST OBSERVED STAR

STORED DIRECTION OF 1ST STAR

CHECK DATA

CHECK VALIDITY OF SIGHTINGS

FC-2710

INPUT: STARADV, STARADG, CATALOGED STAR VECTORS

G0V, 12DV - OBSERVED STAR VECTORS

OUTPUT: FREEFLAG, VOGN05

ARE SIGHTINGS VALID?

NO

FREEFLAG SET?

YES

COMPUTE COORDINATES OF ONE COORDINATE SYSTEM REFERRED TO ANOTHER (DESIRED REFERRED TO PRESENT, IN THIS CASE)

INPUT: STARADV, STARADG, CATALOGED (2 BODIES SYSTEM)

G0V, 12DV - PRESENT (2 BODIES SYSTEM B)

NOTE: SYSTEM A+B ARE THE SAME FOR THIS USE OF AXISGEN

OUTPUT: XDCV, YDCV, ZDCV

AXISGEN

COORDINATE TRANSFORMATION

FC-2740

R55

GYRO TORQUE

SH26

CLEAR PFRATFLG

PREFERRED ATTITUDE IS NOT COMPUTED

NEXT SHEET
FROM PRECEDING SHEET

REQUEST PLEASE PERFORM FINE ALIGN
R1 = 00014
R2 = BLANK
R3 = BLANK

ENDP505
SH6
EXIT

GO PER F1
VSDN25
R1=00014
PROCEED

P52C
SH5
ASTRONAUT WANTS TO RECYCLE

P52
IMU REALIGNMENT

COLOSSUS II
FC-2720
Called by P52 to coarse align the IMU if any gimbal must be moved more than 1 degree.

Input: Theθ₆ₐ₅₊₁, Theθ₆ₐ₅₁₊₁, Theθ₆ₐ₅₊₂ - desired IMU angles (see Calcsa)

Output: X₅₉₅, Y₅₉₅, Z₅₉₅ - new refsmat

- **CALCSA**

- **S52.2**
  **Compute Gimbal Angles**
  **SH9**

- **RCDUS**
  **SH27**
  **Read CDUS**

- **S1**
  **X1**
  **PUSH**
  **STEP COUNTER**
  **INDEX INTO VAC AREA** (CDUS from RCDUS)
  **PUSHLIST POINTER = 4**

- **CALCOP**

- **Check to see that all CDUS are within 1 degree of desired value.

- **Pass One - Check X angles for Drive ≤ 1 degrees**
  \[ |\text{CDUX} - \theta_5| \leq 20 \text{deg} \]
  \[ \theta_5 = \text{The}θ₆ₐ₅ + 1 \]
  \[ \theta_6 = \text{The}θ₆ₐ₅₆₊₂ \]

- **CALCOP**

- **Pass Two - Check Y angles**
  \[ |\text{CDUY} - \theta_6| \leq 20 \text{deg} \]
  \[ \theta_6 = \text{The}θ₆ₐ₅₆₊₁ \]

- **CALCOP**

- **Pass Three - Check Z angles**
  \[ |\text{CDUZ} - \theta_7| \leq 20 \text{deg} \]
  \[ \theta_7 = \text{The}θ₆ₐ₅₆₋₁ \]

- **Fineonly**
  **SH24**

- **NEXT SHEET**
CALCSEMCE

COMPUTE NAV BASE AXES

INPUT: SINCUX, SINCUY, SINCUDZ, COSCUX, COSCUDY, COSCUDZ - SINES, COSINES OF OUTER, INNER, MIDDLE GIMBAL ANGLES
OUTPUT: XNB, YNB, ZNB - CONSIDER THESE THREE VECTORS AS THE TRANSFORMATION MATRIX
\[ [\text{SMNB}] = Q_1 Q_2 Q_3 \] STABLE MEMBER TO NAV BASE WHERE:

\[ Q_1 = \begin{bmatrix}
\cos \text{CUDY} & -\sin \text{CUDY} & 0 \\
0 & 1 & 0 \\
\sin \text{CUDY} & \cos \text{CUDY} & 0
\end{bmatrix} \] (INNER)

\[ Q_2 = \begin{bmatrix}
\cos \text{CUDU} & \sin \text{CUDU} & 0 \\
-\sin \text{CUDU} & \cos \text{CUDU} & 0 \\
0 & 0 & 1
\end{bmatrix} \] (MIDDLE)

\[ Q_3 = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \text{CUDUX} & -\sin \text{CUDUX} & 0 \\
0 & \sin \text{CUDUX} & \cos \text{CUDUX} & 0
\end{bmatrix} \] (OUTER)

RETURN VIA QPRET
COMPUTE AND SEND GYRO PULSES
INPUT: XDC, YDC, ZDC - REF SLM AT W.R.T. PRESENT STABLE MEMBER
OUTPUT: GYRO PULSES

QMIN → Q

CALCULATE REQUIRED TORQUING ANGLES FOR EACH GYRO
INPUT: XDC, YDC, ZDC - DESIRE SM COORD W.R.T. PRESENT (SEE AXISGEN)
OUTPUT: OGC, IGC, MGC - GYRO TORQUING ANGLES (DELTA)

DISPLAY GYRO TORQUING ANGLES
R1 - X GYRO - OGC
R2 - Y GYRO - IGC
R3 - Z GYRO - MGC

GYRO TORQUING ANGLE IS THE ANGLE THROUGH WHICH EACH GYRO MUST BE TORQUED TO COMPLETE THE FINE ALIGNMENT

GROUP 4.31
SET UP RESTARTS TO SCHEDULE RS14 AS A TASK IN 50 MS

PULSE IRIGS THROUGH DESIRED ANGLES ACCORDING TO THREE (DR) WORDS STARTING AT ECAHR ARRIVING IN A (OGC)
INPUT: OGC, IGC, MGC
OUTPUT: TORQUING PULSES

IMUSTALL
WAIT FOR COMPLETION
FC-2210

BAD RETURN → CURTAINS
ALARM 217 BAD RETURN FROM STALL

GROUP 4
SET UP RESTARTS TO SCHEDULE THE NEXT LOCATION AS A FINDVAC JOB WITH PRIORITY 1B

RSRESET

RETURN VIA QMIN
MATMOVE

INPUT: ADDRESS OF MATRIX TO BE MOVED
IN INDEX REG. NO 1
ADDRESS WHERE MATRIX IS TO BE MOVED
IN INDEX REG. NO 2

NOTE: ADDRESSES ARE COMPLEMENTED FOR
THE SUBTRACTIVE INDEXING LOGIC OF THE
INTERPRETER

RETURN VIA QPRET

CALLS CAL53A (BY RTB CALL) TO READ
CDU's INTO VAC AREA WHOSE ADDRESS IS
LOCATED IN FIXLOC

PREVENT CDU'S FROM CHANGING
WHILE READING

RELINT

DANZIG
## Subroutines Called Which Are Flowed on Other Flow Charts

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<td>FC-2270</td>
<td>COMPUTE LOS VECTOR</td>
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<td>WAIT FOR COMPLETION</td>
<td>SH. 25, 26</td>
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### Flags

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**MIT Instrumentation Lab**

**Apollo Guidance and Navigation**

**P52 IMU REALIGNMENT**

**Drawn**

**Approved**

**Colossus II** FC-2720
### FLAGS (CONTINUED)

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<td>EARTH - COMPUTE FISCHER ELLIPSOID MOON - USE FIXED RADIUS</td>
<td>EARTH + USE FIXED RADIUS MOON - USE RCS FOR LUNAR RADIUS</td>
<td>SH. 16</td>
<td>SH. 16</td>
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<td>LESS THAN TWO STARS IN FIELD OF VIEW</td>
<td>TWO STARS IN FIELD OF VIEW</td>
<td>SH. 13, 16</td>
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<td>SIGHTINGS ARE VALID</td>
<td>SIGHTING ANGLE EXCEEDS TOLERANCE</td>
<td>SH. 18</td>
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</table>

### DISPLAYS

<p>| VERB- | TYPE OF | DESCRIPTION OF EACH REGISTER | WHERE EXECUTED |
| NOUN | DISPLAYS | | |
| V04N06 | FLASHING | R1 = 00005: OPTION CODE FOR ASSUMED IMU R2 = OPTION ASSUMED BY THE LG C R3 = BLANK | SH. 1 |
| V06N34 | FLASHING | R1 = TALIGN - HRS R2 = TALIGN - MIN R3 = TALIGN - SEC | SH. 2 |
| V06N22 | FLASHING | R1 = OG ROLL R2 = IG PITCH R3 = MG YAW | SH. 2 |
| V50N35 | PLEASE PERFORM | R1 = 00015: PLEASE PERFORM STAR ACQUISITION R2 = BLANK R3 = BLANK | SH. 5 |
| V05N09 | FLASHING | ALARM 405 - TWO STARS NOT AVAILABLE | SH. 6 |
| V06N69 | FLASHING | R1 = LAT R2 = LONG/2 R3 = ALT | SH. 8 |
| V01N70 | FLASHING | R1 = STARCDE | SH. 18 |
| V50N35 | PLEASE PERFORM | R1 = 00014: PLEASE PERFORM FINE ALIGN R2 = BLANK R3 = BLANK | SH. 21 |
| V50N25 | PLEASE PERFORM | R1 = 00013: DECIDE BETWEEN COARSE ALIGN AND gyro TORQUING R2 = BLANK R3 = BLANK | SH. 3 |
| V15N20 | MONITOR | R1 = OUTER GIMBAL ANGLE - DEG R2 = INNER GIMBAL ANGLE - DEG R3 = MIDDLE GIMBAL ANGLE - DEG | SH. 3 |</p>
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R52
ADVORB
SR52.1
ROTA
R53
CHKSCODE
SXTSM
R56
Sh. 2
Sh. 5
Sh. 6
Sh. 10
Sh. 11
Sh. 12
Sh. 13
Sh. 14
POINT THE STAR LOS OF THE OPTICS AT A STAR OR LANDMARK DEFINED BY THE PROGRAM OR BY DSky input.
POINT THE STAR LOS OF THE OPTICS AT THE LM DURING RENDEZVOUS TRACKING OPERATION.
DO THE TRACKING ATTITUDE ROUTINE (R62) EVERY 16 SEC.
DURING RENDEZVOUS TRACKING OPERATIONS.
INPUT: PRESET BY CALLER-TARG1FLG, TARG2FLG, RNDZFLG, TRACKFLG, MARKINDEX, STARCODE.
THROUGH DSky-LAT-LONG, ALT OF LANDMARK, STARCODE.
OUTPUT: DRIVE SHAFT AND TRUNNION CDUS.

RS2
AUTO OPTICS POSITIONING ROUTINE

SAVEGR52 ← QPRET

CLEAR ADVTRK

NOT ADVANCED GROUND TRACK

RS2VRB

DESOPTT ← CDUT
DESOPTB ← CDUB
OPTIND ← 0

CLEAR RS3FLAG

V51 NOT INITIATED

RS2A

SET TRUNFLAG

DRIVING OF TRUNNION ALLOWED

15 TARG1FLG SET?

YES - LM

IS THE LM TARGET FLAG SET?

NO

CLEAR TERMFLG

DO NOT TERMINATE R52

RS2C

IS OPTICS MODE IN AGC?

NO - MANUAL

YES - AGC

NEXT SHEET

RS2M ← SH3

RS2HA ← SH4

RS2, R53, R56
FROM PRECEDING SHEET

DESOPTS → SAC

DRIVE SHAFT COUS

R52F

A → .5 .5 SEC

DELAYJOB

.5 SEC WAIT .5 SEC

FC-2070

IS THIS A LM?

YES - LM

NO - NOT LM

IS TARGET FLG SET?

NO - NOT LM

SHOULD WE TERMINATE R52?

IS TERMFLG SET?

NO

YES

R52Q

RETURN VIA SAVR52

R52HA

R51CM

PREFERRED TRACKING ATTITUDE ROUTINE

FC-2550

IS TRACKFLG SET?

NO - NOT ALLOWED

1.8SEC

YES - TRACKING ALLOWED

A → .8

R52SYNC

IS UPDATEFLG SET?

YES

NO

R52I

NO - X-AXIS

IS PREFRKTAT SET?

NO

YES - PREFERRED TRACK ATTITUDE

R52D

GH2

COMPUTE PREFERRED TRACKING ATTITUDE AND PERFORM MANEUVER TO THE PREFERRED OR X-AXIS TRACKING ATTITUDE

OUTPUT: CDUX, CDUY, CDUZ - DESIRED OUTER, INNER, MIDDLE COU ANGLES

COLOSSUS 20 FC-2730
KILL MARK SYSTEM

CLEAR MKR No MARK INFORMATION FC-2130

RELEASE VAC AREA MKRELEAS ZERO MARKSTAT FC-2240

SETS UP ADVANCED ORBIT TRACKING OPTCADR 0

ADVCRB

ADVANCED GROUND TRACK SIGHTING WANTED ADVTRK LUNAR LAT-LONG LUNAFLAG MEAN LUNAR RADIUS FRAFLAG

COLOSSUS 2D FC-2730
TARGET and TARGETFLAGS are looked at to determine if TARGET is LEM, STAR or LANDMARK. A reference sighting vector is obtained and transformed into stable member coordinates. Finally a trunnion angle test is made.

**Input:** TARGETFLAG, TARGETFLAG

**Note:** If TARGETFLAG=1, TARGET is LM; if both = 0, TARGET is STAR; if TARGETFLAG=0 and TARGETFLAG=1, TARGET is LANDMARK

**Output:** SAC - Shaft angle desired
            PAC - Trunnion angle desired

**Input:** CALLER CADR saved by
**Output:** CADR in A REG

**GMIN**

**CALLER CADR**

**LOADTIME**

**LOAD COMPUTER CLOCK**

**FC-2100**

**AOPTIME** $\rightarrow$ MPAC + 1.3 SECDP

**PRESENT TIME PLUS 2.4 SECONDS**

In case of LEM or LMK the present time plus 2 seconds is saved in AOPTIME.

**IS TARG1FLAG SET?**

**YES, THE TARGET IS THE LEM**

**LEMS**

**SNB**

**IS TARG2FLAG SET?**

**NO, TARGET IS A STAR**

**STARS2**

**S1=0**

**X1=STARIND**

**IF TARGET IS A STAR, VECTOR IS OBTAINED FROM THE CATALOG**

**STARIND > 0**

**NO, BEST=**

**YES**

**MPACV \rightarrow STARSAV2**

**STAS2ST**

**MPACV \rightarrow STARSAV1**

**NEXT SHEET**
FROM PRECEDING SHEET

COM52 TRANSFORMS THE REFERENCE SIGHTING VECTOR INTO SM COORDS

STAR = UNIT[REFSVMAT*MPACV]

CDUX, CDUY, CDUE
INPUT : CDUX, CDUY, CDUE
SINES, COSINES OF COU COUNTERS
OUTPUT : SINCdUX, SINCdUY, SINCdUE
COSCDUX, COSCDUY, COSCDUE

FC-2270

CALC55A COMPUTE THE SEXTANT SHAFT AND TRUNNION ANGLES
INPUT : STAR - STAR VECTOR REFERRED TO PRESENT SM COORDS
SINCdUX, Z, X ; COSCDUY, Z, X
OUTPUT : SAC - SEXTANT SHAFT ANGLE
PAC - SEXTANT TRUNNION ANGLE

FC-2250

NC - CELESTIAL BODY IS OCCULTED
IS CULTFLAG CLEAR?
YES

TRUNSE

IS THE ANGLE GREATER THAN +50 DEG?

YES

IE PAC - 360 DEGREES
IEP?

NC

IS THE ANGLE LESS THAN -20 DEG?

YES

IE PAC - 360 DEGREES
IEP?

NC

IS THE ANGLE BETWEEN 0 AND 360 DEGREES?

YES

GMIN = GMINT

ELSE

GMINT = 1

ELSE

GMINT = 2

ELSE

GMINT = 3

A = GMIN

RETURN VIA SWCALL
THE CSM IS UPDATED CONICALLY.
THE RADIUS VECTOR FOR THE LANDMARK
IS OBTAINED FROM LALOTORY.

CONIC UPDATES OF THE CSM
AND LEM ARE MADE TO THE
TIME IN AOFFSET.

LMK52

YES

IS
ADVTRK
SET?
NO

ADVTRACK
SH9

TDEC10 \rightarrow AOFFSET6

LEMS2

LEMCONIC
INTEGRATE
STATE VECTOR
FC-2290

INPUT: TDEC1 - TIME OF
INTEGRATION
OUTPUT:
RATT - POSITION VECTOR
VATT - VELOCITY VECTOR
TATT - TIME VECTOR

MPACv \rightarrow AOFFSET6

MPACv \rightarrow ALPHA v

LMKLMCOM

STAV \rightarrow MPACv

TDEC10 \rightarrow AOFFSET6

TIME OF INTEGRATION

MPACv \rightarrow UNIT [STAV \times VATT]

CSMCONIC
INTEGRATE
STATE VECTOR
FC-2290

INPUT: TDEC1 - TIME OF INTEGRATION
OUTPUT:
RATT - POSITION
VATT - VELOCITY
TATT - TIME

THE UNIT OF DIFFERENCE BETWEEN THE
LANDMARK AND CSM RADIUS VECTORS
BECOMES THE REFERENCE SIGHTING VECTOR.
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

FLOWCHART:

ADVTRACK

PUSLOC = 0

PUSH1-5 = UNITR

LOADTIME
LOAD COMPUTER CLOCK
FC-2170

PUSH1-7 = TIMEx, TIME1

CONVERT RP VECTOR IN PLANETARY COORDINATE SYSTEM TO R (SAME VECTOR IN BASIC REFERENCE SYSTEM)

INPUT : RP VECTOR
OUTPUT : MPACx, R VECTORS = FIRST ROTATION VECTOR UR

FIRST ROTATION VECTOR

START = MPACx, TDECx = AORTIME

CEMCONIC INTEGRATE STATE VECTOR
FC-2220

SAO = UNIT [VATTX RATT]
PUSH = UNIT [RATT]
30O = LANDMARK [BIT3-1] X BIT11
AORTIME = 30O X MPERIOD

THE ESTIMATED CSM CONIC VELOCITY VECTOR
THE ESTIMATED CSM CONIC POSITION VECTOR
LANDMARK LOCATION CONTAINS NO OF ORBITS (N)
FIRST ROTATION ANGLE = NO ORBITS X APPROXIMATE LUNAR ROT. ANG. IN 2 HRS X 12

NEXT SHEET
FROM PRECEDING SHEET

ROTATE THE LOCAL VERTICAL VECTOR ABOUT THE POLAR AXIS OF THE MOON TO ACCOUNT FOR LUNAR ROTATION
INPUT: PUSH0-5 = -UNIT [RAT]'
STAR = FIRST ROTATION VECTOR \( \mathbf{R} \)
AOPTIME = ANGLE THROUGH WHICH MOON rotates IN ONE NOMINAL LUNAR-ORBITAL PERIOD X NO OF ORBITS - (\( A = A_{MN} \))
OUTPUT: PUSH0-5

\[ \text{ROTATE VECTOR} \]
AOPTIME \(_D\) = DP1/60-AOPTIME \(_D\)
2ND ROTATION VECTOR = 60\(^\circ\)-A
2ND ROTATION ANGLE = 60\(^\circ\)-A

\[ \text{ROTATE VECTOR TO ORBITAL PLANE} \]
STAR = PUSH0-5

\[ \text{DESIRE} \]
COM52
SH8

\[ \text{INPUT} \]
AOPTIME = ROTATION ANGLE = (A)
STAR = ROTATION VECTOR = (\( \mathbf{R} \))
PUSH0-5 = LOS VECTOR = (\( \mathbf{U}_{\text{LOS}} \))
OUTPUT: PUSH0-5 = FINAL DESIRED LINE OF SIGHT VECTOR (\( \mathbf{U}_{\text{LOS}} \))

\[ \text{PUSH1} = (\sin(AOPTIME) \times \text{STAR}) \]
\[ \text{PUSH12} = 1/2 \times \sin(AOPTIME) \times (\text{STAR} \times \text{LOS}) \]
\[ \text{PUSH13} = 1/2 \times (\text{STAR} \times \text{LOS}) \]
\[ \text{PUSH15} = \cos(AOPTIME) \]
\[ \text{PUSH16} = \text{UNIT} \times (\text{LOS} - 1/2(\text{STAR} \times \text{LOS}) \times \text{STAR} + 1/2 \times \cos(AOPTIME) + 1/2 \times \sin(AOPTIME) \times (\text{STAR} \times \text{LOS}) + 1/2 \times (\text{STAR} \times \text{LOS}) \times \text{STAR}) \]

\[ \text{RETURN VIA GPBRET} \]

\[ \text{ROTATE THE VECTOR} \] \( \mathbf{U}_{\text{LOS}} \) \text{ABOUT} \( \mathbf{R} \) THROUGH THE ANGLE \( A \) BY
\[ \mathbf{U}_{\text{LOS}} = (1 - \cos A)(\mathbf{R} \cdot \mathbf{U}_{\text{LOS}})\mathbf{R} + \mathbf{U}_{\text{LOS}} \cos A + \mathbf{R} \times \mathbf{U}_{\text{LOS}} \sin A \]}
PURPOSE IS TO PERFORM A SATISFACTORY NUMBER OF OPTICAL SIGHTING MARKS FOR THE REQUESTING PROGRAM OR ROUTINE.

INPUT:
- TARGETFLG - TARGET FLAG - STAR OR LANDMARK
- MARKINDEX - NO. OF MARKS WANTED
- STARIND - INDEX TO BEST J OR BEST I

OUTPUT:
- R53FLAG
- TERIFLAG

SET SIGHTING MARK FLAG INDICATES THAT A VS1 REQUEST TO PLEASE MARK HAS BEEN INITIATED.

A = MARKINDEX(BIT3-1)  NO OF MARKS

S6TXMARK
RESERVE VAC AREA CRC SCHEDULE MKVB5I JOB
FC-2240

OPTSTALL
WAIT FOR MARK TO FINISH
FC-2210

CURTAINS
ALARM
OR

FC-2240

HAVE ANY MARKS BEEN DONE?

QPRET = MARKSTAT - NUMBER OF MARKS ACTUALLY PERFORMED
(MKVB5I)

QPRET = MARKSTAT - 1

R53B

IS CALLING PROGRAM P22 OR P23?

CHECKMM
CHECK MODREG
FC-2630

NO - DISPLAY

NEXT SHEET

A = 0

CLEAN DISP
BLANK DISPLAY
REGISTERS
FC-2130

NEXT SHEET

R52, R53, R56
X1 = MARKSTAT
X2 = MKONCOR

ADDRESS OF VAC AREA
WORD 0 IS TIME
DDOWNLINK (EITHER CADR(MARKDOWN) OR CADR(MARKDOWN))

THIS MOVES registers MARKDATA table into DDOWNLINK

TAKES SHAFT AND TRUNNION ANGLES AND CONVERTS THEM TO A UNIT VECTOR REFERENCED TO THE NB COORD SYSTEM
INPUT: VAC AREA LOCS - SHAFT ANGLE
VAC AREA LOCS - TRUNNION ANGLE
X1 - BASE ADDRESS
OUTPUT: 52D, MPAC=1/2 UNIT VECTOR IN NB COORDS

BASE ADDRESS OF ICDU

INPUT: S1 = BASE ADDRESS OF CDU
52D = VECTOR TO BE TRANSFORMED IN NB
OUTPUT: 52D = VECTOR IN SM
MPAC = VECTOR IN SM

MARK DATA TABLE CONSISTS OF 2 WORDS FOR THE TIME AND 5 WORDS FOR THE 2 SXT AND 3 IMU ANGLES
WORD 0 TIME 0
1
2 CDUY
3 CDUS
4 CDUZ
5 CDUT
6 COUX
PERFORM SIGHTING MARKS FOR THE BACKUP ALIGNMENT PROGRAMS

INPUT: STARIND - STAR INDEX = 0 OR 1
OUTPUT: REST2 (STARIND) = STAR CODE x 6

RS6
ALTERNATE SIGHTING MARK ROUTINE

STORE QPRET IN R0SEXIT

ENTER
NEW ANGLES
VOG994

RS6A

GRMKR2
RESERVE
VAC AREA
FC-2240

CLEANSP
CLEAR DISPLAY

RS6A1

PROCEED
GOMARK2
V53

ENTER

SACDP ← MARBUF1+3DP
PACDP ← MARBUF1+5DP

IHINT

SOFTWARE

RS6R

RECYCLE

GOPERF1
VSON2S

PROCEED
NEXT SHEET

REQUEST PLEASE PERFORM ALTERNATE LOS SIGHTING MARK
V53N
R1 = BLANK
R2 = BLANK
R3 = BLANK

OE USING MARKSTAT AS AN INDEX
STORE THE FOLLOWING IN
VAC AREA
VAC +0 ← TIME DP
VAC +2 ← CDU Y
VAC + 4 ← SAC
VAC + 6 ← CDU Z

STORE CDU ANGLES (ACTUAL) AND MANUALLY INSERTED
OPTICAL ANGLES OF NOUN 92

REQUEST PLEASE PERFORM TERMINATION OF THIS ROUTINE
VSON2S
R1 = 00016
R2 = BLANK
R3 = BLANK

CLEAR EXT V8ACT
NO SPECIAL MARK INFORMATION

RS6A, RS3, RS6
<table>
<thead>
<tr>
<th>SUBROUTINE NAME</th>
<th>FLOW CHART</th>
<th>DESCRIPTION</th>
<th>WHERE CALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>R61CSM</td>
<td>FC-2550</td>
<td>PREFERRED TRACKING ATTITUDE</td>
<td>SH. 4</td>
</tr>
<tr>
<td>CLEARMRK</td>
<td>FC-2130</td>
<td>NO MARK INFORMATION</td>
<td>SH. 5, 14</td>
</tr>
<tr>
<td>MKRELEAS</td>
<td>FC-2240</td>
<td>ZERO MARKSTAT</td>
<td>SH. 5</td>
</tr>
<tr>
<td>KLEENEX</td>
<td>FC-2130</td>
<td>CLEAN OUT EXTENDED VERBS</td>
<td>SH. 5</td>
</tr>
<tr>
<td>MAKECADR</td>
<td>FC-2080</td>
<td>COMPUTE CALLERS RETURN CADR</td>
<td>SH. 6</td>
</tr>
<tr>
<td>LOADTIME</td>
<td>FC-2100</td>
<td>LOAD COMPUTER CLOCK</td>
<td>SH. 6</td>
</tr>
<tr>
<td>CDUTRG</td>
<td>FC-2270</td>
<td>SINES, COSINES OF CDU COUNTERS</td>
<td>SH. 7</td>
</tr>
<tr>
<td>CALSCSA</td>
<td>FC-2250</td>
<td>COMPUTE THE SEXTANT SHAFT AND TRUSSON ANGLES</td>
<td>SH. 7</td>
</tr>
<tr>
<td>LALOTORV</td>
<td>FC-2280</td>
<td>CONVERT LAT, LONG TO RADIUS VECTOR</td>
<td>SH. 8</td>
</tr>
<tr>
<td>LEMCONIC</td>
<td>FC-2290</td>
<td>INTEGRATE STATE VECTOR</td>
<td>SH. 8</td>
</tr>
<tr>
<td>CSMCONIC</td>
<td>FC-2290</td>
<td>INTEGRATE STATE VECTOR</td>
<td>SH. 8, 9</td>
</tr>
<tr>
<td>LOADTIME</td>
<td>FC-2100</td>
<td>LOAD COMPUTER CLOCK</td>
<td>SH. 9</td>
</tr>
<tr>
<td>RP-TO-R</td>
<td>FC-2283</td>
<td>CONVERT RP TO R</td>
<td>SH. 9</td>
</tr>
<tr>
<td>SXTMARK</td>
<td>FC-2240</td>
<td>RESERVE VAC AREA AND SCHEDULE MKVBS JOB</td>
<td>SH. 11, 14</td>
</tr>
<tr>
<td>OPTSTALL</td>
<td>FC-2210</td>
<td>WAIT FOR MARK TO FINISH</td>
<td>SH. 11</td>
</tr>
<tr>
<td>CHECKMM</td>
<td>FC-2030</td>
<td>CHECK MODREG</td>
<td>SH. 11</td>
</tr>
<tr>
<td>SXTNB</td>
<td>FC-2250</td>
<td>CONVERT TO UNIT VECTOR</td>
<td>SH. 13</td>
</tr>
<tr>
<td>NBSM</td>
<td>FC-2270</td>
<td>NAV BASE TO STABLE MEMBER</td>
<td>SH. 13</td>
</tr>
</tbody>
</table>
### Flags

<table>
<thead>
<tr>
<th>Name</th>
<th>Meaning When Set</th>
<th>Meaning When Clear</th>
<th>Where Set</th>
<th>Where Cleared</th>
<th>Where Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADVTRK</td>
<td>Advance ground track wanted</td>
<td>Not advanced-ground track</td>
<td>SH, 5</td>
<td>SH, 2</td>
<td>SH, 8</td>
</tr>
<tr>
<td>TRUFLAG</td>
<td>Driving of trunnion allowed</td>
<td>Driving of trunnion not allowed</td>
<td>SH, 2, 3</td>
<td>SH, 3</td>
<td>SH, 3</td>
</tr>
<tr>
<td>TERMINFLG</td>
<td>Terminate R52</td>
<td>Do not terminate R52</td>
<td>SH, 2, 12</td>
<td>SH, 4</td>
<td>SH, 4</td>
</tr>
<tr>
<td>R53FLAG</td>
<td>V51 initiated</td>
<td>V51 not initiated</td>
<td>SH, 11</td>
<td>SH, 3</td>
<td>SH, 3</td>
</tr>
<tr>
<td>TARG1FLG</td>
<td>Sighting LEM</td>
<td>Not sighting LEM</td>
<td>SH, 3 4 6</td>
<td>SH, 3 4 6</td>
<td>SH, 3 4 6</td>
</tr>
<tr>
<td>TRACKFLG</td>
<td>Tracking allowed</td>
<td>Tracking not allowed</td>
<td>SH, 4</td>
<td>SH, 4</td>
<td>SH, 4</td>
</tr>
<tr>
<td>UPDATFLG</td>
<td>Updating by marks allowed</td>
<td>Updating by marks not allowed</td>
<td>SH, 4</td>
<td>SH, 4</td>
<td>SH, 4</td>
</tr>
<tr>
<td>LUNAFLAG</td>
<td>Lunar lat-long</td>
<td>Earth lat-long</td>
<td>SH, 5</td>
<td>SH, 5</td>
<td>SH, 5</td>
</tr>
<tr>
<td>ERAFLAG</td>
<td>Use fixed radius</td>
<td>Use RLS for lunar radius</td>
<td>SH, 5</td>
<td>SH, 5</td>
<td>SH, 5</td>
</tr>
<tr>
<td>TARG2FLG</td>
<td>Sighting landmark</td>
<td>Sighting star</td>
<td>SH, 6</td>
<td>SH, 6</td>
<td>SH, 6</td>
</tr>
<tr>
<td>CULTFLAG</td>
<td>Star occulted</td>
<td>Star not occulted</td>
<td>SH, 7</td>
<td>SH, 7</td>
<td>SH, 7</td>
</tr>
</tbody>
</table>

### Displays

<table>
<thead>
<tr>
<th>Verb-Num</th>
<th>Type of Displays</th>
<th>Description of Each Register</th>
<th>Where Executed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PROLARM - Target out of view - 404</td>
<td>SH, 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CURTAINS - Alarm 217</td>
<td>SH, 11</td>
</tr>
<tr>
<td>01N71</td>
<td>FLASHTING</td>
<td>RESPONSE AND DISPLAY OF CELESTIAL BODY CODE</td>
<td>SH, 12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R1 - CELESTIAL BODY CODE</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R2 - BLANK</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>R3 - BLANK</td>
<td></td>
</tr>
<tr>
<td></td>
<td>V53</td>
<td>PLEASE PERFORM ALTERNATE LOS SIGHTING MARK</td>
<td>SH, 14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R1 - BLANK</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>R2 - BLANK</td>
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</tr>
<tr>
<td></td>
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<td>R3 - BLANK</td>
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<tr>
<td>06N04</td>
<td>FLASHTING</td>
<td>C101 - SHAFT</td>
<td>SH, 14</td>
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<tr>
<td></td>
<td></td>
<td>C102 - TRUNNION</td>
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<td></td>
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<td>C103 - BLANK</td>
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</tr>
<tr>
<td>50N25</td>
<td>PLEASE PERFORM</td>
<td>PLEASE PERFORM TERMINATION OF THIS ROUTINE</td>
<td>SH, 14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R1 - 00016</td>
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</tr>
<tr>
<td></td>
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<td>R2 - BLANK</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>R3 - BLANK</td>
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</table>
### ERASABLE LOCATIONS USED

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING UNITS</th>
<th>AGC UNITS</th>
<th>AGC SCALING</th>
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<tbody>
<tr>
<td>CDUT</td>
<td>OPTICS TRUNNION ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-3</td>
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<tr>
<td>CDUS</td>
<td>OPTICS SHAFT ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
<td></td>
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<tr>
<td>DESOPTT</td>
<td>DISPLAY NOUN FOR TRUNNION ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
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<tr>
<td>DESOPTS</td>
<td>DISPLAY NOUN FOR SHAFT ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>STARS2V2</td>
<td>STAR2 UNIT VECTOR</td>
<td>M</td>
<td>M</td>
<td>2^29</td>
<td></td>
</tr>
<tr>
<td>STARS1V1</td>
<td>STAR1 UNIT VECTOR</td>
<td>M</td>
<td>M</td>
<td>2^29</td>
<td></td>
</tr>
<tr>
<td>RATT_V</td>
<td>CONIC POSITION VECTOR</td>
<td>M/SEC</td>
<td>M/CSEC</td>
<td>2^-7</td>
<td></td>
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<tr>
<td>VATT_V</td>
<td>CONIC VELOCITY VECTOR</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^28</td>
<td></td>
</tr>
<tr>
<td>TATD</td>
<td>TIME OF RATT_V, VATT_V</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^28</td>
<td></td>
</tr>
<tr>
<td>ALPHA1_V</td>
<td>RADIUS VECTOR</td>
<td>M</td>
<td>M</td>
<td>2^29</td>
<td></td>
</tr>
<tr>
<td>LANDMARK</td>
<td>NO OF REVOLUTIONS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOPTIME</td>
<td>TEMPORARY</td>
<td></td>
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<tr>
<td>STARV</td>
<td>TEMPORARY</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>STARIND</td>
<td>STAR INDICATOR</td>
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<tr>
<td>TDECLD</td>
<td>TIME VARIABLE</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^28</td>
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</tr>
<tr>
<td>TSIGHTD</td>
<td>TIME OF SIGHTING</td>
<td>SEC</td>
<td>CSEC</td>
<td>2^28</td>
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</tr>
<tr>
<td>CDUX</td>
<td>OUTER IMU GIMBAL ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
<td></td>
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<tr>
<td>CDUY</td>
<td>INNER IMU GIMBAL ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
<td></td>
</tr>
<tr>
<td>CDUZ</td>
<td>MIDDLE IMU GIMBAL ANGLE</td>
<td>DEGREES</td>
<td>REVS</td>
<td>2^-1</td>
<td></td>
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</tbody>
</table>

### PROGRAM CONSTANTS

<table>
<thead>
<tr>
<th>AGC TAG</th>
<th>GSOP SYMBOL</th>
<th>MEANING</th>
<th>ENGINEERING VALUE AND UNITS</th>
<th>AGC VALUE AND UNITS</th>
<th>AGC SCALING</th>
</tr>
</thead>
<tbody>
<tr>
<td>38TRDEG</td>
<td>50° TO 65° ANGLE CHECK</td>
<td>60 DEGS</td>
<td>1.66666667 REV</td>
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<td>-30 DEGS</td>
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<td>LUNAR ANGULAR ROTATION IN 2 HOURS</td>
<td>1.071432 DEGS</td>
<td>.0029762 REV</td>
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<td>60 DEGS</td>
<td>.166666666 REV</td>
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<td>50 DEGS</td>
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<td>P61</td>
<td>Maneuver to CM/SM separation attitude</td>
<td>Sh. 2</td>
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<td>P62</td>
<td>CM/SM separation and pre-entry maneuver</td>
<td>Sh. 6</td>
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<td>Schedule P63</td>
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<td>P63</td>
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<td>P64</td>
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<td>Sh. 12</td>
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<td>P67</td>
<td>Final entry mode</td>
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<td>Final entry display (N67)</td>
<td>Sh. 17</td>
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<td>P67.2</td>
<td>Calculation for N67 display</td>
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<tr>
<td>S61.1</td>
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<td>Sh. 19</td>
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<td>S61.1C</td>
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<td>Sh. 20</td>
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<td>Check entry IMU alignment</td>
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<td>S61.2</td>
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<td>Compute desired entry attitude</td>
<td>Sh. 30</td>
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</tbody>
</table>
P61: Maneuver to CM/SM Separation Attitude

Called from DSKY via V37E61E

EXT V BACT = 20000
HEADSUP = -1

S61.1
Check state vector and IMU alignment
Sh. 19

Go to Flash:
Display flashing:
V06N61

P61.3

Group 4.1
Set up restart to return to last display

P61.4

End of Job

Test
HEADSUP
-1
+1

ROLL CD = 0°
ROLL CD = 180°

Next Sheet

Lock out extended verbs (protect TFF routines from V82) Set HEADSUP flag to head down (lift up)

1. Call R02 check REFSMMAT & IMU status. Set IMUSE flag
2. Update state vectors VV, RV, to present time + a small tolerance
3. Start AVERAGEG as part of servicer
4. Update sequence
4. Check IMU alignment and do alarm if not satisfactory (10 sec display)

Display noun 61:
R1 - Latitude (splash) xxx. xx deg
R2 - Longitude (splash) xxx. xx deg
R3 - HEADSUP: +1 = heads up (lift down)
               -1 = heads down (lift up)

If HEADSUP = +1,
command 180° roll (lift down)
If HEADSUP = -1,
command 0° roll (lift up)
From Preceding Sheet

AGIN, MON

EXTVBACT = 20008

NEWRNVN

$M_D = \text{PIPTIME}_D$  
Temporary storage for test below

STARTEN

Calculate initial target vector

FC-2770

flagword 6  
bit 3

Clear .5GSW

Input: $\text{PIPTIME}_D$ from AVERAGEG, LAT(SPL)$_D$, LNG(SPL)$_D$

Output:
- $\text{RTINIT}_V$ - initial target vector (at PIPTIME)
- $\text{RTEAST}_V$ - eastward component of RTINIT$_V$
- $\text{RTNORM}_V$ - normal component of RTINIT$_V$
- $\text{RTV}$ - target vector at estimated impact time
- $\text{TIME/RTO}_D$ - time of initial target vector

Enable TICKTTE (FC-2683) to decrement TTE

$\text{RONE}_V \leftarrow \text{RN}_V$

$\text{URONE}_V \leftarrow \text{Unit} (\text{RN}_V)$

$\text{VONE}_V \leftarrow \text{VN}_V$

$\text{UNI}_V = \text{Unit} [\text{VONE}_V \times \text{URONE}_V]$  

Next Sheet

PRELIMINARY
If PIPTIME has been updated, it means that AVERAGEG has run, so above calculations are invalid and must be redone using new state vector.

Input: RONE\textsubscript{V}, VONE\textsubscript{V}, URONE\textsubscript{V}, UNL\textsubscript{V}, UNITW\textsubscript{V}, EMSALT

Output: GMAX = maximum predicted deceleration during entry (in g's)

VPRED = predicted inertial velocity at 400,000 ft

GAMMAEI = predicted flight path angle (\(\gamma\)) at 400,000 ft

RTOGO = range from EMS altitude to splash

VIC = predicted inertial velocity at EMS altitude

TTE = time to go from present position to EMS altitude (EMS altitude = altitude at .05g

G. value = 284.643 ft

Orbital entry = 297.431 ft

Lunar entry)

PRELIMINARY
From Preceding Sheet

(N60 and N63 are unmolested until P64)

R1: XXX.XXg  (GMAX)
R2: XXXXX.ft/sec (VPRD)
R3: XXX.XXdeg (GAMMAEI)

GOFLASH
Display flashing V08N60
Recycle
Terminate
Proceed
GOTOPOOH

Note: TTE is decremented (at a 2 sec. rate) by TICKTTE (in SERVICER, FC-2683) as follows:

\[ TTE_D' = (TTE_D - MM_D) \]
\[ TTE_D = TTE_D' + PITIME_D \]

GOFLASH
Display flashing V16N63
Recycle
Terminate
Proceed
GOTOPOOH

AGIN. MON
Sh. 3

NEWMODEX
Display
Major mode 62
FC-2030

Note: "V32E" may be used to update conic displays on demand.

R1: XXXX.Xnm  (RTGO)
R2: XXXXX.ft/sec (VIO)
R3: XX-XXmin, sec (TTE)

Change major mode to P62 and fall into P62

Set up down-link for entry downlist

DNLSTCOD + 1

Next Sheet

PRELIMINARY

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

DRAWN

PGMNR
ANALST
DOCMR
APPRD

COLOSSUS 2D
FC-2760

P60's

DOCUMENT NO.

REV 1

SHEET 5 OF 35
From Preceding Sheet
Flow in from P61 or by DSKY request

P62
CM/SM separation and pre-entry maneuver
If entered from DSKY, start AVERAGEG also

S61.1
Check state vector and IMU alignment
Sh. 19

POSEXIT ← CADR(P62.3)
Set CM/POSE exit address to calculate desired .05g gimbal angles, but without display via ENTRYVN.

CM/DAPIC
Start entry DAP in idle mode
FC-2780

Start calculations of body rates for entry DAP
Disable entry display: ENTRYDSP flag cleared

POPOOH

Put CM/POSE in SERVICER 2 sec. update sequence for calculation of body attitude following AVERAGEG routine. Remains active until end of entry.

GOPEGFIR
Display flashing V50N25
checklist 41

Immediate return

GOTOPOOH

Next Sheet

ENDOFJOB

---

PRELIMINARY

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.

<table>
<thead>
<tr>
<th>DRAWN</th>
<th>TC.</th>
<th>Aug 8</th>
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<td>APPR'D</td>
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**APOLLO GUIDANCE AND NAVIGATION**

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<th>COLOSSUS 2D</th>
<th>FC-2760</th>
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<tbody>
<tr>
<td>REV</td>
<td>1</td>
<td>SHEET 5 OF 35</td>
</tr>
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</table>
From Preceding Sheet

CM/DAPO\nSwitch over to entry DAP
FC-2760

Disable RCS DAP
Set NO-DOFLAG to inhibit further V37's
Enable entry DAP
Do attitude hold, beginning after first CM/POSE update

(P Beyond this point, "terminate" will not terminate the entry sequence. To unconditionally cancel the P60's, V37E 00E must be used.)

R1: Latitude of splashpoint XXX. XX deg
R2: Longitude of splashpoint XXX. XX deg
R3: HEADSUP: +1 — up; -1 — down ±0000X
(up = lift down, and vice versa)

Proceed

Command appropriate entry DAP roll angle for configuration requested.
If HEADSUP = +1, ROLLC = 180°
(lift down)
If HEADSUP = -1, ROLLC = 0°
(lift up)

PRELIMINARY
Pitch command \( y \) command nominal entry

Yaw command attitude
(ALFAPAD is pad loaded hypersonic trim angle of attack commensurate with expected L/D. \((L/D = 0.28; \text{ALFAPAD} = -18.5^\circ)\))

Enable entry DAP to call WAKEP62 in order to go on to P63 (was set to -1 by CM/DAPON)

Set up entry display: executed in re-entry control (OVERNOUT) to display desired CDU angles.

Set flagword 6 bit 13 to enable entry display

\( |\alpha| < 45^\circ \), go directly to P63, since maneuver to entry attitude is complete, or nearly so. \((\text{CMDAPMOD is set by entry DAP: -0 if } |\alpha| > 135^\circ\)

\(-1 \text{ if } 135^\circ \geq |\alpha| \geq 45^\circ\)

\(-0 \text{ if } |\alpha| < 45^\circ\)

\(-1 \text{ if in atmosphere})\)

PRELIMINARY
Called from entry DAP at transition from $|\alpha| > 45^\circ$ to $|\alpha| < 45^\circ$ if $P63$ flag = $+0$ ($P63$ flag must first become $+1$ which it does when $|\alpha| > 45^\circ$) (See FC-2780)

Schedule P63
Called from WAKEP62, or flow in from P62, when entry attitude has been achieved.
Activate entry guidance.

**NEWMODEX**
Display
Major Mode 63
FC-2030

**POSEXIT - CADR(STARTENT)**

**ENTRYVN - V06N64**
Set up entry display executed in re-entry control (OVERNOUT) to display noun 64 each 2 sec:
R1: XXX. XX g drag acceleration
R2: XXXXX fps velocity
R3: XXXX. X nm distance to splash point (negative if will fall short)

**P63FLAG - -1**
Assure that P63 will not be called out of sequence by skip phase is P66 or P67

**Group 4.0**
Disable Group 4 - display is restarted in re-entry control (Group 5)

**CLEANDSP**
Blank DSKY
R1, R2, R3
FC-2130

Remove V06N22, if present. P63 display begins on second pass thru entry steering
Enable Group 4 - display is restarted in re-entry control (Group 5)
Called from re-entry control when 0.05g is initially exceeded.

P64

NEWMODEX
Display Major Mode 64 FC-2030

ENTRYVN + V06N74

Set up entry display executed in re-entry control (OVERNOUT) to display noun 74 each 2 sec:
- R1: XXX. XX deg roll command (ROLLC)
- R2: XXXXX. fps velocity (VMAGI)
- R3: XXX. XX g drag (D)
(Noun 68 display may still be called up)

Return via DANZIG

Major Mode display P64

PRELIMINARY
P65

Entered when range is within 25 nm of target

NEWMODEX
Display
Major Mode 65
FC-2030

P65, 1
NOVAC job
prio 13
Sh. 14

Group 4.55
Set up restarts to schedule
P65, 1 as a FINDVAC job
with priority 13

Group 5.3
Set up restarts to schedule
REREADAC as a WAITLIST
task in 2 seconds

Group 5
Set up restarts to schedule
next location as a job
with old priority

GOTOADDR ← CADR(UPCONTRL)
Switch to UPCONTROL phase
of entry control

REFAZE10
FC-2770
Return to entry control (and reestablish restart
Group 5 at entry sequencer)

PRELIMINARY
Clear
ENTRYDSP

GOFLASHR
Display flashing V16N89

Monitor noun 69:
R1: ROLLC XXX, XX deg
R2: Q7 XXX, XX g
R3: VL XXXXX, fps

Proceed Note: If P66 or P67 entered before response is made to N69, then proper P66 or P67 display will appear

ENDOFJOB

Enable entry display

ENDOFJOB

P63.1

Group 4.0
Disable Group 4 restarts

PRELIMINARY
Entered when drag <Q7

Set up entry display to display desired gimbal angles (noun 22)
R1: XXX.XX deg
R2: XXX.XX deg
R3: XXX.XX deg
Called from re-entry control when final phase trajectory is entered (when drag level exceeds 0.2 g)

NEWMODEX
Display
Major Mode 67
FC-2030

Set up entry display executed in re-entry control (OVERNOUT) to display noun 66:
R1: XXX. XX deg roll command (ROLLC)
R2: XXXX. X nm cross-range error
R3: XXXX. X nm down-range error

ENTRYVN = A

Enable entry displays in case came from P65. (N69 if still active, will be replaced by current display noun)

KILLGRP4

Group 4.0
Disable Group 4 restarts

Return via DANZIG

Return to caller in interpretive language

PRELIMINARY
Called from STEEROFF (reentry control) when relative velocity first becomes less than 1000 ft/s. Establish final entry display.

- **R1** = RTGO = range to go to target (positive if gone past) XXX.X nm
- **R2** = LAT = latitude of present position (+ is north) XXX.XX deg
- **R3** = LONG = longitude of present position (+ is east) XXX.XX deg

Proceed or terminate

- Terminate entry steering and entry DAP at crew option

Inhibit interrupts

Clear CM/DSTBY
Clear GYMDFSW

Enable interrupts

**AVEGEXIT_D = 2CADR(SERVEEXIT)**

Disconnect entry programs from AVERAGEG/SERVICER cycle

**PRELIMINARY**
Calculation for final display, N67
Called from STEEROFF (reentry control) initially when velocity < 1000 ft/sec. Subsequent calls are from TARGETNG

flagword 1
bit 13
Clear ERADFLAG
Set up inputs for LAT-LONG: use pad radius for altitude

Position vector

MPAC_D ← PIPTIME_D
Corresponding time

flagword 3
bit 12
Clear LUNAFLAG
Compute LAT - LONG for earth

Inputs: =ALPHAV_V (position vector), LUNAFLAG

Outputs: = latitude in LAT, longitude in LONG, altitude in ALT of given position

For display noun 67

P67. 2

LAT-LONG
Compute LAT-LONG
FC-2280

P67. 3

SERVNOUT
FC-2770
Normal entry guidance exit without display (display is done in P67. 1)

PRELIMINARY
Assure that AVERAGEG is operating and check that IMU is aligned properly for entry

Set IMUSE flag to prevent zeroing IMU CDUs by a restart
Possible prog alarm, with alarm code 00210 (IMU not on) or 00220 (IMU orientation not known i.e. no REFSMMAT)

Test flagword 1, bit 1:
Is AVERAGEG on?
Flag set or reset in SERVICER

If AVERAGEG 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: ΔTIME, current time to PIPTIME1

(Save for restart protection relative to TBASE4)

Schedule S61.1C to begin at the start of AVERAGEG to establish PREREAD

PRELIMINARY
S61.1C

S61.1A -1
FINDVAC
job
prio 13
Sh. 11

AVGEXIT_D = 2CADR(SERVEXIT)

Group 4.45
Set up restarts
to schedule S61.1A -1
as a FINDVAC job with
priority 13

Group 5.41
Set up restarts
to schedule PREREAD
as a WAITLIST task
immediately

PREREAD
FC-2683

Set up AVERAGEG exit to go directly
to standard SERVICER exit for the moment.

Protect scheduling of S61.1A

Protect AVERAGEG

This starts READACCS for AVERAGEG updating
of the state vector. (READACCS reschedules itself
every 2 secs and continues running throughout
entry) (PREREAD will go to TASKOVER)

PRELIMINARY
Entry IMU Alignment Check

Clear OVFIND  Initialize overflow indicator

$\text{MPAC}_V = \text{Unit}[\text{REFSMMAT}_M(V_N \times R_N)]$  Unit $(V \times R)$ in stable member coordinates

(unit normal to trajectory plane)

Is $Y$-component negative?

$(\text{MPAC} + 3)_D < 0$?

Yes, IMU is in reversed alignment

No, IMU is in normal alignment

$Y_{SM}$ (or $-Y_{SM}$) not within $30^\circ$ of $V \times R$?

No

$Y_{SM}$ is within $30^\circ$ of $V \times R$?

Yes

$\text{RETRN3}$

Set alarm code 01426 (IMU unsatisfactory)

$\text{FC-2140}$

$\text{GODSPR}$

V05N09  Display alarm code

$\text{DELAYJOB}$

Wait 10 seconds

$\text{FC-2070}$

$\text{RETRN1}$

Return via 60GENRET

Yes

$\text{RETRN2}$

Set alarm code 01427 (IMU reversed)

$\text{FC-2140}$

Preliminary
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.

\[
\text{Load } \frac{1}{\sqrt{\mu}} \text{ for earth orbit}
\]
\[
5005750271 \times 10^{-5} \left( \text{csec}^2 / \text{m}^3 \right)^{1/2}
\]

Conic parameters in pushlist (for use by TFF subroutines)

- MPAC_D
- RONE_V
- URONE_V
- VONE_V
- UNL_V

First guess at terminal radius (R_h) at nominal EMS altitude

\[
R_{\text{TRIAL}_D} = \text{RPAD} + \text{nominal } 0.05 \sigma
\]

altitude = 20, 909, 901.57 ft + 284,643 ft = 21,194,545 ft

Input: terminal radius (MPAC_D) (R_h)

Conic parameters in pushlist (from TFFCONIC)

Output: NRTERM = normalized R_h

\[
\text{TFFX} = \frac{Z^2}{1} \text{ or } \frac{1}{a_2^2}
\]

\[
\text{TFFTEM} = PZ \left| Z \right| \text{ or } \frac{P}{Z} \cdot \text{SGN} \left( Q_o + \frac{R_o}{Z} \right)
\]
From Preceding Sheet

**TFF/TRIG**

Calculate sin, cos transfer angle

FC-2320

**Input:**
- NRTERM
- TFFX
- TFFTEM
- NRMAG

**Output:**
- MPAC = \( \sin (\delta f) \)
- CDELF/2 = \( \cos (\delta f) \)

From CALCTFF

From TFFCONIC

**FISHCALC**

Calculate Fischer radius

FC-2320

**Input:**
- \( \Delta f \)
- UNI
- \( V_o \times R_o \)

**Output:**
- MPAC\(_D\) = \( \frac{\Delta f}{2} \cos (\Delta f) \)

**From CALCTFF**

**From TFFCONIC**

\( \sin (\Delta f) \)

\( \cos (\Delta f) \)

\( \Delta f \) is transfer angle from present to EMS altitude.

**Input:** MPAC\(_D\) = \( \sin (\Delta f) \), UNI\(_v\) = unit \( (V_o \times R_o) \)

**Output:** MPAC\(_D\) = ERADM = Radius of earth \( (R_e) \) at latitude of estimated terminal radius \( (R_h) \)

Corrected estimate of terminal radius \( (R_h) \)

\( \Delta f \) is transfer angle from present to EMS altitude.

EMSALT\(_D\) = 284,643 ft (pad loaded, earth orbital)

EMSALT\(_D\) = 297,431 ft (pad loaded, lunar return)

**Input:** MPAC\(_D\) = terminal radius \( (R_h) \)

**Output:** MPAC\(_D\) = time of flight to EMS altitude from present position.
- NRTERM = normalized \( R_h \)
- TFFX = \( x \) \( Z^2 \) or \( \frac{1}{\alpha x^2} \)
- TFFTEM = \( \frac{PZ \times \alpha}{x} \) or \( \frac{P \times SGN(Q_o + \frac{R_o}{2})}{x} \)

Time till entry (.05g) stored positive Negative for N63 display

**TFF/TRIG**

Calculate sin, cos

FC-2320

**Input:**
- NRTERM
- TFFX
- TFFTEM

**Output:**
- MPAC\(_D\) = \( \sin (\Delta f) \)
- CDELF/2 = \( \cos (\Delta f) \)

From CALCTFF

From TFFCONIC

\( \sin (\Delta f) \)

\( \cos (\Delta f) \)
FISHCALC
Calculate Fischer radius
FC-2320
Input: \( \sin(\delta f) \), \( \cos(\delta f) \), \( \text{UNI}_v \)
Output: \( \text{URH}_v \), unit radius vector at \( 0.05 \text{g} \) point
ERADM, Fischer radius as latitude of estimated \( 0.05 \text{g} \) point

VRCALC
Calculate initial range angle
Sh. 29
Input: \( \text{URH}_v \)
\( \text{RT}_v \) = Unit vector at impact point
Output: \( \text{MPAC}_D \) = Range angle in revolutions

DISPTARG
Update range angle
Sh. 28
Input: \( \text{MPAC}_D \) = range angle
\( \text{RTINIT}_v \), \( \text{RTEAST}_v \), \( \text{RTNORM}_v \)
Output: \( \text{RT}_v \)
\( \text{MPAC}_D \) = range angle, updated

DISPTARG
Update range angle
Sh. 28
Output: \( \text{MPAC}_D \) = range angle

\( \text{RTGOD} \leftarrow \text{MPAC}_D \)
Range angle from EMS altitude to splash for N63 display

Next Sheet
From Preceding Sheet

Input: NRTERM (from CALCTFF)
Conic parameters in Pushlist from TFFCONIC
Output: PDL0_D = terminal velocity (V_h)
MPAC_D = flight path angle (δ_e)
(relative to horizontal)

\[ V_{EMS} = V_h + \frac{-1,510,000}{V_h \cdot \delta_e} \]

Obtain \( V_\delta \) at 300,000 feet altitude for use in GMAX algorithm

ERADM = earth radius at EMS latitude (from FISHCAL)

\[ V_{10_D} \rightarrow \text{PL0}_D + \frac{V_{EMS\text{COND}}}{\text{PL0}_D \cdot \text{MPAC}_D} \]

\[ \text{MPAC}_D \rightarrow \text{ERADM}_D + 300\text{KFT}_D \]

Calculation of maximum G for display (noun 60)

\[ \text{RTERM}_D \rightarrow \text{MPAC}_D \]

Input: MPAC_D = R_h
Conic parameters in Pushlist TFFCONIC
Output PL0_D = terminal velocity (V_h)
MPAC_D = flight path angle (δ_e)

Predicted flight path angle at 300,000 feet (δ_e)

Next Sheet

PRELIMINARY
From Preceding Sheet

\[ v^2 = \left( \frac{V_h - 36,000}{20,000} \right)^2 \]

\[ PL_D = \left( \frac{PL_D - 36KFT/S_D}{20KFT/S_D} \right)^2 \]

\[ G_{\text{MAX}} = \frac{\left( 4 \left( \frac{v}{v_c} - 6.05 - 2.4v^2 \right) \right)}{1 + 4.8v^2} + 10 \]

\[ MPAC_D = \frac{KR^2_D \left[ PL^2_D + (-6.05\text{DEG})_D + (KR^1_D \cdot PL^0_D) \right]}{DP^2 (-4.0)_D + (PL^0_D / KR^4_D)} \]

Is \( MPAC = 0 \) ?

No

Prevent negative value

Yes

\[ MPAC_D \leftarrow 0 \]

GMAX \( \leftarrow \) MPAC

GMAX's for N60 display

Next Sheet

PRELIMINARY
First guess of terminal radius at 400,000 ft
ERAD_{D} = \text{earth radius at EMS latitude (from FISHCALC)}

\[ MPAC_{D} \rightarrow ERAD_{D} + 400\text{KFT}_{D} \]

**CALCTFF**
Calculate time of free fall to 400KFT
FC-2320

**Input:** MPAC\textsubscript{D} = terminal radius
Conic parameters in Pushlist from TFFCONIC

**Output:** NRTERM, TFFX, TFFTEM

**TFF / TRIG**
Calculate sin, cos transfer angle
FC-2320

**Input:** NRTERM, TFFX, TFFTEM (from CALCTFF)

**Output:** NRTERM, TFFX, TFFTEM (from TFFCONIC)

**FISHCALC**
Calculate Fischer radius
FC-2320

**Input:** MPAC\textsubscript{D} = \sin (\delta f) where (\delta f) is the transfer angle
CDELF/2 = \cos (\delta f) from present position to 400,000 ft

**Output:** MPAC\textsubscript{D} = \sin (\delta f)
CDELF/2 = \cos (\delta f)
UNIV = unit \( V_0 \times R \).

MPAC = radius of earth at latitude of 400,000 ft. Terminal radius = ERAD\textsubscript{D}
Corrected estimate of radius at 400,000 feet

Save range angle from EMS attitude (high order half) for Downlink

Input: $\text{MPAC}_D = \text{terminal radius conic parameters in Pushlist from TFFCONIC}$

Output: $\text{MPAC}_D = \text{flight path angle at 400,000 ft (} \delta_e \text{)}$

$\text{PDL}_D = \text{velocity 400,000 ft (} V_h \text{)}$

GAMMAEI is negative for entry
From packed word for Downlink:
put RTGO ( high-word ) into low-word of GAMMAEI

Flight path angle at 400,000 ft for N60 Downlink quantity:
high-word = y e
low-word = range to go

Conic velocity at 400,000 ft for noun 60 display

Note: Effect of RTGO in low-word GAMMAEI on DSKY is negligible (≈0.005 deg)

PRELIMINARY
DISPTARG

Range estimator

Save QPRET in 60GENRET

C ( MPAC_D ) = range angle estimate

DTEAROT = KT \theta_1 + t_{ff}

KT \theta_1 = 1100

TTE = t_{ff} = time of free fall

DTEAROT_D \rightarrow KTETA1_D, MPAC_D + TTE1_D

Input: DTEAROT_D (estimated flight time)

RTINIT_V, RTEAST_V, RTNORM_V, TIME/RTO_D

Output: RT_V, predicted target vector

EARROT2

Locate predicted impact point

FC-2250

VRCALC

Calculate range angle

Sh. 29

Input: URH_V, RT_V

Output: MPAC_D, range angle in revolutions

Return via 60GENRET

PRELIMINARY
\[ \theta = \cos^{-1} \left( \frac{\mathbf{UR}_h \cdot \mathbf{RT}}{\|\mathbf{UR}_h\| \cdot \|\mathbf{RT}\|} \right) \]

\[ \text{MPAC}_D = \text{ACOS} \left[ 4 \cdot \mathbf{UR}_V \cdot \mathbf{RT}_V \right] \]

Input:
- \( \mathbf{UR}_V \) (Unit radius at .05g point)
- \( \mathbf{RT}_V \) (Unit target vector)

Output:
- \( \text{MPAC}_D \), range angle in revolutions

Return via QPRET

PRELIMINARY
If ENTRYDSP = 0, omit entry display \((\text{ENTRYVN})\).

If ENTRYDSP = 1, do entry display \((\text{ENTRYVN})\).

1. Compute desired gimbal angles for entry attitude
2. Generate desired body triad for trimmed flight with respect to relative velocity

\[ \text{YNB}_V = \text{desired body Y axis in}\]
\[ \text{reference coordinates} \]
\[ \text{UYA}_V/2 = \text{normal to trajectory}\]
\[ \text{plane in reference coordinates}\]
\[ \text{from CM/POSE} \]

\[ \text{YNB}_V \leftarrow \text{UYA}_V/2 \cdot \cos (\text{ROLLC}_D) + \text{UZA}_V/2 \cdot \sin (\text{ROLLC}_D) \]

\[ \text{ROLLC}_D = \text{roll command} \]
\[ \text{UZA}_V/2 = \text{trajectory triad Z axis}\]
\[ \text{in reference coordinates from CM/POSE} \]

\[ \text{XNB}_V \leftarrow \text{UXA}_V/2 \cdot \cos (\text{ALFAPAD}) + (\text{YNB}_V \times \text{UXA}_V/2) \cdot \sin (\text{ALFAPAD}) \]

\[ \text{UXA}_V/2 = \text{trajectory triad X axis}\]
\[ \text{in reference coordinates from CM/POSE} \]
\[ \text{ALFAPAD} = \text{pad loaded pitch trim angle} \]

\[ \text{ZNB}_V = (\text{XNB}_V \times \text{YNB}_V) \]

\[ \text{Z axis to complete the triad} \]

Next Sheet

PRELIMINARY
From Preceding Sheet

\[
\begin{align*}
XSM_v & \leftarrow \text{REFSMMAT}_v \\
YSM_v & \leftarrow \text{REFSMMAT} + 6D_v \\
ZSM_v & \leftarrow \text{REFSMMAT} + 12D_v
\end{align*}
\]

Reference coordinate system to stable member transformation matrix, for use by CALCGA

Clear flagword 0, bit 15:

\text{CPHIFLAG} \text{ causes CALCGA to store resulting angles in tp in CPHI}

CALCGA

Calculate desired gimbal angle(s)

\text{FC-2260}

Inputs: \(XNB_v, VNB_v, ZNB_v, XSM_v, YSM_v, ZSM_v\)

Outputs: 3 gimbal angles in MPAC, MPAC +1 and MPAC +2 also in CPHI, +2

From CALCGA

Return via QPRET

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<th>Description</th>
<th>Where Called</th>
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</table>
CM BODY ATTITUDE DETERMINATION FOR ENTRY DAP
(REF. GSOP CH 3.4)

When re-entry, CM/POSE becomes part of the service cycle, and is entered from
average edge every 2 seconds via average

\[ \text{VREL} = K \cdot \text{SCALE} \cdot \text{VWA} = K \text{WE}_0 \text{UNIT W, X UNIT W} \]
\[ \text{UXA/2}_w \text{ UNIT} = \text{VREL} \]

If \( \text{VREL} \leq 1500 \text{ fps} \), don't try to update \( \text{UXA/2}_w \), since \( \text{UXA/2}_w \) will be too close
to collinear with UNIT.

\[ \text{YOUT} = 1000 \text{ F/S} \]

PROG. USES S.P. CONSTANT: 48.771

\[ \text{CM/POSE} \]

\[ \text{UXA/2}_w \text{ UNIT} = \text{VREL} \]

\[ \text{CM/TRIO} \]

Gimbal angles at readaccs update time (average edge fc 2683)

Input: 2's complement angle in MPAC (IN REV/C 2-1)
Output: 1's complement angle in MPAC (IN REV.C)

\[ \text{UBX/2}_v = \text{COS(MPAC)} \]
\[ \text{UXA/2}_w - \text{SIN(MPAC)} \]

First component of \( \text{UBX/2}_v \) (incomplete)
3rd component of \( \text{UBX/2}_v \)

\[ \text{MPAC} \]

Middle gimbal angle (\( \theta \))

\[ \text{PL26} \]

Outer gimbal angle (\( \phi \))

\[ \text{PL24} \]

Apog: PIP
PL25: Apog: PIP
PL23: Apog: PIP

- Input: 2's complement angle in MPAC (IN REV/C 2-1)
- Output: 1's complement angle in MPAC (IN REV.C)

\[ \text{UBX/2}_v = \text{COS(MPAC)} - \text{UBX/2}_v = [\text{SIN(MPAC)}] - [\text{UBX/2}_v + \text{UBX/2}_v - \text{SIN(MPAC)}] \]

\[ \text{UBX/2}_v \text{ COMPLETE} \]

Next sheet
ENTRY INITIALIZATION

REFERENCES:
GDPF, SECT. 5.7
FOLLOW CM/POSE AFTER P63 HAS
SET POSEXT=CADR (STARTENT)

INITIALIZE SWITCHES

ENDYDSP - ENABLE ENTRY DISPLAYS
GONEPAST* - OMIT LATERAL CALCULATIONS
REVELWS - TARGETING USES INERTIAL VELOCITY
EGSW - NOT IN FINAL PHASE
HOSWITCH - ALLOW LATERAL SWITCH OF ROLL ANGLE
HIND - DON'T ITERATE HUNTEST AFTER RANGER
INRLESW - HOLD INITIAL ROLL ATTITUDE UNTIL .05g
EXCEEDED
LATSW - DOWNLIFT NOT INHIBITED
.05gSW - DRAG < .05g

*GONEPAST IS INITIALLY SET TO OMIT LATERAL
STEERING. THUS ROLL WILL REMAIN 0 OR 180° AS DEFINED BY HEADSUP UNTIL
ONSET OF .05g (P64)

[USE PAD LOAD] FINAL PHASE L/D
L/D FOR MIN. ROLL ANGLE WHEN LATERAL
STEERING IS DESIRED
LATERAL SWITCHING SLOPE = .12/SLOPE = 1/24
MINIMUM DRAG FOR UPCONTROL = QFS = 6 FPSS
UPCONTROL FACTOR, INITIAL VALUE = PSDMAX = 1-
2.3 =
INITIAL L/D COMMAND: ROLL = 0°, OR ROLL = 180°

INITIALIZE TARGET AT PRESENT TIME
OUTPUT: RTINIT, INITIAL TARGET VECTOR

RTV, TARGET VECTOR
RTEAST, RTNORM,
THETA = RANGE ANGLE
ALL VECTORS IN REF COORD.

LATANG = LATERAL RANGE AT TARGET
KROLL = INDICATOR FOR LATERAL SWITCH OF
ROLL COMMAND
Q2 = COMPONENT OF FINAL PHASE RANGE
LIFT DEPENDENT
SET FOR INITIAL ENTRY PHASE (SEE SCALEPOP S8)
HEREAFTER, SCALEPOP TO FOLLOW CM/POSE IN
SERVICER SEQUENCE

OMIT ENTRY DISPLAY ON INITIAL PASS AND EXIT

REENTRY CONTROL

REENTRY CONTROL

COLOSSUS IDC
FC-2770
INITIAL TARGETING

INITIALIZE TARGET VECTOR AT PRESENT TIME
CALCULATE PREDICTED TARGET VECTOR (INITIAL GUESS)

SAVE WRT TO IN CNTAGE

CLEAR EARTH FLAG TO 1

LAT, LAT (SPL),
LNG, LNG (SPL),
ALT, TIME/RTO,

LATITUDE, LONGITUDE, ALTITUDE, TIME OF LAST STATE VECTOR UPDATE

INPUTS TO LALOTRY

OUTPUT: TARGET RADIUS VECTOR IN MPAC, AND IN ALPHAV

STORE INITIAL TARGET VECTOR, NOMINAL ENTRY TIME

INPUTS TO EARRT1

INITIALIZE EARTH ROTATOR AND ROTATE TARGET

OUTPUT TARGET VECTOR ROTATED BY DTHEAROT

(COG SEC) IN MPAC, AND RT,
RT (EAST), EASTERLY + NORMAL COMPONENTS
RTGRT, OF RTINIT
(ROTATION DUE TO ROTATION OF EARTH)

RANGE ANGLE, INITIAL ESTIMATION

RETURN VIA GO TO ADDER
ENTRY CONTROL

COME HERE FROM CM/POSE (SERVE ICY CYCLE)

OUTPUTS:
- V: VEHICLE VELOCITY
- V^2: VEHICLE VELOCITY SQUARED (V^2)
- V^2-1: V^2 - 1
- RO: VEHICLE ALTITUDE RATE (\dot{R})
- D: ATMOSPHERIC DRAG (ACCELERATION) (D)
- RT: UPDATED TARGET VECTOR
- LATANG: PREDICTED LATERAL RANGE
- THETA: TARGET RANGE ANGLE (\theta)
- GONEBY: 0 → NOT PAST TARGET; 1 → PAST TARGET

GROUP 5.3
- SET UP RESTARTS TO SCHEDULE THE NEXT JOB WITH THE SAME PRIORITY

GROUP 5
- SET UP RESTARTS TO SCHEDULE THE NEXT JOB WITH THE SAME PRIORITY

GO TO ADDRESS CONTAINS:

INITROLL: HOLDS EARLY ROLL ATTITUDES
HUNTEST: CHECKS IF ESTIMATED RANGE AT NOMINAL L/D IS LESS THAN DESIRED RANGE
UPCONTROL: CONTROLS ROLL DURING SEMI-CIRCULAR PHASE OF ENTRY
KEP2: MONITORS DRAG
PREDICT3: FINAL SUB-OBJECTIVE CONTROL
P67.2: MAINTAINS LAST COMPUTED ROLL ANGLE
ENDEXIT: EXIT
FROM PRECEDING SHEET

FOREHUNT

INITIALIZE

HUNTEST

SH13

GOTOADDR ← CADR(HUNTEST)

HUNTEST

NO

ROOT<0

YES

V42 = V2 + ROOT / LEWD
A02 = V42 / V42 - LEWH2 * LEWD
A12 = D0

V43 = V2 + ROOT / LAD
A03 = V43 / V43 - LAD2 * LAD
A13 = A0

V44 = INITIAL VELOCITY FOR UPCTRL
A04 = INITIAL DRAG
A14 = DRAG VALUE FOR CALCULATION OF FACTOR

C1 = 1.25 (GAIN FACTOR)

PREVENT OVERSHOOT IN DRAG LEVEL CAUSED BY REDUCED RCS RDLL ACCELERATION

VQUIT = 10DD F/S

NEXT SHEET
Calculate exit conditions for upcontrol. If gravity and centripetal accel. negligible.

\[
\begin{align*}
\alpha &= \frac{\gamma}{v_1^2 L/D} \\
\gamma &= \frac{1 - \alpha}{\alpha(\alpha - 1)} \\
F_4 &= \frac{v_1}{A_0} \\
V &= F_4 (1 - \sqrt{\gamma v_2 + \alpha}) \\
V_{exit} &= \frac{L/D(v_2 - v_e)}{v_e}
\end{align*}
\]

Intermediate factors for calculation of VL and GAMMAL.

\[VL = \text{exit velocity for upcontrol}
\]

GAMMAL = flight path angle at exit velocity (*simple* value).

\[
\begin{align*}
VL < \text{VLMIN}_2 & \quad \text{YES} \\
\text{VLBAR} &= \text{VL}^2 \\
\text{IS VL} & > \text{SATellite VELOCITY} ? \\
\text{VL} > 1 & \quad \text{YES} \\
\text{NEXT SHEET} \\
\text{VL} < 1 & \quad \text{NO} \\
\text{RECONST} & \quad \text{SH22}
\end{align*}
\]

VLMIN = 18,000 f/s

Next sheet.
Calculate Flight Path Angle (Altitude Rate) Converted for Neglected Accelerations

\[
\text{DVL}_{\delta} = \text{Velocity Change for which the correction for gravity and centripetal acceleration is applied}
\]

\[
\text{VSL}_0 = \text{Smaller of 1 or } \text{VSL}_0
\]

\[
\text{used to limit the correction}
\]

Get Hook

\[
\text{OHook}_o = \text{Drag at velocity } \text{VSL}_0
\]

(Computation uses OHook97 routine)

\[
\text{AHookV} = \text{AHook VDL}
\]

\[
\text{AHook}_{\delta} = \text{Slope for assumed linear density variation}
\]

\[
\text{MPAC}_{\delta} = \text{Corrected value of flight path angle at exit velocity VL for upcontrol}
\]

\[
\text{CH}_{\delta} = 1 \text{ (consider that } \delta \text{ is part of symbol CH)}
\]

\[
\text{CH}_{\delta} = 0.25
\]

Calculate new exit conditions (VL and CH) for

\[
\text{MPAC}_{\delta} = 0
\]

(PREVIOUS EXIT CONDITIONS CANNOT BE REACHED, SINCE GRAVITY TOO LARGE)

Negama

\[
\text{VL}_{\delta} = \text{Exit Velocity}
\]

\[
\text{Q7}_{\delta} = \text{Exit Drag Level Minimum Drag for Upcontrol (Computation uses OHook97 routine)}
\]

\[
\text{MPAC}_{\delta} = \text{Exit Flight Path Angle}
\]

\[
\text{VL}_{\delta} = \text{VL}_{\delta} + \frac{1}{3} \text{VL}_{\delta}
\]

\[
\text{MPAC}_{\delta} = \left(\frac{1}{3} \text{LEWD} - \text{CH}_{\delta} \cdot \text{DVL} \cdot (\text{AHookD} + \frac{1}{3})\right) / \text{DHook}_{\delta} \cdot \text{VBars}_{\delta}
\]

\[
\text{Q7}_{\delta} = \left(1 - \frac{\text{VL}_{\delta}}{\text{FACT}_{\delta}}\right)^2 - \text{AL}_{\delta} / \text{FACT}_{\delta}
\]

\[
\text{VBars}_{\delta} = (\text{VL}_{\delta})^2
\]

\[
\text{MPAC}_{\delta} = 0
\]

Huntest3

\[
\text{GAMMA}_{\delta} = \text{MPAC}_{\delta}
\]

Next Sheet

\[
\text{FROM PRECEDING SHEET}
\]

\[
\text{YES} \quad \text{VSL}_0 > 1 \quad \text{NO}
\]

\[
\text{DVL}_{\delta} = 1 - \text{VSL}_0
\]

\[
\text{VSL}_0 = \text{VSL}_0 - \text{VSL}_0
\]
FROM PRECEDING SHEET

\[ \text{GAMMAL}_1 = \text{GAMMAL}_1 + Q_{13}(\text{GAMMAL}_1 - \text{GAMMAL}_1) \]

USE WEIGHTED AVERAGE FOR UP-RANGE

\[ Q_{10} = 0.5 \]
\[ C_{12} = 0.5/\text{RE} \]
\[ K_{C3} = -1/\text{RE} \]

\[ Q_3 = 0.07 \text{ NM/FPS} \]
\[ Q_5 = 7.050 \text{ NM/FPS} \]
\[ Q_6 = 0.0349 \text{ RAD} \]

RANGER

\[ \cos \theta = 1 - \frac{(\text{GAMMAL}_1)^2}{2} \]

\[ \text{ASKP}_0 = 2 \sin^{-1} \left( \frac{V_{\text{BAR}_S} + \cos \theta \cdot \text{GAMMAL}_1}{V_{\text{BAR}_S} - \text{GAMMAL}_1} \frac{(\cos \theta)^2 + \frac{V_{\text{BAR}_S}}{2}}{\text{GAMMAL}_1} \right) \]

\[ \text{ASP}_1 = Q_3 \cdot V_{\text{BAR}} + Q_2 \]

\[ \text{ASP}_{UP} = \left( \frac{C_{12}}{\text{GAMMAL}_1} \right) \log \left( \frac{Q_7 \cdot V_{\text{BAR}}^2}{A_0 \cdot V_{\text{BAR}} S_0} \right) \]

\[ \text{ASP}_{DOWN} = \frac{V_{\text{BAR}} \cdot R_{\text{DSS}}}{A_0 \cdot \mu_{\text{LAPD}}} \cdot K_{C3} \]

\[ \text{ASP}_{3} = Q_5 \cdot (Q_6 - \text{GAMMAL}_1) \]

\[ \text{ASP}_{5} (\text{TM}) \leftarrow \text{ASKP}_0 \]
\[ \text{ASP}_{5} (\text{TM}) + 1 \leftarrow \text{ASP}_1 \]
\[ \text{ASP}_{5} (\text{TM}) + 2 \leftarrow \text{ASP}_{UP} \]
\[ \text{ASP}_{5} (\text{TM}) + 3 \leftarrow \text{ASP}_{DOWN} \]
\[ \text{ASP}_{5} (\text{TM}) + 4 \leftarrow \text{ASP}_{3} \]

HIGH ORDER HALF FOR DOWN TELEMETRY

\[ \text{DIFF}_p \leftarrow \text{ASP}_{3} + \text{ASP}_{DOWN} + \text{ASP}_{UP} + \text{ASP}_1 + \text{ASKP}_0 - \text{THETA}_0 \]

DIFF = PREDICTED RANGE - DESIRED RANGE (THETA CALCULATED IN TARGETING)

NEXT SHEET
FROM PRECEDING SHEET

RANGE ERROR IS IN ALLOWABLE LIMITS, AND A
YES, REFERENCE TRIAJECOTIOIs ESTABLISHED

[DIFF < 2.5 NM]?

NO

YES, ITERATION IN
PROGRESS USING
LEWD

HIND DFF ON FIRST
PASS THROUGH HUNTEST

NO, INITIALIZE ITERATION
IF RANGE IS SHORT

DIFF ≥ 0°?

ND, RANGE
SHORT START
ITERATION

CALCULATE L/D FOR CONSTANT DRAG

YES, TO REDUCE RANGE

NDLEWD

(INCREASE UP - CONTROLL REFERENCE L/D
(LEWD) SO AS TO INCREASE PREDICTED RANGE

UPDATE ESTIMATE OF DLEWD

DLEWD = DLEWD - DIFFOLD - DIFF,:

MPAC = LEWD + DLEWD

IF LEWD WOULD BE
NEGATIVE, HALVE THE
INTERVAL AND CONTINUE
ITERATION. YES

MPAC < 0?

ND

MPAC > 1.0?

YES

LEWD WILL EXCEED UNITY
WHICH CAN'T BE ACHIEVED

REVISE ESTIMATE
OF LEWD ON BASIS
OF RANGE ERROR

LEWD = MPAC

SIDE TRAK

NEXT SHEET

LIMIT LEWD
AND GO TO
CONSTANT
DRAG ROUTINE

MIT INSTRUMENTATION LAB
CAMBRIDGE, MASS.

REENTRY CONTROL

COLDUS III FC-2770
FROM PRECEDING SHEET

PHSPRTE = OCT18000

GROUP4,47
RESTART AT PRE-HUNT PRIOR 17

PRE-HUNT

PRI0CHNG
CHANGE PRIOR TO 16
FC-2050

CLEAR HIND

GO TO ADDR = CADR(ENDENT)

FOREHUNT
INITIALIZE HUNTEST SH13

HUNTEST SH13

DIFFLO2 = DIFFO

Q7 = Q7F

HUNTEST SH13

RETURN FOR RE-ITERATION

DROP GRP 5 RESTART PRIOR TO 16 SO GRP 4 WILL BE HIGHER

SET UP RESTARTS TO SCHEDULE PRE-HUNT AS A JOB WITH LOWER PRIORITY THAN SERVIGEC

LOWER PRIOR OF CURRENT SERVIGEC CYCLE (GRP 5) SO THAT GRP 4 TAKES PRECEDENCE IF RESTART OCCURS BEFORE END OF CURRENT CYCLE

UNTIL HUNTEST IS THROUGH ITERATION PROCESS, SIDE TRACK FUTURE CALLS FROM SERVIGEC THEY WILL DO ENTRY DISPLAY

INDICATE ITERATION IS BEING DONE

SAVE FOR ITERATION

Q7F = 6 FPSS
GO TO UPSY

P65

START P65:
ESTABLISH DISPLAYS
RESTART PROTECT
GO TO ODOR-- CADDUP (UPCONTRL)
FC-2760

UPCONTRL

D< C21?
YES

SET NOSWITCH

TO PREVENT LOSS OF
RANGING CAPABILITY,
SUPPRESS LATERAL SWITCH
AT HIGH D<

IS VELOCITY TOO HIGH FOR REFERENCE?

YES, VELOCITY IS ABOVE DESIRED INITIAL VELOCITY
FOR UPCONTROL (Vv) COMPUTED IN HUNTEST

Vv >= V1v?
NO

DOWN CNTL

REDUCE VELOCITY:

IS D< Q7 FOR UPCONTROL?
(Q7 COMPUTED IN HUNTEST)

YES

KEP

SH24

GO TO BALLISTIC
PHASE

NO

CLEAR OVFL
INDICATOR FOR CONSTO

PLO0 = LAO0 + K2D0[ROOT-1 LAD(V1v-V0)]

MPAC0 = AO0-VSQURE - (V1v-V0)^2 LAO0

LAD

K2D : C17 = -.001

CONSTD

SH22

COMPONENTS OF
DESIRED L/D

MPAC = D<REF

NEXT SHEET

MAINTAIN CONSTANT D<
HAS FINAL PHASE BEGUN?

NO

ROOT < 0?

YES

VLTEST

ALTITUDE IS DECREASING:
IS VELOCITY BELOW VL?
(EXIT VELOCITY FOR UPCTRL)

YES

V < VL + C1B?

YES, ENTER FINAL PHASE

C1B = 500 FPS

NO

PREFINAL

SHEE

HAS UP-PHASE BEGUN?

NO, D exceeds starting drag for upctrl

D < AO?

YES

FLY UP-PHASE
REFERENCE TRAJ.

CONT 3

MPAC — LAO

FLY FULL LIFT UP

(LIMITL/D)

STORE D

SH29

VREF = REFERENCE VELOCITY
RDOTREF = REFERENCE ALTITUDE RATE

VREF = FACT1(1 — FACT2.D + ALP2)

RDOTREF = LEWOS (V15 — VREF)

VREF > VSL?

YES

VS1 = SMALLER OF V1 OR SATELLITE VELOCITY V5

NO, CORRECT FOR THE NEGLECTED ACCELERATIONS:
GRAVITY AND CENTRIPETAL

RDOTREF — RDOTREF = CH1 ((VSL — VREF)4) ((VSL — VREF)2)

CH1 = 1 (CONSIDER THAT D IS PART OF SYMBOL CH1)

NEXT SHEET
FROM PRECEDING SHEET

CONTINUZ

DON'T UPDATE FACTOR IF
DRAG IS TOO LOW (< QMIN FT./SEC²)
QMIN = 0.4 FTPS

FACTORS = \( \frac{D_0 - Q_{70}}{A_2 - Q_{70}} \)

UPCNTRL

FACTORS = \( \frac{\text{KBOT} - \text{RDOTREF} + V_0 - \text{VREF}}{\text{KB1}} \)

(\( A_1 = \text{EITHER AG OR D}, \text{COMPUTED}
\text{IN HUNTEST} \))

\( P_{/D} = \frac{-1}{\text{KB2D}} \left[ \frac{\text{FACTORS} \cdot \text{KBOT} - \text{RDOTREF} + V_0 - \text{VREF}}{\text{KB1}} \right] \)

OPTIMIZED GAINS

\( A_1 / D = \text{PLO}_0 \)

KB1 = 3.4
KB2 = 0.0034

OVERFLOW

\( |A|/D| \geq 16 \)

(\( A / D \) IS NOW SCALED 2⁻⁴)

(QUICK EXIT FOR OVERFLOW)

\( |\text{SH29}| = \text{SOMAXL/D} \)

\( \text{SH29} < \text{SOMAXL/D} \)

\( \text{SH29} \)

\( \text{NEXT 1} \)

\( \text{L/D} = \text{L/D}_0 + \Delta L/D \)

\( \Delta L/D = \text{PDL OOD LIMIT GAINS}
\text{FOR LARGE COMMANDS} \)

\( \text{L/D} = \text{L/D}_0 + \Delta L/D \)

(GOOD RESCALED TO 2⁻⁴ BEFORE ADDITION)
ENTRY FROM RANGER

SAVE OLD VALUE OF DIFF FOR NEXT PASS THROUGH HUNTEST.
SET Q7 TO NOMINAL Q7F VALUE

ENTRY FROM HUNTEST

RESET MODE FOR HUNTEST
IN CASE ITERATION WAS DONE

TURN OFF GRP4 IN CASE HUNTEST ITERATED

ENTRY FROM INITROLL

CLEAR OVF1 INDICATOR

COMPONENTS DF DESIRED L/D
\( C/D0 = \frac{\text{INITROLL}}{D0} \)

\( D0 = \text{DESIRED DRAG} \)

\( K2D = C17 = -0.02 \)

ENTRY FROM DOWNCNTL, DREF IN MPAC

CALCULATE DESIRED L/D
DESIRED DRAG LEVEL IN MPAC

\( K1D = C16 = 0.01 \)

NEXT SHEET
FROM PRECEDING SHEET

NEGTESTS

OVERFLOW?

IF \(|L/D| \geq 1\), USE MAXIMUM VALUE

L/D COMMAND

IF DRAG > C20 AND IF L/D NEG, LIFT UP
C20 = 210 FPS

00D = L/D

CLEAR LATSW

FORCE ROLL OVER THE TOP

NO

YES

ELLITL/D

SH29

NEGATIVE L/D, SET TO ZERO FOR LIFT UP
LUNAR ENTRY: COME HERE FROM UPCONTROL (P65) AND DO 3 AXIS ALTITUDE HOLD TO TRIM IF D < .05 g. ALSO ROLL C = 0 IF D < .05 g. OTHERWISE MAINTAIN SAME ROLL C.

SET UP KEPLER PHASE
ENTRY DISPLAYS
N22
R1: XXX.XX DEG DESIRED
R2: XXX.XX DEG GIMBAL
R3: XXX.XX DEG ANGLES
COMPUTED BY S62.3 (FC-2760)

SET VARIABLE ADDRESS TO
KEPLER PHASE

ORBITAL ENTRY: COME HERE FROM INITROLL IN P64 AND HOLD CONSTANT L/D UNTIL DRAG GREAT ENOUGH TO ENTER FINAL PHASE.

INITIALIZE P68

KEP

P66

ESTABLISH P66 AND ENTRY DISPLAY (ENTRYVN)

FC-2760

GOTOADDR ← CADR(KEP2)

KEP2

q7f × Q7FKDMIN ?

YES

ENTER FINAL PHASE

q7FKDMIN = 8.5 FPSS

NO

IN BALLISTIC FLIGHT

YES

.05gSW SET ?

NO

FOR ENTRY DAP

ROLL C ← 0

ROLL HOLD ← 0

IF D < .05 g, SET ROLL COMMAND TO 0, OTHERWISE LEAVE IT ALONE. (FOR BACK-UP PROCEDURES)

P62.3

COMPUTE DESIRED GIMBAL ANGLES FOR TRIM ENTRY AND EXIT VIA ENTRY DISPLAY (ENDEXIT)

FC-2760

(CAUSE S62.3 TO EXIT TO ENDEXIT; AS SHOWN BELOW)

OUTPUT:

CPhi1, +1, +2 DESIRED GIMBAL ANGLES FOR NON 22 DISPLAY VIA ENTRYVN
<table>
<thead>
<tr>
<th>$V_{\text{REF}}$ (FPS)</th>
<th>$\Delta R/\Delta d$ (NM/FPS)</th>
<th>$-\Delta R/\Delta \dot{R}$ (NM/FPS)</th>
<th>$\dot{R}_{\text{REF}}$ (FPS)</th>
<th>$R_{1000}$ (NM)</th>
<th>$-\Delta R_{\text{REF}}$ (FPSS)</th>
<th>$\Delta R/\Delta dL/D$ (NM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2103</td>
<td>.0555</td>
<td>-0.0039</td>
<td>-0.719</td>
<td>26.6</td>
<td>10.4</td>
<td>-60.0</td>
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<tr>
<td>3022</td>
<td>.00703</td>
<td>0.00703</td>
<td>0.00703</td>
<td>26.6</td>
<td>25.6</td>
<td>-61.5</td>
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<tr>
<td>6295</td>
<td>.1410</td>
<td>0.01410</td>
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<td>46.3</td>
<td>-93.9</td>
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<td>9531</td>
<td>.178</td>
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<td>75.4</td>
<td>-98.5</td>
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<td>10.01</td>
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<td>99.9</td>
<td>94.70</td>
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<tr>
<td>14.014</td>
<td>.06139</td>
<td>0.06139</td>
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<td>170.9</td>
<td>187.44</td>
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<td>18.05</td>
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<td>20.819</td>
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<tr>
<td>VREF+12:35000</td>
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<td>0.3046</td>
<td>26.6</td>
<td>794.3</td>
<td>1508</td>
</tr>
</tbody>
</table>

This table is stored sequentially beginning at location "VREF".

$V_{\text{REF}} =$ velocity, the independent variable
$\Delta R/\Delta d =$ change in range vs. change in atmospheric drag
$-\Delta R/\Delta \dot{R} =$ change in range vs. change in altitude rate (negated)
$\dot{R}_{\text{REF}} =$ altitude rate of reference trajectory
$R_{1000} =$ range to 50G of reference trajectory
$-\Delta R_{\text{REF}} =$ atmospheric drag of reference trajectory
$\Delta R/\Delta dL/D =$ change in range vs. change in lift/drag

Selection of the tabulated values is by index. An index parameter "jj" is set to the location of the appropriate velocity value. The location of the corresponding $\Delta R/\Delta d$ is $jj + 13$; of $-\Delta R/\Delta \dot{R}$ is $jj + 26$; etc.

For instance: if $v = 14014$, $jj = 6$ since $V_{\text{REF}} = 14014$. Then $\Delta R/\Delta d = V_{\text{REF}} + 13 + 6 = .3305$;
$-\Delta R/\Delta \dot{R} = V_{\text{REF}} + 26 + 6 = .06139$; $\dot{R}_{\text{REF}} = V_{\text{REF}} + 39 + 6 = .352$; $R_{1000} = V_{\text{REF}} + 52 + 6 = 170.9$;
$\Delta R_{\text{REF}} = V_{\text{REF}} + 54 + 6 = 119.7$; and $\Delta R/\Delta dL/D = V_{\text{REF}} + 78 + 6 = 329.4$

In practice, $v$ generally falls between two tabulated values. Linear interpolation is then used in the table for each of the parameters.
FROM PRECEDING SHEET

GONEBY SET?

NO

HAVDRNG

DNRNGERR - MAXRNG

SET GONEPAST

MAXRNG YIELDS 9990.9 NM ON DSKY

DNRNGERR - MPAC

GONEGLAD

SH29

MPAC - (4 - DNRNGERR) / FX

FX - R/D - L/D REFERENCE USE MAXIMUM L/D

( NOTE: AT THIS POINT, FX1 CONTAINS +0 )

MPAC - 1.0

NO

MPAC = LOD + MPAC

GOMAXL/D

SH29

MPAC - 1.0

YES, |DNRNGERR| ≥ FX/4

NO

L/D - MPAC

GLIMITER

SH29

L/D = LOD + 4( THETAH - PREDANG ) / FX
ENTER HERE FOR MAXIMUM NEGATIVE L/D IF PAST TARGET (CALLED FROM PREFINAL)

TAG FOR NEGATIVE L/D

ENTER HERE FOR MAXIMUM L/D, SIGN SPECIFIED BY SIGN(MPAC) (USES ROUTINE "SIGNMPAC")

IF MPAC > 0; ROLL COMMAND WILL = 0° (LIFT UP)

IF MPAC < 0; ROLL COMMAND WILL = 180° (LIFT DOWN)

ENTER HERE WITH CALCULATED L/D, SUBJECT TO THE TESTS WHICH FOLLOW

GMAX = 8.9

YES - 0 BUILD-UP IS EXCESSIVE, LIFT FULL UP REGARDLESS OF

PREVIOUS COMPUTATIONS

MPAC = ROOT + X = AMOUNT

BY WHICH ALT. RATE EXCEEDS

LIMIT (ROOT IS RES)

MPAC = \sqrt{2 HS GM \times S Q \times \text{VSQUARE}} 

MPAC < 0 ?

YES, LIFT UP TO REDUCE ALTITUDE RATE

GO TO SLAD

MPAC = LAD

STORE L/D

L/D = MPAC

LIMIT L/D

L/D1 = L/D COMMAND USED IN ROLL COMMAND CALCULATION

\sqrt{v^2}

NO

YES, PAST TARGET

GONEPAST SET

NO

L350

L355

LATITZ ERROR

LIMIT (DEADZONE) = Y = K.LAT.V^2 + LATBIAS N.M.

(DEADZONE GETS NARROWER TOWARDS END OF ENTRY AS VELOCITY DECREASES) LATBIAS = .41252961 N.M., BIAS TO PERMIT FEWER SWITCHES NEAR END OF MISSION.

NEXT SHEET
LATERAL LOGIC

WILL L/D RESULT IN A ROLL COMMAND WHOSE MAGNITUDE IS AWAY FROM 15° FULL LIFT UP OR DOWN?

NEARLY FULL UP OR DOWN LIFT IS DESIRED

IF A ROLL IN THE DIRECTION OF SIGN (K2 ROLL) WOULD REDUCE THE LATERAL ERROR, COMMAND A ± 15° ROLL DEVIATION FROM FULL LIFT. THE RESULTING L/D IS BARELY LESS THAN THE DESIRED L/D.

PLO₂ → Y/2 USE A DEAD ZONE HALF AS LARGE FOR THIS CASE

L/AIDS → L/D CMIN × SIGN (L/D)

WILL RESULT IN A ROLL COMMAND OF ± 15° OR 180° ± 15°.

IN DEADZONE

IN UP CONTROL; SUPPRESS LATERAL REVERSAL IF D > C21 (140 FPS)

CLEAR NOSWITCH

LATERAL ERROR EXCEEDS LIMIT; SWITCH SIGN OF ROLL

NEXT SHEET
FROM PRECEDING SHEET
L355

CLEAR
NO

SIGN
KROLL
COS
\( \frac{L/D_{19}}{LAD_0} \)

ROLL COMMAND FOR ENTRY AUTOPilot
(IF \( L/D_{19} \geq LAD_0 \))

SIGN
\( \frac{L/D_{19}}{LAD_0} \)

ENDEXIT

OVERNOUT

INTERPRETIVE ENTRY POINT

(BASIC ENTRY POINT)

ALL ENTRY PHASES
COME HERE FOR
DISPLAY AND
TERMINATION

NO OMIT DISPLAY
ENTRYOSP
SET

YES

DO ENTRY DISPLAY SPECIFIED BY
VERB-NOUN CODE IN "ENTRYYN" 
AS SET BY APPROPRIATE P60 PROGRAM
VOSNXX

REGOUSR
DISPLAY ENTRYYN

NO

INHINT

TO PROTECT SERVICER IN GRPS, SINCE IT
POSSIBLE TO COME HERE IN GRP4 (RESTARTED HUNT LOOP),
WE MUST ASSURE THAT A NEW SERVICER CYCLE
IS NOT WAITING BEFORE GOING TO SERVEXIT.

NEWJOB

YES, IS A NEW JOB WAITING ?

NO

STARTENT
AND P67.2
COME HERE

START NEW JOB

SERVEXIT

EXIT VIA NORMAL
SERVICER EXIT

P.M. Draft 8 Oct 68

COLOSSUS INC
FC-2770
<table>
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<th>Description</th>
<th>Page</th>
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</thead>
<tbody>
<tr>
<td>CM/DAPIC</td>
<td>ENTRY DAP START ROUTINE</td>
<td>SH. 4</td>
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<tr>
<td>CM/DAPON</td>
<td>RCS DAP ENTRY TO DAP CHANGEOVER ROUTINE</td>
<td>SH. 5</td>
</tr>
<tr>
<td>READGYMB</td>
<td>READ GIMBAL ANGLES</td>
<td>SH. 6</td>
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<tr>
<td>ATTRATES</td>
<td>INTRA-ATMOSPHERIC DAP</td>
<td>SH. 9</td>
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<tr>
<td>EXDAP</td>
<td>EXTRA-ATMOSPHERIC DAP</td>
<td>SH. 11</td>
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<tr>
<td>CM/RCS</td>
<td>ENTRY ROLL DAP</td>
<td>SH. 14</td>
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<td>CM/FDAI</td>
<td>FDAI ERROR DISPLAY AND DOWNLINK</td>
<td>SH. 20</td>
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<tr>
<td>BIASEDZ</td>
<td>ATTITUDE/RATE DEAD ZONE TEST</td>
<td>SH. 21</td>
</tr>
<tr>
<td>3DDZ</td>
<td>3 DEGREE ATTITUDE DEADZONE TEST</td>
<td>SH. 21</td>
</tr>
<tr>
<td>4D/SDZ</td>
<td>4 DEGREE/SEC RATE DEADZONE TEST</td>
<td>SH. 21</td>
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<tr>
<td>2D/SDZ</td>
<td>2 DEGREE/SEC RATE DEADZONE TEST</td>
<td>SH. 22</td>
</tr>
<tr>
<td>FLUSHJET</td>
<td>TURN OFF ALL RCS JETS</td>
<td>SH. 23</td>
</tr>
<tr>
<td>RATEAVG</td>
<td>AVERAGE RATE ROUTINE</td>
<td>SH. 23</td>
</tr>
<tr>
<td>ANGOVCOR</td>
<td>ANGLE OVERFLOW CORRECTION ROUTINE</td>
<td>SH. 23</td>
</tr>
<tr>
<td>SETJTAG</td>
<td>ENABLE ENTRY ROLL DAP</td>
<td>SH. 24</td>
</tr>
</tbody>
</table>

**PRELIMINARY**
ENTRY DAP START ROUTINE

START ENTRY DAP IN IDLE MODE TO INITIALIZE ATTITUDES AND RATES

CM/DAPIC Called in P62

INHIBIT INTERRUPTS

CM/DAP2C

\[ \text{JETEM-TIME1}[\text{PIPTIME+1}] \] \( \Delta \) TIME SINCE LAST PIPA UPDATE

\[ \text{IF JETEM IS NEG, RESULT OF FORCING OVERFLOW, TO TAKE CARE OF CASE} \]
\[ \text{JETEM+JETEM+2-OCT2000\# WHERE TIME1 OVERFLOWED SINCE PIPA READ} \]

\[ k = \text{JETEM} - 9 \]

PIPA UPDATE COMES EVERY 200CS. WE WANT DAP TO COME BETWEEN 50 INTERRUPTS WON'T COINCIDE

MAKE SURE DAP STARTS AS SOON AS POSSIBLE, WITHOUT SKIPPING A CYCLE

A MUST BE AT LEAST 1CS SINCE WAITLIST WILL NOT FUNCTION PROPERLY WITH A ZERO \( \Delta \) TIME FOR RESTART, \( \Delta \) TIME

CM/GYMDT+A

READSYM SCHEDULE IN
\[ [A] \text{ CSEC VIA WAITLIST} \]

SH6

CM/FLAGS:
CLEAR BIT 13
CLEAR BIT 12
CLEAR BIT 11
SET BIT 4
CLEAR BIT 3
SET BIT 2
CLEAR BIT 1

OMIT ENTRY DISPLAY
DAP IDLE
DON'T CALCULATE \( \gamma_e \) IN SERVICER
DOWN LIFT NOT INHIBITED
DRAG 0.05G
ENTRY DAP IS ON
ACDU'S AND BODY RATES NOT TO BE CALCULATED YET

\[ \text{BETA/100} \rightarrow 0 \]
SW/INDX \( \rightarrow 1 \)

YAW AXIS ATTITUDE
INITIALIZE DOWNLINK/ERROR DISPLAY ROUTINE (CM/FDAIR)

CM/GYMDT WAS SET ABOVE RELATIVE TO PIPA READ TIME. THIS RESTART SETS TBASE6 SO THAT READSYM WILL BE SCHEDULED FOR TIME (TBASE6+CM/GYMDT).
CM/GYMDT IS UPDATED WHEN CM/GYMDT RUNS;
TBASE6 IS UPDATED IN SERVICER TO PIPA READ TIME AND CM/GYMDT IS SET TO 5 CS.
(Phase change routine does release of interrupts)

GROUP 6:11
SET UP RESTARTS TO SCHEDULE RESTARTS AS A TASK IN CM/GYMDT.CS

GROUP 4
SET UP RESTARTS TO SCHEDULE NEXT LOCATION AS A JOB WITH PRIORITY 13

RETURN TO CALLER (P62)

P62.2 FC 2760
RCS DAP TO ENTRY DAP CHANGEOVER ROUTINE

STOP RCS DAP
PUT ENTRY DAP IN RUN MODE
ESTABLISH ATTITUDE HOLD

CM/DAPON CALLED IN PG2
(WITH INTERRUPT, INHIBITED)

CLEAR BITS
DAPBIT1, DAPBIT2

RCS DAP AND TWC DAP NOT ON
(FLAGS FOR RESTART OF T6 RUPT)

TSLOC+2CADR(T51DLOC)
TSLOC+2CADR(T51DLOC)

STOP RCS-DAP CALLS
(BOTH RUPTS WILL
SIMPLY GO DIRECTLY
TO RESUME)

SELF CHANGS AND CHANGS

SET CONFIGURATION BITS OF NOUN 46 TO ZERO
FOR ENTRY DAP

HAS CM/POSE RUN FOR
FIRST TIME YET?

WAIT UNTIL CM/POSE
UPDATES ATTITUDES
FOR 1ST TIME

NO

NOT YET

DELAY JOB
WAIT .5 SECS
FC-2070

YES

RCSFLAGS = -1
PSLAG = 0
PAXERR = 0

INHIBIT
INTERUPTS

PITCH COMMAND
YAW COMMAND
ROLL COMMAND

ALFACOM = ALFA/180
BETACOM = BETA/180
ROLLHOLD = ROLL/180
ROLLC = ROLL/180

SET ATTITUDE COMMANDS TO PRESENT ATTITUDES
TO ESTABLISH ATTITUDE HOLD UNTIL ENTRY
GUIDANCE ISSUES CONTROL COMMANDS
(ROLLC IS AUTOPILOT ROLL COMMAND, SCALED
AT 1 REV.)

PUT DAP IN RUN MODE
INHIBIT V37 ENTRIES (NO MODE CHANGES FROM
NOW TO END OF FLIGHT EXCEPT P00)

RETURN TO CALLER (PG2)
CALCULATION OF RATES IN BODY CO-ORDS.

FROM PRECEDING SHEET

\[
\text{JETEM}_p = \left((-\sin \phi \cdot \Delta \text{LAM}) + (\cos \phi \cdot \cos \Theta \cdot \Delta \text{LAT})\right) / \text{OLDELQ} - \text{OLDELQ} + \text{JETEM}
\]

\[\Delta \text{PITCH} = \dot{\phi} \sin \phi + \ddot{\phi} \cos \phi \cos \Theta \]

SAVE FOR NEXT CYCLE

INPUT: \( \dot{\phi}, \Theta, \Delta \text{PITCH VALUE} \) IN REV/SEC AT \( 2^{-1} \)

JETEM, \( \dot{\phi}, \Delta \text{PITCH VALUE} \)

OUTPUT: \( \dot{\phi} \), \( \dot{\Theta} \)

PITCH AXIS ANGULAR RATE IN REV/SEC AT \( 10^{-2} \)

(1.E. REV/SEC AT 180 DEG.)

\[\Delta \text{YAW} = \dot{\phi} \cos \phi - \ddot{\phi} \cos \Theta \sin \phi \]

SAVE FOR NEXT CYCLE

\[
\text{JETEM} = \left((-\cos \phi \cdot \Delta \text{LAM}) + (\sin \phi \cdot \Delta \text{LAT})\right) / \text{OLDELQ} - \text{OLDELQ} + \text{JETEM}
\]

YAW AXIS ANGULAR RATE IN REV/SEC AT \( 2^{-1} \)

\[\sin \psi \text{ (NEEDED TO COMPUTE ROLL RATE)}\]

\[
\text{JETEM} = \left(-\Delta \text{LAT} + (\sin \psi \cdot \Delta \text{LAM})\right) / \text{OLDELQ} - \text{OLDELQ} + \text{JETEM}
\]

\[\Delta \text{ROLL} = \dot{\phi} + \ddot{\psi} \sin \psi \]

SAVE FOR NEXT CYCLE

\[
\text{JETEM} = \left((-\Delta \text{LAT} + (\sin \psi \cdot \Delta \text{LAM})\right) / \text{OLDELQ} - \text{OLDELQ} + \text{JETEM}
\]

ROLL AXIS ANGULAR RATE IN REV/SEC AT \( 2^{-1} \)

\[\text{GAMMA IS ANGLE BETWEEN S/C VELOCITY VECTOR AND THE LOCAL HORIZON. GAMMDOT IS THE CHANGE IN THIS ANGLE, CALCULATED IN CM BODY ATTITUDE ROUTINE (FC 2770)}\]

\[\text{ROLL/GO = ROLL AXIS ATTITUDE}
\]

\[\text{SINTRIM} = -\sin \alpha \]

\[\text{COSTRIM} = \cos \alpha \]

WHERE \( \alpha \) IS THE TRIM ANGLE NOMINAL VALUE, -20°

YES

GAMMDOT = \( \dot{\psi} \text{ (\$0)} \)

NO (\( \#0 \))

\[\text{JETEM}_{+1} = \text{GAMMDOT} \cdot \sin \left(\text{ROLL}/180\right)\]

\[\text{PREL} = \text{PREL} + \text{SINTRIM} \cdot \left(\text{JETEM}_{+1}\right)\]

\[\text{GREL} = \text{GREL} - \text{GAMMDOT} \cdot \cos \left(\text{ROLL}/180\right)\]

\[\text{RREL} = \text{RREL} - \text{COSTRIM} \cdot \left(\text{JETEM}_{+1}\right)\]

NOGAMMDOT

IS DAP ARMED?

YES, GO ON

CMDAPARM

SET?

YES, GO ON

TO NEXT SHEET

---

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APOLLO GUIDANCE AND NAVIGATION

ENTRY DIGITAL AUTOPilot

COLOSSUS

SHEET 7 OF 24
FROM PRECEDING SHEET

ATTRATES
SCHEDULE
IN PERIOD
VIA TO RUMP
SH. B

TASKOVER

SCHEDULE CALCULATION OF ATTITUDES, AND
CALCULATION AND EXECUTION OF JET COMMANDS

END OF ATTITUDE
AND RATE CALCULATIONS
INTRA ATMOSPHERIC DAP

PITCH AND YAW RATE DAMPING

ENTRY FROM T5RUP
SCHEDULED IN READGMB, SH.8

SAVE REGISTERS FOR INTERRUPTED JOB

SAVE CONTENTS OF SHIFT REGISTER AND DOUBLE TO COMPENSATE FOR AUTOMATIC RIGHT SHIFT ON READ IN

RATE AND ATTITUDE UPDATE:

\[
\begin{align*}
\alpha &= \delta + \theta \\
&= \text{pitch angle (angle of attack)} \\
\cos \alpha &= \text{cos} \\
\sin \alpha &= \text{sin} \\
\phi &= \delta \cos \alpha + \theta \sin \alpha \\
&= \text{roll rate} \\
\beta &= \delta \cos \alpha - \theta \sin \alpha \\
&= \text{yaw rate} \\
\psi &= \phi \sin \beta \\
&= \text{yaw attitude} \\
\chi &= \phi \cos \beta \\
&= \text{pitch attitude, biased} \\
\epsilon &= \chi - \theta \\
&= \text{pitch attitude error} \\
\gamma &= \psi + \phi \\
&= \text{roll attitude}
\end{align*}
\]

IS DRAG > .08 G?
YES
NO; OUT OF ATMOSPHERE

DO EXTRA ATMOSPHERIC ENTRY DAP - ATTITUDE AND RATE CONTROL IN 3 AXES

(FLAG IS SET/CLEARED IN RE-ENTRY CONTROL)

CMDAPMOD ← 1

EXDAP ← 11

IN ATMOSPHERE

ZERO PITCH AND YAW ERROR DISPLAYS

A ← \delta \tan |\alpha| \text{ biased yaw rate for co-ordinated roll}

INPUT: A = rate (yaw axis)

OUTPUT: A = +1 if rate > 2°/sec
A = -1 if rate < -2°/sec
A = 0 if -2°/sec ≤ rate ≤ 2°/sec (in dead zone)

JET COMMAND WORD FOR YAW (CHAN 5)

OCT 120 ⇒ JETS 5 AND 7
OCT 240 ⇒ JETS 6 AND 8

+YAW JETS ← 1

-JAY JETS ← 1

JETEM ← OCT 120

JETEN ← 0

JETEM ← OCT 240

A ← QREL

PITCH RATE

2D/5D2

TEST RATE DEAD ZONE

SH.52

TO NEXT SHEET
FROM PRECEDING SHEET

RETURN POINT FROM EXTRA-ATMOSPHERIC ENTRY DAP WITH PITCH CODE IN A (SEE SH.9)

+PITCH JETS

EXDAPIN

TEST A

0

JETEM ← JETEM + OCT5
JETEM ← JETEM + OCT12

-PITCH JETS

ADD IN PITCH COMMANDS (CHAN 6)

OCT 5 → JETS 1 AND 3
OCT 12 → JETS 2 AND 4

(+ PITCH)

(- PITCH)

PYJETS ← JETEM

(PYJETS ← CHAN 5)

TURN ON PITCH AND YAW JETS

<0, NO

TIME FOR ROLL DAP?

>0, YES

TEST JETAG ?

+0, NO

CM/FDAI-1
SH.20

UPDATE ERROR DISPLAY AND DOWNLINK

CM/FDAI-1
SH.20

CM/RCS
SH.16

DO ENTRY ROLL DAP, THEN UPDATE DISPLAY AND DOWNLINK
EXTRA ATMOSPHERIC DAP

EXDAP

CMDAPMOD

(\theta = \pi \text{ FROM ATTRATES})

\text{INDICATES OUT OF ATMOSPHERE WITH |\theta| < 45^\circ}

\text{WILL LATER BE SET TO \text{\(-0\) IF |\theta| < 135^\circ,}}

\text{OR \text{\(+0\) IF 45^\circ < |\theta| < 135^\circ).}}

JETEM + 1 = \text{BETACOM - \text{BETA/100}}

\text{YAW AXIS ATTITUDE ERROR (COMMANDED-OBSERVED ANGLE)}

CALPA \leq 45^\circ ?

\text{YES}

\text{DO AUTOPILOT WITH PITCH AND ROLL EXCHANGED}

\text{NO}

CALPA > 45^\circ ?

\text{YES}

\text{WILL BE \text{\(+0\) ONLY ON FIRST PASS AFTER |\theta| BECOMES LESS THAN 45^\circ}}

\text{GROUP 4.33}

\text{SET UP RESTARTS TO SCHEDULE WAKE P62 AS A WAITLIST TASK IN 21 SECS}

\text{TBAS4 \text{= TIME}}

\text{P63FLAG = -1}

\text{WAKE P62 WAITLIST TASK IN 21 SECONDS}

\text{FC 2760}

\text{EXDAP4}

\text{IF JETAG = \text{-1}, THIS IS THE FIRST PASS SINCE EXDAP2 WAS RUN}

\text{ROLLJETS}

\text{STOP THE ROLL JETS STARTED IN EXDAP2 (ROLLJETS = CHNG)}

\text{JETAG \rightarrow 0}

\text{RESTORE PROPER VALUE; \text{\(+0\) INDICATES ROLL DAP IS NOT TO RUN}}

\text{TO NEXT SHEET}
FROM PRECEDING SHEET

EXDAP3

CALFA < 0 ?

YES

|X| > 135° (NORMALLY ONLY AT BEGINNING OF INITIAL MANEUVER)

CMDAPMOD ← 0

A ← RAXERR

NO

CMDAPMOD = ±2

A ← BETADOT

YAW RATE (BETADOT IS MORE PRECISE VALUE IF X < 25°, OTHERWISE USE RREL)
(BETADOT IS LOCATION RREL + 1)

INPUTS: RATE IN A, ATTITUDE ERROR IN L (AERR)
OUTPUT: L = 0 IF |AERR| ≤ 3° OR |RATE| = 4°/SEC
L = -1 IF AERR > 3° AND |RATE| = 4°/SEC
L = +1 IF AERR < -3° AND |RATE| = 4°/SEC
A = +0 IF |RATE| = 2°/SEC
A = +1 IF RATE > 2°/SEC
A = -1 IF RATE < -2°/SEC

BIASED2

TEST ATTITUDE RATE DEAD-ZONE

SH=21

POSITIVE JETS = 1

TEST AVL

NO

0 JETS

JETEM = OCT 120

JETEM = O

JETEM = OCT 240

+1 NEGATIVE JETS

SUM WILL BE 0 IN DEADZONE, NONZERO OUTSIDE:

OCT 240 → JETS 6+8 (-YAW)
OCT 120 → JETS 5+7 (+YAW)

L ← QAXERR

A ← OREL

PITCH ATTITUDE ERROR
PITCH RATE

BIASED2

TEST ATTITUDE RATE DEAD-ZONE

SH=21

A ← AVL

EXDAPIN

SH=10

RETURN TO ENTRY DAP TO EXECUTE COMMANDS, AND CALL ROLL DAP IF NECESSARY.
IF $45^\circ < |\alpha| < 135^\circ$ COME HERE, EXCHANGE ROLL AND YAW, PROVIDE ROLL CONTROL

INDICATE $45^\circ < |\alpha| < 135^\circ$, AND THAT ROLL DAP SHOULD NOT BE CALLED TO SIGNAL EXDAPZ HAS RUN (TESTED IN EXDAP 4, SH8).

IF WAKE P62 HAS NOT BEEN RUN, SET P63 FLAG TO 0 SO WAKE P62 WILL BE RUN WHEN $\alpha$ BECOMES $45^\circ$.

$(\alpha = \sin(\alpha))$ Since $|\alpha|$ IS IN THE RANGE $45^\circ$ TO $135^\circ$, $\alpha$ CANNOT BE 0.

ROLL ERROR = COMPLEMENT IF $\alpha$ IS IN RANGE $+45^\circ$ TO $+135^\circ$ SINCE + YAW IN TRAJECTORY TRIAD $= -$ ROLL FOR E/C

INPUT FOR DEADZONE ROUTINE
(SCALED FOR ERROR DISPLAY ROUTINE)

ROLL RATE = COMPLEMENT IF $\alpha$ IS IN RANGE $+45^\circ$ TO $+135^\circ$

INPUTS: RATE IN $\alpha$, ATTITUDE ERROR IN $L$ (AERR)
OUTPUT: $L = 0$ IF $|AERR| \leq 3^\circ$ OR $|ROR| \leq 4^\circ$/SEC
$L = -1$ IF $AERR > 3^\circ$ AND $|ROR| \leq 4^\circ$/SEC
$L = +1$ IF $AERR < 3^\circ$ AND $|ROR| > 4^\circ$/SEC
$A = +0$ IF $|ROR| < 2^\circ$/SEC
$A = +1$ IF $ROR > 2^\circ$/SEC
$A = -1$ IF $ROR < -2^\circ$/SEC

ROLL JET CODE:
OCT12 : JETS 10 + 12 ; (-ROLL)
OCT5 : JETS 9 + 11 ; (+ROLL)
0 : NO JETS

ROLLJETS = CHAN 6
TURN ON ROLL JETS

L = ROLLHOLD - ROLL/180
YAW ATTITUDE ERROR

COIPL $= \text{TEST ROLL FA}$
COMPLEMENT IF $\alpha$ IS IN RANGE $-135^\circ$ TO $-45^\circ$ SINCE + ROLL IN TRAJECTORY TRIAD $= -$ YAW FOR E/C

RETURN FOR YAW JETS AND PITCH CONTROL

---

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APOLLO GUIDANCE AND NAVIGATION
ENTRY DIGITAL AUTOPILOT

COLOSSUS FC 2780

DOCUMENT NO.

REV SHEET 13 OF 24
ENTRY ROLL DAP

CM/RC

JUNTX+1

-VT/180-L-400-PERL
SR=ROLL/180

SET FOR NEGATIVE 1ST BURN ROLL JETS NOW, CHANGE LATER IF NECESSARY

ROLL RATE X 2 SEC IN REV'S AT 2^-2
(TO SCALE 360') SR=SHIFT RIGHT REGISTER

IS ROLL OVER THE TOP ENFORCED?

YES

NO; TAKE SHORTEST PATH

GETLCX

LCX/360+ROLLC+SR
-L/VT/180-L/VT/180=1864A

ROLL ATT. ERROR IN CALFA

L = SIGMA(V) / 360A^2 (°)

(V) = (A=4.55 ACCELERATION OF ONE JET IN DEG/SEC^2

(T^2/2=4)

LCX/360+ROLLC+SR

ROLL ATTITUDE ERROR = ROLL COMMAND - ROLL ATTITUDE

A=2A_1 t^2 - COS(K) x

TRTAGPI

OVERFLOW

OVERFLOW

IF STATE WOULD PASS OUTSIDE OF SHORTEST PATH CONTOUR, SHIFT ORIGIN BY 360° TO CAUSE ROLL OVER THE TOP

COMPAT

LCX/360+LCX/360+CALFA

COMPENSATE FOR ASSUMED TRIM ANGLE (COSTRIM = COS(°))

[A>4.5] RATE DAMPING ONLY

ZERO ATT. ERROR

0

EXIT, ROLL AXIS WAS DONE > 0 IN EXTRA ATMOSPHERE DAP

LCX/360+?

ERROR = LCX/360

+API/4

SR = (-VT/180)

-VT/180 = (-VT/180)

VSQ/4API = (-VT/180)^2 - 180/BATT

SAVE FOR ERROR DISPLAY SCALE 180° FOR PHASE PLANE LOGIC

SCALE FOR DOWNTIME EQUATION OF TERMINAL TRAJECTORY,

A = 2 JET ACCELERATION

WHICHALF

IN TOP HALF OF PHASE PLANE CO

IN BOTTOM HALF OF PHASE PLANE

ON X AXIS

A = LCX/360 - 2VSQ/4API - BUFLIM

TO NEXT SHEET
FROM PRECEDING SHEET

GETON2

TON2=180/BATT*4(VDT/180)

SECOND BURN TIME $T = \frac{AV}{A}$ (TIME FROM INTERCEPT OF PARABOLA TO ORIGIN)

YES

TON2=0

THRUST OTHER WAY

NO

GETOFF

$\frac{XD}{360} = \frac{-(VDT/180) \cdot TON2}{\Delta ANGLE DURING SECOND BURN (TEMP STORAGE)}$

YES, DON'T TRY TO DIVIDE

VDT/180 = 0

NO

L=TON2 (-VT/180 - VDT/180) + XD/360 + L cx/360

A=0

A,L = $\frac{A}{VDT/180}$

NO, DIVIDE OVERFLOW

YES

A=0

DIVIDE WILL NOT OVERFLOW SINCE THE RESULT WAS ZERO, THE REMAINDER IN L IS NOW EQUAL TO THE ORIGINAL NUMERATOR

TOFFOVL

A = 2JETT

IN CS AT 2^14

LONG ENOUGH TO ASSURE DRIFT FOR FULL 2 SEC.

GETOFFZ

$2JETT = 400$ AT 2^14: 1 AT 2^14

DIVISION FOR REAL THIS TIME

RESULTS IN CS, SCALED AT 2^14

TIMSCAL

TOFF = A

NEXT SHEET
FROM PRECEDING SHEET

TON1, TON2 COMPUTED IN C.S. SCALED AT 400 AND FOR 4 JETS JETS 2 AT 2^16/400, SO NOW: 2 JET TIME IN C.S. AT 2^16

SO ROLL DAP WILL NOT RUN AGAIN UNTIL SERVICER RESETS THE FLAG TO + INITIALIZES DOWN LINK ROUTINE (CM/FDAIR) TO START AT THE TOP OF THE LIST

TIMETST

TUSED = TUSED + TIME1 - 203CS

TUSEO = OLD T1 (FROM SJUTAG), NOW CONTAINS A TIME = 203CS.

IF TUSED IS NEG, TUSED = TUSED + 2^2020000

RESULT OF FORCING OVERFLOW (SEE SH4 FOR FURTHER EXPLANATION)

TOO SHORT, SUPPRESS 1ST BURN

YES

TON1SEC?

NO

-ROLL

TEST

+1

JVDX?

0

TIBITS = OCT 5

TIBITS = 0

TIBIM = OCT 12

JET CODE FOR 1ST BURN (CHANG)

OCT 12 = JETS 10 AND 12 (-ROLL)

OCT 5 = JETS 9 AND 11 (+ROLL)

TIMETST1

TUSEO = TUSEO + TON1

TIME REMAINING IN 2 SEC PERIOD AFTER FIRST BURN

TON1 = 1

SKIP 1ST BURN

YES, TON1 TOO LONG FOR 1 CYCLE

TUSED > 0?

NO

TOPFTEST

TOO SHORT, SUPPRESS QUIESCENT PERIOD

YES

TOFFS 2CS?

NO

TIMETST2

SKIP DRIFT PERIOD

TIME REMAINING IN 2 SEC PERIOD AFTER DRIFT TIME

TUSEO = TUSED + TOFF

NEXT SHEET

A = -1

(A TIME OF 0 MEANS THE BURN OR DRIFT PERIOD EXTENDS TO THE END OF THE 2 SEC. ROLL DAP CYCLE TIME)

(A NEGATIVE TIME MEANS SKIP THE BURN OR DRIFT PERIOD ENTIRELY AND GO ON TO THE NEXT (IF ANY) AT ONCE)
FROM PRECEDING SHEET

TOFF TOO LONG FOR 1 CYCLE
YES
A ← 0
NO
TUSED ≥ 0

TONZ ≥ 2CS.?
YES
TOFF ← A
NO
TONZ < 2CS, SUPPRESS 2ND BURN

+ ROLL
TEST UNDXresh)_1_0
- ROLL

T2BITS ← OCT5
T2BITS ← OCT12
JET CODE FOR 2ND BURN

TUSED ← TUSED + TONZ

TONZ TOO LONG FOR 1 CYCLE
YES
TONE ← 0
NO
TUSED > 0

JETCALLS
SN19

AT THIS POINT ALL JET-ON TIMES AND DRIFT TIME WHICH WILL FIT INTO WHAT REMAINS OF THE 2 SEC ROLL DAP PERIOD HAVE BEEN SET UP, AND THE REST SUPPRESSED, SINCE THEY WILL BE RE-COMPUTED IN THE NEXT CYCLE OF THE ROLL DAP.
When 2 sec. roll DAP is operating, get roll error between updates by interpolation. (\( \alpha_{\text{LAT}} = \cos \phi \))

\[ \alpha_{\text{LAT}} + \alpha_{\text{LAT}} = \frac{1}{\phi} \alpha_{\text{LAT}} \]

\[ \alpha_{\text{LAT}} = \text{input for pitch error} \]

Needle drive rescale to 560°

Alternate paths

\[ \text{SW/NDX} - \text{SW/NDX} \leq 0 ? \]

Yes

\[ \text{CM/TMFILE} \]

No, recycle list

\[ \text{CM/END} \]

\[ 5R - \frac{1}{2} \text{CM/SAVE} \]

\[ T_S \text{LOC} - 2 \text{ADR} \times (T_S \text{IDLOC}) \]

Resume

End of entry DAP

Downlink list will contain:

\[ \text{UPBUFF} = 2: \text{CM/TMTIME} \]

- 3: SW/NDX
- 4: PREL
- 5: GREL
- 6: PREL
- 7: GREL (2 sec later)
- 8: GREL (2 sec later)
- 9: PREL

So at any instant, the list will contain 5 sets of rates, spanning the last 1 sec. of operation of the entry DAP. SW/NDX will show the location of the most recent set, and CM/TM TIME the time of the most recent set.
DEADZONE TEST ROUTINE

ENTRY FOR ATTITUDE RATE DEADZONE
ATTITUDE ERROR IN L, RATE IN A

BIASEDP

JETEM2+A

SAVE RATE

<0

A=L+CM/BIAS

TEST A

>0

A=L-CM/BIAS

BIAS FOR HYSTERESIS EFFECT:
BIAS ATTITUDE ERROR BY -6° SIGN (RATE)
(CM/BIAS = .6°)

SAVE Q IN L

SAVE FOR ULTIMATE RETURN TO CALLER

3DDDZ

<0

A=|A|+YAWLIM

TEST A

>0

A=|A|-YAWLIM

YAWLIM IS CHosen so this will OvERFLOW IF |A| > 3.6°
(9.6° = 3.6° + BIAS)

OZCOM

OZNOCOM

A=±A

COMPLEMENT 50 + ERROR out of OZ
WILL PRODUCE - TAG in CASE of OVERFLOW

OUT OF OZ, - ERROR

OUT OF OZ, + ERROR

(OVERFLOW tag created by DUMMY TS INSTRUCTION)
if ERROR > 3°, A = -1
if ERROR < -3°, A = +1
if |ERROR| < 3°, A = +0

TEST OVERFLOW

+OVFL

NONE IN OZ

A=+1

A=0

RETURN VIA Q

Q=L

L=A

RESTORE RETURN ADDRESS OF CALLER
SAVE ATTITUDE DEADZONE TAG

40/SDZ

4°/SEC RATE DEADZONE TEST

YES

JETEM2 = 0?

NO

A=0

A=|JETEM2|+440/SLIM

40/SLIM so that this will OVERFLOW IF |JETEM2| > 4°

TO NEXT SHEET

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FROM PRECEDING SHEET

TEST OVERFLOW?

NO

A = JETM2

TEST RATE

IF |RATE| > 4°, IGNORE ATTITUDE ERROR, SET TAG = 0.

RATE

TEST 2.7SEC RATE DEADZONE

RATE IN A

20/SD2

<0

A = |A| - 1 + YDOTLIM

>0

A = |A| + 1 + YDOTLIM

OVERFLOW IF |RATE| > 2°

NEGATIVE TAG IF OVERFLOW WITH NEGATIVE RATE

DZCOM

A = -A

DZNCOM

- OVEL

TEST OVERFLOW

+ OVEL

A = -1

A = 0

A = 1

RETURN VIA Q

PHASE PLANE LOGIC

RATE ERROR

4°/SEC

2°/SEC

BIASED ATTITUDE ERROR

+1, 0 +1, 0 +1, 0 +1, 0

+1, 1 +1, 1 +1, 1 +1, 1

0, 1 0, 0 0, 0 0, 0

0, 1 0, 0 0, 0 0, 0

0, -1 0, -1 0, -1 0, -1

-1, 1 -1, 1 -1, 1 -1, 1

-1, 0 -1, 0 -1, 0 -1, 0

-3°

TAGS GIVEN IN FORM A, L.

IF SUM OF TAGS = 0, STATE IS IN DEADZONE.

ABOVE OR TO THE LEFT, SUM > 0;
NEGATIVE JETS FIRED.

BELOW OR TO THE RIGHT, SUM < 0;
POSITIVE JETS FIRED.
**JET TURN OFF ROUTINE**

1. FLUSHJET
2. ROLLJETS=0
3. PYJETS=0
4. CHANNEL 4
5. CHANNEL 5
6. TURN OFF ALL RCS JETS
7. RETURN VIA Q

**AVERAGE RATE ROUTINE**

1. RATE AVG
2. ESTIMATE AVERAGE RATE ASSUMING CONSTANT ACCELERATION
3. \( \Delta \theta = \text{OLD RATE} \cdot \Delta T \\
    JETEM = \text{NEW RATE} \cdot \Delta T \\
    \text{RATE} = \frac{\Delta \theta_1 - \Delta \theta_2}{2} \)
4. A=JETEM+\frac{1}{2}(JETEM-A)
5. RETURN VIA Q

**ANGLE OVERFLOW CORRECTION ROUTINE**

1. ANGOCOR
2. CORRECT FOR OVERFLOW ON ANGLE COMPUTATIONS
3. A = RESULT, WITH POSSIBLE OVERFLOW.
4. ANGLES SCALED 180°
5. OVERFLOW (L=POS MAX + 180°)
6. OVERFLOW (L=POS MAX - 180°)
7. L=A
8. L=A+180°
9. L=A-180°
10. A=RESULT, CORRECTED FOR OVERFLOW (i.e., expressed in the range \(-180° \leq A \leq 180°\))
**Routine to Enable Entry Roll Dap**

1. SET JTAG
2. **Saved Current Time for Use by Entry Roll Dap**
3. JTAG = 1
4. **Entry Roll Dap to Be Done in Next Cycle of Entry Dap (see SH.7)**
5. GROUP 1.0
6. **Don't Restart Group 1 (SET JTAG Was Protected in Group 1.3 by Servicer)**
7. KILL GROUP 1 RESTARTS
8. TASKOVER
ACCMP FC-2300 Orbital Integration ENTRY 9
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MRUPTFLG FC-2070 Service Routines C-6
MXM3 FC-2340 R60 Attitude Maneuver CALLED 6,7
PC-2350 Maneuver Calculations and Steering ENTRY 25
NBONLY FC-2060 Waitlist CALLED 20
NBSM FC-2550 P20 Rendezvous Navigation CALLED 38
FC-2730 R52, R53, R56 CALLED 13
NEEDPLG FC-2380 DAP Interface Initialization and Phase I
NFEDLER FC-2370 DAP Interface and Service Routines ENTRY 20
FC-2380 DAP Interface Initialization and Phase I CALLED 5
FC-2430 TVC Start-up, Executive, and Service Routines CALLED 7,11
FC-2460 Roll Autopilot CALLED 5
FC-2540 P11 Earth Orbit Insertation Monitor CALLED 4,16,17,20,21
NEEDLES3 FC-2370 DAP Interface and Service Routines S-19 C-18
NFEDLPLG FC-2370 DAP Interface and Service Routines S-19 C-18
FC-2070 Service Routines C-6
FC-2690 Thrust Programs (P40, P41) S-12,13 C-12
FC-2310 Conic Subroutines ENTRY 21
NFWPFLG FC-2290 Integration Initialization S-8
FC-2300 Orbital Integration C-6 T-6
FC-2070 Service Routines C-6
NFWMODFA FC-2020 Fresh Start and Restart CALLED 42
FC-2030 Phase Table Maintenance ENTRY 2
FMODFA FC-2540 P11 Earth Orbit Insertation Monitor CALLED 4
FC-2030 Phase Table Maintenance ENTRY 2
FC-2760 P60's Entry Programs CALLED 5,10,12,13,15,16
NEWPHASE FC-2030 Phase Table Maintenance ENTRY 4
NEWSTATE FC-2310 Conic Subroutines ENTRY 35
NEPXCOL FC-2300 Orbital Integration ENTRY 35
NJETSFLG FC-2370 DAP Interface and Service Routines S-15 C-15
FC-2070 Service Routines C-6
FC-2642 P37 Return To Earth T-11
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NOCACY FC-2400 RCS DAP Jet Selection Logic ENTRY 8
NOATTOFF FC-2200 TURPT CALLED 34,35
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NODUPFLG FC-2290 Integration Initialization S-3 C-4

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17-15
PREREAD1 FC-2540 P11 Earth Orbit Insertation Monitor CALLED 4
FC-2683 Service ENTRY 3
PRESWTCH FC-2430 TVC Start-up, Executive, and Service Routines ENTRY 28
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PRE40.6 FC-2680 Thrust Program (P40, P41) ENTRY 44
PREVGM FC-2681 Clocktask and Clockjob CALLED 13
PPFTRKAT FC-2361 P09 (R03) S-3 C-3
FC-2550 P20 Rendezvous Navigation S-3 T-5
FC-2070 Service Routes C-6
PRE4190 Extended Verbs S-3 C-3 T-5
PPLOCHNG FC-2340 R06 Attitude Maneuver CALLED 8
FC-2370 DAP Interface and Service Routines CALLED 6
FC-2550 P20 Rendezvous Navigation CALLED 6, 19, 31
FC-2650 Orbital Parameters Display CALLED 2
FC-2650 Orbital Parameters Display CALLED 2
FC-2700 P47 Thrust Monitor CALLED 5
PREQDFLG FC-2070 Service Routes C-6
PREQDFSR FC-2140 Alarm and Abort CALLED 10
PROCALM FC-2140 Alarm and Abort ENTRY 3
PROCKEY FC-2200 TRUPT CALLED 5
PROG20 FC-2550 P20 Rendezvous Navigation ENTRY 3
PROG21 FC-2580 P21 Ground Track Determination ENTRY 2
PPOG22 FC-2590 P22 Orbital Navigation ENTRY 2
PROG52 FC-2720 P52 IMU Realignment Program ENTRY 1
PRONVFLG FC-2070 Service Routes C-6
PRTUT FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 37
FC-2540 P11 Earth Orbit Insertation Monitor CALLED 5
PTOACSM FC-2290 Integration Initialization ENTRY 5
PTOALEM FC-2290 Integration Initialization ENTRY 5
PULSEIMU FC-2100 RT8 Op Codes ENTRY 12
P11 FC-2540 P11 Earth Orbit Insertation Monitor ENTRY 3
FC-2545 P17/P77--TPI Search Programs ENTRY 3
P17-1 FC-2545 P17/P77--TPI Search Programs ENTRY 3
P17-2 FC-2545 P17/P77--TPI Search Programs ENTRY 3
P17-3 FC-2545 P17/P77--TPI Search Programs ENTRY 12
P20FLGON FC-2545 P17/P77--TPI Search Programs CALLED 3
FC-2627 P33, P73--CDH CALLED 1
FC-2630 P34/P74 TPI Targeting CALLED 2
FC-2640 P35-P75 TPM Targeting CALLED 6
FC-2644 P38/P78: P39/P79 CALLED 3, 9
P21FLAG FC-2580 P21 Ground Track Determination ENTRY 4
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P22FLGON FC-2200 Fresh Start and Restart ENTRY 2
FC-2600 P23 Cislunar Midcourse Navigation ENTRY 3
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P22SUBDP FC-2600 P23 Cislunar Midcourse Navigation CALLED 6
P23 FC-2600 P23 Cislunar Midcourse Navigation ENTRY 3
P3XORP7X FC-2626 P32, P72--CSI ENTRY 23
P30 FC-2620 P30, P31 ENTRY 2
P30/P31 FC-2620 P30, P31 ENTRY 2
P31 FC-2620 P30, P31 ENTRY 7
P32 FC-2626 P32, P72--CSI ENTRY 2
P33 FC-2627 P33, P73--CDH ENTRY 1
P34 FC-2630 P34/P74 TPI Targeting ENTRY 2
P35 FC-2640 P35-P75 TPM Targeting ENTRY 1
P37 FC-2642 P37 Return To Earth ENTRY 3
P38 FC-2644 P38/P78: P39/P79 ENTRY 3
P39 FC-2644 P38/P78: P39/P79 ENTRY 9
P39/P39.79SW FC-2070 Service Routes C-6 T-6, 8
FC-2644 P38/P78: P39/P79 S-9
P39/P79SW FC-2644 P38/P78: P39/P79 S-9
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FC-2681 Cloktask and Clockjob CALLED 4
P40CSM FC-2630 P34/P74 TPI Targeting ENTRY 4
P40RCS FC-2630 P34/P74 TPI Targeting ENTRY 29
P41CSM FC-2630 P34/P74 TPI Targeting ENTRY 5
P47BODY FC-2700 P47 Thrust Monitor ENTRY 4
P47CSM FC-2700 P47 Thrust Monitor ENTRY 3
P52LS FC-2720 P52 IMU Realignment Program ENTRY 7
P61 FC-2760 P60's Entry Programs ENTRY 2
P62 FC-2760 P60's Entry Programs ENTRY 6
P62-3 FC-2760 P60's Entry Programs ENTRY 30
P63 FC-2760 P60's Entry Programs ENTRY 10
P64 FC-2760 P60's Entry Programs ENTRY 12
P65 FC-2760 P60's Entry Programs ENTRY 13
P66 FC-2760 P60's Entry Programs ENTRY 15
P67 FC-2760 P60's Entry Programs ENTRY 16
P67-1 FC-2760 P60's Entry Programs ENTRY 17
P67-2 FC-2760 P60's Entry Programs ENTRY 18
P72 FC-2626 P32, P72--CSI ENTRY 2
P73 FC-2627 P33, P73--CDH ENTRY 1
P74 FC-2630 P34/P74 TPI Targeting ENTRY 2
P75 FC-2640 P35--P75 TTM Targeting ENTRY 1
P76 FC-2670 P76 TPI Target Delta V Program ENTRY 2
P76SU01 FC-2647 P76 TPI Target Delta V Program ENTRY 3
P77 FC-2545 P17/P77--TPI Search Programs ENTRY 3
P78 FC-2644 P38/P78; P39/P79 ENTRY 3
P79 FC-2644 P38/P78; P39/P79 ENTRY 9
*RBON* FC-2325 Rendezvous Parameters Displays CALLED 5
*SMNB* FC-2360 R64 (R06)--S-Band Antenna CALLED 4
QCETFRIG FC-2681 Cloktask and Clockjob CALLED 4
QUIKDSF PC-2200 T4RUPT ENTRY 46
QUIKREAD FC-2683 Servicer ENTRY 15
QUITFLAG FC-2300 Orbital Integration T-3
FC-2070 Service Routines C-6
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RADSTALL FC-2550 P20 Rendezvous Navigation CALLED 32
RANGERSR FC-2550 P20 Rendezvous Navigation ENTRY 32
RATELIM FC-2460 Roll Autopilot ENTRY 4
RCSATT FC-2370 DAP Interface and Service Routines CALLED 4
FC-2380 DAP Interface Initialization and Phase I ENTRY 2
FC-2390 RCS DAP Phase 2 CALLED 2,3
FC-2400 RCS DAP Jet Selection Logic CALLED 16
RCSDAPON FC-2370 DAP Interface and Service Routines ENTRY 4
FC-2380 DAP Interface Initialization and Phase I CALLED 2
FC-2460 Roll Autopilot CALLED 2
FC-2020 Fresh Start and Restart CALLED 31
FC-2680 Thrust Programs (P40, P41) CALLED 25
FC-2681 Cloktask and Clockjob CALLED 9,13
RCSDAPUP FC-2370 DAP Interface and Service Routines ENTRY 4
RCSFLAGS FC-2350 Maneuver Calculations and Steering S-10 C-26
FC-2380 DAP Interface Initialization and Phase I S-2,3,8,5 C-8.5 T-3.5
FC-2400 RCS DAP Jet Selection Logic S-16 C-16
FC-2540 P11 Earth Orbit Insertation Monitor S-4,17,20 T-17
RCSUP FC-2380 DAP Interface Initialization and Phase I ENTRY 2
RDCHP FC-2720 P52 IMU Realignment Program ENTRY 27
READACCs FC-2683 Servicer ENTRY 5

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READCDUK FC-2340 R60 Attitude Maneuver CALLED 5
FC-2350 Maneuver Calculations and Steering ENTRY 24
RPADPIP FS-2100 RT8 Op Codes ENTRY 4
RECT.1 FC-2600 P23 Cislunar Midcourse Navigation ENTRY 17
RECTIFY FC-2300 Orbital Integration ENTRY 43
FC-2610 Measurement Incorporation CALLED 11
FC-2290 Integration Initialization CALLED 8,9
RECTIFY+ FC-2290 Integration Initialization CALLED 14
RECTOUT FC-2300 Orbital Integration ENTRY 40
FC-2790 Integration Initialization CALLED 9
REDO FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 31
REDORCS FC-2380 DAP Interface Initialization and Phase I ENTRY 2
REDOAT FC-2370 DAP Interface and Service Routines CALLED 5
PC-2540 P11 Earth Orbit Insertion Monitor ENTRY 20
REDOTVC FC-2740 TVC Start-up, Executive, and Service Routines ENTRY 18
REELFG FC-2720 P52 IMU Realignment Program T-20
RFPFAZEO FC-2760 P60's Entry Programs CALLED 13
RFSSMFLG FC-2540 P11 Earth Orbit Insertion Monitor S-8
FC-2550 P20 Rendezvous Navigation T-6,31
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FC-2620 P30, P31 T-5,9
FC-2626 P32, P72--CSI T-6
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RFINTFLG FC-2300 Orbital Integration S-33,38
FC-2610 Measurement Incorporation S-7
FC-2020 Fresh Start and Restart C-20,6
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FC-2290 Integration Initialization C-13 T-10,12
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REDLSP FC-2020 Fresh Start and Restart CALLED 32,37,42
RELVEST FC-2070 Service Routines C-6
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RENDFLGL FC-2300 Orbital Integration C-37
FC-2550 P20 Rendezvous Navigation S-23 T-4,21,23
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FC-2605 Navigation Extended Verbs C-5,7
FC-2070 Service Routines C-6
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REPACF FC-2400 RCS DAP Jet Selection Logic ENTRY 19
RPPLACEY FC-2400 RCS DAP Jet Selection Logic ENTRY 19
REP11 FC-2740 P11 Earth Orbit Insertation Monitor ENTRY 6
REREADAC FC-2683 Servicer ENTRY 12
RESETX2 FC-2310 Conic Subroutines ENTRY 30
RESTARTS FC-2020 Fresh Start and Restart ENTRY 43
RETROFLG FC-2070 Service Routines C-6
FC-2640 P37 Return To Earth S-16 C-16 T-31
RLIMTEST FC-2440 TVC DAP ENTRY 15
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RNDREP FR FC-2200 T4RUPT CALLED 31,32
RNDVZFLG FC-2550 P20 Rendezvous Navigation S-3 C-8 T-8,17
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FC-2020 Fresh Start and Restart C-37,6 T-37,39,39
FC-2220 T4RUPT C-33
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ROLLDAP  FC-2430  TVC Start-up, Executive, and Service Routines CALLED 11
FC-2460  Roll Autopilot ENTRY 1
ROLLTMF  FC-2400  RCS DAP Jet Selection Logic ENTRY 9
ROTA  FC-2730  R52, R53, R56 ENTRY 10
ROTAPE  FC-2626  P32, P72--CSI ENTRY 9
ROUENT  FC-2070  Service Routines ENTRY 12
ROPLFLAG  FC-2070  Service Routines C-6 T-44
RP-TOR  FC-2300  Orbital Integration S-22
FC-2290  Integration Initialization S-8
FC-2300  Orbital Integration CALLED 20
FC-2590  P22 Orbital Navigation CALLED 7,14
FC-2290  Integration Initialization CALLED 21
FC-2720  P52 IMU Realignment Program CALLED 7
FC-2730  R52, R53, R56 CALLED 9
RTFNW  FC-2626  P37 Return To Earth ENTRY 28
RTCON  FC-2290  Integration Initialization ENTRY 9 T-22
RVSW  FC-2310  Conic Subroutines
FC-2545  P17/P77--TPI Search Programs S-6
FC-2626  P32, P72--CSI S-13,14
FC-2627  P33, P73--CDH C-8
FC-2630  P34/P74 TPI Targeting S-4
FC-2070  Service Routines C-6
FC-2642  P37 Return To Earth S-37 C-13,27
RIVITY  FC-2300  Orbital Integration CALLED 15
FC-2590  P22 Orbital Navigation CALLED 13,21
RO2BOTH  FC-2360  R66 (R05)--S-Band Antenna CALLED 3
FC-2361  V89 (R63) CALLED 2
FC-2550  P20 Rendezvous Navigation CALLED 3
FC-2590  P22 Orbital Navigation CALLED 3
FC-2190  Extended Verbs CALLED 2,3
FC-2680  Thrust Programs (P40, P41) CALLED 6
FC-2700  P47 Thrust Monitor CALLED 3
FC-2720  P52 IMU Realignment Program CALLED 1
FC-2760  P00's Entry Programs CALLED 19
R21MARK  FC-2550  P20 Rendezvous Navigation S-18 C-18
FC-2020  Fresh Start and Restart C-8,36,6
R22  FC-2550  P20 Rendezvous Navigation ENTRY 19
FC-2070  Service Routines C-6
R22CALFLG  FC-2070  Service Routines C-6
R23CSM  FC-2550  P20 Rendezvous Navigation ENTRY 18
R23FLAG  FC-2550  P20 Rendezvous Navigation S-17 C-17 T-17,18,25
FC-2070  Service Routines C-6
R23.55  FC-2600  P23 Cislunar Midcourse Navigation ENTRY 10
R31FLG  FC-2325  Rendezvous Parameters Displays S-2 C-2 T-3,4
FC-2070  Service Routines C-6
R36  FC-2631  R36 (V90) ENTRY 3
R51  FC-2720  P52 IMU Realignment Program ENTRY 18
R52  FC-2550  P20 Rendezvous Navigation CALLED 7
FC-2590  P22 Orbital Navigation CALLED 4
FC-2600  P23 Cislunar Midcourse Navigation CALLED 8
FC-2720  P52 IMU Realignment Program CALLED 19
FC-2730  R52, R53, R56 ENTRY 2
R53  FC-2600  P23 Cislunar Midcourse Navigation CALLED 4
FC-2730  R52, R53, R56 ENTRY 11
R53FLAG  FC-2070  Service Routines C-6
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R55  FC-2720  P52 IMU Realignment Program ENTRY 26
P56  FC-2720  P52 IMU Realignment Program CALLED 19
FC-2730  R52, R53, R56 ENTRY 14
P57  FC-2600  P23 Cislunar Midcourse Navigation CALLED 4,8
FC-2242  P57 Optics Calibration Routine ENTRY 2

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R57FLAG FC-2600 P23 Cislunar Midcourse Navigation S-8 C-3,9 T-8
FC-2070 Service Routines C-6

R60CSM FC-2330 R62 Crew Defined Maneuver (V49) CALLED 3
FC-2340 R60 Attitude Maneuver ENTRY 2
FC-2361 V89 (R63) CALLED 3
FC-2550 P20 Rendezvous Navigation CALLED 10
FC-2600 P23 Cislunar Midcourse Navigation CALLED 8
FC-2190 Extended Verbs CALLED 3
FC-2680 Thrust Programs (P40, P41) CALLED 8

R60FLAG FC-2070 Service Routines C-6
R61CSM FC-2550 P20 Rendezvous Navigation ENTRY 10
FC-2730 R52, R53, R56 CALLED 4
R62DISP FC-2330 R62 Crew Defined Maneuver (V49) ENTRY 3
R63 FC-2361 V89 (R63) ENTRY 4
FC-2550 P20 Rendezvous Navigation CALLED 11
FC-2190 Extended Verbs ENTRY 4

SATSTICK FC-2540 P11 Earth Orbit Insertion Monitor ENTRY 21
SATSTKON FC-2370 DAP Interface and Service Routines ENTRY 5
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SAVECPLG FC-2600 P23 Cislunar Midcourse Navigation S-9 C-4 T-5,6
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SBANDANT FC-2360 R64 (R05)—S-Band Antenna ENTRY 3
SCALEPREP FC-2220 P06 GNCS Power Down ENTRY 7
SCNDOLS FC-2626 P32, P72—CSI ENTRY 21
SELECTMV FC-2626 P32, P72—CSI CALLED 2
FC-2627 P33, P73—CDH CALLED 1
FC-2630 P34/P74 TPI Targeting ENTRY 17
FC-2640 P35—P75 TPM Targeting CALLED 1
FC-2641 Common Targeting Subroutines ENTRY 14
FC-2644 P38/P78; P39/P79 CALLED 4,9

SELPCNF FC-2700 Inter-bank Communication ENTRY 3
FC-2120 AGC Block Two Selfcheck ENTRY 2
SERVEXIT FC-2683 Servicer ENTRY 27
FC-2700 P47 Thrust Monitor CALLED 7
SERVICER FC-2693 Servicer ENTRY 16
SERVNOUT FC-2760 P60's Entry Programs CALLED 18
SETCHARS FC-2200 TACRUPT CALLED 43

SETGWLST FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 14
SFTINTG FC-2600 P23 Cislunar Midcourse Navigation ENTRY 14
SETISSW FC-2200 TACRUPT ENTRY 30
SETJTAG FC-2683 Servicer CALLED 7
SFTMAXDS FC-2370 DAP Interface and Service Routines ENTRY 24
FC-2630 P34/P74 TPI Targeting ENTRY 25
FC-2020 Fresh Start and Restart CALLED 25
SETMINDB FC-2370 DAP Interface and Service Routines ENTRY 24
FC-2630 P34/P74 TPI Targeting ENTRY 25
FC-2020 Fresh Start and Restart CALLED 25
SETHRE FC-2250 P22 Orbital Navigation CALLED 24
SPT75 FC-2380 DAP Interface Initialization and Phase I ENTRY 2
SPTVOAPS FC-2020 Fresh Start and Restart CALLED 19
SET1/PET FC-2720 P32 IMU Realignment Program CALLED 23
SONAGPE PC-2300 Orbital Integration CALLED 4
FC-2100 RTB Op Codes ENTRY 5
FC-2631 R36 (V90) CALLED 6

SHIFTR1 FC-2641 Common Targeting Subroutines ENTRY 10
SHORTMP FC-2220 P06 GNCS Power Down CALLED 5
SHOW FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 25
SIGNMPAC FC-2300 Orbital Integration CALLED 5
FC-2320 TPCComics CALLED 9
FC-2350 Maneuver Calculations and Steering CALLED 7,16,17,18,19,20

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RTB Op Codes ENTPY 14 C-32 T-34

P20 Rendezvous Navigation C-6

P20 Fresh Start and Restart S-8

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P20 Service Routines C-6

Service Routines C-6

P37 Return To Earth S-4 C-4 T-20

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RCS DAP Phase 2 CALLED 10

P20 Rendezvous Navigation CALLED 13

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P20 Service Routines C-6

Conic Subroutines ENTRY 2

Prelaunch Initialization and Gyro Compassing ENTRY 37

AGC Block Two Selfcheck ENTRY 13

P20 Rendezvous Navigation S-33 C-20 T-24,26,27.

Single Precision Subroutines ENTRY 2

P34/P74 TPI Targeting ENTRY 27

Clocktask and Clockjob CALLED 9,12

Orbital Parameters Display ENTRY 15

P30.1

P52, P53, P56 ENTRY 6

DAP Interface and Service Routines ENTRY 29,30

P52 IMU Realignment Program S-18

P60's Entry Programs CALLED 3

P20 Fresh Start and Restart ENTRY 8

P20 Fresh Start and Restart ENTRY 8

P20 Fresh Start and Restart ENTRY 2

Orbital Integration S-37 C-3,38 T-38

P22 Orbital Navigation S-10,18

P23 Cislunar Midcourse Navigation S-14

P30.1

Service Routines C-6

Clocktask and Clockjob S-20

DAP Interface and Service Routines C-18

RCS DAP Phase 2 S-3

P20 Fresh Start and Restart C-36,6

DAP Interface and Service Routines C-6

P20 Fresh Start and Restart C-26,6

P20 Rendezvous Navigation CALLED 9

P20 Fresh Start and Restart CALLED 21,25

P20 Rendezvous Navigation CALLED 21,25

Orbital Parameters Display ENTRY 15

P20 Fresh Start and Restart ENTRY 2

P20 Fresh Start and Restart ENTRY 8

AGC Block Two Selfcheck ENTRY 13

P20 Rendezvous Navigation CALLED 13

Conic Subroutines ENTRY 2

Prelaunch Initialization and Gyro Compassing ENTRY 37

AGC Block Two Selfcheck ENTRY 13

P20 Rendezvous Navigation S-33 C-20 T-24,26,27.

Single Precision Subroutines ENTRY 2

P34/P74 TPI Targeting ENTRY 27

Clocktask and Clockjob CALLED 9,12

Orbital Parameters Display ENTRY 15

P30.1

P52, P53, P56 ENTRY 6

DAP Interface and Service Routines ENTRY 29,30

P52 IMU Realignment Program S-18

P60's Entry Programs CALLED 3

P20 Fresh Start and Restart ENTRY 8

P20 Fresh Start and Restart ENTRY 8

P20 Fresh Start and Restart ENTRY 2

Orbital Integration S-37 C-3,38 T-38

P22 Orbital Navigation S-10,18

P23 Cislunar Midcourse Navigation S-14

P30.1

Service Routines C-6

Clocktask and Clockjob S-20

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P20 Fresh Start and Restart C-36,6

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P20 Fresh Start and Restart C-26,6

P20 Rendezvous Navigation CALLED 9

P20 Fresh Start and Restart CALLED 21,25

P20 Rendezvous Navigation CALLED 21,25

Orbital Parameters Display ENTRY 15

P20 Fresh Start and Restart ENTRY 2

P20 Fresh Start and Restart ENTRY 8

AGC Block Two Selfcheck ENTRY 13

P20 Rendezvous Navigation S-33 C-20 T-24,26,27.

Single Precision Subroutines ENTRY 2

P34/P74 TPI Targeting ENTRY 27

Clocktask and Clockjob CALLED 9,12

Orbital Parameters Display ENTRY 15

P30.1

P52, P53, P56 ENTRY 6

DAP Interface and Service Routines ENTRY 29,30

P52 IMU Realignment Program S-18

P60's Entry Programs CALLED 3

P20 Fresh Start and Restart ENTRY 8

P20 Fresh Start and Restart ENTRY 8

P20 Fresh Start and Restart ENTRY 2

Orbital Integration S-37 C-3,38 T-38

P22 Orbital Navigation S-10,18

P23 Cislunar Midcourse Navigation S-14

P30.1

Service Routines C-6

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DAP Interface and Service Routines C-18

RCS DAP Phase 2 S-3

P20 Fresh Start and Restart C-36,6

DAP Interface and Service Routines C-6
FC-2680 Thrust Programs (P40, P41) ENTRY 32
STSHOSUN FC-2120 AGC Block Two Selfcheck ENTRY 7
SUPTACAL FC-2080 Inter-bank Communication ENTRY 3
FC-2120 AGC Block Two Selfcheck CALLED 9
SUPERSW FC-2080 Inter-bank Communication ENTRY 2
SURPLAN FC-2290 Integration Initialization
SVDWN1 FC-2325 Rendezvous Parameters Displays CALLED 6
FC-2290 Integration Initialization CALLED 5
SVDWN2 FC-2610 Measurement Incorporation CALLED 11
FC-2610 Measurement Incorporation CALLED 11
SWCALL FC-2080 Inter-bank Communication ENTRY 1
SWCOVSV FC-2370 DAP Interface and Service Routines CALLED 2
FC-2430 TVC Start-up, Executive, and Service Routines ENTRY 28
SWRTURN FC-2080 Inter-bank Communication ENTRY 1
SWTOVET FC-2430 TVC Start-up, Executive, and Service Routines S-29 ENTRY 7
FC-2070 Fresh Start and Restart C-25, 6
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SXTMARK FC-2730 R52, R53, R56 CALLED 11, 14
SXTN8 FC-2325 Rendezvous Parameters Displays CALLED 6
FC-2550 P20 Rendezvous Navigation CALLED 38
FC-2730 R52, R53, R56 CALLED 13
SXTSM FC-2720 P52 IMU Realignment Program CALLED 19
FC-2730 R52, R53, R56 ENTRY 13
SYSTEST FC-2530 Prelaunch Initialization and Gyro Compassing ENTRY 31
S11-1 FC-2540 P11 Earth Orbit Insertion Monitor ENTRY 18
FC-2700 P47 Thrust Monitor CALLED 6
S17-1 FC-2545 P17/P77--TPI Search Programs ENTRY 3
S17-2 FC-2545 P17/P77--TPI Search Programs ENTRY 6
S22-1 FC-2590 P22 Orbital Navigation ENTRY 9
S30-1 FC-2620 P30, P31 ENTRY 2
S31-1 FC-2620 P30, P31 ENTRY 7
S32-1F1 FC-2626 P32, P72--CSI C-11, 21 ENTRY 7
FC-2070 Service Routines C-6
S32-1F2 FC-2626 P32, P72--CSI S-11, 21 ENTRY 6
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S32-1F3A FC-2626 P32, P72--CSI S-18, 19 ENTRY 6
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S32-1F3B FC-2070 Service Routines C-6
S32/33.7 FC-2626 P32, P72--CSI ENTRY 8
S32/33.1 FC-2626 P32, P72--CSI ENTRY 5
S32/33.8 FC-2627 P33, P73--CDH CALLED 4
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FC-2644 P38/P78; P39/P79 CALLED 11
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FC-2644 P38/P78; P39/P79 CALLED 6, 10
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S40.15 FC-2370 DAP Interface and Service Routines ENTRY 17
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## COLOSSUS 2C

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FLOW CHARTS ONLY

R. Gilbert MIT/IL  
P. O. Box 21025  
Kennedy Space Center  
Florida 32815

J. Tadich  
L-S Eng - 62  
Kennedy Space Center  
Florida 32815

R. Lingg  
AC Electronics Division  
P. O. Box 21026  
Kennedy Space Center  
Florida 32815

F. Hughes  
CFK/Flight Crew Operations Branch  
Flight Crew Training Building (M7-409)  
Kennedy Space Center  
Florida 32899

G. Parker  
CFK/Flight Crew Operations Branch  
Flight Crew Training Building (M7-409)  
Kennedy Space Center  
Florida 32899

R. Pearson  
CFK/Flight Crew Operations Branch  
Flight Crew Training Building (M7-409)  
Kennedy Space Center  
Florida 32899

F. Brokaski (1)  
AC Electronics  
Dept 32-31  
Oak Creek, Wisconsin 53154

J. Evans (1)  
AC Electronics  
Dept 32-31  
Oak Creek, Wisconsin 53154

J. Walcholz (1)  
AC Electronics  
Dept. 32-31  
Oak Creek, Wisconsin 53154

M. Adams MIT/IL - Plant #25 (1)  
Grumman Aircraft Engineering Corp.  
Bethpage  
Long Island, New York
A. Heffron (1)
Bellcomm, Inc.
1100 17th Street NW
Washington, D.C. 20036

R. Seamans (1)
Raytheon Co.
Apollo Systems Support
Seyon Street
Waltham, Mass.

A. Sohler FB59 (1)
NR Corp.
Space Division
12214 Lakewood Blvd.
Downey, California 90241

T. Lawton - EG/MIT (1)
NASA Manned Spacecraft Center
Houston, Texas 77058

R. O'Donnell MIT/IL (1)
NASA-MSC/AMR Operations
Kennedy Space Center
Florida 32899

R. Gilgen (2)
AC Electronics
Dept. 32-31
Oak Creek, Wisconsin 53541

M. Sherman (5)
S&ID
12214 Lakewood Blvd
Downey, California 90241

J. Williams FS 5 (50)
NASA Manned Spacecraft Center
Houston, Texas 77058