MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE, NAVIGATION AND CONTROL

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APOLLO GUIDANCE AND NAVIGATION PROGRAM

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CHARLES STARK DRAPER LABORATORY

E-2471
(Rev. 2)

Volume I of II

APOLLO GUIDANCE AND NAVIGATION FLOWCHARTS

PROGRAM LUMINARY 1D
(Rev. 173)
JUNE 1970

MIT CHARLES STARK DRAPER LABORATORY
CAMBRIDGE, MASSACHUSETTS, 02139

ACKNOWLEDGEMENT

This report was prepared under DSR Project 55-23870, sponsored by the Manned Spacecraft Center of the National Aeronautics and Space Administration through Contract NAS 9-4065.

Foreword

This document comprises all flowcharts completed by the date of publication for Luminary 1D programs, routines, and subroutines. (Reference Exhibit D, Paragraph 3.3, of M.I.T. Statement of Work, NAS 9-4065, period 1 January 1968 - 30 June 1970.)

Those flowcharts not completed and not included within the current edition are denoted by an asterisk on the table of contents. As they become available, newly completed flowcharts will be forwarded for inclusion, with an updated contents and index. The index to the present volume is an alphabetical listing of flag bits, subroutines, and major entries. In addition to the flowchart and sheet number for each entry, the index gives the flowchart and sheet number where each flag bit is set (S), cleared (C), or tested (T).

Jack C Reed

Jack C. Reed
Group Leader
Apollo Documentation

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1.0 INTRODUCTION

1.0 INTRODUCTION

By Roberta M. Entes

APOLLO Guidance and Navigation Flowcharts presents in one document all flowcharts completed for the most recent release of the LUMINARY program. The purpose of these flowcharts is (1) to help those not familiar with APOLLO Guidance Computer (AGC) coding to understand and follow the AGC programs, and (2) to present a guide to the listing for those who want to follow the program coding in close detail.

1.1 ORGANIZATION

The entire LUMINARY program has been divided into 11 sections according to the role the segment of coding plays with respect to the entire mission. Each section has a number of separate flowcharts.

The sections have been ordered such that basic system programs and routines are presented first (Section 2.0), followed by general routines (Section 3.0–7.0), Digital Autopilot (Section 8.0), and then major modes (Sections 9.0–12.0). Routines appropriate to a particular major mode are usually flowed in the same section as the major mode. Subsection 1.4 cross-references routines, major modes, and flowcharts.

1.2 USER INFORMATION

A flowchart is a graphical representation of a computer program. They can be used for a number of purposes. For example, a programer unfamiliar with a certain area of coding uses flowcharts as an aid in understanding the program; a programer updating his own program uses flowcharts because they show, in a convenient form, the logic of the present program. Each of the following program functions has a unique symbol: (1) setting and clearing (resetting) of flags; (2) channel operations; (3) external subroutines called; (4) displays used; and (5) restart protection. Therefore these functions are found easily in flowcharts once the user is aware of symbol usage. (See Subsection 1.3 for a complete description of symbol usage.)

APOLLO Guidance and Navigation Flowcharts are used for flight support training to train instructors and to prepare training manuals. Engineers use flowcharts to determine program requirements when reviewing designs.

During flights, APOLLO Guidance and Navigation Flowcharts may be used to help explain why certain things are occurring. For example, because alarms and displays have a unique symbol in flowcharts, they can be found more easily in flowcharts than in other forms of documentation or in the listing.

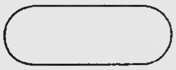
How a flowchart should be read depends on why the flowcharts is being used. Everyone using flowcharts should familiarize himself with the symbols peculiar to APOLLO Guidance and Navigation Flowcharts (Subsection 1.3) and with the Index (Section 13.0).

1.3 SYMBOL USAGE

APOLLO Guidance and Navigation Flowchart symbols do not conform to standard usage because so many operations and functions are unique to the AGC.

Flowchart symbols represent program functions. The shape of the symbol indicates the type function. Generally, the AGC mneumonic is written inside the symbol, and comments are written outside. The following conventions for symbol shapes are used in APOLLO Guidance and Navigation Flowcharts:

1.3.1

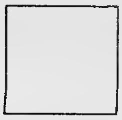


Symbols of this shape and size denote the name of an AGC location, i.e., a tag, label, or entry.

1.3.2

Symbols of the above shape, but drawn with a broken line, denote an entry point that does not have a label or tag.

1.3.3



Squares denote bookkeeping tasks, such as manipulation of returns and INHINT (inhibit interrupts) and RELINT (allow or release interrupts) instructions.

1.3.4

Rectangles denote mathematical calculations and data manipulation.

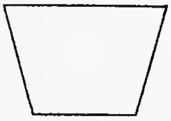
1.3.5

Rectangles divided by broken lines have the GSOP, NASA publication R-567, Section 5, equation above and the AGC equation below the broken line.

1.3.6

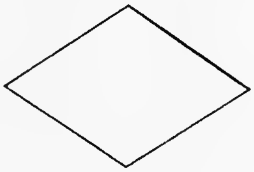
Symbols of this shape denote flags being set, cleared (reset), or inverted.

1.3.7



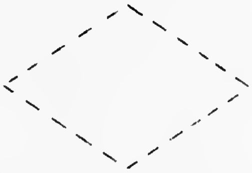
Symbols of this shape denote channel bits being set, cleared, inverted, or tested.

1.3.8



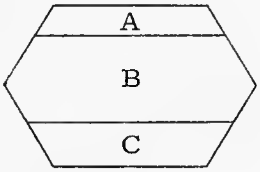
Diamonds denote branching and any testing except channel bits. Any number of lines may be drawn from the diamond. Each line is labeled with an answer to the question asked within the diamond.

1.3.9



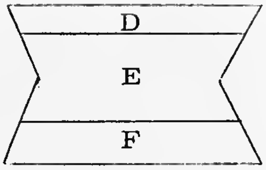
Diamonds drawn with broken lines denote testing which occurs in the logic but is not explicit in the coding.

1.3.10



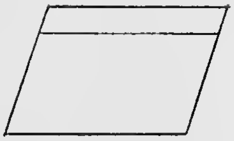
Symbols of this shape denote subroutines called directly. The tag or name of the subroutine is written in space A, a short description of what the subroutine does in B, and the sheet number or flowchart number where the subroutine is flowed is in space C. The sheet number is in space C if the subroutine is flowed in the same flowchart as the calling routine and the flowchart number is in space C if the subroutine is flowed in another flowchart.

1.3.11



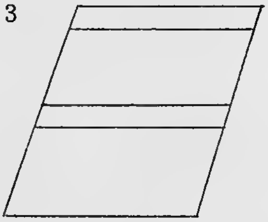
Symbols of this shape denote subroutines (i.e., jobs or tasks) which are scheduled. The subroutine tag or name is in space D, the name of the scheduling routine and the scheduled time or priority is in space E, and the flowchart or sheet on which the scheduled subroutine is flowed is in space F. As above, the sheet number is used in space F if the subroutine is flowed in the same flowchart as the calling routine and the flowchart number is in space F if the subroutine is flowed in another flowchart.

1.3.12



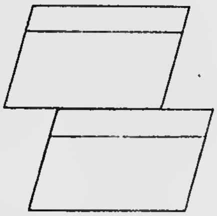
Symbols of this shape denote restart protection. The restart group number is written above the line. This number may be followed by a period and the phase number. A description of the restart protection is written below the line.

1.3.13



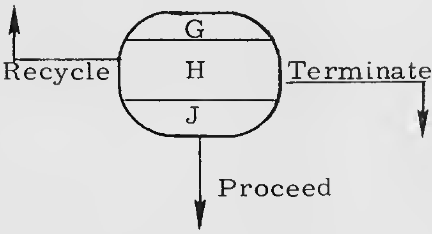
This variation of the above symbol denotes Type B (variable and fixed) restarts. The restart protection described by these two symbols is accomplished simultaneously.

1.3.14



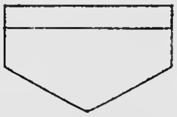
This variation of the above symbol denotes 2 group restart protection set up via calls to 2PHSCHNG. The restart protection described by these two symbols is accomplished simultaneously.

1.3.15



Symbols of this shape and size denote display interfaces. The name of the display interface routine is in space G, the type display and verb and noun are in space H, and the number of the flowchart in which the display interface routine is flowed is in space J. There usually are three exits from this symbol (depending on astronaut options), as shown: terminate, proceed, and recycle (or enter).

1.3.16



Symbols of this shape are connectors showing direct transfer to another sheet, another flowchart, or a location on the same sheet that cannot be easily reached by arrows. The name of the entry to which transfer is being made is written above the line and the flowchart number or sheet number of the entry is written below the line.

1.3.17  Symbols of this shape denote termination of a subroutine, task, job, or major mode.

1.4 CROSS-REFERENCE FOR MAJOR MODES, ROUTINES, AND FLOWCHARTS

Below are tables that cross-reference major modes and flowcharts (Subsection 1.4.1) and routines and flowcharts (Subsection 1.4.2). The major mode or routine is given first, followed by the flowchart in which the major mode or routine is flowed. The sheet number on which the major mode or routine begins is given, unless the major mode or routine comprises the entire flowchart or is scattered throughout the flowchart. An asterisk (*) before the flowchart number indicates this flowchart has not been completed and is not in APOLLO Guidance and Navigation Flowcharts.

1.4.1 CROSS-REFERENCE FOR MAJOR MODE AND FLOWCHARTS

MAJOR MODE	FLOWCHART	SHEET	MAJOR MODE	FLOWCHART	SHEET
P00	FC-3010	27	P41	FC-3810	
P06	*FC-3200		P42	FC-3820	
P07	*FC-3270		P47	FC-3830	
P12	*FC-3950		P51	FC-3500	
P20	FC-3600	11	P52	FC-3510	
P21	FC-3610		P57	FC-3520	
P22	FC-3600	11	P63	FC-3900	
P25	FC-3620		P64	FC-3900	6
P27	FC-3120		P65	FC-3900	6
P30	FC-3700		P66	FC-3900	30
P32	FC-3720		P68	FC-3910	
P33	FC-3730		P70	FC-3970	
P34	FC-3740		P71	FC-3970	
P35	FC-3750		P72	FC-3720	
P40	FC-3800		P73	FC-3730	
			P74	FC-3740	
			P75	FC-3750	
			P76	FC-3640	

1.4.2 CROSS-REFERENCES FOR ROUTINES AND FLOWCHARTS

ROUTINE	FLOWCHART	SHEET	ROUTINE	FLOWCHART	SHEET
R00	FC-3010	26	R36	FC-3790	3
R01	no flowchart		R40	FC-3850	10
R02	FC-3220	32	R41	FC-3350	26
R03	FC-3440	2	R47	FC-3250	
R04	FC-3280		R50	FC-3510	9
R05	FC-3435		R51	FC-3510	22
R09	FC-3930		R52	FC-3510	42
R10	FC-3930		R53	FC-3530	
R11	FC-3930		R54	FC-3510	46
R12	FC-3935		R55	FC-3510	48
R13	FC-3940		R56	FC-3510	34
R20	FC-3600	63	R57	FC-3530	18
R21	FC-3600	30	R58	FC-3500	11
R22	FC-3600	54	R59	FC-3520	25
R23	FC-3600	28	R60	FC-3420	
R24	FC-3600	49	R61	FC-3600	24
R25	FC-3210		R62	FC-3410	
R26	FC-3210		R63	FC-3400	
R29	FC-3980		R65	FC-3600	24
R30	FC-3770		R76	FC-3100	3
R31	FC-3780		R77	FC-3280	
R33	FC-3240				

2.0 GENERAL MANAGEMENT AND SERVICE ROUTINES

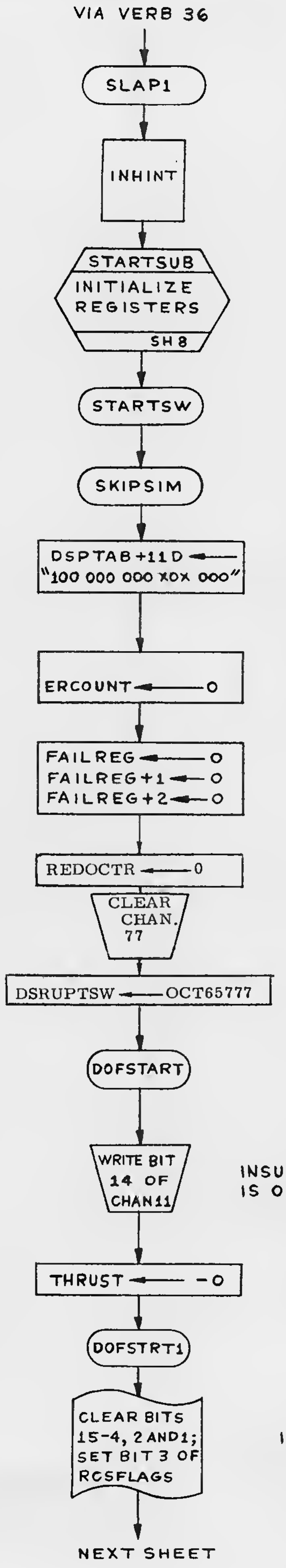
FRESH START AND RESTART

Major Subroutines On This Chart

SLAP1	Sh. 2
GOPROG	Sh. 15
V37	Sh. 23

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION		
DRAWN	J. Goldstein	12/4/69	FRESH START AND RESTART	
PRGMR	Densmore	12/9/69	LUMINARY 1D	DOCUMENT NO. FC-3010
ANALST				
DOCMR	W. Dietrich	12/9/69		
APPR'D	W. Dosgrith	12/16/69	REV . 3	SHEET 1 OF 39

FRESH START



ASTRONAUT INITIATED FRESH START

REGISTERS COMMON TO BOTH FRESH START AND RESTART

THIS LOCATION IS USED TO PATCH FOR SIMULATION PURPOSES ONLY

TURN OFF ALL C RELAYS AND LIGHTS EXCEPT "GIMBAL LOCK" AND "NO ATT". A ONE IN BIT-POSITION 15 OF DSPTAB+11D INDICATES TO PROGRAM T4RUPT THAT A CHANGE HAS OCCURRED IN BIT-POSITIONS 11-1 SINCE THE LAST TIME DSPTAB+11D WAS PROCESSED BY T4RUPT

INDICATES NO MALFUNCTIONS.

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

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

INITIALIZE COUNTER FOR T4RUPT, STARTING OUTPUT OF DISPLAYS TO DSKY (VIA ROUTINE QUIKDSP)

INSURE ENGINE IS OFF

INITIALIZE FOR THROTTLING ROUTINE

INITIALIZE ATTITUDE ERROR DISPLAY FLAGS

1APR68
5-31-68
C. G. Beck 5-31-68
5-31-68

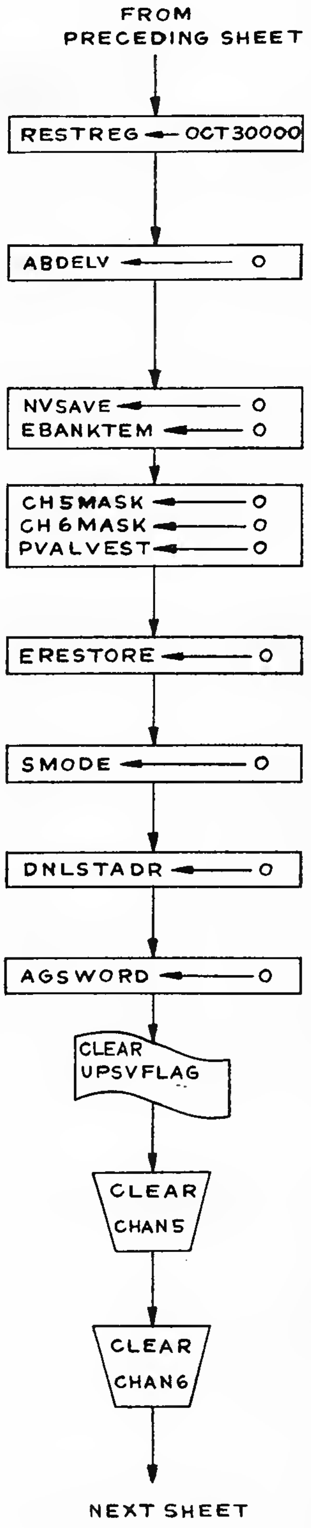
FRESH START AND RESTART

LUMINARY 1D

FC-3010

3

2 39



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

INITIALIZE ACCELERATION TO ZERO FOR DAP

CLEAR DISPLAY-INTERFACE-ROUTINES SAVE REGISTERS

INITIALIZE FOR RCS DAP FAILURE CHECKING

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

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

SELECT P00 DOWNLIST

RESTART PROTECTION FOR DNLSTADR

ZERO UPDATE STATE VECTOR REQUEST FLAGWRD

TURN OFF RCS JETS

TURN OFF RCS JETS

P. Rye 2APR68
5-31-68
C. G. Beck 5-31-68
5-31-68

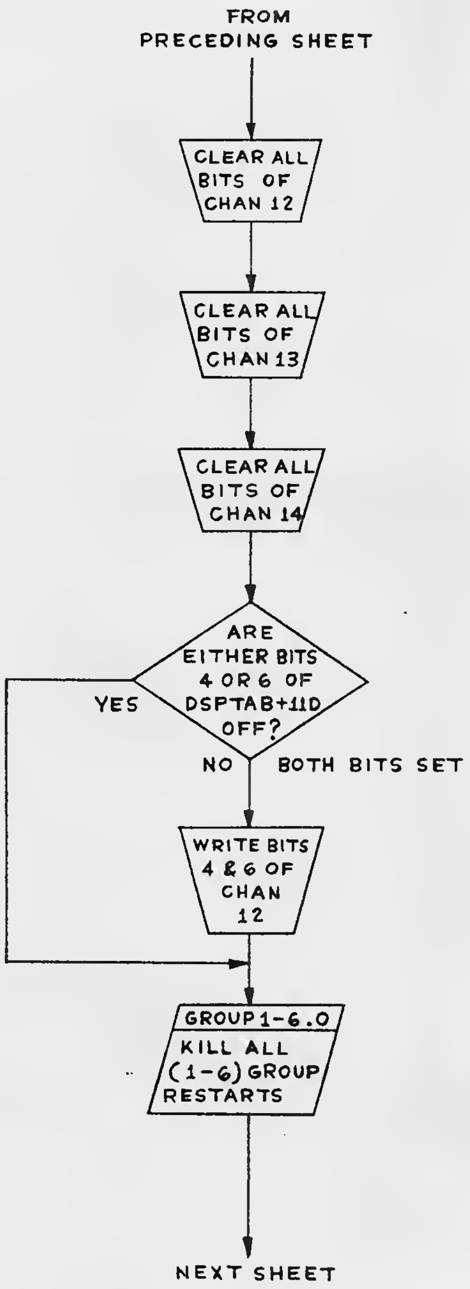
FRESH START AND RESTART

LUMINARY 1D

FC-3010

3

3 39



TERMINATES THE DRIVING OF MISCELLANEOUS NAVIGATION AND SPACECRAFT HARDWARE

TERMINATES THE CONTROL OF MISCELLANEOUS NAVIGATION SYSTEM FUNCTIONS

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

THE IMU WAS IN COARSE ALIGN IN GIMBLE LOCK, SO PUT IT BACK INTO COARSE ALIGN.

ALL GROUPS MADE INACTIVE VIA SUBROUTINES MR. KLEAN, POOKLEAN AND V37KLEAN

MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN a. J. Longitto 12MAY69
PRGMR E J Hughes 8 AUG 69
ANALST
DOCMR W C Dyforth 6 AUG 69
APPR'D Alexa M. Sorant 8 AUG 69

APOLLO
GUIDANCE AND NAVIGATION

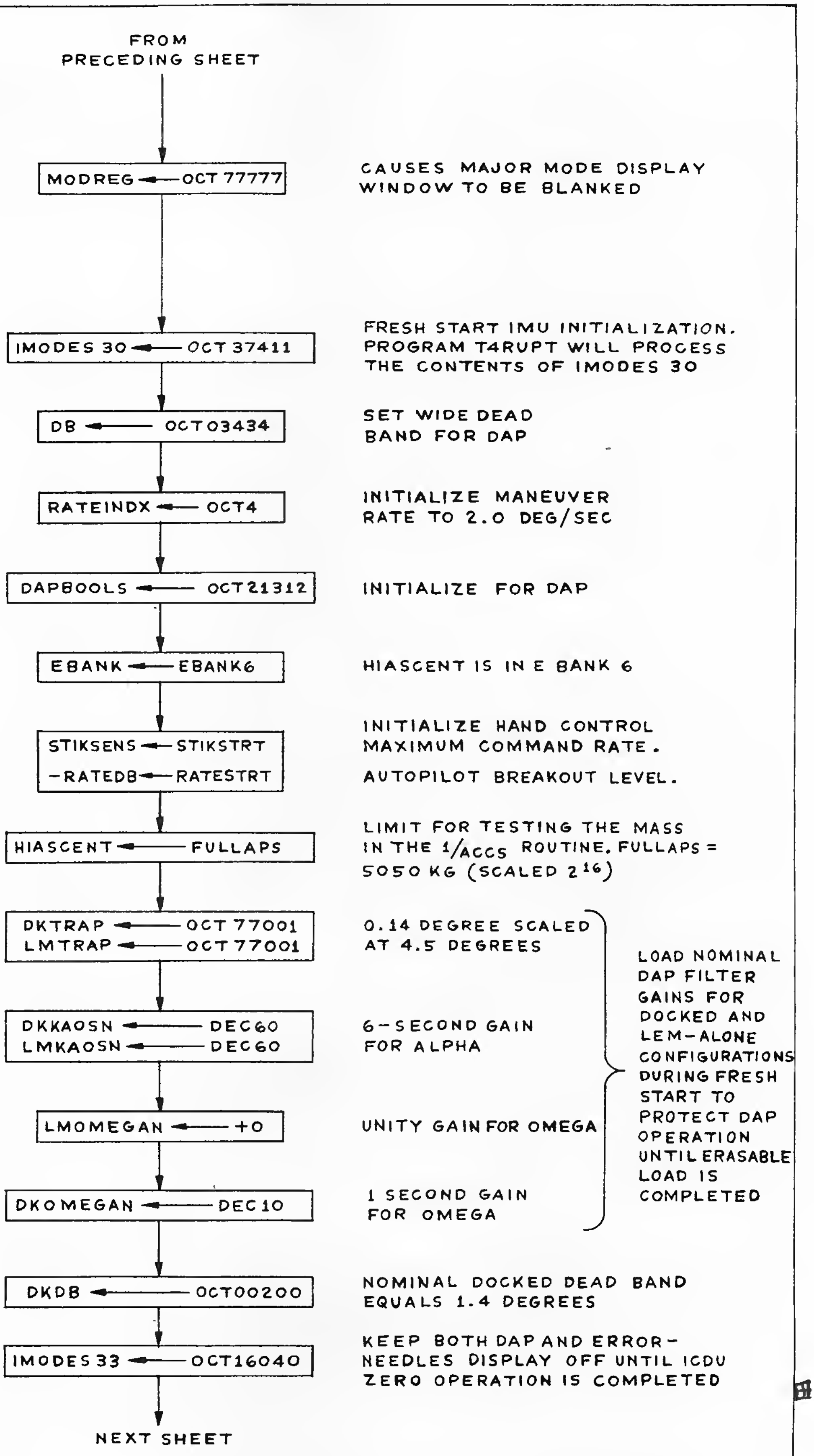
FRESH START AND RESTART

LUMINARY 1D

DOCUMENT NO.
FC-3010

REV 3

SHEET 4 OF 39



CAUSES MAJOR MODE DISPLAY WINDOW TO BE BLANKED

FRESH START IMU INITIALIZATION. PROGRAM T4RUPT WILL PROCESS THE CONTENTS OF IMODES 30

SET WIDE DEAD BAND FOR DAP

INITIALIZE MANEUVER RATE TO 2.0 DEG/SEC

INITIALIZE FOR DAP

HIASCENT IS IN E BANK 6

INITIALIZE HAND CONTROL MAXIMUM COMMAND RATE.

AUTOPILOT BREAKOUT LEVEL.

LIMIT FOR TESTING THE MASS IN THE $1/_{ACCS}$ ROUTINE. FULLAPS = 5050 KG (SCALED 2^{16})

0.14 DEGREE SCALED AT 4.5 DEGREES

6-SECOND GAIN FOR ALPHA

UNITY GAIN FOR OMEGA

1 SECOND GAIN FOR OMEGA

LOAD NOMINAL DAP FILTER GAINS FOR DOCKED AND LEM-ALONE CONFIGURATIONS DURING FRESH START TO PROTECT DAP OPERATION UNTIL ERASABLE LOAD IS COMPLETED

NOMINAL DOCKED DEAD BAND EQUALS 1.4 DEGREES

KEEP BOTH DAP AND ERROR-NEEDLES DISPLAY OFF UNTIL ICDU ZERO OPERATION IS COMPLETED

4APR68
5-31-68
C. G. Beck 5-31-68
5-31-68

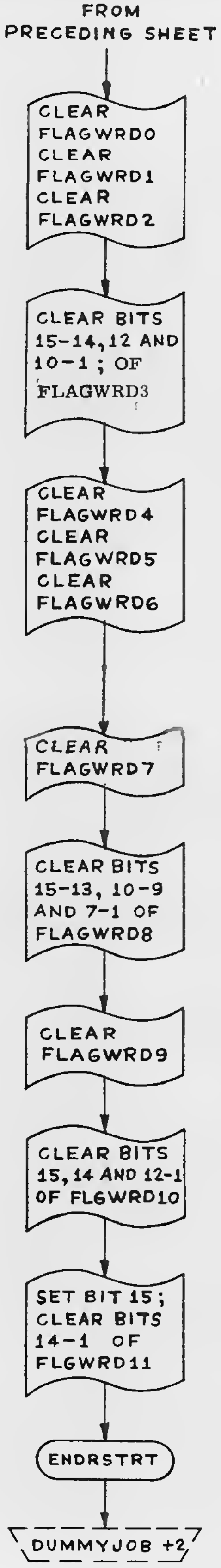
FRESH START AND RESTART

LUMINARY 1D

FC-3010

3

5 59



DO NOT ALTER
BIT 13 (REFSMFLG)
BIT 11 (NODOPO7)

DO NOT ALTER BITS 12 (CMOONFLG), 11 (LMOONFLG) AND 8 (SURFFLAG)

DO NOT ALTER
BIT 13 (APSFLAG)

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CAMBRIDGE, MASS.

DRAWN 12 MAY69
PROGMR J. Hughes 8 AUG 69
ANALST
DOCMR W.C. Danforth 6 AUG 69
APPR'D 8 AUG 69

APOLLO
GUIDANCE AND NAVIGATION

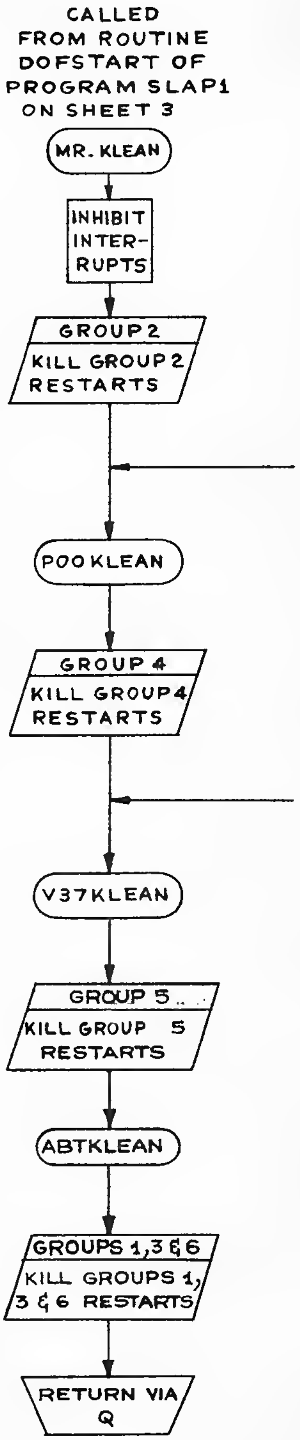
FRESH START AND RESTART

LUMINARY 1D

DOCUMENT NO. FC-3010

REV 3

SHEET 6 OF 39



SUBROUTINE FOR MAKING ALL GROUPS INACTIVE

GROUP 2 IS INACTIVE

THIS ENTRY IS USED BY PROGRAM V37 (ROUTINE GOMOD) VIA IBANKCALL. SEE SHEET 29

GROUP 4 IS INACTIVE

THIS ENTRY IS USED BY PROGRAM V37 (ROUTINE SEUDOPOO). SEE SHEET 29

GROUP 5 IS INACTIVE

GROUPS 1, 3 AND 6 ARE INACTIVE

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8APR68
5-31-68
C. G. Beck 5-31-68
5-31-68

FRESH START AND RESTART

LUMINARY 1D

FC-3010

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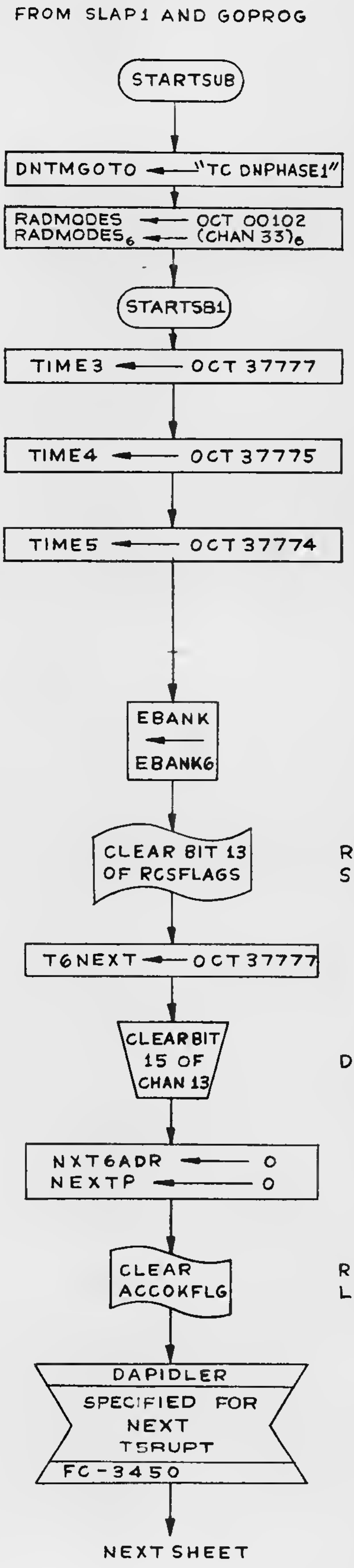

SUBROUTINE
USE BY BOTH FRESH START AND RESTART.
FOR INITIALIZATION OF REGISTERS COMMON TO BOTH.

INITIALIZES PROGRAM DOWN TELEMETRY

INITIALIZE LANDING RADAR

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

WILL CAUSE TIME COUNTER TIME4 TO OVERFLOW IN 30 MILLISECONDS FROM NOW TO IN TURN INITIATE THE EXECUTION OF INTERRUPT PROGRAM T4RUPT

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

RESTART OR FRESH START SINCE LAST 1/ACCS

DISABLE TIME6 INTERRUPT

DISABLE TIME6 CLOCK

RESTART OR FRESH START SINCE LAST 1/ACCS; OUTPUTS SUSPECT

SCHEDULE LEM AUTOPILOT. TIME5 WAS SET IN STARTSB1 TO OVERFLOW IN 40 MS.

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A. J. Lanzillo 13MAY69
J. Hughes 8AUG69
M C Danforth 8AUG69
Alejo M. Grant 8AUG69

GUIDANCE AND NAVIGATION

FRESH START AND RESTART

LUMINARY 1D

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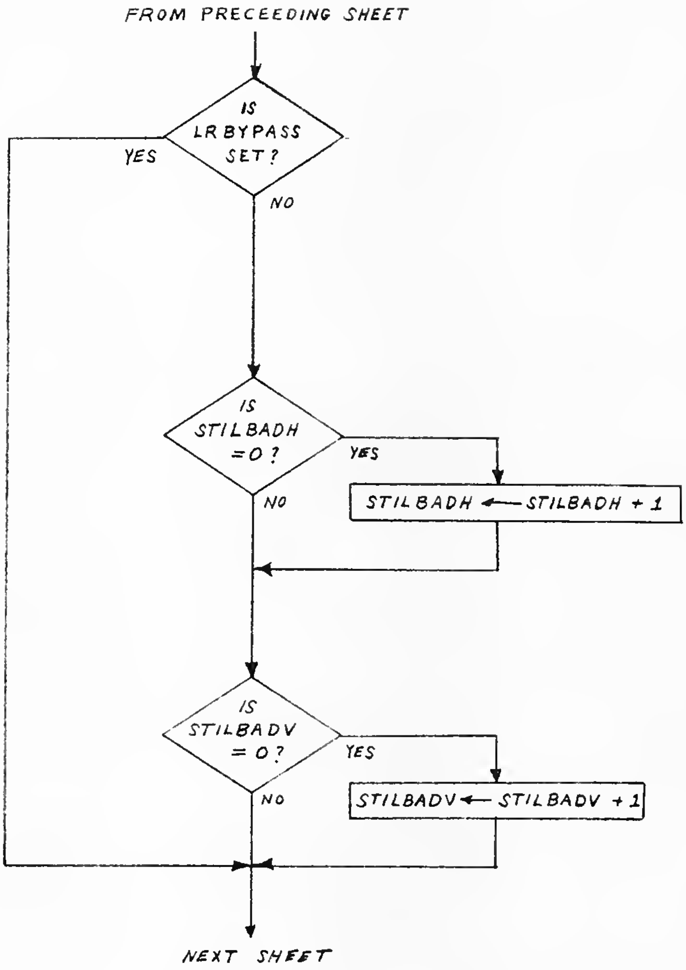
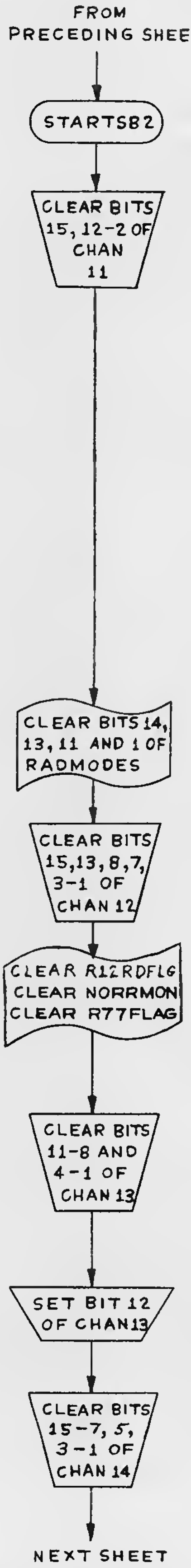


MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	12/8/69	FRESH START AND RESTART	
PRGMR Densmore	12/9/69	LUMINARY 1D	DOCUMENT NO. FC-3010
ANALST			
DOCMR	12/8/69		
APPR'D	12/16/69	REV 3	SHEET 9 OF 39



TURN OFF INDIVIDUAL INDICATORS OF THE DISPLAY SYSTEM. LEAVE ISS WARNING INDICATOR (BIT 1) AND ENGINE BITS (BITS 14 AND 13) INTACT

CLEAR REMODE (14), CDU ZEROING (13) REPOSITION (11) AND TURN-ON (1) FLAGS

WILL TERMINATE THE DRIVING OF MISCELLANEOUS NAVIGATION AND SPACECRAFT HARDWARE AND LEAVE ENABLE CDU IMU ERROR COUNTER, ZERO IMU CDUS AND ENABLE COARSE ALIGNMENT OF IMU, GIMBAL TRIM DRIVES AND RR LOCK-ON ENABLE INTACT

PERFORM RR GIMBAL MONITOR
R77 IS NOT ON

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

ENABLE PROGRAM INTERRUPTED NO. 10

TERMINATES PULSES FROM CDU AND GYRO OUTPUT COUNTERS CDUXCMO, COUYCMO, COUZCMD, CDUTCMO, CDUSCMO AND GYROCMD. ALSO TERMINATES PULSES FROM THROTTLE AND ATTITUDE OUTPUT CONTAINERS THRUST ANO ALTIMETER CONTROL OF TORQUING PULSES TO TORQUE THE GYROS REMAIN INTACT

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CAMBRIDGE, MASS
13 MAY69
E J Hughes 8 AUG 69
W C Danforth 8 AUG 69
8 AUG 69

APOLLO
GUIDANCE AND NAVIGATION

FRESH START AND RESTART

LUMINARY 1D

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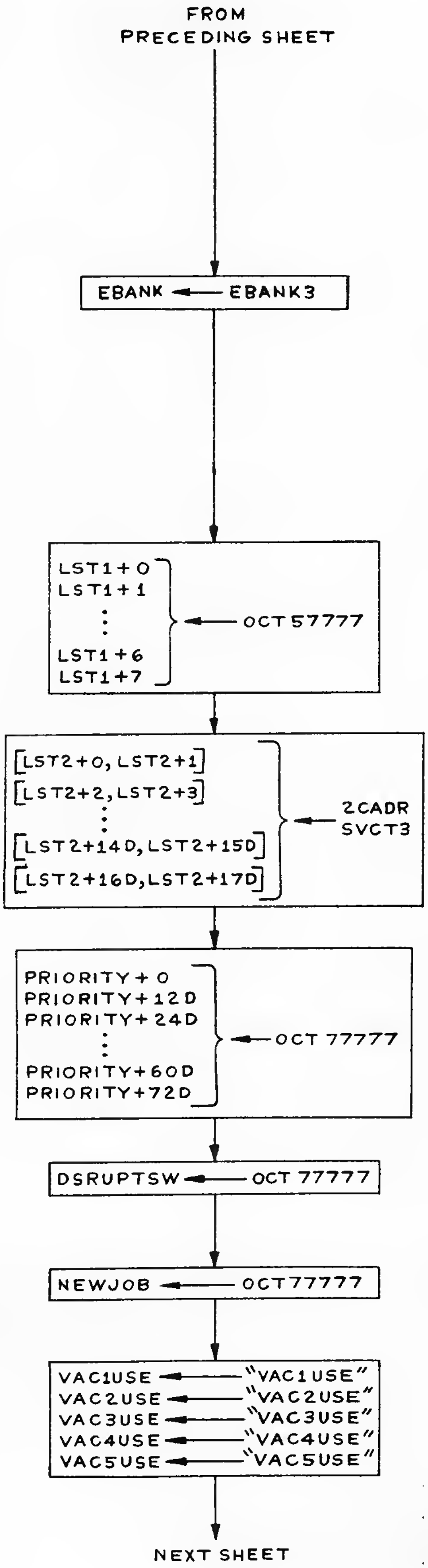


LST1 AND LST2 ARE IN E BANK 3

SCHEDULE TASK SVCT3 IN WAITLIST TO BE EXECUTED 81.93 SECONDS FROM NOW AND EVERY 81.93 SECONDS THEREAFTER UNTIL A REGULAR TASK HAS BEEN SCHEDULED. T3RUPT WILL PLACE OCT 17777 (OCT 57777 PLUS OCT 37777) INTO COUNTER TIME3 WHICH WILL RESULT IN 81.93 SECONDS

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

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

INITIALIZES T4RUPT. SEQUENCE OF T4RUPT FUNCTIONS WILL START OVER AGAIN. FRESH START CHANGES THIS; RESTART DOES NOT

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

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

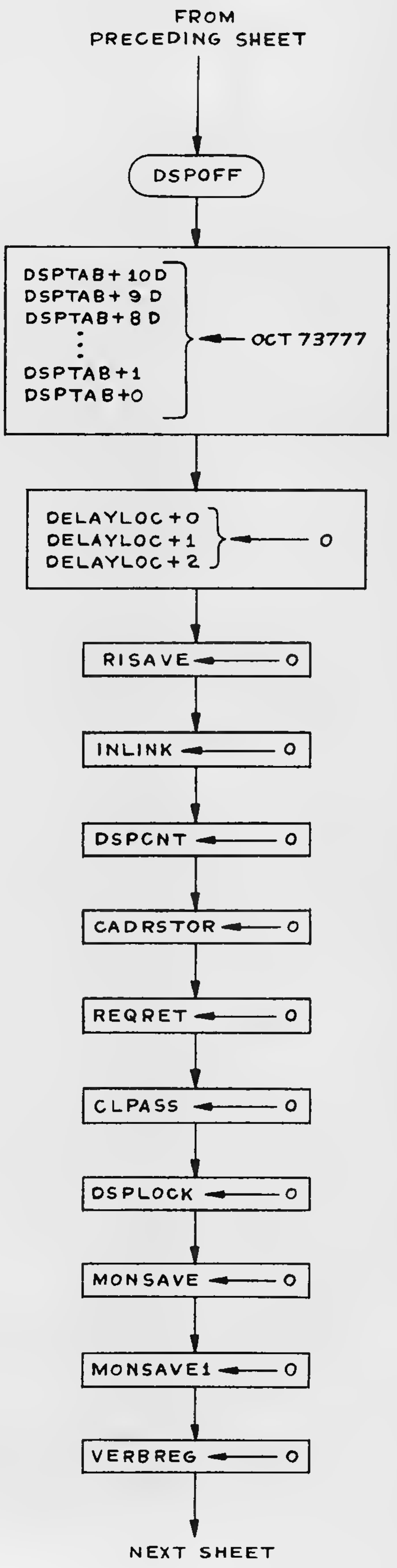
G. J. Lanzillo 10APR68
P. Rye 5-31-68
C. G. Beck 5-31-68
J. Henig 5-31-68

FRESH START AND RESTART

LUMINARY 1D

FC-3010

3 11 39



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

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

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

CLEAR THE INLINK COUNTER OF ALL UPLINK DATA

CAUSES T4RUPT TO SCAN THE DSPTAB TABLE AT DSPTAB+0 FOLLOWED BY DSPTAB+10, +9, ETC

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

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

THE CLEAR BUTTON MAY BE USED TO CLEAR THE DISPLAY REGISTERS CONSECUTIVELY

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

THE VERB DISPLAY WINDOW IS BLANK

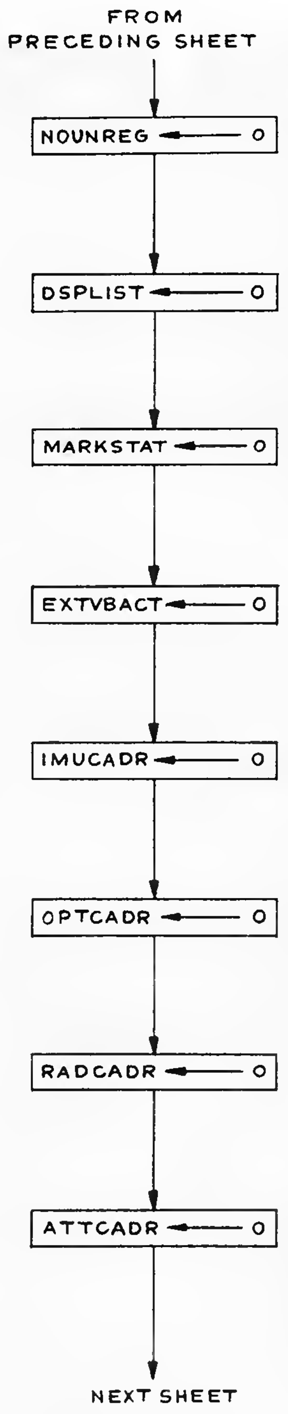
J. J. Lanzillo 17APR68
P. Kyr 5-31-68
C. G. Beck 5-31-68
J. Heinz 5-31-68

FRESH START AND RESTART

LUMINARY 1D

FC-3010

3 12 39



THE NOUN DISPLAY WINDOW IS BLANK

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

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

TERMINATES EXTENDED VERB AND MARK ACTIVITY

NO JOB IS IN THE DORMANT STATE AWAITING THE COMPLETION OF AN IMU MODE SWITCH. SEE NOTES A & B BELOW

NO JOB IS IN THE DORMANT STATE AWAITING THE COMPLETION OF AN OPTICS MODE SWITCH. SEE NOTES A & B BELOW

NO JOB IS IN THE DORMANT STATE AWAITING THE COMPLETION OF A RADAR MODE SWITCH. SEE NOTES A & B BELOW

PROGRAM KALCMANU IS AVAILABLE (FREE). SEE NOTE B BELOW

NOTES:

A. THE SYSTEM IS PREPARED TO PUT A JOB REQUESTING A MODE CHANGE INTO A DORMANT STATE UNTIL THE SWITCH HAS BEEN COMPLETED

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

17APR 68
P. Kye 5-31-68
C. G. Beck 5-31-68
J. Heniza 5-31-68

FRESH START AND RESTART

LUMINARY 1D

FC-3010

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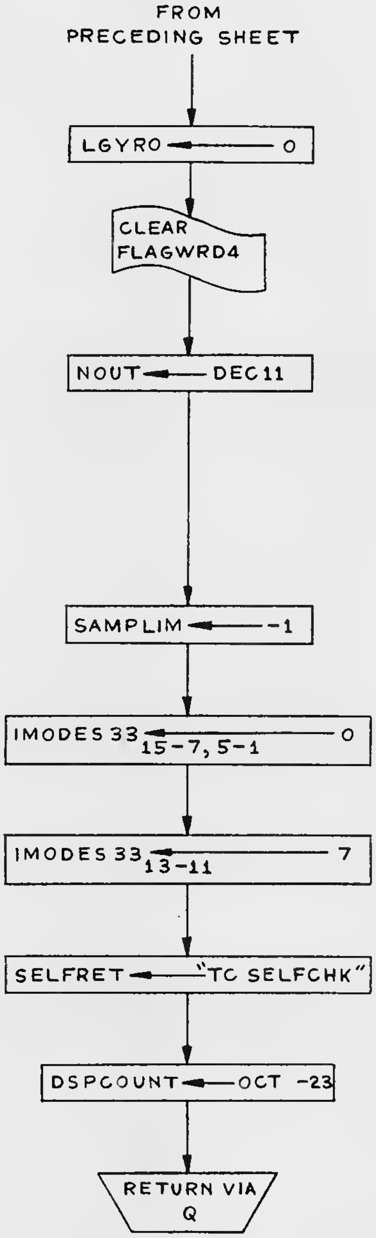

THE GYROS ARE AVAILABLE TO BE PULSED

TURN OFF INTERFACE DISPLAYS

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

INHIBIT RADAR READ ROUTINE IN P20-P25 PROGRAM

LEAVE DAP ENABLE SWITCH INTACT (BIT 6)

NO ACCELEROMETER FAIL. DOWN TELEMETRY AND UPLINK RATES ARE NORMAL

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

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

END OF SUBROUTINE STARTSUB

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DRAWN 18 APR68
PRGMR 5-31-68
ANALST
DOCMR C. G. Beck 5-31-68
APPR'D 5-31-68

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GUIDANCE AND NAVIGATION

FRESH START AND RESTART

LUMINARY 1D

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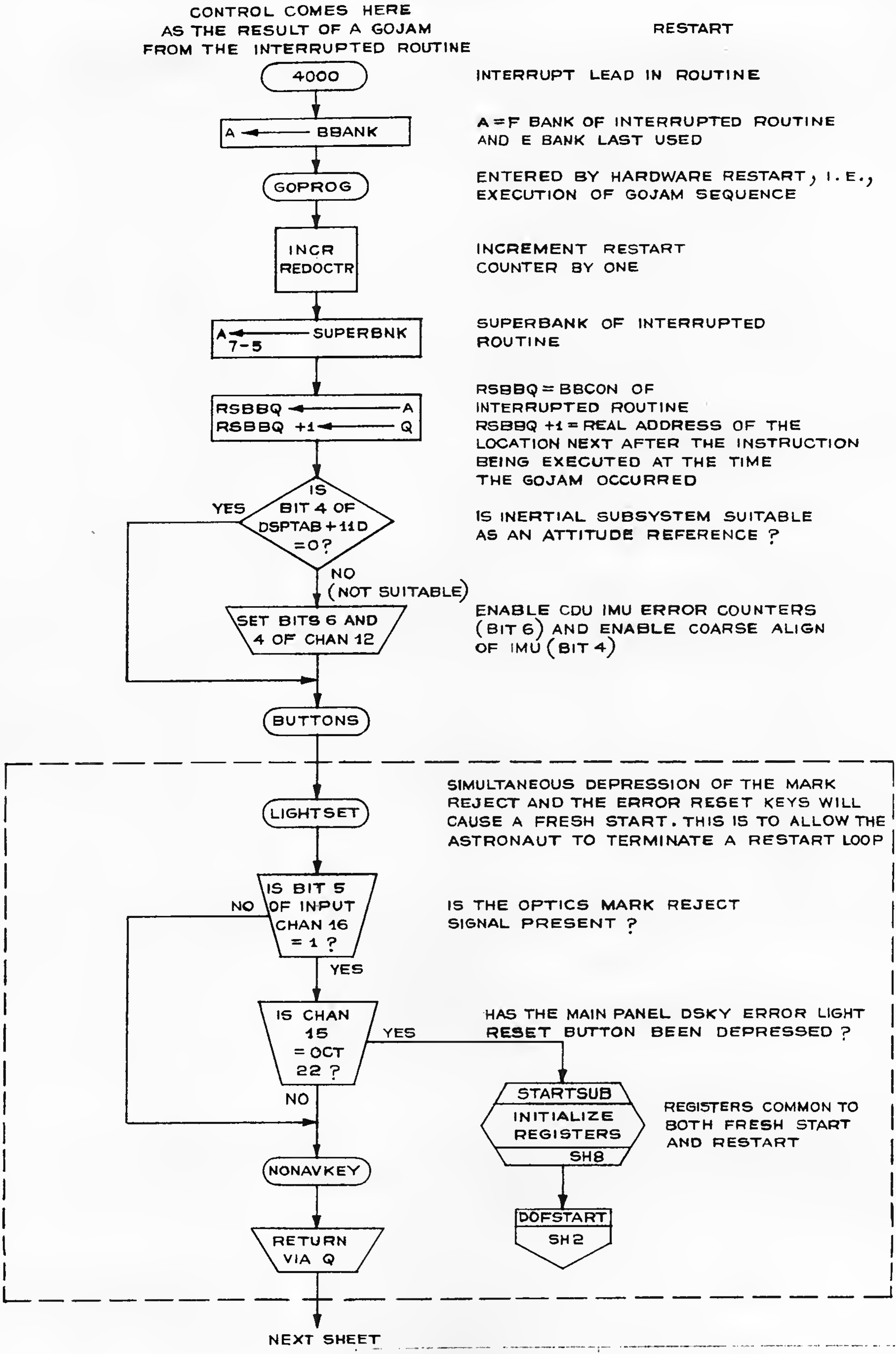
CONTROL COMES HERE
AS THE RESULT OF A GOJAM
FROM THE INTERRUPTED ROUTINE

RESTART



INTERRUPT LEAD IN ROUTINE

A = F BANK OF INTERRUPTED ROUTINE
AND E BANK LAST USED

ENTERED BY HARDWARE RESTART, I.E.,
EXECUTION OF GOJAM SEQUENCE

INCREMENT RESTART
COUNTER BY ONE

SUPERBANK OF INTERRUPTED
ROUTINE

RSBBQ = BBCON OF
INTERRUPTED ROUTINE
RSBBQ +1 = REAL ADDRESS OF THE
LOCATION NEXT AFTER THE INSTRUCTION
BEING EXECUTED AT THE TIME
THE GOJAM OCCURRED

IS INERTIAL SUBSYSTEM SUITABLE
AS AN ATTITUDE REFERENCE ?

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

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

IS THE OPTICS MARK REJECT
SIGNAL PRESENT ?

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

REGISTERS COMMON TO
BOTH FRESH START
AND RESTART

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DRAWN 28MAY69
CHKR E. Hughes 8 AUG 69
ANALST
DOLMR 6 AUG 69
APPRVD 8 AUG 69

APOLLO
GUIDANCE AND NAVIGATION

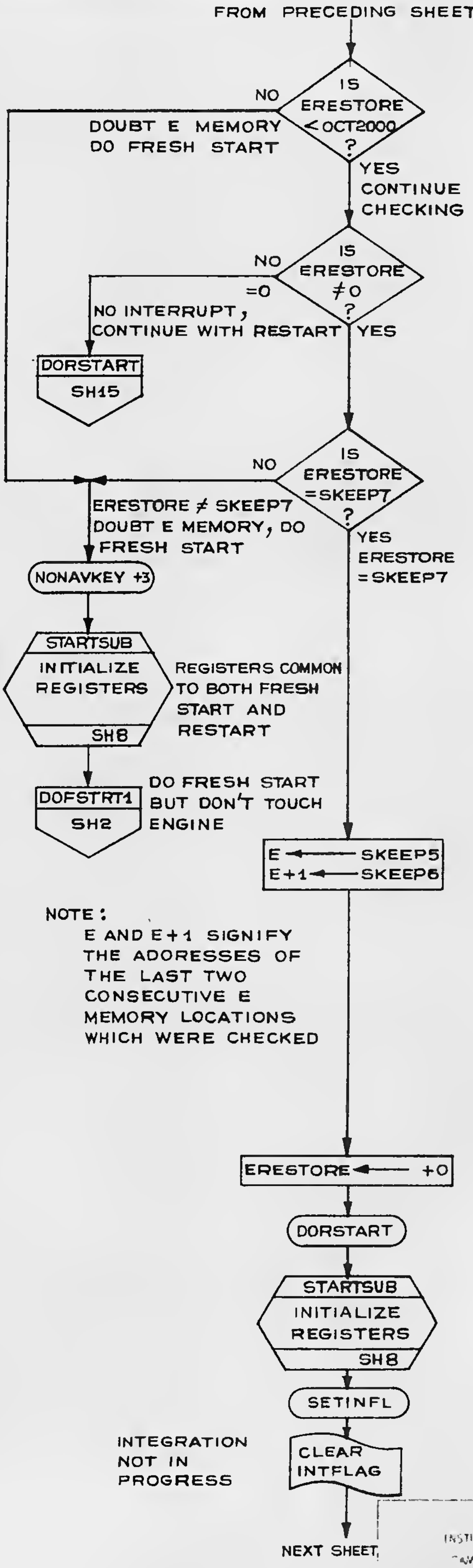
FRESH START AND RESTART

LUMINARY 1D

DOCUMENT NO.
FC-3010

REV 3

SHEET 15 OF 39



DOES E MEMORY SATISFY INITIAL CHECK ?

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

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

IS E MEMORY SATISFACTORY ?

NOTE:
THE E MEMORY ADDRESS TO BE CHECKED WAS STORED IN BOTH REGISTERS BY ROUTINE ERASCHK PRIOR TO THE CHECKING
PRIOR TO CHECKING E MEMORY LOCATIONS E AND E+1, THE ORIGINAL CONTENTS OF E AND E+1 WERE TEMPORARILY STORED INTO REGISTERS SKEEP 5 AND SKEEP 6, RESPECTIVELY. ALSO ADDRESS E WAS STORED INTO REGISTERS SKEEP7 AND ERESTORE

RESTORE ORIGINAL CONTENTS

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

OCT 1461 $\leqq$ E $\leqq$ OCT 1776
IN E BANK 0
OR OCT 1400 $\leqq$ E $\leqq$ OCT 1776
IN E BANK 1, 3, 4, 5, 6 OR 7
OR OCT 1400 $\leqq$ E $\leqq$ OCT 1772
IN E BANK 2

INDICATES THAT

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

REGISTERS COMMON TO BOTH FRESH START AND RESTART

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CAMBRIDGE, MASS.

DRAWN 28MAY69
CHECKED E. Hughes 8AUG69
ANALYST
ENGINEER WC Danforth 8AUG69
APPROVED 8AUG69

3

APOLLO
GUIDANCE AND NAVIGATION

FRESH START AND RESTART

LUMINARY 1D

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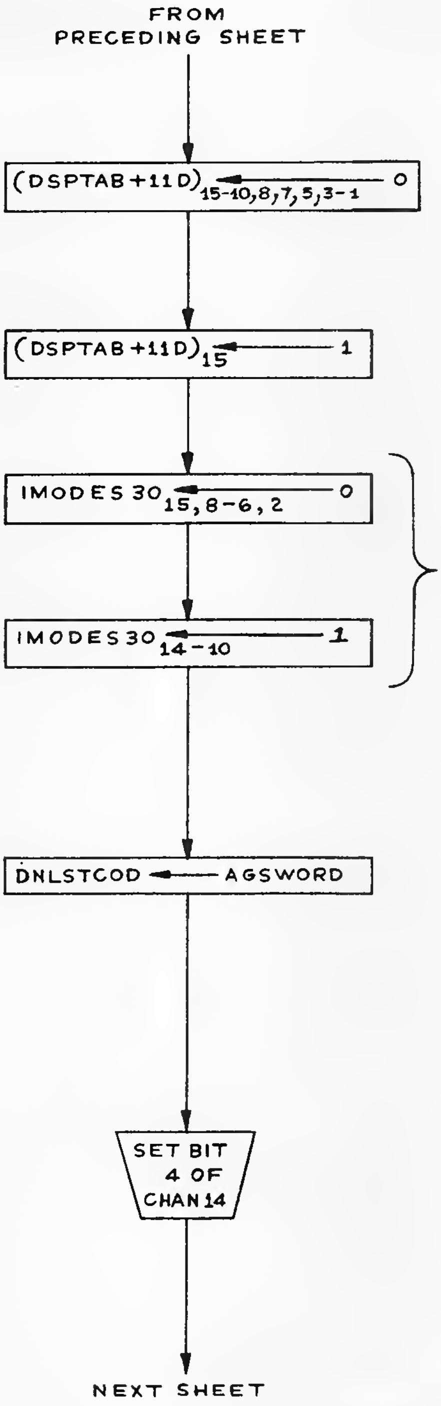

NO OPTICS CDU MALFUNCTION. PROGRAM ALARM, GIMBAL LOCK AND NO-ATTITUDE LAMPS REMAIN INTACT (BITS 4, 6 AND 9)

A CHANGE (BIT 8) IN DSPTAB + 11D HAS TAKEN PLACE SINCE THE LAST TRANSMISSION OF ITS CONTENTS BY T4RUPT PROGRAM

INITIALIZE FAILURE CODES AND TURN-ON REQUEST. FAILURE INHIBITS REMAIN INTACT (BITS 9, 5-3 AND 1)

CORRECT DOWNLIST

ENABLE THRUST DRIVE COMMANDS

A. J. Lanzillo 24APR68
P. Keys 5-31-68
C. G. Beck 5-31-68
J. Heinz 5-31-68

FRESH START AND RESTART

LUMINARY 1D

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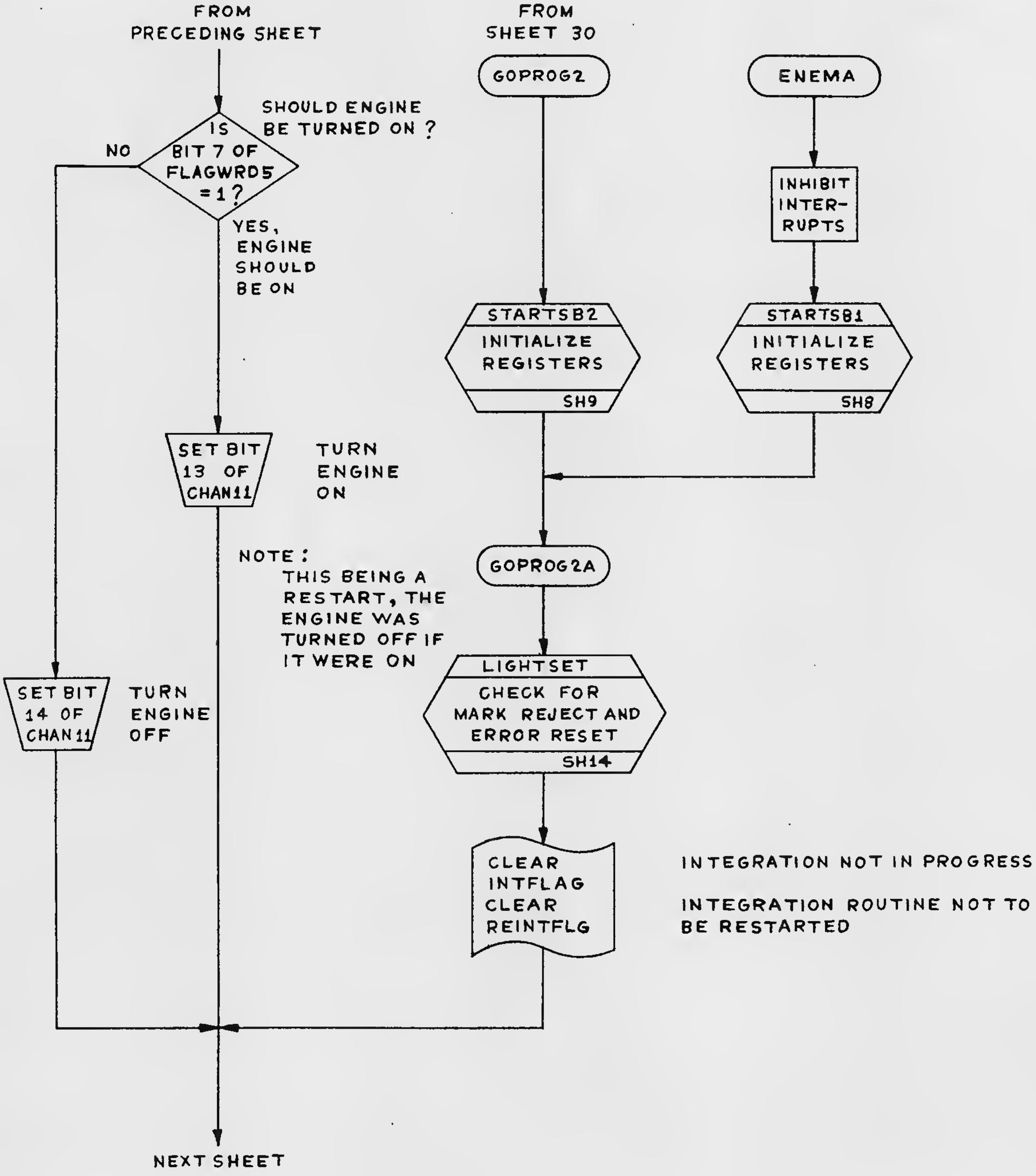

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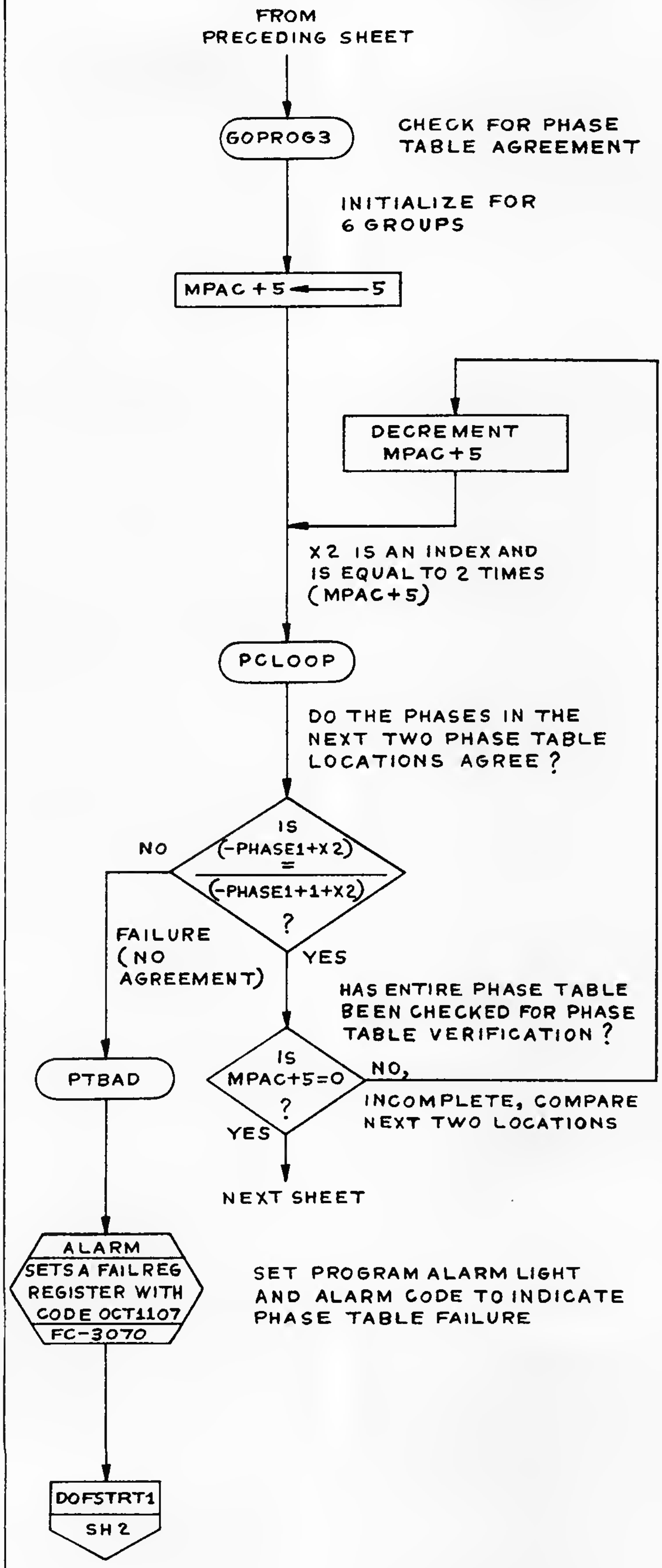
DRAWN	15 MAY 69	FRESH START AND RESTART
PRGMR	8 AUG 69	
ANALYST		LUMINARY 1D — DOCUMENT NO. FC-3010
DCLMR	8 AUG 69	
APPR	8 AUG 69	REV 3 — SHEET 18 OF 39



PHASE TABLE REGISTERS

- PHASE1			
PHASE1	EQUALS	-PHASE1	+1
- PHASE2	"	"	+2
PHASE2	"	"	+3
- PHASE3	"	"	+4
PHASE3	"	"	+5
- PHASE4	"	"	+6
PHASE4	"	"	+7
- PHASE5	"	"	+8D
PHASE5	"	"	+9D
- PHASE6	"	"	+10D
PHASE6	"	"	+11D

DOES THE PHASE (IN COMPLEMENT FORM) IN THE 11TH (-PHASE6), 9TH (-PHASE5), ... 1ST (-PHASE1) LINES OF THE PHASE TABLE AGREE WITH THE PHASE (IN TRUE FORM) IN THE 12TH (PHASE6), 10TH (PHASE5), ... 2ND (PHASE1) LINES, RESPECTIVELY, OF THE PHASE TABLE ?

MPAC + 5	A	IS
5	10	-PHASE6 = PHASE6 ?
4	8	-PHASE5 = PHASE5 ?
3	6	-PHASE4 = PHASE4 ?
2	4	-PHASE3 = PHASE3 ?
1	2	-PHASE2 = PHASE2 ?
0	0	-PHASE1 = PHASE1 ?

25APR68
P. Rye 5-31-68
C. G. Beck 5-31-68
5-31-68

FRESH START AND RESTART

LUMINARY 1D

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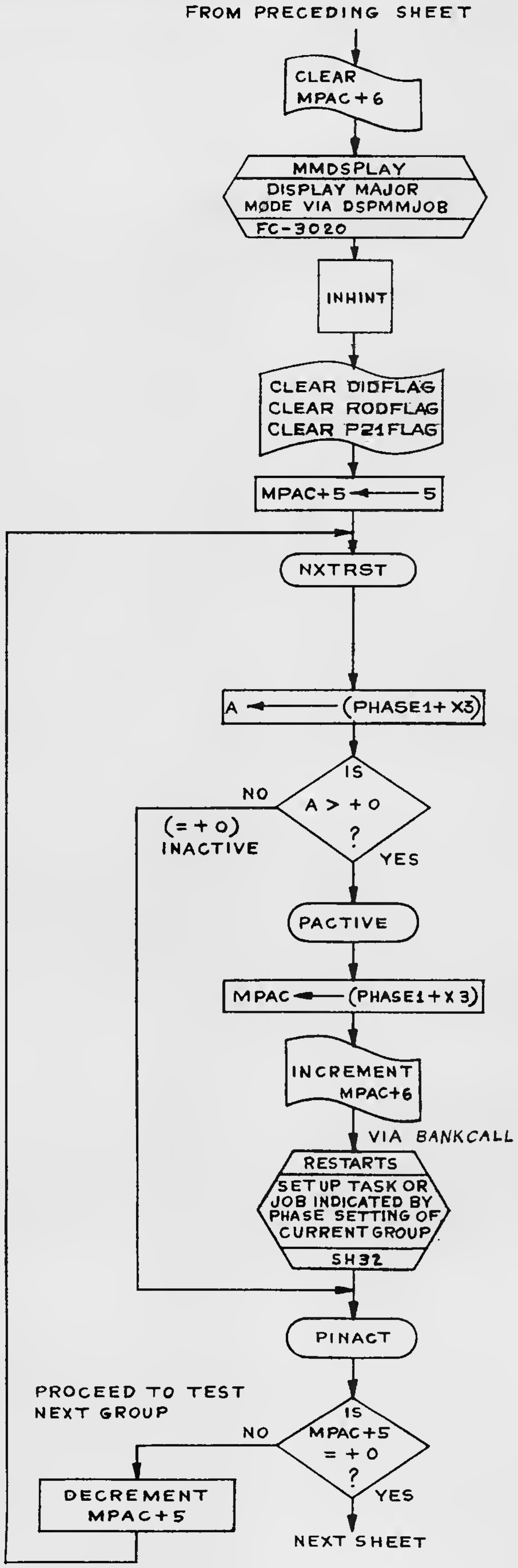

RESET PHASE ACTIVITY FLAG
TO INDICATE INACTIVE STATUS

PERFORM DATA DISPLAY INITIALIZATION FUNCTIONS
IF IN P66 RE-INITIALIZATION IS PERFORMED
CALCULATE NEW BASE STATE VECTORS

INITIALIZE INDEX
FOR SIX GROUPS

SEARCH FOR ACTIVE GROUP

X3 IS A NOTATION FOR THE INDEX AND IS EQUAL TO THE DOUBLE OF THE CONTENTS OF MPAC+5

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 GROUP 5, THEN 4, 3, 2 AND LAST 1 ARE TESTED FOR ACTIVE STATUS

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

SET PHASE ACTIVITY FLAG BY INCREMENTING MPAC+6

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

HAVE ALL GROUPS BEEN TESTED FOR ACTIVE STATUS ?

E. J. Langille 29APR68
P. Rye 5-31-68
C. G. Beck 5-31-68
J. Heinz 5-31-68

FRESH START AND RESTART

LUMINARY 1D

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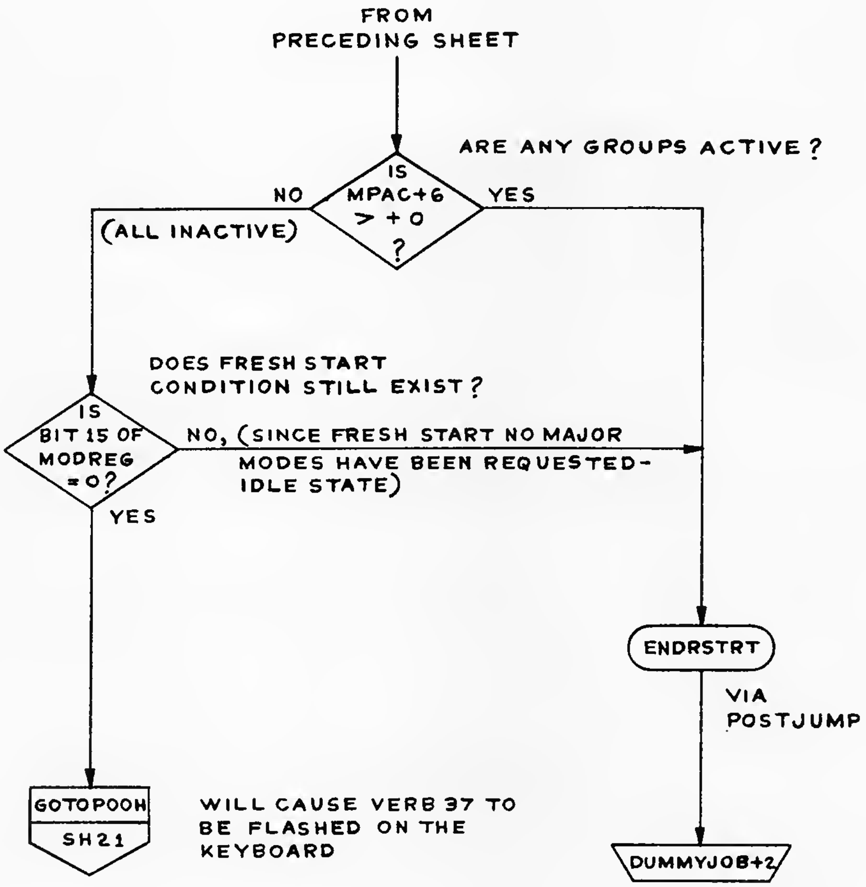

END OF RESTART
(GOPROG AND GOPROG2)

A. J. Lanzillo 30APR68
P. Rye 5-31-68
C. G. Beck 5-31-68
J. Heinze 5-31-68

FRESH START AND RESTART

LUMINARY 1D

FC-3010

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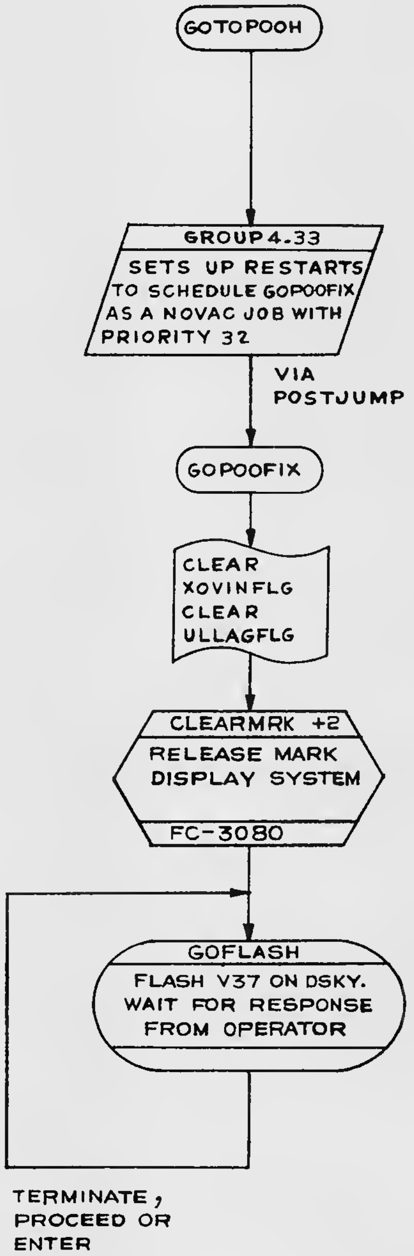
21

FUNCTION:

FLASH V37 ON DSKY REQUESTING ASTRONAUT TO SELECT NEW MAJOR MODE

CALLING SEQUENCE:

TC GOTOPOOH



X - AXIS OVERRIDE OKAY

NO INTERNAL ULLAGE REQUEST

30APR68
5-31-68
C. G. Beck 5-31-68
5-31-68

FRESH START AND RESTART

LUMINARY 1D

3

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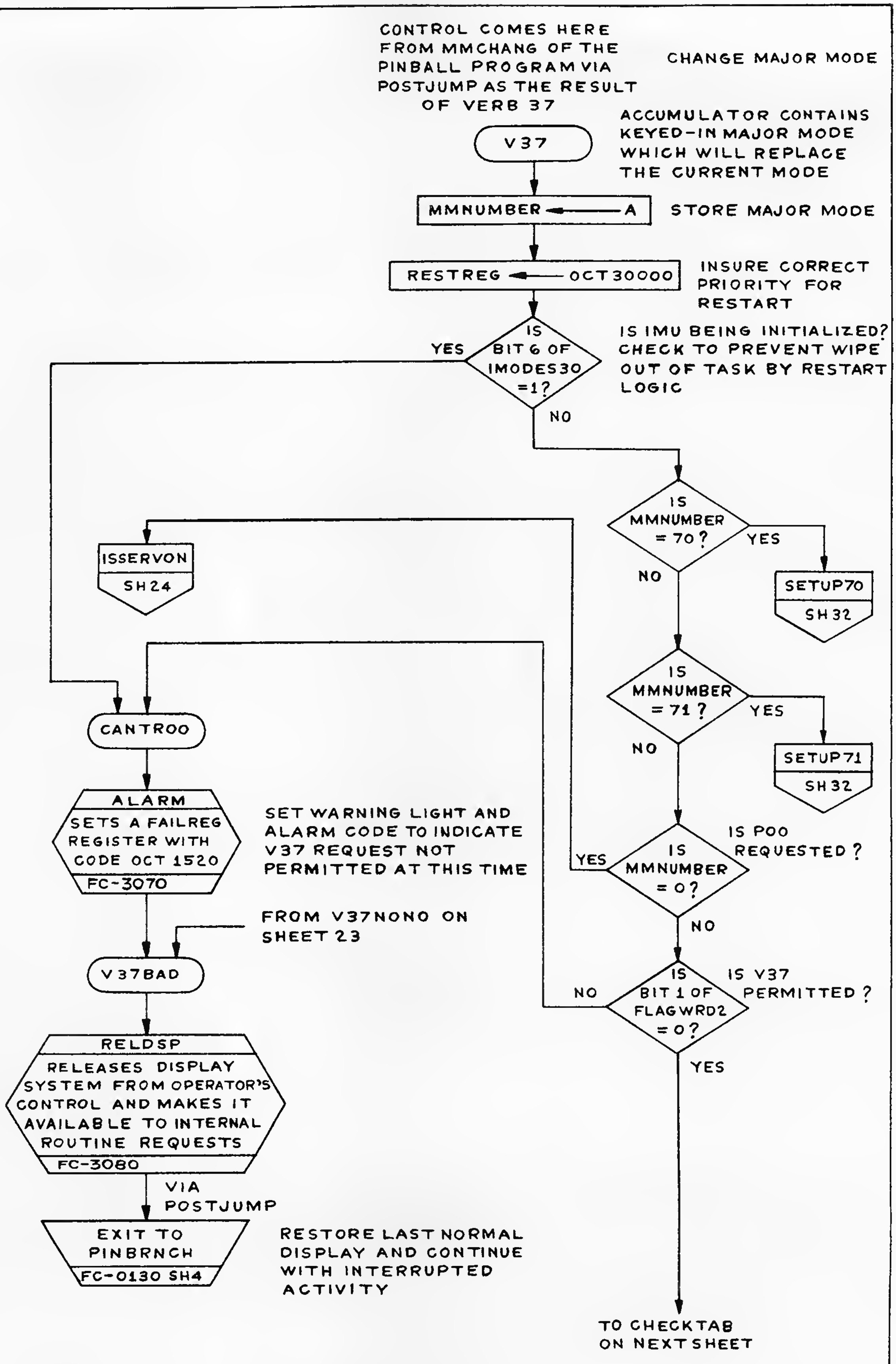

FRESH START AND RESTART

LUMINARY 1D

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G. J. Lanzilli 30APR68
P. Rye 5-31-68
C. G. Beck 5-31-68
J. Heinz 5-31-68

3

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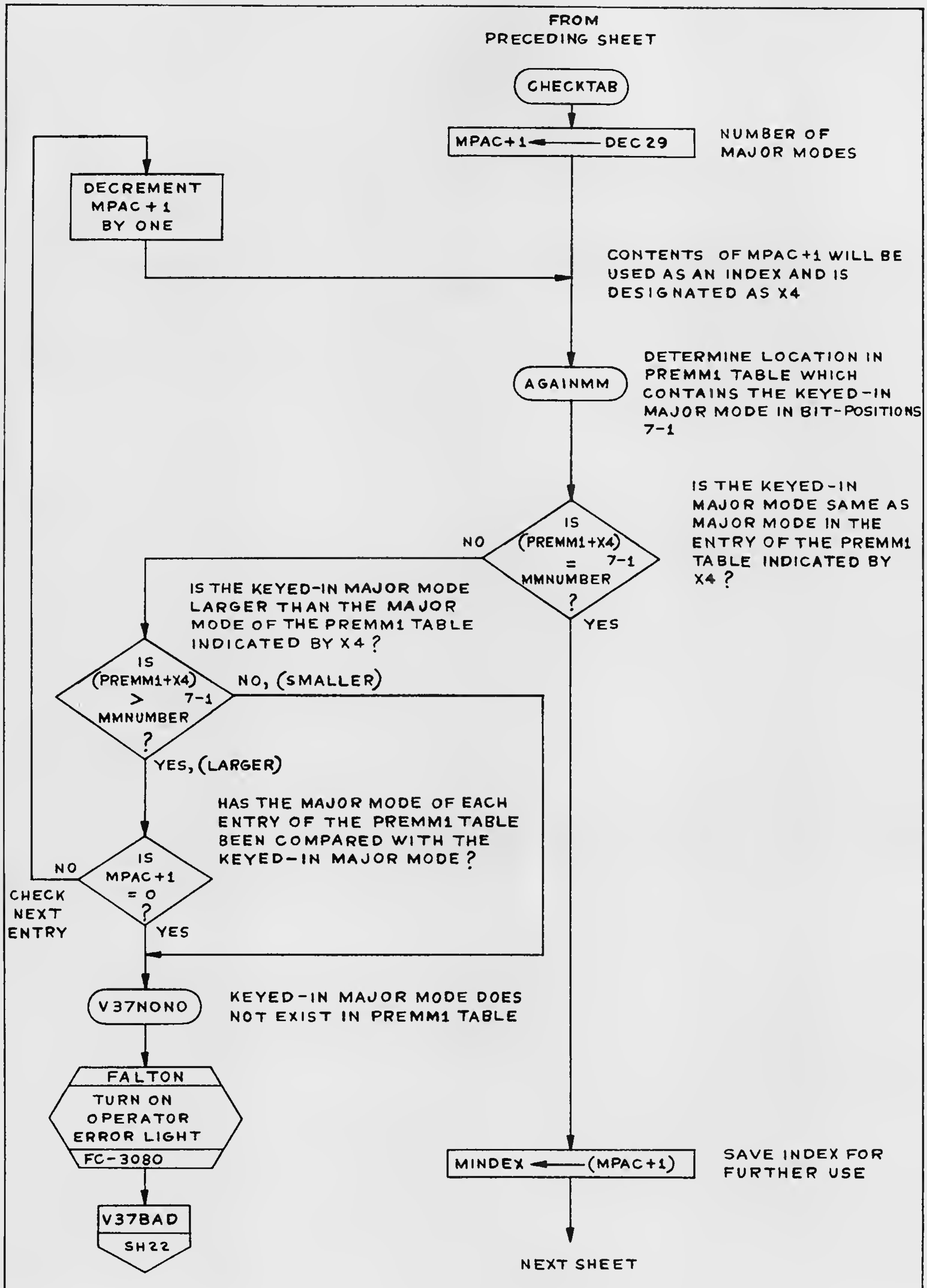

A. J. Langillo 1MAY68
P. Rye 5-31-68
C. G. Beck 5-31-68
J. Heinz 5-31-68

FRESH START AND RESTART

LUMINARY 1D

3

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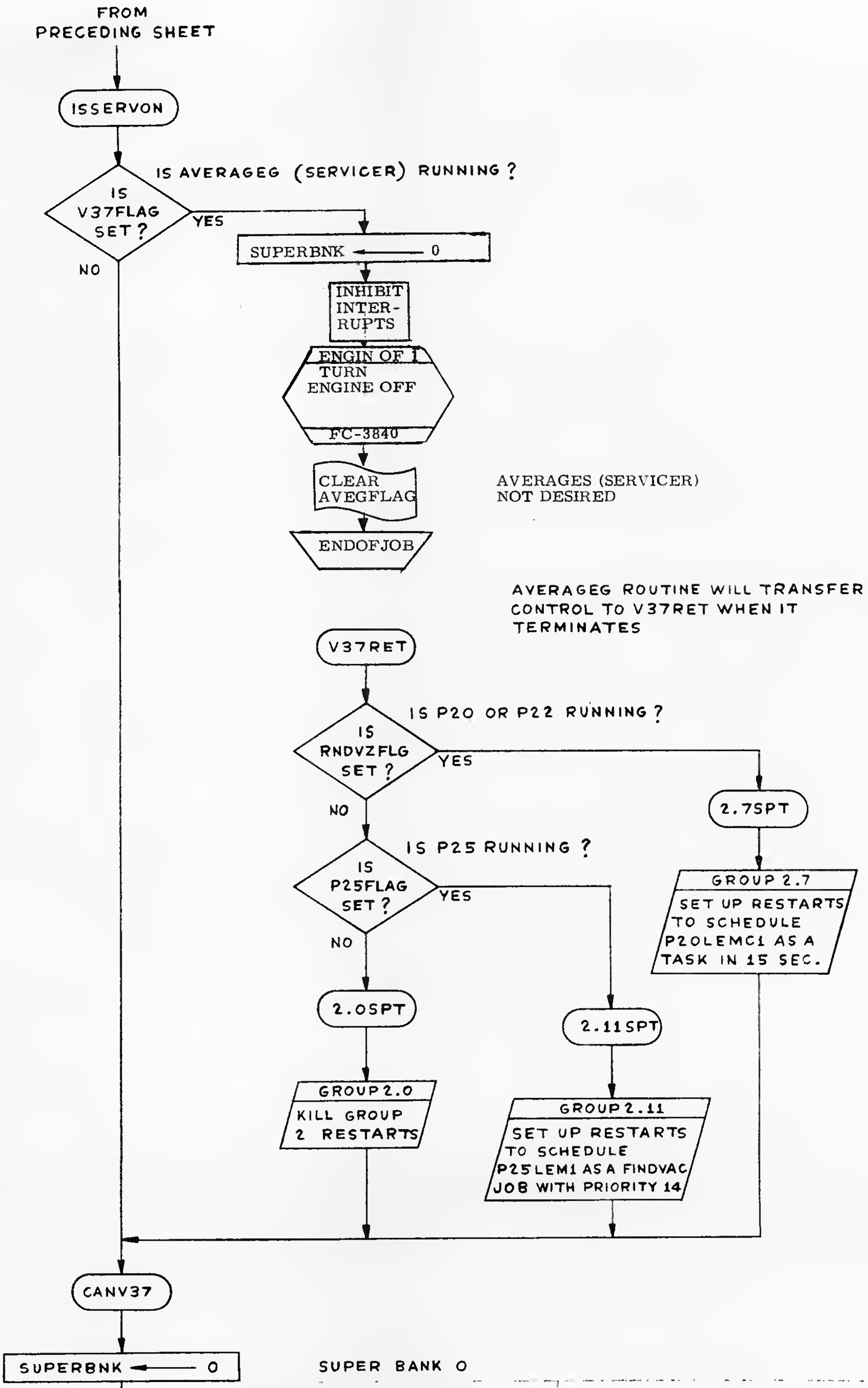


MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS

DRAWN A. J. Lanzillo 16 MAY 69
CHECKED E. Hughes 8 AUG 69
ANALYST
PROG MGR McDonforth 6 AUG 69
APPR'D Alex M. Lorane 8 AUG 69

APOLLO
GUIDANCE AND NAVIGATION

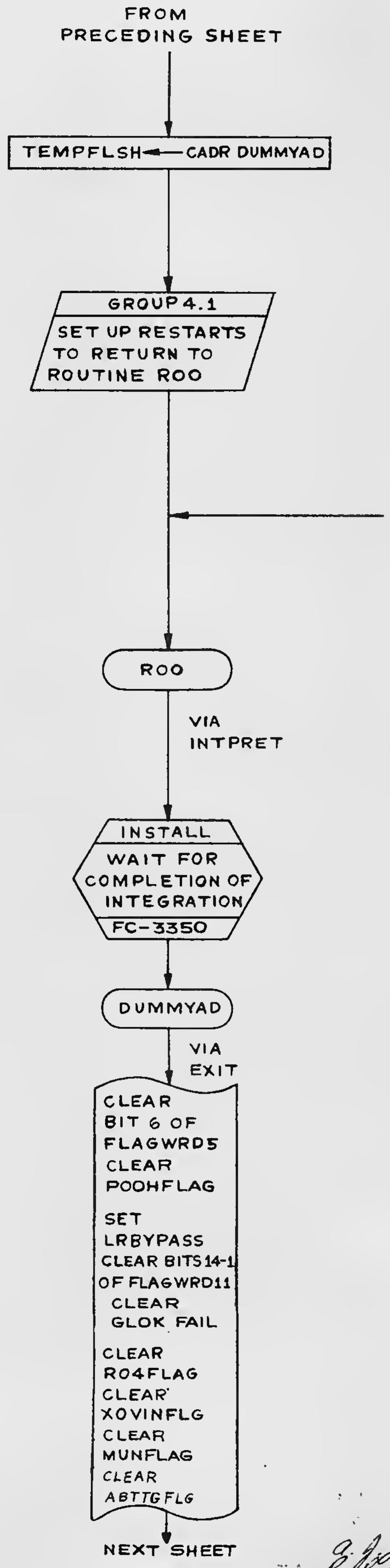
FRESH START AND RESTART

LUMINARY 1D

REV 3

DOCUMENT NO.
FC-3010

SHEET 25 OF 39



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)

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

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

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

MANEUVER SPECIFIED BY ONE AXIS (CLEAR 3AXISFLG)

BYPASS ALL LANDING RADAR UPDATES

NOT READING RR DATA PERSUANT TO R29

X-AXIS OVERRIDE OKAY

SERVICER CALLS CALCRVG

FRESH START AND RESTART

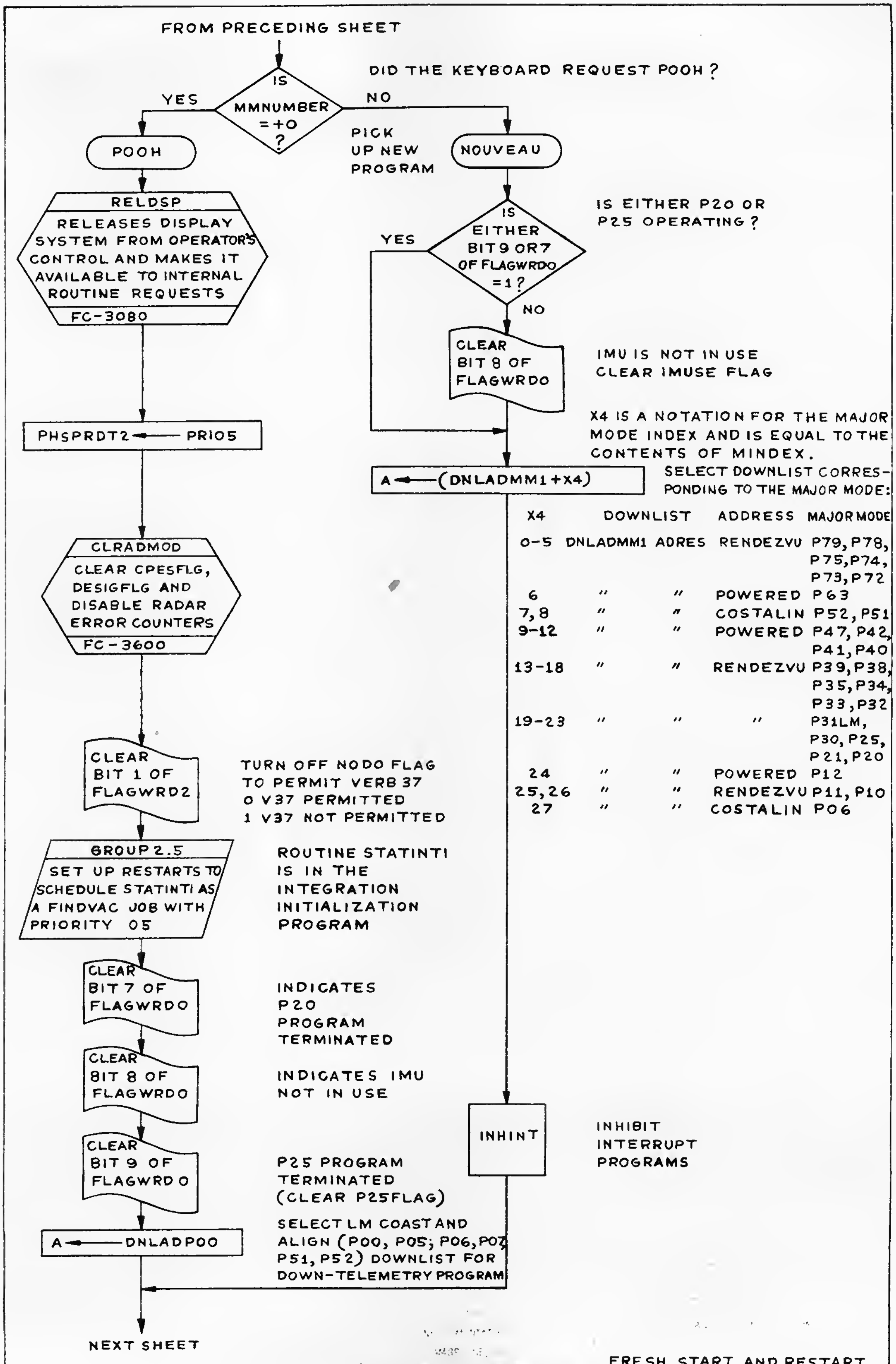
J. J. Lanzillo 2MAY68
P. Kyz 5-31-68
C. G. Beck 5-31-68
J. Henize 5-31-68

LUMINARY 1D

FC-3010

3

26 39



X4	DOWNLIST	ADDRESS	MAJOR MODE
0-5	DNLADMM1 ADRES	RENDEZVU	P79, P78, P75, P74, P73, P72
6	" "	POWERED	P63
7,8	" "	COSTALIN	P52, P51
9-12	" "	POWERED	P47, P42, P41, P40
13-18	" "	RENDEZVU	P39, P38, P35, P34, P33, P32
19-23	" "	"	P31LM, P30, P25, P21, P20
24	" "	POWERED	P12
25,26	" "	RENDEZVU	P11, P10
27	" "	COSTALIN	P06

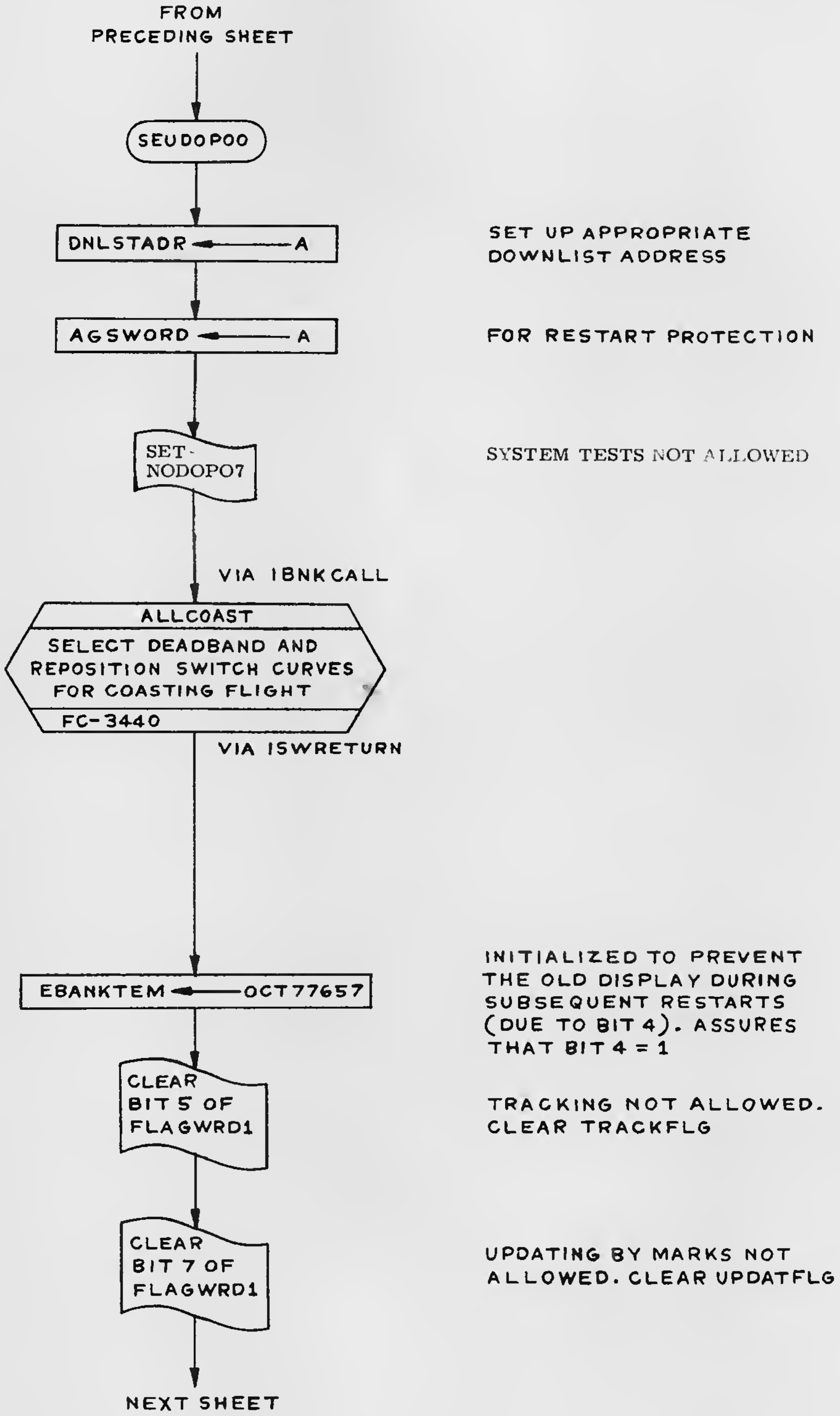
3MAY68
5-31-68.
C. G. Beck 5-31-68
J. Henige 5-31-68

FRESH START AND RESTART

LUMINARY 1D

FC-3010

3 27 39



G. J. Fangillo 3MAY68
P. Rye 5-31-68
C. G. Beck 5-31-68
J. Heinz 5-31-68

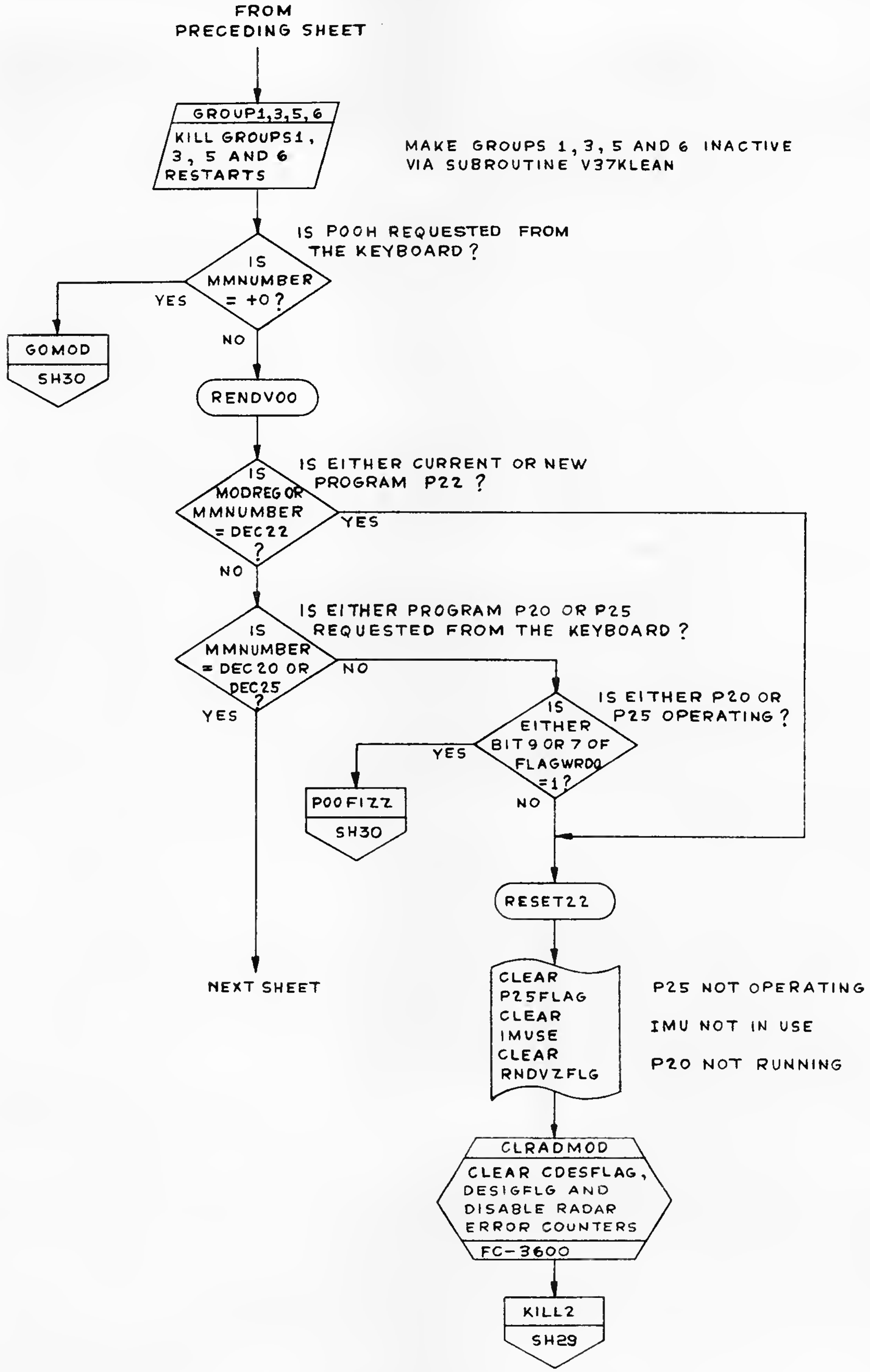
FRESH START AND RESTART

LUMINARY 1D

FC-3010

8

28 39



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a. J. Lanzillo 19MAY69
T. J. Hughes 8 AUG 69
W C Danforth 6 AUG 69
Alicia M. Sorant 8 AUG 69

REV 3

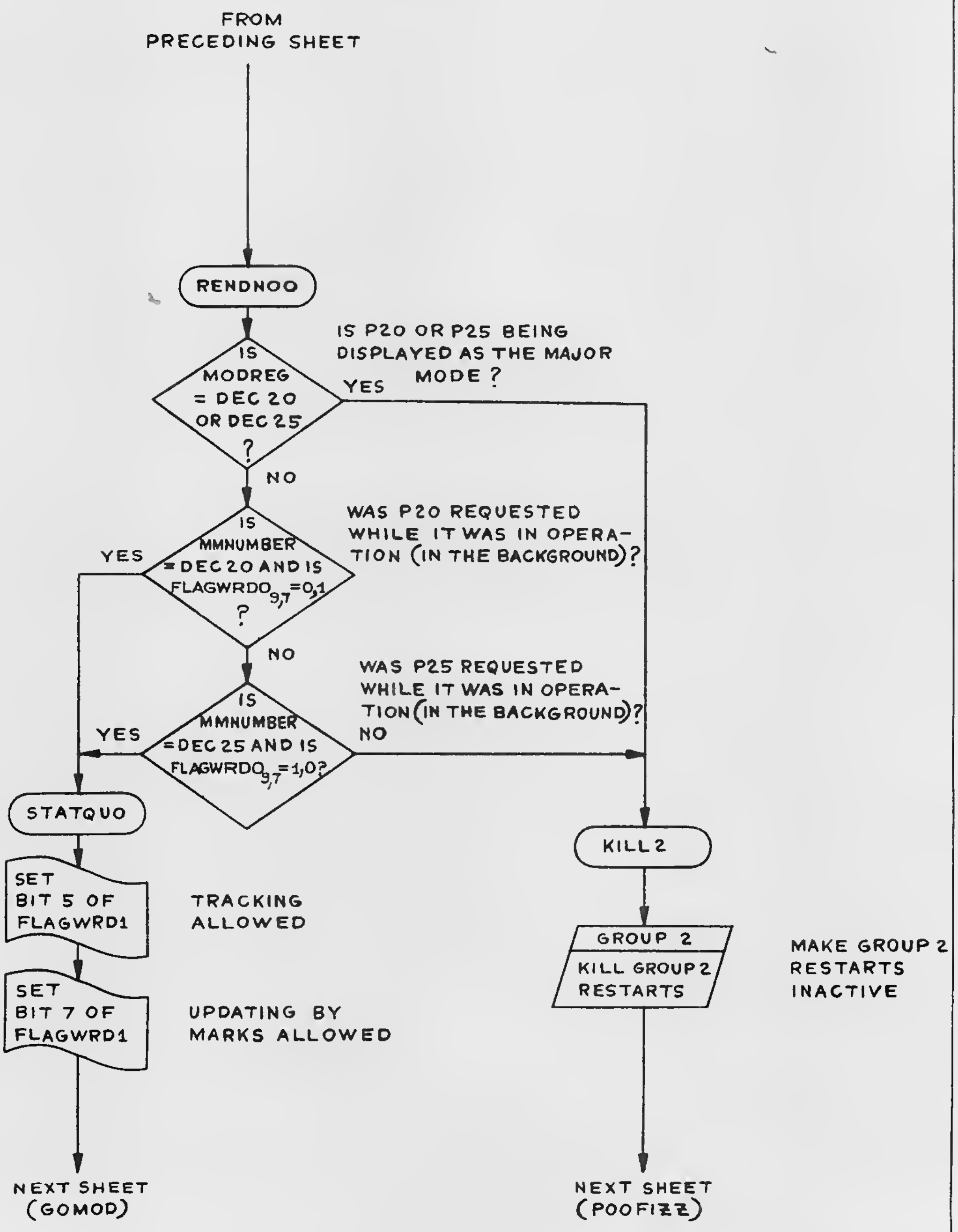
APOLLO
GUIDANCE AND NAVIGATION

FRESH START AND RESTART

LUMINARY 1D

DOCUMENT NO.
FC-3010

SHEET 29 OF 39



a.j. Lanzillo 6MAY68
P. Rye 5-31-68
C. G. Beck 5-31-68
J. Heinz 5-31-68

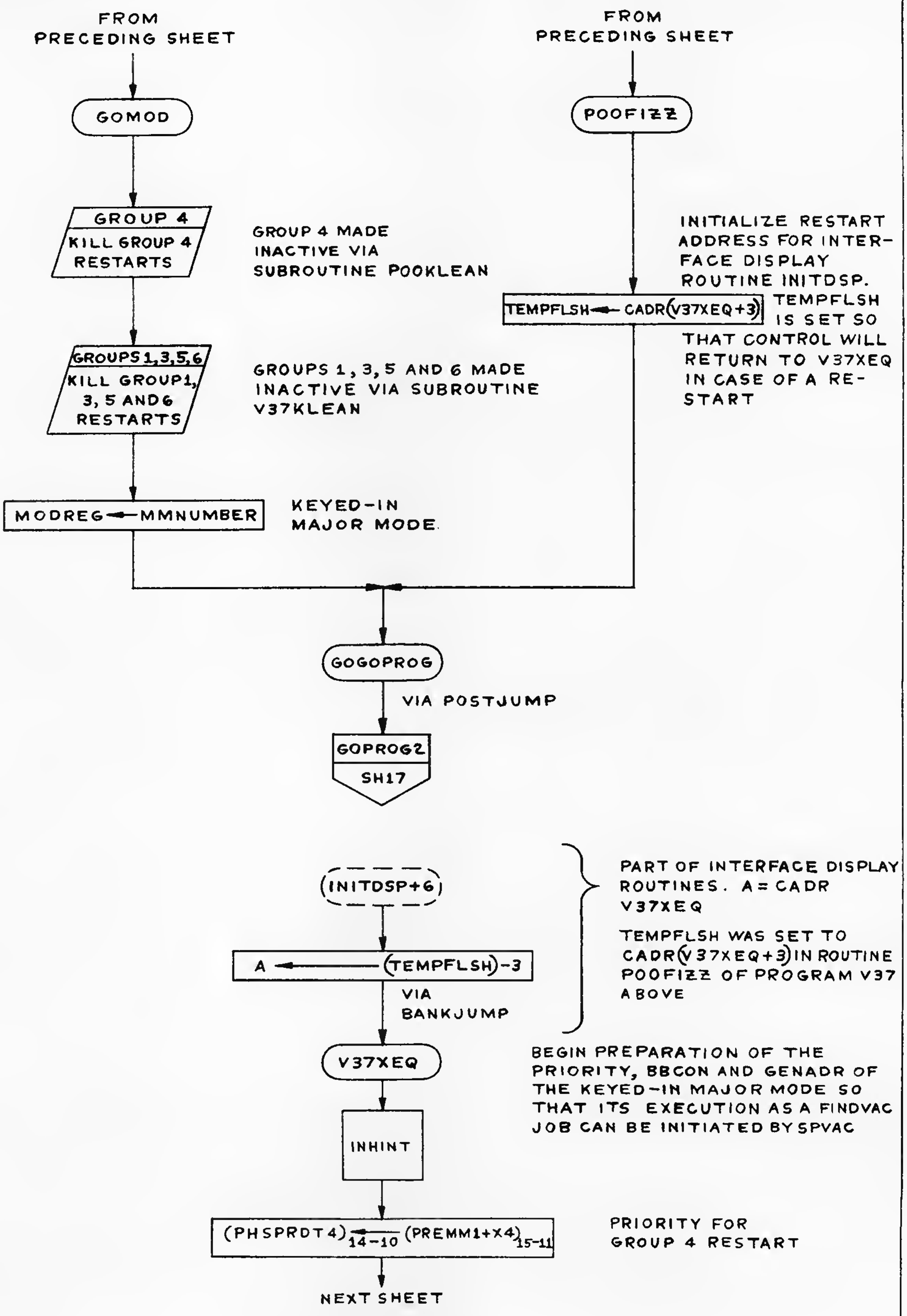
FRESH START AND RESTART

LUMINARY 1D

FC-3010

3

30 39



6MAY68
5-31-68
C. G. Beck 5-31-68
5-31-68

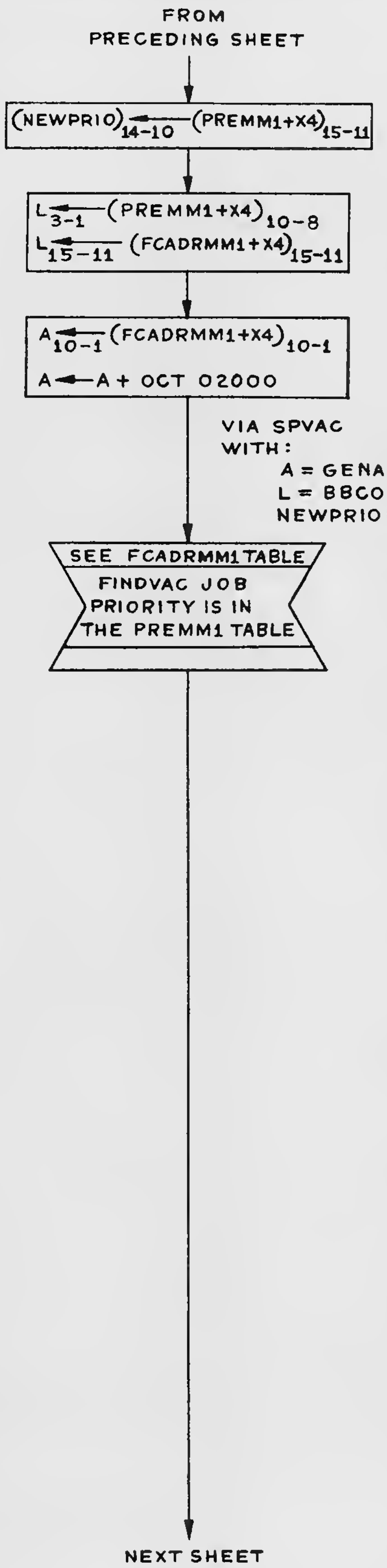
FRESH START AND RESTART

LUMINARY 1D

FC-3010

3

31 39



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

PRIORITY STORED INTO BIT-POSITIONS 14 - 10 OF NEWPRIO

EBANK }
FBANK } BBCON FORMED IN L

GENADR FORMED IN A

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

REQUEST THE EXECUTIVE PROGRAM TO INITIATE THE EXECUTION OF THE KEYED-IN MAJOR MODE ACCORDING TO THE PRIORITY IN NEWPRIO. THE 2CADR AND PRIORITY OF THE KEYED-IN MAJOR MODE WERE DERIVED ABOVE FROM THE FCADRMM1 AND PREMM1 TABLES AS FOLLOWS:

$PREMM1_{15-11}$ = PRIORITY
$PREMM1_{10-8}$ = E BANK NUMBER
$PREMM1_{7-1}$ = MAJOR MODE NUMBER
FCADRMM1 = FCADR OF THE MAJOR MODE

PREMM1 TABLE (OCT)	PRIORITY (OCT)	E BANK NO.	MAJOR MODE NO. (DEC)	FCADRMM1 TABLE FCADR OF
27717	13	7	79	P79
27716	13	7	78	P78
27713	13	7	75	P75
27712	13	7	74	P74
27711	13	7	73	P73
27710	13	7	72	P72
27677	13	7	63	P63LM
27264	13	5	52	PROG52
27263	13	5	51	P51
27657	13	7	47	P47LM
27652	13	7	42	P42LM
27651	13	7	41	P41LM
27650	13	7	40	P40LM
27647	13	7	39	P39
27646	13	7	38	P38
27643	13	7	35	P35
27642	13	7	34	P34
27641	13	7	33	P33
27640	13	7	32	P32
27637	13	7	31	P31LM
27636	13	7	30	P30
27631	13	7	25	PROG25
27625	13	7	21	PROG21
27624	13	7	20	PROG20
27614	13	7	12	P12LM
27613	13	7	11	P11
27612	13	7	10	P10
27006	13	4	06	P06

A. J. Lanzillo 7MAY68
P. Rye 5-31-68
C. G. Beck 5-31-68
J. Haig 5-31-68

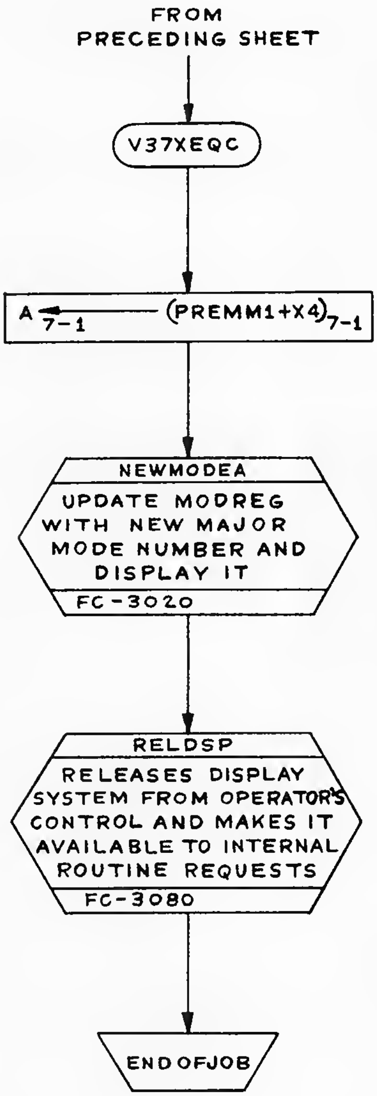
FRESH START AND RESTART

LUMINARY 1D

3

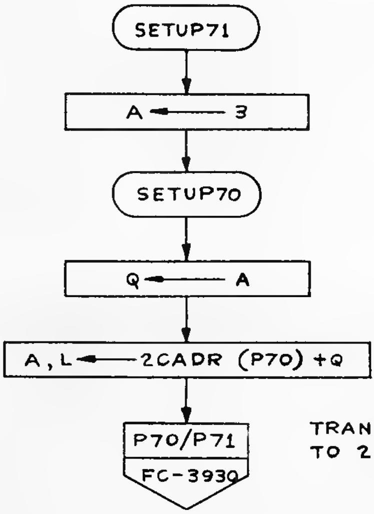
FC-3010

32 39



NEW (KEYED-IN)
MAJOR MODE NUMBER

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



TRANSFER CONTROL
TO 2CADR IN A, L

8MAY68
5-31-68
C. G. Beck 5-31-68
5-31-68

FRESH START AND RESTART

LUMINARY 1D

FC-3010

3 33 39

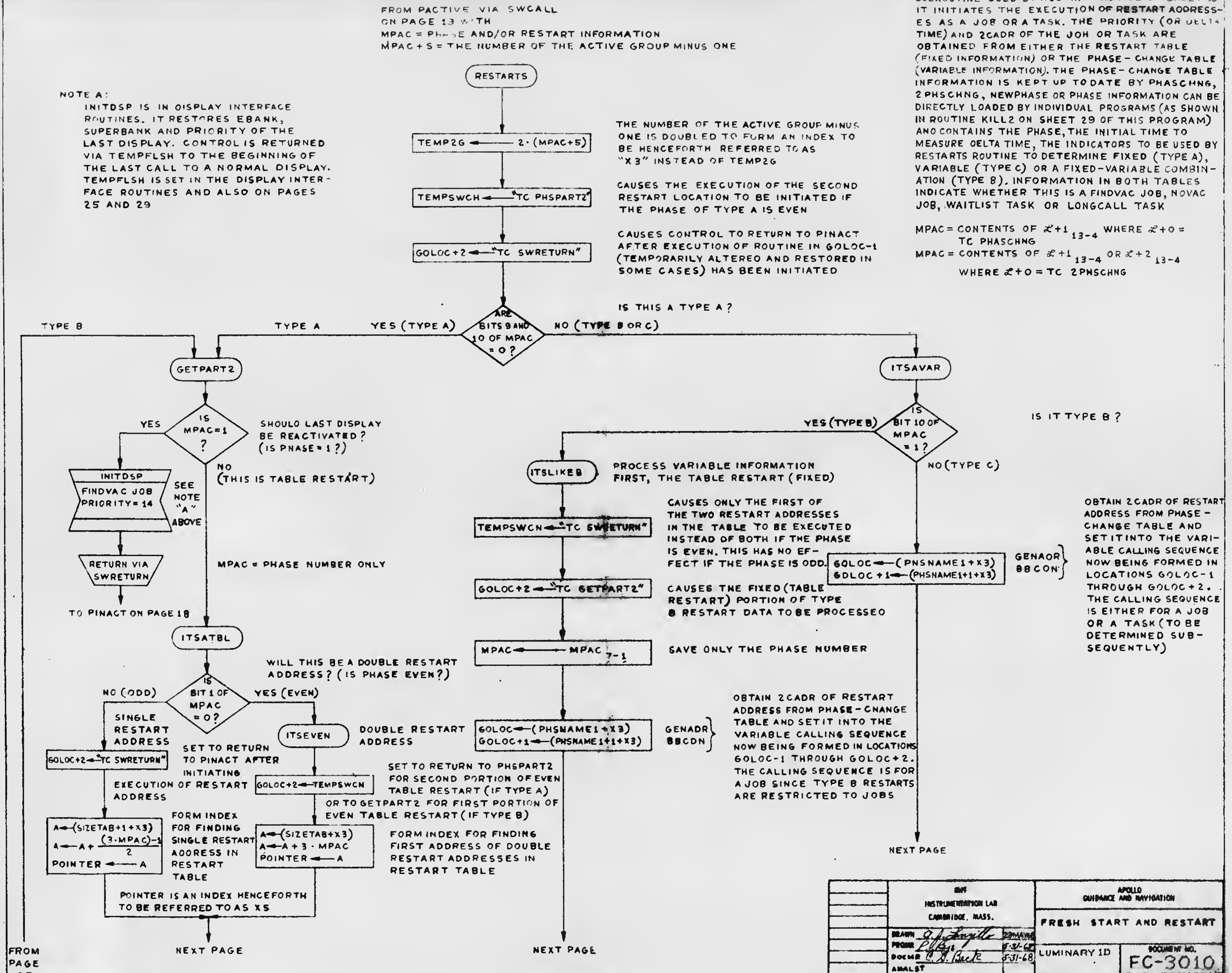
SUBROUTINE USED BY ROUTINE PACTIVE ON SHEET 19 IT INITIATES THE EXECUTION OF RESTART ADDRESSES AS A JOB OR A TASK. THE PRIORITY (OR DELTA TIME) AND 2CADR OF THE JOB OR TASK ARE OBTAINED FROM EITHER THE RESTART TABLE (FIXED INFORMATION) OR THE PHASE-CHANGE TABLE (VARIABLE INFORMATION). THE PHASE-CHANGE TABLE INFORMATION IS KEPT UP TO DATE BY PHASCHNG, 2PHSCHNG, NEWPHASE OR PHASE INFORMATION CAN BE DIRECTLY LOADED BY INDIVIDUAL PROGRAMS (AS SHOWN IN ROUTINE KILL2 ON SHEET 29 OF THIS PROGRAM) AND CONTAINS THE PHASE, THE INITIAL TIME TO MEASURE DELTA TIME, THE INDICATORS TO BE USED BY RESTARTS ROUTINE TO DETERMINE FIXED (TYPE A), VARIABLE (TYPE C) OR A FIXED-VARIABLE COMBINATION (TYPE B). INFORMATION IN BOTH TABLES INDICATE WHETHER THIS IS A FINDVAC JOB, NOVAC JOB, WAITLIST TASK OR LONGCALL TASK

MPAC = CONTENTS OF $\mathcal{L}+1_{13-4}$ WHERE $\mathcal{L}+0$ = TC PHASCHNG

MPAC = CONTENTS OF $\mathcal{L}+1_{13-4}$ OR $\mathcal{L}+2_{13-4}$ WHERE $\mathcal{L}+0$ = TC 2PHSCHNG

NOTE A:

INITDSP IS IN DISPLAY INTERFACE ROUTINES. IT RESTORES EBANK, SUPERBANK AND PRIORITY OF THE LAST DISPLAY. CONTROL IS RETURNED VIA TEMPFLSH TO THE BEGINNING OF THE LAST CALL TO A NORMAL DISPLAY. TEMPFLSH IS SET IN THE DISPLAY INTERFACE ROUTINES AND ALSO ON PAGES 25 AND 29



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DRAWN Q. J. Longillo 29MAY68
PROGR P. Koz 5-31-68
DOCMR C. H. Beck 5-31-68
ANALST
APPR'D J. Henig 5-31-68
USED ON

APOLLO
GUIDANCE AND NAVIGATION

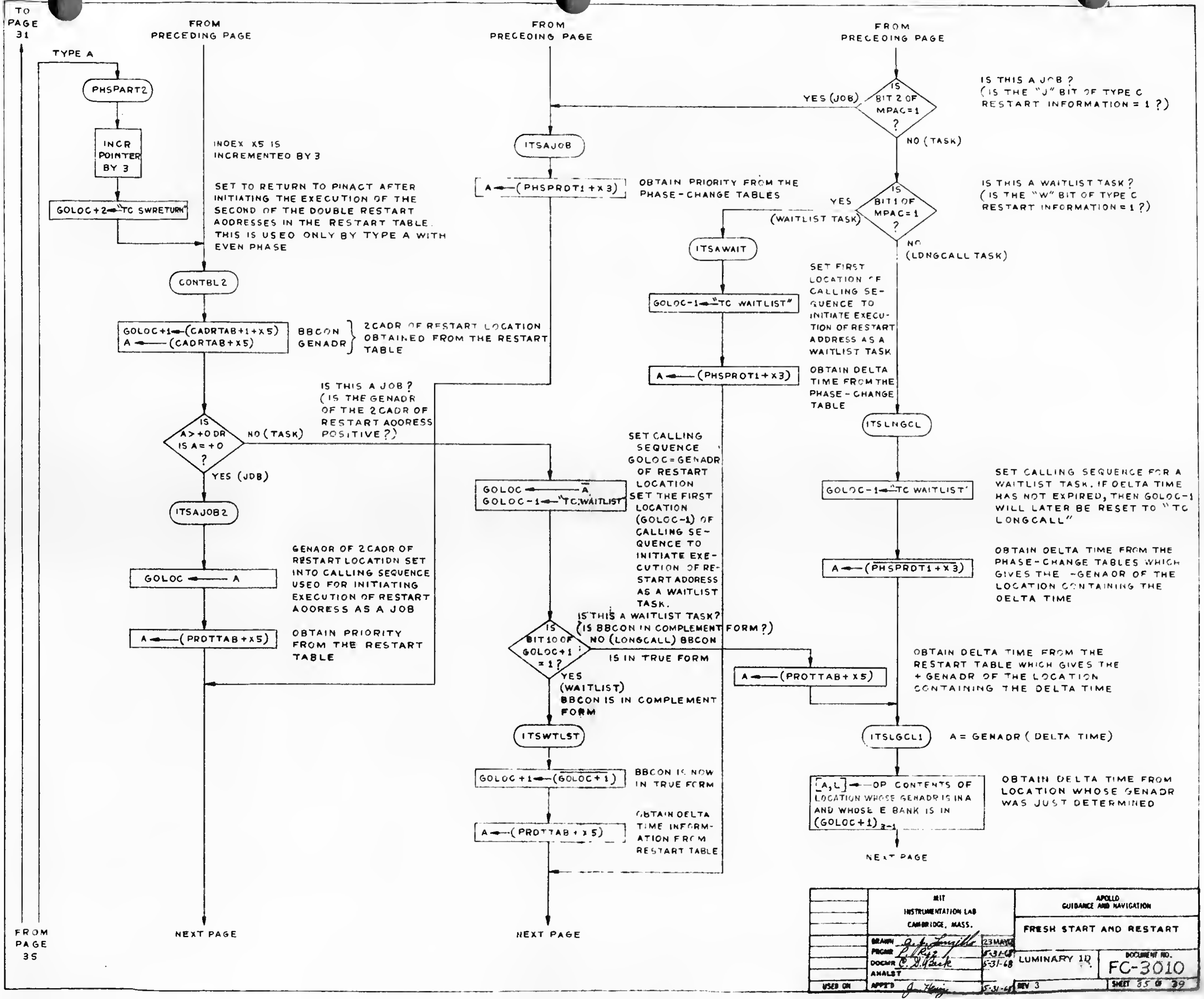
FRESH START AND RESTART

LUMINARY 1D

DOCUMENT NO. FC-3010

REV 3

SHEET 34 OF 39



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APOLLO
GUIDANCE AND NAVIGATION

FRESH START AND RESTART

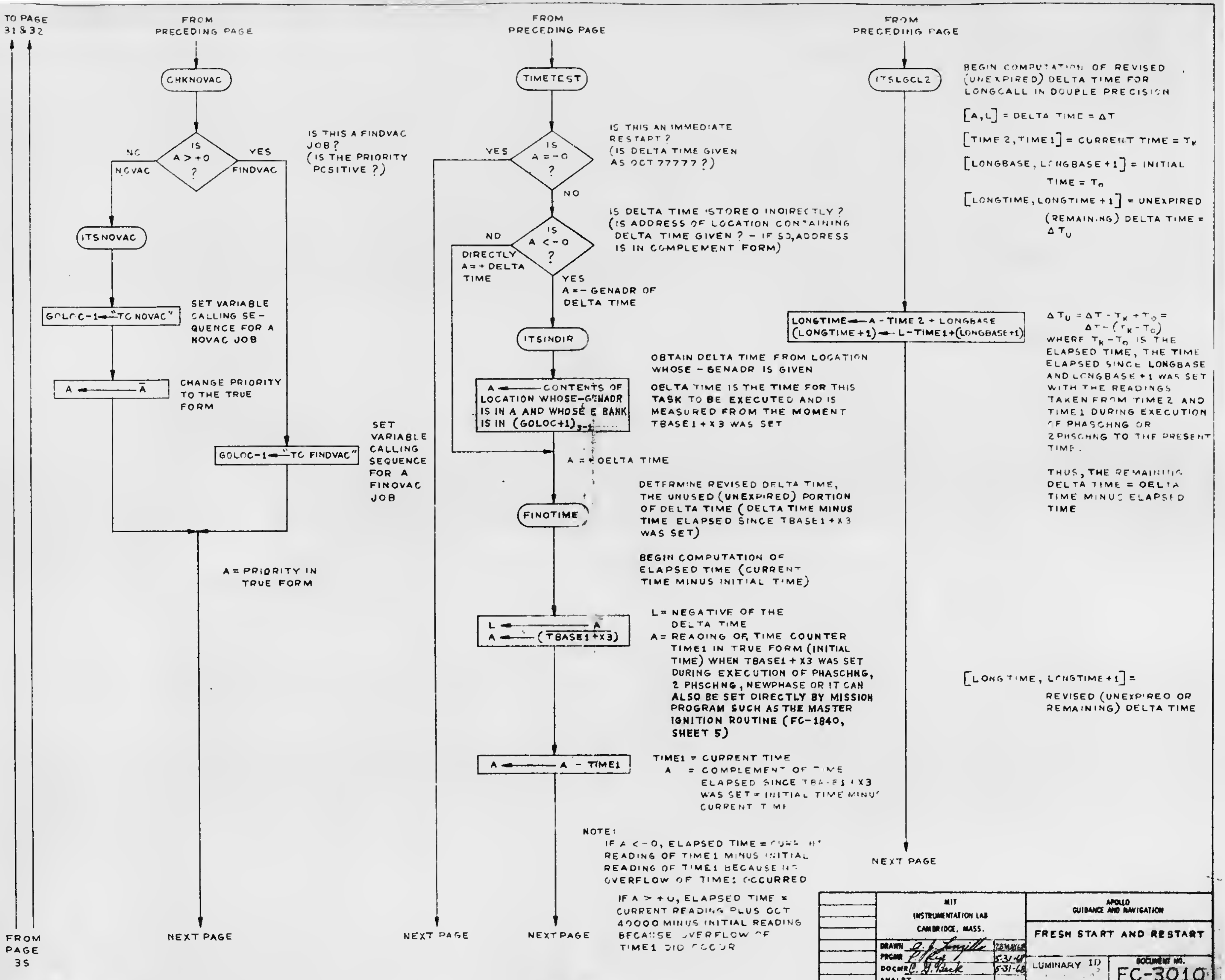
DRAWN 23MAY68
PRGMR 5-31-68
DOCMR 5-31-68
ANALST
APP'D 5-31-68
USED ON

LUMINARY 1D

REV 3

DOCUMENT NO.
FC-3010

SHEET 35 OF 39



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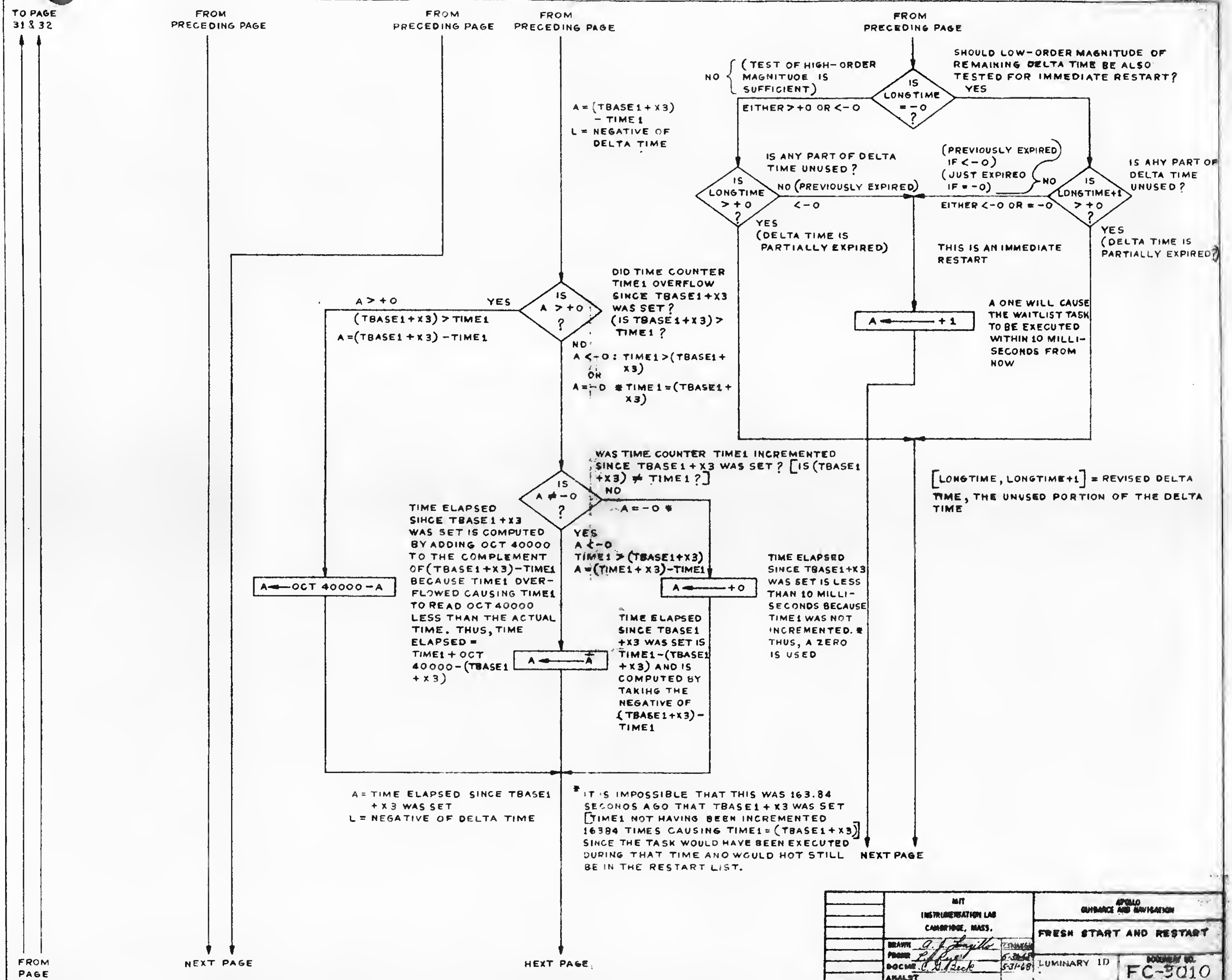
	DRAWN	28MAY68	FRESH START AND RESTART
	PRGMR	5-31-68	LUMINARY 1D
	DOCMR C. G. Beck	5-31-68	DOCUMENT NO. FC-3010
	ANALST		
USED ON	APPR'D	5-31-68	REV 3 SHEET 36 OF 39



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DRAWN A. J. Langillo
PROGR
DOC'MR C. G. Beck 5-31-68
ANALST
APPR'D

APOLLO
GUIDANCE AND NAVIGATION

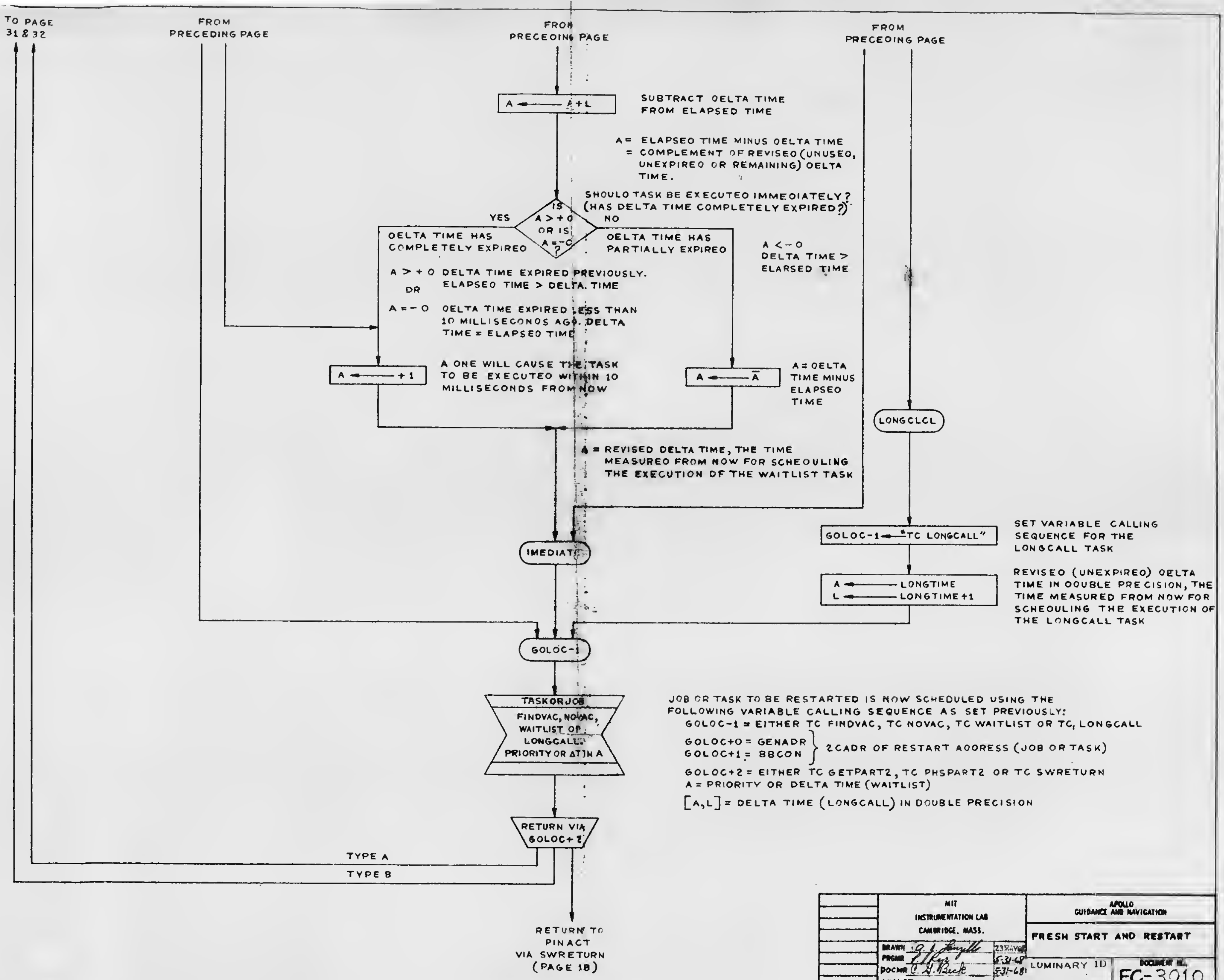
FRESH START AND RESTART

LUMINARY 1D

DOCUMENT NO. FC-5010

REV 3

SHEET 37 OF 39



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DRAWN G. J. Fenzille 23MAY68
PRGMR E. Kerz 5-31-68
DOCMR C. G. Beck 5-31-68
ANALST
APPR'D J. Haig 5-31-68
USED ON

APOLLO
GUIDANCE AND NAVIGATION

FRESH START AND RESTART

LUMINARY 1D
DOCUMENT NO. FC-3010
REV 3
SHEET 28 OF 39

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
ALARM	FC-3070	STORE ALARM CODE AND TURN ON PROGRAM ALARM	SH. 19
ALLCOAST	FC-3440	INITIALIZE FOR COASTING FLIGHT	SH. 28
CLRADMOD	FC-3600	CLEAR COESFLAG, DESIGFLG AND DISABLE RADAR ERROR COUNTER	SH. 27, 29
DAPIDLER	FC-3450	LM AUTOPILOT	SH. 8
ENGINOF1	FC-3840	TURN ENGINE OFF	SH. 25, 28
FALTON	FC-3080	TURN ON OPERATOR ERROR LIGHT	SH. 24
INSTALL	FC-3350	TEST AVAILABILITY OF INTEGRATION	SH. 26
NEWMODEA	FC-3020	UPDATE AND DISPLAY MODREG	SH. 33
RELDSP	FC-3080	RELEASE DISPLAY SYSTEM FOR INTERNAL CONTROL	SH. 27, 33

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DRAWN	G. D. Hart	19 MAY 69	FRESH START AND RESTART
CHKMR	E. Hughes	8 AUG 69	
ANALYST			LUMINARY 1D
DOC MR	W C Danforth	6 AUG 69	DOCUMENT NO FC-3010
APPR'D	Alida M. Stewart	8 AUG 69	REV 3 · SHEET 39 OF 39

WAITLIST

TWIDDLE	SH. 6
WAITLIST	SH. 6
DLY2	SH. 7
FIXDELAY	SH. 7
VARDELAY	SH. 7
T3RUPT	SH. 14
TASKOVER	SH. 16
LONGCALL	SH. 19

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION		
DRAWN J. Flaherty	5/27/70	WAITLIST		
PRGMR L. Rosenberg	6/15/70		DOCUMENT NO.	
ANALST				
DOCMR W. Danforth	6/10/70	LUMINARY 1D	FC-3040	
APPR'D RM Eaton	6/15/70	REV		SHEET 1 OF 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 ΔT) AND IS EQUAL TO T_N - T, WHERE T_N IS THE TIME FOR TASK N TO BE EXECUTED AND T IS CURRENT TIME.

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

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

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

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

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

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

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

(2) $-(T_I - T_N) + 1$ IS SET INTO LST1+0; $-(T_2 - T_1) + 1$ IS SHIFTED FROM LST1+0 TO LST1+1; $-(T_3 - T_2) + 1$ IS SHIFTED FROM LST1+1 TO LST1+2; ETC; AND $-(T_9 - T_8) + 1$ IS DISCARDED.

(3) THE 2CADR OF THE NEW TASK IS PLACED INTO LST2+0 AND LST2+1; THE 2CADR OF TASK I IS SHIFTED FROM LST2+0 AND LST2+1 TO LST2+2 AND LST2+3, ETC; THE 2CADR OF TASK 9 IS DISCARDED.

(4) IF THE 2CADR OF TASK 9 WAS A 2CADR OF A REGULAR TASK (NOT A DUMMY TASK), A RESTART IS INITIATED VIA BAILOUT (AN ABORT), OTHERWISE RETURN TO THE CALLER.

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

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

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION		
DRAWN J. Lutkevich	5/29/70	WAITLIST		
PRGMR	6/5/70	LUMINARY 1D	DOCUMENT NO. FC-3040	
ANALST				
DOCMR	6/10/70			
APPR'D	6/15/70	REV		SHEET 3 OF 23

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

THE LONGCALL TASK IS USED TO SCHEDULE TASKS WHOSE DELTA TIME IS IN DOUBLE PRECISION, WHICH CANNOT BE HANDLED BY THE WAITLIST (SINGLE-PRECISION) ENTRY. LONGCALL WILL HANDLE DELTA TIMES FROM OCT 00001 (0.01 SECOND) TO [OCT 37777, OCT 37777] (2,684,354.55 SECONDS OR 745 HOURS, 39 MINUTES, AND 14.55 SECONDS). THE LONGCALL ROUTINE SCHEDULES ROUTINE LONGCYCL AS A WAITLIST TASK EVERY 81.92 SECONDS (ΔT = 81.92 SECONDS) IN A LOOP UNTIL THE UNUSED (REMAINING OR UNEXPIRED) PORTION OF THE DELTA TIME IS LESS THAN OR EQUAL TO 81.92 SECONDS. THEN ROUTINE GETCADR IS SCHEDULED AS A WAITLIST TASK TO BE EXECUTED AT THE END OF A TIME PERIOD EQUAL TO THE UNUSED LONGCALL DELTA TIME, THUS USING UP THE ENTIRE LONGCALL DELTA TIME. ROUTINE GETCADR WILL TRANSFER CONTROL DIRECTLY TO THE LONGCALL TASK, WHICH WILL TERMINATE WITH ROUTINE TASKOVER.

EXECUTION OF THE TASKS USES THE T3RUPT ENTRY. ASSUME TASKS 1 THROUGH 9 ARE SCHEDULED AND THEIR TIME DATA AND 2CADR'S ARE IN THE TIME3 (TASK 1) COUNTER AND LST1 AND LST2 TABLES. THEN CONTROL IS TRANSFERRED TO ENTRY T3RUPT VIA THE LEAD-IN INTERRUPT ROUTINE AFTER INTERRUPTING SOME ROUTINE ELSEWHERE. WHEN $T = T_I$, THEN OCT 40000 - $(T_I - T)$ IN TIME COUNTER TIME3 WILL EQUAL OCT 40000, THE OVERFLOW CONDITION. ACTUALLY, TIME3 WILL CHANGE FROM OCT 37777 TO OCT 00000 WITH THE LAST (BEFORE $T = T_1$) INCREMENT OF THE TIME COUNTER. UPON OVERFLOW, INTERRUPT CONDITION IS STARTED. THIS CAUSES (1) THE INSTRUCTION AFTER THE INSTRUCTION BEING EXECUTED AT THE MOMENT THE INTERRUPT TOOK PLACE TO BE SAVED IN REGISTER BRUPT, AND (2) THE ADDRESS OF THE LOCATION AFTER THE LOCATION CONTAINING THE INSTRUCTION IN BRUPT TO BE SAVED IN REGISTER ZRUPT (THIS INSTRUCTION AND THIS ADDRESS ARE LATER RESTORED BY INSTRUCTION RESUME WHEN THE INTERRUPTED ROUTINE IS RESUMED). THEN INTERRUPT CAUSES CONTROL TO BE TRANSFERRED TO THE T3RUPT LEAD-IN ROUTINE FOR SAVING CONTENTS OF CERTAIN REGISTERS. CONTROL IS THEN TRANSFERRED TO ROUTINE T3RUPT. BEFORE TASK 1 IS EXECUTED, TIME3 WILL BE SET FOR TASK 2. THE TIME INTERVALS FOR EACH TASK WILL BE SHIFTED UPWARD ONE REGISTER, AND THE TIME INTERVAL (81.92 SECONDS) BETWEEN TASK 9 AND A DUMMY TASK WILL BE PLACED INTO THE LAST REGISTER LST1+7. IN ORDER TO SET TIME3 FOR TASK 2, THE CONTENTS $(T - T_I)$ OF TIME3, OCT 37777, AND THE TIME INTERVAL $-(T_2 - T_I) + 1$ FOR TASK 2 ARE ALL ADDED TOGETHER TO OBTAIN OCT 40000 - $(T_2 - T)$ WHICH IS PLACED INTO TIME3. IF TASK 2 WAS SCHEDULED FOR THE SAME TIME AS TASK 1 $(T_1 = T_2)$ OR THE T3RUPT WAS DELAYED BY AN INHIBIT OR ANOTHER INTERRUPT $(T \geq T_2)$, THEN ROUTINE TASKOVER IS NOTIFIED THAT TASK 2 SHOULD BE EXECUTED IMMEDIATELY AFTER TASK 1 INSTEAD OF RESUMING THE INTERRUPTED ROUTINE. THE 2CADRS IN THE LST2 ADDRESS TABLE ARE SHIFTED UPWARD, AND THE 2CADR OF A DUMMY TASK IS PLACED INTO THE LAST TWO REGISTERS LST2+18D AND LST2+17D. CONTROL IS THEN TRANSFERRED TO TASK 1 AT THE LOCATION WHOSE 2CADR WAS IN REGISTERS LST2+0 AND LST2+1 (THE TOP OF THE LIST). THEN THE TASK IS EXECUTED.

ALL TASKS TERMINATE IN A TRANSFER OF CONTROL TO ROUTINE TASKOVER. IF $T \geq T_2$ WHEN CONTROL ARRIVED AT T3RUPT TO EXECUTE TASK 1, THEN CONTROL WILL PASS FROM ROUTINE TASKOVER TO T3RUPT2 LOCATION OF T3RUPT TO INITIATE THE EXECUTION OF TASK 2, SET TIME3 FOR TASK 3, AND SHIFT THE LST1 AND LST2 TABLES UPWARD. OTHERWISE, ROUTINE TASKOVER WILL TRANSFER CONTROL TO ROUTINE RESUME TO RESTORE ORIGINAL CONTENTS OF CERTAIN REGISTERS FOR RESUMING THE EXECUTION OF THE INTERRUPTED ROUTINE. LAST, CONTROL IS TRANSFERRED TO THE INTERRUPTED ROUTINE.

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

SUMMARY OF THE TWO SALIENT OPERATIONS

SCHEDULING A NEW TASK: THE DELTA TIME OF THE NEW TASK IS $T_N - T = \Delta T_N$. IF $T_{\alpha-1} \leq T_N < T_\alpha$, THE TIME INTERVAL $-(T_N - T_{\alpha-1})+1$ REPLACES $-(T_\alpha - T_{\alpha-1})+1$ AND $-(T_\alpha - T_N)+1$ REPLACES $-(T_{\alpha+I} - T_\alpha)+I$, WHICH IN TURN REPLACES $-(T_{\alpha+2} - T_{\alpha+1})+1$, ETC. IN THE LST1 TABLE. IF $T_I > T_N$, THE TIME INTERVAL COUNTER VALUE OCT 40000 - $(T_N - T)$ REPLACES OCT 40000 - $(T_1 - T$ IN TIME COUNTER TIME3 AND $-(T_1 - T_N)+1$ REPLACES $-(T_2 - T_1)+I$, WHICH IN TURN REPLACES $-(T_3 - T_2)+1$, ETC. IN THE LST1 TABLE. IF $T_N > T_9$, THERE IS NO ROOM IN THE LST TABLES FOR THE NEW TASK, AND A RESTART IS INITIATED.

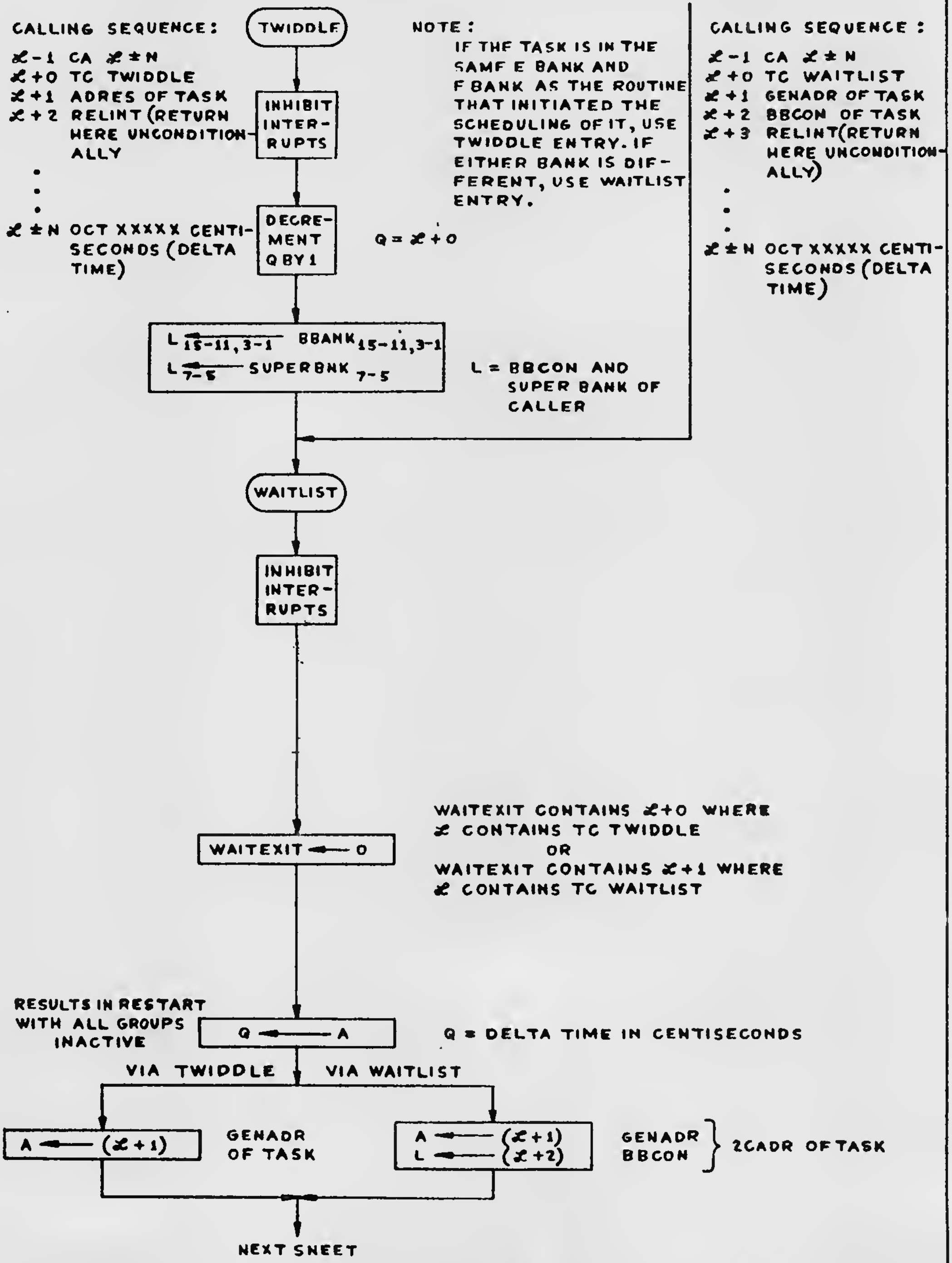
INITIATING THE EXECUTION OF A TASK(TASK1): THE $-(T_2 - T_1) + I$ IN THE TOP OF THE LST1 TABLE, THE $(T - T_1)$ IN TIME3 $(T \geq T_1)$ AND OCT 37777 ARE ADDED TOGETHER TO OBTAIN OCT 40000 - $(T_2 - T)$ TO BE SET INTO TIME3 FOR TASK 2 AND ALL OTHER TIME INTERVALS IN THE LST1 TABLE ARE MOVED UP.

MAIN (DETAILED) FLOW CHART

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

ENTERED FROM 5 LOCATIONS WITH A = DELTA TIME

WAITLIST ENTRY ENTERED FROM 58 LOCATIONS WITH A = DELTA TIME



CALLING SEQUENCE:

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

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

CALLING SEQUENCE:

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

WAITEXIT CONTAINS ℒ+0 WHERE ℒ CONTAINS TC TWIDDLE
OR
WAITEXIT CONTAINS ℒ+1 WHERE ℒ CONTAINS TC WAITLIST

RESULTS IN RESTART WITH ALL GROUPS INACTIVE

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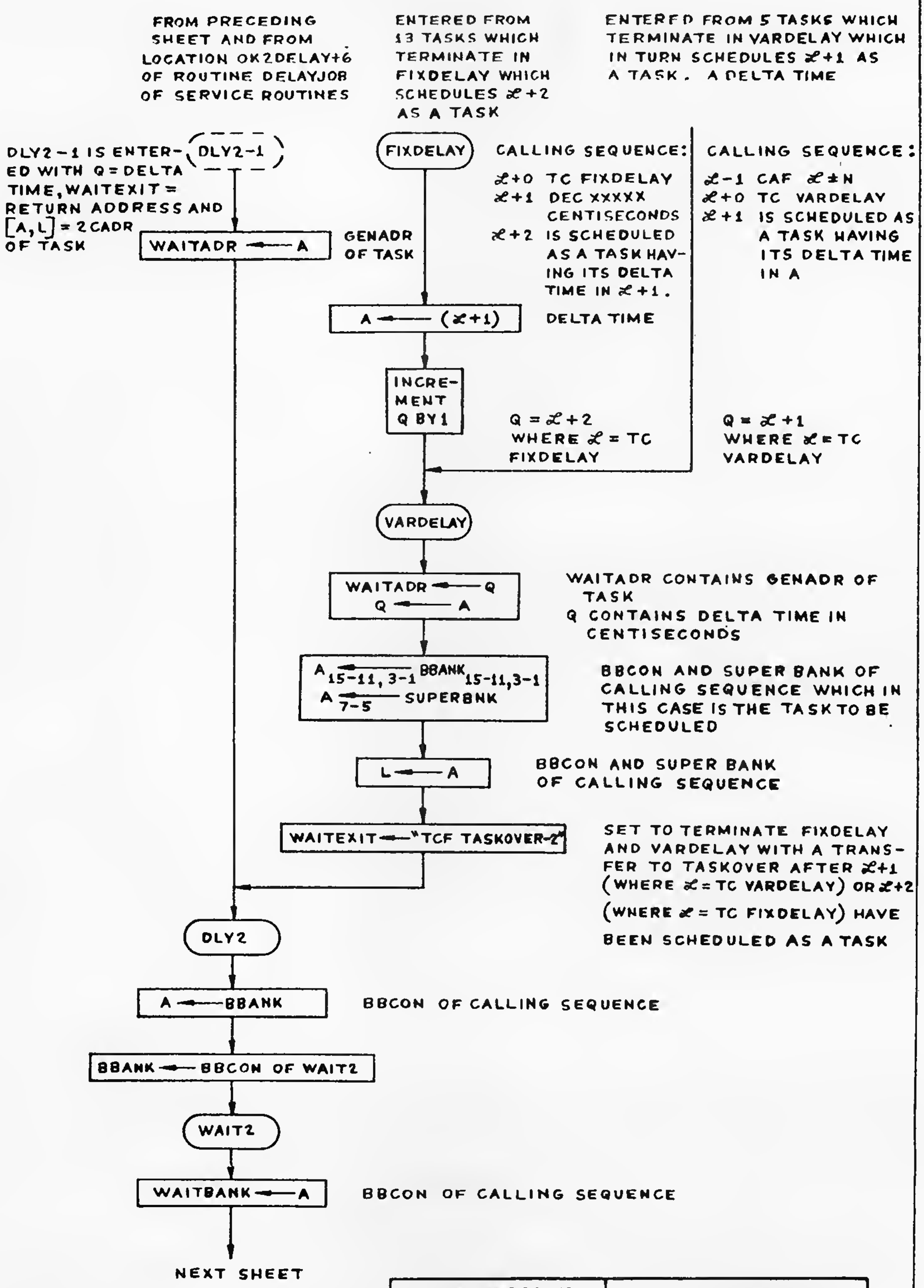
MAIN (DETAILED) FLOW CHART



FROM PRECEDING SHEET AND FROM LOCATION OK2DELAY+6 OF ROUTINE DELAYJOB OF SERVICE ROUTINES

ENTERED FROM 13 TASKS WHICH TERMINATE IN FIXDELAY WHICH SCHEDULES $\mathcal{L}+2$ AS A TASK

ENTERED FROM 5 TASKS WHICH TERMINATE IN VARDELAY WHICH IN TURN SCHEDULES $\mathcal{L}+1$ AS A TASK. A DELTA TIME

DLY2−1 IS ENTERED WITH Q = DELTA TIME, WAITEXIT = RETURN ADDRESS AND [A, L] = 2CADR OF TASK

CALLING SEQUENCE:

$\mathcal{L}+0$ TC FIXDELAY
$\mathcal{L}+1$ DEC XXXXX CENTISECONDS
$\mathcal{L}+2$ IS SCHEDULED AS A TASK HAVING ITS DELTA TIME IN $\mathcal{L}+1$.

CALLING SEQUENCE:

$\mathcal{L}-1$ CAF $\mathcal{L}\pm N$
$\mathcal{L}+0$ TC VARDELAY
$\mathcal{L}+1$ IS SCHEDULED AS A TASK HAVING ITS DELTA TIME IN A

GENADR OF TASK

DELTA TIME

Q = $\mathcal{L}+2$ WHERE $\mathcal{L}$ = TC FIXDELAY

Q = $\mathcal{L}+1$ WHERE $\mathcal{L}$ = TC VARDELAY

WAITADR CONTAINS GENADR OF TASK
Q CONTAINS DELTA TIME IN CENTISECONDS

BBCON AND SUPER BANK OF CALLING SEQUENCE WHICH IN THIS CASE IS THE TASK TO BE SCHEDULED

BBCON AND SUPER BANK OF CALLING SEQUENCE

SET TO TERMINATE FIXDELAY AND VARDELAY WITH A TRANSFER TO TASKOVER AFTER $\mathcal{L}+1$ (WHERE $\mathcal{L}$ = TC VARDELAY) OR $\mathcal{L}+2$ (WHERE $\mathcal{L}$ = TC FIXDELAY) HAVE BEEN SCHEDULED AS A TASK

BBCON OF CALLING SEQUENCE

BBCON OF CALLING SEQUENCE

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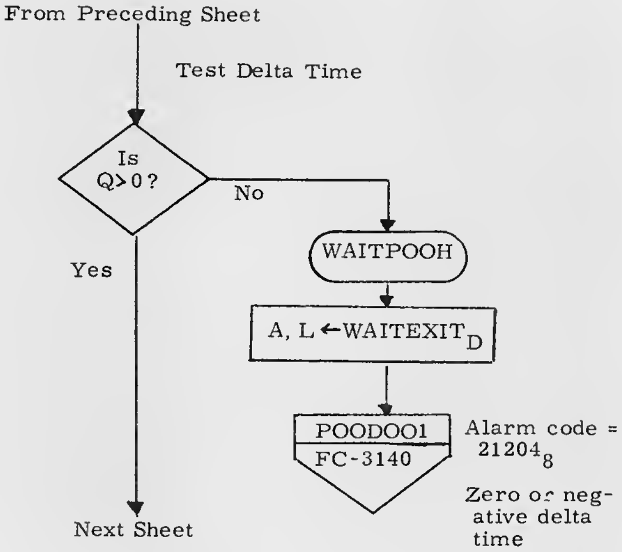

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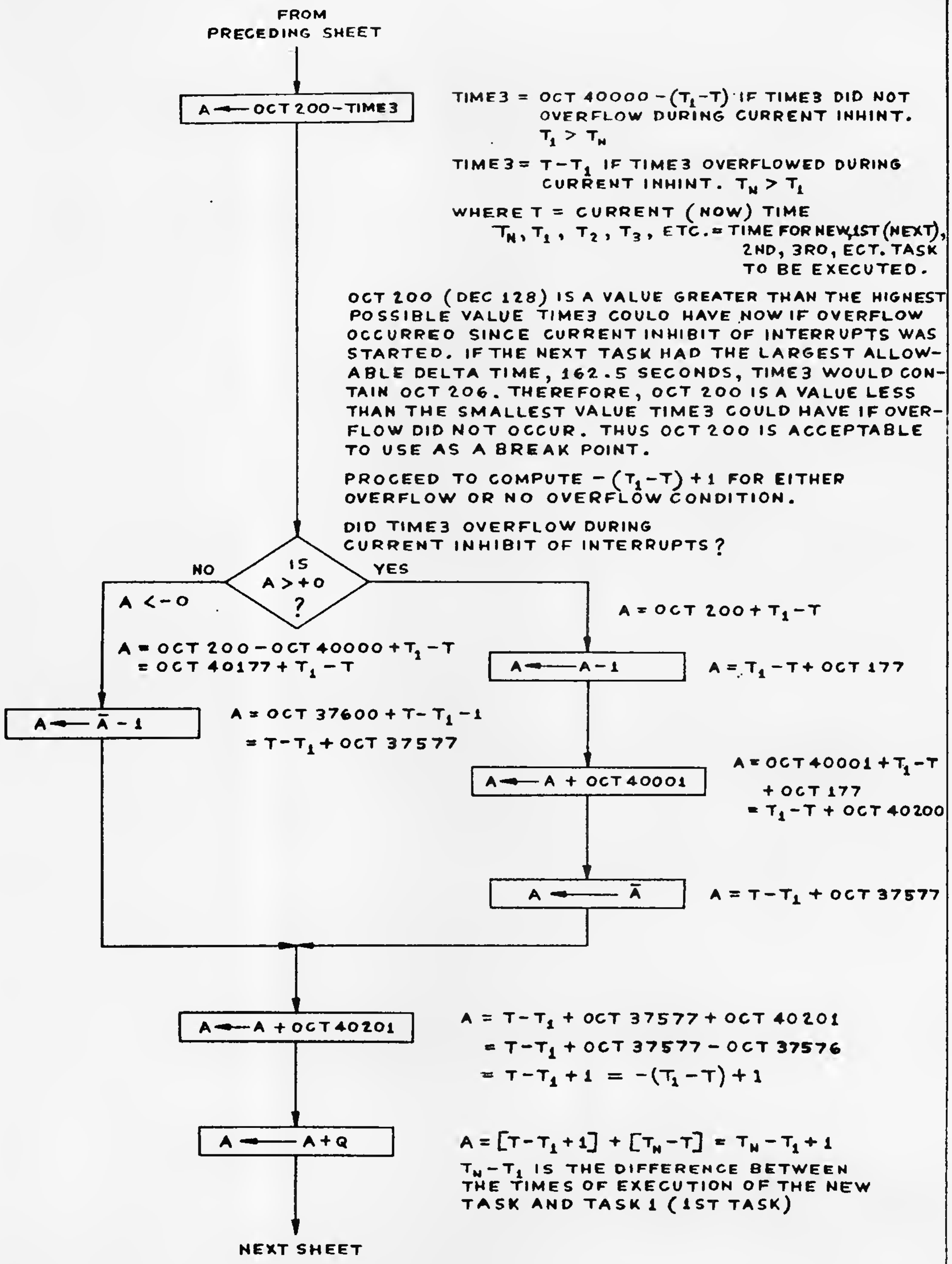

$TIME3 = OCT\ 40000 - (T_1 - T)$ IF TIME3 DID NOT OVERFLOW DURING CURRENT INHINT. $T_1 > T_N$

$TIME3 = T - T_1$ IF TIME3 OVERFLOWED DURING CURRENT INHINT. $T_N > T_1$

WHERE T = CURRENT (NOW) TIME
T_N, T_1, T_2, T_3, ETC. = TIME FOR NEW, 1ST (NEXT), 2ND, 3RD, ECT. TASK TO BE EXECUTED.

OCT 200 (DEC 128) IS A VALUE GREATER THAN THE HIGHEST POSSIBLE VALUE TIME3 COULD HAVE NOW IF OVERFLOW OCCURRED SINCE CURRENT INHIBIT OF INTERRUPTS WAS STARTED. IF THE NEXT TASK HAD 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. THUS OCT 200 IS ACCEPTABLE TO USE AS A BREAK POINT.

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

DID TIME3 OVERFLOW DURING CURRENT INHIBIT OF INTERRUPTS?

$A = OCT\ 200 - OCT\ 40000 + T_1 - T$
$= OCT\ 40177 + T_1 - T$

$A = OCT\ 37600 + T - T_1 - 1$
$= T - T_1 + OCT\ 37577$

$A = OCT\ 200 + T_1 - T$

$A = T_1 - T + OCT\ 177$

$A = OCT\ 40001 + T_1 - T$
$+ OCT\ 177$
$= T_1 - T + OCT\ 40200$

$A = T - T_1 + OCT\ 37577$

$A = T - T_1 + OCT\ 37577 + OCT\ 40201$
$= T - T_1 + OCT\ 37577 - OCT\ 37576$
$= T - T_1 + 1 = -(T_1 - T) + 1$

$A = [T - T_1 + 1] + [T_N - T] = T_N - T_1 + 1$

$T_N - T_1$ IS THE DIFFERENCE BETWEEN THE TIMES OF EXECUTION OF THE NEW TASK AND TASK 1 (1ST TASK)

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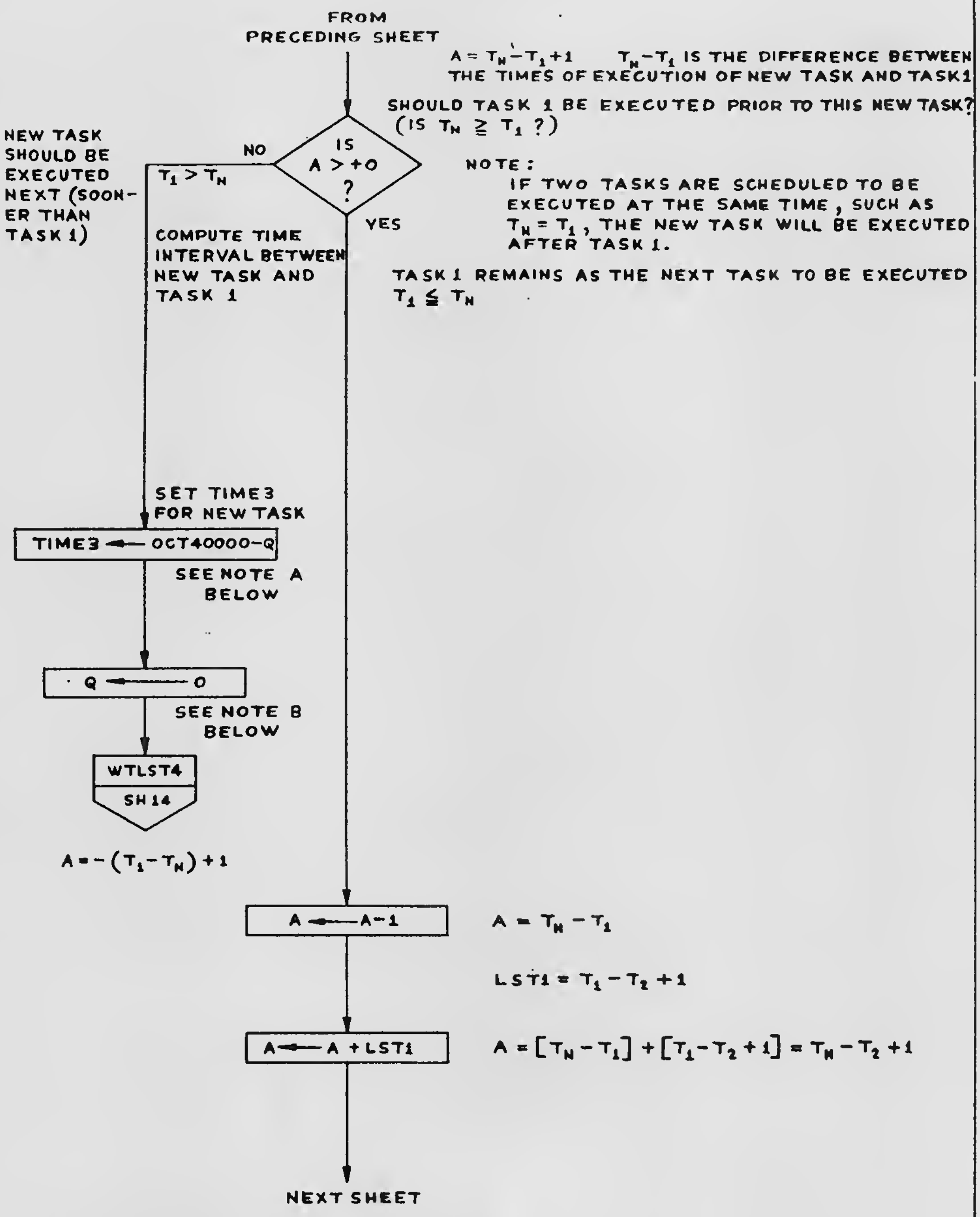

NOTE A: SET TIME COUNTER TIME3 TO OVERFLOW DELTA TIME CENTISECONDS FROM NOW (AT TIME T_N)

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

TIME3 IS NOW SET FOR THE NEW TASK

NOTE B: SET INDEX HEREAFTER REFERRED TO AS X1.
X1 = 0

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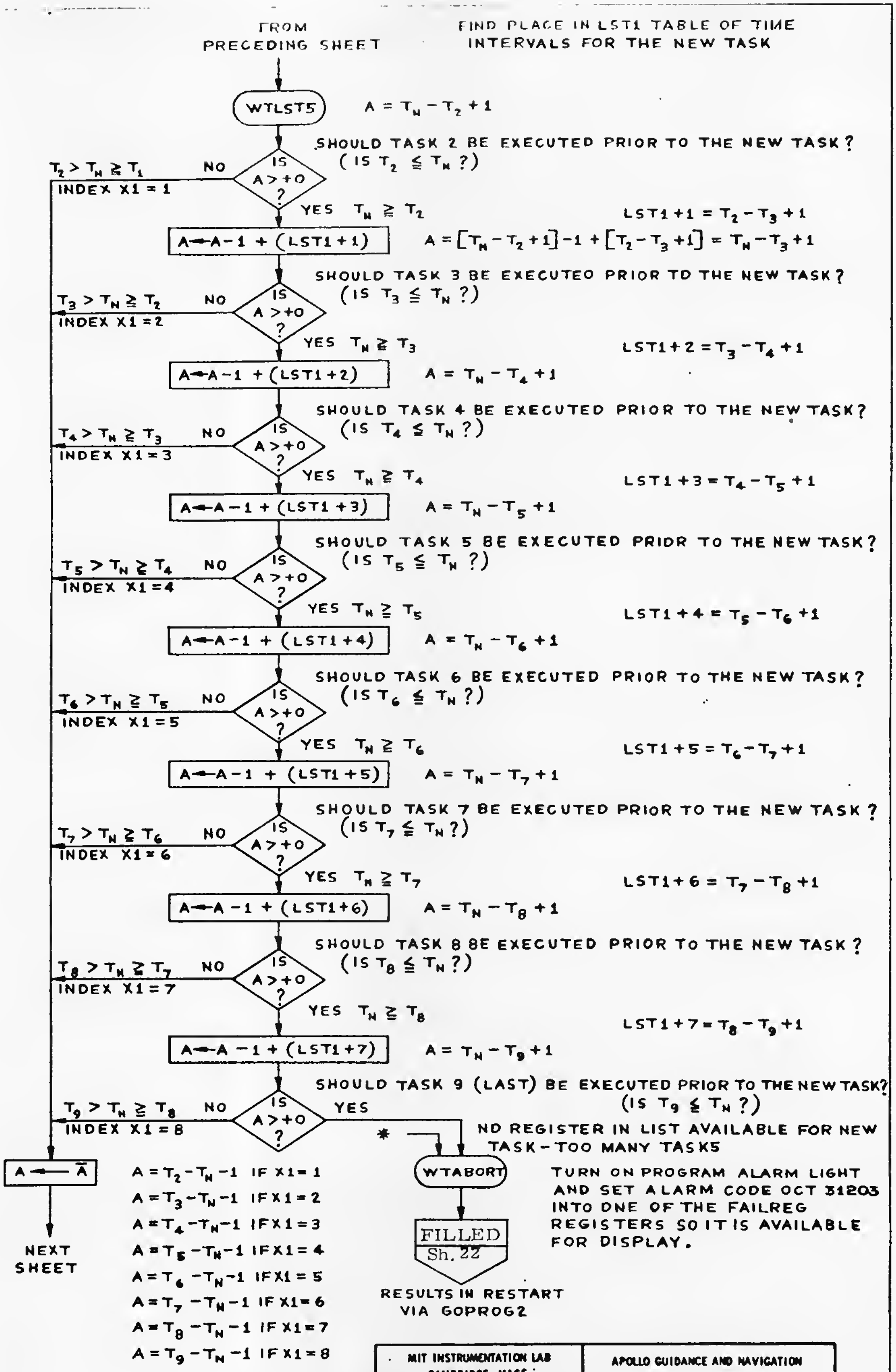

* FROM SHEET 15

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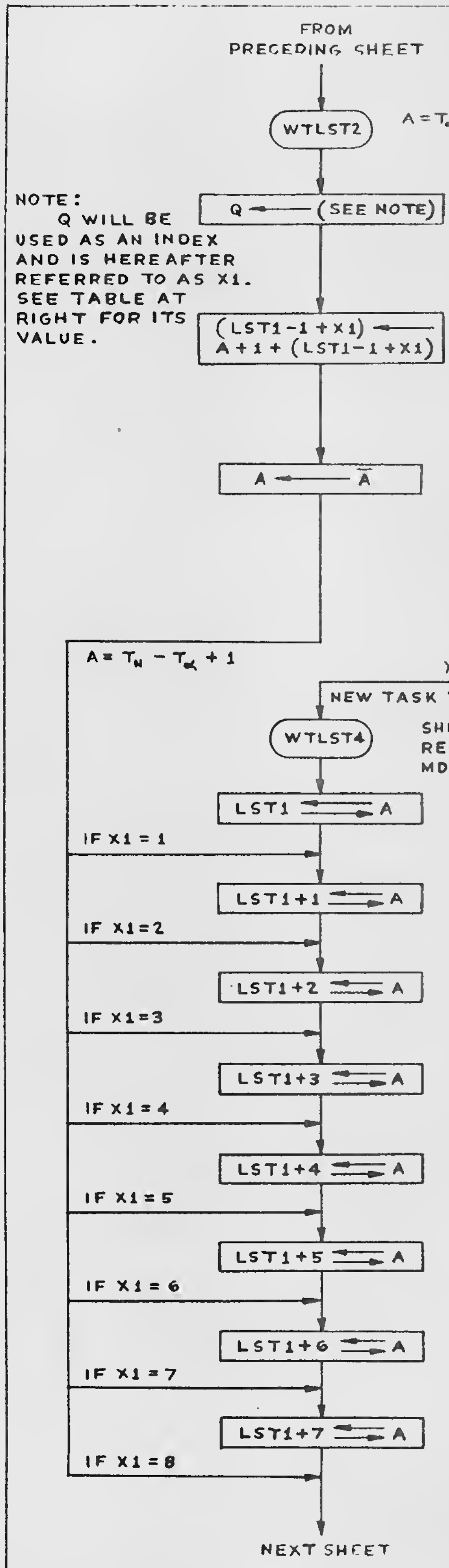

NOTE:
Q WILL BE USED AS AN INDEX AND IS HEREAFTER REFERRED TO AS X1. SEE TABLE AT RIGHT FOR ITS VALUE.

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

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

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

NOW:

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

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

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

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

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

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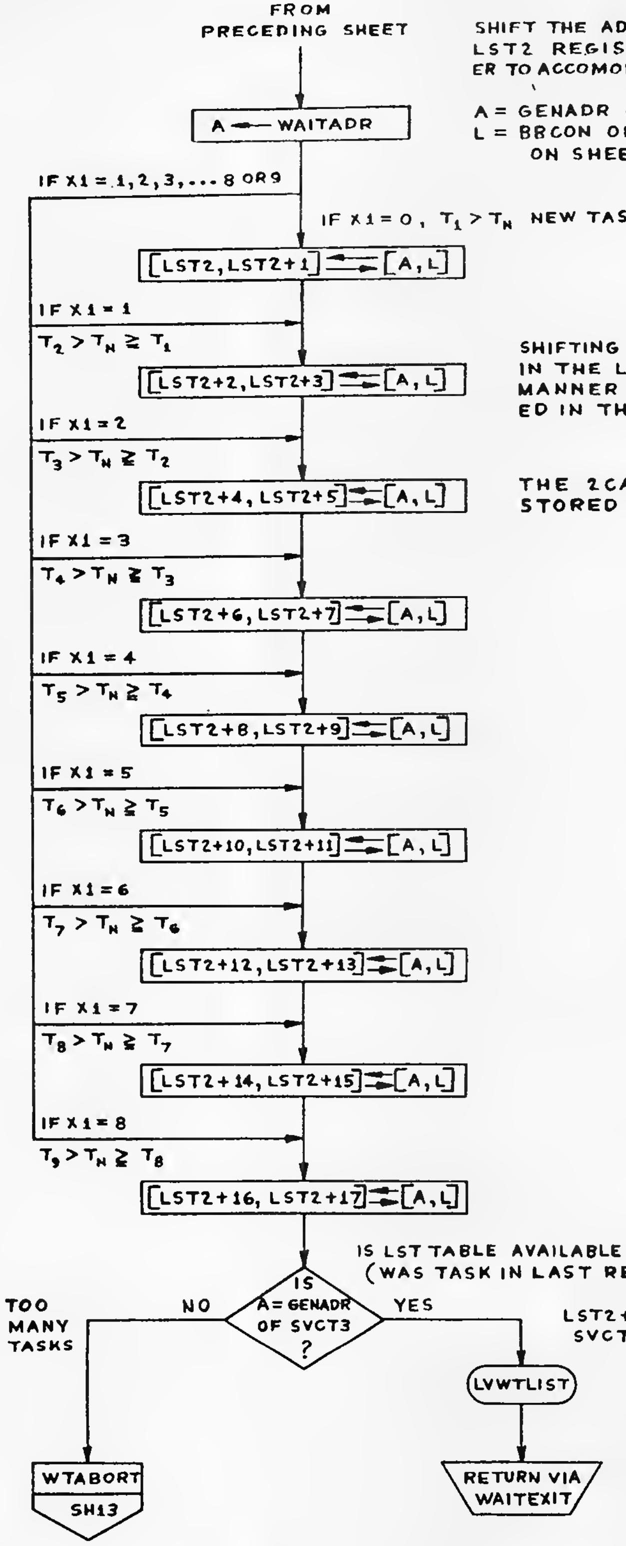

SHIFT THE ADDRESS OF TASKS IN SOME OR ALL LST2 REGISTERS TO THE NEXT LST2 REGISTER TO ACCOMODATE THE ADDRESS OF THE NEW TASK

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

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

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

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

LST2+16 PREVIOUSLY CONTAINED GENADR SVCT3, THE DUMMY TASK

RETURN TO CALLING SEQUENCE
$\mathcal{L}+2$ WHERE $\mathcal{L}$ = TC TWIDDLE,
$\mathcal{L}+3$ WHERE $\mathcal{L}$ = 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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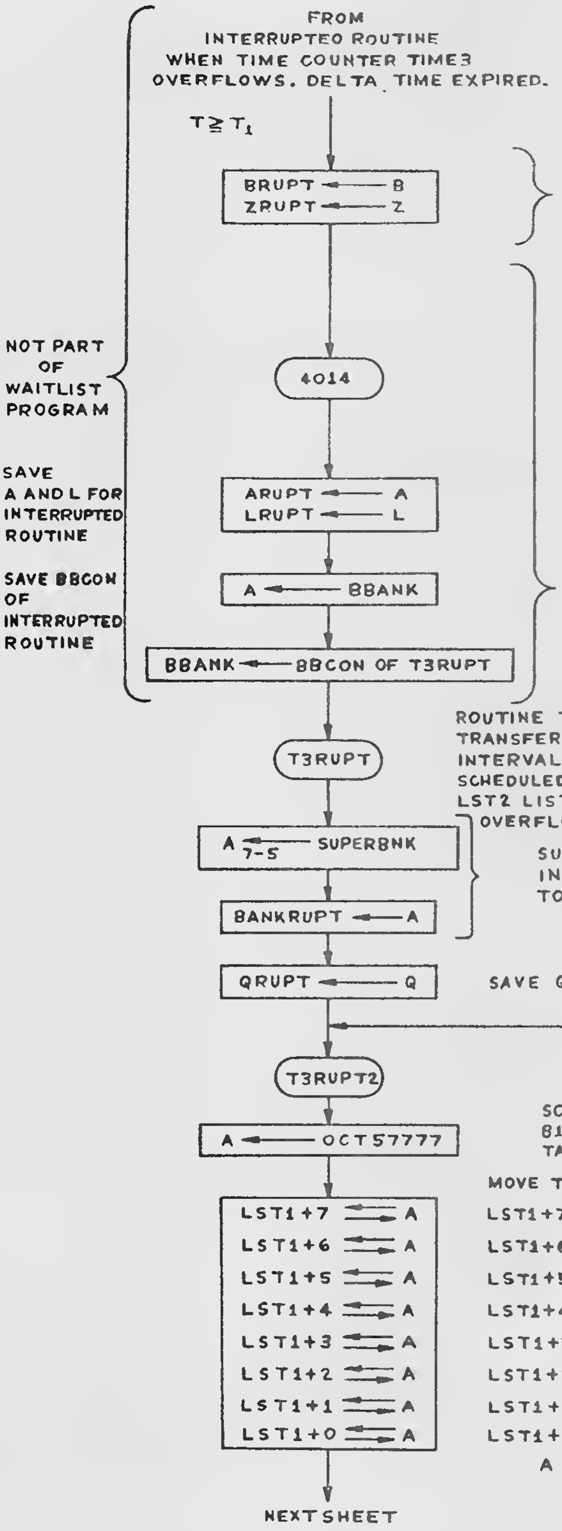

INTERRUPTED ROUTINE SEQUENCE

$\mathcal{L}+0$ α (α IS INSTRUCTION BEING EXECUTEO WHEN INTERRUPT REGAN)

$\mathcal{L}+1$ β (β IS INSTRUCTION TO BE EXECUTED FIRST UPON RESUMING INTERRUPTED ROUTINE)

$\mathcal{L}+2$

SAVE NEXT INSTRUCTION β AND ADDRESS $\mathcal{L}+2$ IN BRUPT AND ZRUPT, RESPECTIVELY.

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

NOTE:

IF, WHEN TIME COUNTER TIME3 OVERFLOWS, INTERRUPTS ARE INHIBITED BY AN INHINT OR ANOTHER INTERRUPT IS IN PROGRESS AND/OR WAITING (T_6, T_5), TRANSFER OF PROGRAM CONTROL TO LOCATION 4014 WILL BE DELAYED UNTIL THE INHIBIT IS RELEASED (RELINT) OR INTERRUPT IN PROGRESS IS TERMINATED AND/OR T6 OR T5 INTERRUPT IS ALSO COMPLETED IF WAITING

INTERRUPT LEAD IN ROUTINE

ROUTINE T3RUPT CAUSES PROGRAM CONTROL TO BE TRANSFERRED TO TASK 1. ALSO, IT MOVES THE TIME INTERVAL DATA AND 2CADR FOR THE REMAINING SCHEDULED TASKS UPWARD ONE PLACE IN THE LST1 AND LST2 LISTS SO TASK 2 WILL BE READY NEXT TIME TIME3 OVERFLOWS.

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

SAVE Q

FROM ROUTINE TASKOVER ON SHEET 18

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

MOVE TIME DATA UPWARD ONE REGISTER IN LST1 TABLE

LST1+7 = OCT 57777* DUMMY TASK SVCT3
LST1+6 = $-(T_9-T_8)+1$ TASK 9
LST1+5 = $-(T_8-T_7)+1$ TASK 8
LST1+4 = $-(T_7-T_6)+1$ TASK 7
LST1+3 = $-(T_6-T_5)+1$ TASK 6
LST1+2 = $-(T_5-T_4)+1$ TASK 5
LST1+1 = $-(T_4-T_3)+1$ TASK 4
LST1+0 = $-(T_3-T_2)+1$ TASK 3
A = $-(T_2-T_1)+1$ TASK 2

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

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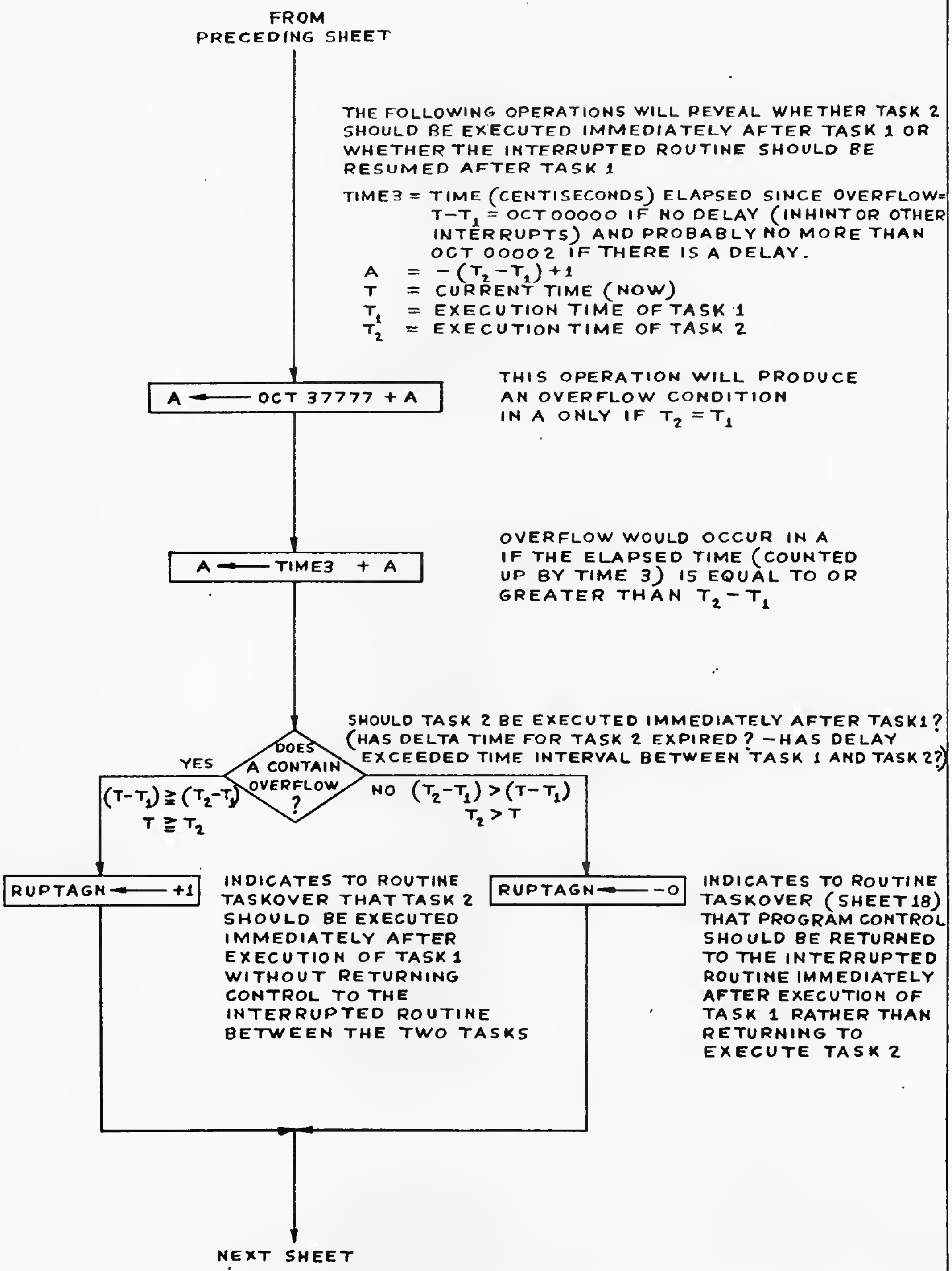

THE FOLLOWING OPERATIONS WILL REVEAL WHETHER TASK 2 SHOULD BE EXECUTED IMMEDIATELY AFTER TASK 1 OR WHETHER THE INTERRUPTED ROUTINE SHOULD BE RESUMED AFTER TASK 1

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

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

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?)

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

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

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ANALST
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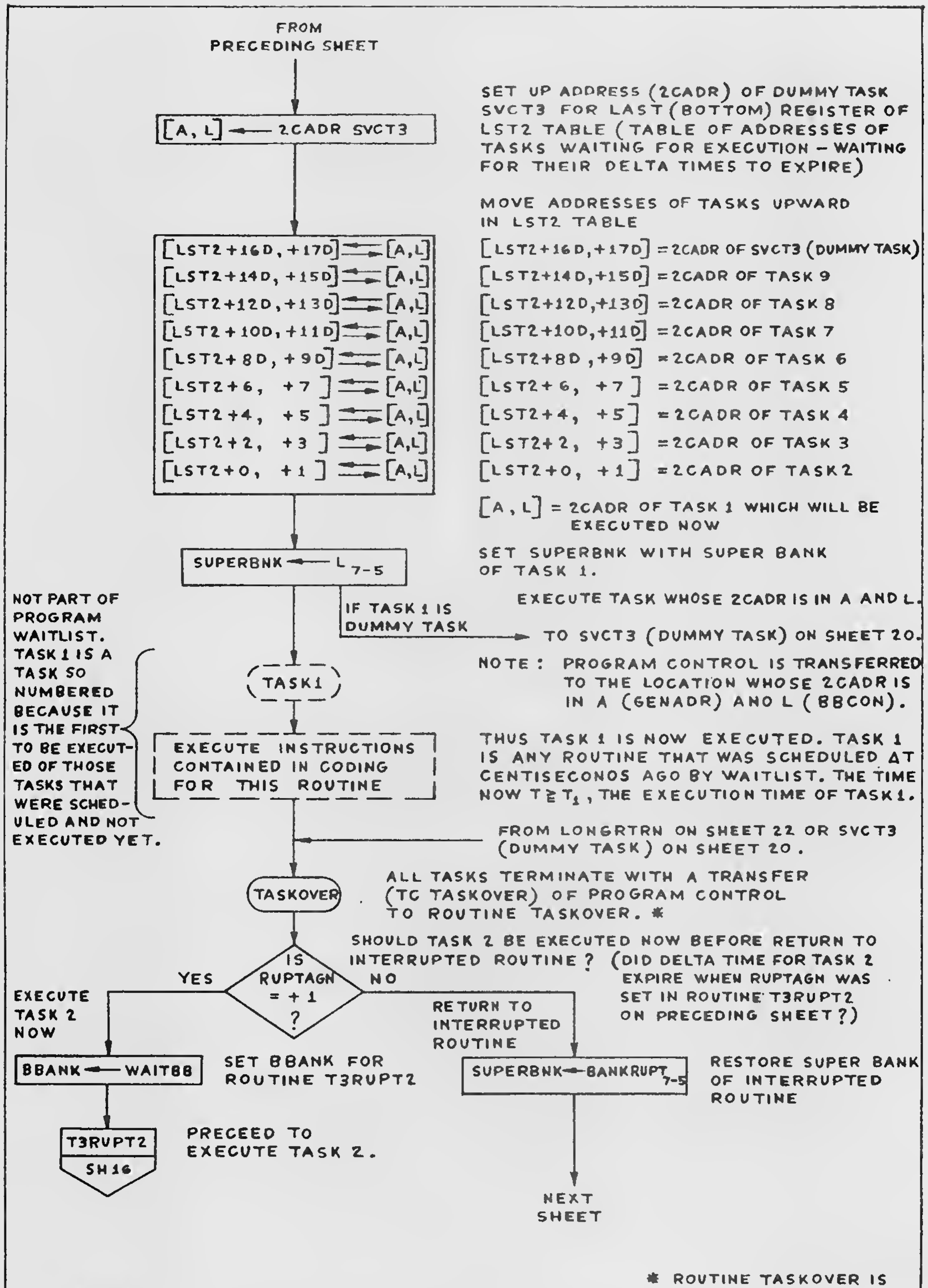
APOLLO GUIDANCE AND NAVIGATION

WAITLIST

LUMINARY 1D

DOCUMENT NO. FC-3040

REV



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

MOVE ADDRESSES OF TASKS UPWARD IN LST2 TABLE

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

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

SET SUPERBNK WITH SUPER BANK OF TASK 1.

EXECUTE TASK WHOSE 2CADR IS IN A AND L.

TO SVCT3 (DUMMY TASK) ON SHEET 20.

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

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

THUS TASK 1 IS NOW EXECUTED. TASK 1 IS ANY ROUTINE THAT WAS SCHEDULED ΔT CENTISECONDS AGO BY WAITLIST. THE TIME NOW $T \geq T_1$, 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 RUPTAGN WAS SET IN ROUTINE T3RUPT2 ON PRECEDING SHEET?)

SET BBANK FOR ROUTINE T3RUPT2

PRECEED TO EXECUTE TASK 2.

RESTORE SUPER BANK OF INTERRUPTED ROUTINE

* ROUTINE TASKOVER IS ENTERED FROM 73 LOCATIONS DIRECTLY.

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

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ANALST			
DOCMR W. Dufort	6/10/70		
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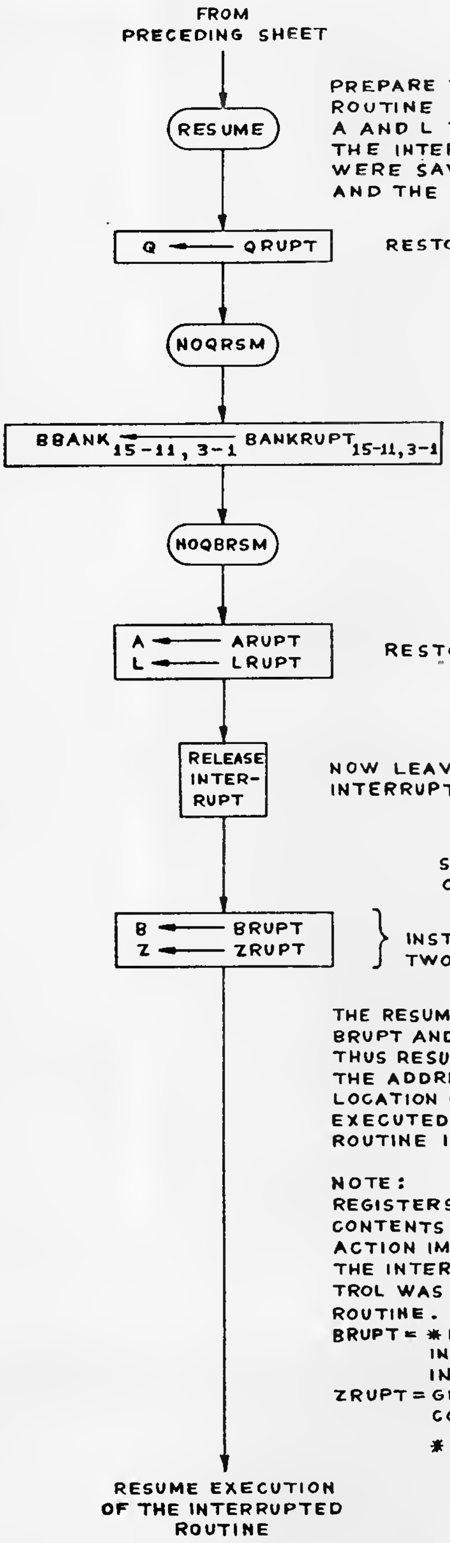

PREPARE TO RESUME EXECUTION OF INTERRUPTED ROUTINE BY RESTORING TO REGISTERS Q, BBANK, A AND L THE CONTENTS THEY HAD AT THE TIME THE INTERRUPTION OCCURRED. THESE CONTENTS WERE SAVED BY THE INTERRUPT LEAD-IN ROUTINE AND THE INTERRUPT ROUTINE.

RESTORE Q

RESTORE BBANK

RESTORE A AND L

NOW LEAVING
INTERRUPT MODE

SET UP TO EXECUTE NEXT INSTRUCTION
OF INTERRUPTED ROUTINE

INSTRUCTION RESUME (COMPRISES THESE TWO OPERATIONS)

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

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

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

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

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

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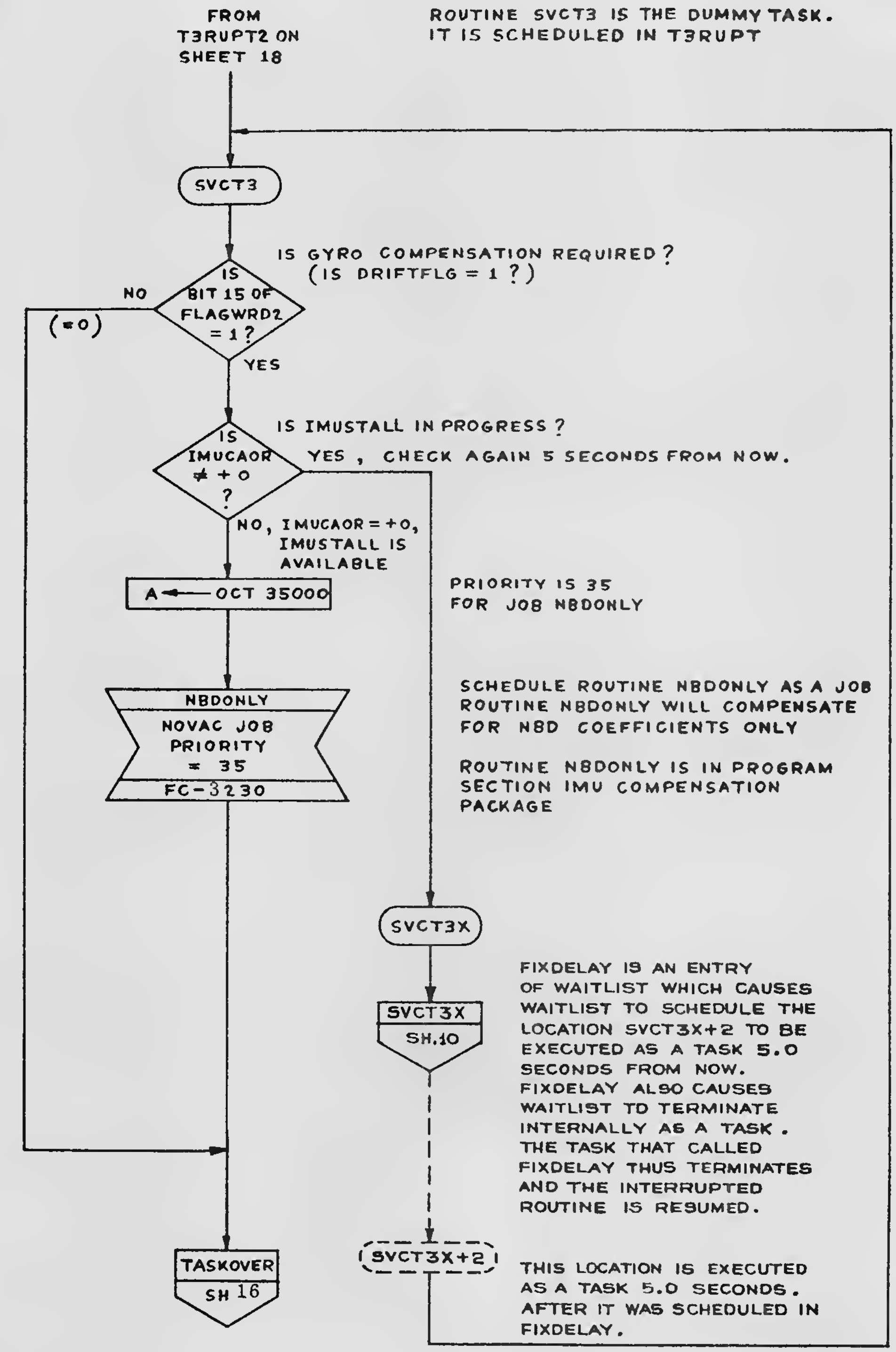
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3040
DOCMR	6/10/70		
APPR'D	6/17/70	REV	SHEET 17 OF 23



ROUTINE SVCT3 IS THE DUMMY TASK.
IT IS SCHEDULED IN T3RUPT

IS GYRO COMPENSATION REQUIRED?
(IS DRIFTFLG = 1 ?)

IS IMUSTALL IN PROGRESS ?

PRIORITY IS 35
FOR JOB NBDONLY

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

ROUTINE NBDONLY IS IN PROGRAM
SECTION IMU COMPENSATION
PACKAGE

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.

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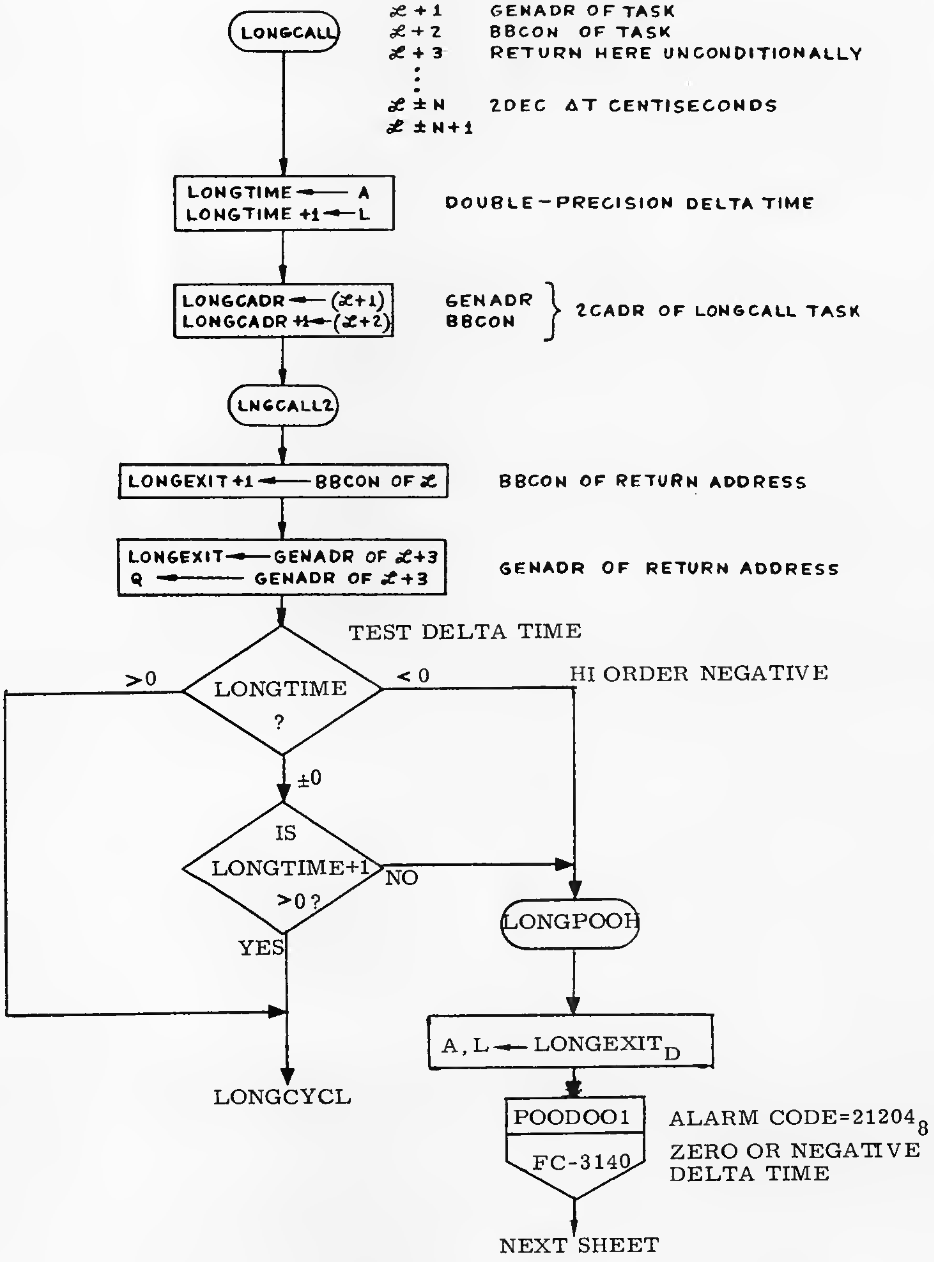
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3040
DOCMR W Doughty	6/10/70		
APPR'D R M Eates	6/15/70	REV	SHEET 18 OF 23

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 OCT00001 (0.01 SECOND) TO [OCT 37777, OCT 37777] (2,684,354.55 SECONDS OR 745 HOURS 39 MINUTES AND 14.55 SECONDS OR APPROXIMATELY ONE MONTH). [OCT 37777, OCT 37777] = OCT 1,777,777,777 = DEC 268,435,455

CALLING SEQUENCE:

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



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WAITLIST

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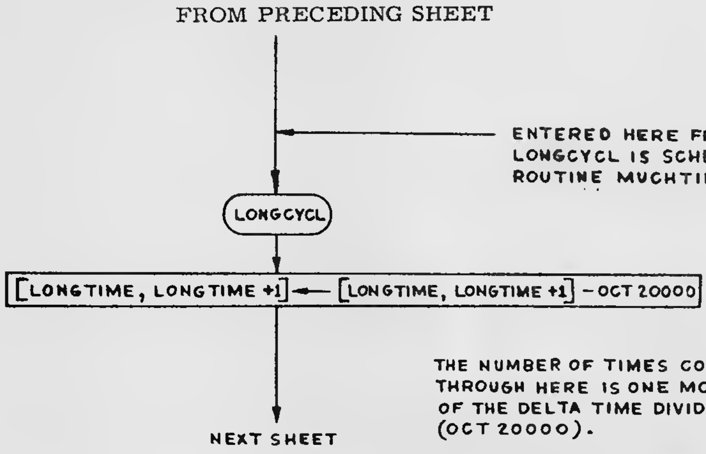
SHEET 19 OF 23



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

SUBTRACT 81.92 SECONDS FROM DELTA TIME (OR REMAINING DELTA TIME)

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

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.

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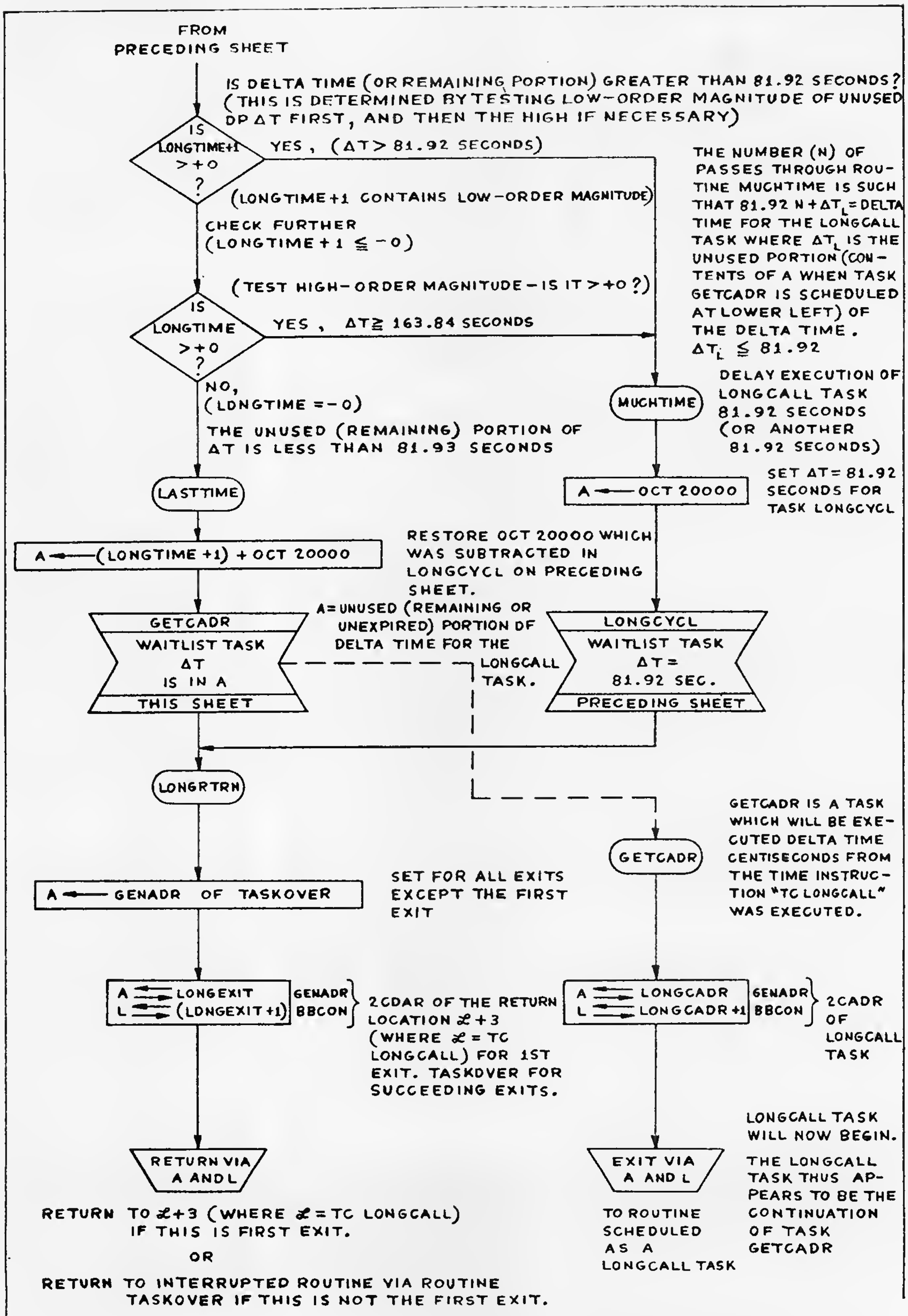
PRGMR	S. Rosenberg	6/13/70	LUMINARY 1D	DOCUMENT NO. FC-3040
ANALST				
DOCMR	W Goforth	6/10/70		
APPR'D	RM Estes	6/15/70	REV	SHEET 20 OF 23



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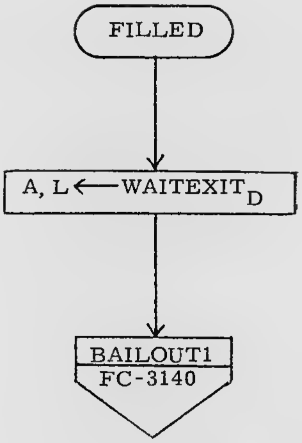
DRAWN	5/22/70	WAITLIST	
PRGMR J. Rosenberg	6/15/70	LUMINARY 1D	DOCUMENT NO. FC-3040
ANALST			
DOCMR	6/16/70		
APPR'D	6/15/70	REV	SHEET 21 OF 23



Alarm code = 31203_8

Too many tasks

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ANALST		LUMINARY 1D	DOCUMENT NO. FC-3040
DOCMR W. C. Dugdale	6/10/70		
APPR'D R. M. Enter	6/15/70	REV	SHEET 22 OF 23

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
BAILOUT1	FC-3140	TURNS ON PROGRAM ALARM LIGHT AND SETS ALARM CODE OCT 1203 INTO ONE OF THE FAILREG REGISTERS SO IT IS AVAILABLE FOR DISPLAY. EXITS TO DO SOFTWARE RESTART VIA GOPROG2.	SH. 22
POODOO1	FC-3140	TURNS ON PROGRAM ALARM LIGHT AND SET ALARM CODE OCT31204 INTO ONE OF THE FAILREG REGISTERS SO IT IS AVAILABLE FOR DISPLAY. EXITS TO DO SOFTWARE RESTART VIA GOPROG2. IF SERVICER IS NOT RUNNING, ALL RESTART GROUPS ARE MADE INACTIVE.	SH. 8,19
NBDONLY (JOB)	FC-3230	COMPENSATES FOR NBD COEFFICIENTS ONLY.	SH. 18

ERASABLE LOCATIONS USED

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

FLAGS

Flag	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
DRIFTFLG flag 2 bit 15	T3RUPT calls gyro compensation	T3RUPT does no gyro compensation			Sh. 20

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DRAWN	WAITLIST	
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DOCMR		
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SERVICE ROUTINES

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ENTRY	BRIEF DESCRIPTION	SHEET
SUBROUTINE UPENT2	SETS SELECTED BIT POSITIONS OF A SELECTED FLAG WORD (LIMITED SELECTION BY CODE)	2
SUBROUTINE DOWNENT2	CLEARS SELECTED BIT POSITIONS OF A SELECTED FLAG WORD (LIMITED SELECTION BY CODE)	2
SUBROUTINE UPFLAG	SETS A BIT POSITION OF A FLAG WORD (BOTH DETERMINED BY THE FLAG NAME)	3
SUBROUTINE DOWNFLAG	CLEARS A BIT POSITION OF A FLAG WORD (BOTH DETERMINED BY THE FLAG NAME)	3
SUBROUTINE DELAYJOB	PLACES CURRENT JOB TO SLEEP FOR ΔT CENTISECONDS, AND IS AWAKENED AT LOCATION α +2 (α CONTAINS TC DELAY JOB)	6
SUBROUTINE GENTRAN	COPIES CONTENTS OF N CONSECUTIVE LOCATIONS INTO ANY N CONSECUTIVE LOCATIONS	9
ROUTINE B5OFF	CLEARS BIT-POSITION 5 OF REGISTER EXTVBACT AND TERMINATES AS A JOB. INDICATES THAT THE DISPLAY HAS BEEN ANSWERED	10
SUBROUTINE TRFAILON	TURNS TRACKER FAIL LIGHT (OPTICS CDU FAIL) ON	11
SUBROUTINE TRFAILOF	TURNS TRACKER FAIL LIGHT (OPTICS CDU FAIL) OFF	11

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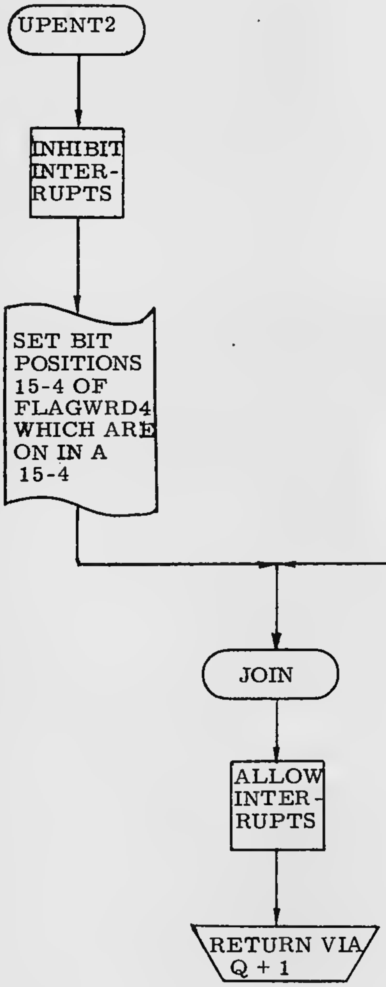
ANALST			
DOCMR	6/8/70		
APPR'D	6/15/70	REV	SHEET 1 OF 12



RETURN TO ℒ +2 OF CALLING SEQUENCE

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ANALST		LUMINARY 1D	FC-3050
DOCMR	6/8/70		
APPR'D	6/15/70	REV	SHEET 2 OF 12

SERVICE ROUTINES (UPFLAG AND DOWNFLAG)

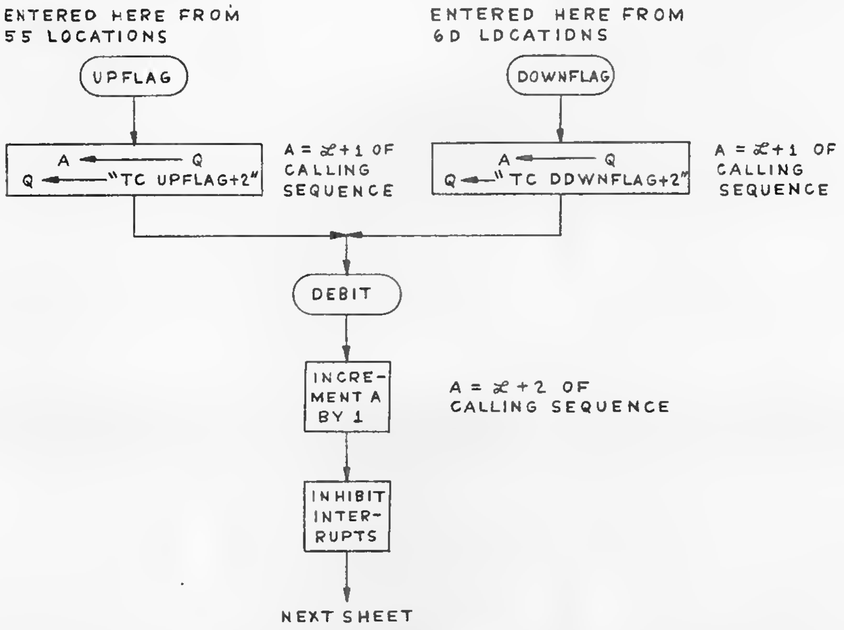
THESE SUBROUTINES, UPFLAG AND DOWNFLAG, ARE USED FOR SETTING AND CLEARING, RESPECTIVELY, ANY FLAG. A FLAG IS ANY BIT POSITION THAT HAS A NAME SUCH AS "MIDAVFLG" FOR EXAMPLE. THESE BIT POSITIONS ARE BIT-POSITIONS 15-1 OF CONSECUTIVE FLAG WORDS FLAGWRD0, FLAGWRD1, FLAGWRD2, ..., FLGWRD10 AND FLGWRD11. A FEW OF THE LATTER DO NOT YET HAVE NAMES. EACH FLAG HAS A CODE NUMBER WHICH DETERMINES THE FLAG WORD AND THE BIT POSITION IN THAT FLAG WORD TO BE SET OR CLEARED. THE FLAG WORD (FLAGWRDα WHERE α IS 0, 1, 2, ..., 10 OR 11) AND THE BIT POSITION β (WHERE β IS 15, 14, 13, ..., 2 OR 1) ARE OBTAINED BY DIVIDING THE CODE BY 15 SO THAT THE FLAG WORD WILL BE FLAGWRD0 + THE QUOTIENT (THE QUOTIENT IS α) AND THE BIT POSITION OF THAT FLAG WORD WILL BE β (β IS 15 MINUS $\mathcal{R}$, THE REMAINDER). THUS, THE CODE NUMBER IS $15\alpha + \mathcal{R}$ OR $15\alpha + 15 - \beta$. AS AN EXAMPLE, THE CODE NUMBER FOR MIDAVFLG IS DEC 148. THE QUOTIENT OF $148 \div 15$ IS 9 AND THE REMAINDER IS 13 ($\alpha = 9$, $\mathcal{R} = 13$, $\beta = 15 - \mathcal{R} = 2$). THUS, THE FLAG MIDAVFLG IS IN FLAG WORD FLAGWRD0+9 WHICH IS FLAGWRD9. FLAG MIDAVFLG IS BIT-POSITION2 OF FLAGWRD9.

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

CALLING SEQUENCE:

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

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



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APOLLO GUIDANCE AND NAVIGATION

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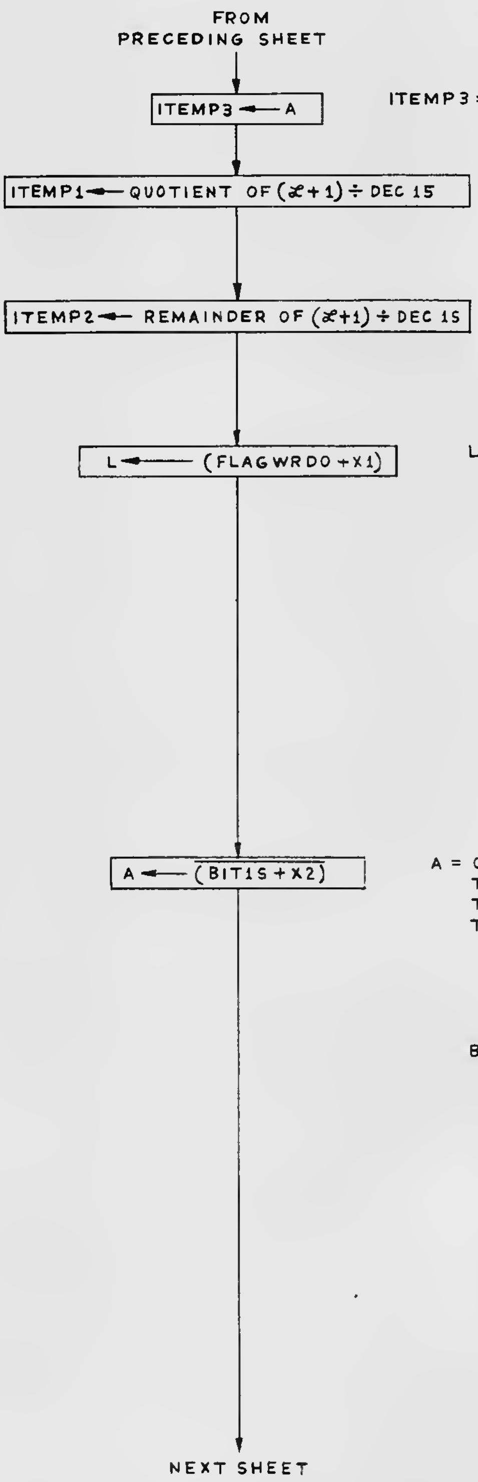
ANALST
DOCMR W Dougherty 6/8/70
APPR'D R M Enton 6/15/70

SERVICE ROUTINES
LUMINARY 1D
DOCUMENT NO. FC-3050
REV
SHEET 3 OF 12

SERVICE ROUTINES
(UPFLAG AND DOWNFLAG)



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

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

ITEMP2 = $\mathscr{R}$ (THE REMAINDER)
THE REMAINDER WILL BE USED AS AN INDEX FOR SELECTING THE BIT POSITION IN THE SELECTED FLAG WORD AND WILL BE REFERRED TO AS "X2"

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

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

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

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

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SERVICE ROUTINES

LUMINARY 1D

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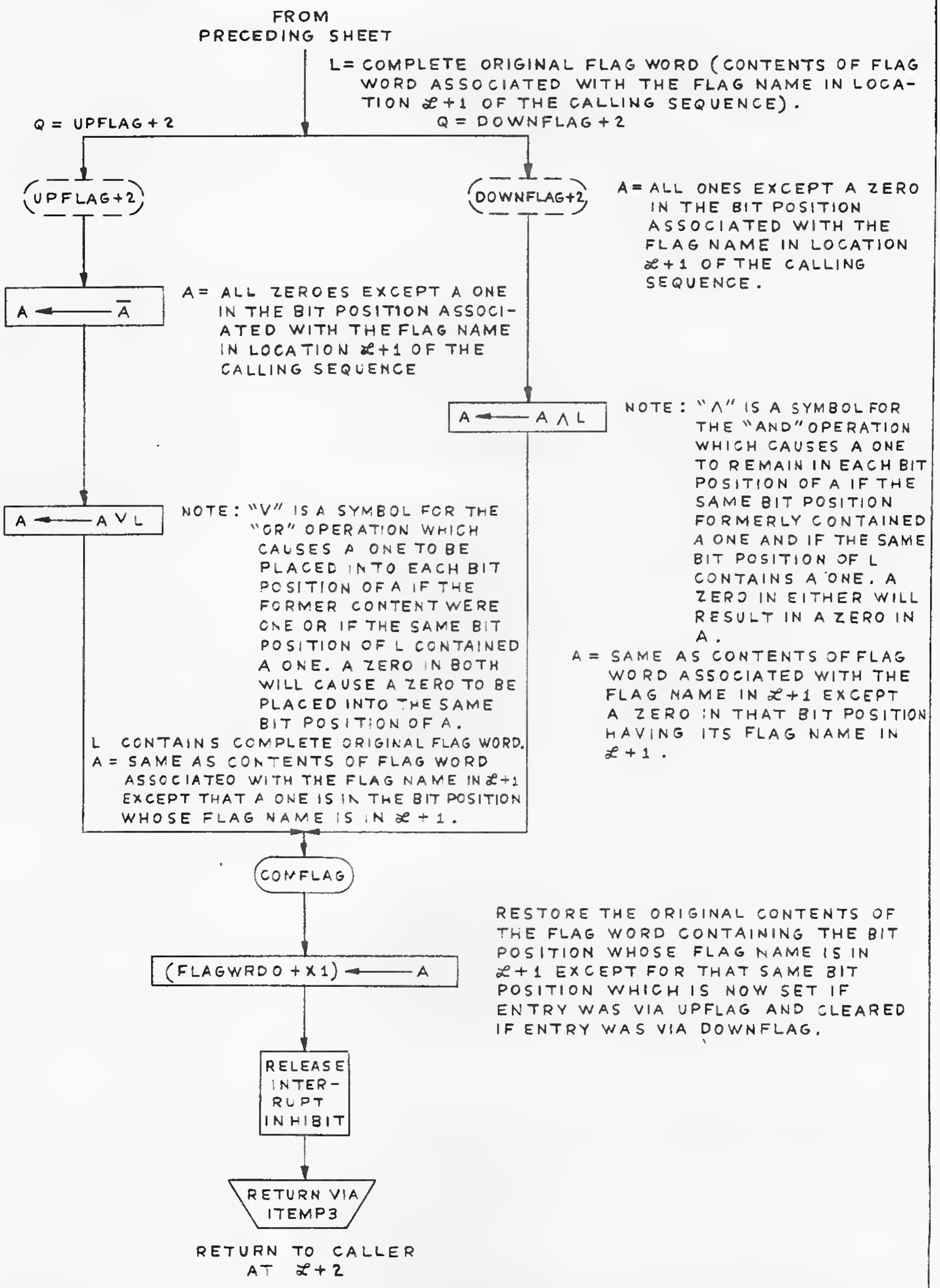
REV

SHEET 4 OF 12

SERVICE ROUTINES
(UPFLAG AND DOWNFLAG)



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

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

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

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

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

NOTE: "V" 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.

L CONTAINS COMPLETE ORIGINAL FLAG WORD.

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

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

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DRAWN	6/5/70	SERVICE ROUTINES	
PRGMR	6/15/70	LUMINARY 1D	DOCUMENT NO. FC-3050
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DOCMR	6/10/70		
APPR'D	6/15/70	REV	SHEET 5 OF 12

SERVICE ROUTINES (DELAYJOB)

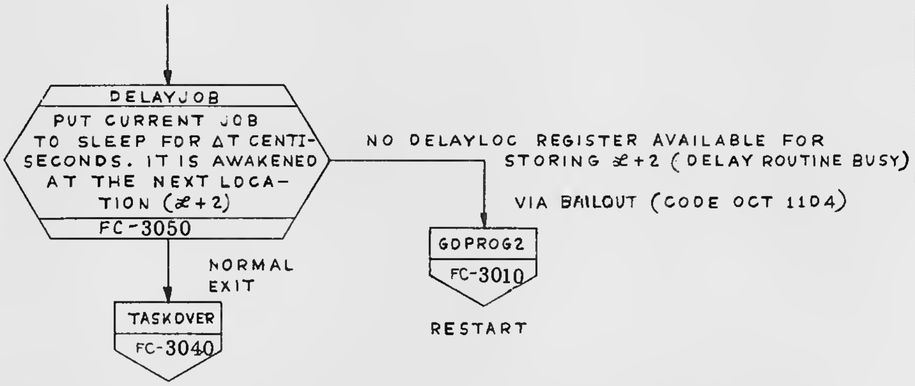
SUBROUTINE DELAYJOB IS USED TO PUT THE CURRENT JOB TO SLEEP FOR ΔT CENTISECONDS. AT THE END OF THIS TIME PERIOD THIS JOB IS AWAKENED AT THE NEXT LOCATION (ℒ+2 OF THE CALLING SEQUENCE).

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

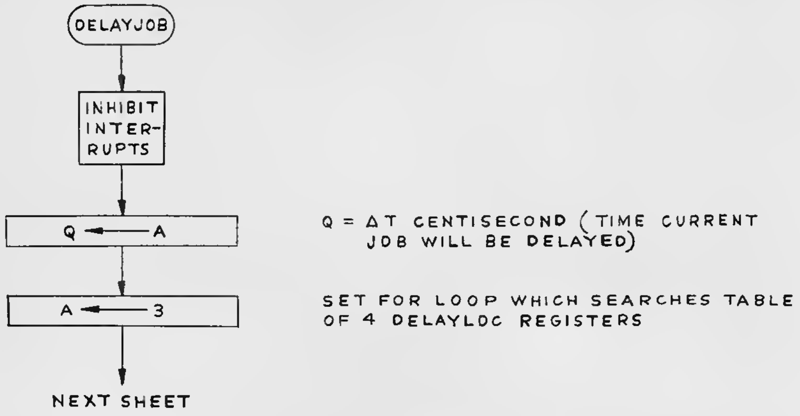
CALLING SEQUENCE:

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

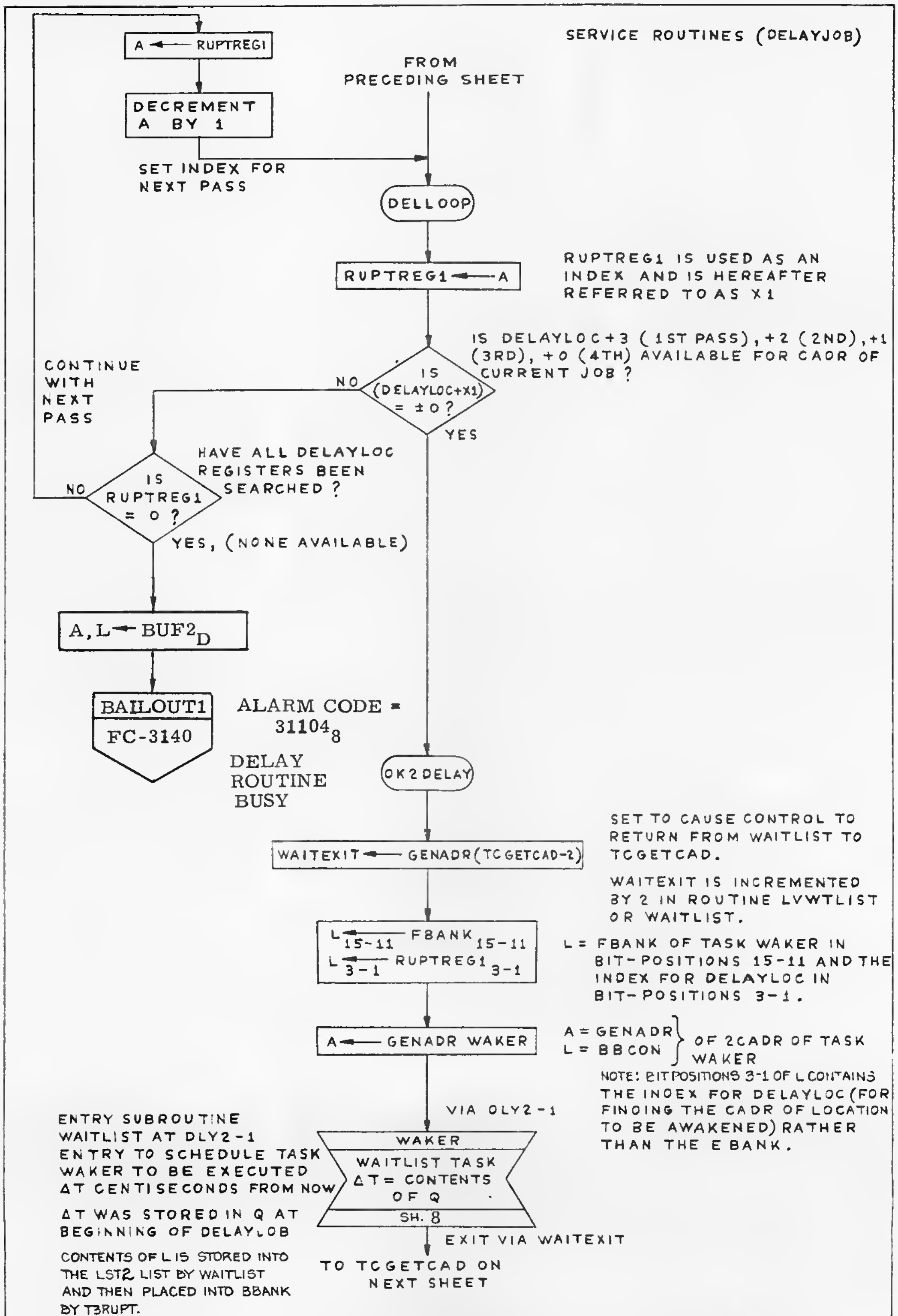
THIS SUBROUTINE WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING IT:



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



SERVICE ROUTINES (DELAYJOB)



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ANALST
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APPR'D 6/15/70

APOLLO GUIDANCE AND NAVIGATION

SERVICE ROUTINES

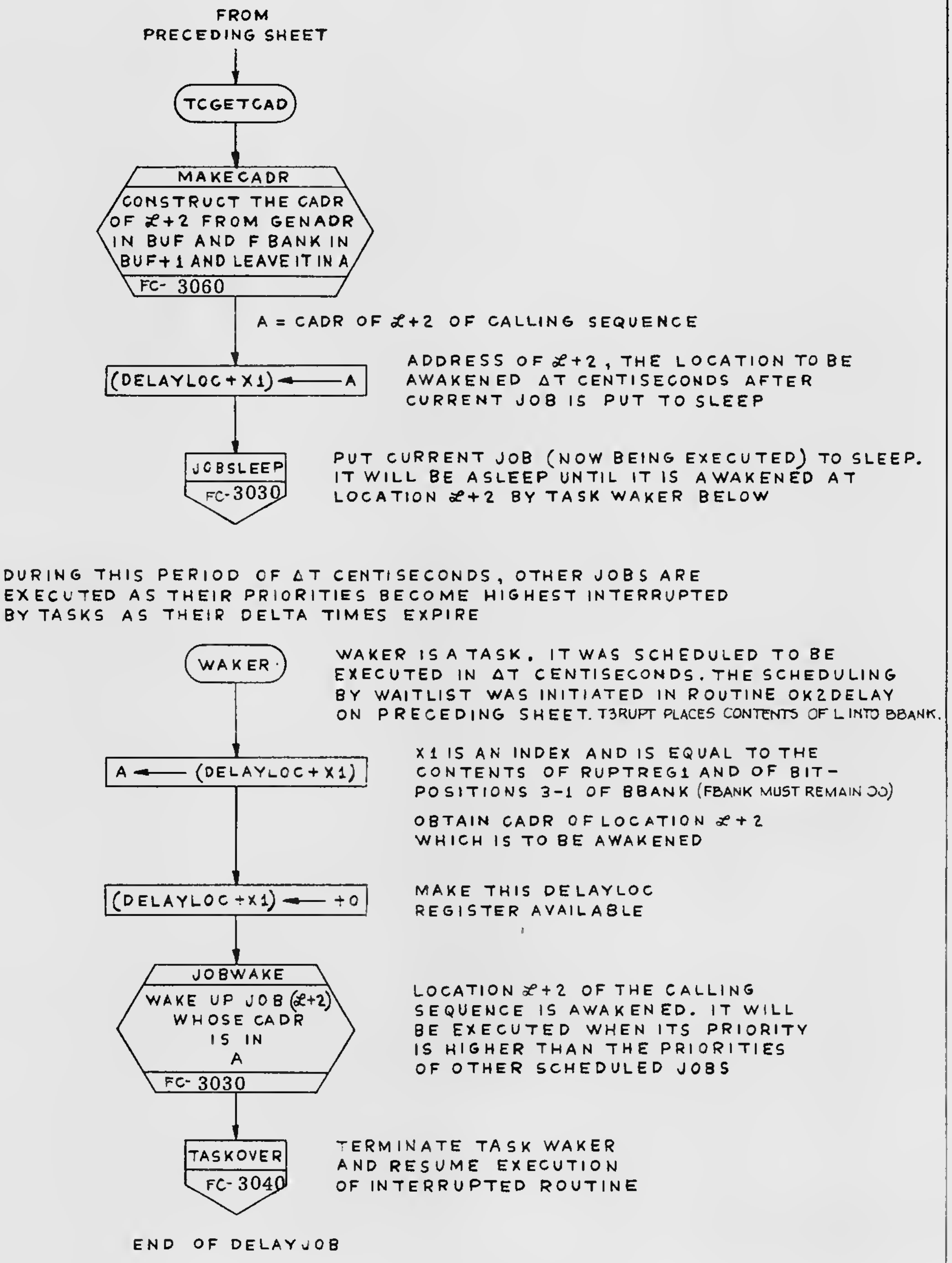
LUMINARY
1D

DOCUMENT NO.
FC-3050

REV

SHEET 7 OF 12

SERVICE ROUTINES (DELAYJOB)



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

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

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

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

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

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

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

MAKE THIS DELAYLOC REGISTER AVAILABLE

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

TERMINATE TASK WAKER AND RESUME EXECUTION OF INTERRUPTED ROUTINE

END OF DELAYJOB

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ANALST			
DOCMR W Danforth	6/8/70		
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SERVICE ROUTINES (GENTRAN)

THIS SUBROUTINE IS USED FOR COPYING CONTENTS OF N CONSECUTIVE LOCATIONS WHOSE INITIAL ADDRESS IS $\mathcal{M}$ INTO N CONSECUTIVE LOCATIONS WHOSE INITIAL ADDRESS IS $\mathcal{W}$.

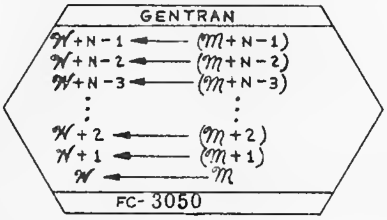
THE CALLING SEQUENCE IS:

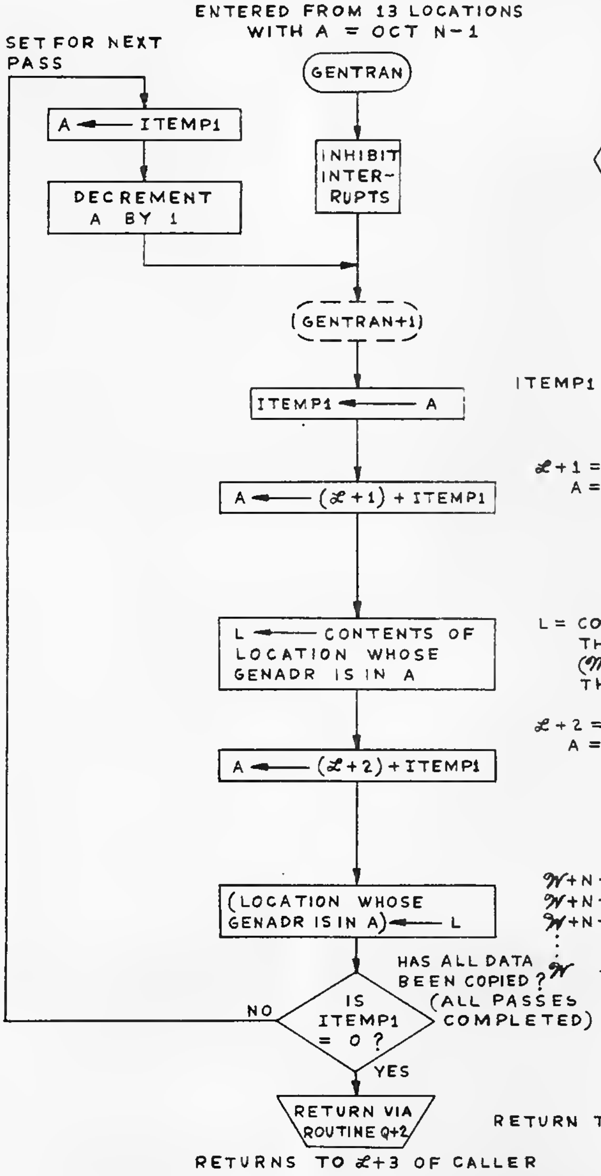
```
L-1    CAF      L±α
L+0    TC       GENTRAN
L+1    ADRES    M
L+2    ADRES    W
L+3    RETURN HERE UNCONDITIONALLY
 :       :        :
L±α    OCT      N-1
```

EXAMPLE OF CALLING SEQUENCE :

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

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





ITEMP1 = (N-1) FOR 1ST PASS, (N-2) FOR 2ND PASS, (N-3) FOR 3RD, . . ., AND 0 FOR LAST PASS

$\mathcal{L}$+1 = ADRES $\mathcal{M}$
A = ADRES ($\mathcal{M}$+N-1) FOR 1ST PASS,
ADRES ($\mathcal{M}$+N-2) FOR 2ND PASS,
ADRES ($\mathcal{M}$+N-3) FOR 3RD PASS, . . .
⋮
ADRES $\mathcal{M}$ FOR LAST PASS

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

$\mathcal{L}$+2 = ADRES $\mathcal{W}$
A = ADRES ($\mathcal{W}$+N-1) FOR 1ST PASS,
ADRES ($\mathcal{W}$+N-2) FOR 2ND PASS,
ADRES ($\mathcal{W}$+N-3) FOR 3RD PASS, . . .
⋮
ADRES $\mathcal{W}$ FOR LAST PASS

$\mathcal{W}$+N-1 ← $\mathcal{M}$+N-1 FOR 1ST PASS,
$\mathcal{W}$+N-2 ← $\mathcal{M}$+N-2 FOR 2ND PASS,
$\mathcal{W}$+N-3 ← $\mathcal{M}$+N-3 FOR 3RD PASS, . . .
⋮
$\mathcal{W}$ ← $\mathcal{M}$ FOR LAST PASS

RETURN TO CALLER AT $\mathcal{L}$+3

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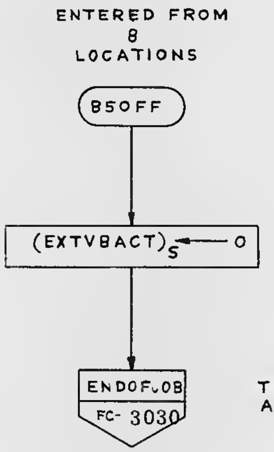
DOCMR W. Doolittle 6/8/70		
APPR'D RMM Eaton 6/15/70	REV	SHEET 9 OF 12

SERVICE ROUTINES (B5OFF)

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

CALLING SEQUENCE:

$\mathcal{L}$+0 TC B5OFF



DISPLAY HAS BEEN ANSWERED

TERMINATE AS A JOB

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PRGMR	S. Rosenberg	6/15/70	LUMINARY 1D	DOCUMENT NO. FC-3050
ANALST				
DOCMR	W. Danforth	6/8/70		
APPR'D		6/15/70	REV	SHEET 10 OF 12

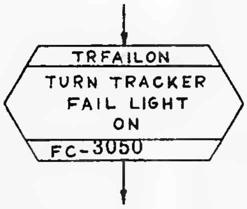
SERVICE ROUTINES
(TRFAILON AND TRFAILOF)

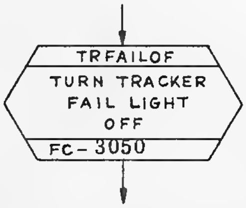
SUBROUTINES TRFAILON AND TRFAILOF ARE USED TO TURN THE TRACKER FAIL LIGHT (OPTICS CDU FAIL) ON AND OFF, RESPECTIVELY

THE CALLING SEQUENCES ARE:

```
ℒ+0  TC  TRFAILON                    ℒ+0  TC  TRFAILOF
ℒ+1      RETURN HERE                 ℒ+1      RETURN HERE
         UNCONDITIONALLY                      UNCONDITIONALLY
```

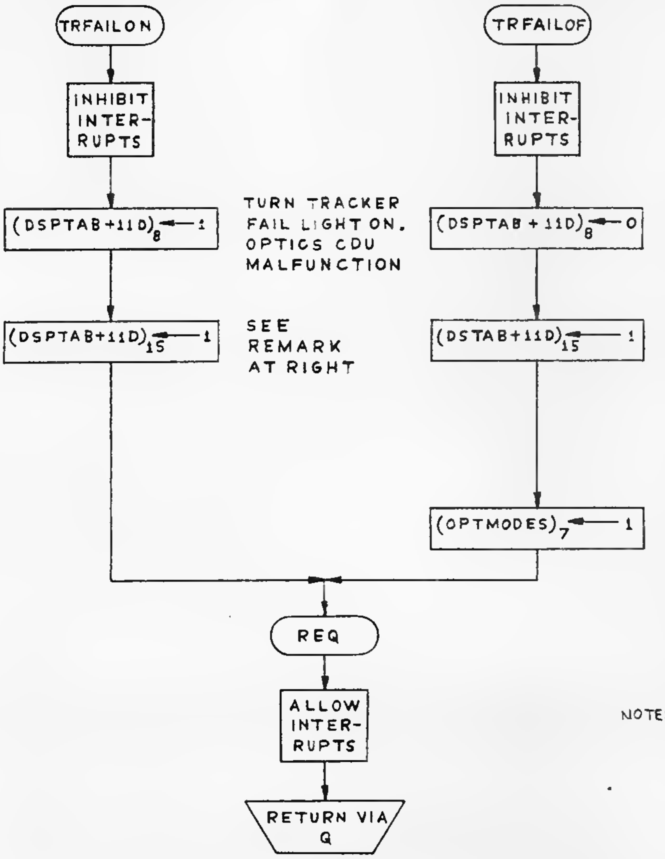
THESE SUBROUTINES WILL BE SHOWN AS FOLLOWS IN PROGRAMS USING THEM:





ENTERED FROM ROUTINE LIGHTON OF PROGRAM P20-P25

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



TURN TRACKER FAIL LIGHT ON. OPTICS CDU MALFUNCTION

SEE REMARK AT RIGHT

TURN TRACKER FAIL LIGHT OFF. NO OPTICS CDU MALFUNCTION

INDICATES TO PROGRAM T4RUPT THAT A CHANGE HAS OCCURRED IN BIT-POSITIONS 11-1 SINCE THE LAST TIME DSPTAB+11D 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 CDU FAIL INDICATION HAS BEEN GENERATED BY THE OPTICS CDU FAILURE

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

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

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ANALST				
DOCMR	6/8/70			
APPR'D	6/16/70	REV		SHEET 11 OF 12

ROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

ROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
MAKECADR	FC-3060	CONSTRUCT THE CADR OF A LOCATION WHOSE GENADR IS IN BUF AND F BANK IS IN BUF+1 AND LEAVE IT IN A	SH. 8
JOBWAKE	FC-3030	WAKE UP JOB WHOSE CADR IS IN A	SH. 8
JOBSLEEP	FC-3030	PUT JOB TO SLEEP	SH. 8

ERASABLE LOCATIONS USED (FLAGS)

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
EXTVBACT BIT 5	DISPLAY WAITING TO BE ANSWERED	DISPLAY HAS BEEN ANSWERED	—	SH. 10	—
DSPTAB+11D BIT 8	TURNS TRACKER FAIL LIGHT ON (OPTICS CDU MALFUNCTION)	TURNS TRACKER FAIL LIGHT OFF (NO OPTICS CDU MALFUNCTION)	SH. 11	SH. 11	—
OPTMODES BIT 7	NO OPTICS CDU FAIL INDICATION HAS BEEN GENERATED	OPTICS CDU FAIL INDICATION HAS BEEN GENERATED	SH. 11	—	—

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PRGMR S. Rosenberg	6/15/70	LUMINARY 1D	DOCUMENT NO. FC-3050
ANALST			
DOCMR	6/9/70		
APPR'D	6/15/70	REV	SHEET 12 OF 12

INTER-BANK COMMUNICATION

BANKCALL	Sh. 2
SWCALL	Sh. 2
SWRETURN	Sh. 3
POSTJUMP	Sh. 3
BANKJUMP	Sh. 3
MAKECADR	Sh. 4
SUPDACAL	Sh. 4
IBNKCALL	Sh. 5
ISWCALL	Sh. 6
ISWRETRN	Sh. 6
USPRCADR	Sh. 7
SUPERSW	Sh. 7

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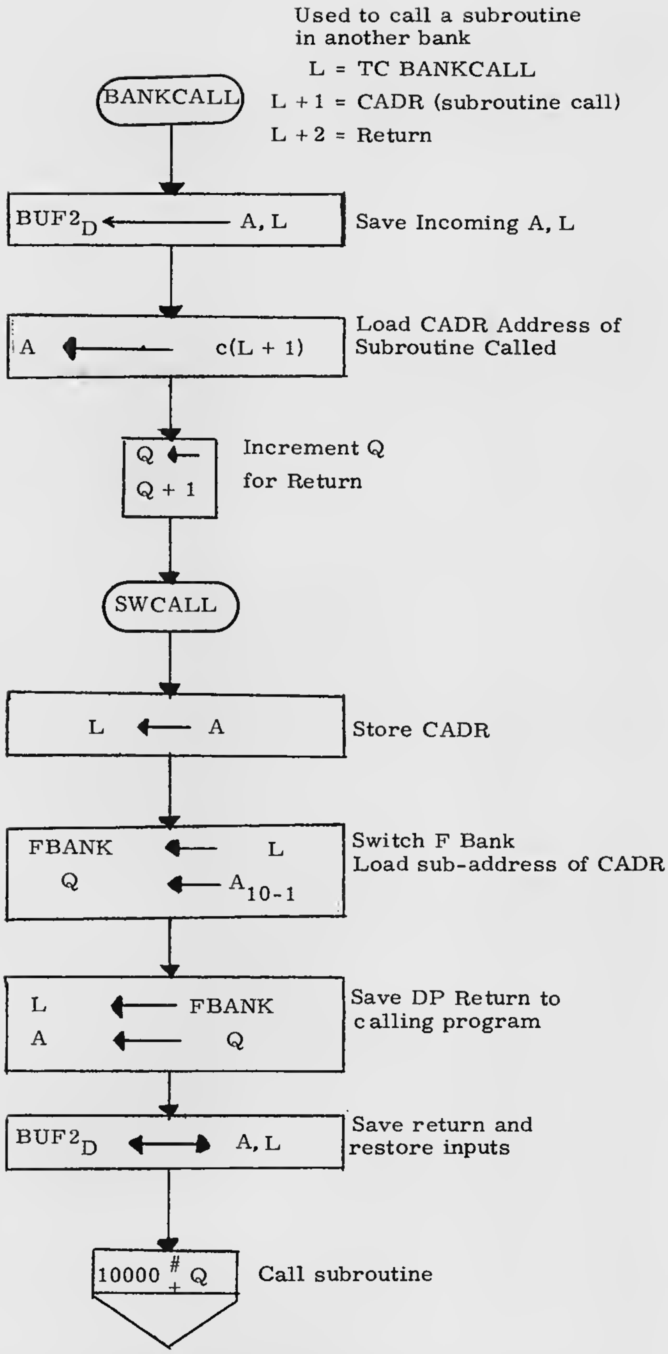
DRAWN J. Bisbee	10/11/69	Inter-Bank Communication	
PRGMR Frances Kirwen	12/1/69	LUMINARY 1 D	DOCUMENT NO. FC-3060
ANALST			
DOCMR W Danforth	10/22/69		
APPR'D Roberta M. Eustes	12/1/69	REV 1	SHEET 1 OF 7



Used to call a subroutine in another bank

L = TC BANKCALL
L + 1 = CADR (subroutine call)
L + 2 = Return

Save Incoming A, L

Load CADR Address of Subroutine Called

Increment Q for Return

Store CADR

Switch F Bank
Load sub-address of CADR

Save DP Return to calling program

Save return and restore inputs

Call subroutine

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DOCMR W Danforth 10/22/69
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APOLLO GUIDANCE AND NAVIGATION

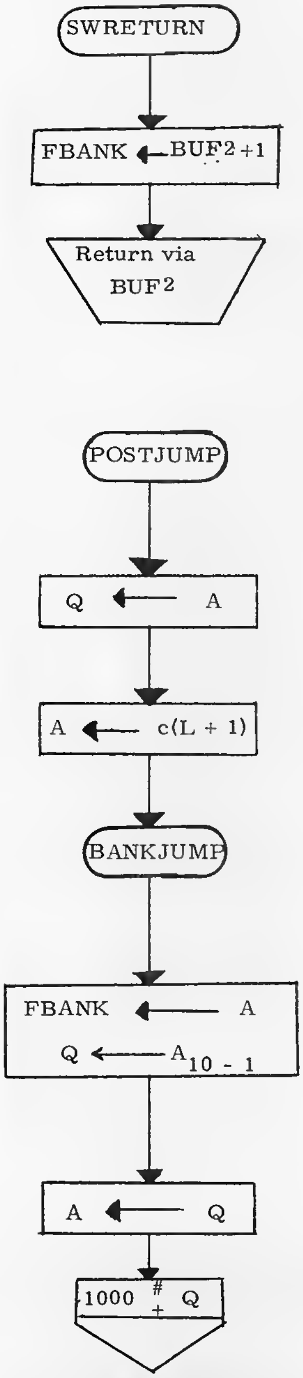
Inter-Bank Communication

LUMINARY 1D

DOCUMENT NO. FC-3060

REV 1

SHEET 2 OF 7



Restore caller FBANK

Return to caller

Used as a unilateral bank jump

L = TC POSTJUMP

L + 1 = CADR of BANK-JUMP

Save incoming A

Load CADR address

Switch FBANK

Load sub-address of CADR

Restore input A

Go to new bank

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ANALST
DOCMR W Danforth 10/22/69
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APOLLO GUIDANCE AND NAVIGATION

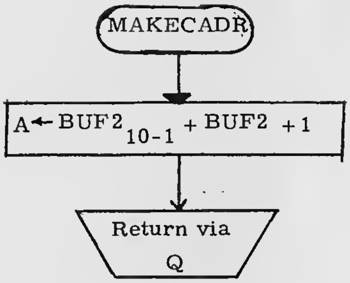
Inter-Bank Communication

LUMINARY 1D

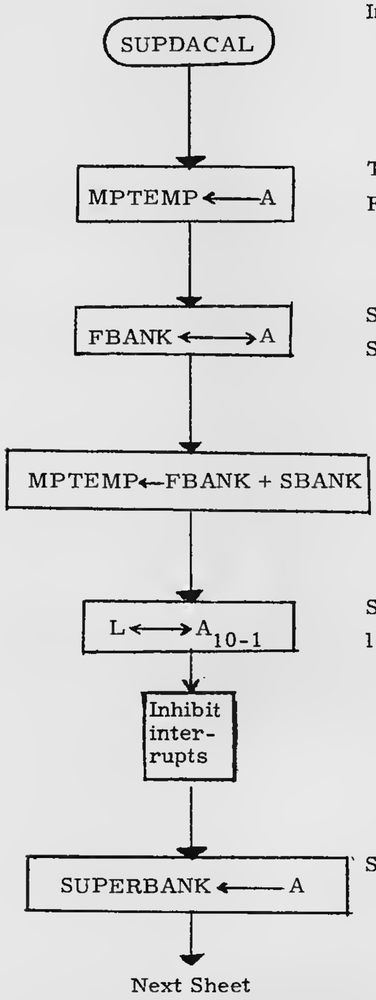
DOCUMENT NO. FC-3060

REV 1

SHEET 3 OF 7



Load return CADR saved By BANKCALL or SWCALL



Input : A = FCADR,
L = SUPERBITS

Temporary storage for FCADR

Set new FBANK
Save old FBANK

Save old FBANK and SBANK

Save rel. address in bank
load input SUPERBITS

Set SUPERBANK for data

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ANALST
DOCMR W Dogherty 10/22/69
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APOLLO GUIDANCE AND NAVIGATION

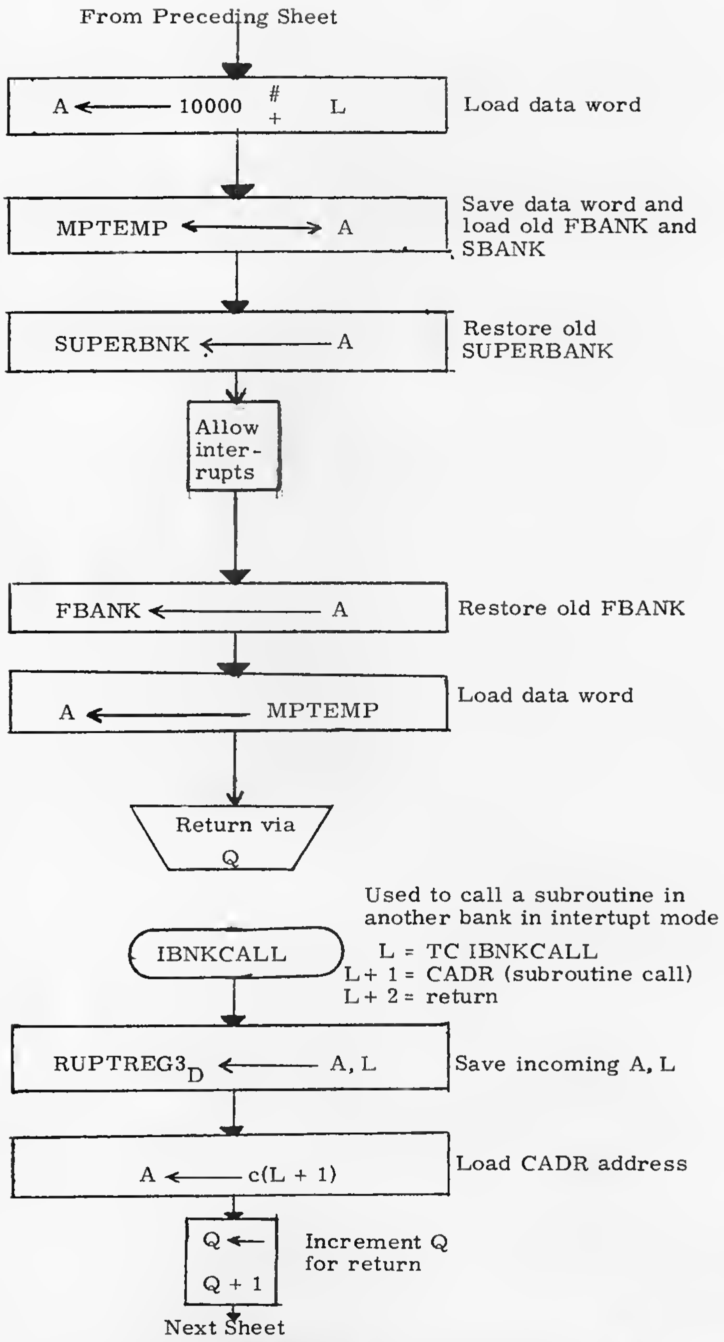
Inter-Bank Communication

LUMINARY 1D

DOCUMENT NO. FC-3060

REV 1

SHEET 4 OF 7



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DOCMR W Danforth 10/22/69
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APOLLO GUIDANCE AND NAVIGATION

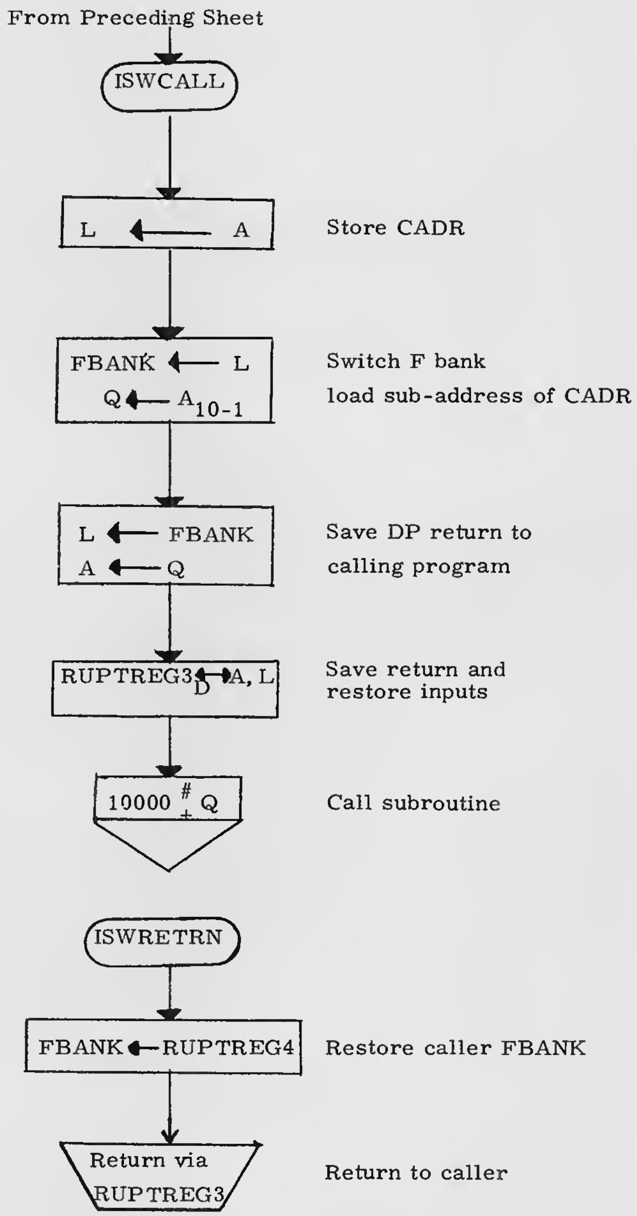
Inter-Bank Communication

LUMINARY 1D

DOCUMENT NO. FC-3060

REV 1

SHEET 5 OF 7



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APOLLO GUIDANCE AND NAVIGATION

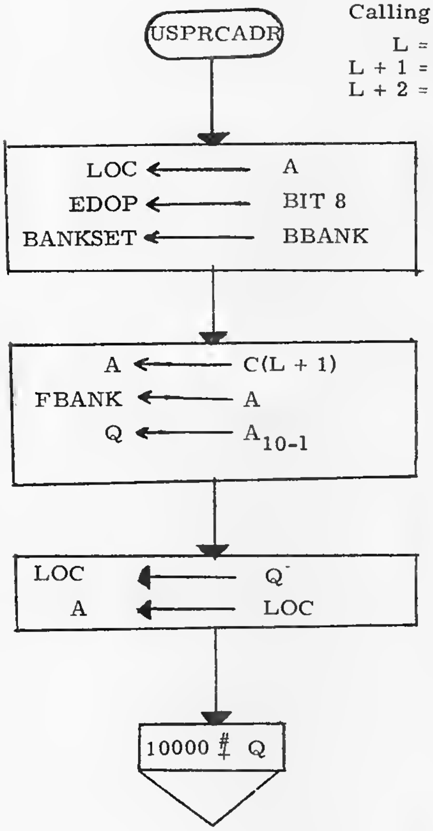
Inter-Bank Communication

LUMINARY 1D

DOCUMENT NO.
FC-3060

REV 1

SHEET 6 OF 7



Calling sequence

L = TC USPRCADR
L + 1 = CADR INTPRETX
L + 2 = Return

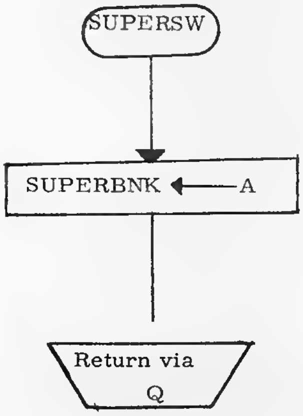
Temporary storage for input in A

Load CADR address

Interpretive BANK to FBANK

Interpretive address to Q

Restore input A



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ANALST
DOCMR W Danforth 10/22/69
APPR'D Roberta M. Sutton 12/1/69

APOLLO GUIDANCE AND NAVIGATION

Inter-Bank Communication

LUMINARY 1D

DOCUMENT NO. FC-3060

REV 1

SHEET 7 OF 7

EXTENDED VERBS

ALM/END	Sh. 2
CHKPOOH	Sh. 2
TESTXACT	Sh. 3
GOLOADLV	Sh. 4

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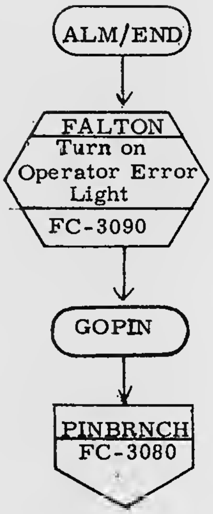
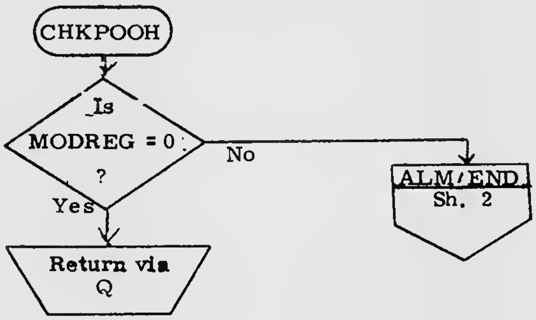
PRGMR Frances Rivera 10/26/69
ANALST
DOCMR W Dagforth 10/20/69
APPR'D Roberta M. Easton 12/3/69

APOLLO GUIDANCE AND NAVIGATION
Extended Verbs
LUMINARY 1D
DOCUMENT NO. FC-3100
REV 1
SHEET 1 OF 5





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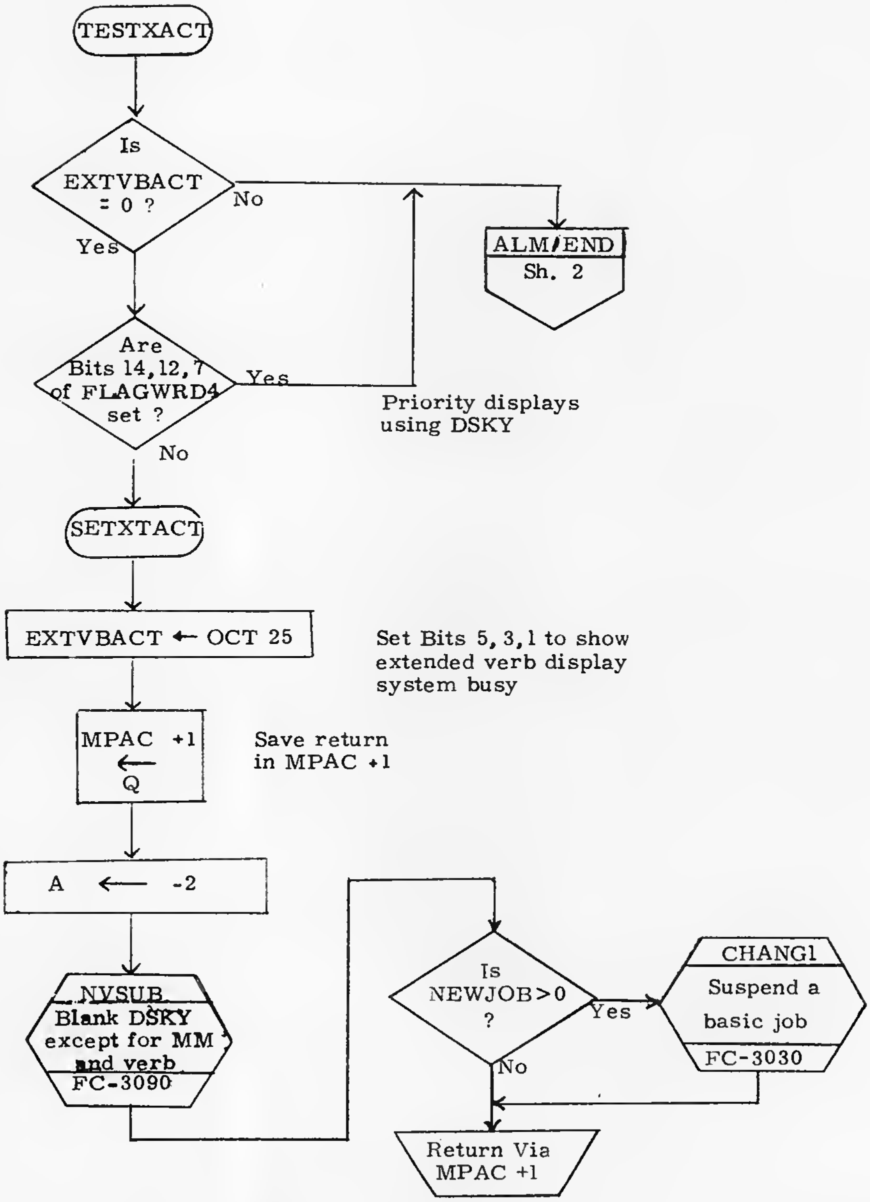
DRAWN	10/14	Extended Verbs	
PRGMR	11/26/69		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3100
DOCMR	10/29/69		
APPR'D	12/3/69	REV 1	SHEET 2 OF 5



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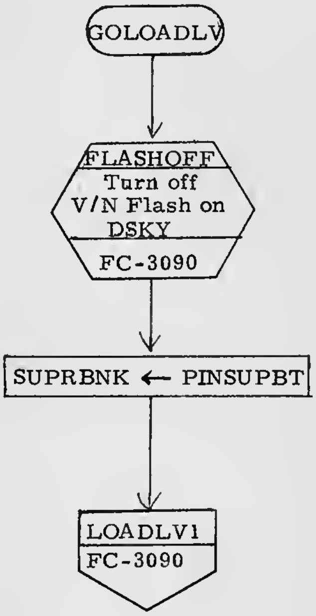
DRAWN R. Houston	10/14	Extended Verbs	
PRGMR Frances Kiever	11/26/69		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3100
DOCMR	10/20/69		
APPR'D Roberta M. Eaton	12/10/69	REV 1	SHEET 3 OF 5



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DRAWN R. Hunter	[illegible]	Extended Verbs	
PRGMR Frances Rieven	[illegible]/69		DOCUMENT NO.
ANALST			
DOCMR W. Daybrook	[illegible]/69	LUMINARY 1D	FC-3100
APPR'D Roberta M. Eaton	[illegible]/69	REV 1	SHEET 4 OF 5

Subroutines Called on Other Flowcharts

Subroutine	Flowchart	Description	Where Called
FALTON	FC-3090	Turn on operator error light	Sh. 2
NVSUB	FC- 3090	Blank DSKY except for MM and verb	Sh. 3
FLASHOFF	FC 3090	Turn off V/N flash on DSKY	Sh. 4
CHANG1	FC- 3030	Suspend a basic job	Sh. 3

FLAGS

Name	Meaning When Set	Meaning When Cleared	Where Set	Where Cleared	Where Tested
PRIODFLG Flag 4 Bit 14	Priority display in ENDIDLE	No priority display in ENDIDLE			Sh. 3
PDSPFLAG Flag 4 Bit 12	P20 sets a normal display into a priority display in R60	Leave as normal display			Sh. 3
PRONVFLG Flag 4 Bit 7	Astronaut using keyboard when priority display initiated	Astronaut not using keyboard when priority display initiated			Sh. 3

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PRGMR Frances Viven	11/26/69	LUMINARY 1D	DOCUMENT NO. FC-3100
ANALST			
DOCMR W Dagforth	11/25/69		
APPR'D Roberta M. Estes	12/3/69	REV 1	SHEET 5 OF 5

KEYRUPT and UPRUPT

KEYRUPT1 Sh. 4
UPRUPT Sh. 6

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PROGMR	J. Vella	10/28/69		
ANALST			LUMINARY 1D	DOCUMENT NO. FC-3110
DOCMR	Roberta M. Eites	10/28/69		
APPR'D	Roberta M. Eites	10/28/69	REV 2	SHEET 1 OF 11

KEYRUPT AND UPRUPT

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

Several ways are available to communicate with the computer. A command may be keyed in (Verb-Noun combination) by depressing keys VERB, V1, V2, NOUN, N1, N2, and ENTER, where V1, V2, N1, and N2 represent numerical keys (0, 1, 2, ..., 8 or 9). Data may be entered on request from the computer by depressing several numerical keys (and a sign key) and key ENTER. Keys CLEAR, ERROR RESET, KEY RLSE may also be depressed. Each time a key is depressed, routine KEYRUPT which requests the execution of job CHARIN (in Pinball program, FC-3090 is executed. Each time job CHARIN is executed, it performs an operation determined by the key that was depressed. When key ENTER is depressed, the command (which has been keyed in as a Verb-Noun combination) is executed or the data (which has been keyed in) is accepted. Routine UPRUPT is executed each time an uplink word has been received from the ground; it also requests the execution of job CHARIN. Each uplink word contains information similar to that generated by depressing a key on a DSKY.

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

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

When uplink counter INLINK overflows, the routine being executed 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 ia a 16-bit word consisting of a one in bit-position 16 and the key code (5-bit configuration) is in bit position 15-11 and 5-1 and its complement in 10-6. When the one in bit-position 16 of the 16-bit word reaches bit-position 16 of INLINK during the serial loading (shifting left in INLINK one bit-position at a time), overflow occurs causing interrupt No. 7. Control will arrive at routine UPRUPT via its lead-in interrupt routine.

The characters are represented by the following key codes:

Character (or action)	Key Code (binary)	Character (or action)	Key Code (binary)
0	10 000	VERB	10 001
1	00 001	ERROR RESET	10 010
2	00 010	KEY RELEASE	11 001
3	00 011	+	11 010
4	00 100	-	11 011
5	00 101	ENTER	11 100
6	00 110	CLEAR	11 110
7	00 111	NOUN	11 111
8	01 000		
9	01 001		

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

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

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

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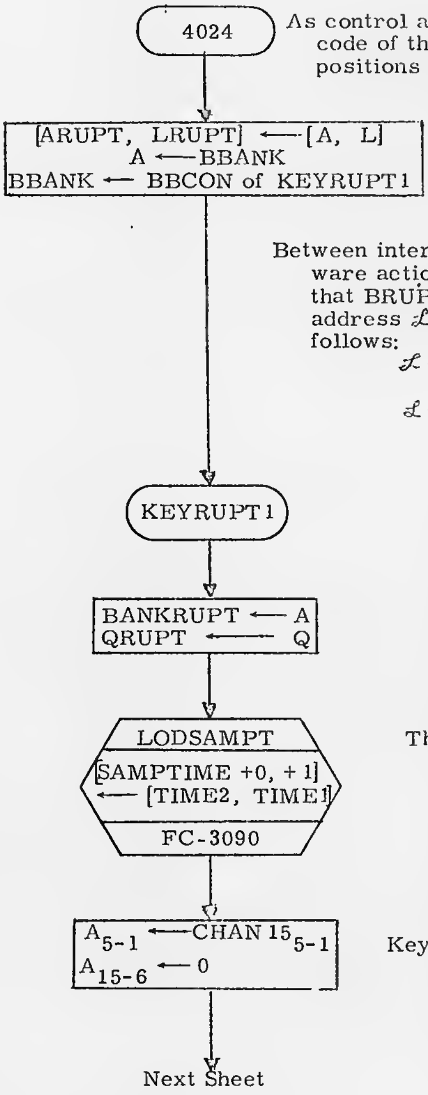
ANALST			
DOCMR			
APPR'D Roberta M. Eutes	10/28/69	REV 2	SHEET 3 OF11

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

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

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

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

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

The current time is saved in double precision

Key Code

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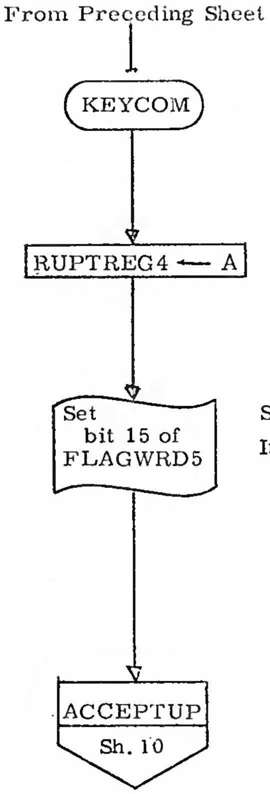

Key Code (0-0-K)

Set DSKYFLAG
Indicates that displays were sent to the DSKY.

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KEYRUPT and UPRUPT

LUMINARY 1D

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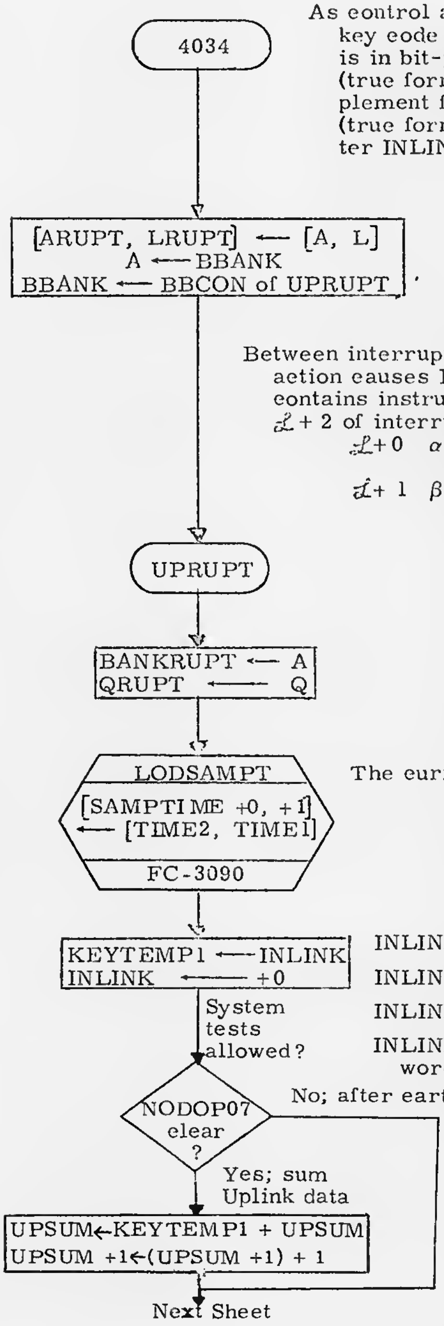
FC-3110

REV 2

SHEET 5 OF 11

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 β and ZRUPT contains address $\mathcal{L}+2$ of interrupted routine sequence as follows:

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

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

The current time is saved in double precision

INLINK_{5-1} = Key code in true form

INLINK_{10-6} = Key code in complement form

INLINK_{15-11} = Key code in true form

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

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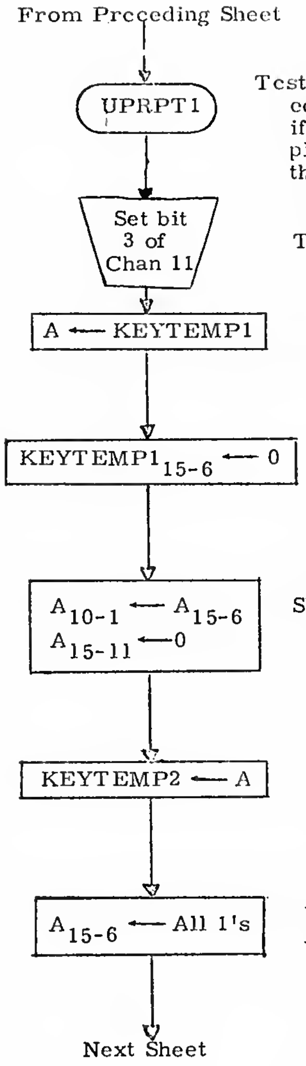

Test for triple character redundancy. If the key codes in bit-positions 5-1 and 15-11 agree and if the key code in bit-positions 10-6 is the complement of the key code in bit positions 5-1, then the key code is accepted.

Turn on UPLINK activity light

Key code (three in K-$\overline{\text{K}}$-K arrangement)

KEYTEMP1_{5-1} = Key code in true form
KEYTEMP1_{15-6} = 0

Shift key code arrangement to the right 5 bit positions so that A contains the 0-K-$\overline{\text{K}}$ arrangement

Key code arranged 0-K-$\overline{\text{K}}$ will be used for second part of redundancy test.

A_{5-1} = Key code in complement form
A_{15-6} = Binary 111 111 111 1

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KEYRUPT and UPRUPT
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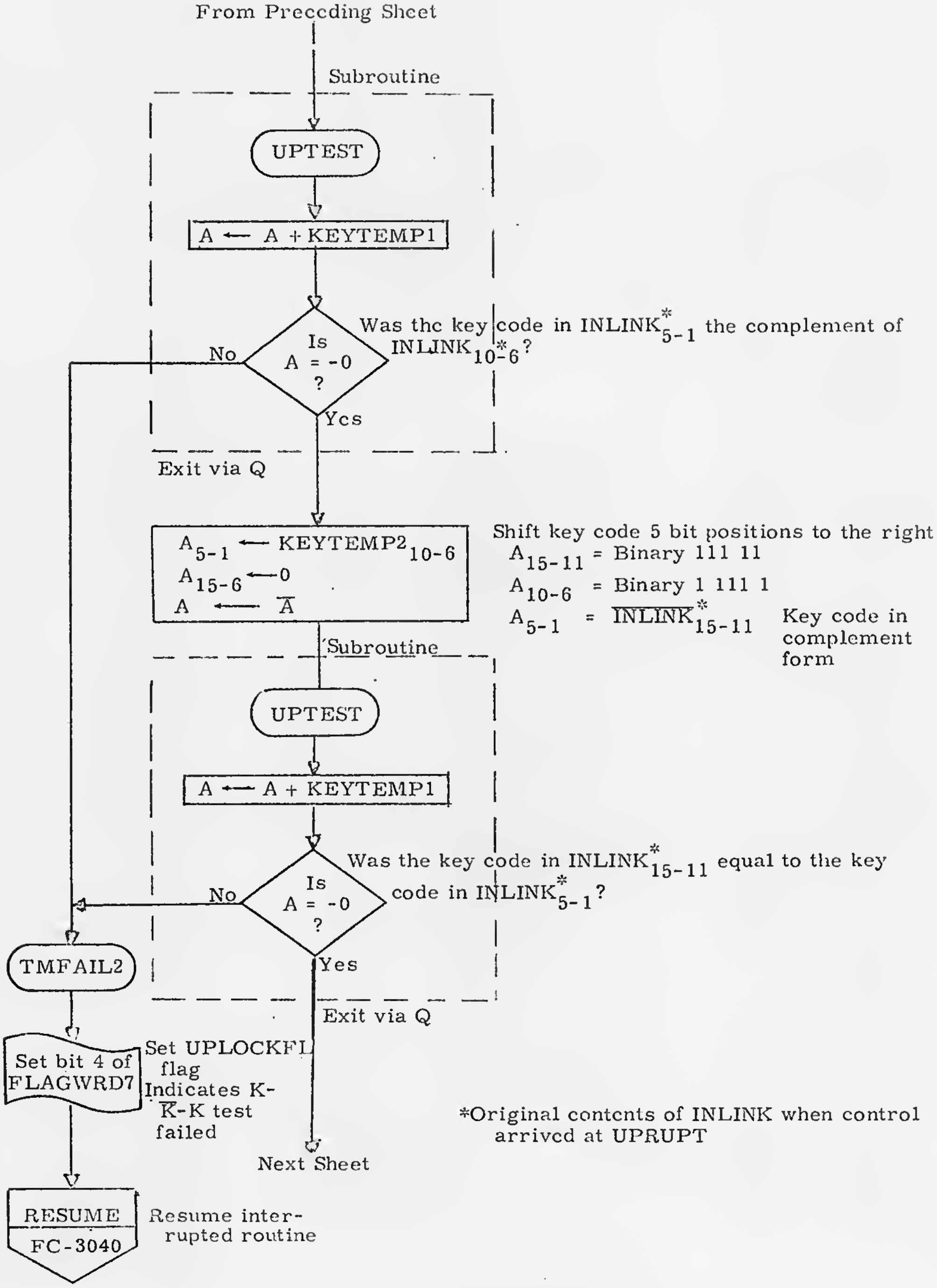
REV 2.
SHEET 7 OF 11



*Original contents of INLINK when control arrived at UPRUPT

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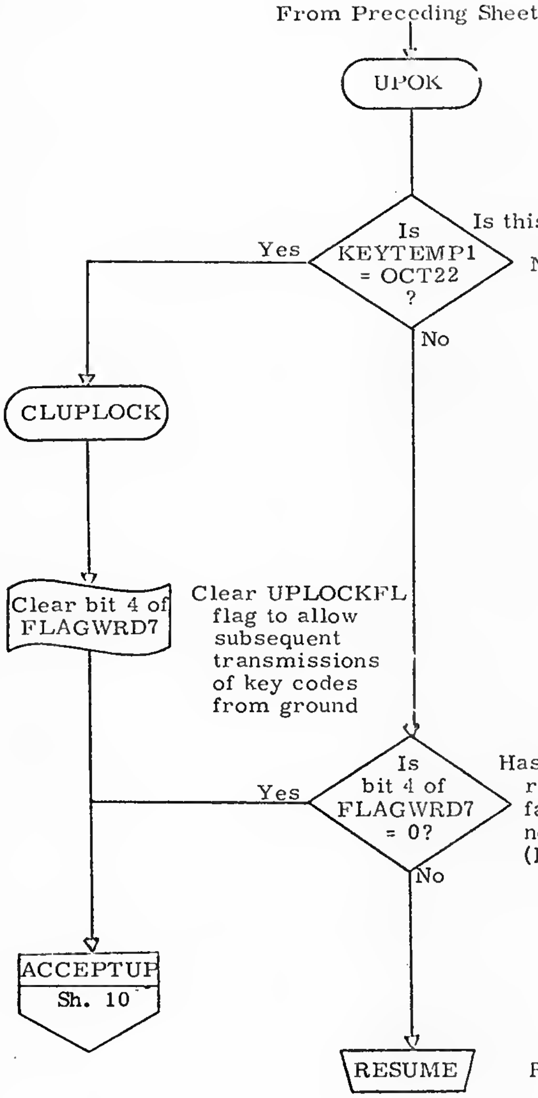
From Preceding Sheet



Is this key code the error reset code?

Note: If the transmission of a key code was not satisfactory (K-$\overline{\text{K}}$-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.

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

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?)

Resume the interrupted routine

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KEYRUPT and UPRUPT

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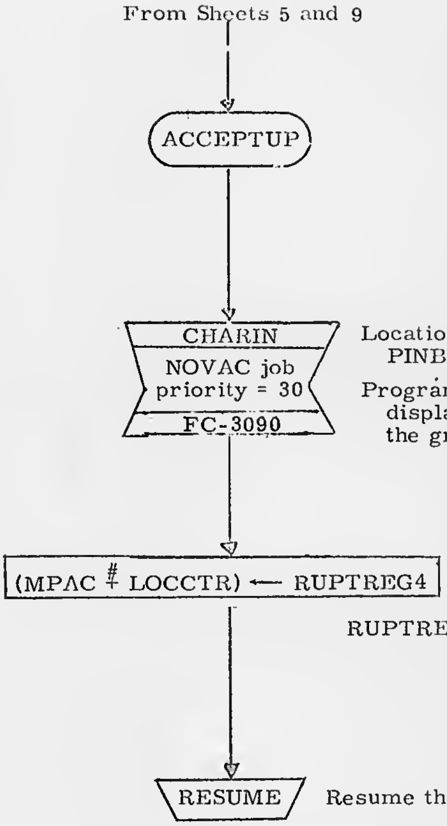
REV 2

SHEET 9 OF 11



Location CHARIN is the beginning of program PINBALL (its entry point)

Program PINBALL executes the requests for displays from the operator (key board) and the ground

RUPTREG4 = KEYTEMP1 and contains the key code in the 0-0-K arrangement

Resume the interrupted routine

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KEYRUPT and UPRUPT

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FC-3110

REV 2

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FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
DSKYFLAG (Flagword 5 bit 15)	Displays sent to DSKY.	No displays to DSKY.	Sh. 5		
NODOP07 (Flagword 3 bit 11)	System tests not allowed	System tests allowed			Sh. 6
UPLOCKFL (Flagword 7 bit 4)	K-$\bar{K}$-K fail	No K-$\bar{K}$-K fail	Sh. 8	Sh. 9	Sh. 9

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
CHARIN	FC-3090	Entry to PINBALL	Sh. 10
LODSAMPT	FC-3090	Save current time in double precision	Sh. 4, 6
RESUME	FC-3040	Resume interrupted routine	Sh. 8, 9, 10

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KEYRUPT and UPRUPT

LUMINARY 1D

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UPDATE PROGRAM - P27

V70UPDAT Sh 2
V71UPDAT Sh 2
V72UPDAT Sh 2
V73UPDAT Sh 2

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DRAWN E. Motta 5/28/70
PRGMR Sharon Albert 5/28/70
ANALST
DOCMR 5/28/70
APPR'D 5/27/70

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UPDATE PROGRAM

LUMINARY 1D

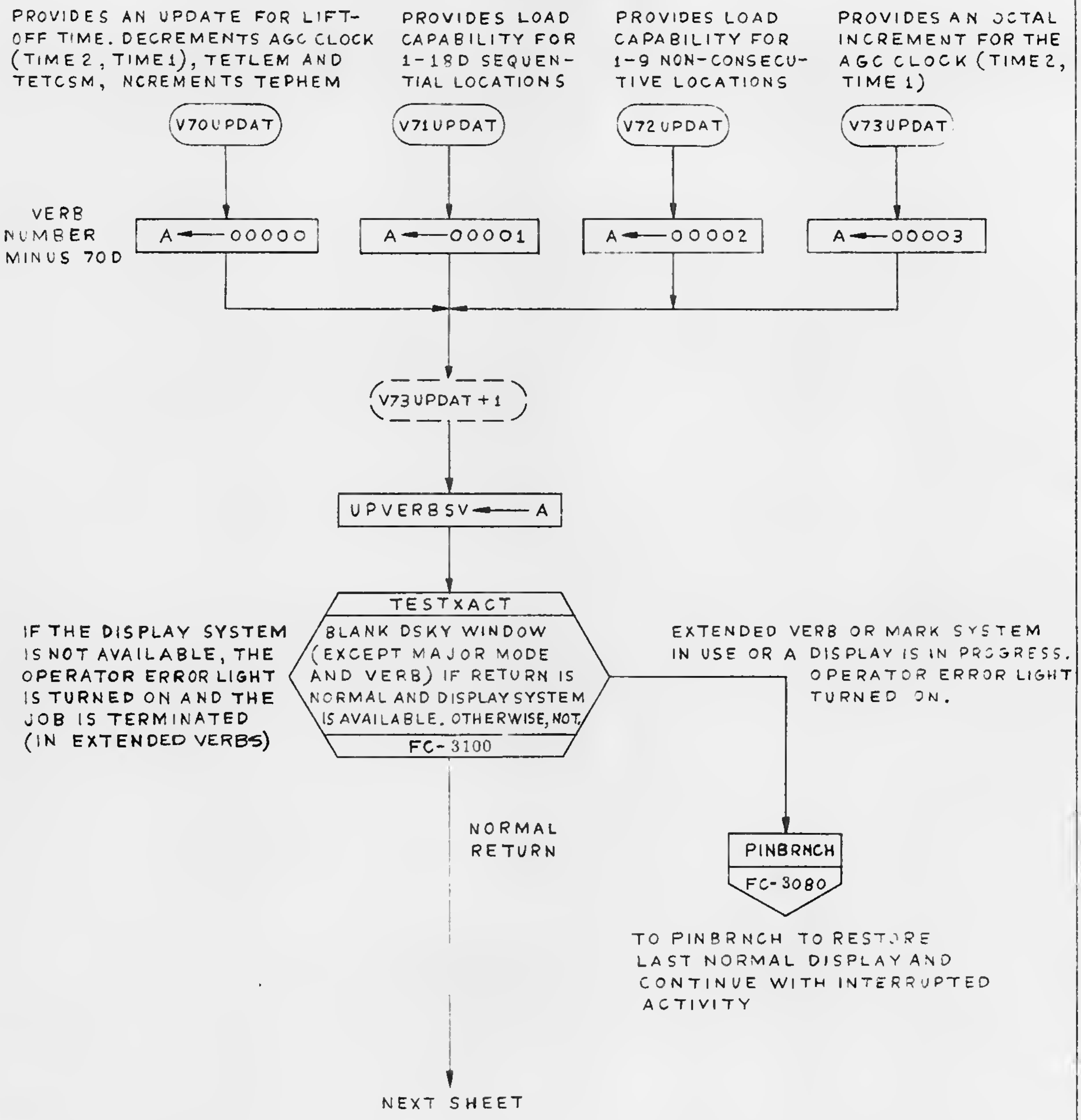
DOCUMENT NO.
FC-3120

REV

SHEET 1 OF 15

UPDATE PROGRAM (P27)

THE PURPOSE OF P27 IS TO PROCESS COMMANDS AND DATA INSERTIONS REQUESTED BY THE GROUND VIA UPLINK. THE FOUR TYPES OF UPDATES ARE ENTERED BY UPLINK ENTRY OF VERBS 70, 71, 72 OR 73 AS FOLLOWS: (NOTE: THE ASTRONAUT MAY ALSO USE P27 BY KEYING IN VERBS 70, 71, 72 OR 73 ON THE DSKY)



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PRGMR 12-9-68
ANALST
DOCMR C. H. Beck 12-9-68
APPR'D John A. Moore 12-9-68
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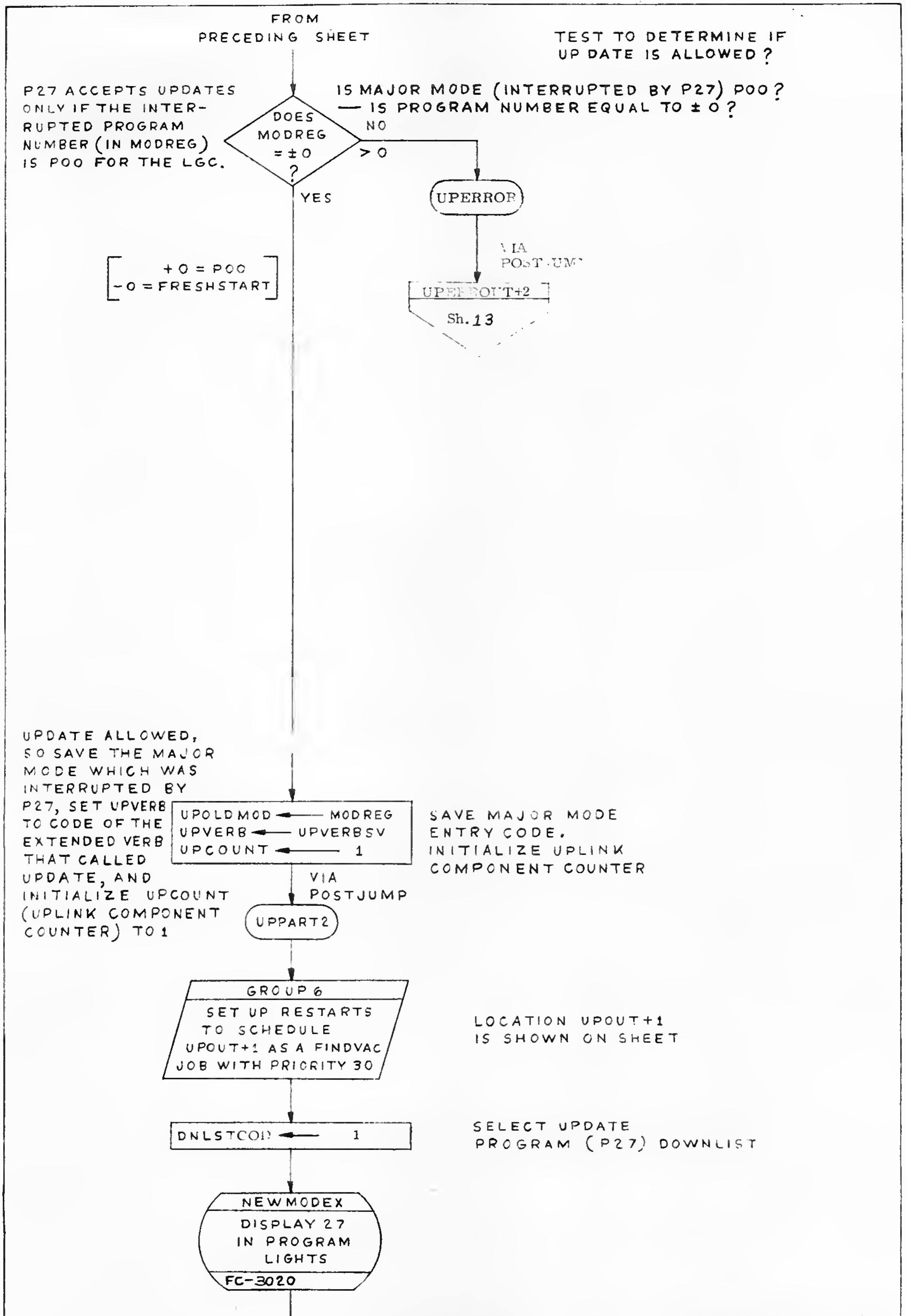

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DOCUMENT NO. FC-3120
REV
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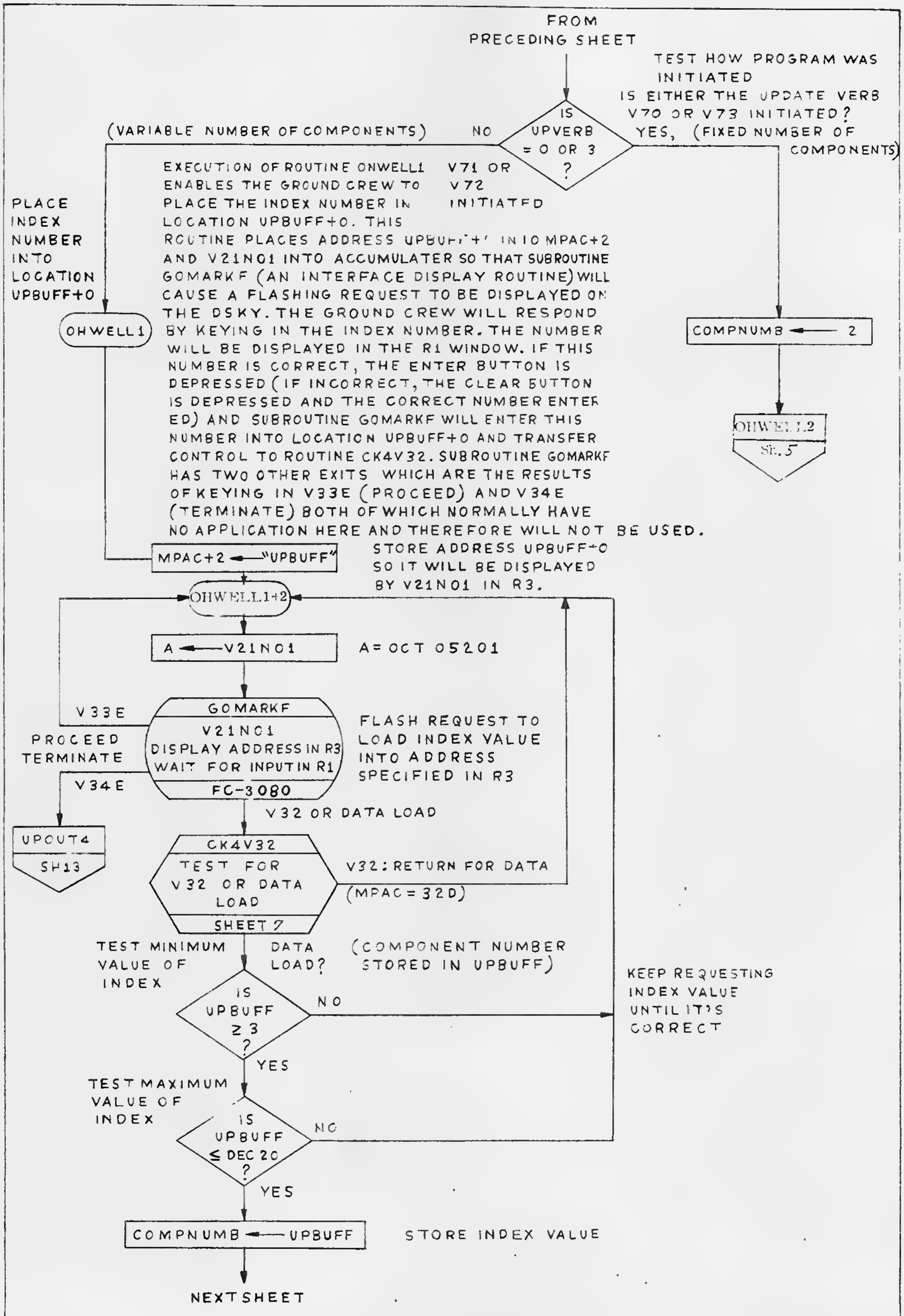

TEST HOW PROGRAM WAS INITIATED
IS EITHER THE UPDATE VERB V70 OR V73 INITIATED?

EXECUTION OF ROUTINE ONWELL1 ENABLES THE GROUND CREW TO PLACE THE INDEX NUMBER IN LOCATION UPBUFF+0. THIS ROUTINE PLACES ADDRESS UPBUFF+' INTO MPAC+2 AND V21N01 INTO ACCUMULATER SO THAT SUBROUTINE GOMARKF (AN INTERFACE DISPLAY ROUTINE) WILL CAUSE A FLASHING REQUEST TO BE DISPLAYED ON THE DSKY. THE GROUND CREW WILL RESPOND BY KEYING IN THE INDEX NUMBER. THE NUMBER WILL BE DISPLAYED IN THE R1 WINDOW. IF THIS NUMBER IS CORRECT, THE ENTER BUTTON IS DEPRESSED (IF INCORRECT, THE CLEAR BUTTON IS DEPRESSED AND THE CORRECT NUMBER ENTERED) AND SUBROUTINE GOMARKF WILL ENTER THIS NUMBER INTO LOCATION UPBUFF+0 AND TRANSFER CONTROL TO ROUTINE CK4V32. SUBROUTINE GOMARKF HAS TWO OTHER EXITS WHICH ARE THE RESULTS OF KEYING IN V33E (PROCEED) AND V34E (TERMINATE) BOTH OF WHICH NORMALLY HAVE NO APPLICATION HERE AND THEREFORE WILL NOT BE USED.

STORE ADDRESS UPBUFF+0 SO IT WILL BE DISPLAYED BY V21N01 IN R3.

A = OCT 05201

FLASH REQUEST TO LOAD INDEX VALUE INTO ADDRESS SPECIFIED IN R3

(COMPONENT NUMBER STORED IN UPBUFF)

TEST MINIMUM VALUE OF INDEX

TEST MAXIMUM VALUE OF INDEX

KEEP REQUESTING INDEX VALUE UNTIL IT'S CORRECT

STORE INDEX VALUE

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	UPDATE PROGRAM (P27)
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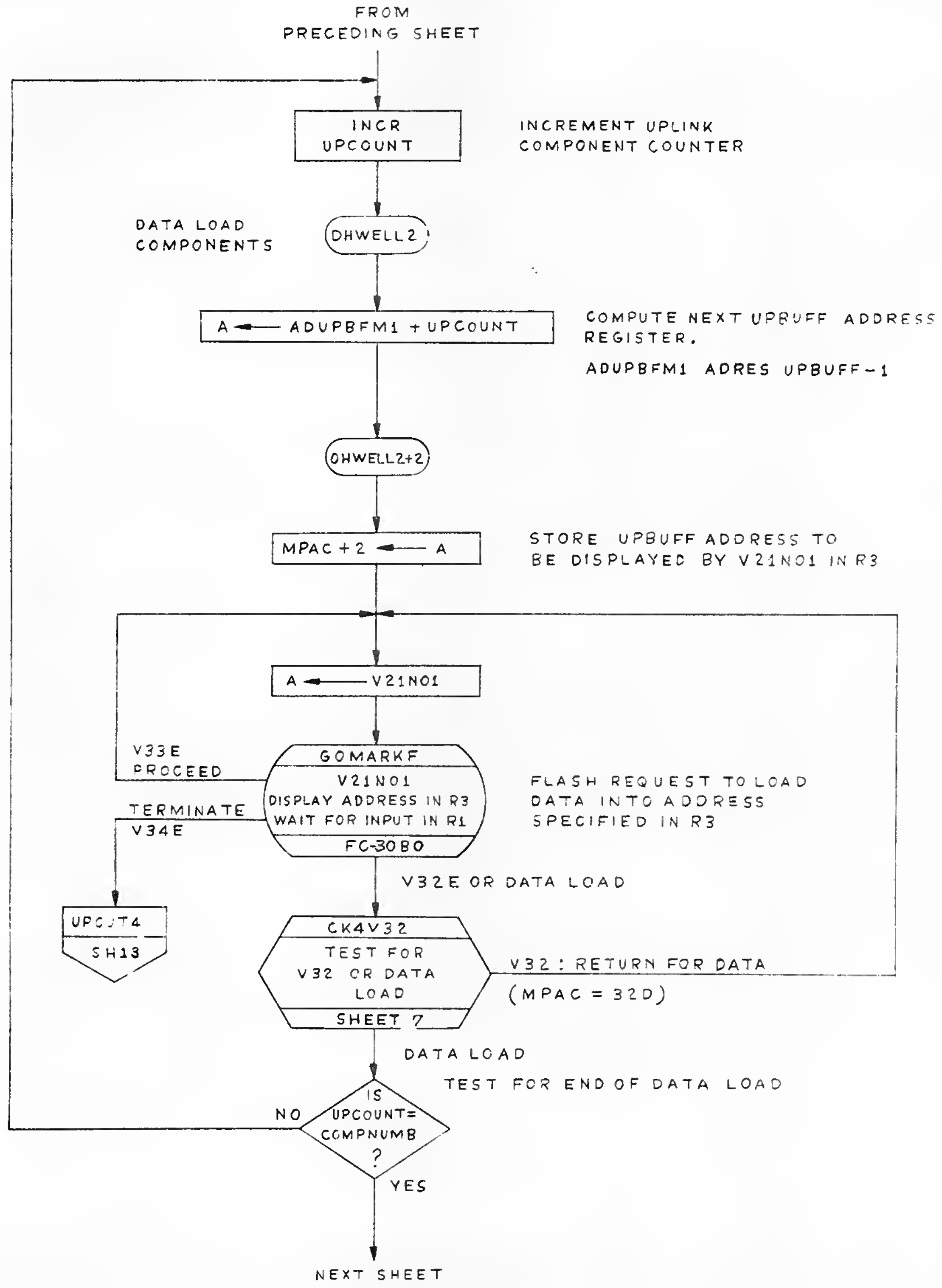
PRGMR	
ANALST	LUMINARY 1D
DOCMR P. G. Beck 12-9-68	DOCUMENT NO. FC-3120
APPR'D	REV / SHEET 4 OF 15



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ANALST		
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UPDATE PROGRAM (P27)

LUMINARY 1D

DOCUMENT NO.
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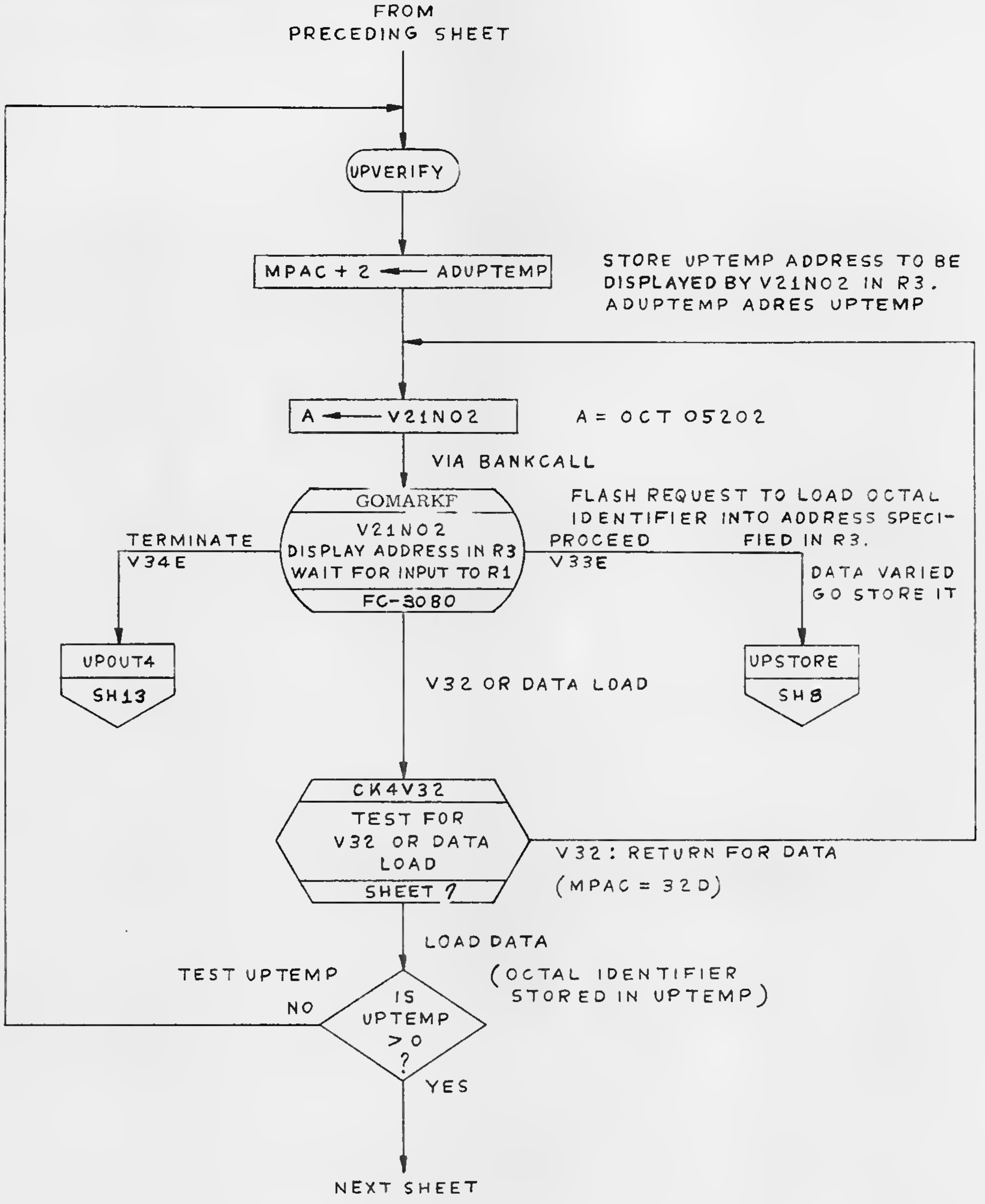

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DOCUMENT NO.
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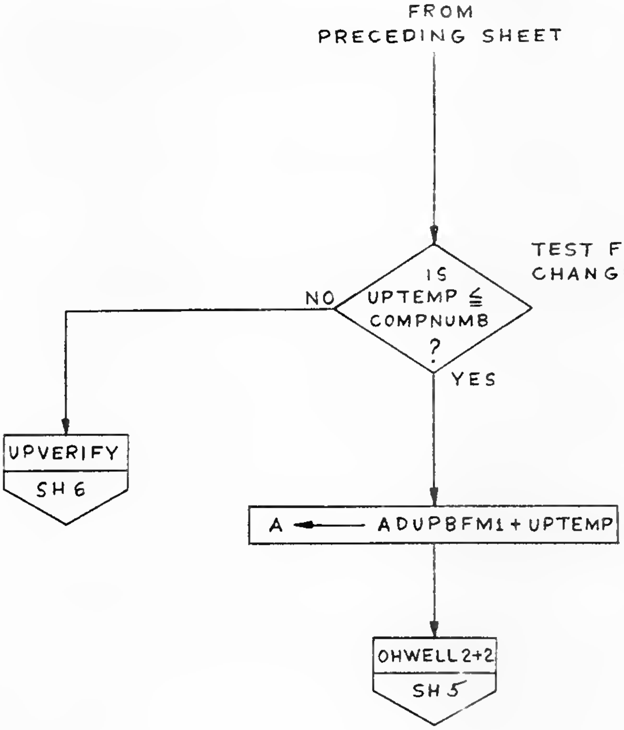
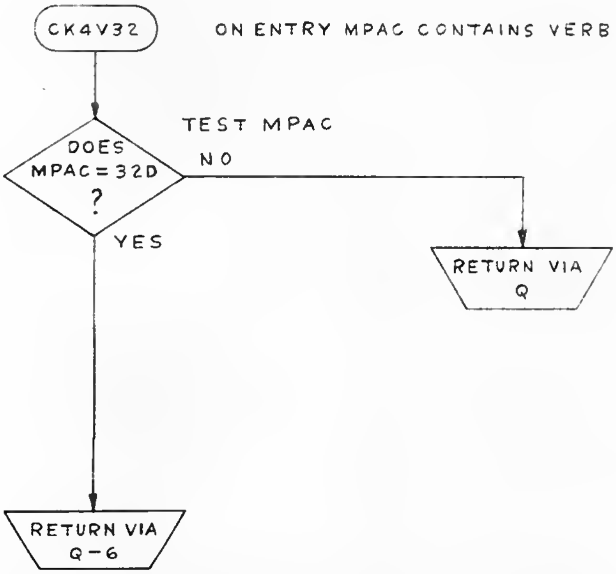
SHEET 6 OF 15



TEST FOR DATA CHANGES TO BE MADE

COMPUTE ADDRESS OF COMPONENT TO BE CORRECTED (ADUPBFM1=ADRES UPBUFF-1)



ON ENTRY MPAC CONTAINS VERB

TEST MPAC

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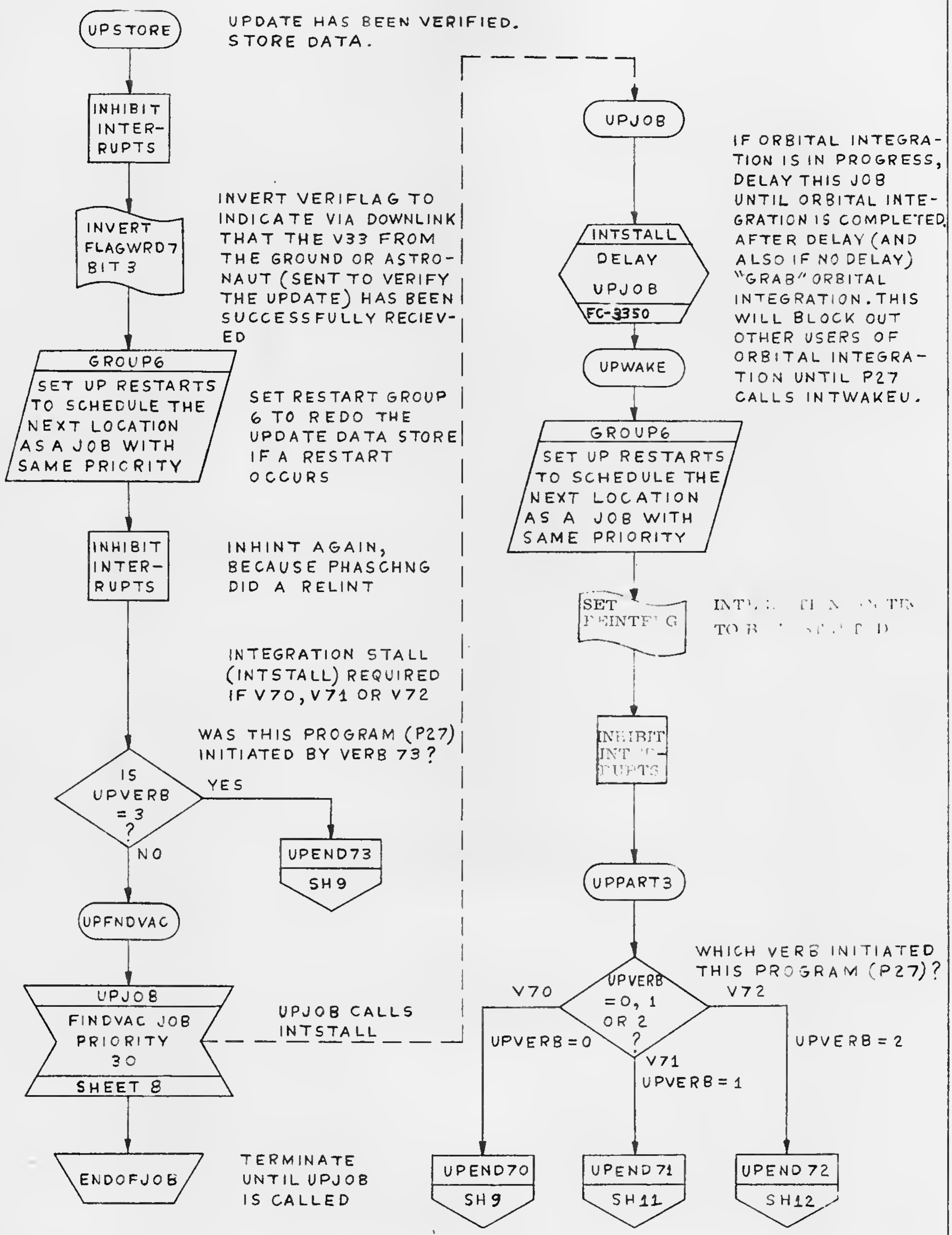
SHEET 7 OF 15



UPDATE HAS BEEN VERIFIED. STORE DATA.

INVERT VERIFLAG TO INDICATE VIA DOWNLINK THAT THE V33 FROM THE GROUND OR ASTRONAUT (SENT TO VERIFY THE UPDATE) HAS BEEN SUCCESSFULLY RECIEVED

SET RESTART GROUP 6 TO REDO THE UPDATE DATA STORE IF A RESTART OCCURS

INHINT AGAIN, BECAUSE PHASCHNG DID A RELINT

INTEGRATION STALL (INTSTALL) REQUIRED IF V70, V71 OR V72

WAS THIS PROGRAM (P27) INITIATED BY VERB 73?

UPJOB CALLS INTSTALL

TERMINATE UNTIL UPJOB IS CALLED

IF ORBITAL INTEGRATION IS IN PROGRESS, DELAY THIS JOB UNTIL ORBITAL INTEGRATION IS COMPLETED. AFTER DELAY (AND ALSO IF NO DELAY) "GRAB" ORBITAL INTEGRATION. THIS WILL BLOCK OUT OTHER USERS OF ORBITAL INTEGRATION UNTIL P27 CALLS INTWAKEU.

INTEGRATION [illegible] TO BE RESTARTED

WHICH VERB INITIATED THIS PROGRAM (P27)?

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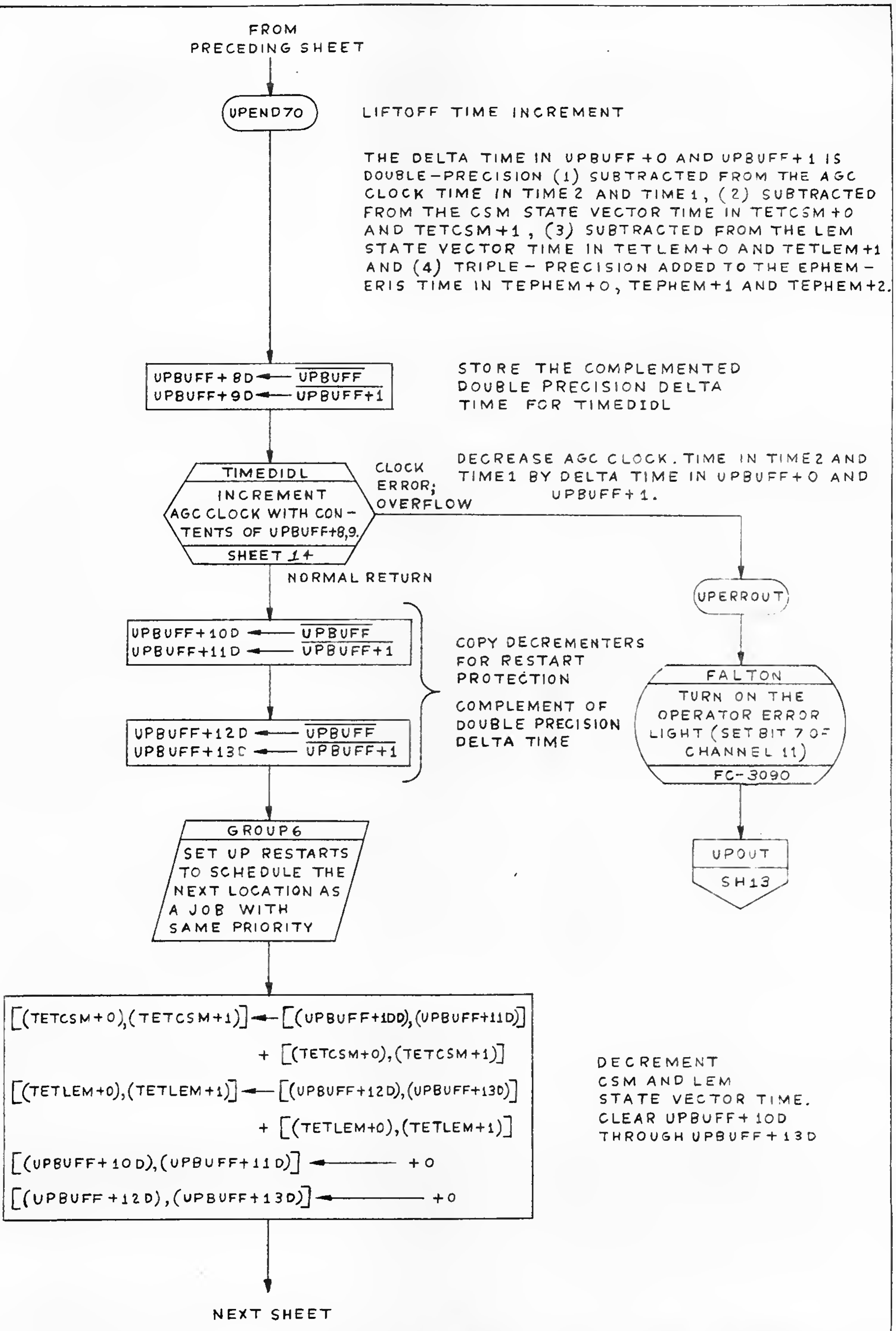
PRGMR Rafael Wiffin	12-9-68	
ANALST		LUMINARY 1D — DOCUMENT NO. FC-3120
DOCMR C. G. Beck	12-9-68	
APPR'D John A. Moore	12-9-68	REV — SHEET 8 OF 15



LIFTOFF TIME INCREMENT

THE DELTA TIME IN UPBUFF+0 AND UPBUFF+1 IS DOUBLE-PRECISION (1) SUBTRACTED FROM THE AGC CLOCK TIME IN TIME2 AND TIME1, (2) SUBTRACTED FROM THE CSM STATE VECTOR TIME IN TETCSM+0 AND TETCSM+1, (3) SUBTRACTED FROM THE LEM STATE VECTOR TIME IN TETLEM+0 AND TETLEM+1 AND (4) TRIPLE-PRECISION ADDED TO THE EPHEMERIS TIME IN TEPHEM+0, TEPHEM+1 AND TEPHEM+2.

STORE THE COMPLEMENTED DOUBLE PRECISION DELTA TIME FOR TIMEDIDL

DECREASE AGC CLOCK. TIME IN TIME2 AND TIME1 BY DELTA TIME IN UPBUFF+0 AND UPBUFF+1.

COPY DECREMENTERS FOR RESTART PROTECTION

COMPLEMENT OF DOUBLE PRECISION DELTA TIME

DECREMENT CSM AND LEM STATE VECTOR TIME. CLEAR UPBUFF+10D THROUGH UPBUFF+13D

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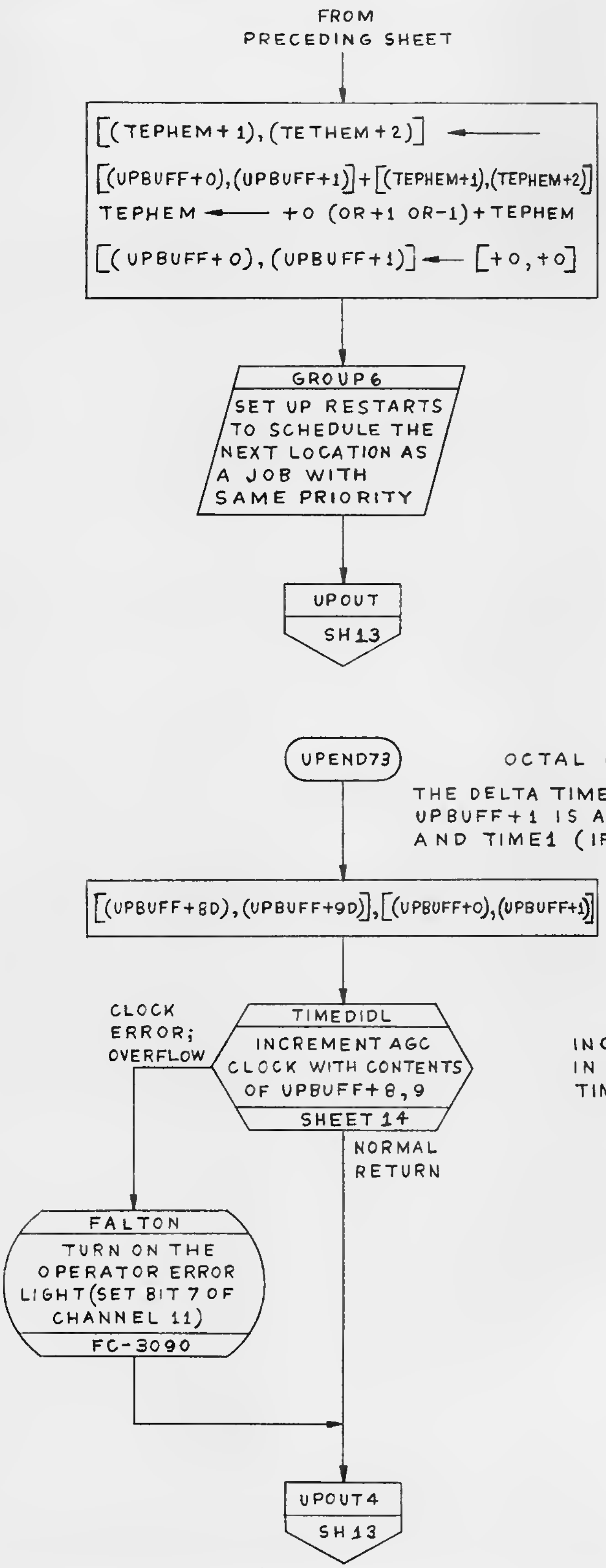
ANALST			LUMINARY 1D
DOCMR	C. G. Beck	12-9-68	DOCUMENT NO. FC-3120
APPR'D	John A. Moore	12-9-68	REV / SHEET 9 OF 15



INCREMENT TRIPLE PRECISION TEPHEM (TIME IN EPHEMERIS DAYS). AFTER INCREMENTING TEPHEM+1 AND TEPHEM+2, IF OVERFLOW IS POSITIVE ADD+1 TO TEPHEM: IF OVERFLOW IS NEGATIVE SUBTRACT 1. TEPHEM UNCHANGED (+0) IF NO OVERFLOW

OCTAL CLOCK INCREMENT

THE DELTA TIME (DOUBLE PRECISION) IN UPBUFF+0 AND UPBUFF+1 IS ADDED TO THE CLOCK TIME IN TIME2 AND TIME1 (IF NO OVERFLOW)

INCREASE AGC CLOCK TIME IN TIME2 AND TIME1 BY DELTA TIME IN UPBUFF+0 AND UPBUFF+1

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ANALST
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UPDATE PROGRAM (P27)

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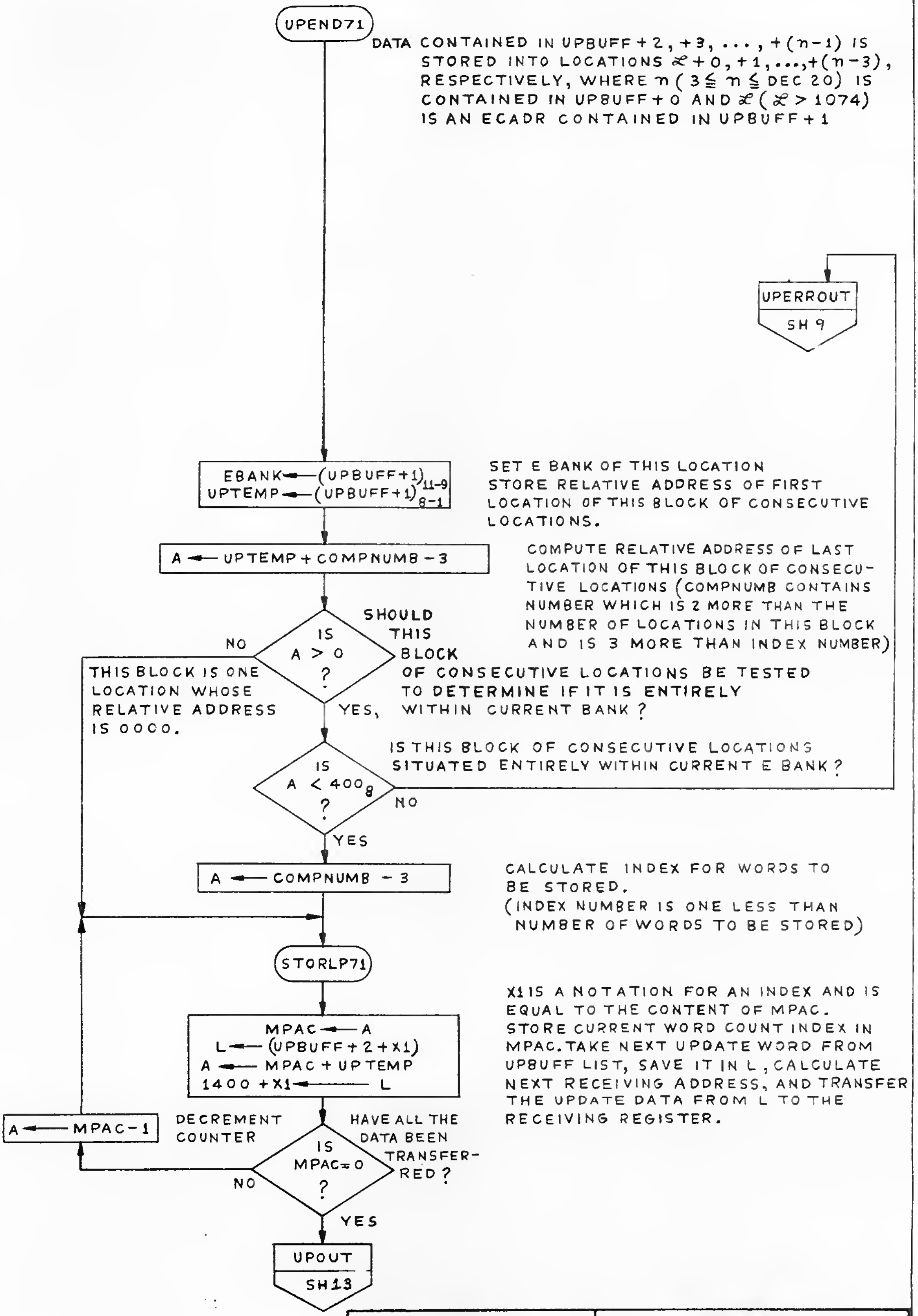
FC-3120

REV

SHEET 10 OF 15

PERFORM CONTIGUOUS BLOCK UPDATE.



DATA CONTAINED IN UPBUFF + 2, +3, . . . , +(n−1) IS STORED INTO LOCATIONS $\mathscr{X}$ + 0, +1, ..., +(n−3), RESPECTIVELY, WHERE n (3 ≦ n ≦ DEC 20) IS CONTAINED IN UPBUFF + 0 AND $\mathscr{X}$ ($\mathscr{X}$ > 1074) IS AN ECADR CONTAINED IN UPBUFF + 1

SET E BANK OF THIS LOCATION
STORE RELATIVE ADDRESS OF FIRST LOCATION OF THIS BLOCK OF CONSECUTIVE LOCATIONS.

COMPUTE RELATIVE ADDRESS OF LAST LOCATION OF THIS BLOCK OF CONSECUTIVE LOCATIONS (COMPNUMB CONTAINS NUMBER WHICH IS 2 MORE THAN THE NUMBER OF LOCATIONS IN THIS BLOCK AND IS 3 MORE THAN INDEX NUMBER)

SHOULD THIS BLOCK OF CONSECUTIVE LOCATIONS BE TESTED TO DETERMINE IF IT IS ENTIRELY WITHIN CURRENT BANK ?

THIS BLOCK IS ONE LOCATION WHOSE RELATIVE ADDRESS IS 0000.

IS THIS BLOCK OF CONSECUTIVE LOCATIONS SITUATED ENTIRELY WITHIN CURRENT E BANK ?

CALCULATE INDEX FOR WORDS TO BE STORED. (INDEX NUMBER IS ONE LESS THAN NUMBER OF WORDS TO BE STORED)

X1 IS A NOTATION FOR AN INDEX AND IS EQUAL TO THE CONTENT OF MPAC. STORE CURRENT WORD COUNT INDEX IN MPAC. TAKE NEXT UPDATE WORD FROM UPBUFF LIST, SAVE IT IN L, CALCULATE NEXT RECEIVING ADDRESS, AND TRANSFER THE UPDATE DATA FROM L TO THE RECEIVING REGISTER.

DECREMENT COUNTER

HAVE ALL THE DATA BEEN TRANSFERRED ?

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DRAWN 23OCT68
PROGMR 12-9-68
ANALST
DOCMR C. L. Beck 12-9-68
APPR'D John A. Moore 12-9-68

APOLLO
GUIDANCE AND NAVIGATION

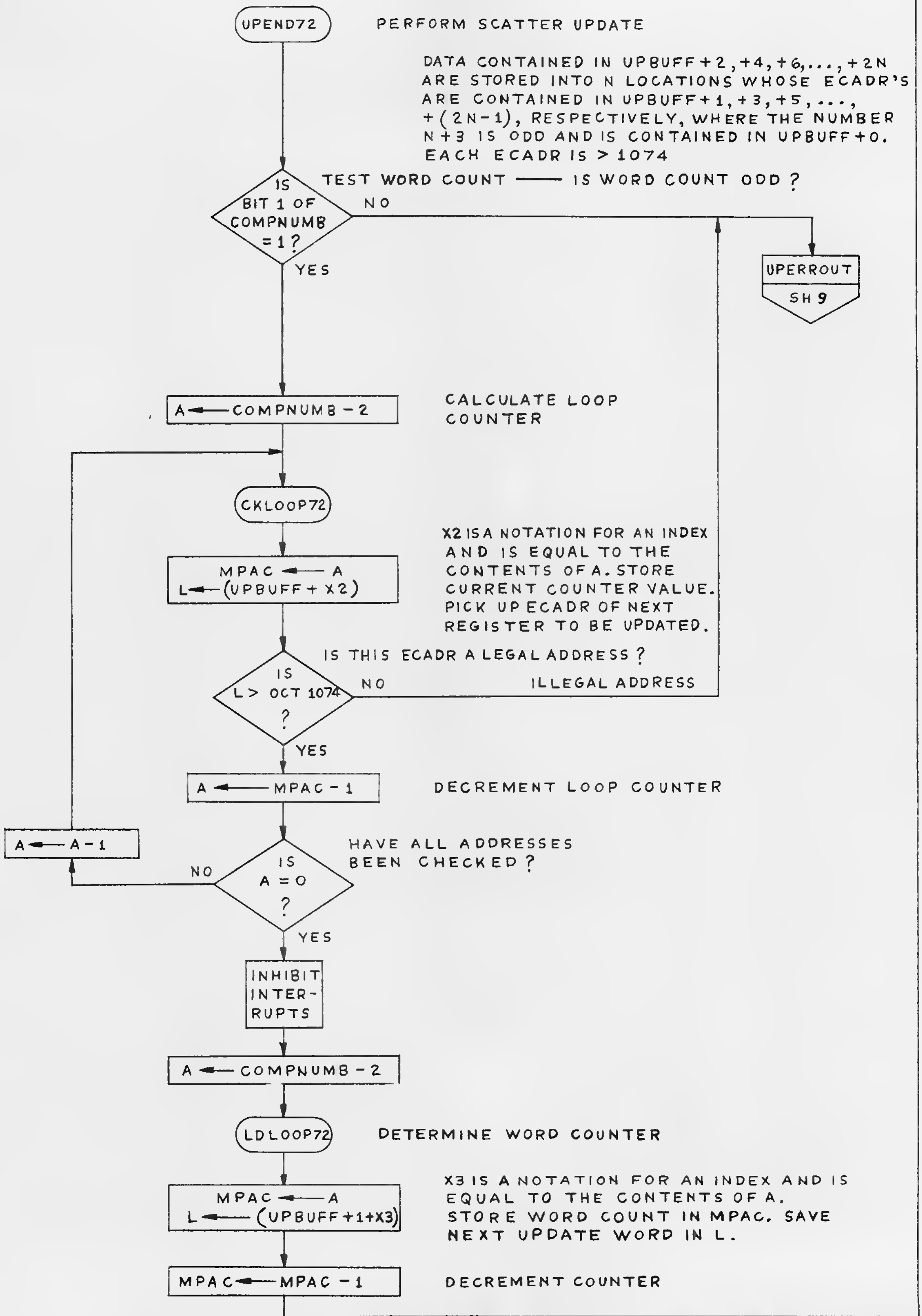
UPDATE PROGRAM (P27)

LUMINARY 1D

DOCUMENT NO.
FC-3120

REV

SHEET 11 OF 15



PERFORM SCATTER UPDATE

DATA CONTAINED IN UPBUFF+2, +4, +6, ..., +2N ARE STORED INTO N LOCATIONS WHOSE ECADR'S ARE CONTAINED IN UPBUFF+1, +3, +5, ..., +(2N−1), RESPECTIVELY, WHERE THE NUMBER N+3 IS ODD AND IS CONTAINED IN UPBUFF+0. EACH ECADR IS > 1074

TEST WORD COUNT —— IS WORD COUNT ODD ?

CALCULATE LOOP COUNTER

X2 IS A NOTATION FOR AN INDEX AND IS EQUAL TO THE CONTENTS OF A. STORE CURRENT COUNTER VALUE. PICK UP ECADR OF NEXT REGISTER TO BE UPDATED.

IS THIS ECADR A LEGAL ADDRESS ?

ILLEGAL ADDRESS

DECREMENT LOOP COUNTER

HAVE ALL ADDRESSES BEEN CHECKED ?

DETERMINE WORD COUNTER

X3 IS A NOTATION FOR AN INDEX AND IS EQUAL TO THE CONTENTS OF A. STORE WORD COUNT IN MPAC. SAVE NEXT UPDATE WORD IN L.

DECREMENT COUNTER

NEXT SHEET

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ANALYST		
DOCMR		12-9-68
APPR'D		12-9-68

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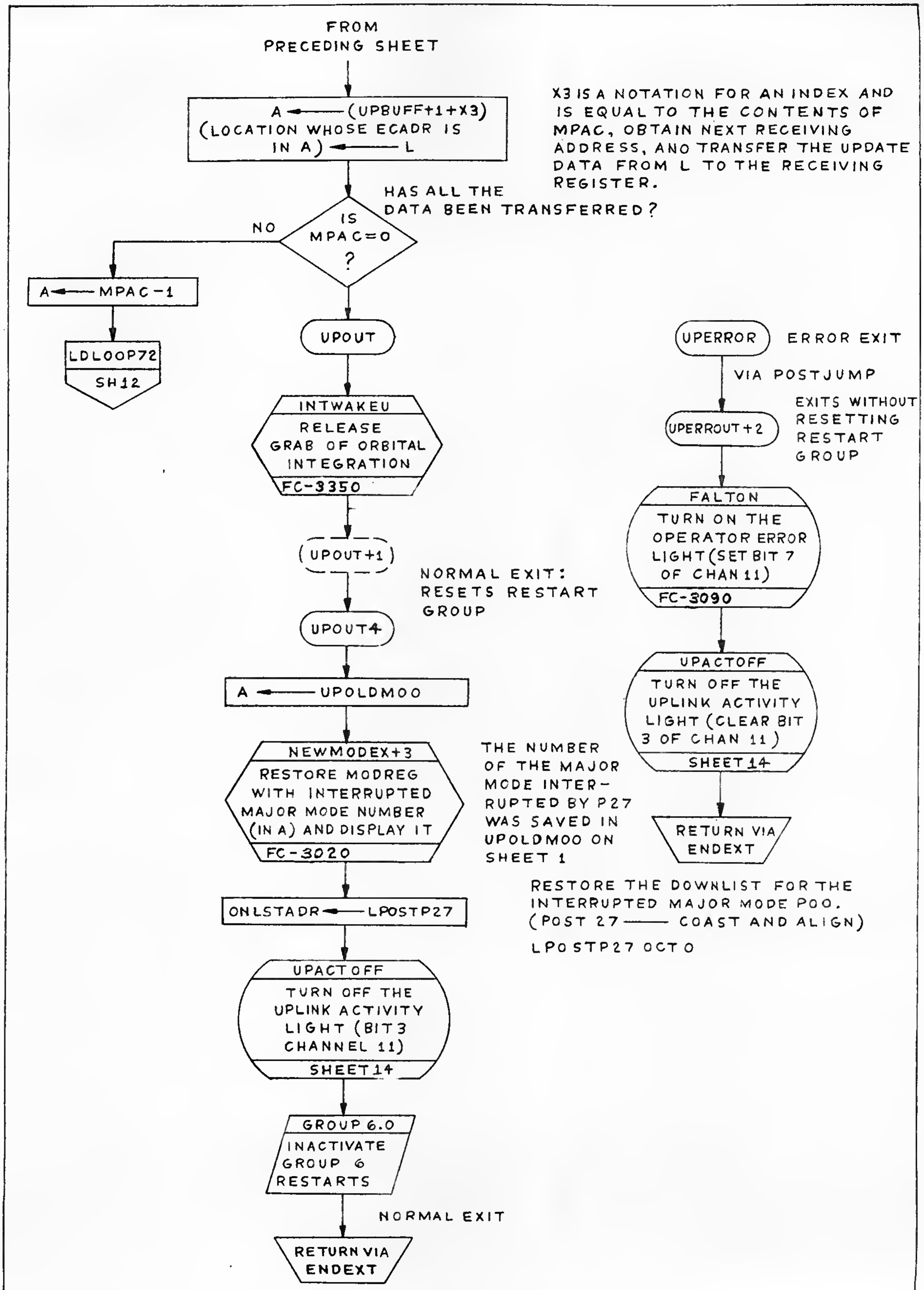
SHEET 12 OF 15



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ANALST —
DOCMR C. G. Beck 12-9-68
APPR'D John A. More 12-9-68

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DOCUMENT NO. FC-3120

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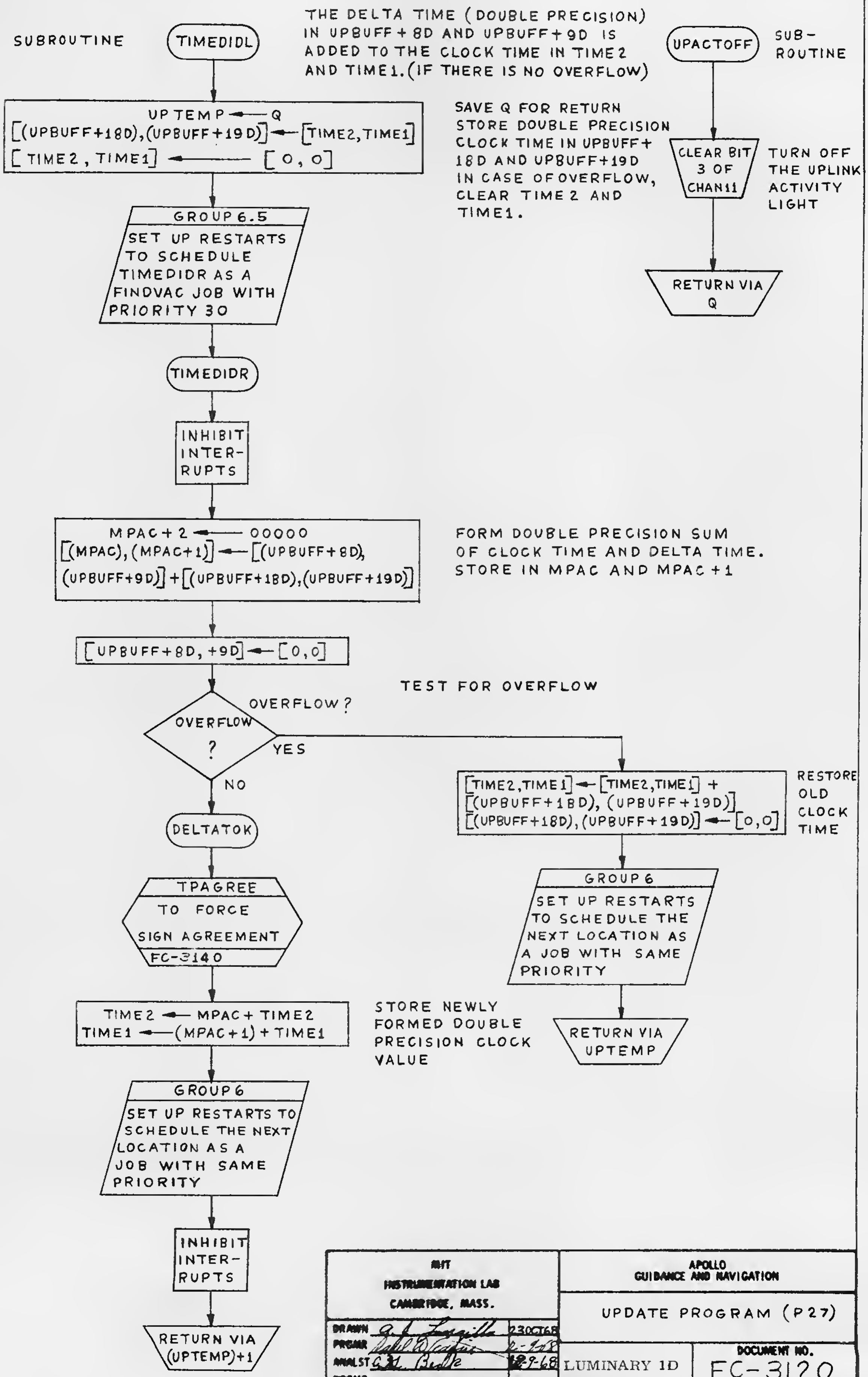
SHEET 13 OF 15

UPDATE AGC CLOCK TIME



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ANALST 12-9-68
DOCMR
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LUMINARY 1D
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ROUTINES CALLED ON OTHER FLOW CHARTS

SUBROUTINE	FLOWCHART	WHERE CALLED
FALTON	FC-3090	SH. 9, 10, 13
GOMARKF	FC-3080	SH. 4, 5, 6
INSTALL	FC-3350	SH. 8
INTWAKEU	FC-3350	SH. 13
NEWMODEX	FC-3020	SH. 3, 13
PINBRNCH	FC-3080	SH. 2
TESTXACT	FC-3100	SH. 2
TPAGREE	FC-3140	SH. 14

FLAGS

	MEANING WHEN SET	MEANING WHEN CLEARED	WHERE SET	WHERE CLEARED	WHERE TESTED
REINTFLG FLAG10 BIT 7	Integration Routine To be restarted	Integration Routine Not to be restarted	SH. 8		
VERIFLAG FLAG 7 BIT 3	Changed when V33E occurs at end of P27		SH. 8	SH. 8	

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DRAWN C. Metta	5/28/7	UPDATE PROGRAM	
PRGMR Sharon Albert	5/28/70		**DOCUMENT NO.**
ANALST		LUMINARY 1D	FC-3120
DOCMR	5/28/70		
APPR'D	5/28/70	**REV**	**SHEET** 15 **OF** 15

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 detected 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, ALARM1 and ALARM2. Failures which are serious use the following entries: BAILOUT, POODOO, CCSHOLE, BAILOUT1 and POODOO1.

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ANALST		LUMINARY 1D	FC-3140
DOCMR	C. Geo. Beck 12-16-69		
APPR'D	W. 12-18-69	REV 2	SHEET 1 OF 24

Each entry will make the alarm code available for display and turn on the program alarm light (if off). Only entry PRIOLARM will display the alarm codes in the three FAILREG registers. The return location and the location containing the alarm code is given in the calling sequence for each entry shown at the top of sheets 3, 4, 5, 7 and 8.

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

PRIOLARM	Sh. 3	Displays the alarm codes via PRIODSPR (V05N09) and returns. Used by the "target out of view" alarm condition.
VARALARM	Sh. 3	Calling sequence obtains a variable alarm code from an applicable register. Returns to calling sequence.
CURTAINS	Sh. 4	Alarm code OCT 217 is only one used. Used for bad returns from stall routines. Returns to calling sequence.
ALARM	Sh. 4	Used for alarm conditions such as improper input data, etc. Returns to calling sequence.
ALARM1	Sh. 8	Alarm code OCT 01301 is the only code used. Used by interpretive-coded routines via the Interpretive Program for alarm conditions such as improper input data. Returns to calling sequence.
ALARM2	Sh. 4	Alarm code OCT 1102 is only code used. Used only by self check program when an error is detected. Returns to calling sequence.
BAILOUT and BAILOUT1	Sh. 5 Sh. 7	Terminates in a software restart. Used by alarm conditions such as no vac areas available, too many tasks, etc.
POODOO and POODOO1	Sh. 5 Sh. 7	Inactivates all restart groups except those associated with the Servicer (if running) and terminates in a software restart, and GOTOPOOH and flash verb 37 for operator to select new major mode. Used by alarm conditions such as an attempt to take the square root of a negative number, illegal flashing display, etc.
CCSHOLE	Sh. 5	Alarm code OCT 21103 is only code used. Inactivates all restart groups except those associated with the Servicer (if running) 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.

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APPR'D	W. Dogherty	12-18-69	REV 2	SHEET 2 0-24

Two of the Six
Non-Abortive Entries with Return

Displays Alarm Code

From 7 locations via BANKCALL with A = ALARM code. [BUF2, BUF2+1] = 2CADR of $\mathcal{L}$+2

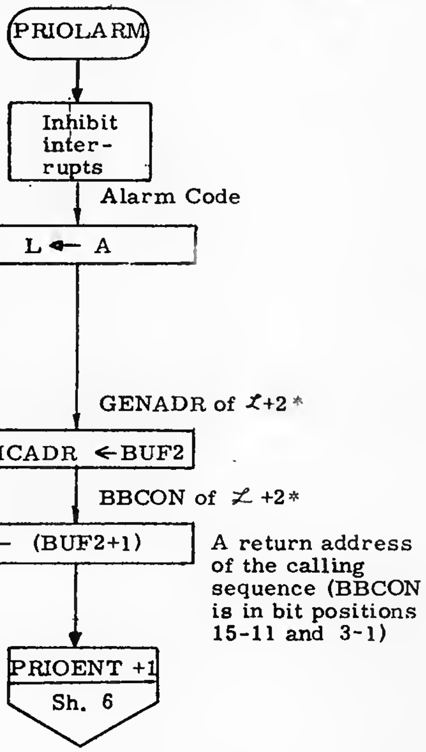
Calling sequence

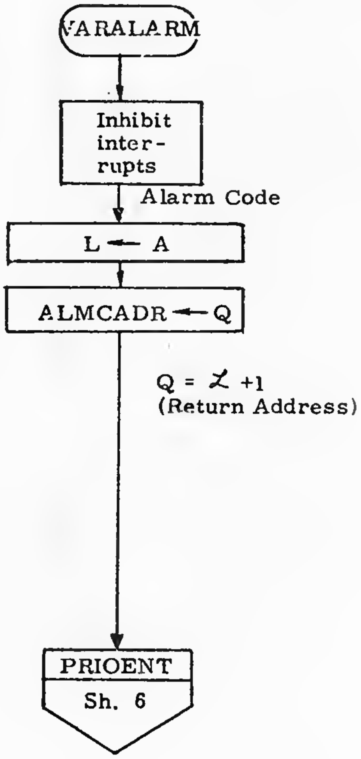
$\mathcal{L}$ +0	TC	BANKCALL
$\mathcal{L}$ +1	CADR	PRIOLARM
$\mathcal{L}$ +2		Terminate
$\mathcal{L}$ +3		Proceed
$\mathcal{L}$ +4		Enter
$\mathcal{L}$ +5		Immediate Return

From 4 locations with A = alarm code

Calling sequence

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





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

* The address stored in register ALMCADR is not used as a return address for these entries (PRIOLARM, ALARM, ALARM1, ALARM2 via self check, BAILOUT, BAILOUT1, POODOO, POODOO1 and CCSHOLE) while the other two entries (VARALARM and CURTAINS) do use the address as a return address. However, the address associated with each entry in register ALMCADR and its BBCON in register ALMCADR +1 and the contents of register ERCOUNT are available for display by VERB 05 and NOUN 08.

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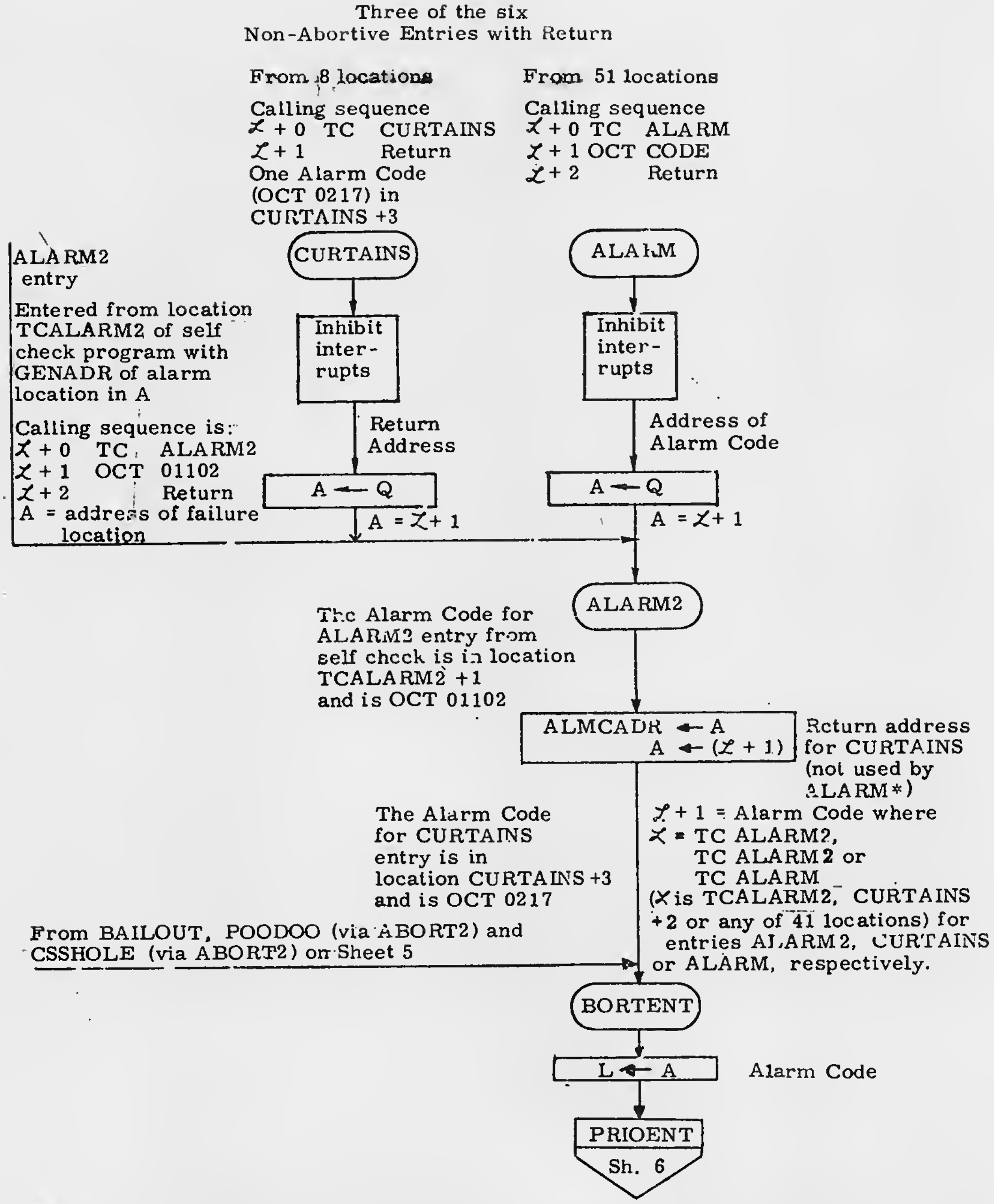
DOCMR C. Geo. Beck	12-16-69	
APPR'D Roberta M Entes	2/20/70	REV 2 / SHEET 3 OF 24



* The address stored in register ALMCADR is not used as a return address for these entries (PRIOLARM, ALARM, ALARM1, ALARM2 via self check, BAILOUT, BAILOUT1, POODOO, POODOO1 and CCSHOLE) while the other two entries (VARALRM 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 and its BBCON in register ALMCADR +1 and the contents of register ERCOUNT are available for display by VERB 05 and NOUN 08.

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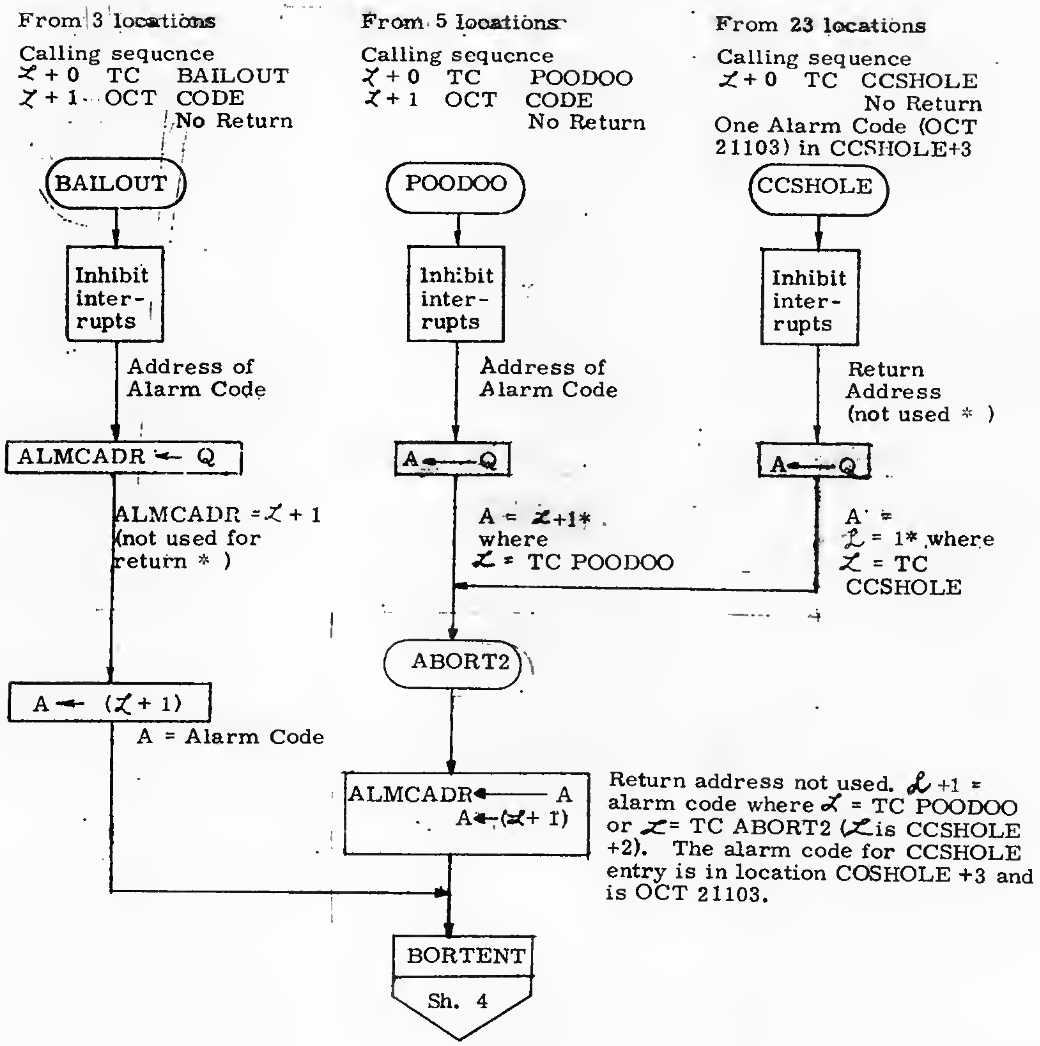
APOLLO GUIDANCE AND NAVIGATION
Alarm and Abort
LUMINARY 1D
DOCUMENT NO. FC-3140
REV 2
SHEET 4 O 24

Abortive Entries Ending in Restart



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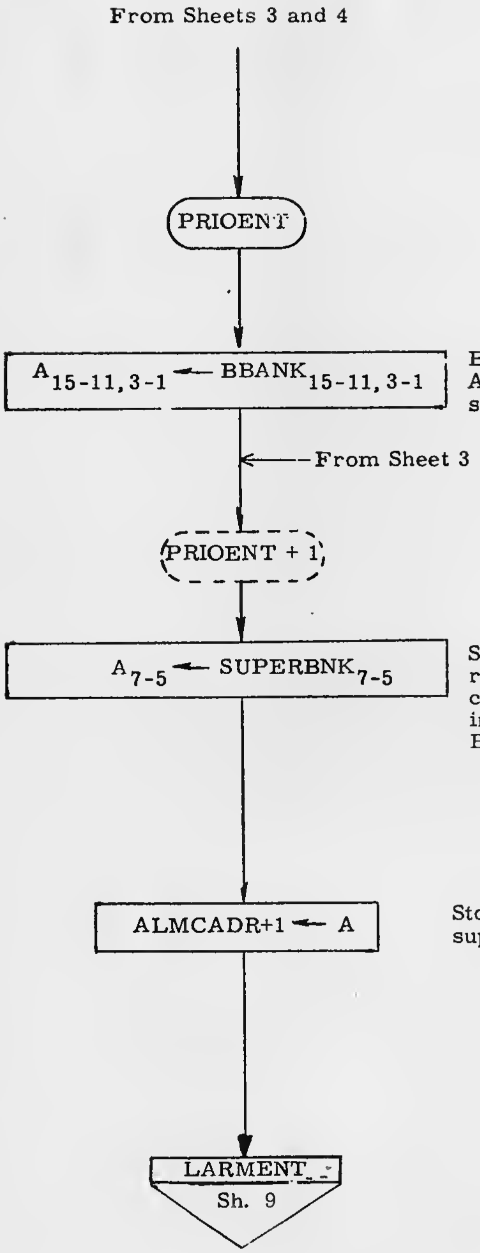
* The address stored in register ALMCADR is not used as a return address for these entries (PRIOLARM, ALARM, ALARM1, ALARM2 via self check, BAILOUT, BAILOUT1, POODOO, POODOO1 and CCSHOLE) while the other two entries (VARALARM and CURTAINS) do use the address as a return address. However, the address associated with each entry in register ALMCADR and its BBCON in register ALMCADR+1 and the contents of register ERCOUNT are available for display by VERB 05 and NOUN 08.



BBCON of the Return Address of the calling sequence

Super bank of the return address of the calling sequence included with the BBCON

Store BBCON and super bank

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APOLLO GUIDANCE AND NAVIGATION

Alarm and Abort

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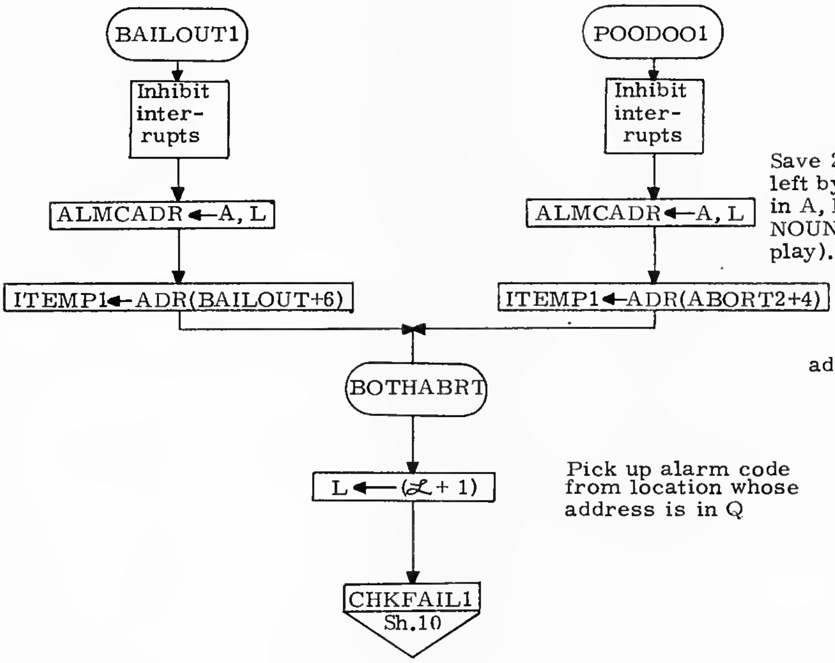
SHEET 6 OF 24

BAILOUT1 stores an alarm code and an alarm 2CADR, and then does a restart

POODOO1 stores an alarm code and an alarm CADR, cleans out the restart table (except for servicer) and then does a restart

ℒ TC BAILOUT1
ℒ + 1 OCT code
A, L = Alarm 2CADR
No Return

ℒ : TC POODOO1
ℒ + 1 OCT code
A, L = Alarm 2CADR
No Return



Save 2CADR left by caller in A, L (for NOUN 8 display).

Set up exit address

Pick up alarm code from location whose address is in Q

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APOLLO GUIDANCE AND NAVIGATION

Alarm and Abort

LUMINARY 1D

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FC-3140

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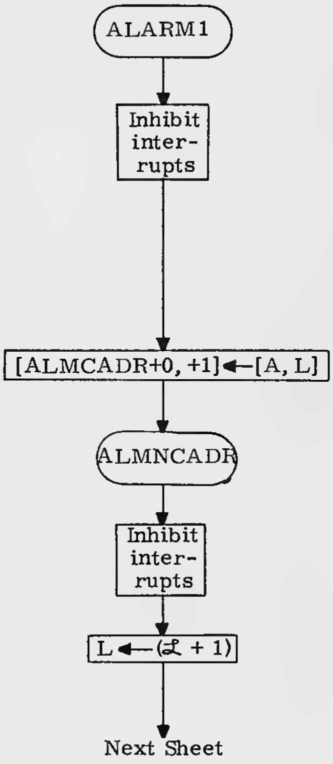
SHEET 7 OF 24

From location ACOSABRT +2
of the interpreter program

$\mathcal{L}+0$ TC ALARM1
$\mathcal{L}+1$ OCT code (01301)
$\mathcal{L}+2$ Return here

A, L = 2CADR of alarm location



ALARM1 stores an alarm code and the 2CADR of the location associated with the alarm condition and returns to the calling sequence at $\mathcal{L}+2$. Control arrives with the 2CADR in A and L.

Though control comes from the interpreter program, the 2CADR is of a location in an interpretive--coded routine that is elsewhere.

2CADR of location of the alarm condition

Alarm code

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APOLLO GUIDANCE AND NAVIGATION

Alarm and Abort

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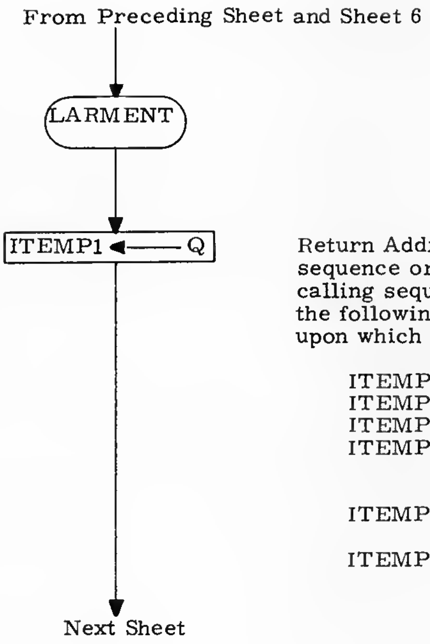
SHEET 8 OF 24



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

ITEMP1 = PRIOLARM+6
ITEMP1 = VARALARM+5
ITEMP1 = CURTAINS+3
ITEMP1 = ∡ + 1 where ∡ = TC ALARM or ∡ = TC ALARM1 or ∡ = TC ALARM2
ITEMP1 = BAILOUT+6 if via BAILOUT or BAILOUT1
ITEMP1 = ABORT2 + 4 if via POODOO, POODOO1 or CSSHOLE

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

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DOCMR C. Geo. Beck	12-16-69	
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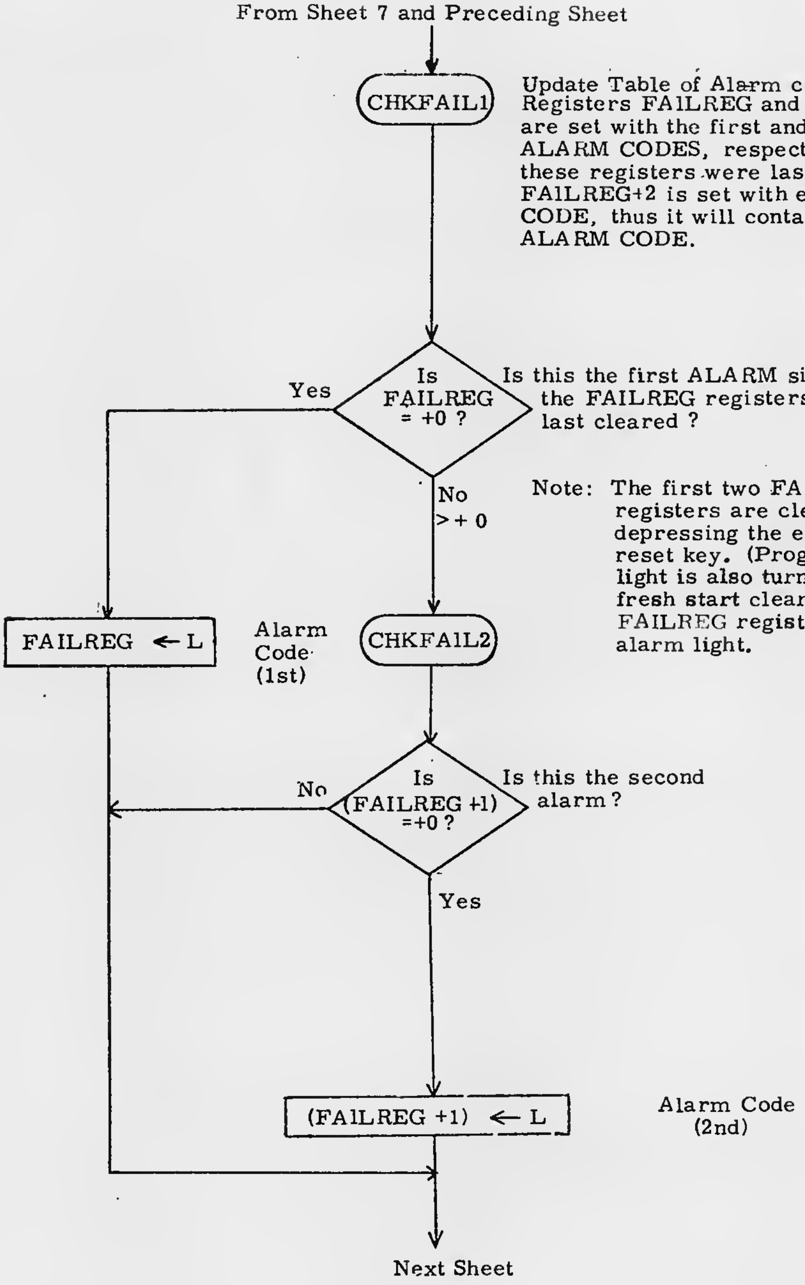

Update Table of Alarm conditions. Registers FAILREG and FAILREG+1 are set with the first and second ALARM CODES, respectively, since these registers were last cleared. FAILREG+2 is set with each ALARM CODE, thus it will contain the last ALARM CODE.

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

Note: The first two FAILREG registers are cleared by depressing the error light reset key. (Program alarm light is also turned off). A fresh start clears all three FAILREG registers and the alarm light.

Is this the second alarm?

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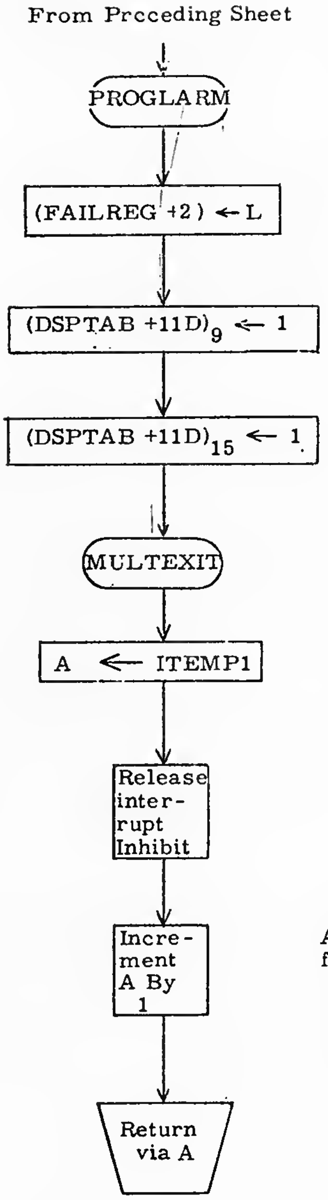

Most recent Alarm Code

Turn on Program Alarm light

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

Return Address

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

A = PRIOLARM +7
A = VARALARM +6
A = CURTAINS +4
A = ($\not\angle$ +2) where $\not\angle$ = TC ALARM or TC ALARM1 or
$\not\angle$ = TC ALARM2
A = BAILOUT +7 if via BAILOUT or BAILOUT1.
A = ABORT 2 + 5 if via POODOO or CCSHOLE or
POODOO1.

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ANALST		LUMINARY 1D	FC-3140
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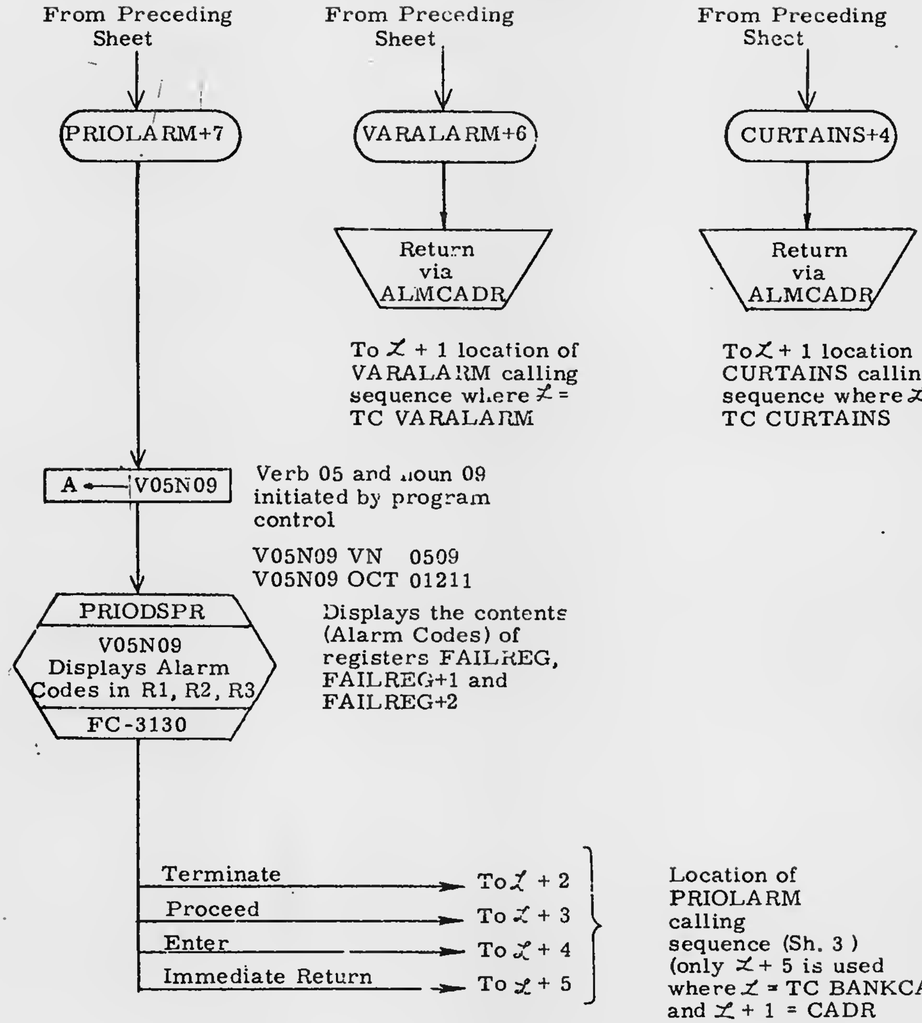
APPR'D Robert M Enter	2/20/70	REV 2	SHEET 11 OF 24



To $\cancel{L}$ + 1 location of VARALARM calling sequence where $\cancel{L}$ = TC VARALARM

To $\cancel{L}$ + 1 location of CURTAINS calling sequence where $\cancel{L}$ = TC CURTAINS

Verb 05 and noun 09 initiated by program control

V05N09 VN 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 $\cancel{L}$ + 5 is used where $\cancel{L}$ = TC BANKCALL and $\cancel{L}$ + 1 = CADR PRIOLARM

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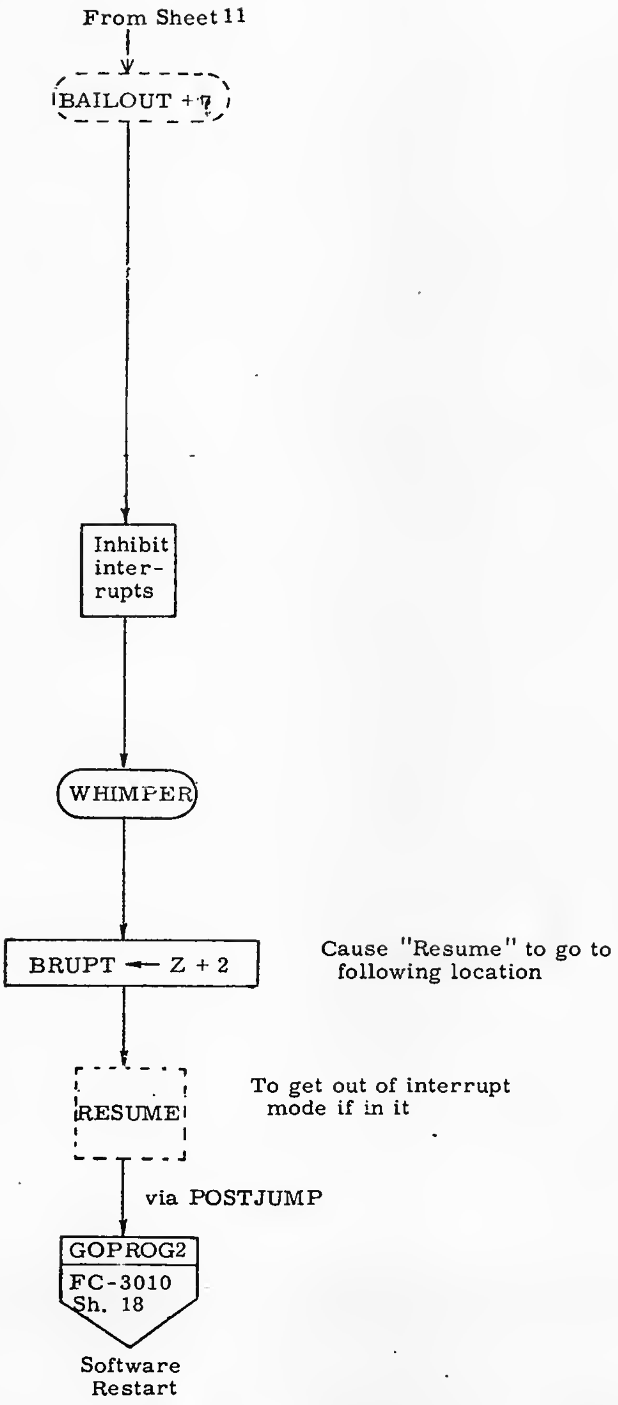
DOCMR C. Geo. Beck	12-16-69		
APPR'D	2/20/70	REV 2	SHEET 12 OF 24



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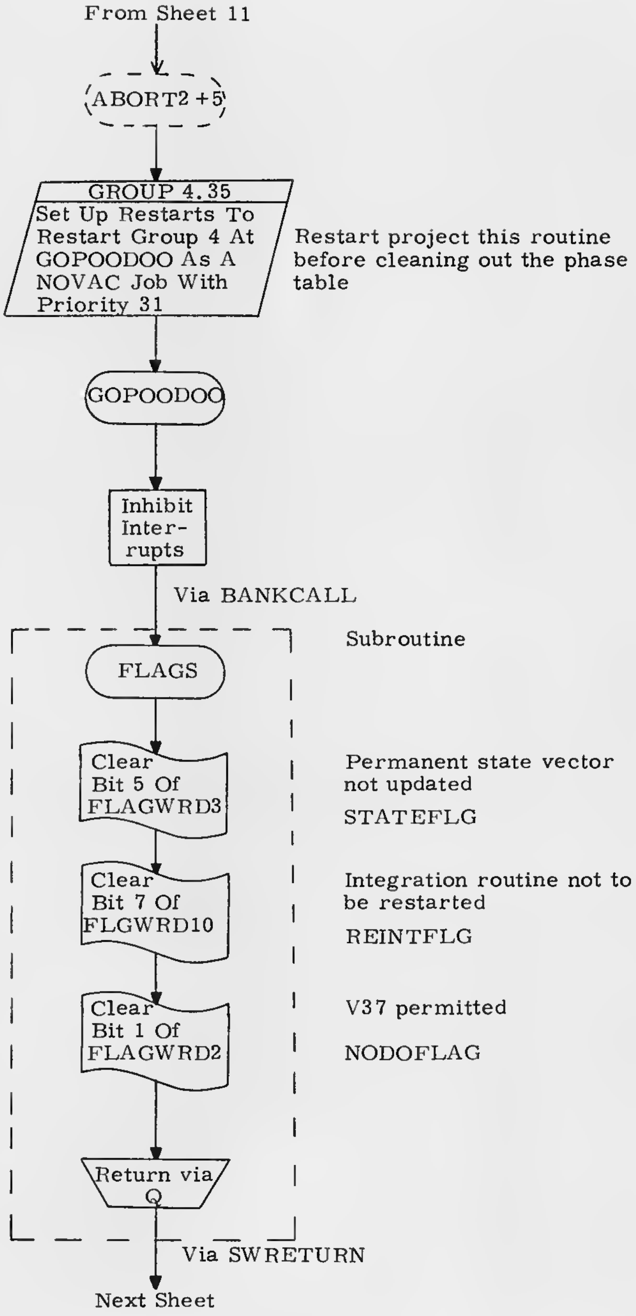
DRAWN	[illegible]	[illegible]	Alarm and Abort	
PRGMR	Bruce J McCoy	12-17-69	LUMINARY 1D	DOCUMENT NO. FC-3140
ANALST				
DOCMR	C. Geo. Beck	12-16-69		
APPR'D	Robert M Estes	2/20/70	REV 2	SHEET 13 OF 24



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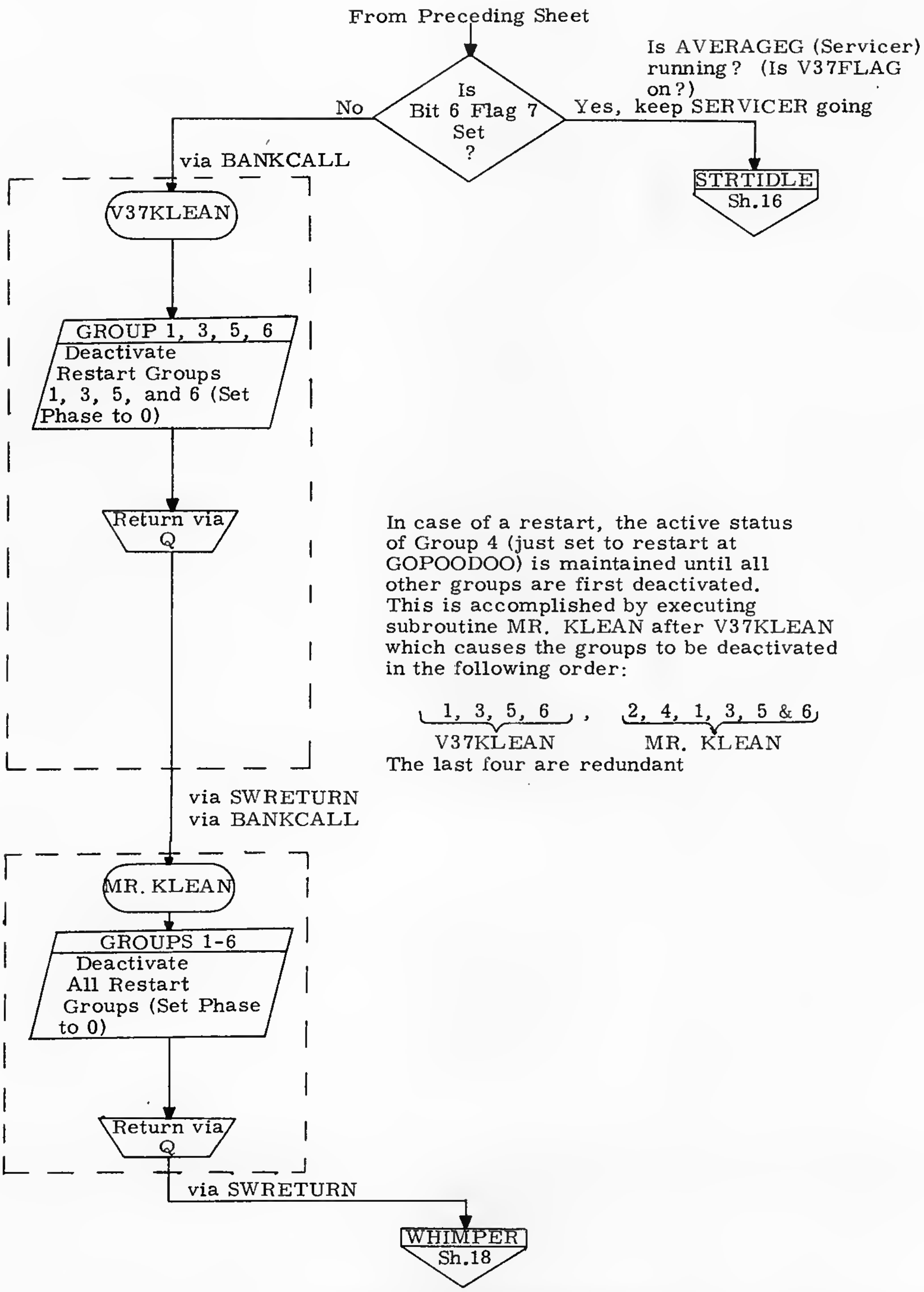
ANALST		**DOCUMENT NO.** FC-3140
DOCMR	C. Geo. Beck 12-16-69	
APPR'D	Roberta M [illegible] 2/20/70	**REV** 2 — **SHEET** 14 **OF** 24



In case of a restart, the active status of Group 4 (just set to restart at GOPOODOO) is maintained until all other groups are first deactivated. This is accomplished by executing subroutine MR. KLEAN after V37KLEAN which causes the groups to be deactivated in the following order:

$$\underbrace{1,\ 3,\ 5,\ 6}_{\text{V37KLEAN}},\ \underbrace{2,\ 4,\ 1,\ 3,\ 5\ \&\ 6}_{\text{MR. KLEAN}}$$

The last four are redundant

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APOLLO GUIDANCE AND NAVIGATION

Alarm and Abort

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ANALST		
DOCMR	C. Geo. Beck	12-16-69
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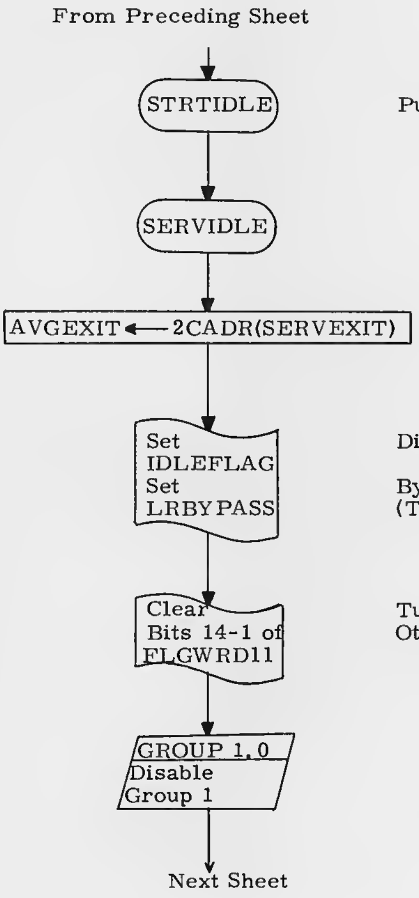

Put servicer in idle mode

Disconnect
servicer from
any guidance

Disconnect ΔV monitor

Bypass LR
(Terminate P12)

Turn off R12 if running.
Otherwise, no effect

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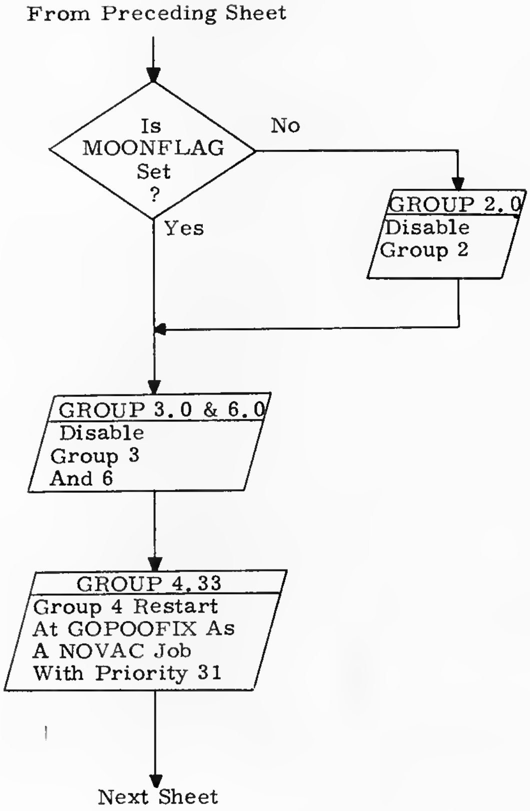
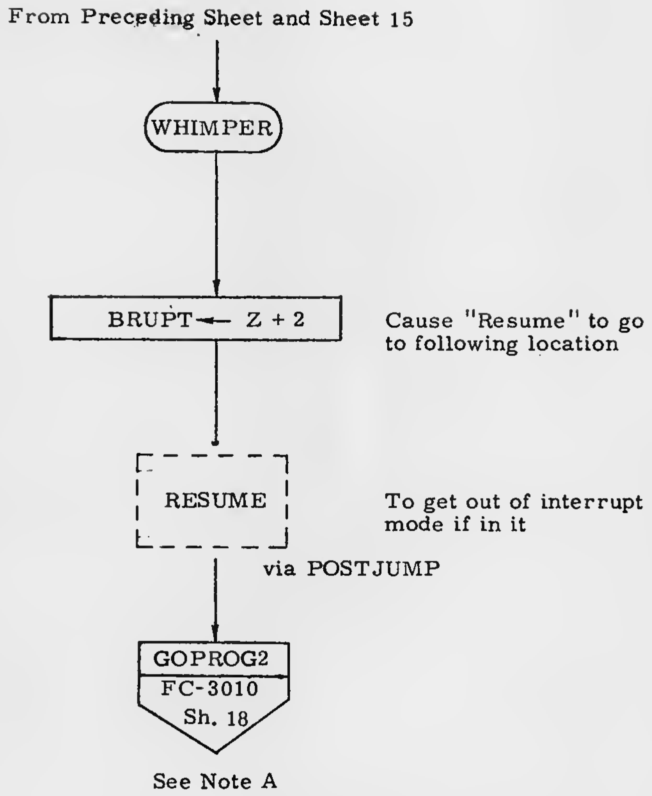
PRGMR Bruce J McCoy	12-17-69		
ANALST		LUMINARY 1D	**DOCUMENT NO.** FC-3140
DOCMR C. Geo. Beck	12-16-69		
APPR'D Roberta M Eyles	2/20/70	**REV** 2	**SHEET** 16 **OF** 24



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	D. Tucholke	11-21-69	Alarm and Abort	
PRGMR	Bruce J McCoy	12-17-69	LUMINARY 1D	DOCUMENT NO. FC-3140
ANALST				
DOCMR	C. Geo. Beck	12-16-69		
APPR'D	Roberta M Estes	2/20/70	REV 2	SHEET 17 OF 24



Note A: Go to routine GOTOPOOH and display flashing verb 37 unless no major mode was active in which case control goes to DUMMYJOB +2 (see restart, Sheet 21 of FC-3010).

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	2-12-[illegible]	Alarm and Abort	
PRGMR Bruce J McCoy	12-17-69		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3140
DOCMR C. Geo. Beck	12-16-69		
APPR'D Roberta M Eaton	2/20/70	REV 2	SHEET 18 OF 24

ALARM AND ABORT

TABLE OF ALARM CODES

Alarm Code	Alarm Condition	Set By	Alarm Entry Used
00107	More than 5 mark pairs	AOTMARK	ALARM
00111	Mark missing	AOTMARK	ALARM
00112	Mark or mark reject not being accepted	AOTMARK	ALARM
00113	No inbits	AOTMARK	ALARM
00114	Mark made but not desired	AOTMARK	ALARM
00115	No marks in last pair to reject	AOTMARK	ALARM
00206	Zero encode not allowed with coarse align and gimbal lock.	IMU mode switching routines	ALARM
00207	ISS turnon request not present for 90 sec	T4RUPT	ALARM
00210	IMU not operating	IMU mode switching routines	VARALARM, ALARM
00211	Coarse align error	IMU mode switching routines	ALARM
00212	PIPA fail but PIPA is not being used	IMU mode switching routines, T4RUPT	ALARM
00213	IMU not operating with turn-on request	T4RUPT	ALARM
00214	Program using IMU when turned off	T4RUPT	ALARM
00217	Bad return from IMUSTALL	P51-P53	CURTAINS
00220	IMU not aligned - no REFSMMAT	AGS initialization IMU mode switching routines	ALARM, VARALARM
00401	Desired gimbal angle yields gimbal lock	IMU-2 inflight alignment routines, FINDCDUW - GUIDAP interface, attitude maneuver routine	ALARM

Alarm Code	Alarm Condition	Set By	Alarm Entry Used
00402	FINDCDUW not controlling attitude	FINDCDUW - GUIDAP interface	ALARM
00404	Two stars not available in any detent	P51-P53	ALARM
00405	Two stars not available	P51-P53	ALARM
00421	W-matrix overflow	Orbital integration	ALARM
00501	Radar antenna out of limits	P20-P25	PRIOLARM
00502	Bad radar gimbal angle input	P20-P25	ALARM
00503	Radar antenna designate fail	P20-P25, extended verbs	PRIOLARM, ALARM
00510	Radar auto discrete not present	P20-P25	ALARM
00511	LR antenna out of position 1 or 2 for more than 10 seconds	SERVICER	ALARM
00514	RR goes out of auto mode while in use	P20-P25	PRIOLARM
00515	RR CDU fail discrete present	T4RUPT	ALARM
00520	Radar rupt not expected at this time	P20-P25 (radar read)	ALARM
00522	Landing radar position change	Radar lead-in routines (radar read)	ALARM
00523	LR antenna didn't achieve position 2	V59	ALARM
00525	Delta theta greater than 3 degrees	P20-P25	PRIOLARM
00526	Range greater than 400 naut. miles	P20-P25	PRIOLARM
00527	LOS not in mode 2 coverage while on lunar surface	P20-P25	ALARM
00530	LOS not in mode 2 coverage on lunar surface after 600 seconds	P20-P25	PRIOLARM
00600	Imaginary roots on first iteration	P32-P35, P72-P75	VARALARM
00601	Perigee altitude CSI IT PMINI	P32-P35, P72-P75	VARALARM
00602	Perigee altitude CDH LT PMIN2	P32-P35, P72-P75	VARALARM
00603	CSI to CDH time LT TMINI2	P32-P35, P72-P75	VARALARM
00604	CDH to TPI time LT TMIN23 or computed CDH time greater than input TPI time	P32-P35, P72-P75	VARALARM
00605	Number of iterations exceeds loop maximum	P32-P35, P72-P75	VARALARM
00606	DV exceeds maximum	P32-P35, P72-P75	VARALARM

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APOLLO GUIDANCE AND NAVIGATION
Alarm and Abort
LUMINARY 1D
DOCUMENT NO. FC-3140
REV 2
SHEET 20 OF 24

Alarm Code	Alarm Condition	Set By	Alarm Entry Used
00611	No TIG for given elev angle	P32-P35, P72-P75 P34-P35 P74-P75	ALARM
00701	Illegal option code selected	P51-P53	ALARM
00777	PIPA fail caused the ISS warning	T4RUPT	VARALARM
01102	AGC self test error	Self check	ALARM2
01105	Downlink too fast	T4RUPT	ALARM
01106	Uplink too fast	T4RUPT	ALARM
01107	Phase table failure. Assume erasable memory is suspect.	Fresh start and restart (restart)	ALARM
01301	ARCSIN-ARCCOS argument too large	Interpreter	ALARM1
01406	Bad return from ROOTPSRS	Lunar landing guidance equations	ALARM
01407	VG increasing (delta-V accumulated . GT. 90 degrees away from desired thrust vector.)	P40-P47	ALARM
01410	Unintentional overflow in guidance	Lunar landing guidance equations	ALARM
01412	Descent IGNALG not converging	Lunar landing guidance equations	ALARM
01520	V37 request not permitted at this time	Fresh start and restart (V37)	ALARM
01600	Overflow in drift test	IMU performance tests 4	ALARM
01601	Bad IMU torque	IMU performance tests 4	VARALARM
01703	Ignition time slipped	Integration initialization	ALARM
01706	Incorrect program requested for vehicle configuration	Master ignition routine	ALARM
02001	Jet failures have disabled Y-Z trans.	P-axis RCS autopilot	ALARM
02002	Jet failures have disabled X translation	Q, R-axis RCS autopilot	ALARM
02003	Jet failures have disabled P-rotation	P-axis RCS autopilot	ALARM
02004	Jet failures have disabled U-V rotation	Q, R-axis RCS autopilot	ALARM
03777	ICDU fail caused the ISS warning	T4RUPT	VARALARM

Alarm Code	Alarm Condition	Set By	Alarm Entry Used
04777	ICDU, pipa fails caused the ISS warning	T4RUPT	VARALARM
07777	IMU fail caused the ISS warning	T4RUPT	VARALARM
10777	IMU, PIPA fails caused the ISS warning	T4RUPT	VARALARM
13777	IMU, ICDU fails caused the ISS warning	T4RUPT	VARALARM
14777	IMU ICDU, PIPA fails caused ISS warning	T4RUPT	VARALARM
	The following codes indicate the more serious POODOO aborts that result in the program going to ROO.		
20105	AOTMARK system in use	AOTMARK	POODOO
20430	Acceleration overflow in integration	Orbital integration	POODOO
20607	No soln from time-theta or time-radius	Conic subroutines	POODOO
21103	Unused CCS branch executed	TJET LAW, T6RUPT programs, executive, interpreter, pinball, IMU performance tests 2	CCSHOLE
21204	WAITLIST. VARDELAY. FIXDELAY, or LONGCALL called with zero or negative delta-time	Waitlist	POODOO1
21302	SORT called with negative argument	Interpreter	POODOO1
21406	Bad return from ROOTPSRS	Lunar landing guidance equations	POODOO1
21501	Keyboard and display alarm during internal use (NVSUB). abort	Pinball	POODOO
	The following codes indicate a bailout abort that results in a software restart		
31104	Delay routine busy	Service routines	BAILOUT1
31201	Executive overflow-no VAC areas	Executive	BAILOUT1
31202	Executive overflow-no core sets	Executive	BAILOUT1
31203	Waitlist overflow-too many tasks	Waitlist	BAILOUT1
31206	Second job attempts to go to sleep via keyboard and display program	Pinball	BAILOUT
31207	No VAC areas for marks	AOTMARK	BAILOUT1
31210	Two programs using device at same time	IMU mode switching routines	BAILOUT1
31211	Illegal interrupt of extended verb	AOTMARK	BAILOUT1

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Alarm Code	Alarm Condition	Set By	Alarm Entry Used
31502	Two priority displays waiting	Display interface routines	BAILOUT
32000	DAP still in progress at next TIME5 RUPT	P-axis RCS aotopilot	BAILOUT

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
STATEFLG FLAGWRD3 Bit 5	Permanent state vector updated	Permanent state vector not updated		Sh. 14	
REINTFLG FLGWRD10 Bit 7	Integration routine to be restarted	Integration routine not to be restarted		Sh. 14	
NODOFLAG FLAGWRD2 Bit 1	V37 is not permitted	V37 permitted		Sh. 14	
V37FLAG FLAGWRD7 Bit 6	Keep servicer (AVERAGEG) running	Servicer (AVERAGEG) off			Sh. 15
IDLEFLAG FLAGWRD7 Bit 7	Disconnect ΔV monitor	Connect ΔV monitor	Sh. 16		
LRBYPASS FLGWRD11 Bit 15	Bypass all (terminate P12) landing radar updates	Do not bypass landing radar updates	Sh. 16		
FLGWRD11 Bit 14-1	Leave R12 intact	Turn off R12 if running. Otherwise, no effect		Sh. 16	
MOONFLAG FLAGWRD0 Bit 12	Moon is sphere of influence	Earth is sphere of influence			Sh. 17

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ANALST				
DOCMR	C. Geo. Beck	12-16-69	LUMINARY 1D	FC-3140
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SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Flow Chart	Description	Where Called
V37KLEAN	FC-3010	Deactivate restart groups 1, 3, 5, 6	Sh. 15
MR. KLEAN	FC-3010	Deactivate all (1-6) restart groups	Sh. 15
PRIODSPR	FC-3130	See displays below	Sh. 12
GOPROG2	FC-3010	Software restart (see Note "A" on sheet 18)	Sh. 13 & 18

DISPLAYS

Verb-Noun	Type of Display	Description	Where Executed
V05N09	PRIODSPR	Displays the contents (alarm codes) of registers FAILREG, FAILREG +1 and FAILREG + 2 in R1, R2 and R3	Sh. 12

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APOLLO GUIDANCE AND NAVIGATION

Alarm and Abort

LUMINARY 1D

DOCUMENT NO. FC-3140

REV 2

SHEET 24 OF 24

RTB OP CODES

LOADTIME	Sh. 2
CDULOGIC	Sh. 3
SGNAGREE	Sh. 3
1STO2S	Sh. 4
V1STO2S	Sh. 5
2V1STO2S	Sh. 7
1TO2SUB	Sh. 8
CDUINC	Sh. 9
PULSEIMU	Sh. 11
VECSGNAG	Sh. 11
NORMUNX1	Sh. 12
NORMUNIT	Sh. 12
SIGNMPAC	Sh. 14
TPMODE	Sh. 6
DPMODE	Sh. 14

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ANALST
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APPR'D Roberta M. Estes 9/8/69

APOLLO GUIDANCE AND NAVIGATION

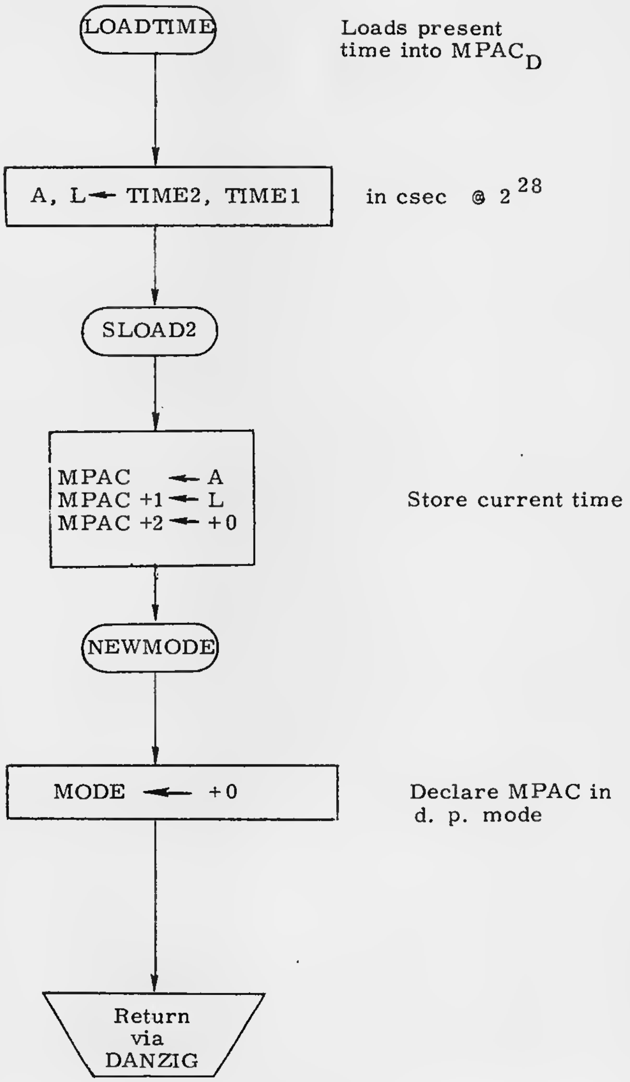
RTB Op Codes

LUMINARY 1D

DOCUMENT NO. FC-3150

REV 2

SHEET 1 OF 14



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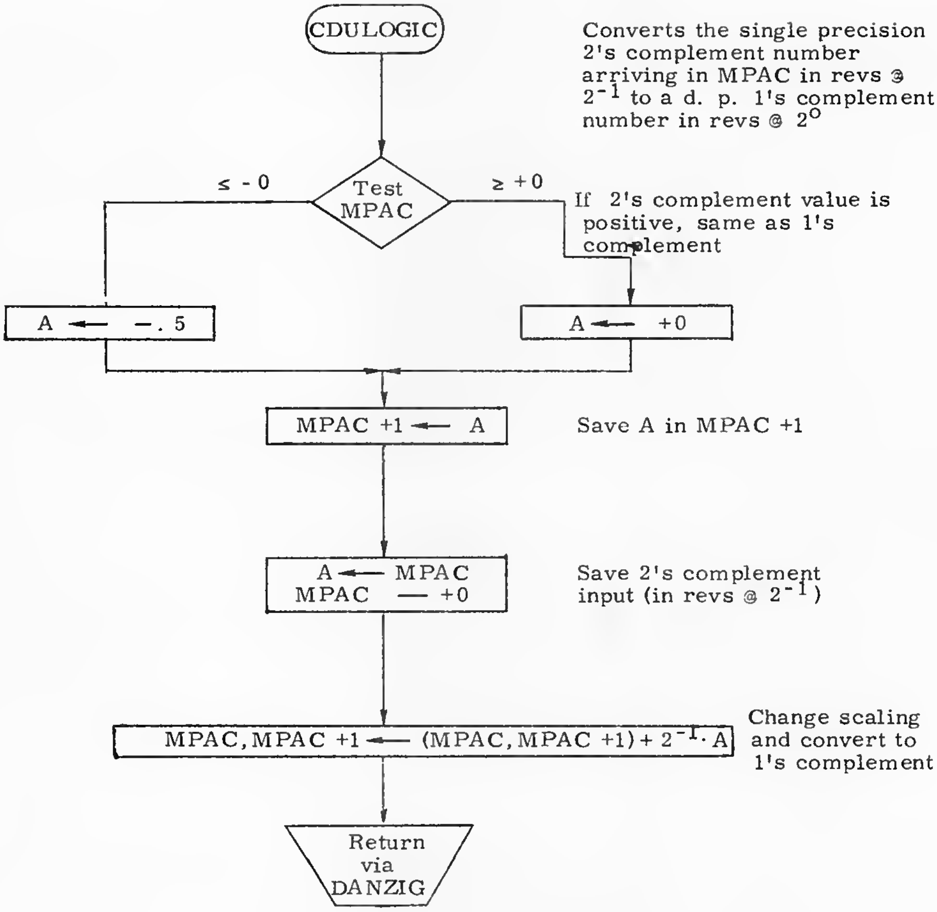
DRAWN	8-4-69	RTB Op Codes	
PRGMR	9/8/69		**DOCUMENT NO.**
ANALST		LUMINARY 1D	FC-3150
DOCMR	9/8/69		
APPR'D	9/8/69	REV 2	SHEET 2 OF 14



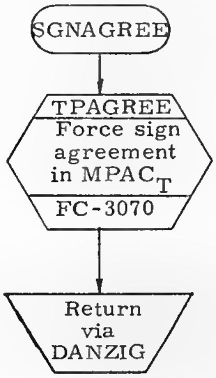
Converts the single precision 2's complement number arriving in MPAC in revs @ 2^{-1} to a d. p. 1's complement number in revs @ 2^{0}

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

Save A in MPAC +1

Save 2's complement input (in revs @ 2^{-1})

Change scaling and convert to 1's complement



Forces sign agreement in $MPAC_T$

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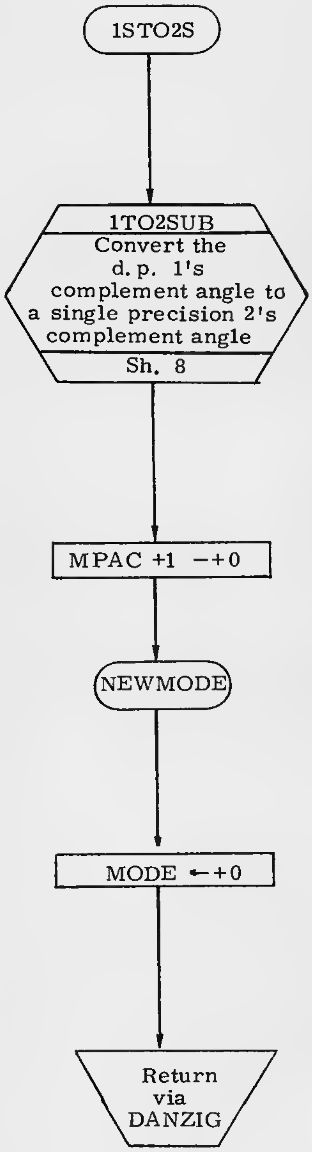
DRAWN	8/14/69	RTB Op Codes	
PRGMR	9/8/69		
ANALST		LUMINARY ID	DOCUMENT NO. FC-3150
DOCMR Roberta M. Estes	9/8/69		
APPR'D Roberta M. Estes	9/8/69	REV 2	SHEET 3 OF 14



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

Input:
$MPAC_D$ = 1's complement angle in revs @ 2^0

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

Declare MPAC in d.p. mode

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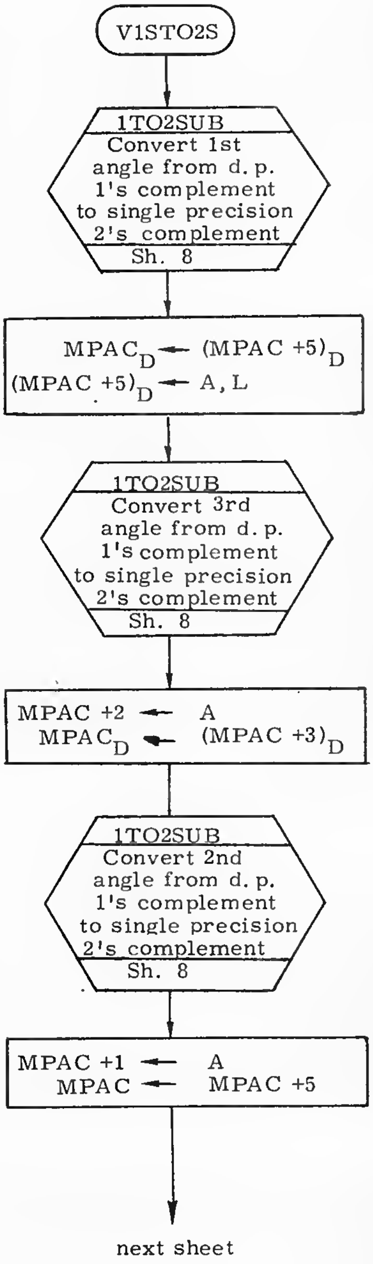
APOLLO GUIDANCE AND NAVIGATION
RTB Op Codes
LUMINARY 1D
DOCUMENT NO. FC-3150
REV 2 .
SHEET 4 OF 14



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

Input:
$MPAC_D$ = 1st 1's complement angle in revs @ 2^0

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

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

Input:
$MPAC_D$ = 3rd 1's complement angle in revs @ 2^0

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

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

Input:
$MPAC_D$ = 2nd 1's complement angle in revs @ 2^0

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

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

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ANALST
DOCMR Roberta M. Estes 9/8/69
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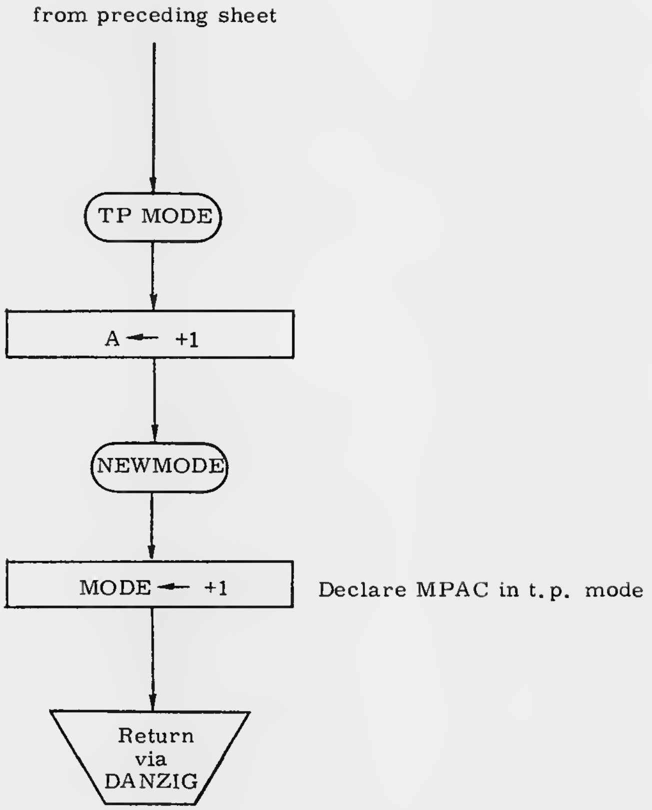
APOLLO GUIDANCE AND NAVIGATION
RTB Op Codes
LUMINARY 1D
DOCUMENT NO. FC-3150
REV 2
SHEET 5 **OF** 14



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APOLLO GUIDANCE AND NAVIGATION

RTB Op Codes

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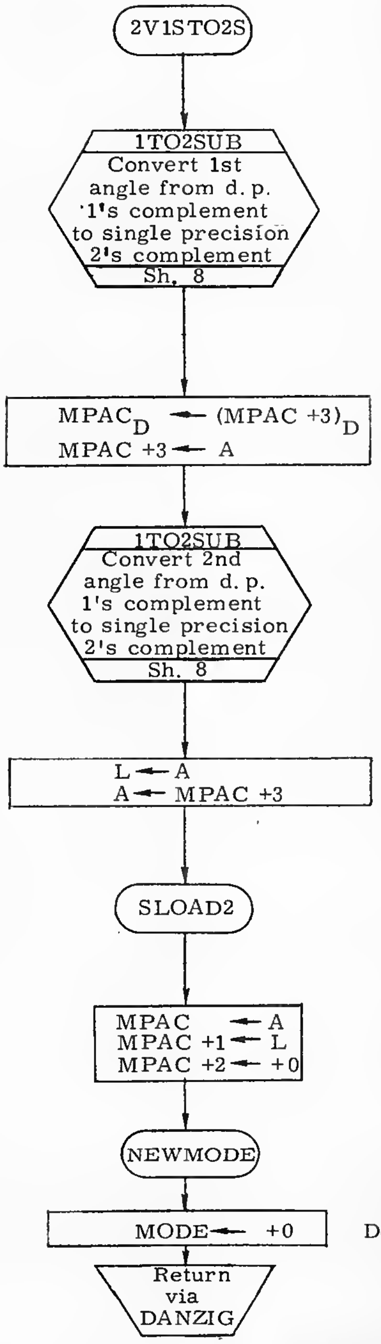
ANALST
DOCMR Robert M. Estes 9-8-69
APPR'D Robert M. Estes 9-8-69

LUMINARY 1D

DOCUMENT NO. FC-3150

REV 2

SHEET 6 **OF** 14



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

Input:
MPAC$_D$ = 1st 1's complement angle in revs @ 2^0

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

Load 2nd angle for input

Save 1st angle result in MPAC +3

Input:
MPAC$_D$ = 2nd 1's complement angle in revs @ 2^0

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

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

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

Declare MPAC in d.p. mode

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ANALST
DOCMR Robert M. Estes 9-8-69
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APOLLO GUIDANCE AND NAVIGATION

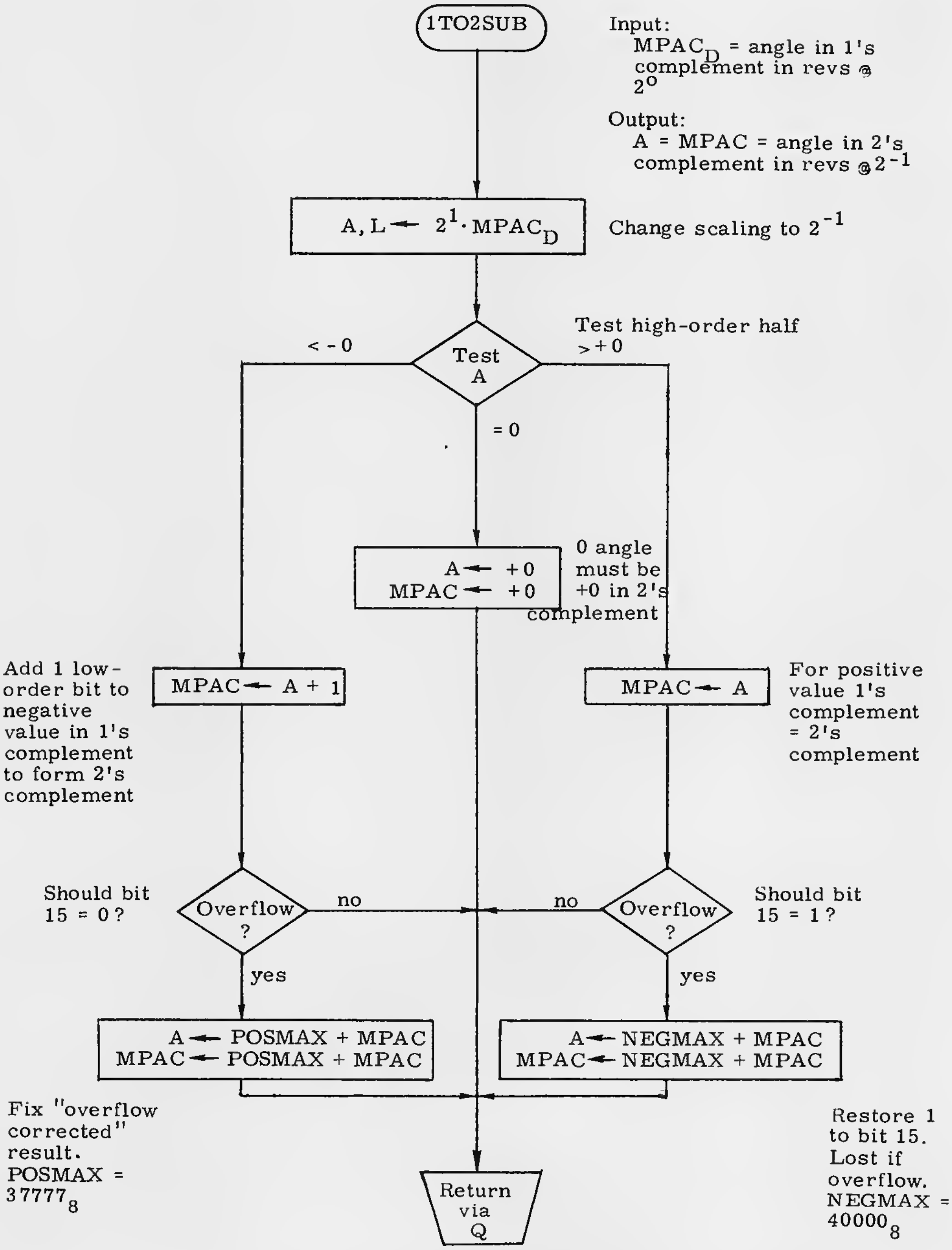
RTB Op Codes

LUMINARY 1D

DOCUMENT NO.
FC-3150

REV 2

SHEET 7 OF 14



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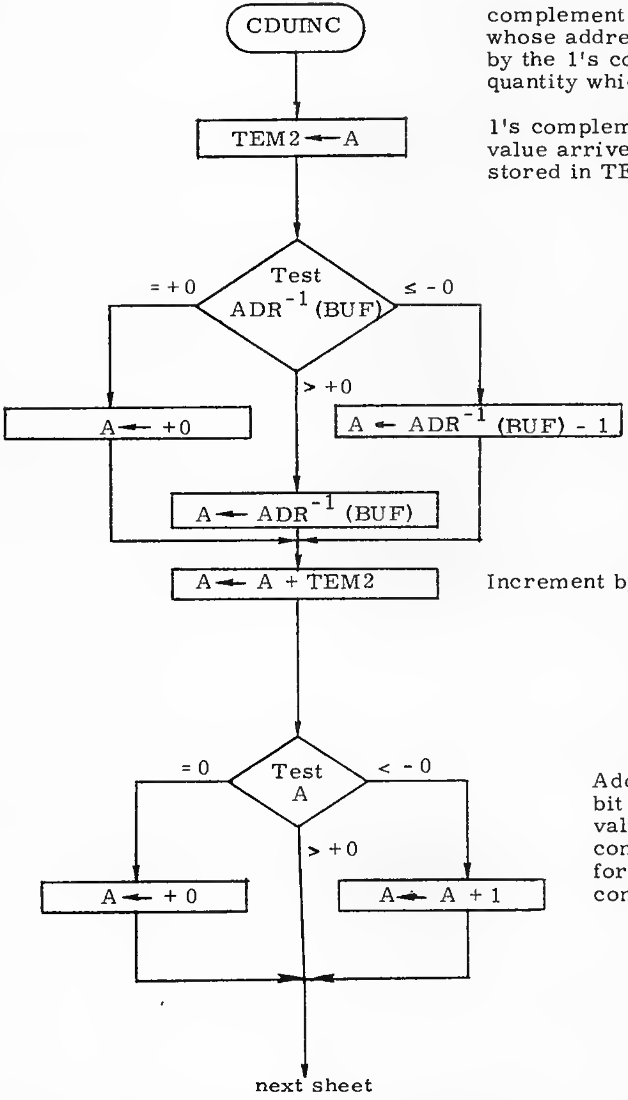
DRAWN	8-26-69	RTB Op Codes	
PRGMR	9/9/69		
ANALST			DOCUMENT NO.
DOCMR Roberta M. Estes	9-8-69	LUMINARY I D	FC-3150
APPR'D Roberta M. Estes	9-8-69	REV 2	SHEET 8 OF 14



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

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

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

Increment by input value

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

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APOLLO GUIDANCE AND NAVIGATION

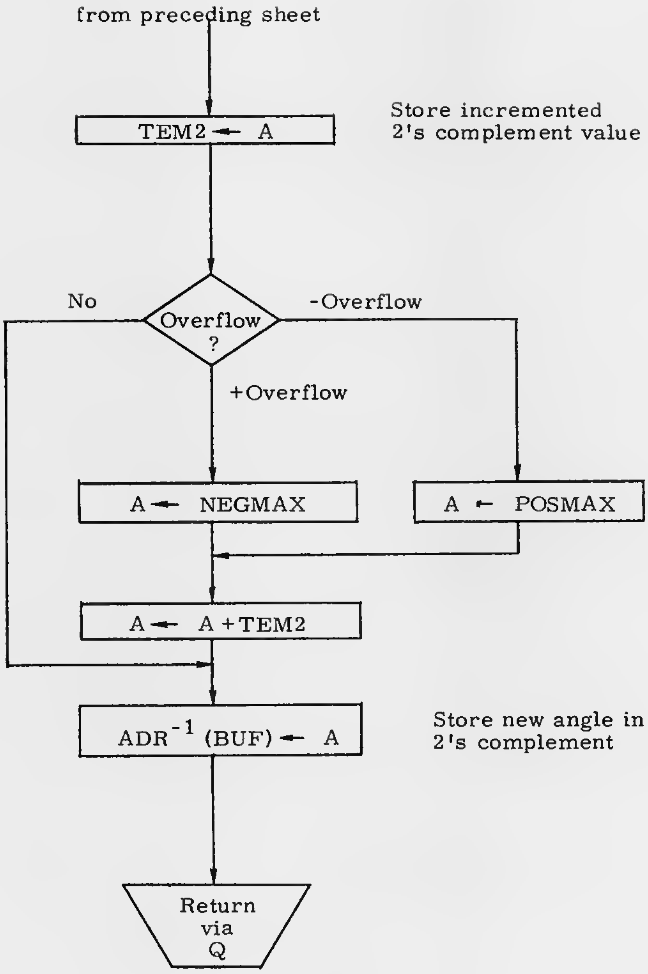
RTB Op Codes

LUMINARY 1D

DOCUMENT NO. FC-3150

REV 2

SHEET 9 OF 14



Store incremented 2's complement value

If overflow, fix bit 15 by adding POSMAX (37777_8) or NEGMAX (40000_8) (quantity @ 2^{-1})

Store new angle in 2's complement

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DOCMR Roberta M. Estes
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APOLLO GUIDANCE AND NAVIGATION

RTB Op Codes

LUMINARY ID

DOCUMENT NO.
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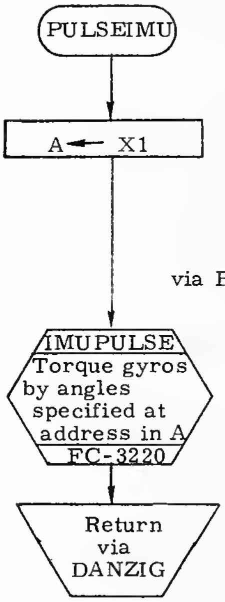
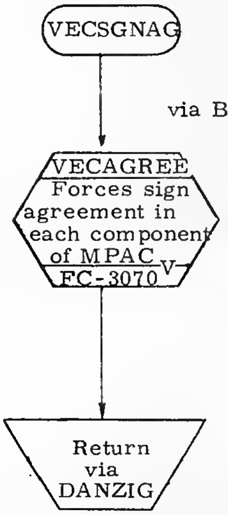
REV 2

SHEET 10 OF 14



Enter with address of gyro torquing angles in X1

Load the address of $\mathcal{X}$, where $\mathcal{X}_D$, $(\mathcal{X}+2)_D$, $(\mathcal{X}+4)_D$ contain gyro torquing angles in revs @ 2^0



Forces sign agreement of $MPAC_V$

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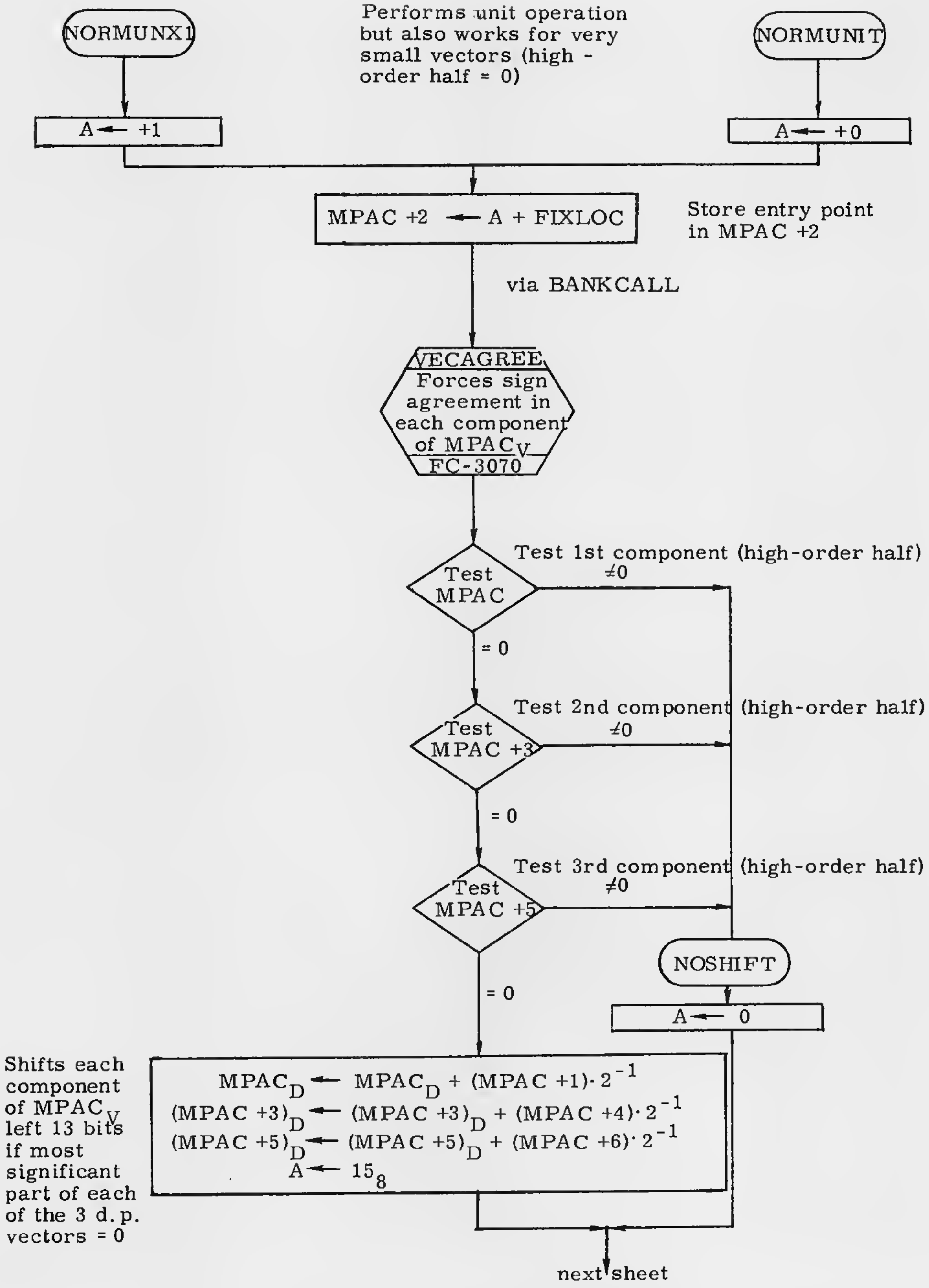
DRAWN A. Zutkevich	8-26-69	RTB Op Codes
PRGMR	9/8/69	DOCUMENT NO.
ANALST		
DOCMR Roberta M. Eustis	9-8-69	LUMINARY 1D — FC-3150
APPR'D Roberta M. Eustis	9-8-69	REV 2 — SHEET 11 OF 14



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

Store entry point in MPAC +2

Test 1st component (high-order half)

Test 2nd component (high-order half)

Test 3rd component (high-order half)

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

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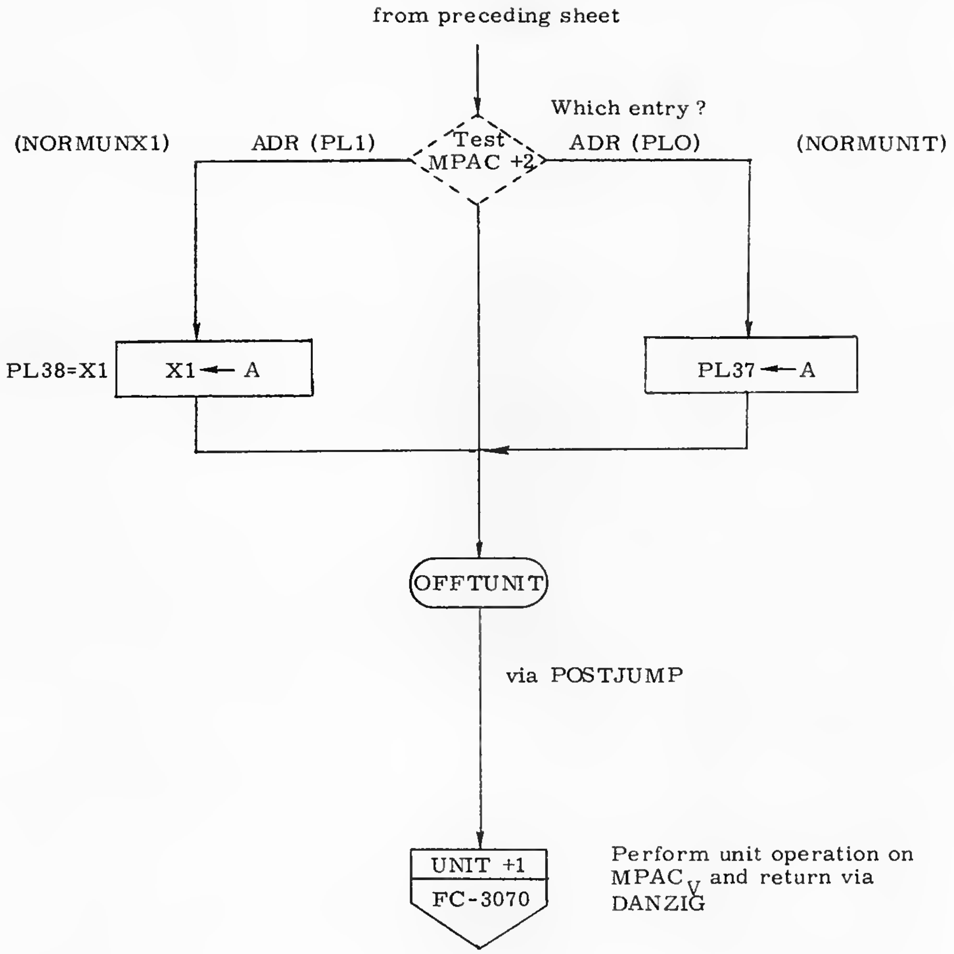
ANALST		LUMINARY ID	FC-3150
DOCMR	9-8-69		
APPR'D	9-8-69	**REV** 2	**SHEET** 12 **OF** 14



Perform unit operation on MPAC_V and return via DANZIG

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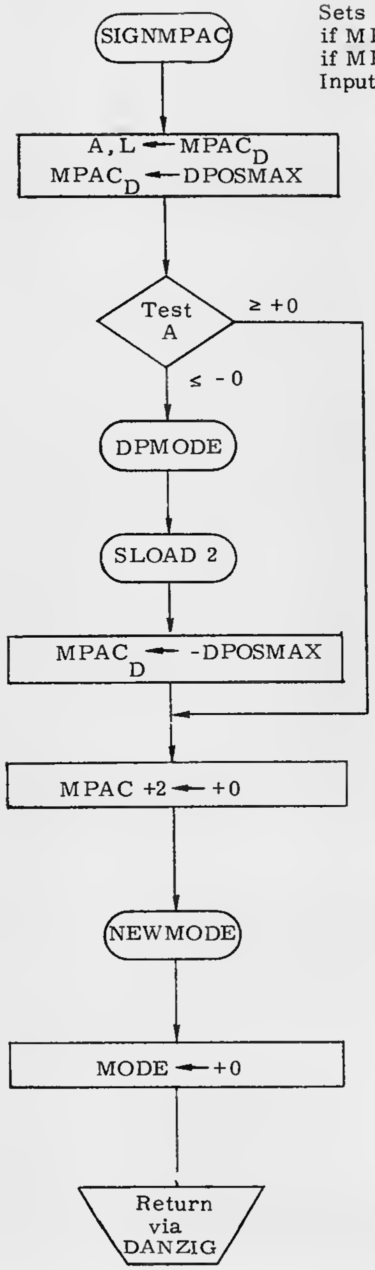
PRGMR D. Eyles	9/8/69		DOCUMENT NO.
ANALST		LUMINARY ID	FC-3150
DOCMR Roberta M. Estes	9-8-69		
APPR'D Roberta M. Estes	9-8-69	REV 2	SHEET 13 OF 14



Sets contents of $MPAC_D$ to DPOSMAX if MPAC is positive and to −DPOSMAX if MPAC is negative

Input: $MPAC_D$

DPOSMAX = 37777_8, 37777_8

For positive MPAC, set $MPAC_D$ = DPOSMAX

For negative MPAC, set $MPAC_D$ = −DPOSMAX = maximum d.p. negative magnitude

Declare MPAC in d.p. mode

Output:
$MPAC_D$ containing
DPOSMAX or −DPOSMAX

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	8-11-69	RTB Op Codes	
PRGMR	9/8/69		
ANALST			DOCUMENT NO.
DOCMR Robert M. Estes	9-8-69	LUMINARY I D	FC-3150
APPR'D Robert M. Estes	9-8-69	REV 2	SHEET 14 OF 14

Single Precision Subroutines

SPCOS	Sh. 2
SPSIN	Sh. 2

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DRAWN L. Goldstone 9/23/69
PRGMR
ANALST D. S. 9/30/69
DOCMR Roberta M. Ente 10/9/69
APPR'D Roberta M. Ente 10/9/69

APOLLO GUIDANCE AND NAVIGATION

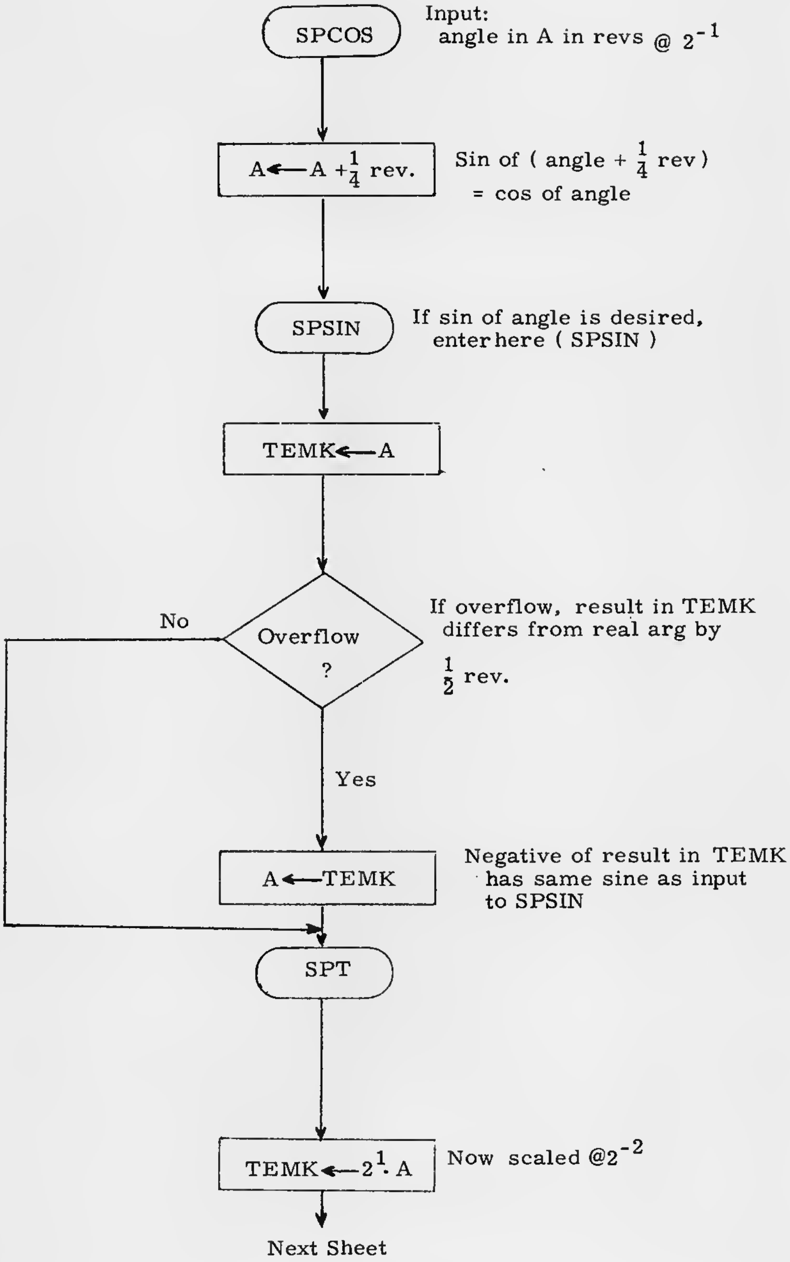
Single Precision Subroutines

LUMINARY
1D

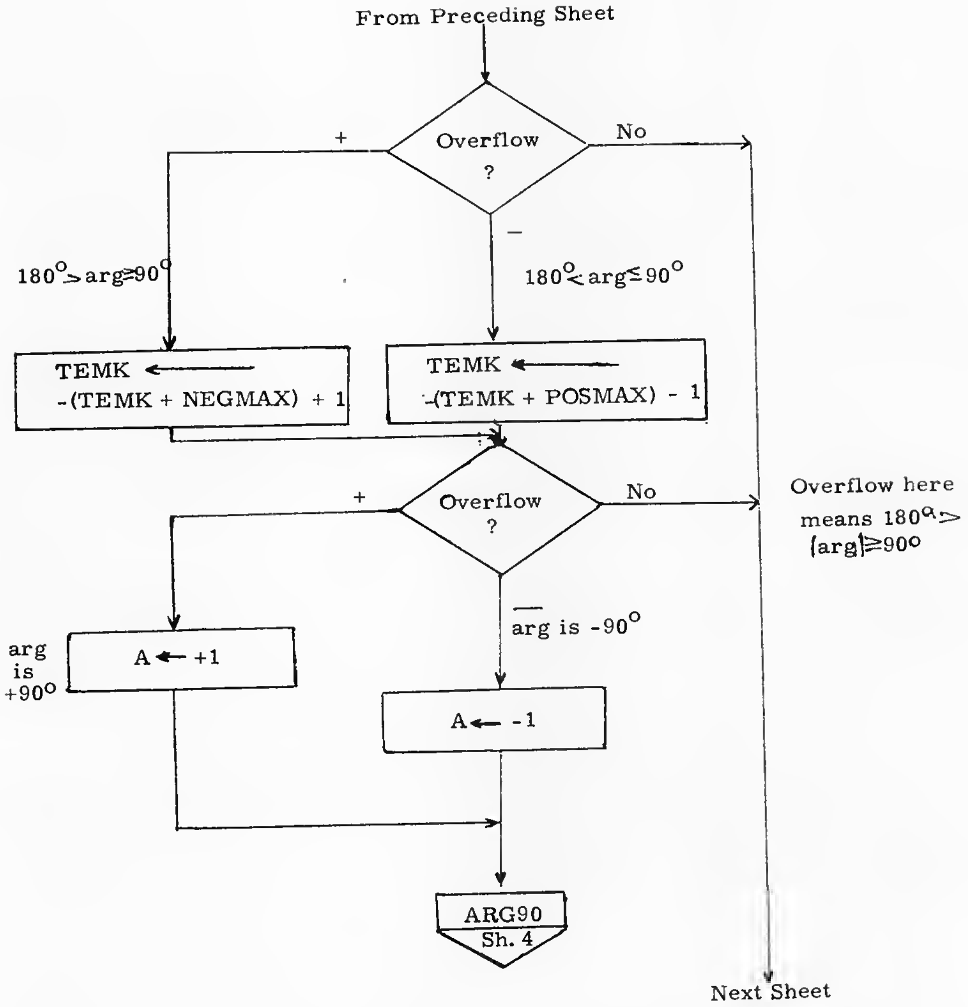
DOCUMENT NO.
FC-3160

REV 1

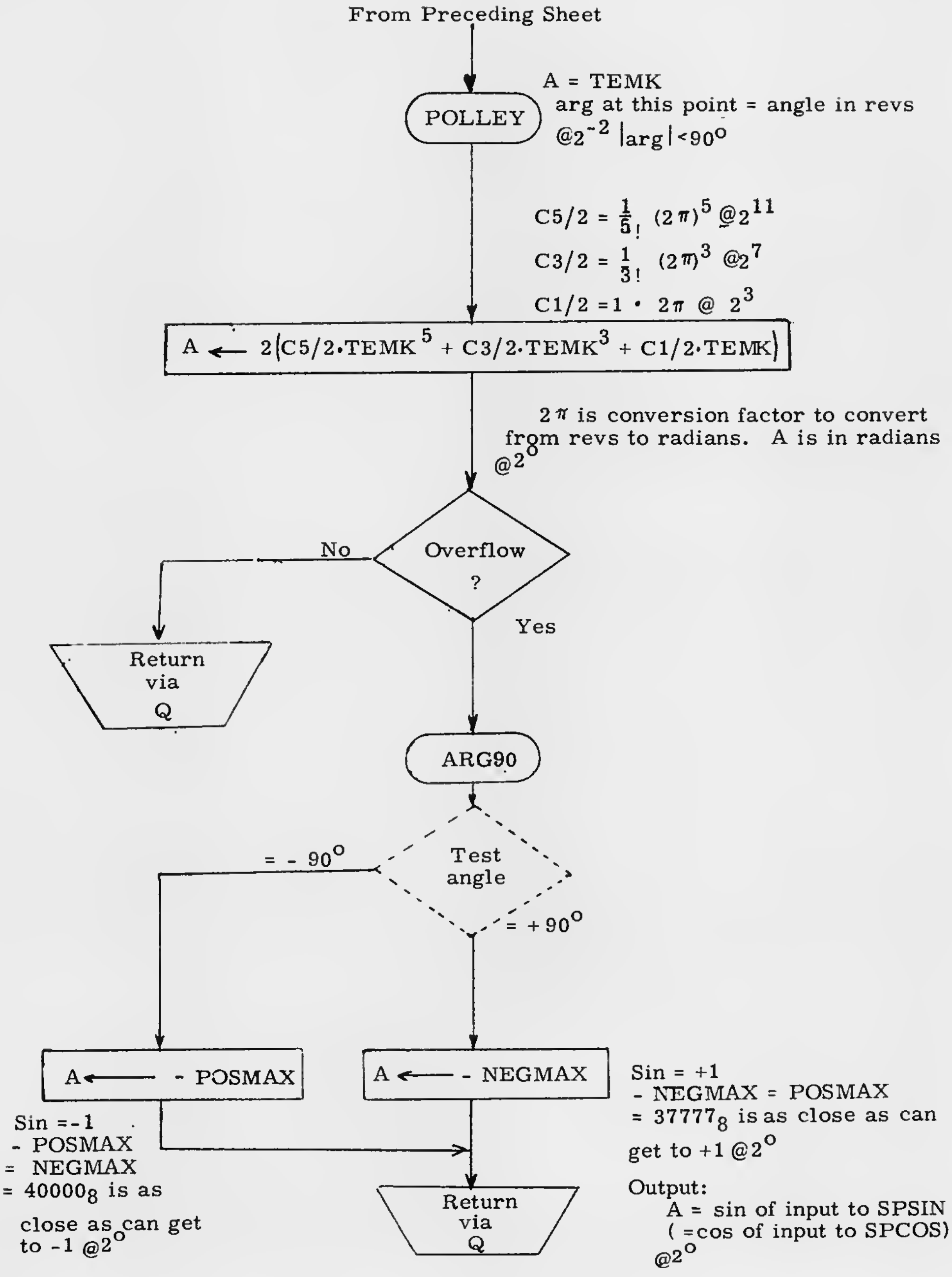
SHEET 1 OF 4



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	7/23/69	Single Precision Subroutines	
PRGMR			
ANALST	9/30/69	LUMINARY 1D	DOCUMENT NO. FC-3160
DOCMR Roberta M. Estes	10/9/69		
APPR'D Roberta M. Estes	10/9/69	REV 1	SHEET 2 OF 4



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN Z. Gollston	9/26/69	Single Precision Subroutines
PRGMR		
ANALST	9/30/69	LUMINARY 1D
DOCMR Robert M. Estes	10/9/69	DOCUMENT NO. FC-3160
APPR'D Robert M. Estes	10/9/69	REV 1
		SHEET 3 OF 4



A = TEMK
arg at this point = angle in revs
$@2^{-2}$ $|arg| < 90^{o}$

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

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

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

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

Sin = -1
- POSMAX
= NEGMAX
= 40000_8 is as close as can get to -1 $@2^0$

Sin = +1
- NEGMAX = POSMAX
= 37777_8 is as close as can get to +1 $@2^0$

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

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PRGMR
ANALST 9/30/69
DOCMR Roberta M. Estes 10/9/69
APPR'D Roberta M. Estes 10/9/69

APOLLO GUIDANCE AND NAVIGATION

Single Precision Subroutines

LUMINARY 1D

DOCUMENT NO. FC-3160

REV 1

SHEET 4 OF 4

3.0 PGNCS INTERFACE ROUTINES

T4RUPT

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

T4RUPT	Sh. 2
CDRVE	Sh. 4
RCSMONIT	Sh. 8
RRAUTCHK	Sh. 10
RRCDUCHK	Sh. 12
RRGIMON	Sh. 14
NORRGMON	Sh. 17
RRTURNON	Sh. 18
RRZEROSB	Sh. 19
DORREPOS	Sh. 22
IMUMON	Sh. 25
TLIM	Sh. 28
LAMPTEST	Sh. 28
ITURNON	Sh. 29
SETISSW (= IMUFAIL = ICDUFAIL)	Sh. 31
IMUCAGE	Sh. 33
IMUOP	Sh. 35
TNONTEST	Sh. 37
ENDTNON	Sh. 40
C33TEST	Sh. 45
PIPFAIL	Sh. 49
DNTMFAST	Sh. 51
UPTMFAST	Sh. 52
GLOCKMON	Sh. 53
CAGESUB	Sh. 56
CAGESUB1	Sh. 56
CAGESUB2	Sh. 56
GPMATRIX (= DAPT4S = ENDRRMON)	Sh. 57
QUIKDSP	Sh. 60
DSPOUTSB	Sh. 63

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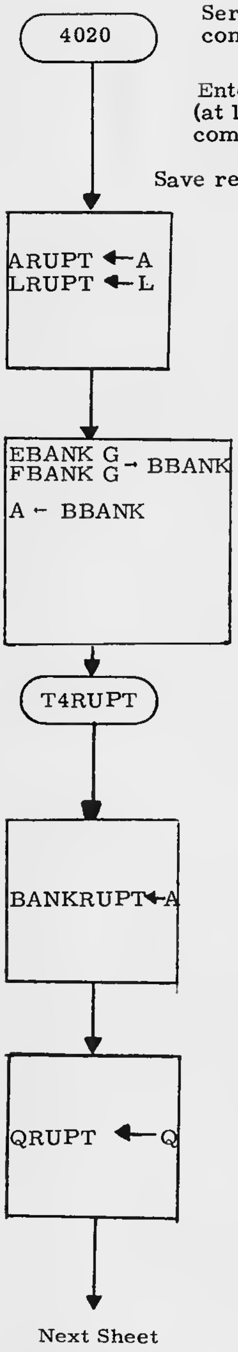
DRAWN 12/3/69
PRGMR 2/5/70
ANALST
DOCMR A. M. Sorant
APPR'D Roberta M Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION
T4RUPT
LUMINARY 1D
DOCUMENT NO. FC-3210
REV 1
SHEET 1 OF 80

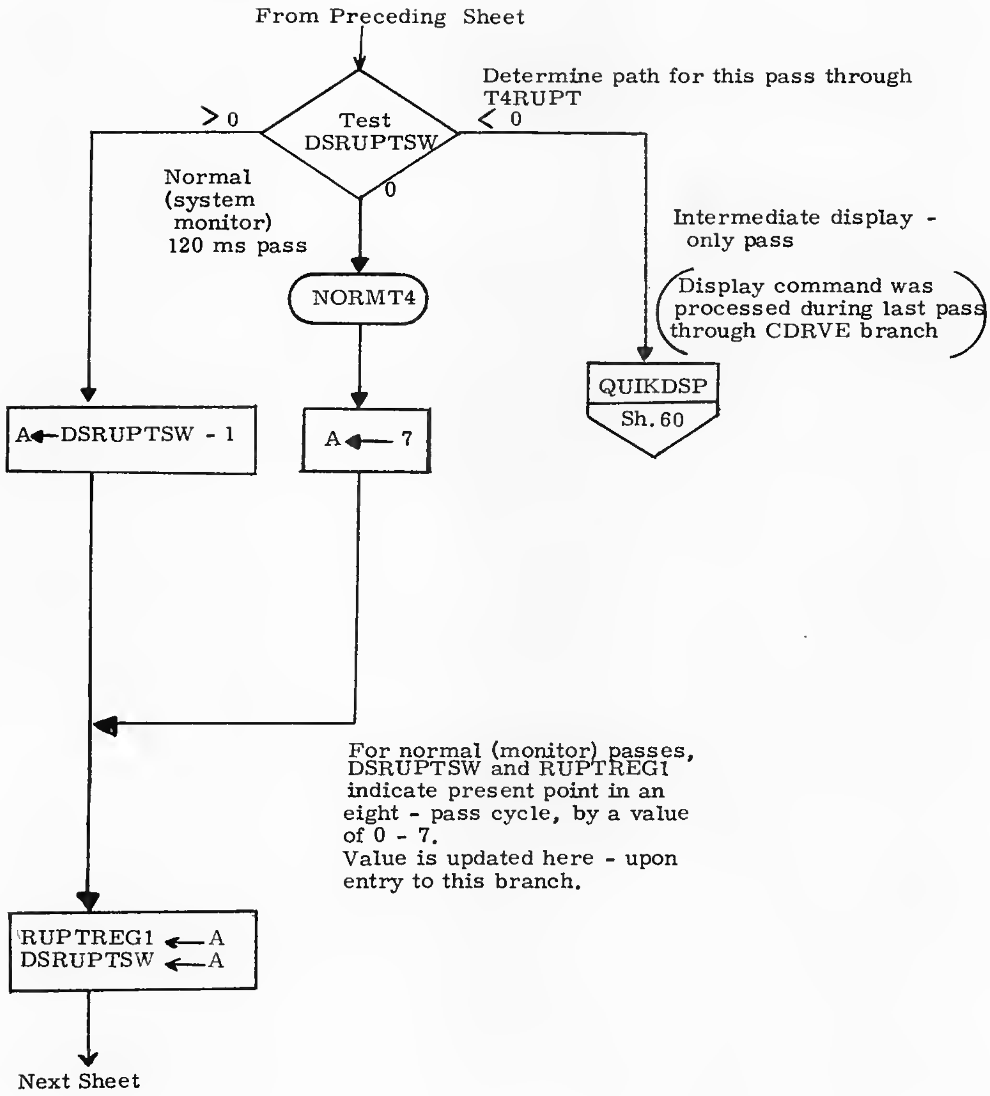


Service routine which processes display commands and monitors various systems

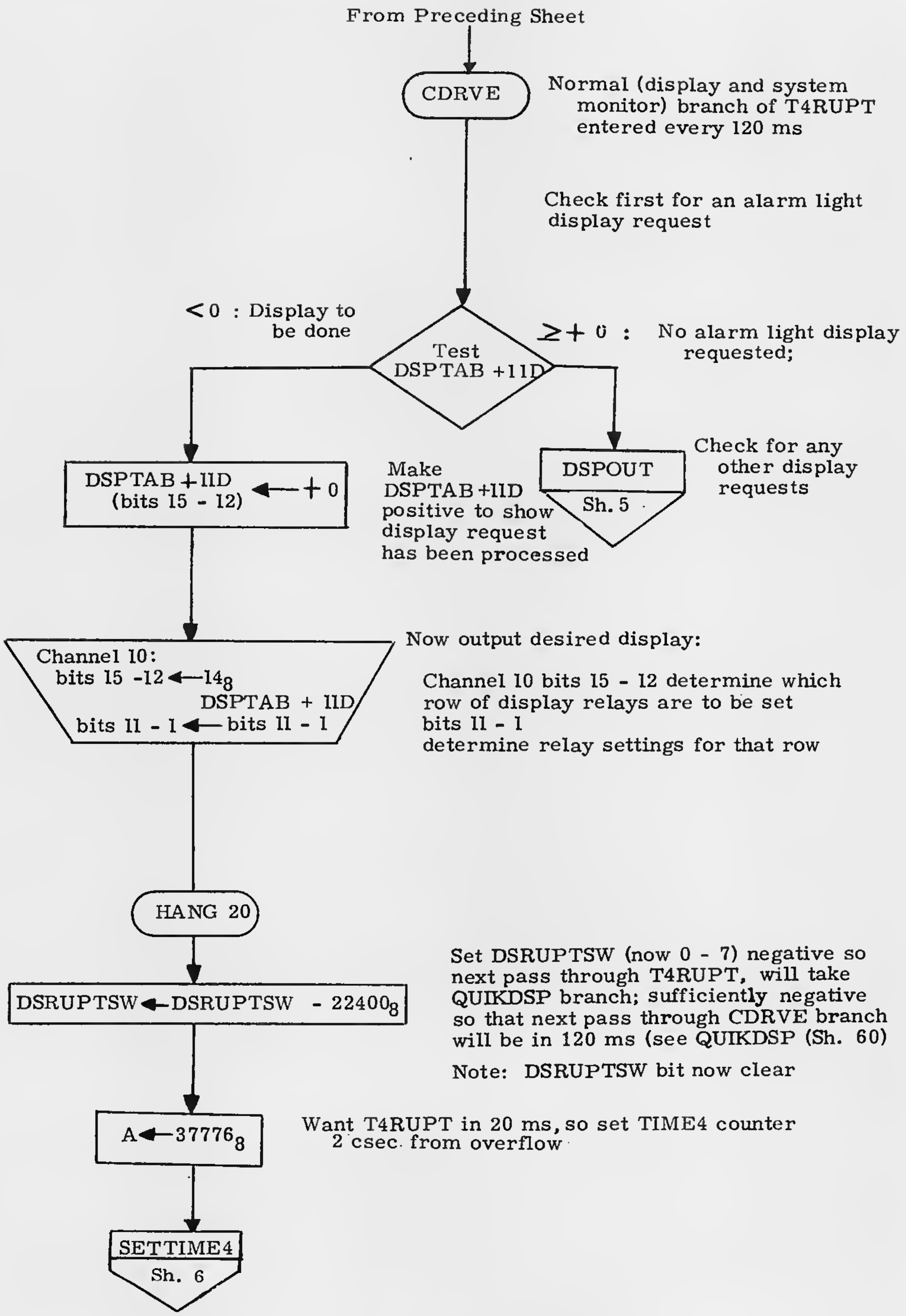
Entered via hardware whenever TIME4 counter overflows (at least every 120 ms: oftener when display commands are processed)

Save registers for interrupted program

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		T4RUPT	
PRGMR R. Gilbert	2/5/70		DOCUMENT NO.
ANALST		LUMINARY 1D	FC - 3210
DOCMR A.M. Sorant			
APPR'D	2/5/70	REV 1	SHEET 2 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN		T4RUPT
PRGMR R. Gilbert	2/5/70	
ANALST		LUMINARY 1D
DOCMR		DOCUMENT NO. FC - 3210
APPR'D	2/5/70	REV 1 · SHEET 3 OF 80



Normal (display and system monitor) branch of T4RUPT entered every 120 ms

Check first for an alarm light display request

No alarm light display requested;

Check for any other display requests

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

Set DSRUPTSW (now 0 - 7) negative so next pass through T4RUPT, will take QUIKDSP branch; sufficiently negative so that next pass through CDRVE branch will be in 120 ms (see QUIKDSP (Sh. 60)

Note: DSRUPTSW bit now clear

Want T4RUPT in 20 ms, so set TIME4 counter 2 csec from overflow

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DRAWN
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D R M Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

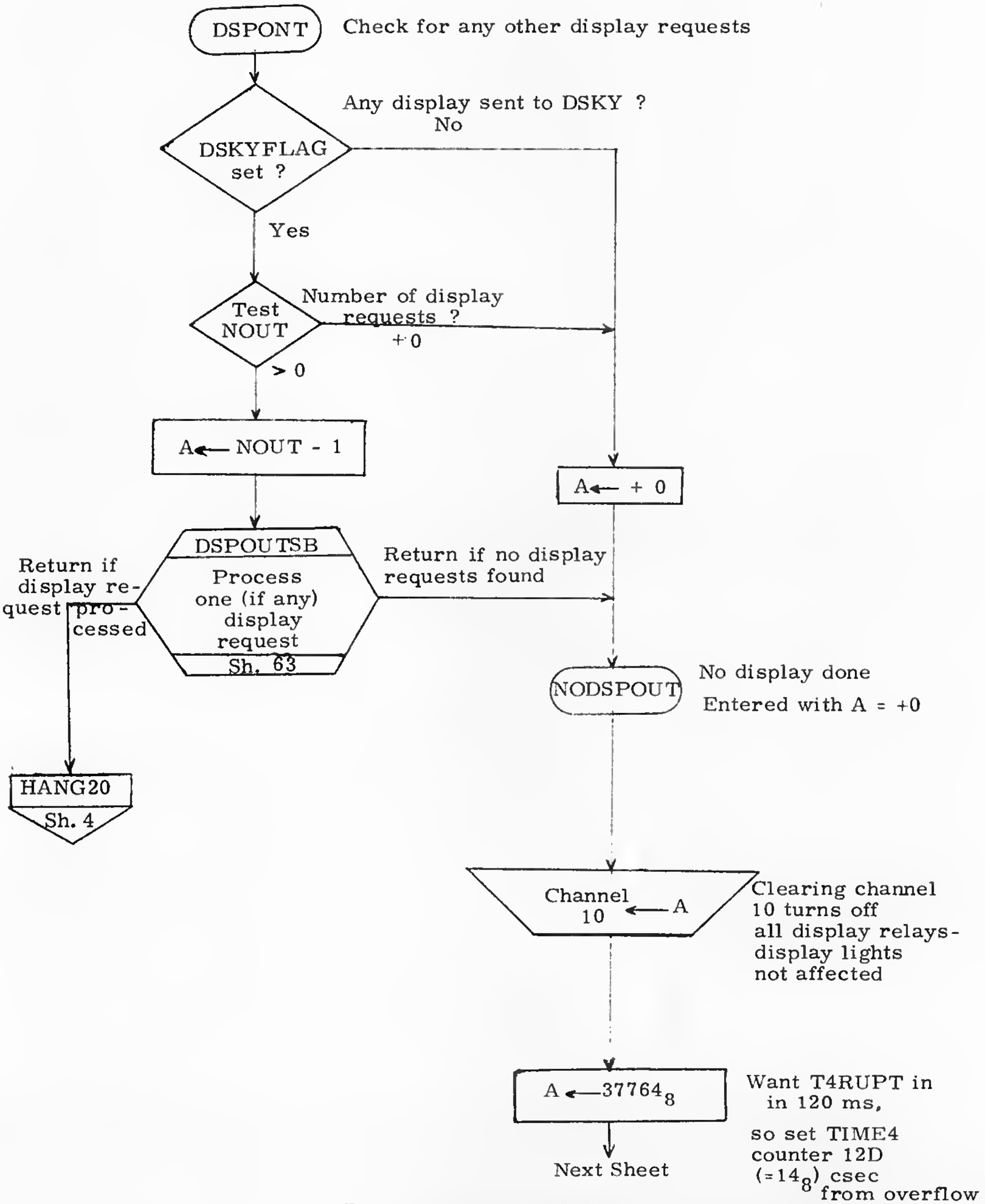
T4RUPT

LUMINARY 1D

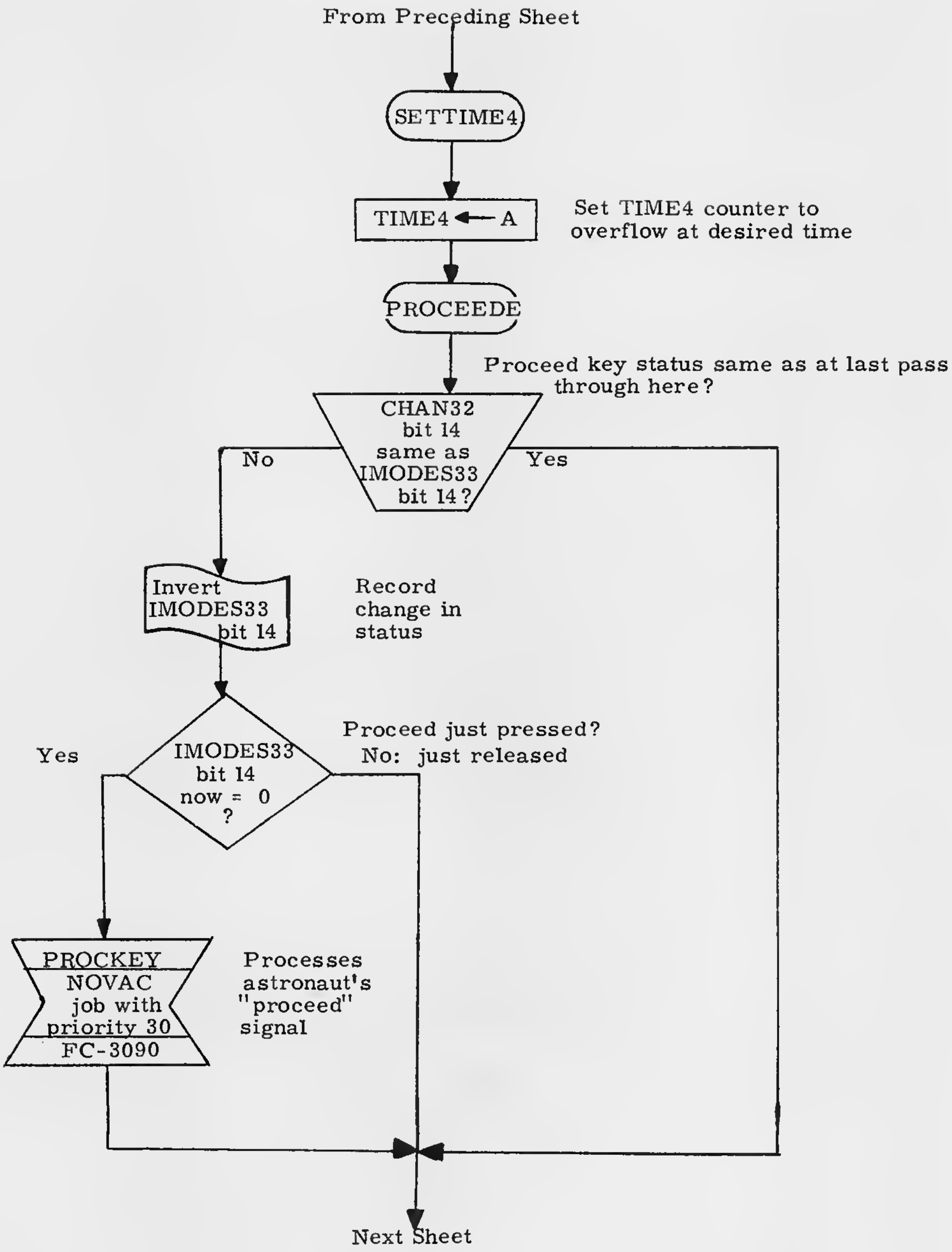
DOCUMENT NO. FC -3210

REV 1

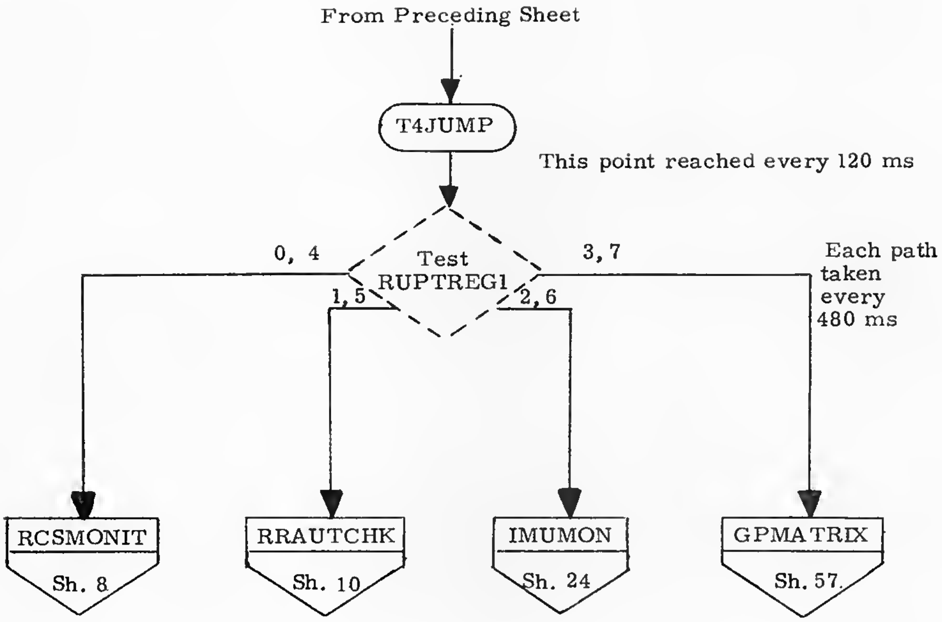
SHEET 4 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	12/15/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3210
DOCMR			
APPR'D P M Eaton	2/5/70	REV 1	SHEET 5 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	T4RUPT
PRGMR 2/5/70	
ANALST	LUMINARY 1D
DOCMR	DOCUMENT NO. FC - 3210
APPR'D 2/5/70	REV 1 · SHEET 6 OF 80



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CAMBRIDGE, MASS.

DRAWN

PRGMR R. Gilbert 2/5/70

ANALST

DOCMR

APPR'D 2/5/70

APOLLO GUIDANCE AND NAVIGATION

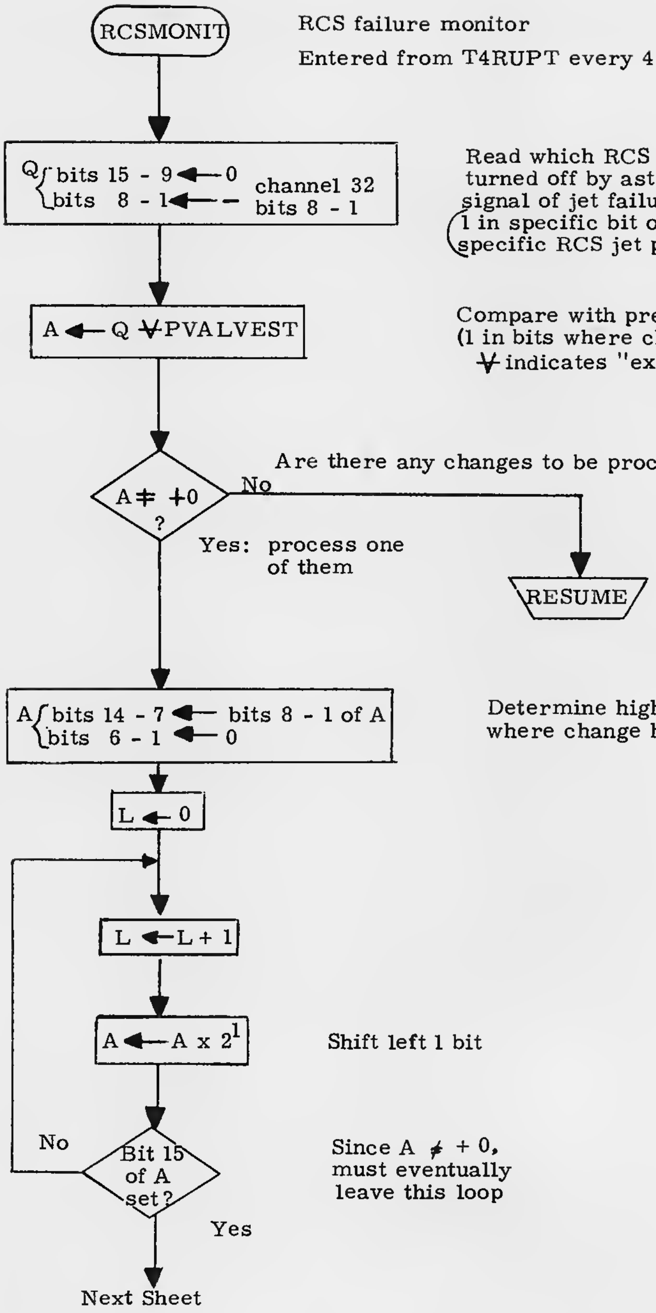
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC- 3210

REV 1

SHEET 7 OF 80



RCS failure monitor

Entered from T4RUPT every 480 ms

Read which RCS jets have been turned off by astronaut (due to signal of jet failure)
(1 in specific bit of Q indicates a specific RCS jet pair turned off)

Compare with previous valve state:
(1 in bits where change has occurred)
⊻ indicates "exclusive or" operation.

Are there any changes to be processed?

Yes: process one of them

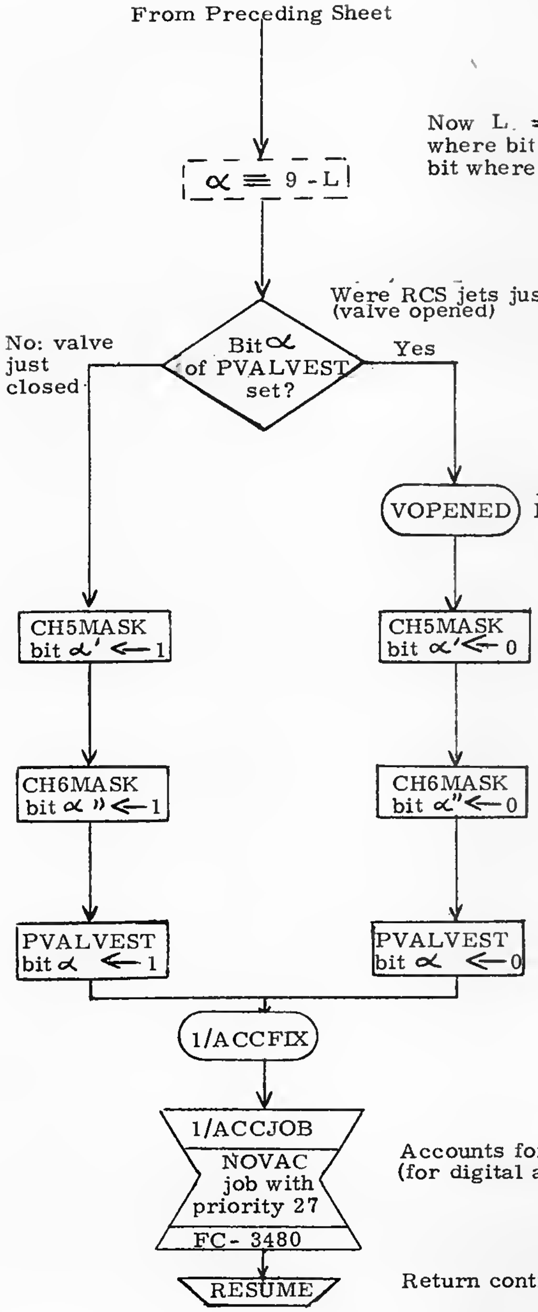
Return control to interrupted program

Determine highest order bit (bit α) where change has occurred:

Shift left 1 bit

Since A ≠ + 0, must eventually leave this loop

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	T4RUPT
PRGMR R. Gilbert 2/5/70	
ANALST	LUMINARY 1D
DOCMR	DOCUMENT NO. FC - 3210
APPR'D 2/5/70	REV 1
	SHEET 8 OF 80



Now $L = 9 - \alpha$,
where bit α is the highest (8 - 1)
bit where change has occurred

Were RCS jets just turned on ?
(valve opened)

Adjust CH5MASK, CH6MASK, and
PVALVEST to account for the change

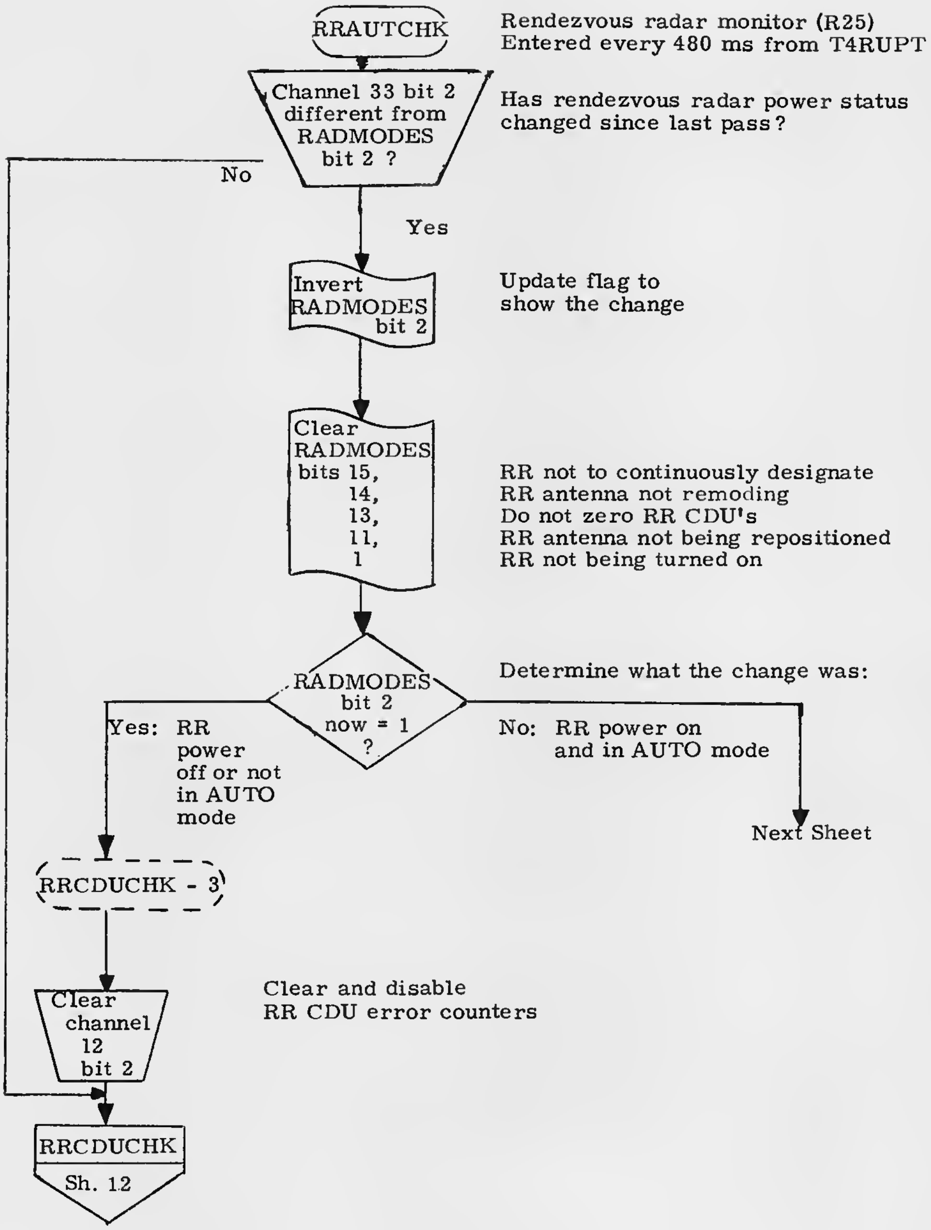
α	α'	α''
8	6	4
7	5	5
6	7	3
5	8	8
4	4	1
3	1	2
2	3	6
1	2	7

PVALVEST indicates states
of RCS jet pairs;
CH5MASK and CH6MASK indicate
states of individual RCS jets

Accounts for change in RCS jet status
(for digital autopilot)

Return control to interrupted program

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN		T4RUPT
PRGMR R. Gilbert	2/5/70	
ANALST		LUMINARY 1D
DOCMR		DOCUMENT NO. FC - 3210
APPR'D [illegible]	2/5/70	REV 1 SHEET 9 OF 80



Rendezvous radar monitor (R25)
Entered every 480 ms from T4RUPT

Has rendezvous radar power status changed since last pass?

Update flag to show the change

RR not to continuously designate
RR antenna not remoding
Do not zero RR CDU's
RR antenna not being repositioned
RR not being turned on

Determine what the change was:

Clear and disable RR CDU error counters

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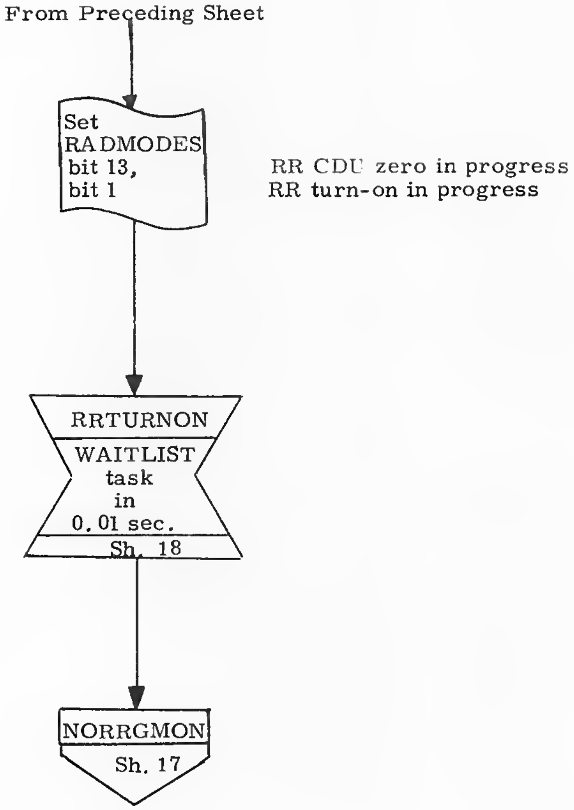
DRAWN	T4RUPT
PRGMR R. Gilbert 2/5/70	
ANALST	LUMINARY 1D
DOCMR	DOCUMENT NO. FC 3210
APPR'D 2/5/70	REV 1
	SHEET 10 OF 80



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DRAWN
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D 2/5/70

APOLLO GUIDANCE AND NAVIGATION

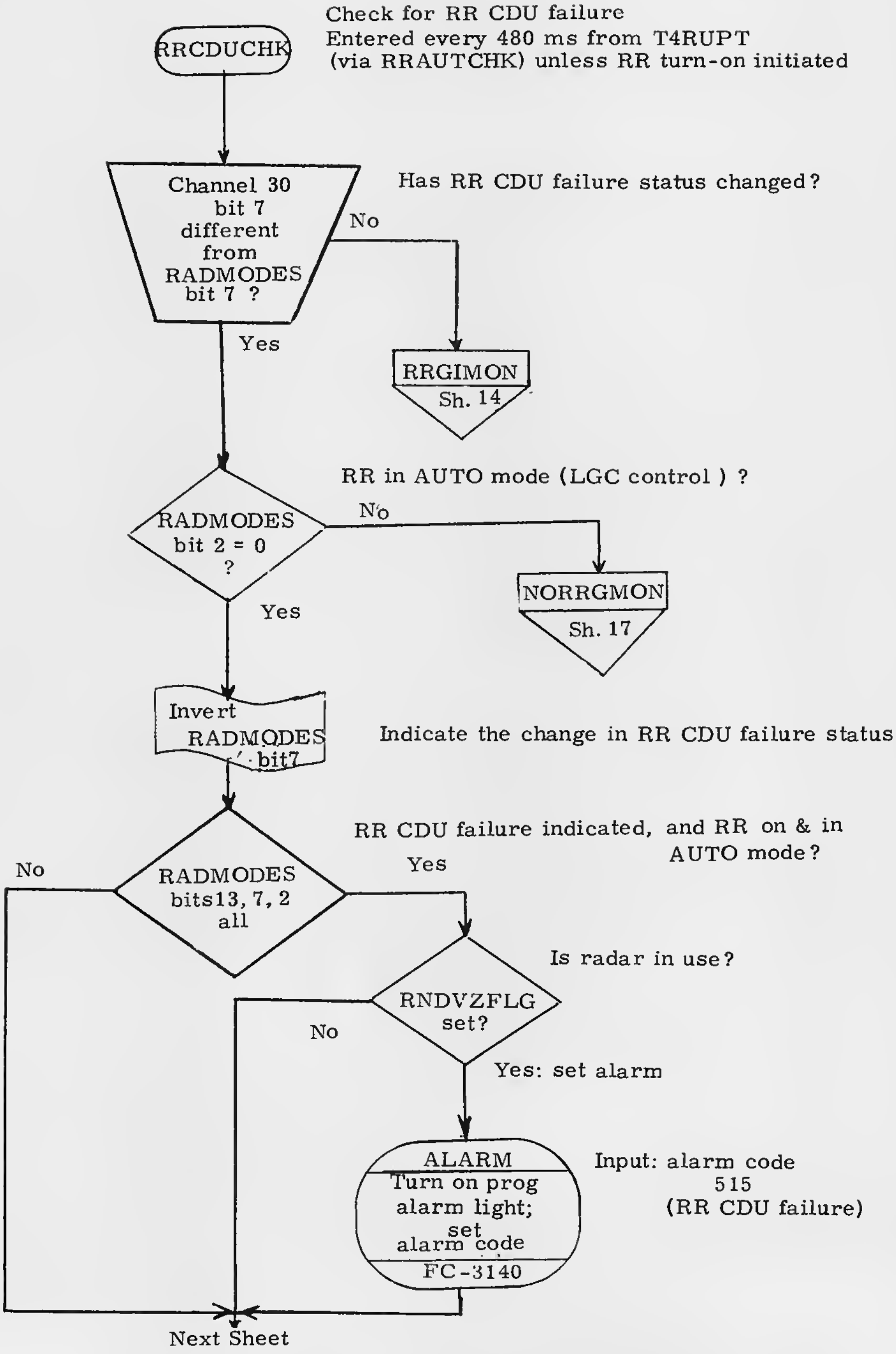
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC 3210

REV 1

SHEET 11 OF 80



Check for RR CDU failure
Entered every 480 ms from T4RUPT
(via RRAUTCHK) unless RR turn-on initiated

Has RR CDU failure status changed?

RR in AUTO mode (LGC control) ?

Indicate the change in RR CDU failure status

RR CDU failure indicated, and RR on & in AUTO mode?

Is radar in use?

Input: alarm code 515 (RR CDU failure)

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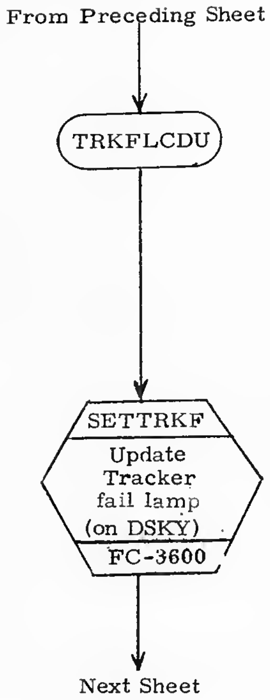
DRAWN L. Adelstone	12/3/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3210
DOCMR			
APPR'D RM Estes	2/5/70	REV 1	SHEET 12 OF 80



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CAMBRIDGE, MASS.

DRAWN 12/7/69
PRGMR 2/5/70
ANALST
DOCMR
APPR'D 2/5/70

APOLLO GUIDANCE AND NAVIGATION

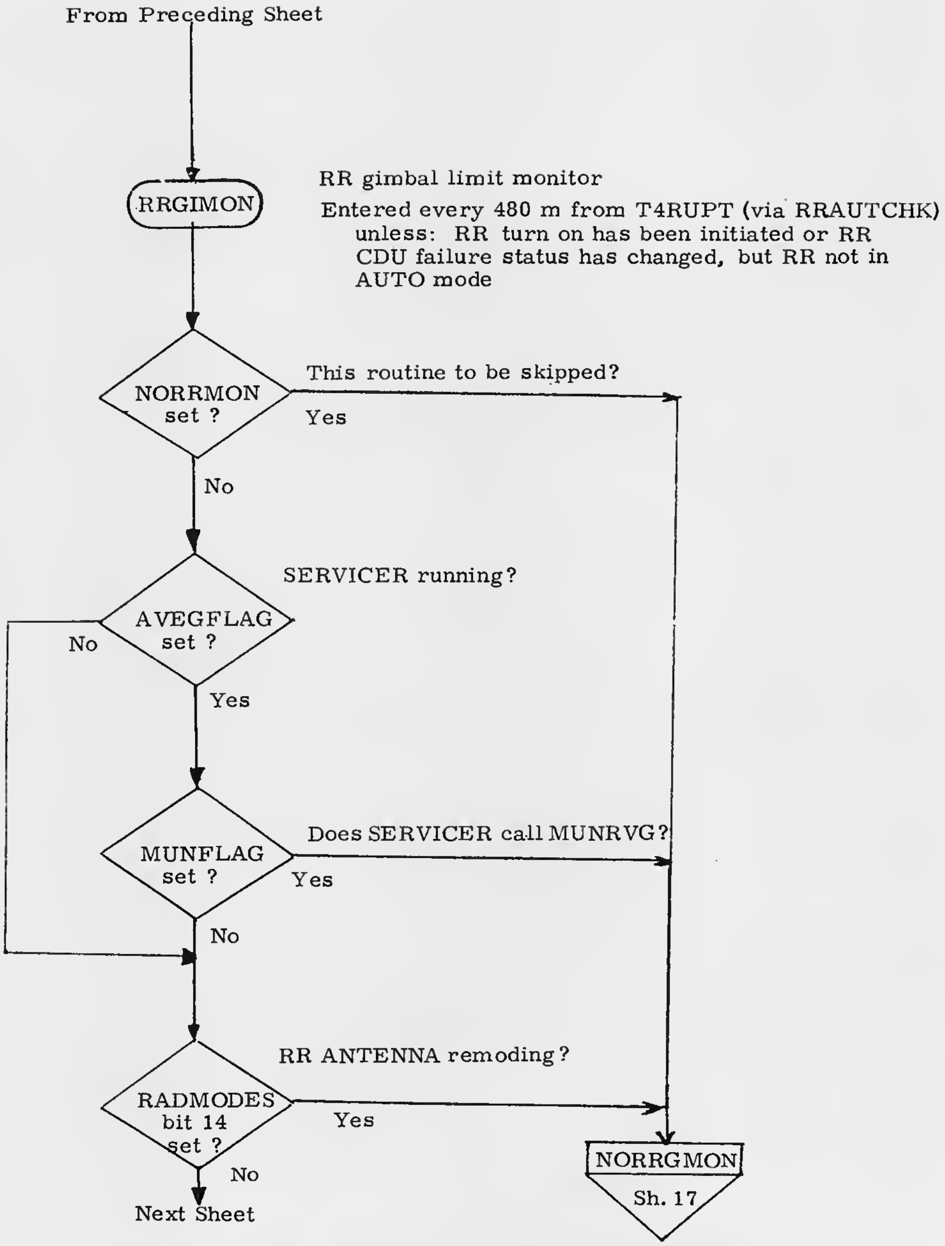
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

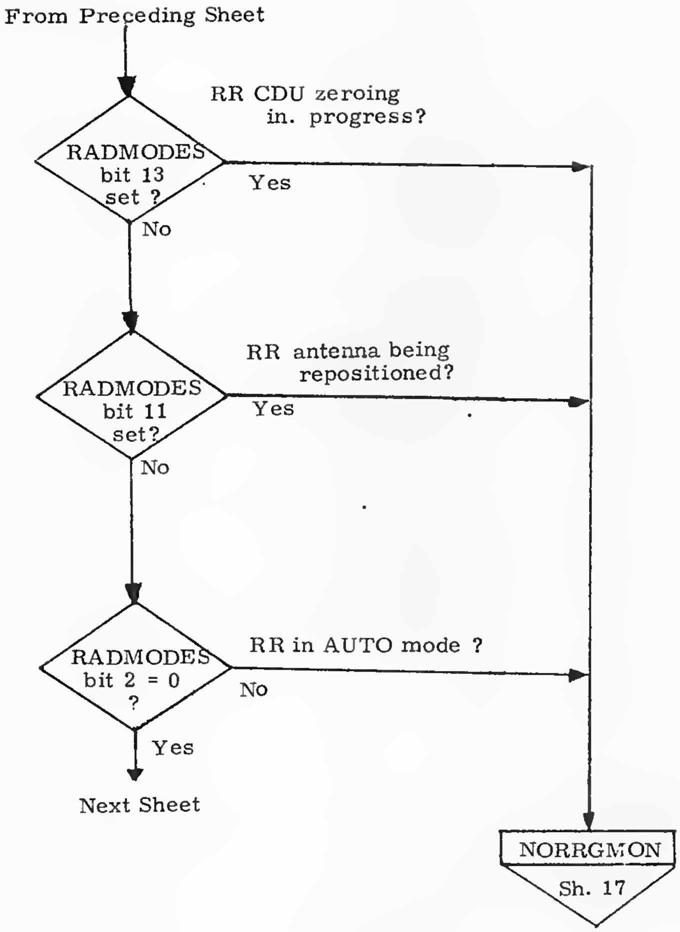
SHEET 13 OF 80



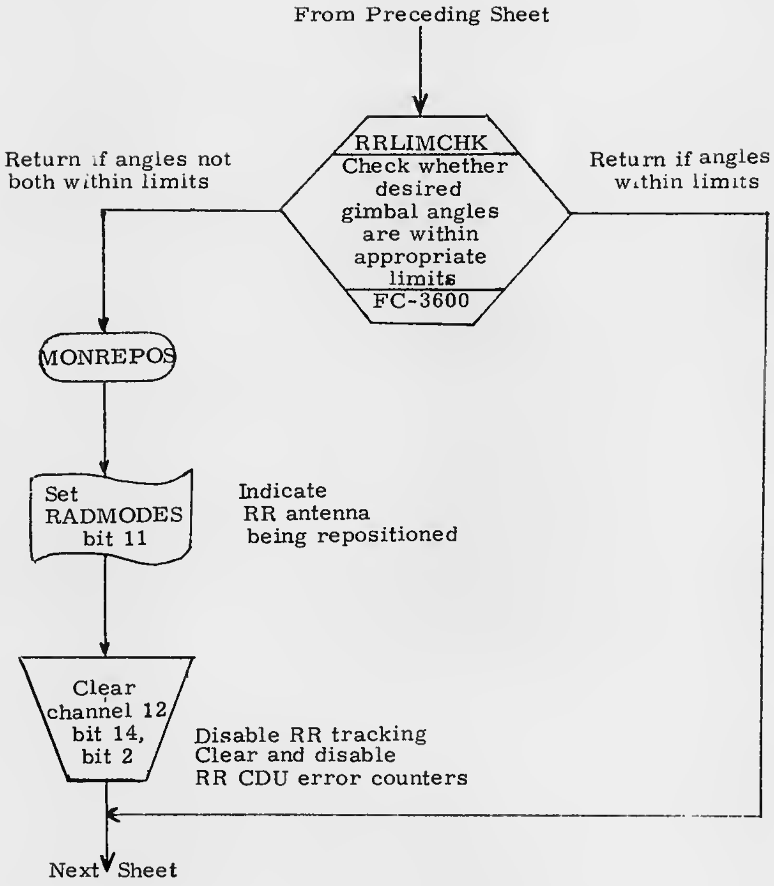
RR gimbal limit monitor

Entered every 480 m from T4RUPT (via RRAUTCHK) unless: RR turn on has been initiated or RR CDU failure status has changed, but RR not in AUTO mode

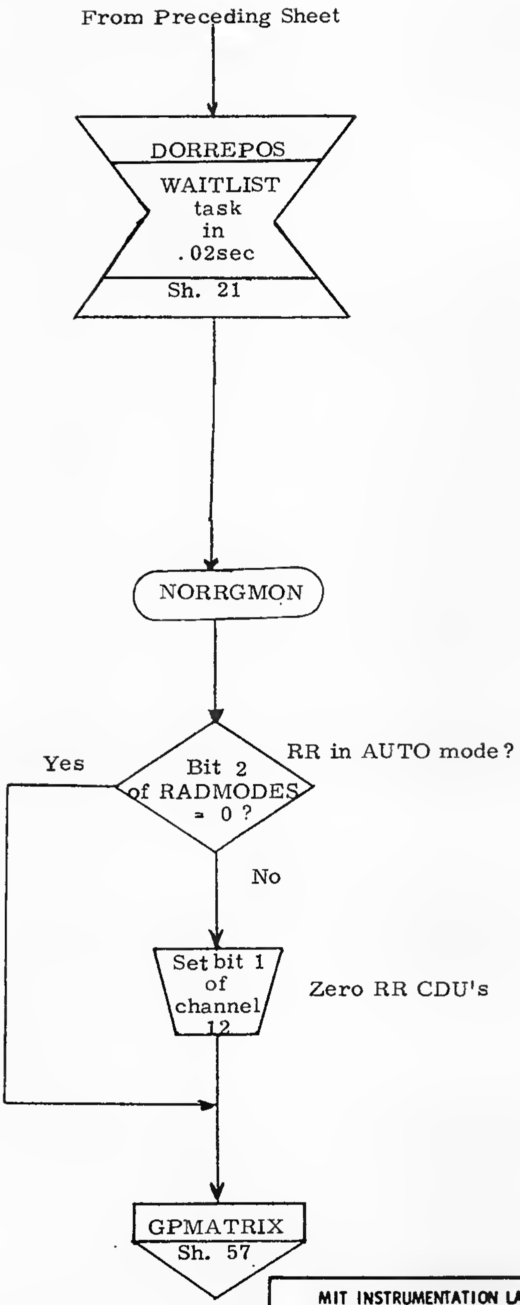
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Quinton	12/3/69	T4RUPT	
PRGMR R. G. West	2/5/70		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3210
DOCMR			
APPR'D R M Estes	2/5/70	REV 1	SHEET 14 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	12/3/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3210
DOCMR			
APPR'D R M Estes	2/5/70	REV 1	SHEET 15 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	12/3/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3210
DOCMR			
APPR'D RM Estes	2/5/70	REV 1	SHEET 16 OF 80



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CAMBRIDGE, MASS.

DRAWN L. Goldstone 12/3/69
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

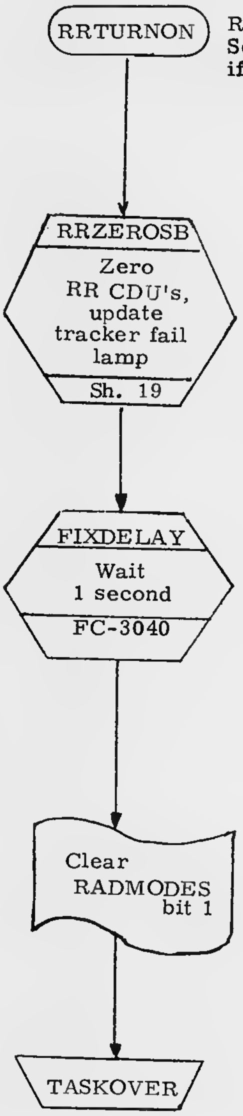
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 17 OF 80



Rendezvous radar turn-on sequence
Set up as a task by RRAUTCHK (Sh. 10)
if RR power on & AUTO mode discrete detected

RR turn-on completed

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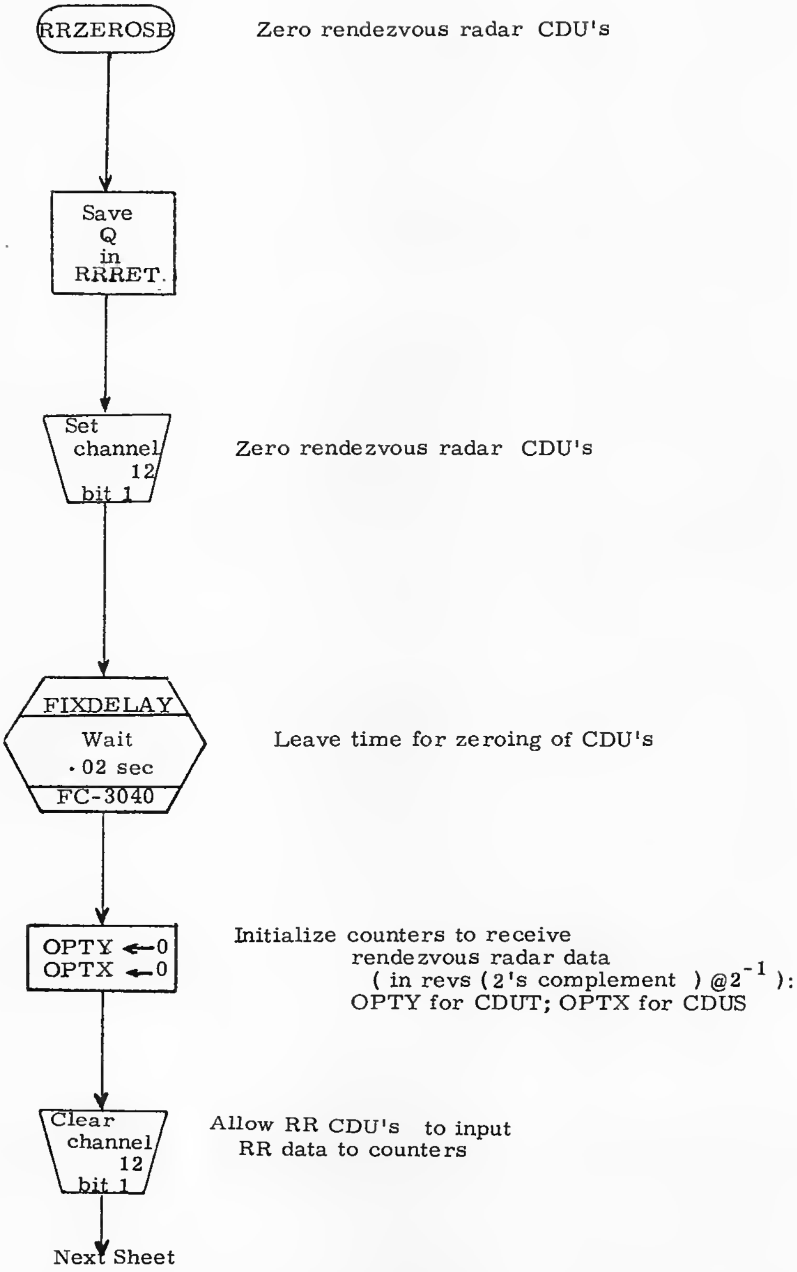
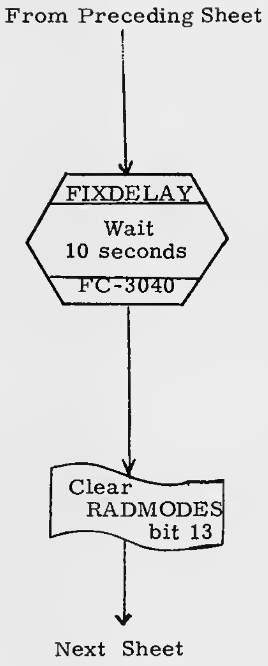
DRAWN 12/3/69
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D R M Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION
T4RUPT
LUMINARY 1D
DOCUMENT NO. FC-3210
REV 1
SHEET 18 OF 80



MIT INSTRUMENTATION LAB **CAMBRIDGE, MASS.**		**APOLLO GUIDANCE AND NAVIGATION**	
DRAWN	12/3/69	T4RUPT	
PRGMR R Gilbert	2/5/70		
ANALST		LUMINARY 1D	**DOCUMENT NO.** FC-3210
DOCMR			
APPR'D RM Estes	2/5/70	**REV** 1	**SHEET** 19 **OF** 80



Wait for counters to
count back up to true data

CDU zeroing process finished

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CAMBRIDGE, MASS.

DRAWN 12/3/69
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D R M Estey 2/5/70

APOLLO GUIDANCE AND NAVIGATION

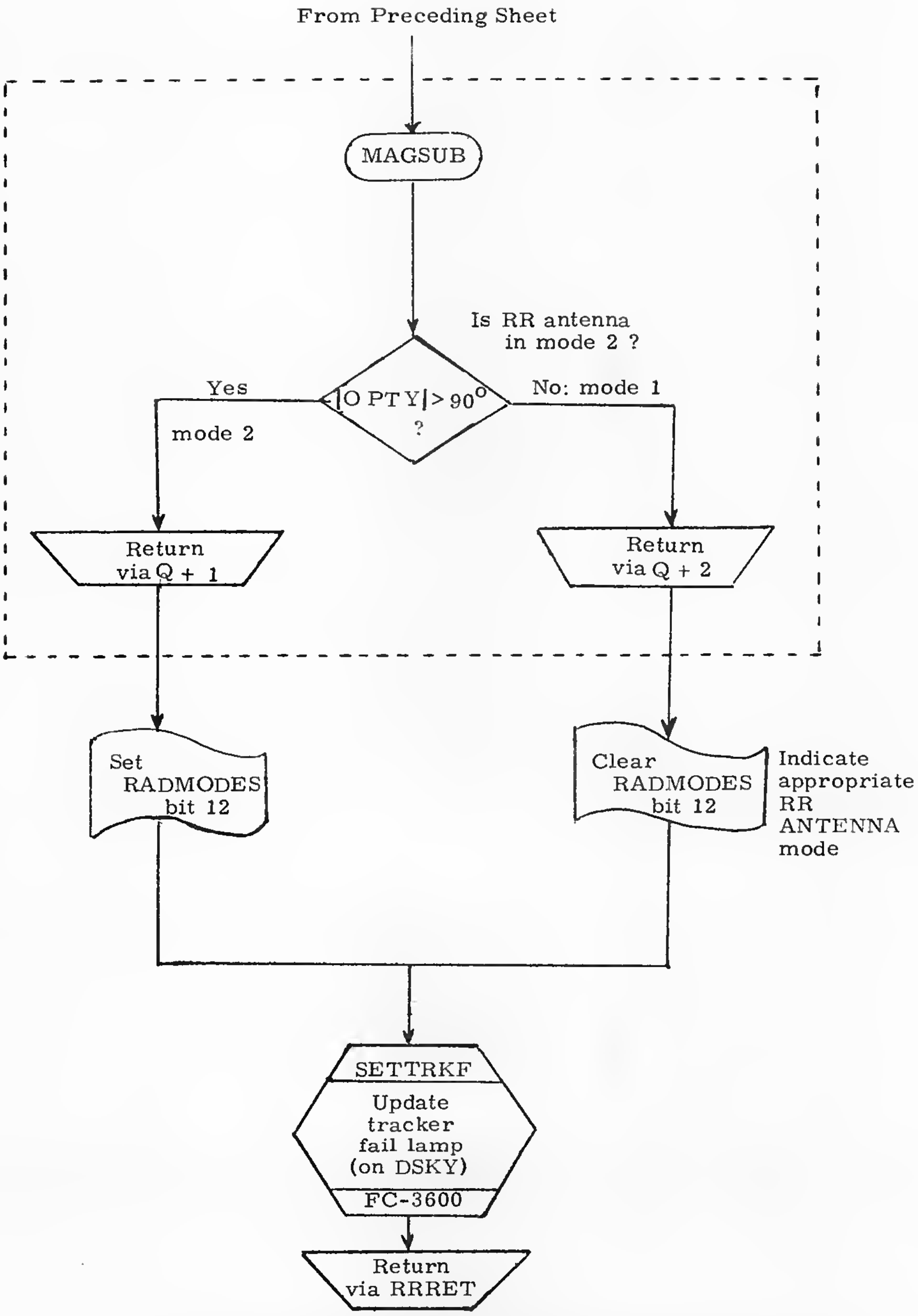
T4RUPT

LUMINARY 1D

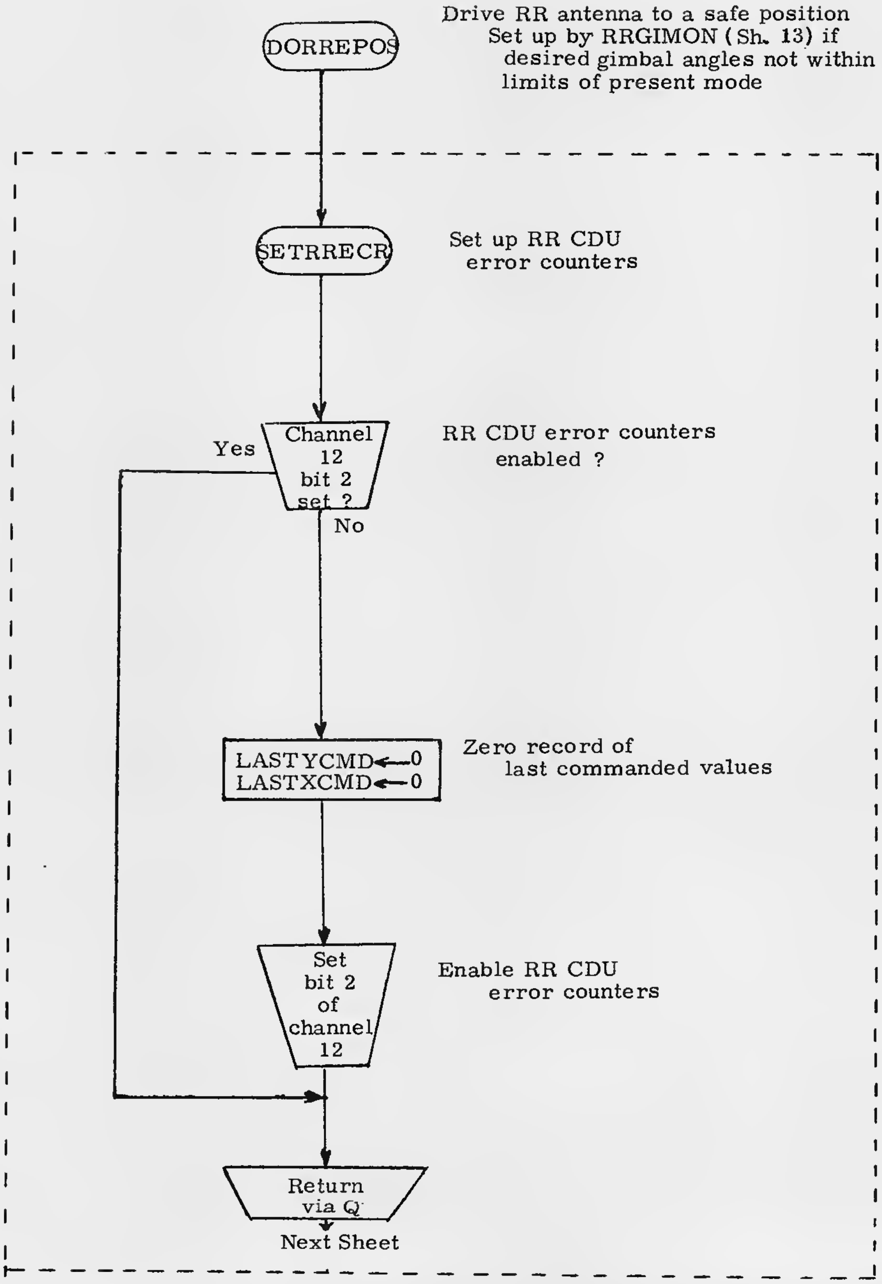
DOCUMENT NO. FC-3210

REV I

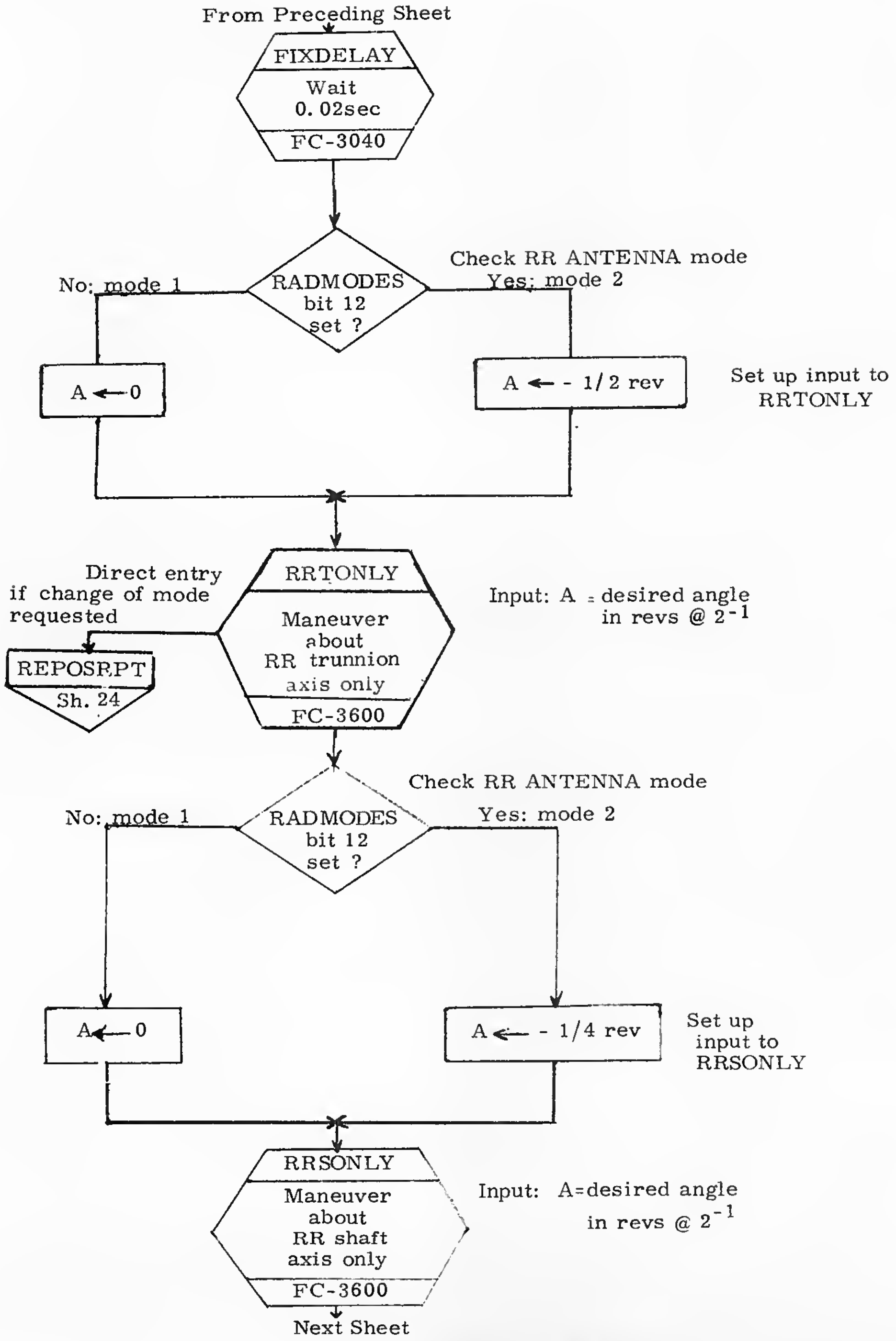
SHEET 20 OF 80



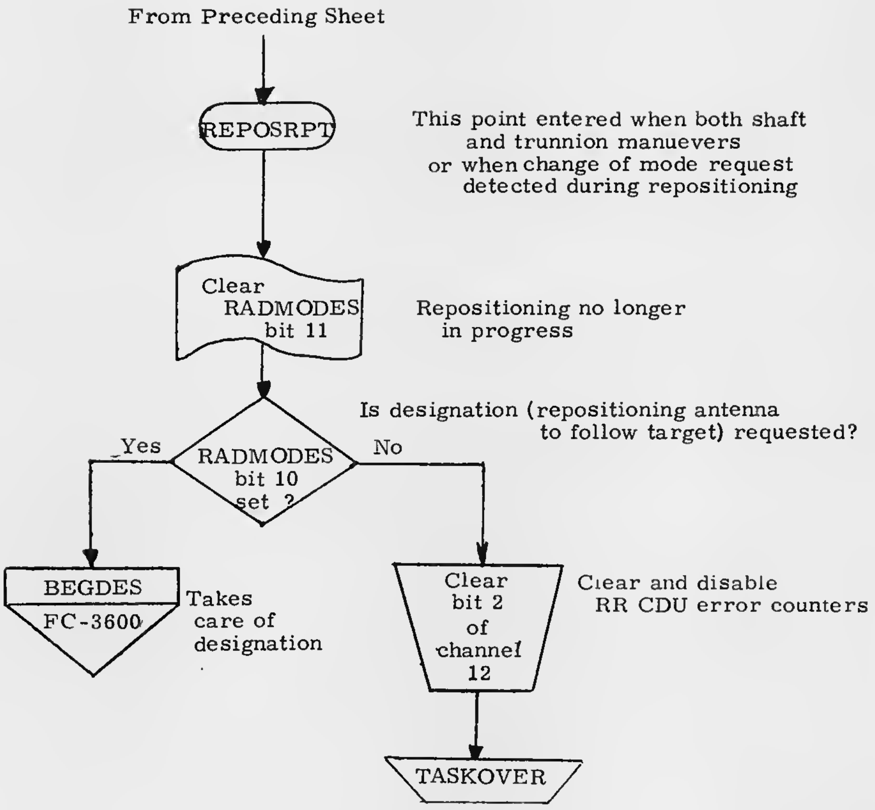
MIT INSTRUMENTATION LAB **CAMBRIDGE, MASS.**		**APOLLO GUIDANCE AND NAVIGATION**
DRAWN	[illegible]	T4RUPT
PRGMR R. Gilbert	2/5/70	
ANALST		LUMINARY 1D
DOCMR		**DOCUMENT NO.** FC-3210
APPR'D R M Estes	2/5/70	**REV** 1 **SHEET** 21 **OF** 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN	12/3/69	T4RUPT
PRGMR R Gilbert	2/5/70	
ANALST		DOCUMENT NO.
DOCMR		LUMINARY 1D FC-3210
APPR'D R M Estes	2/5/70	REV 1 SHEET 22 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN		T4RUPT	
PRGMR	2/5/70	LUMINARY 1D	DOCUMENT NO. FC3210
ANALST			
DOCMR			
APPR'D	2/5/70	REV 1	SHEET 23 OF 80



This point entered when both shaft and trunnion manuevers or when change of mode request detected during repositioning

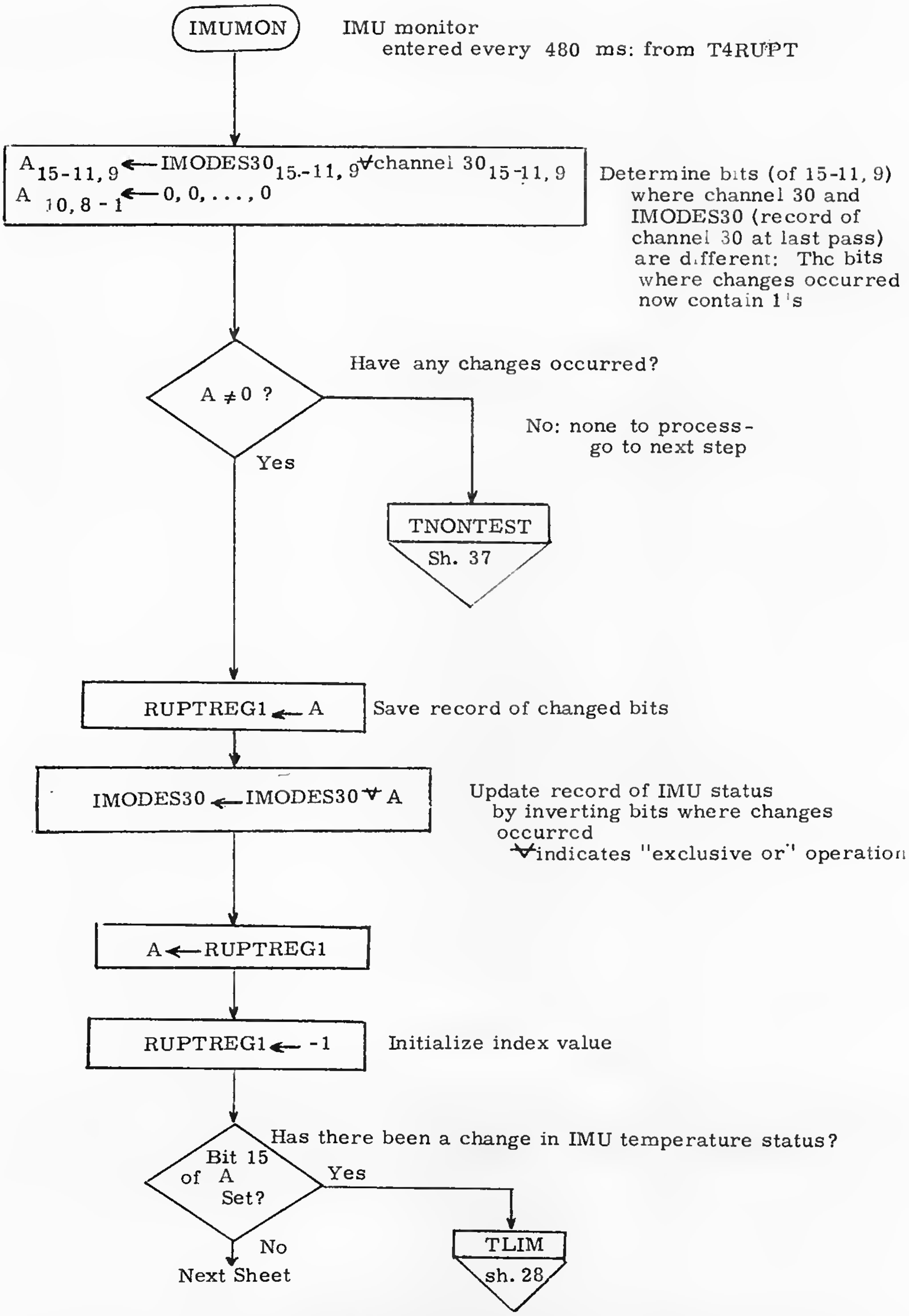
Repositioning no longer in progress

Is designation (repositioning antenna to follow target) requested?

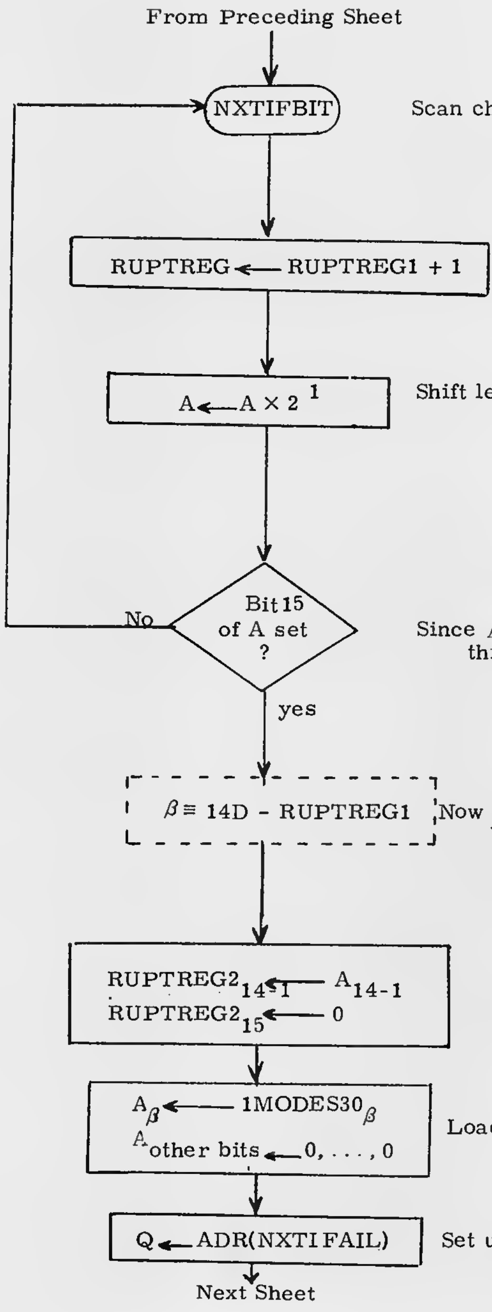
Takes care of designation

Clear and disable RR CDU error counters

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION		
DRAWN L. Adlington	12-5-69	T4RUPT		
PRGMR R.J. Best	2/5/70	LUMINARY 1D	DOCUMENT NO. FC-3310	
ANALST				
DOCMR				
APPR'D R M Estes	2/5/70	REV 1		SHEET 24 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	12/3/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		DOCUMENT NO.
ANALST		LUMINARY1D	FC-3210
DOCMR			
APPR'D R M Estes	2/5/70	REV 1	SHEET 25 OF 80



Scan changed bits

Increment index values

Shift left 1 bit

Since A ≠ +0, must eventually leave this loop

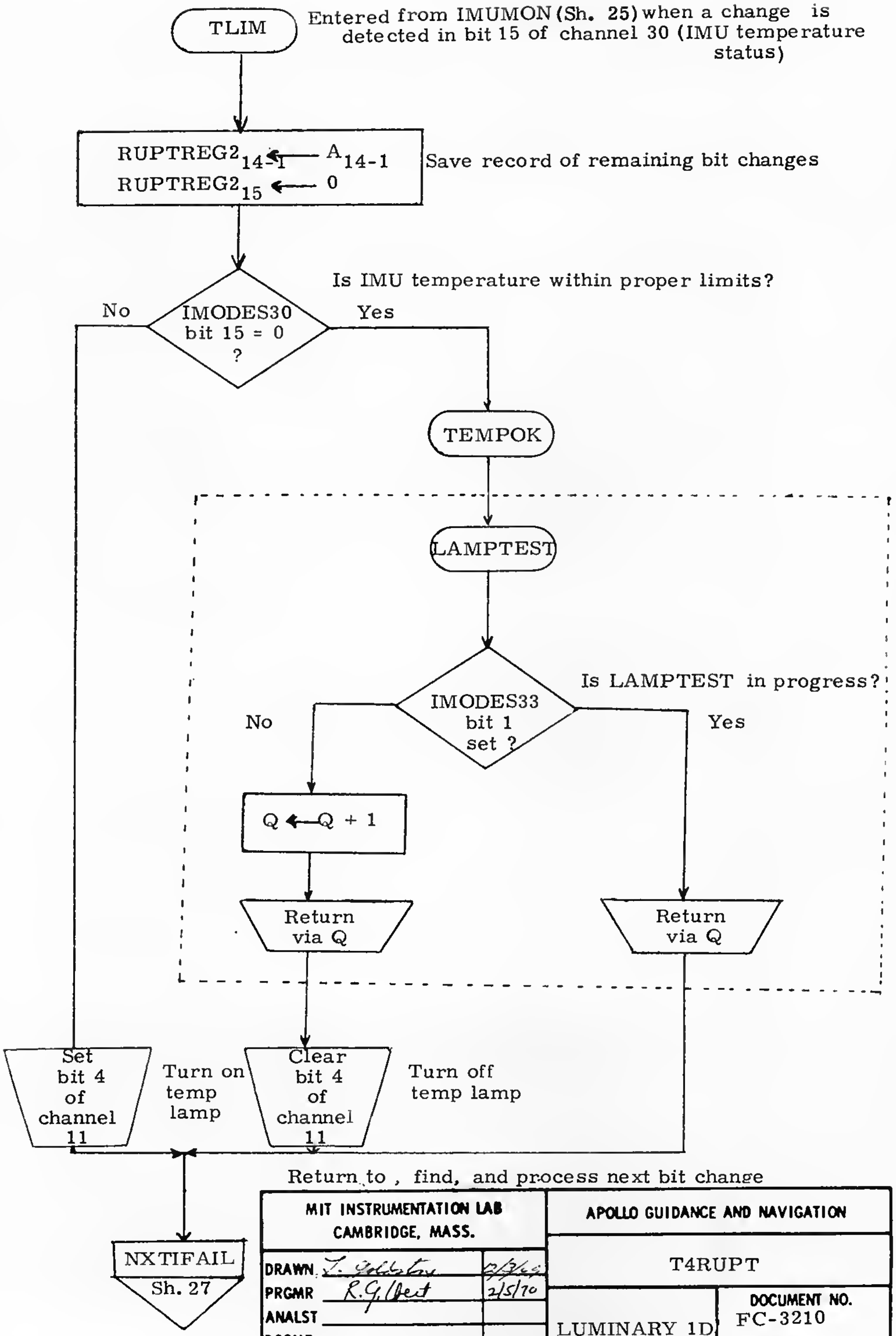
Now RUPTREG1 = 14D - β Where β is the (next) highest bit (of 15 - 11, 9) of channel 30 where change occurred

Save record of remaining bit changes

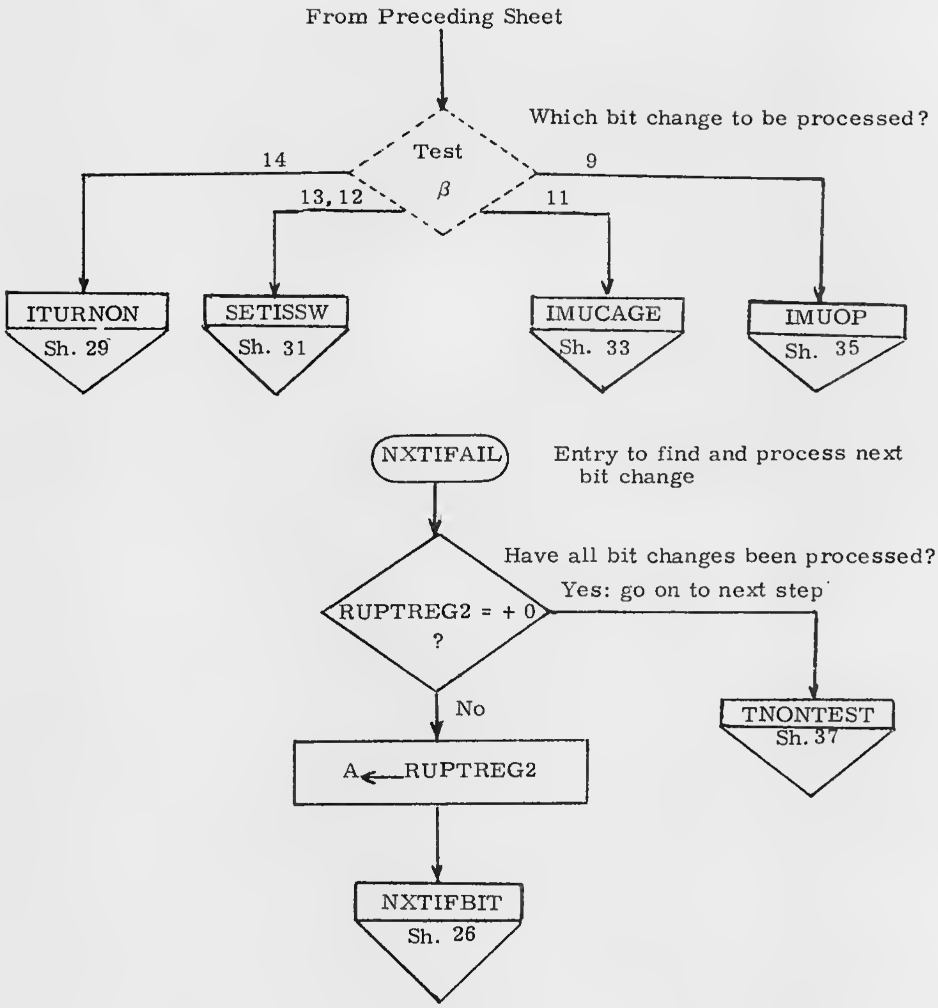
Load status flag for appropriate bit change

Set up appropriate return from SETISSW

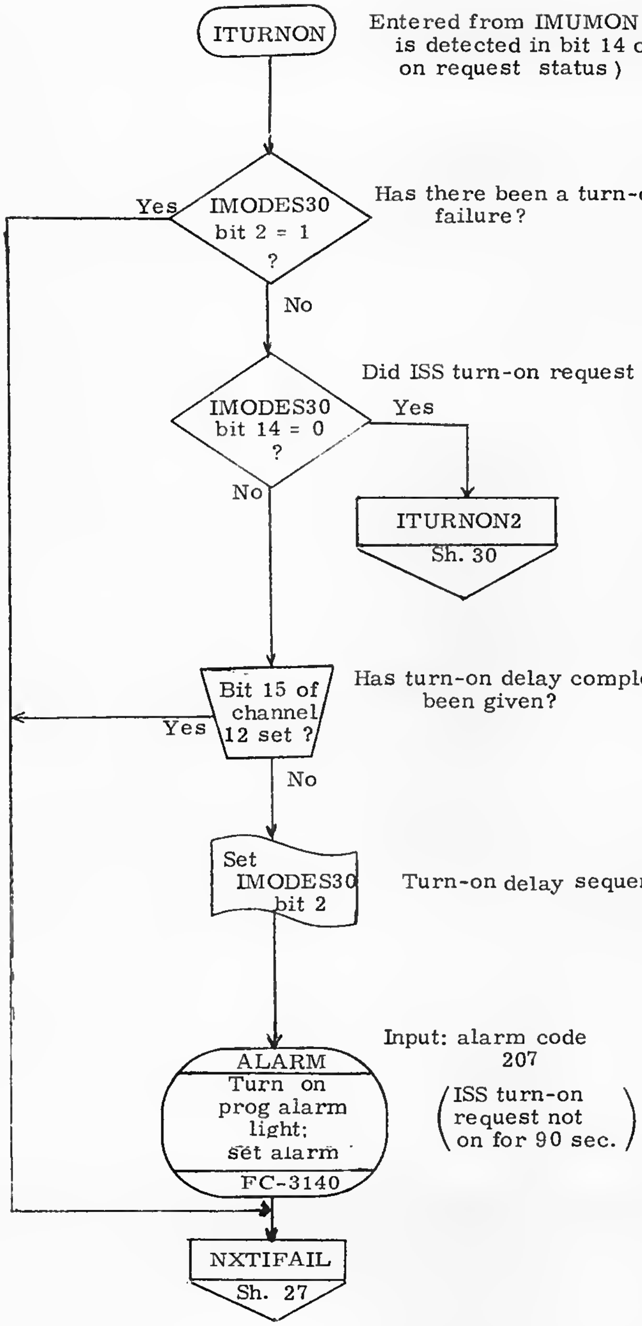
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Wilton	12/3/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		
ANALST			DOCUMENT NO.
DOCMR		LUMINARY 1D	FC-3210
APPR'D R. M. Estes	2/5/70	REV 1	SHEET 26 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN [illegible]	[illegible]	T4RUPT	
PRGMR R.Gilbert	2/5/70	LUMINARY 1D	DOCUMENT NO. FC-3210
ANALST			
DOCMR			
APPR'D RM Cates	2/5/70	REV 1	SHEET 28 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	12/3/69	T4RUPT	
PRGMR R. G. Obert	2/5/70		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3210
DOCMR			
APPR'D RM Estes	2/5/70	REV 1	SHEET 27 OF 80



Entered from IMUMON Sh. 25 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?

Has turn-on delay complete signal been given?

Turn-on delay sequence failure

Input: alarm code 207

(ISS turn-on request not on for 90 sec.)

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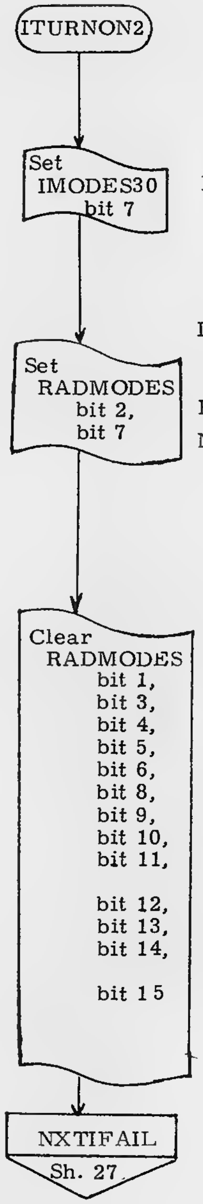
DRAWN [illegible]	12/3/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		DOCUMENT NO.
ANALST			
DOCMR		LUMINARY 1D	FC-3210
APPR'D R M Estes	2/5/70	REV 1	SHEET 29 OF 80



First turn on cycle

Initialize rendezvous radar flags:

RR off or not in AUTO mode
No RR CDU failure

RR not in turn-on
RR data scaled low
RR data good
LR range data good
LR antenna in position 1
LR velocity data good
LR data scaled low
Antenna not designating
Antenna not being repositioned
RR antenna in mode 1
RR CDU's not being zeroed
RR ANTENNA not remoding
Antenna not continuously designating

Return to, find , and process next bit change

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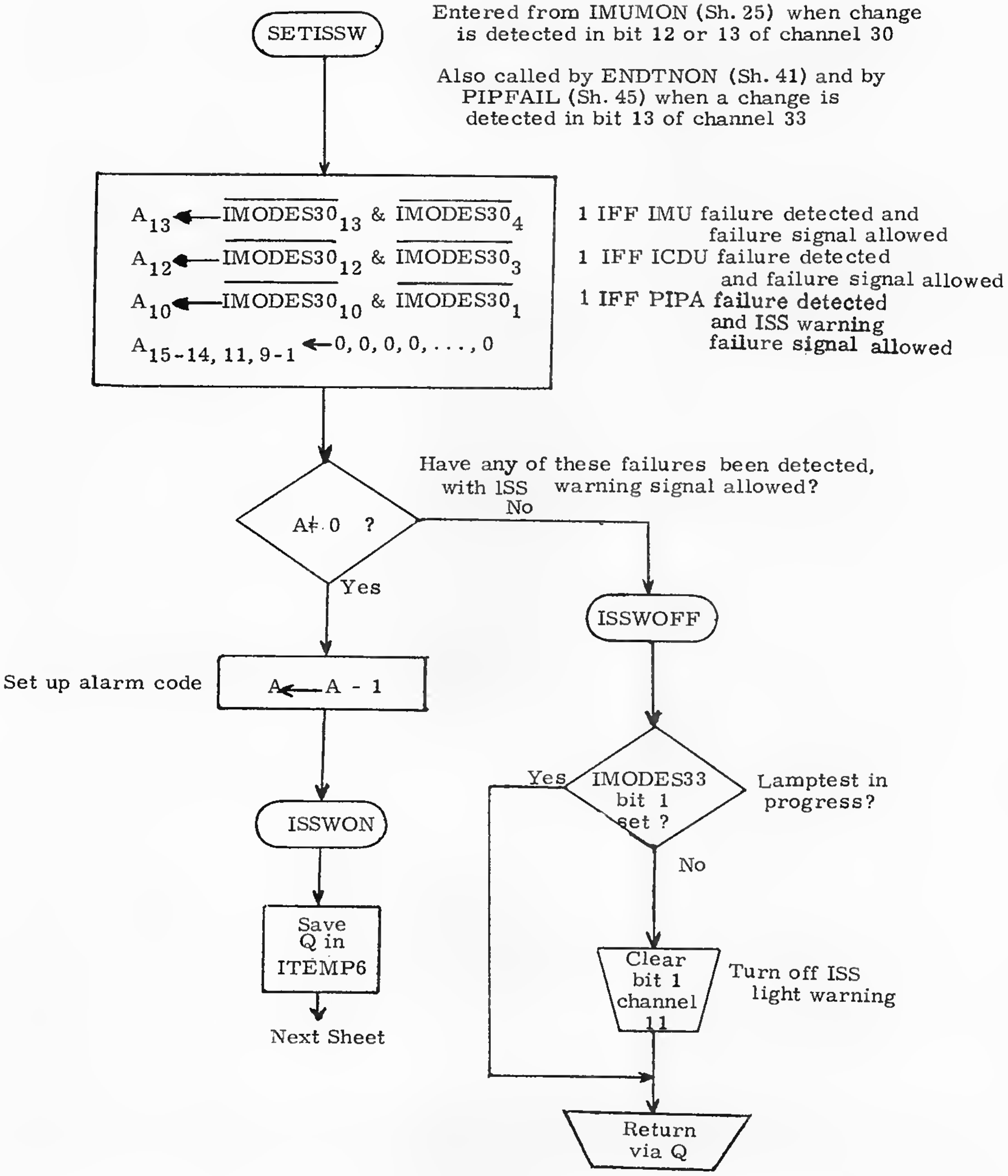
DRAWN [illegible]	[illegible]	T4RUPT	
PRGMR R. G. Abert	2/5/70	LUMINARY 1D	DOCUMENT NO. FC-3210
ANALST			
DOCMR			
APPR'D RM Estes	2/5/70	REV 1	SHEET 30 OF 80



Entered from IMUMON (Sh. 25) when change is detected in bit 12 or 13 of channel 30

Also called by ENDTNON (Sh. 41) and by PIPFAIL (Sh. 45) when a change is detected in bit 13 of channel 33

1 IFF IMU failure detected and failure signal allowed

1 IFF ICDU failure detected and failure signal allowed

1 IFF PIPA failure detected and ISS warning failure signal allowed

Have any of these failures been detected, with ISS warning signal allowed?

Set up alarm code

Lamptest in progress?

Turn off ISS light warning

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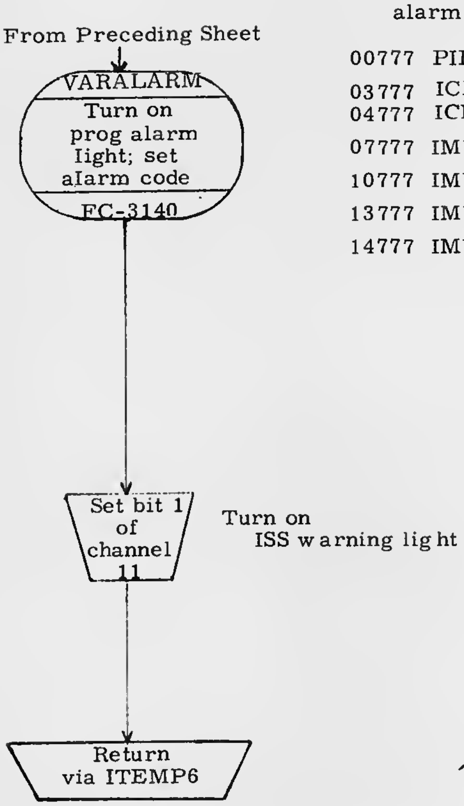
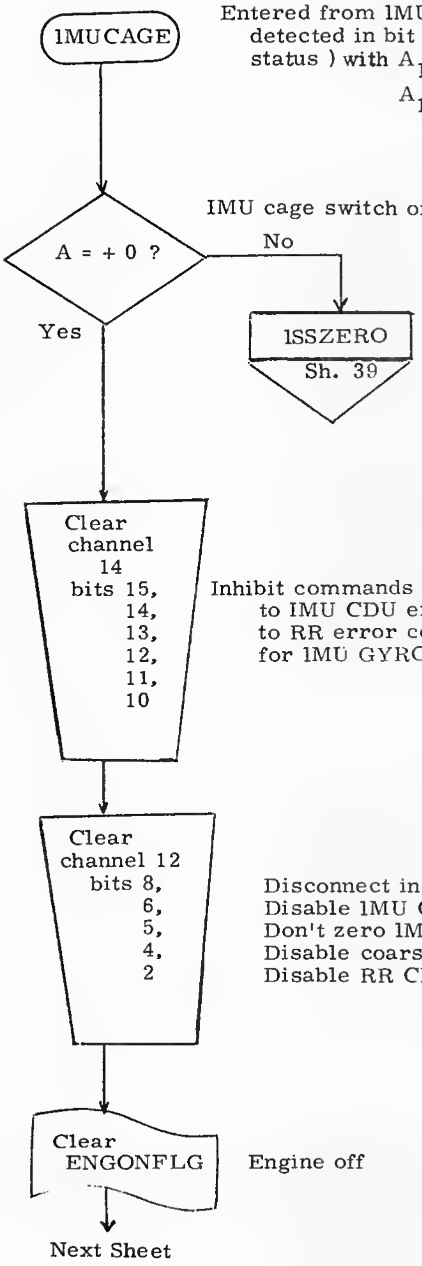
DRAWN	12/3/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3210
DOCMR			
APPR'D RM Estes	2/5/70	REV 1	SHEET 31 OF 80

Input: A = appropriate alarm code:

00777	PIPA failure
03777	ICDU failure
04777	ICDU PIPA failures
07777	IMU failure
10777	IMU, PIPA failures
13777	IMU, ICDU failures
14777	IMU,ICDU,PIPA failures





Entered from 1MUMON (Sh. 25) when a change is detected in bit 11 of channel 30 (1MU cage switch status) with $A_{11} = 1MODES30_{11}$

$A_{15-12, 10-1} = 0, \ldots, 0, 0, \ldots, 0$

IMU cage switch on?

Inhibit commands
to IMU CDU error counters
to RR error counters
for 1MU GYRO TORQUING

Disconnect inertial data display
Disable 1MU CDU error counters
Don't zero 1MU CDU's
Disable coarse alignment of 1MU
Disable RR CDU error counters

Engine off

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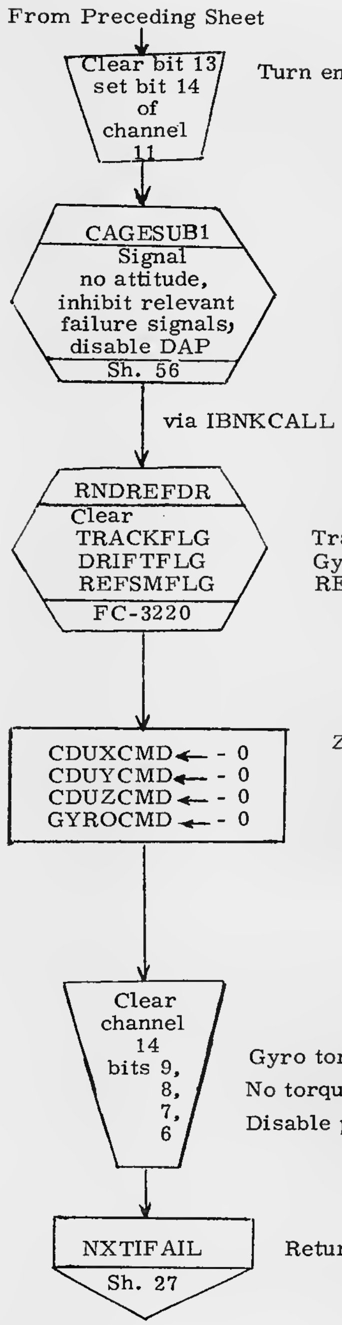
DRAWN	12/3/69	T4RUPT	
PRGMR	2/5/70		DOCUMENT NO.
ANALST			
DOCMR		LUMINARY 1D	FC-3210
APPR'D	2/5/70	REV 1	SHEET 33 OF 80



Turn engine off

Tracking not allowed
Gyro compensation not to be done
REFSMMAT matrix invalid

Zero
IMU CDU command values

gyro torquing command value

Gyro torquing command polarity unspecified
No torque output (no axis)
Disable power supply for torquing pulses

Return to, find, and process next bit change

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APOLLO GUIDANCE AND NAVIGATION

DRAWN 12/3/69
PRGMR R. G. Obert 2/5/70
ANALST
DOCMR
APPR'D R M Estes 2/5/70

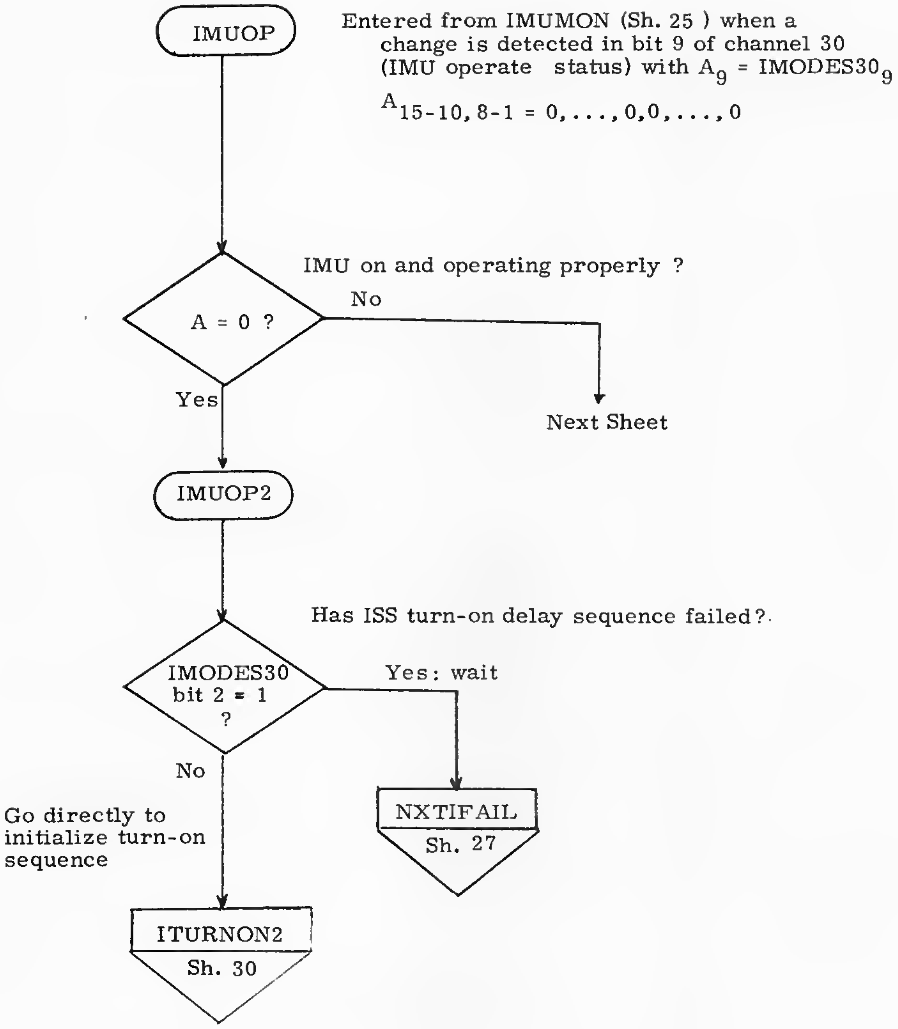
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 34 OF 80



Entered from IMUMON (Sh. 25) when a change is detected in bit 9 of channel 30 (IMU operate status) with A_9 = $IMODES30_9$

$A_{15-10,8-1} = 0,\ldots,0,0,\ldots,0$

IMU on and operating properly ?

Has ISS turn-on delay sequence failed?

Go directly to initialize turn-on sequence

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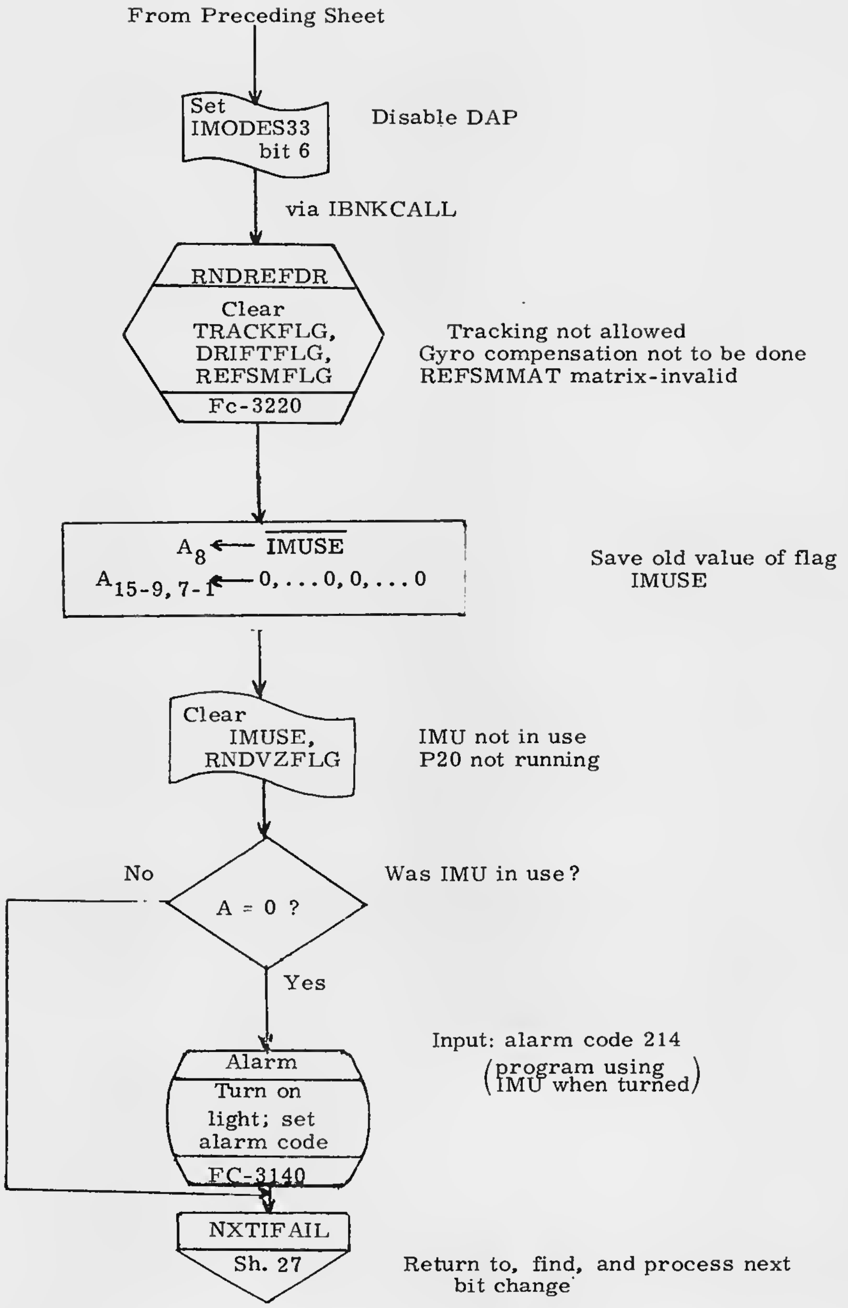
DRAWN L. Johnston	12/3/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3210
DOCMR			
APPR'D RM Estes	2/5/70	REV 1	SHEET 35 OF 80



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DRAWN J. Gilstone [illegible]
PRGMR E. Gilbert 2/5/70
ANALST
DOCMR
APPR'D R M Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

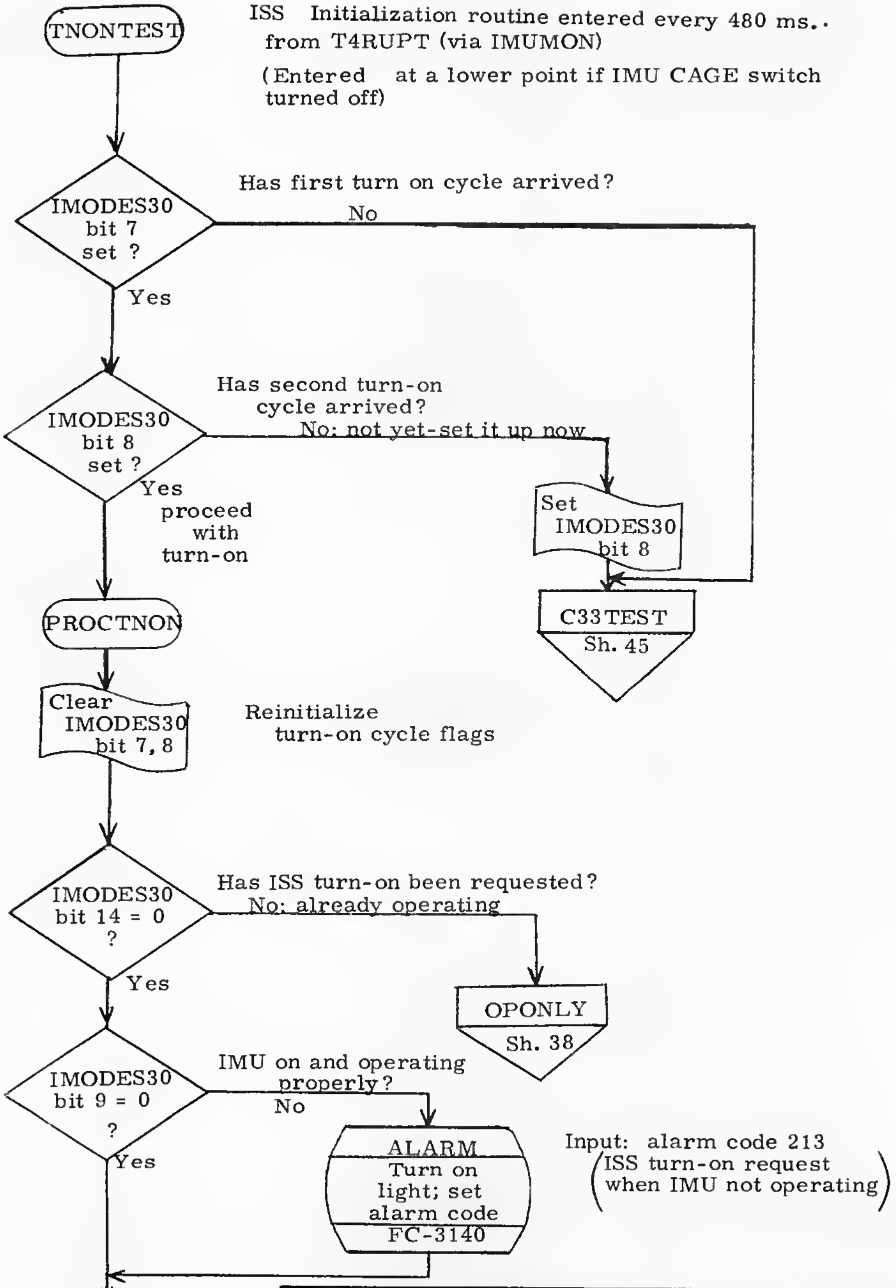
T4RUPT

LUMINARY 1D

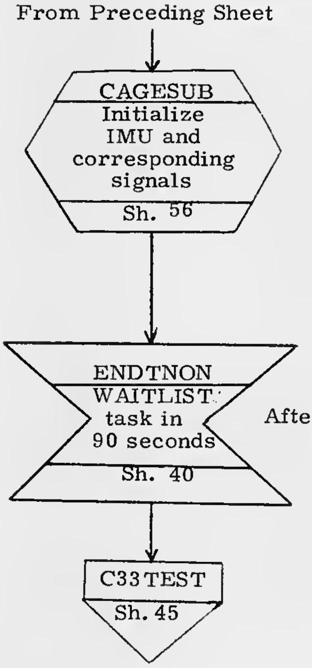
DOCUMENT NO. FC-3210

REV 1

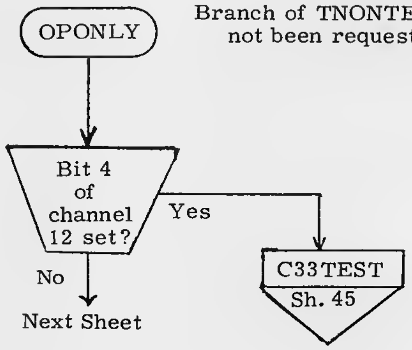
SHEET 36 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	Nov 1969	T4RUPT	
PRGMR R. Gilbert	2/5/70		DOCUMENT NO.
ANALST			
DOCMR		LUMINARY 1D	FC-3210
APPR'D R M Estes	2/5/70	REV 1	SHEET 37 OF 80



After 90 seconds, end turn-on sequence



Branch of TNONTEST entered if ISS turn-on has not been requested (operating only)

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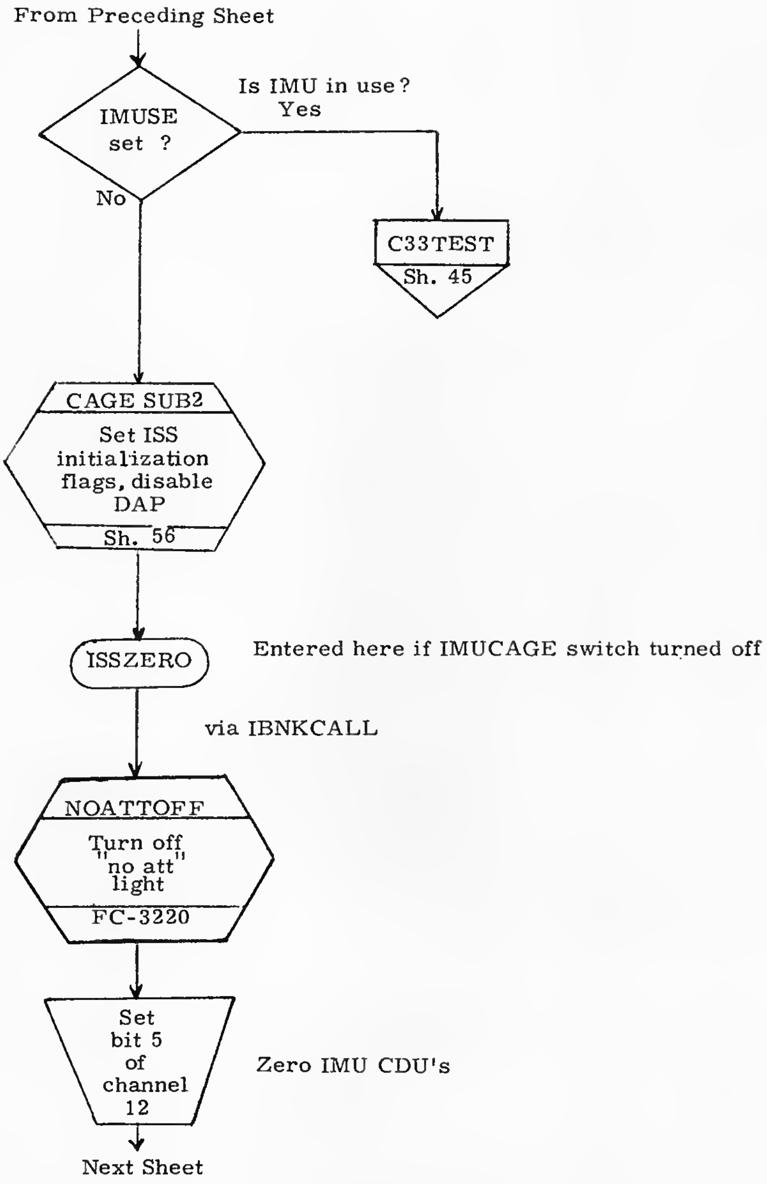
DRAWN	J. Gilston	Nov 1969	T4RUPT	
PRGMR	R.G. Ubert	2/5/70		
ANALST			LUMINARY 1D	DOCUMENT NO. FC-3210
DOCMR				
APPR'D	R.M. Entes	2/5/70	REV 1	SHEET 38 OF 80



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DRAWN L. Appleton 11-18/69
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

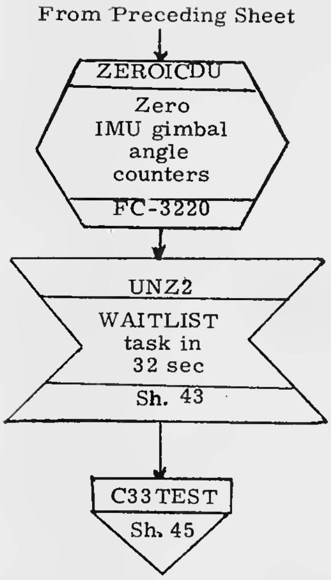
T4RUPT

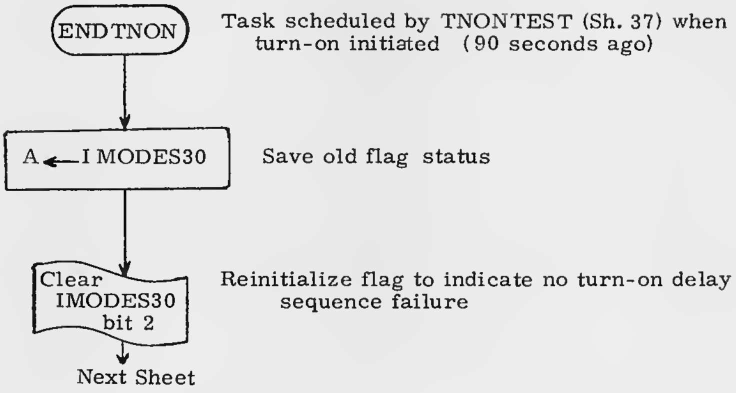
LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 39 OF 80





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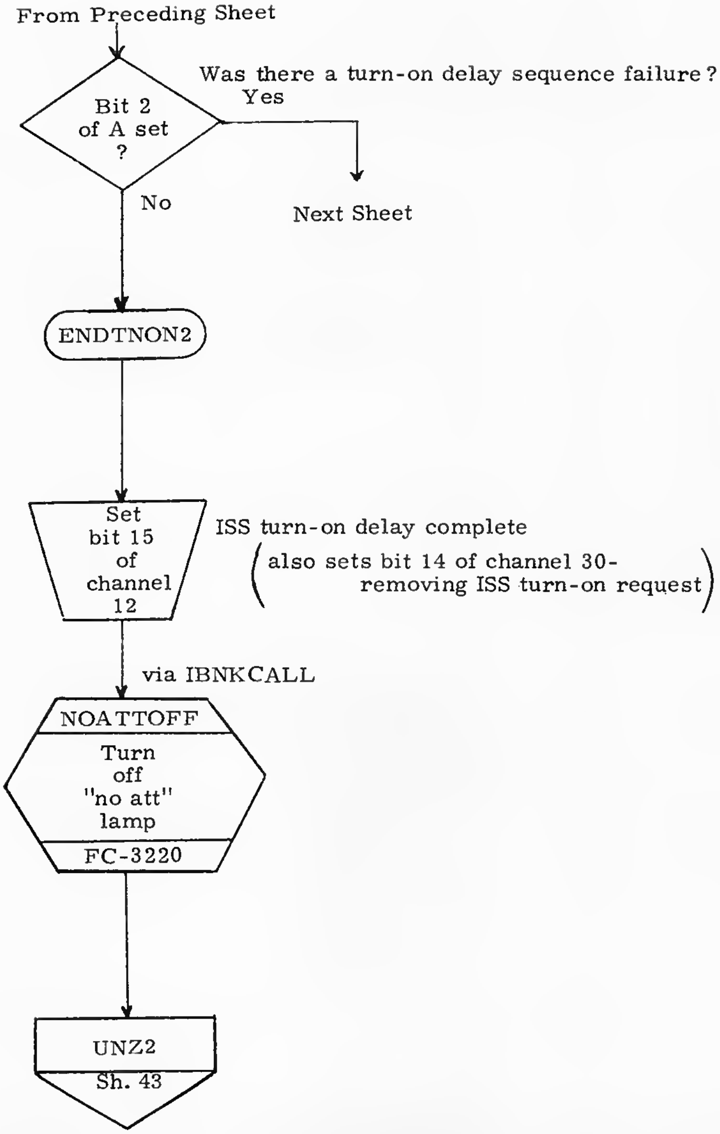
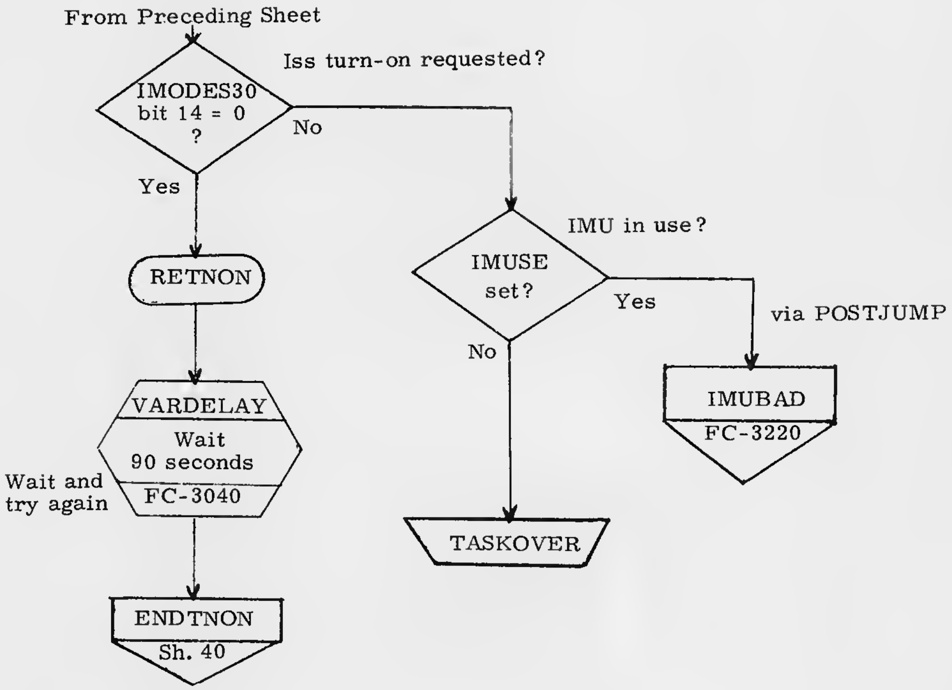
DRAWN Laura Allston	11/18/68	T4RUPT		
PRGMR R. Gilbert	2/5/70	LUMINARY 1D	DOCUMENT NO. FC-3210	
ANALST				
DOCMR				
APPR'D RM Estes	2/5/70	REV 1	SHEET 40 OF 80	



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Gallatone	11/18/69	T4RUPT	
PRGMR R. Gilbert	2/5/70	LUMINARY 1D	DOCUMENT NO. FC-3210
ANALST			
DOCMR			
APPR'D RM Estes	2/5/70	REV 1	SHEET 41 OF 80



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DRAWN Laura Allton [illegible]
PRGMR R. Gilbert 2/8/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

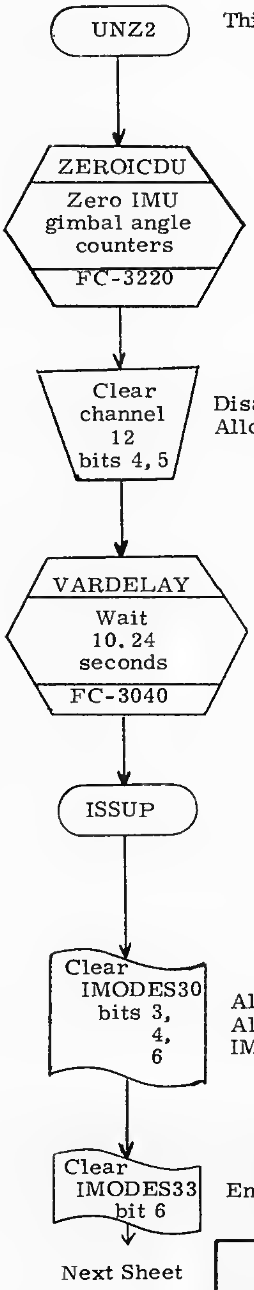
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 42 OF 80



This point also scheduled by OPONLY (Sh. 38)

Disable coarse alignment of IMU
Allow IMU gimbal angle counters to receive true data

Wait for counters to count up

Allow ICDU failure signal
Allow IMU failure signal
IMU not being initialized

Enable DAP

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DRAWN		11/18/67
PRGMR	R. Gilbert	2/5/70
ANALST		
DOCMR		
APPR'D	R M Eaton	2/5/70

APOLLO GUIDANCE AND NAVIGATION

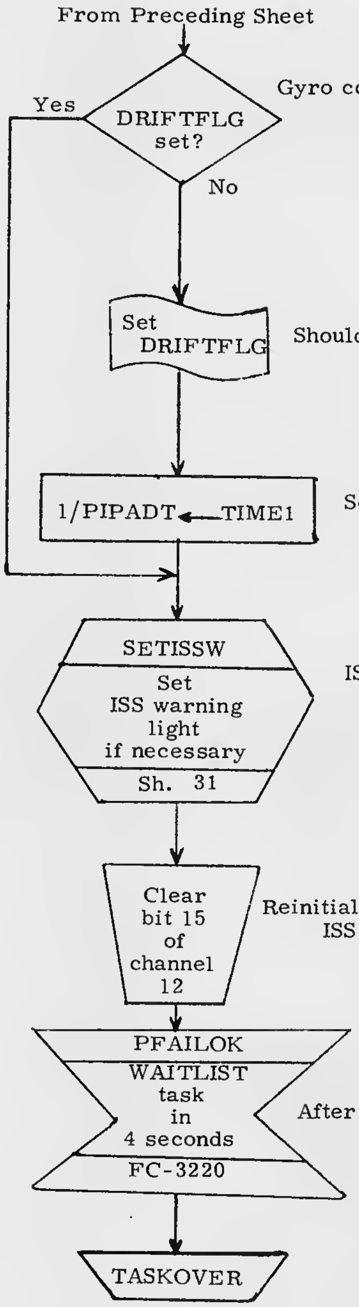
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 43 OF 80



Gyro compensation allowed?

Should be set

Set time of last compensation to the present time in CSEC @ 2^{14}

ISS warning signal may have been inhibited before - now allowed

Reinitialize situation:
ISS turn-on delay sequence not complete

After 4 seconds, PIPA failure program alarm signal will be allowed.

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DRAWN L. Gilstone 11/20/69
PRGMR R. J. Ubert 2/5/70
ANALST
DOCMR
APPR'D R M Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

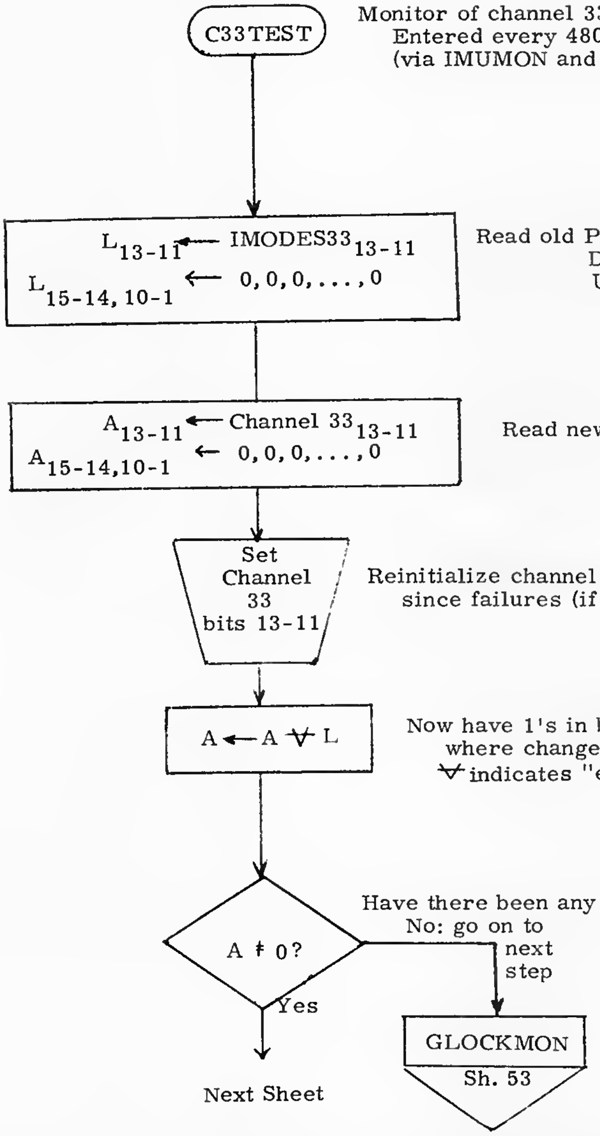
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 44 OF 80



Monitor of channel 33 (bits 11-12)
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's in bits (13-11)
where changes have occurred
$\forall$ indicates "exclusive or" operation

Have there been any changes?
No: go on to next step

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DRAWN Nov 69
PRGMR R. Gilbert 2/5/70
ANALST
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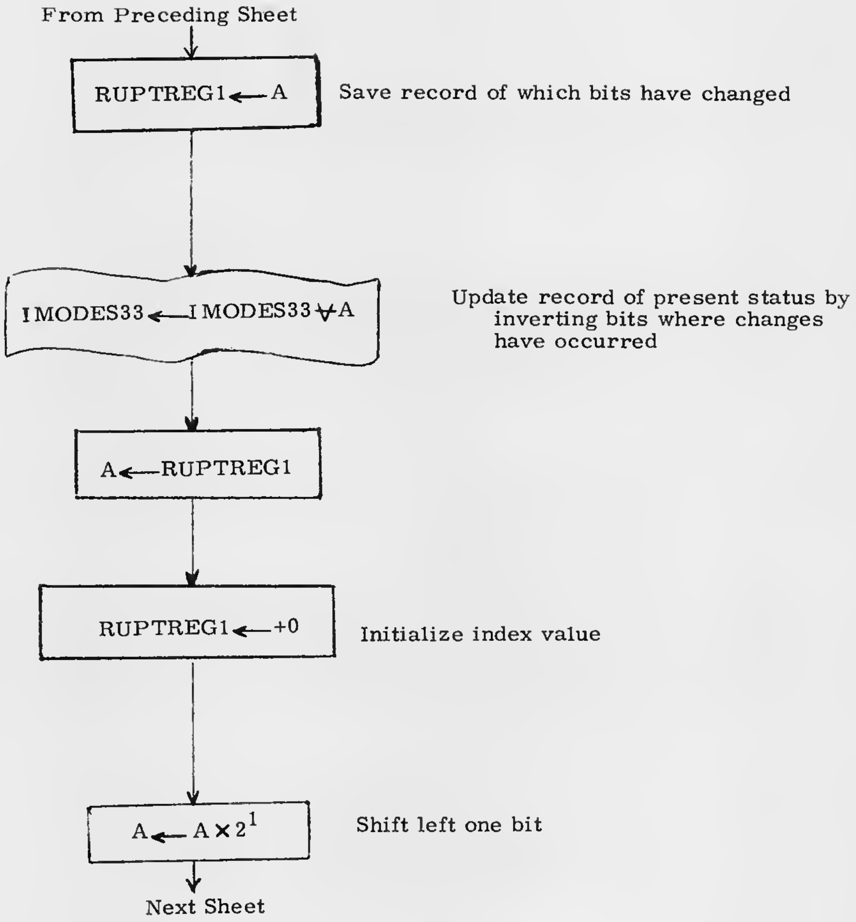
APOLLO GUIDANCE AND NAVIGATION

T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1



Save record of which bits have changed

Update record of present status by inverting bits where changes have occurred

Initialize index value

Shift left one bit

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DRAWN [illegible] [illegible]
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

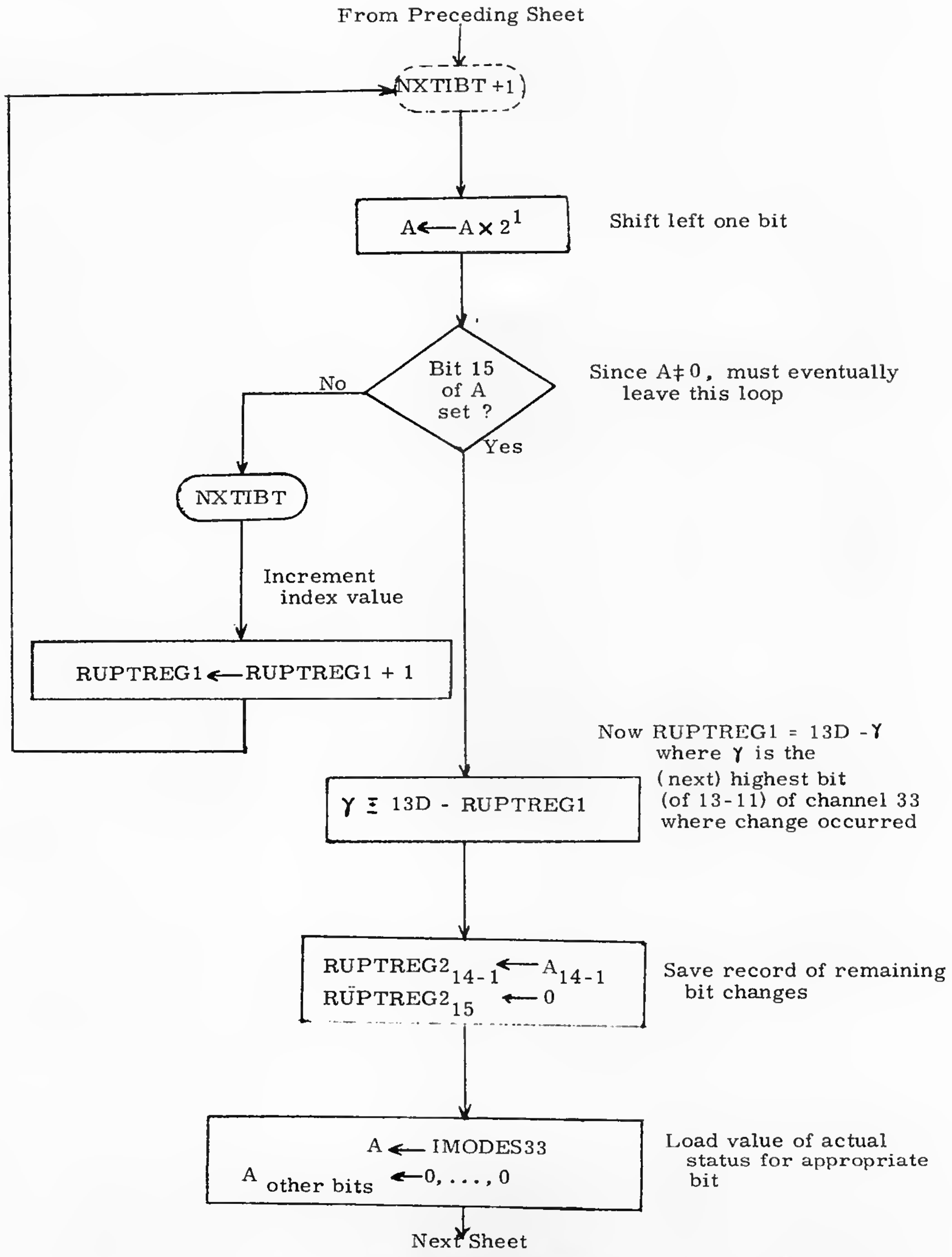
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 46 OF 80



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APOLLO GUIDANCE AND NAVIGATION

T4RUPT

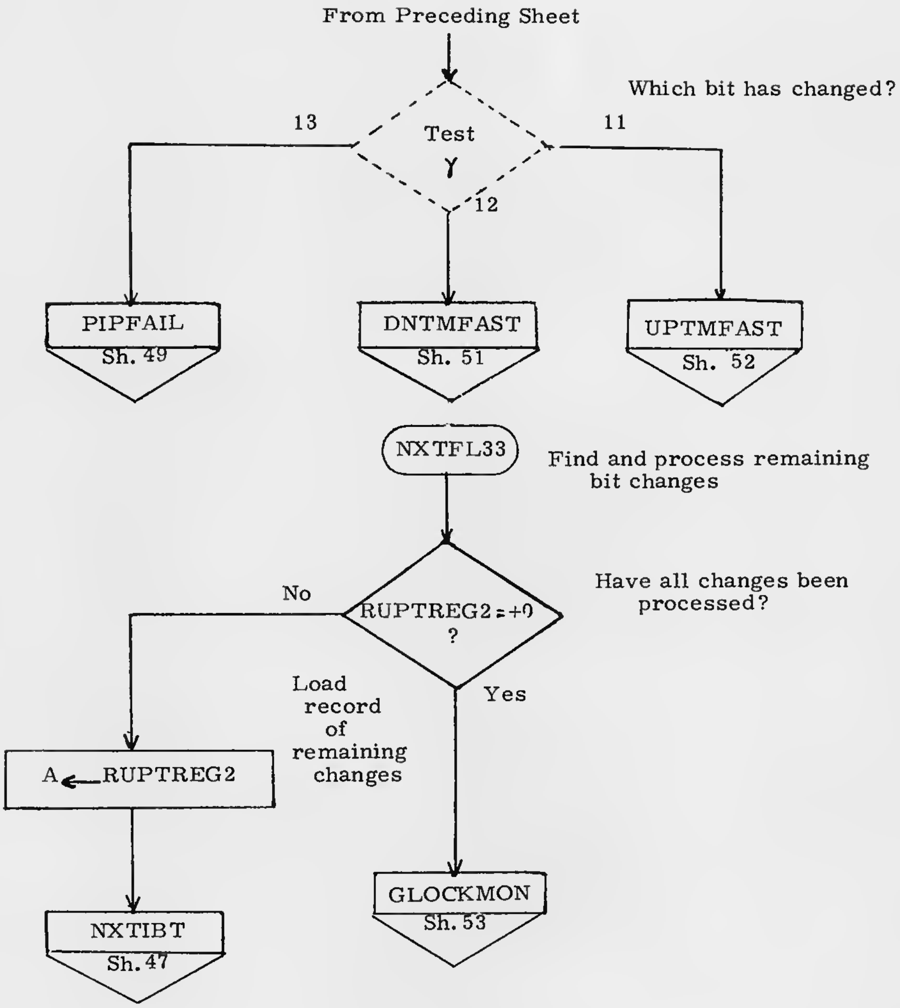
DRAWN J. Gilstone Nov 20 '69
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D R M Erles 2/5/70

LUMINARY 1D

DOCUMENT NO.
FC-3210

REV 1

SHEET 47 OF 80



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DRAWN Goldstone Nov 20 67
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

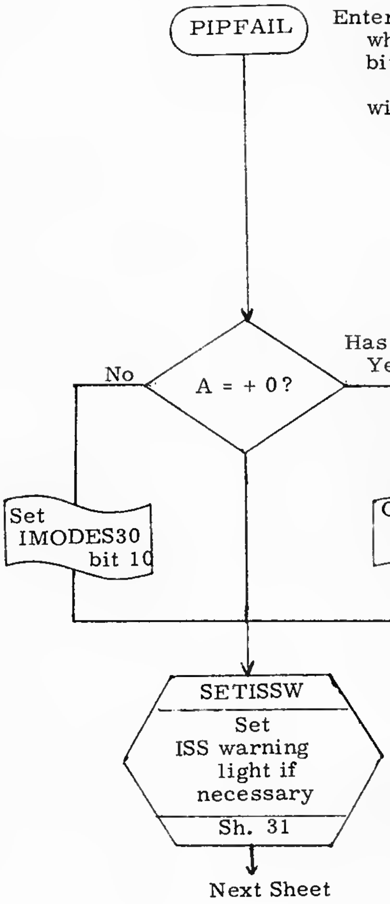
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 48 OF 80



Entered from C33TEST (Sh. 45)
when a change is detected in
bit 13 of channel 33 (PIPA failure status)

with $A_{13} = \text{IMODES33}_{13}$
$A_{15-14,\,12-1} = 0, 0, 0, \ldots, 0$

Has PIPA failure occurred?

Update other PIPA
failure flag
appropriately

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DRAWN 12/4/69
PRGMR 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

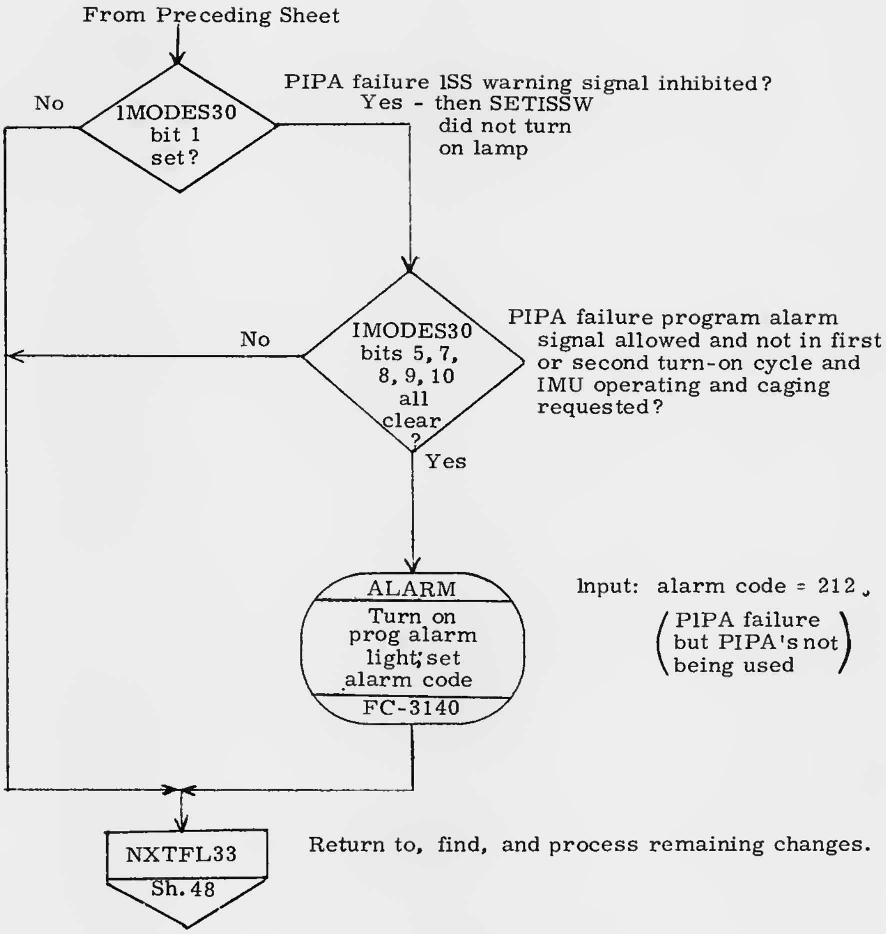
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 49 OF 80



PIPA failure ISS warning signal inhibited?
Yes - then SETISSW 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?

Input: alarm code = 212
(PIPA failure but PIPA's not being used)

Return to, find, and process remaining changes.

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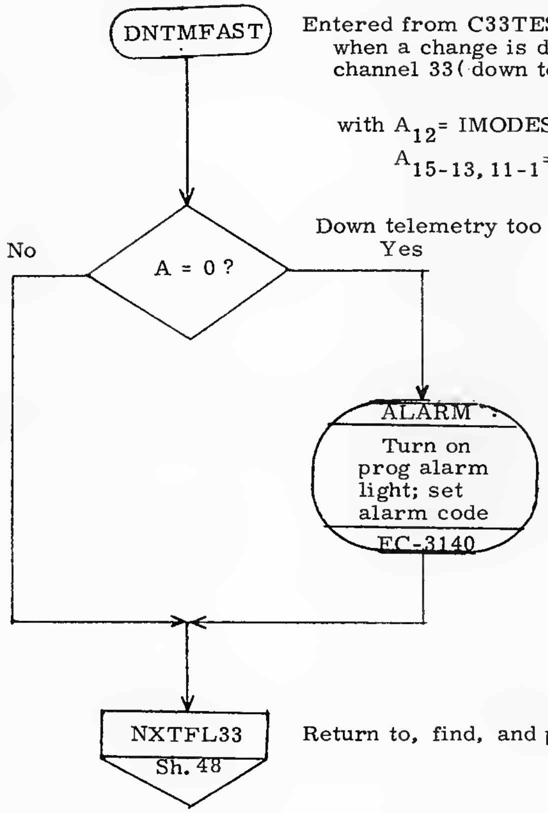
DRAWN J. Golistov	12/4/69	T4RUPT	
PRGMR R. Gilbert	2/5/70		
ANALST			DOCUMENT NO.
DOCMR		LUMINARY 1D	FC-3210
APPR'D RM Estes	2/5/70	REV 1	SHEET 50 OF 80



Entered from C33TEST (Sh. 45) when a change is detected in bit 12 of channel 33 (down telemetry speed status)

with $A_{12} = \text{IMODES33}_{12}$

$A_{15-13,\,11-1} = 0, \ldots, 0, 0, \ldots, 0$

Down telemetry too fast?

Input: alarm code = 1105 (downlink too fast)

Return to, find, and process remaining changes

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DRAWN L. Goldston 11/21/69
PRGMR R. Gilbert 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

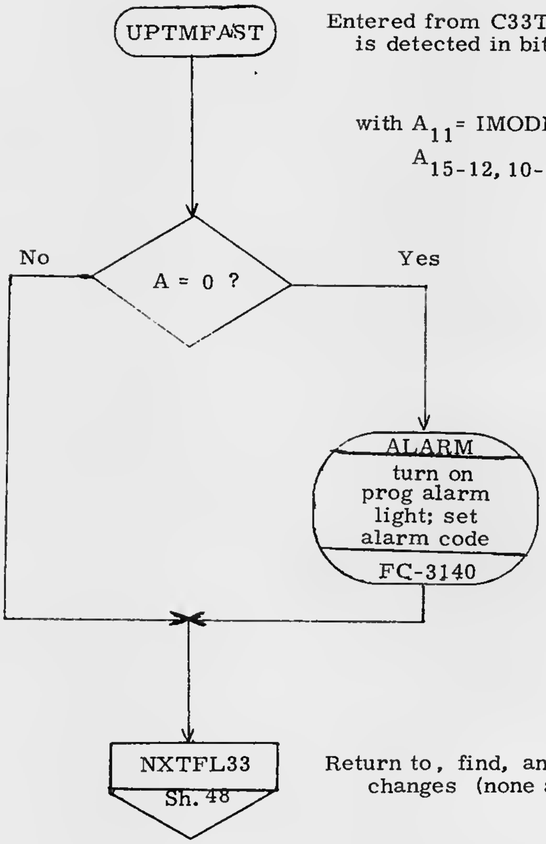
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 51 OF 80



Entered from C33TEST (Sh. 45) when a change is detected in bit 11 of channel 33 (up telemetry speed status)

with $A_{11} = \text{IMODES33}_{11}$

$A_{15-12, 10-1} = 0, \ldots, 0, 0 \ldots, 0$

Input: alarm code = 1106 (uplink too fast)

Return to, find, and process remaining changes (none at this point)

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DRAWN L. Vollstine 12/4/69
PRGMR R.G. Ubert 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

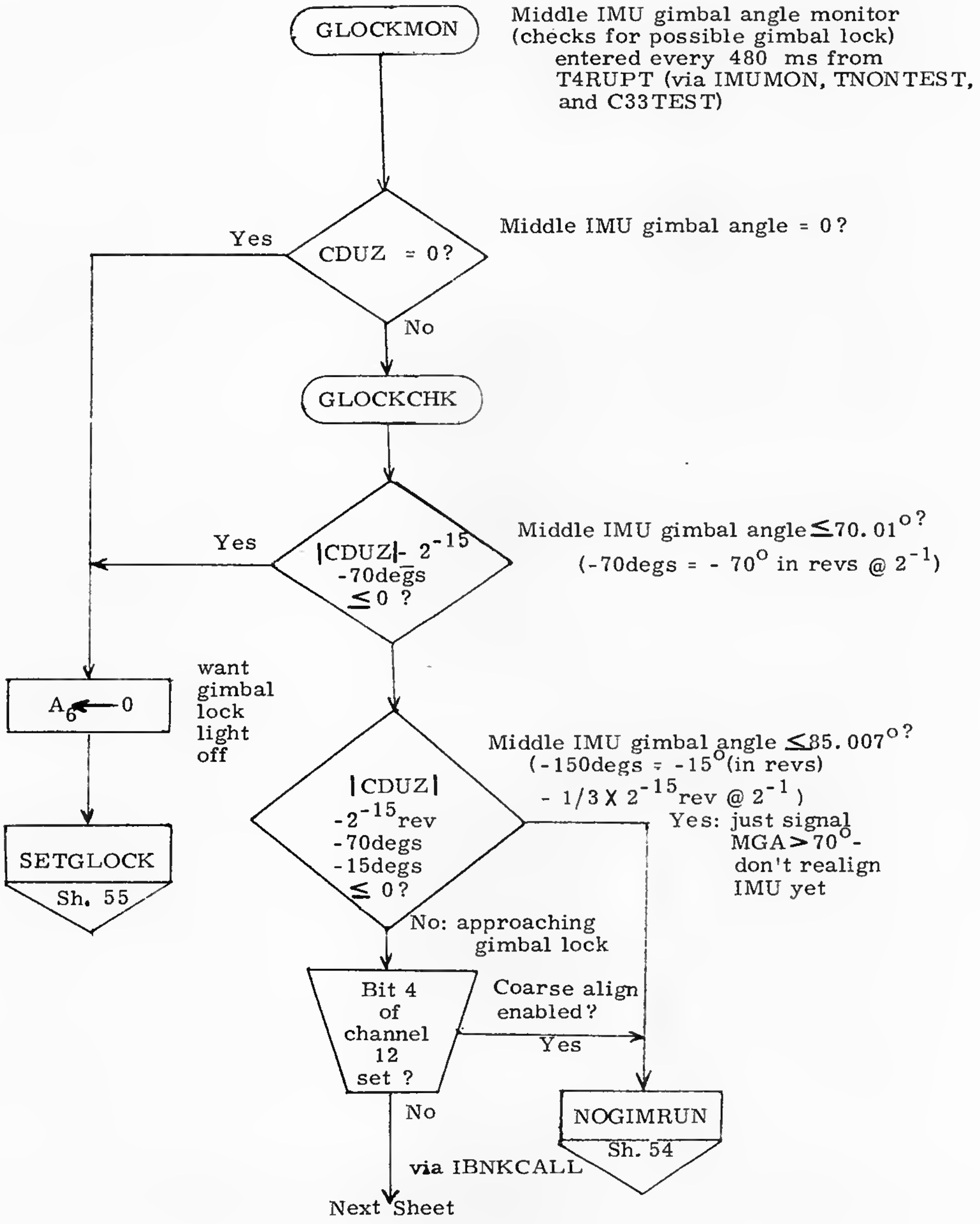
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 52 OF 80



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DRAWN 12/4/69
PRGMR 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

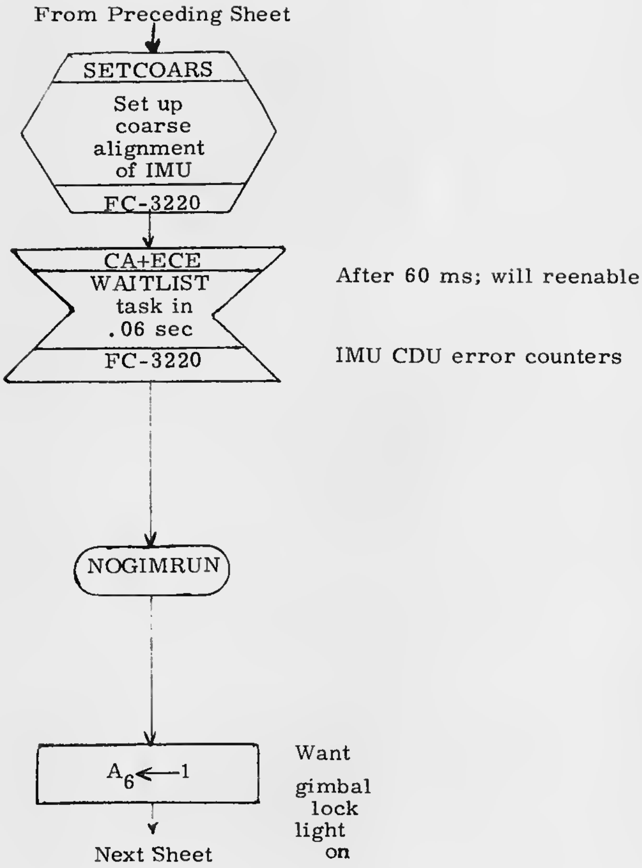
T4RUPT

LUMINARY 1D

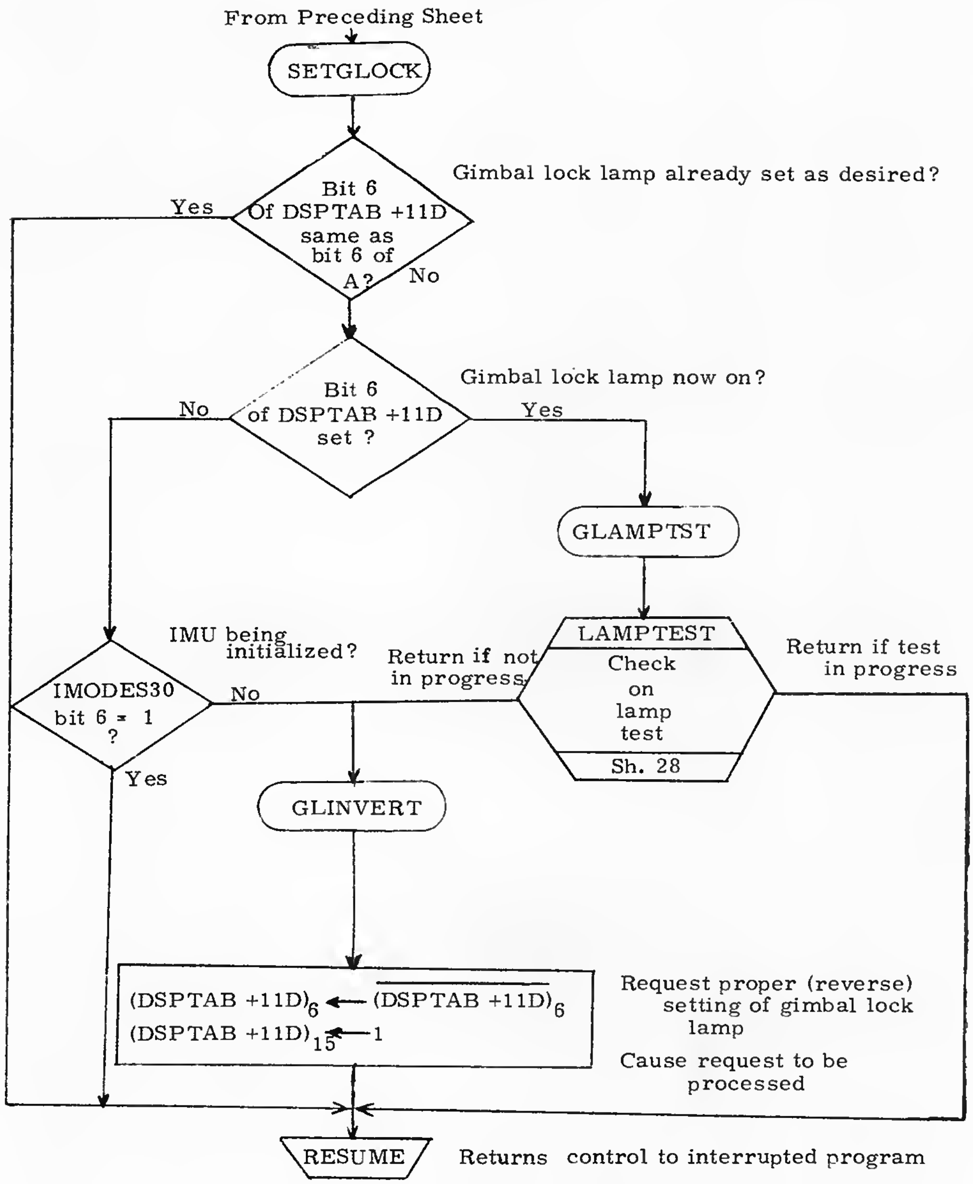
DOCUMENT NO. FC-3210

REV 1

SHEET 53 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN L. Goldstone	12/14/65	T4RUPT	
PRGMR R. G.	2/5/70		DOCUMENT NO.
ANALST			
DOCMR		LUMINARY 1D	FC-3210
APPR'D R M Estes	2/5/70	REV 1	SHEET 54 OF 80



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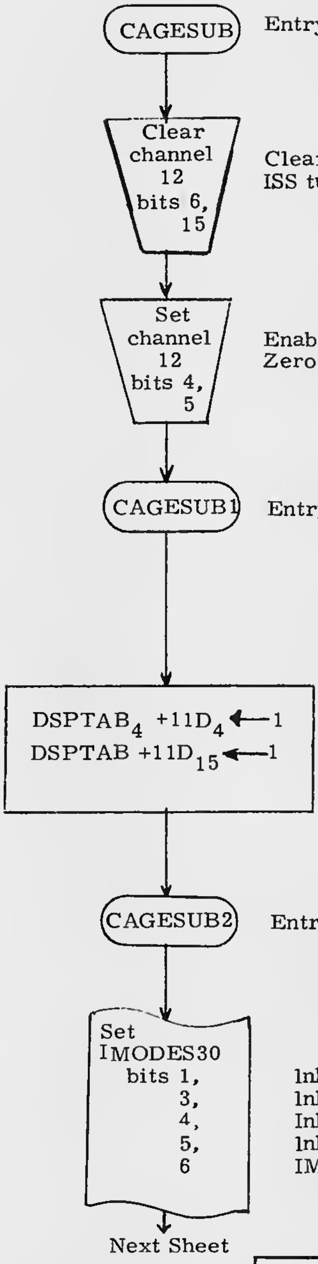
DRAWN	12/4/6	T4RUPT
PRGMR	2/6/70	
ANALST		DOCUMENT NO.
DOCMR		LUMINARY 1D FC-3210
APPR'D	2/5/70	REV 1 SHEET 55 OF 80



Entry called by TNONTEST (Sh. 37)

Clear and disable IMU CDU error counters
ISS turn-on delay not done

Enable coarse alignment of IMU
Zero IMU CDU's

Entry: called by IMUCAGE (Sh. 33)

Request "no att" light turn-on
Cause request to be processed

Entry called by OPONLY (Sh. 38)

Inhibit PIPA failure ISS warning signal
Inhibit ICDU failure signal
Inhibit IMU failure signal
Inhibit PIPA failure program alarm signal
IMU being initialized

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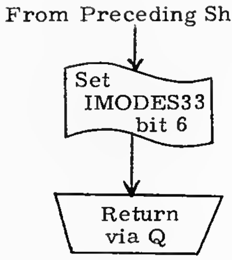
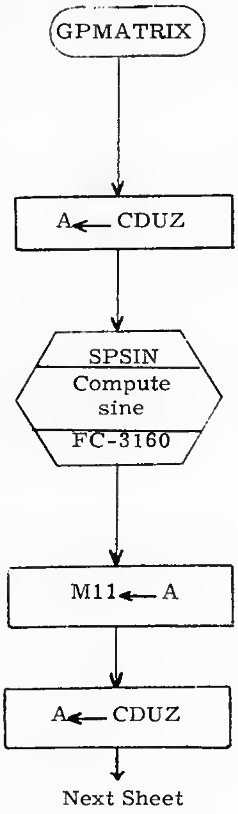
ANALST		LUMINARY 1D	FC-3210
DOCMR			
APPR'D R M Estes	2/5/70	REV 1	SHEET 56 OF 80



Disable DAP



Compute current values for SM-SC. coordinate transformation matrix $[M_{GP}]$

(used by LM DAP)

Entered every 240 ms from T4RUPT

(every 480 ms directly and in between, via REAUTCHK)

Read middle IMU gimbal angle (2's complement) in revs @ 2^{-1}

Input: A = angle in revs @ 2^{-1}

Output: A = sine of angle @ 2^{0}

Save sin (MGA) @ 2^{0}

Read middle IMU gimbal angle (2's complement) in revs @ 2^{-1}

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APOLLO GUIDANCE AND NAVIGATION

DRAWN
PRGMR 2/5/70
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T4RUPT

LUMINARY 1D

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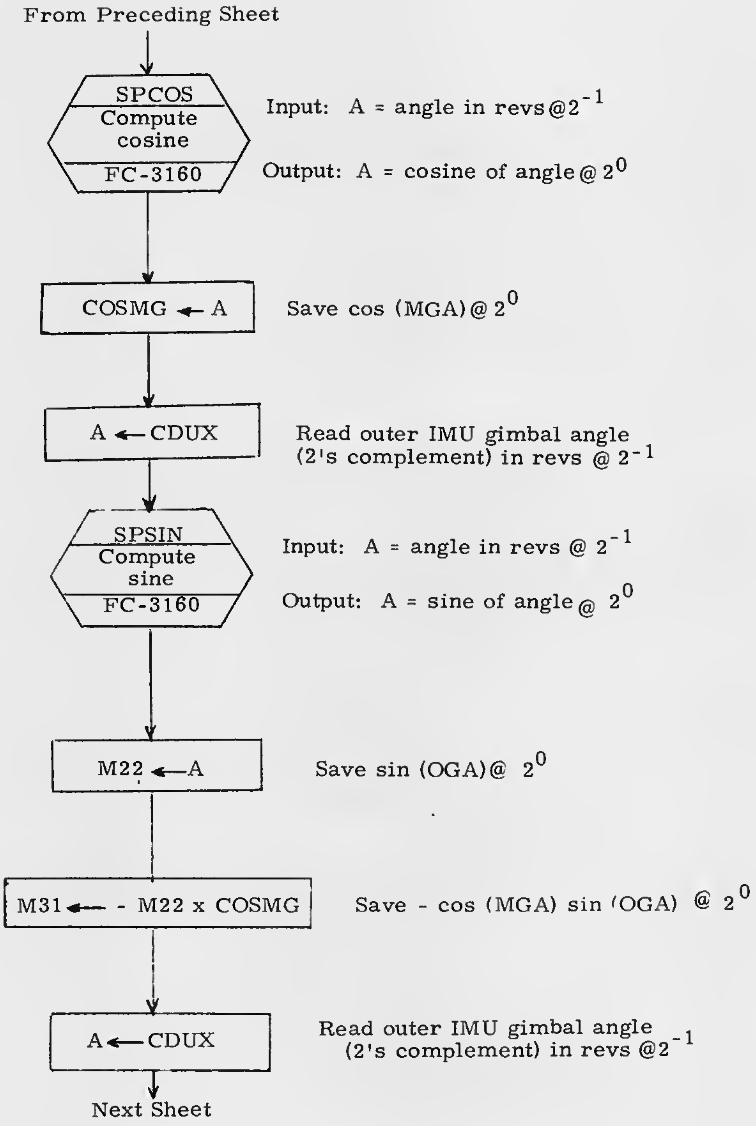
REV 1



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ANALST
DOCMR
APPR'D RMM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

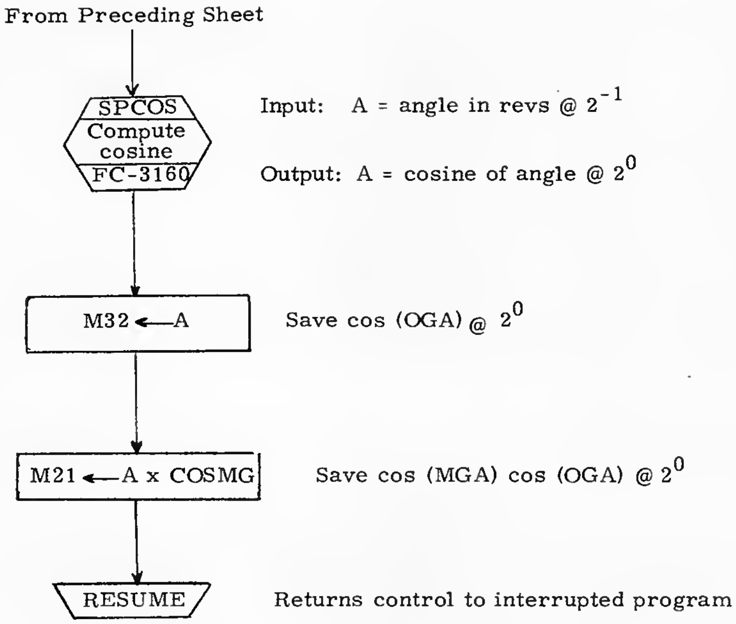
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 58 OF 80



Have obtained values for matrix:

$$[M_{GP}] = \begin{bmatrix} M11 & 0 & 1 \\ M21 & M22 & 0 \\ M31 & M32 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} \sin(MGA) & 0 & 1 \\ \cos(MGA)\cos(OGA) & \sin(OGA) & 0 \\ -\cos(MGA)\cos(OGA) & \cos(OGA) & 0 \end{bmatrix}$$

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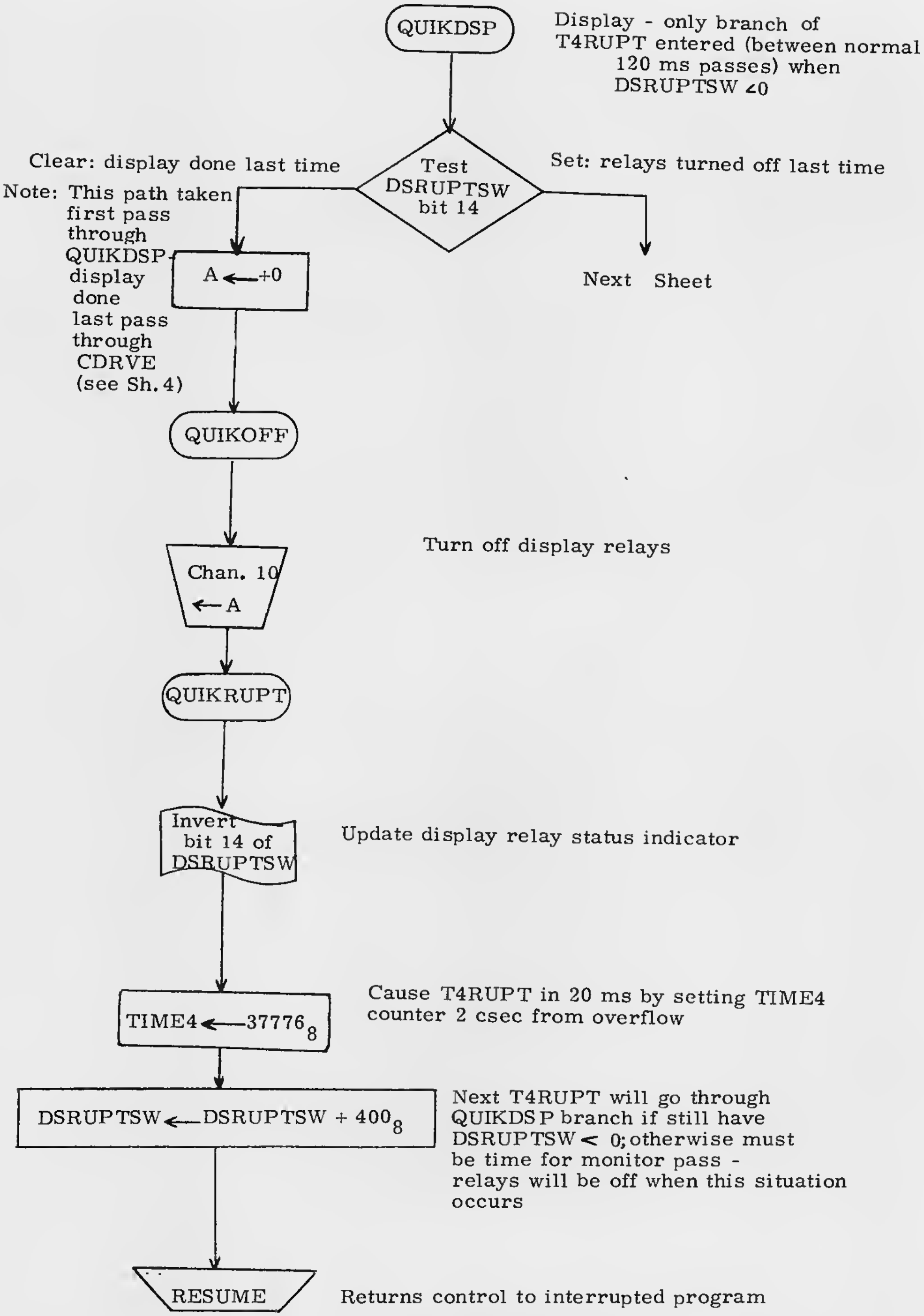
DRAWN		T4RUPT	
PRGMR	2/5/70		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3210
DOCMR			
APPR'D	2/5/70	REV 1	SHEET 59 OF 80



Display - only branch of T4RUPT entered (between normal 120 ms passes) when DSRUPTSW ∠0

Clear: display done last time

Note: This path taken first pass through QUIKDSP-display done last pass through CDRVE (see Sh. 4)

Set: relays turned off last time

Turn off display relays

Update display relay status indicator

Cause T4RUPT in 20 ms by setting TIME4 counter 2 csec from overflow

Next T4RUPT will go through QUIKDSP branch if still have DSRUPTSW < 0; otherwise must be time for monitor pass - relays will be off when this situation occurs

Returns control to interrupted program

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ANALST
DOCMR
APPR'D R.M. Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

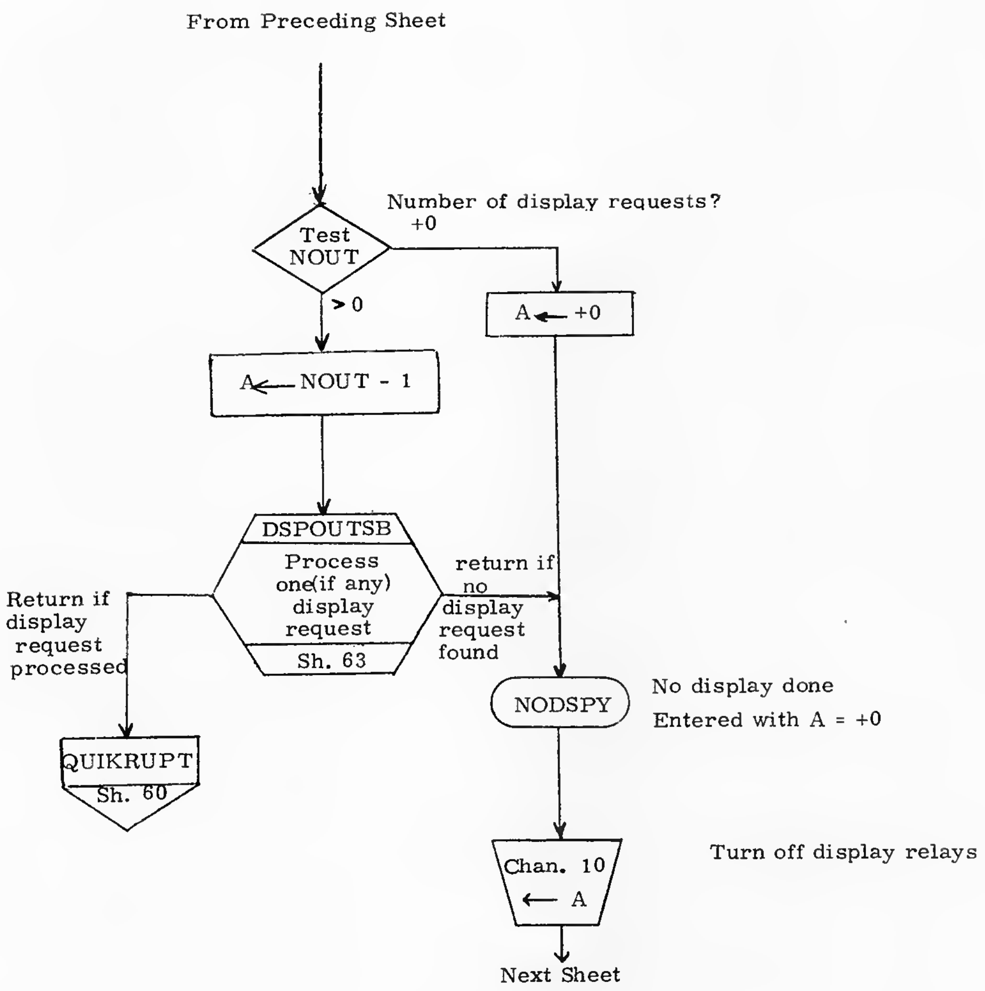
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 60 OF 80



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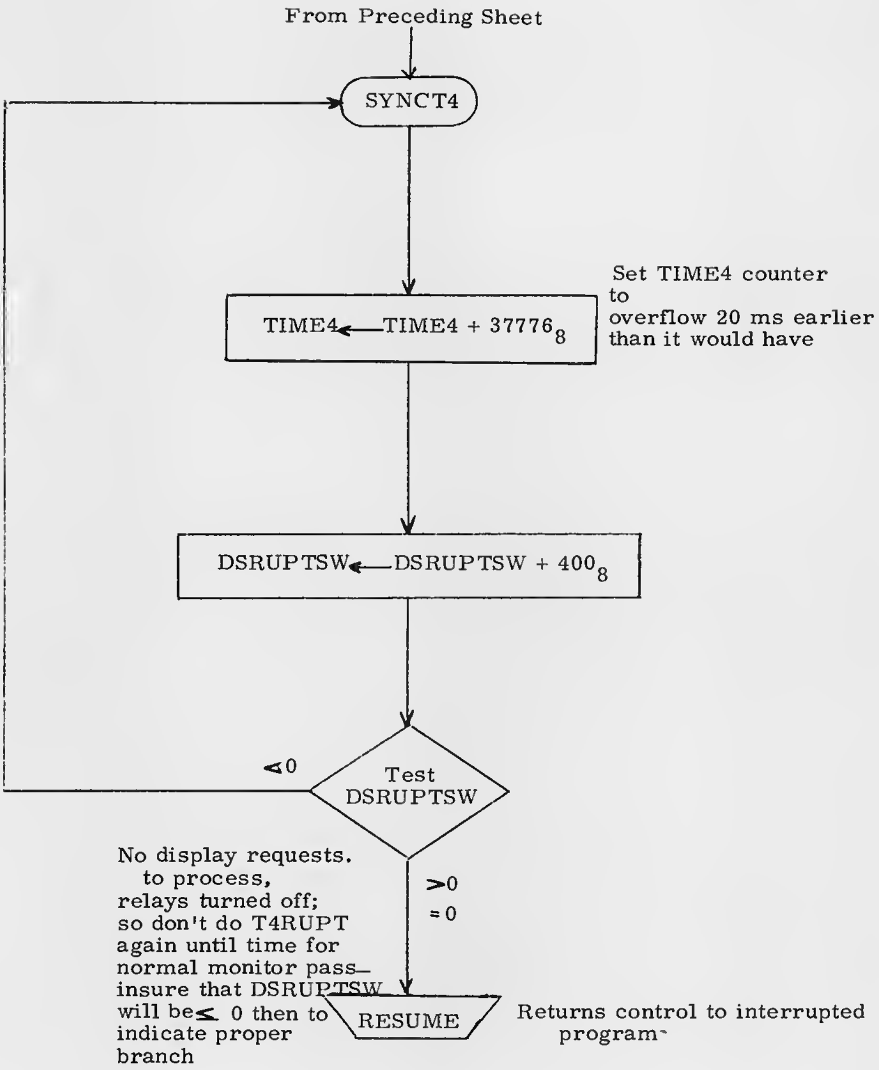
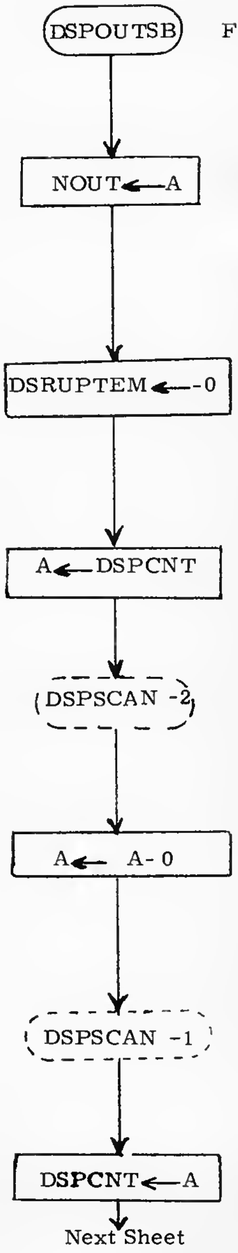
DRAWN J. Gilstone		T4RUPT	
PRGMR R. G. Ast	2/5/70		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3210
DOCMR			
APPR'D RM Estes	3/5/70	REV 1	SHEET 61 OF 80



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION		
DRAWN	[illegible]	[illegible]	T4RUPT	
PRGMR	R. Gilbert	2/5/70		
ANALST			LUMINARY 1D	DOCUMENT NO. FC-3210
DOCMR				
APPR'D	RM Estes	2/5/70	REV 1	SHEET 62 OF 80



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 +0 value

Store current index value

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APPR'D RM Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

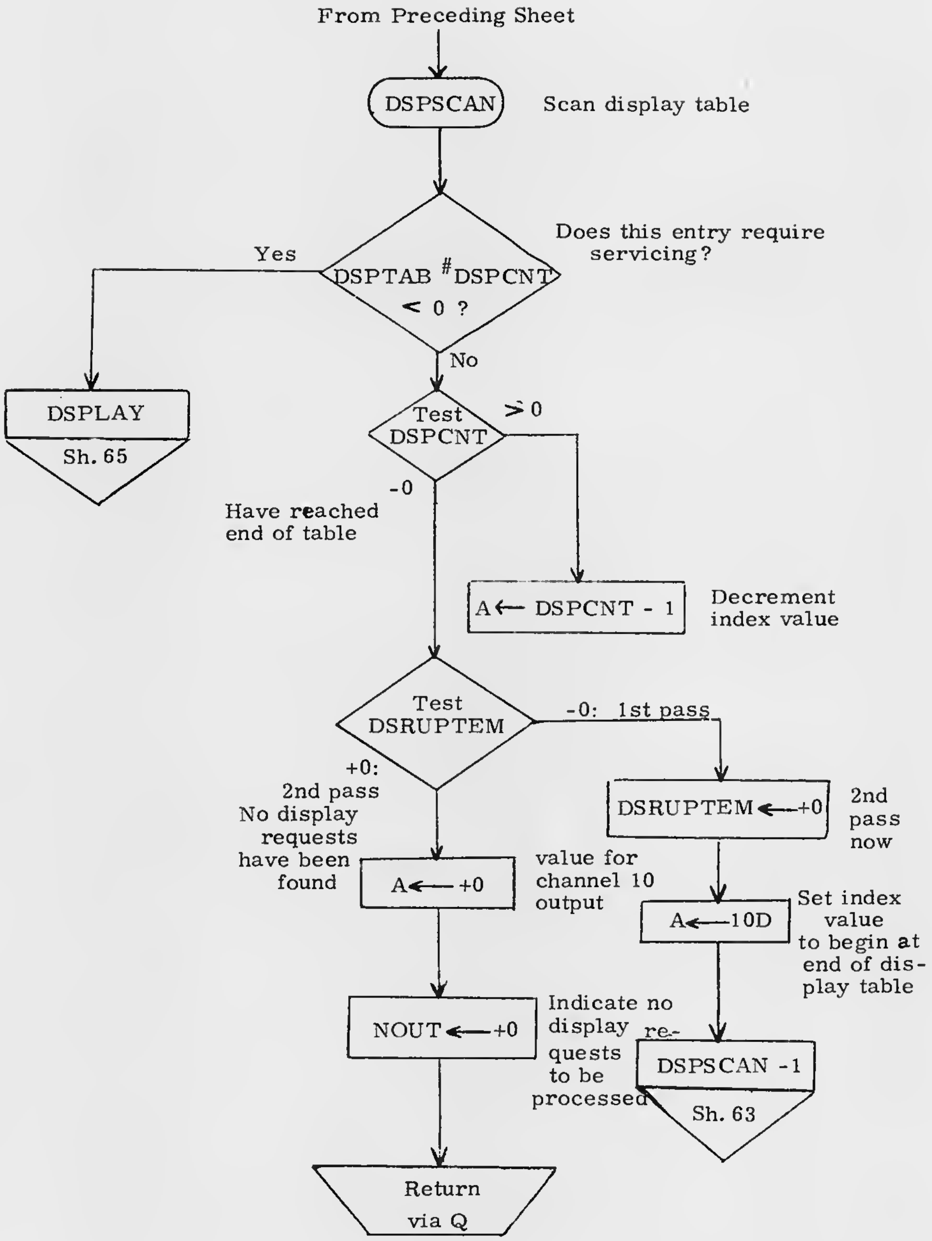
T4RUPT

LUMINARY 1D

DOCUMENT NO. FC-3210

REV 1

SHEET 63 OF 80



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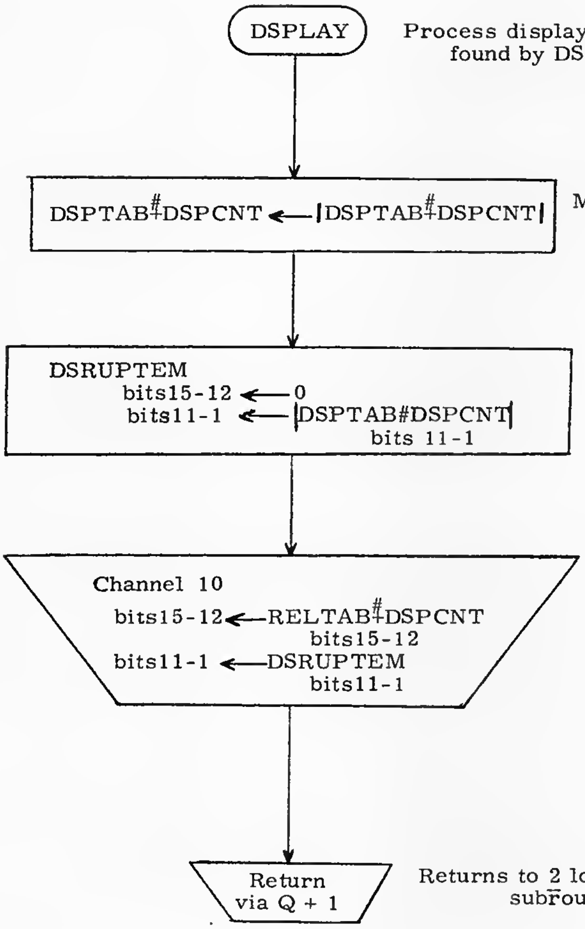
DRAWN L. Goldstone	12/4/69	T4RUPT	
PRGMR R. Gilbert	2/5/70	LUMINARY 1D	DOCUMENT NO. FC-3210
ANALST			
DOCMR			
APPR'D R M Estes	2/5/70	REV 1	SHEET 64 OF 80



Process display request found by DSPCAN

Make table entry nonnegative to show request has been processed

Mask out bits 11-1, which give desired display relay settings for one row (of relays)

Output display command via channel 10:

bits 15-12 specify relay row

bits 11-1 specify settings for relays in that row

Returns to 2 locations beyond subroutine call

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DRAWN 12/3/69
PRGMR 2/5/70
ANALST
DOCMR
APPR'D RM Estes 2/5/70

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T4RUPT

LUMINARY 1D

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Subroutines Called Which Are Flowed on Other Flow Charts

Subroutine Name	Flow Chart	Description	Where Called
ALARM	3140	Turn on program alarm light; set alarm code	Sh. 12 Sh. 29 Sh. 36 Sh. 37 Sh. 50, 51 Sh. 52
BEGDES	3600	Do designation of RR antenna	Sh. 24
CA+ECE	3220	Enable IMU CDU error counters	Sh. 54
IMUBAD	3220	Error end of IMU task	Sh. 42
NOATTOFF	3220	Turn off "no att " lamp	Sh. 39 Sh. 41
PFAILOK	3220	Allow program alarm in case of PIPA failure	Sh. 44
PROCKEY	3090.	Process astronaut's "proceed" signal	Sh. 6
RNDREFDR	3220	Clear TRACKFLAG (no tracking), DRIFTFLG (no gyro compensation), REFSMFLG (REFSMMAT matrix invalid)	Sh. 34 Sh. 36
RRLIMCHK	3600	Check whether desired RR gimbal angles are within limits of present mode	Sh. 16
RRSONLY	3600	Maneuver RR antenna about shaft axis	Sh. 23
RRTONLY	3600	Maneuver RR antenna about trunnion axis	Sh. 23
SETCOARS	3220	Set up coarse alignment of IMU	Sh. 54
SETTRKF	3600	Update tracker fail lamp	Sh. 13, 21

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ANALST		LUMINARY 1D	FC-3210
DOCMR			
APPR'D R M Estes	2/5/70	REV 1	SHEET 66 OF 80

Subroutines Called Which Are
Flowed on Other Flow Charts (Cont.)

Subroutine Name	Flow Chart	Description	Where Called
SPCOS	3160	Compute cosine of angle	Sh. 58, 59
SPSIN	3160	Compute sine of angle	Sh. 57, 58
VARALARM	3140	Turn on program alarm lights Set alarm code	Sh. 32
ZEROICDU	3220	Zero IMU gimbal angle counters	Sh. 40 Sh. 43
1/ACCJOB	3480	Process changes (including RCS jet failures, staging) relevant to autopilot	Sh. 9
FIXDELAY	3040	Delay task	Sh. 18, 19, 20, 23
VARDELAY	3040	Delay task	Sh. 42, 43

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DRAWN L. Goldstone 12/4/68
PRGMR R Gilbert 2/5/70
ANALST
DOCMR
APPR'D R M Estes 2/5/70

APOLLO GUIDANCE AND NAVIGATION

T4RUPT

LUMINARY 1D

DOCUMENT NO.
FC-3210

REV 1

SHEET 67 OF 80

Flags

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
AVEGFLAG FLAGWORD7 bit 5	SERVICER is running	SERVICER not running			Sh. 14
DRIFTFLG FLAGWORD2 bit 15	T3RUPT calls gyro compensation	T3RUPT does no gyro compensation	Sh. 44		Sh. 44
DSKYFLAG FLAGWORD5 bit 15	Display sent to DSKY	No display sent to DSKY			Sh. 5
ENGONFLG FLAGWORD5 bit 7	Engine is on	Engine is off		Sh. 33	
IMODES30 bit 1	PIPA failure not to cause ISS warning	PIPA failure signal allowed	Sh. 56		Sh. 31,50
IMODES30 bit 2	ISS delay-sequence failure	No ISS delay-sequence failure	Sh. 29	Sh. 40	Sh. 29,35
IMODES30 bit 3	ICDU failure signal inhibited	ICDU failure signal allowed	Sh. 56	Sh. 43	Sh. 31
IMODES30 bit 4	IMU failure signal inhibited	IMU failure signal allowed	Sh. 56	Sh. 43	Sh. 31
IMODES30 bit 5	PIPA failure not to cause prog alarm	PIPA failure signal allowed	Sh. 56		Sh. 50
IMODES30 bit 6	IMU being initialized	IMU not being initiallized	Sh. 56	Sh. 43	Sh. 55
IMODES30 bit 7	First ISS turn-on cycle has arrived	First ISS turn-on cycle has not arrived	Sh. 30	Sh. 37	Sh. 37, 50
IMODES30 bit 8	Second ISS turn-on cycle has arrived	Second ISS turn-on cycle has not arrived	Sh. 37	Sh. 37	Sh. 37, 50

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DRAWN 12/4/69
PRGMR 2/5/70
ANALST
DOCMR
APPR'D 2/5/70

APOLLO GUIDANCE AND NAVIGATION

T4RUPT

LUMINARY 1D

DOCUMENT NO.
FC-3210

REV 1

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Flags (Cont.)

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
IMODES30 bit 9	ISS not operating	ISS operating	Sh.25	Sh.25	Sh.37 Sh.50
IMODES30 bit 10	No PIPA failure	PIPA failure	Sh.49	Sh.49	Sh.31 Sh.50
IMODES30 bit 11	IMUCAGE not requested	IMUCAGE requested	Sh.25	Sh.25	
IMODES30 bit 12	No ICDU failure	ICDU failure	Sh. 25	Sh. 25	Sh. 31
IMODES30 bit 13	No IMU failure	IMU failure	Sh.25	Sh. 25	Sh. 31
IMODES30 bit 14	ISS turn-on not requested	ISS turn-on requested	Sh. 25	Sh. 25	Sh. 29 Sh. 37, 42
IMODES30 bit 15	ISS temperature not within limits	ISS temperature within limits	Sh. 25	Sh. 25	Sh. 28
IMODES33 bit 1	LAMPTEST in progress	LAMPTEST not in progress			Sh. 28, 31
IMODES 33 bit 6	Autopilot disabled	Auto pilot enabled	Sh. 36 Sh. 57	Sh.43	
IMODES33 bit 11	Uplink not too fast	Uplink too fast	Sh. 46	Sh. 46	Sh.45
IMODES33 bit 12	Downlink not too fast	Downlink too fast	Sh. 46	Sh. 46	Sh. 45
IMODES33 bit 13	No PIPA failure	PIPA failure	Sh. 46	Sh. 46	
IMODES33 bit 14	Proceed key not depressed	Proceed key depressed	Sh.6	Sh. 6	Sh. 6

Flags (Cont.)

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
DSRUPTSW bit 14	Display relays turned off last pass through T4RUPT	Display done at last pass-turn off relays	Sh. 60	Sh.60	Sh.3, 60, 62
IMUSE FLAGWRD0 bit 8	IMU in use	IMU not in use		Sh.36	Sh.36 Sh. 39 Sh.42
MUNFLAG FLAGWRD6 bit 8	SERVICER calls MUNRVG	SERVICER calls CALCRVG			Sh. 14
NORRMON FLAGWRO5 bit 4	RR gimbal limit monitor to be bypassed	RR gimbal limit monitor to be done			Sh. 14
RADMODES bit 1	RR turn-on in progress	RR turn-on not in progress	Sh.11	Sh.10, 18, 30	
RADMODES bit 2	RR power off or not in LGC mode	RR power on and in AUTO mode	Sh.10 Sh.30	Sh. 10	Sh.10 Sh.12 Sh.15, 17
RADMODES bit 3	RR data scaled high	RR data scaled low		Sh. 30	
RAMODES bit 4	RR data failure	RR data good		Sh. 30	
RADMODES bit 5	LR range data failure	LR range data good		Sh. 30	
RADMODES bit 6	LR antenna not in position 1	LR antenna in position 1		Sh. 30	
RADMODES bit 7	No RR CDU failure	RR CDU failure	Sh. 12 Sh. 30	Sh. 12	Sh. 12
RADMODES bit 8	LR velocity data failure	LR velocity data good		Sh. 30	
RADMODES bit 9	LR data scaled high	LR data scaled low		Sh. 30	

Flags (Cont.)

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
RADMODES bit 10	Designation (moving antenna to follow target) to be done	No designation to be done		Sh. 30	Sh. 24
RADMODES bit 11	RR antenna being repositioned	RR antenna not being repositioned	Sh. 16	Sh. 10 Sh. 24 Sh. 30	Sh. 15
RADMODES bit 12	RR antenna in mode 2 (top of LM)	RR antenna in mode 1 (front of LM)	Sh. 21	Sh. 21 Sh. 30	Sh. 23
RADMODES bit 13	RR CDU zeroing (and recounting) in progress	RR CDU zeroing not in progress	Sh. 11	Sh. 10 Sh. 20, Sh. 30	Sh. 12, 15
RADMODES bit 14	RR antenna remoding	RR antenna not remoding		Sh. 10 Sh. 30	Sh. 14
RADMODES bit 15	RR antenna to continously designate stay in one position relative to vehicle	RR antenna not to continuously designate		Sh. 10 Sh. 30	
RNDVZFLG FLAGWRD0 bit 7	Radar in use	Radar not in use		Sh. 36	Sh. 12

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APOLLO GUIDANCE AND NAVIGATION

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Channel Bits

Channel Bit	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
Channel 10 bits 15-12	Row of dispaly relays to be set as specified by 11-1		Sh. 4 , 65		
bits 11-1	Desired setting of display relays of row specified by bits 15-12		Sh. 4, 65		
Note	If bits 15-1 of channel 10 are all set to zero all display relays are turned off-this does not affect display light settings				
Channel 11 bit 1	ISS warning light on	ISS warning light off	Sh. 32	Sh. 31	
bit 4	Temperature caution light off	Temperature caution light off	Sh. 28	Sh. 28	
bit 13	Engine-on signal	No engine-on signal		Sh. 34	
bit 14	Engine-off signal	No engine-off signal	Sh. 34		
Channel 12 bit 1	Zero RR CDU's	Allow counters to receive RR angle data	Sh. 17, 19	Sh. 19	
bit 2	Enable RR CDU's	Clear and disable RR CDU's	Sh. 22	Sh. 10, 16, 24, 33	Sh. 22
bit 4	Enable coarse alignment of IMO	Disable coarse alignment of IMU	Sh. 56	Sh. 33, 43	Sh. 38, 53
bit 5	Zero IMU CDU's	Allow counters to receive IMU gimbal angle data	Sh. 39, 56	Sh. 33, 43	
bit 6	Enable IMU CDU's	Clear and disable IMU CDU's		Sh. 33, 56	

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Channel Bits (Cont.)

Channel Bit	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
bit 8	Connect inertial data display	Disable inertial data display		Sh. 33	
bit 14	Enable RR lock-on	Disable RR lock-on		Sh. 16	
bit 15	ISS turn-on delay complete; bit 14 of channel 30 set.	ISS turn-on delay not complete	Sh. 41	Sh. 44, 56	Sh. 29
Channel 14 bit 6	Enable gyro torquing power supply	Disable gyro torquing power supply		Sh. 34	
bits 8-7	Specify axis for gyro torquing	both bits zero indicates no axis		Sh.34	
bit 9	Negative polarity specified for syro torquing output	No polarity specified for gyro torquing output		Sh. 34	
bit 10	Send gyro torquing command from GYROCMD	Send no gyro torquing command from GYROCMD		Sh. 33	
bit 11	Send RR antenna angle command from OPTXCMD	Send no RR antenna angle command from OPTXCMD		Sh. 33	
bit 12	Send RR antenna angle command from OPTYCMD	Send no RR antenna angle command from OPTYCMD		Sh. 33	
bit 13	Send IMU angle or FDAI command from CDUZCMD	Send no command from CDUZCMD		Sh. 33	
bit 14	Send IMU angle or FDAI command from CDUYCMD	Send no command from CDUYCMD		Sh. 33	
bit 15	Send IMU angle or FDAI command from CDUXCMD	Send no command from CDUXCMD		Sh. 33	
Channel 30 bit 7	No RR CDU failure	RR CDU failure			Sh.12

Channel Bits (Cont.)

Channel Bit	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
Channel 30 bit 9	IMU not on or not operating properly	IMU on and operating properly			Sh. 25
bit 11	IMU cage command switch off	IMU cage command switch is on			Sh. 25
bit 12	No IMU CDU failure	IMU CDU failure			Sh. 25
bit 13	No IMU failure	IMU failure			Sh. 25
bit 14	No ISS turn-on request	ISS turn-on requested or in progress			Sh. 25
bit 15	SM temperature out of design limits	SM temperature within design limits			Sh. 25
Channel 32 bit 14	PRO key on DSKY not depressed	PRO key on DSKY depressed			Sh. 6
Channel 33 bit 11	Uplink not too fast	Uplink too fast	Sh. 45		Sh. 45
bit 12	Downlink not too fast	Downlink too fast	Sh. 45		Sh. 45
bit 13	No PIPA failure	PIPA failure	Sh. 45		Sh. 45

Displays

Verb-Noun	Type of Display	Description of Each Resgister	Where Executed
	Alarm	Prog alarm light on; R1, R2, R3 not affected	Sh. 12, 29, 32, 36, 37, 50, 51, 52

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APOLLO GUIDANCE AND NAVIGATION

T4RUPT

LUMINARY 1D

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REV 1

SHEET 75 OF 80

Erasable Location Used

AGC TAG	GSOP SYMBOL	Meaning	Engineering Units	AGC Units	AGC Scaling
A		Accumulator register (in AGC central processor)			
ARUPT		Temporary storage for A (above) during interrupt			
BANKRUPT		Temporary storage for BBANK (below) during interrupt			
BBANK		Central register containing address information (used by central processor)			
CDUX		Outer IMU gimbal angle (2's complement)	Degrees	Revs	2^{-1}
CDUXCMD		Commanded value for outer IMU gimbal angle	Degrees	Revs	2^{1}
CDUYCMD		Commanded value for inner IMU gimbal angle	Degrees	Revs	2^{1}
CDUZ		Middle IMU gimbal angle (2's complement)	Degrees	Revs	2^{-1}
CDUZCMD		Commanded value for middle IMU gimbal angle	Degrees	Revs	2^{-1}
CH5MASK		Record of failure status of RCS jets which control translation along the vehicle X-axis and rotation about the U, V axes, where:			

Erasable Location Used (Cont.)

AGO TAG	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGO Scaling
		bit: 8 set means jet: 14 off 7 13 6 10 5 9 4 6 3 5 2 2 1 1			
CH6MASK		Record of failure status of RCS jets which control translation along the Y, Z axes and rotation about the X - axis, where bit: 8 set means jet: 16 off 7 4 6 8 5 12 4 11 3 15 2 3 1 7			
COSMG	cos (MGA)	Cosine of middle IMU gimbal angle			2^0

Erasable Location Used (Cont.)

AGO TAG	GSOP SYMBOL	Meaning	Engineering Units	AGC Units	AGC Scaling
DSPCNT		Index value pointing to entry in display request table (see DSPTAB below)			
DSPTAB, DSPTAB +11D		Twelve locations containing codes for display relays to be set for each of 12 rows of relays. Each entry must be set negative in order to be processed.			
DSRUPTSW		Pointer to path through T4RUPT: If nonnegative, cycles (every 960ms) between values of 0 - 7, to indicate which service routine is to be done this pass, If negative, an intermediate pass (between passes of above type, which occur every 120 ms) which does display routine only			
GYROCMD		IMU gyro torquing command	degrees	revs	2^7
L		Low-order accumulator register (in AGC central processor)			
LRUPT		Temporary storage for L (above) during interrupt			
LASTXCMD		Last commanded value for RR shaft angle	degrees	revs	2^{-1}
LASTYCMD		Last commanded value for RR trunnion angle	degrees	revs	2^{-1}

Erasable Location Used (Cont.)

AGO TAG	GSOP SYMBOL	Meaning	Engineering Units	AGC Units	AGC Scaling
M11	sin (MGA)	Sine of middle IMU gimbal angle			2^0
M21	cos (MGA cos (OGA)	Cosine of middle IMU gimbal angle times cosine of outer IMU gimbal angle			2^0
M22	sin (OGA)	Sine of outer IMU gimbal angle			2^0
M31	-cos (MGA) sin (OGA)	- Cosine of middle IMU gimbal angle times sine of outer IMU gimbal angle			2^0
M32	cos (OGA)	Cosine of outer IMU gimbal angle			2^0
NOUT		Number of output display requests to be processed			2^{14}
OPTX		RR shaft angle (2's complement)	degrees	revs	2^{-1}
OPTY		RR trunnion angle (2's complement)	degrees	revs	2^{-1}
PVALVEST		Record of failure status of RCS jet pairs, where: bit: 8 set means jet: 10, 11 off 7 9, 12 6 13, 15 5 14, 16 4 6, 7 3 1, 3 2 5, 8 1 2, 4			

Erasable Location Used (Cont.)

AGO TAG	GSOP SYMBOL	Meaning	Engineering Units	AGC Units	AGC Scaling
Q		Central processor register used for returns from subroutines			
QRUPT		Temporary storage for Q (above) during interrupt			
$TIME2_D$=	TIME2, TIME1	Present time	secs	csecs	2^{28}
TIME4		Counter which controls timing of T4RUPT			
1/PIPADT		Time last PIPA compensation	sec	csecs	2^{14}

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DRAWN		T4RUPT	
PRGMR	2/5/70		
ANALST		LUMINARY 1 D	DOCUMENT NO. FC-3210
DOCMR			
APPR'D R.M. Estes	2/5/70	REV 1	SHEET 80 OF 80

IMU MODE SWITCHING ROUTINES

IMUZERO	SH. 2
IMUZERO2	SH. 4
IMUCOARS	SH. 6
SETCOARS	SH. 7
RNDREFDR	SH. 8
COARS	SH. 9
CA+ECE	SH. 14
IMUFINE	SH. 15
IMUFINED	SH. 16
IFAILOK	SH. 17
PFAILOK	SH. 18
PIPUSE	SH. 19
PIPUSE1	SH. 19
PIPFREE	SH. 20
IMUPULSE	SH. 21
STRTGYRO	SH. 24
R02BOTH	SH. 33
ENDIMU	SH. 34
IMUGOOD	SH. 34
IMUBAD	SH. 34
GOODEND	SH. 34
BADEND	SH. 34
IMUSTALL	SH. 35
AOTSTALL (= OPTSTALL)	SH. 35
RADSTALL	SH. 35
MODEEXIT	SH. 36
CAGETEST	SH. 37
CAGETSTJ	SH. 37
CAGETSTQ	SH. 37
NOATTOFF	SH. 38
ZEROICDU	SH. 39

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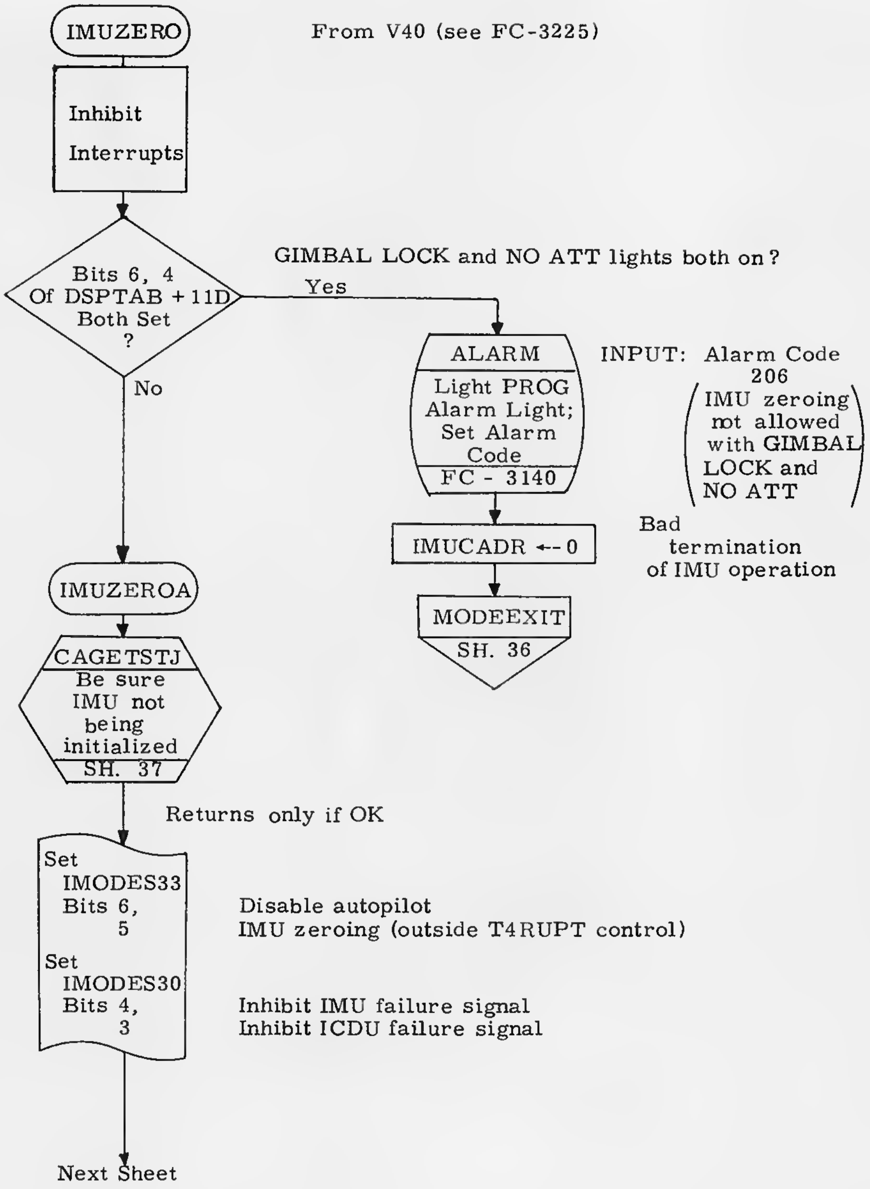
DRAWN		IMU Mode Switching Routines	
PRGMR D Millard	8/28/69		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3220
DOCMR	28 AUG 69		
APPR'D	28 AUG 69	REV 2	SHEET 1 OF 41



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DRAWN
PRGMR
ANALST
DOCMR
APPR'D

APOLLO GUIDANCE AND NAVIGATION

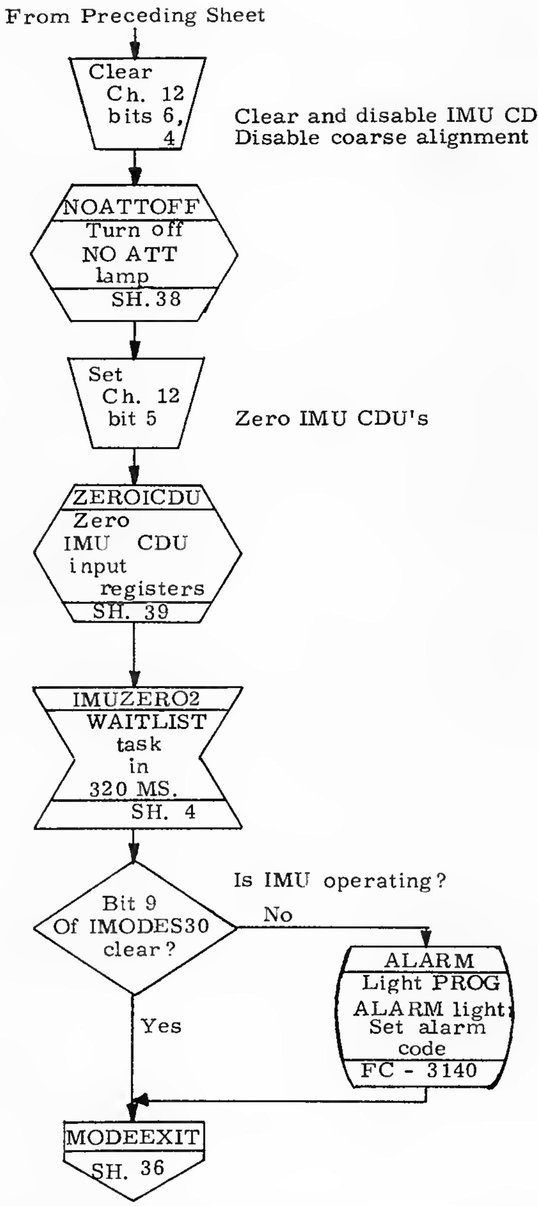
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO.
FC-3220

REV 2

SHEET 2 OF 41



Clear and disable IMU CDU error counters
Disable coarse alignment of IMU

Zero IMU CDU's

Is IMU operating?

Input: Alarm Code 210

(IMU not operating)

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ANALST
DOCMR Alida M. Sorentz
APPR'D Alida M. Sorentz

APOLLO GUIDANCE AND NAVIGATION

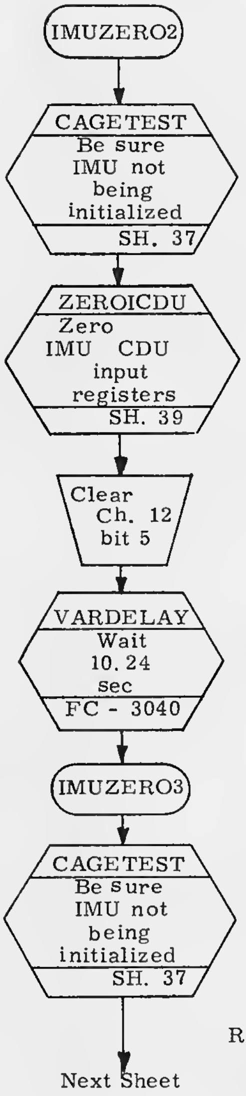
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO. FC-3220

REV 2

SHEET 3 OF 41



Returns only if OK

Allow IMU CDU's to receive data
(Input registers will receive
corresponding data)

Wait for counters to
receive data

Returns only if OK

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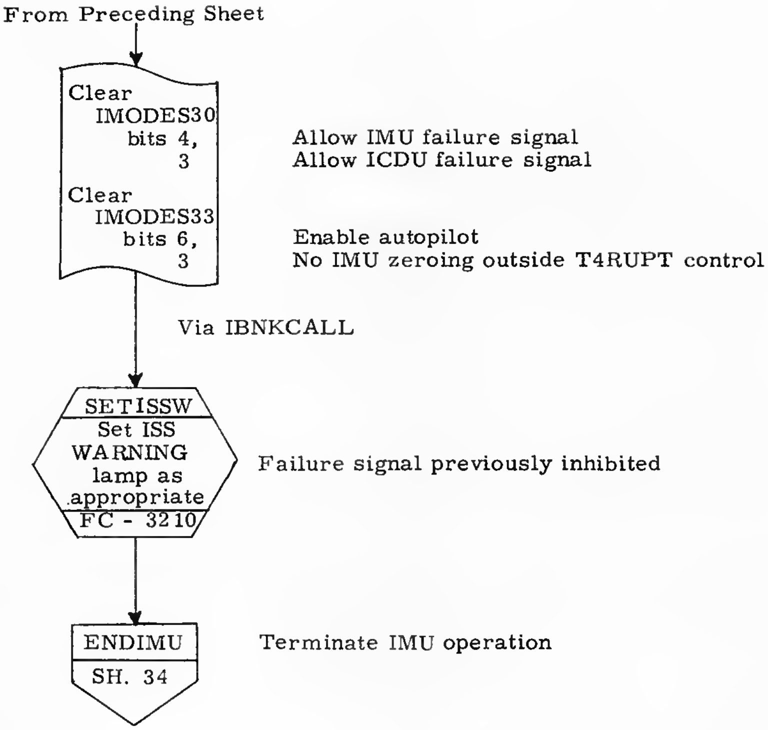
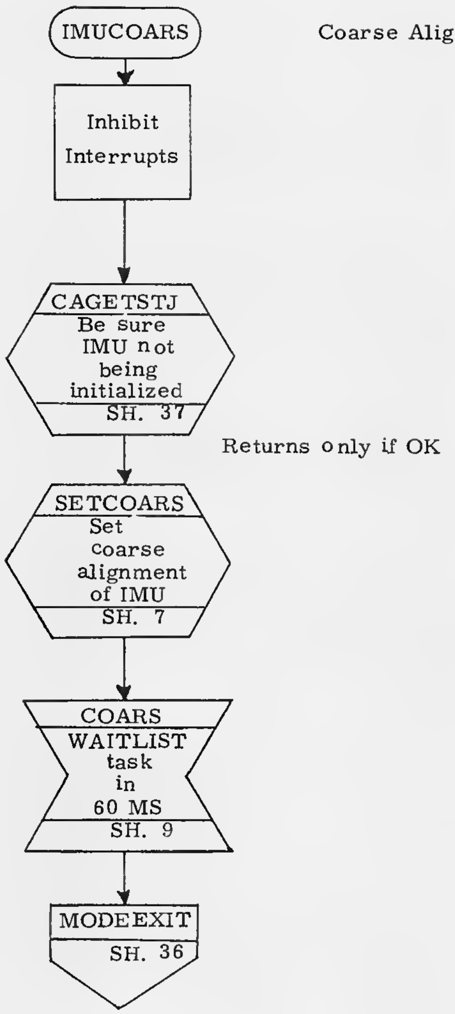
ANALST
DOCMR A. M. Grant 28AUG69
APPR'D A. M. Grant 28AUG69

APOLLO GUIDANCE AND NAVIGATION
IMU Mode Switching Routines
LUMINARY 1D
DOCUMENT NO. FC-3220
REV 2
SHEET 4 OF 41



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	IMU Mode Switching Routines
PRGMR D. Millard	
ANALST	LUMINARY 1D
DOCMR 28AUG68	DOCUMENT NO. FC-3220
APPR'D 28AUG68	REV 2 SHEET 5 OF 41

Coarse Alignment of IMU



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DRAWN
PRGMR
ANALST
DOCMR A. M. Sorent 22 AUG 69
APPR'D A. M. Sorent 22 AUG 69

APOLLO GUIDANCE AND NAVIGATION

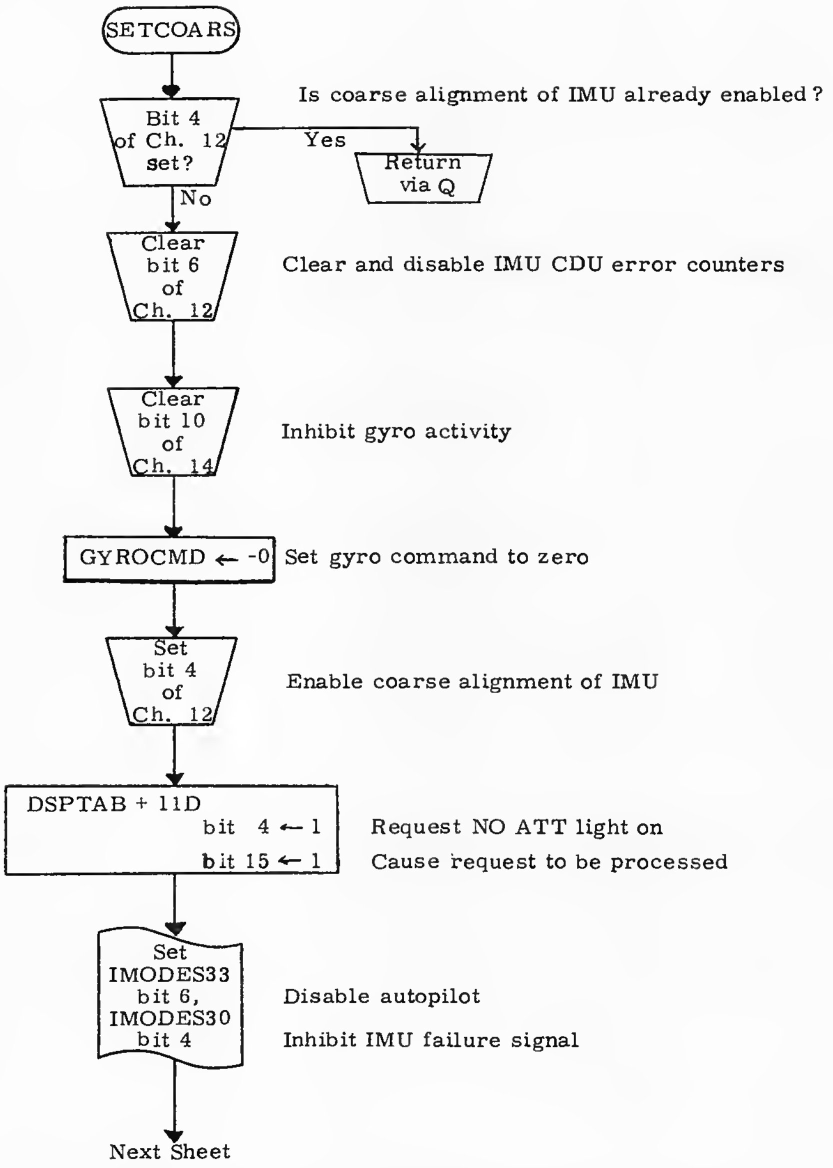
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO.
FC-3220

REV 2

SHEET 6 OF 41



Is coarse alignment of IMU already enabled?

Clear and disable IMU CDU error counters

Inhibit gyro activity

Set gyro command to zero

Enable coarse alignment of IMU

Request NO ATT light on

Cause request to be processed

Disable autopilot

Inhibit IMU failure signal

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PRGMR D. L. Millard 8/22/69
ANALST
DOCMR G. M. Levant 28 AUG 69
APPR'D G. M. Levant 28 AUG 69

APOLLO GUIDANCE AND NAVIGATION

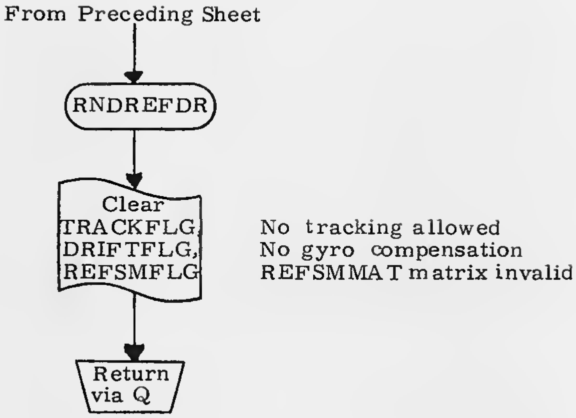
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO. FC-3220

REV 2

SHEET 7 OF 41



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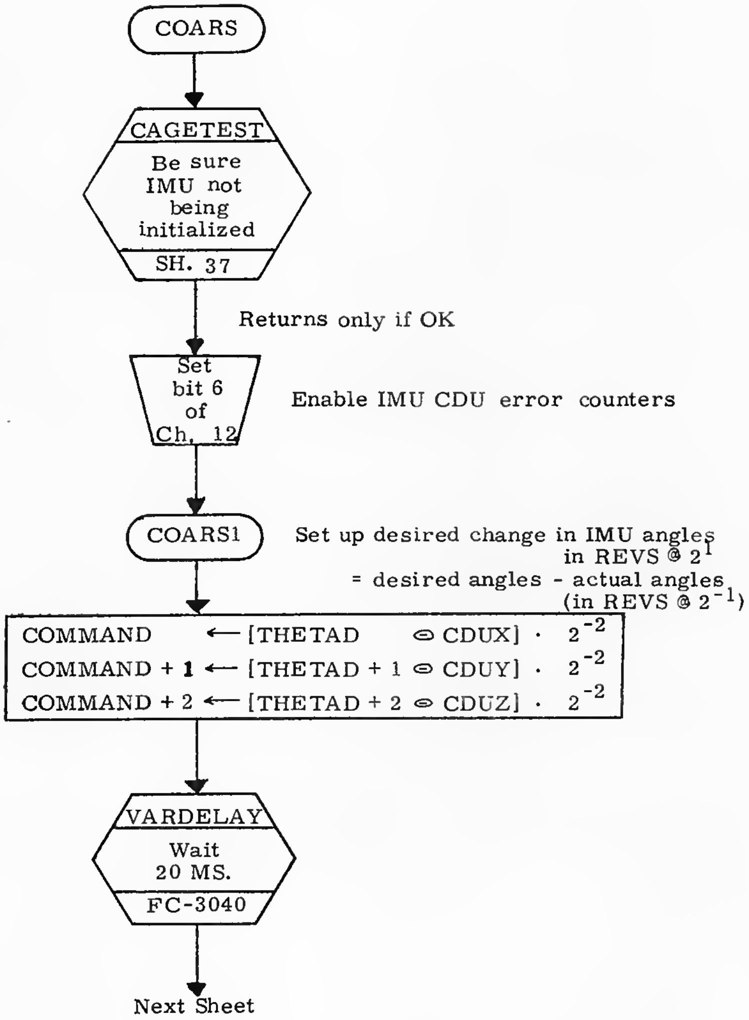
ANALST
DOCMR 8/28/69
APPR'D. 8/28/69

APOLLO GUIDANCE AND NAVIGATION
IMU Mode Switching Routines
LUMINARY 1D
DOCUMENT NO. FC-3220
REV 2
SHEET 8 OF 41



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DRAWN
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ANALST
DOCMR A. M. Sorant 28 AUG 69
APPR'D A. M. Sorant 27 AUG 69

APOLLO GUIDANCE AND NAVIGATION

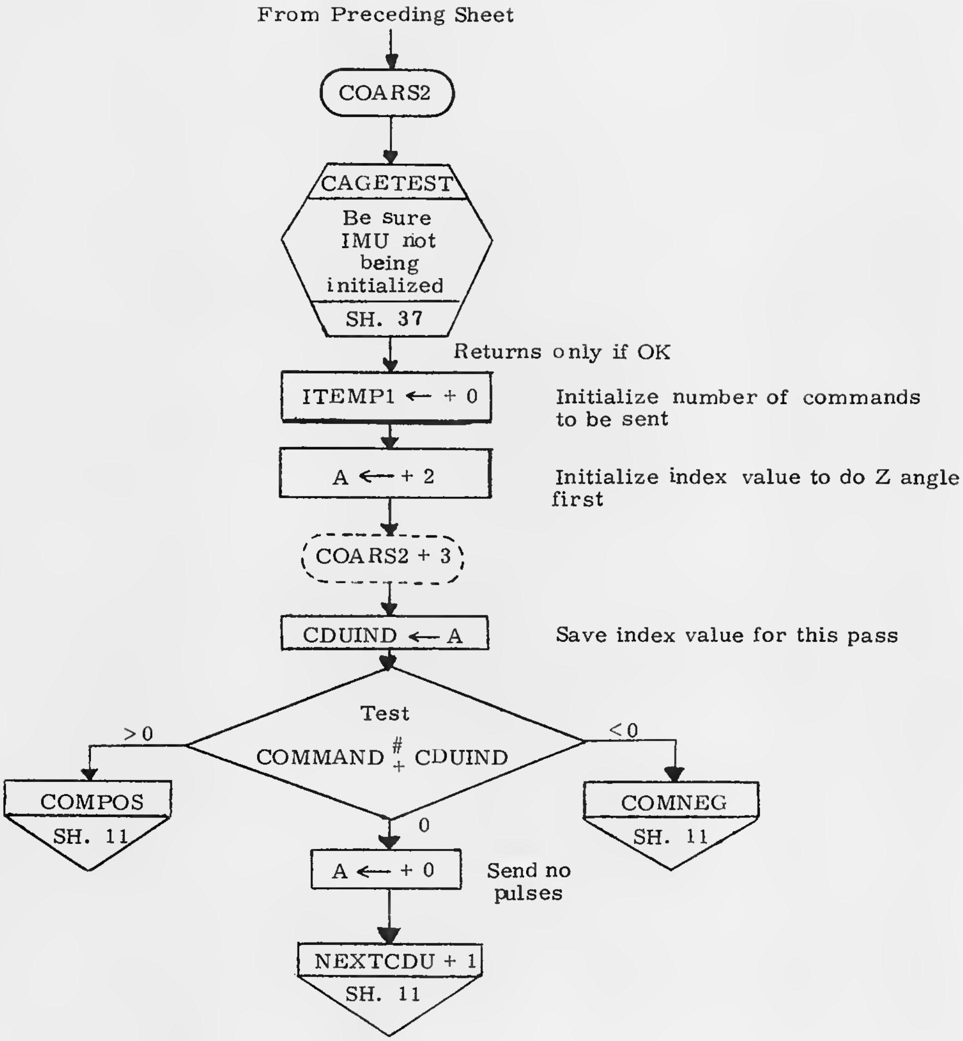
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO.
FC-3220

REV 2

SHEET 9 OF 41



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IMU Mode Switching Routines

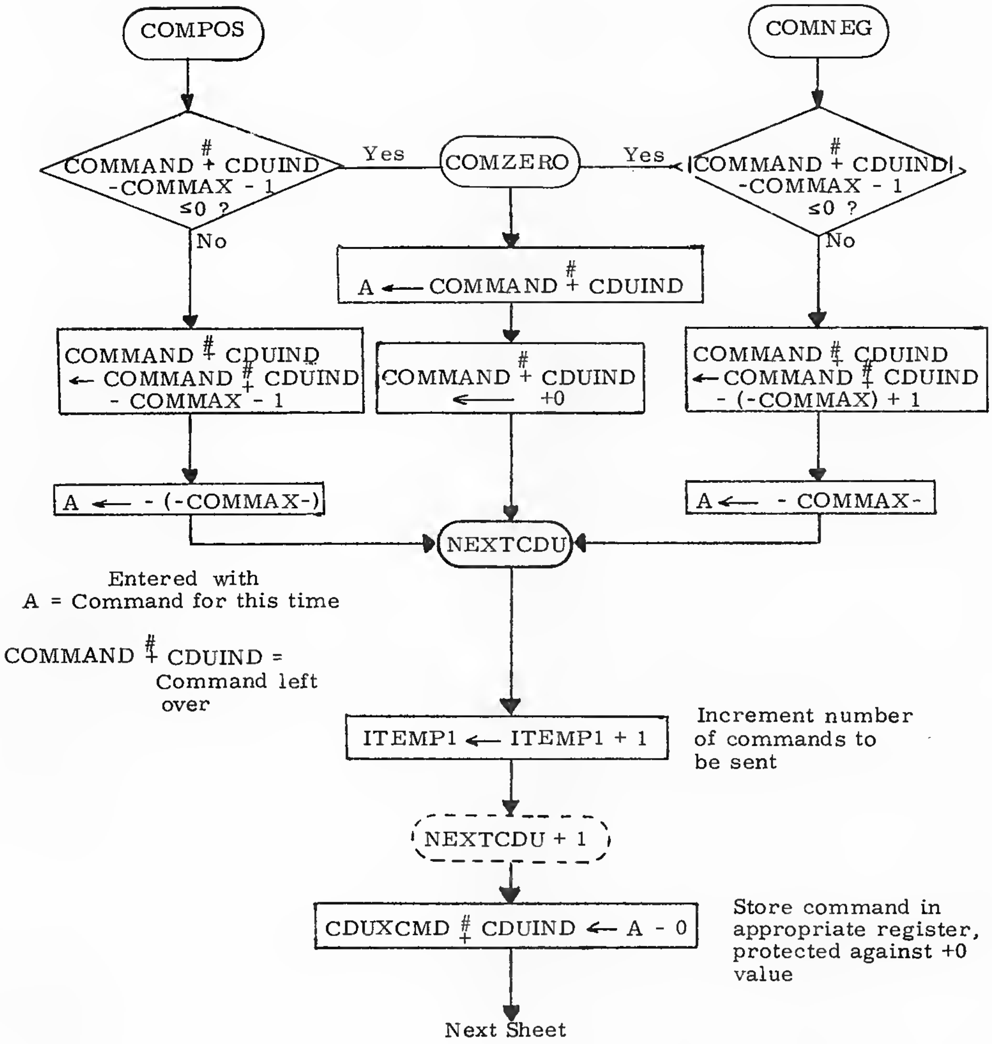
DRAWN
PRGMR D. Millard 5/28/69
ANALST
DOCMR A. M. Sorantz 28 AUG 69
APPR'D A. M. Sorantz 28 AUG 69

LUMINARY 1D

DOCUMENT NO.
FC-3220

REV 2

SHEET 10 OF 41



Entered with
A = Command for this time

COMMAND $\overset{\#}{+}$ CDUIND =
Command left
over

Increment number
of commands to
be sent

Store command in
appropriate register,
protected against +0
value

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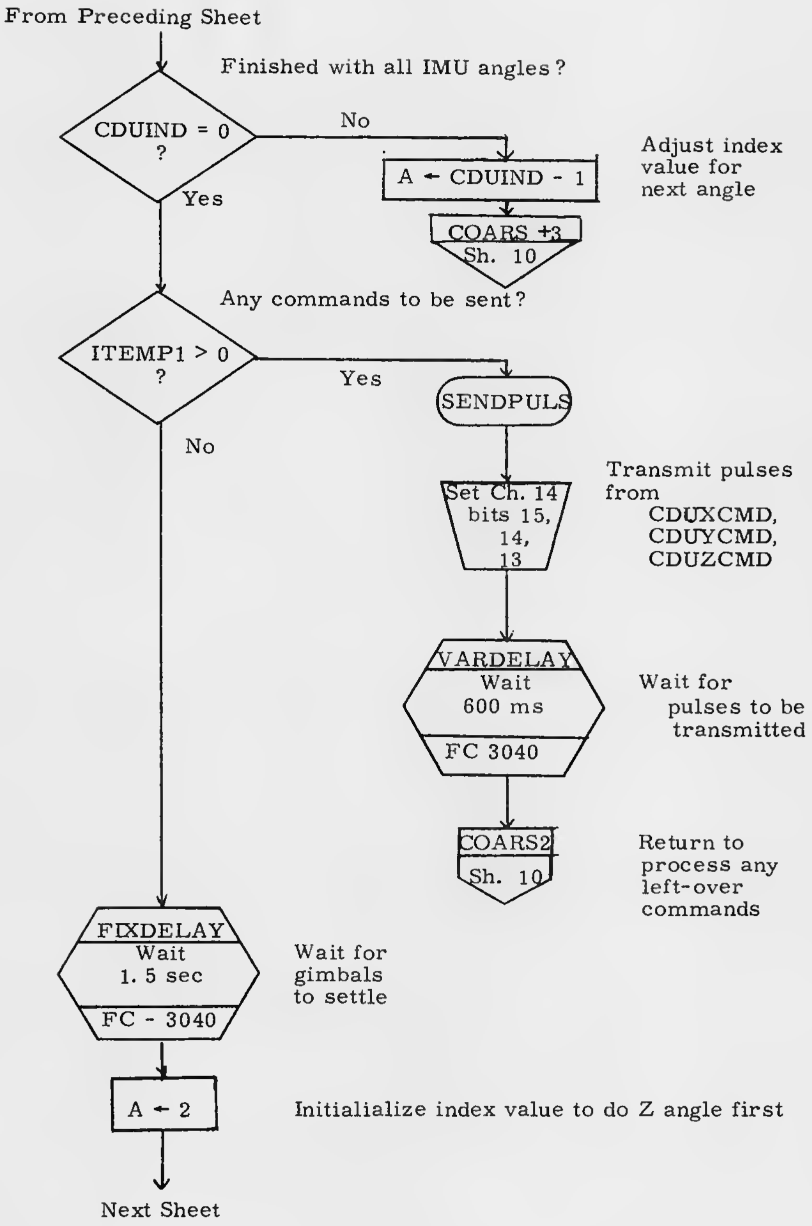
DRAWN PRGMR D Millard 4/22/69 ANALST DOCMR A. M. Sorantz APPR'D A. M. Sorantz	IMU Mode Switching Routines
	LUMINARY 1D
	DOCUMENT NO. FC-3220
	REV 2
	SHEET 11 OF 41



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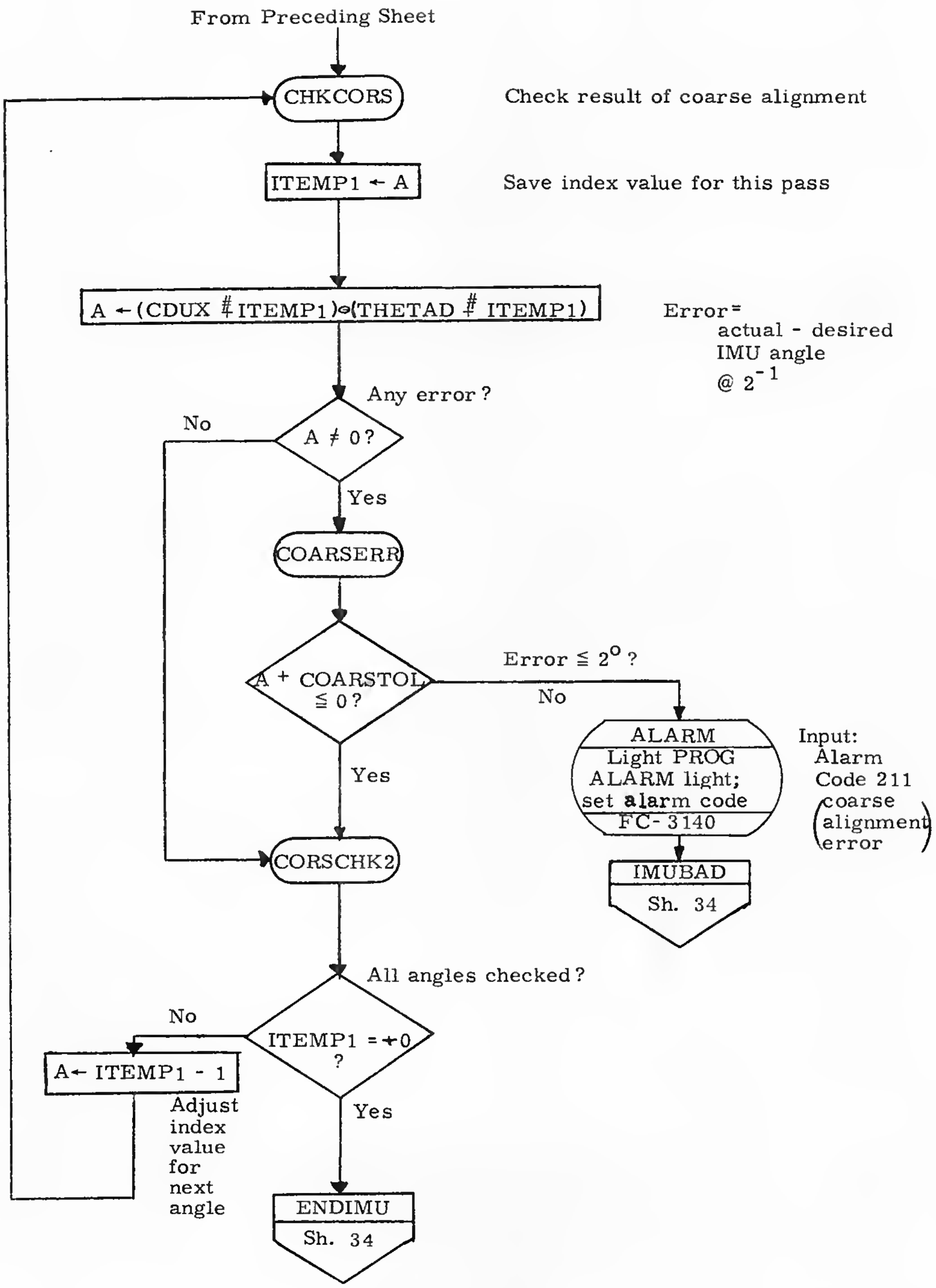
DRAWN		IMU Mode Switching Routines	
PRGMR D. A. Millard	8/28/69		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3220
DOCMR	28 Aug 69		
APPR'D	28 Aug 69	REV 2	SHEET 12 OF 41



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APOLLO GUIDANCE AND NAVIGATION

IMU Mode Switching Routines

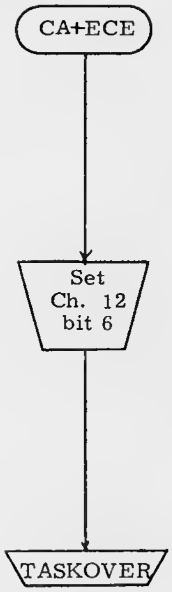
DRAWN
PRGMR D Millard 8/25/69
ANALST
DOCMR A. M. Sorant 28 Aug
APPR'D A. M. Sorant 28 Aug

LUMINARY 1D

DOCUMENT NO. FC-3220

REV 2

SHEET 13 OF 41



Enable IMU CDU error counters

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DRAWN
PRGMR D.L. Millard 8/28/69
ANALST
DOCMR G. M. Levant 28 Aug 69
APPR'D G. M. Levant 28 Aug 69

APOLLO GUIDANCE AND NAVIGATION

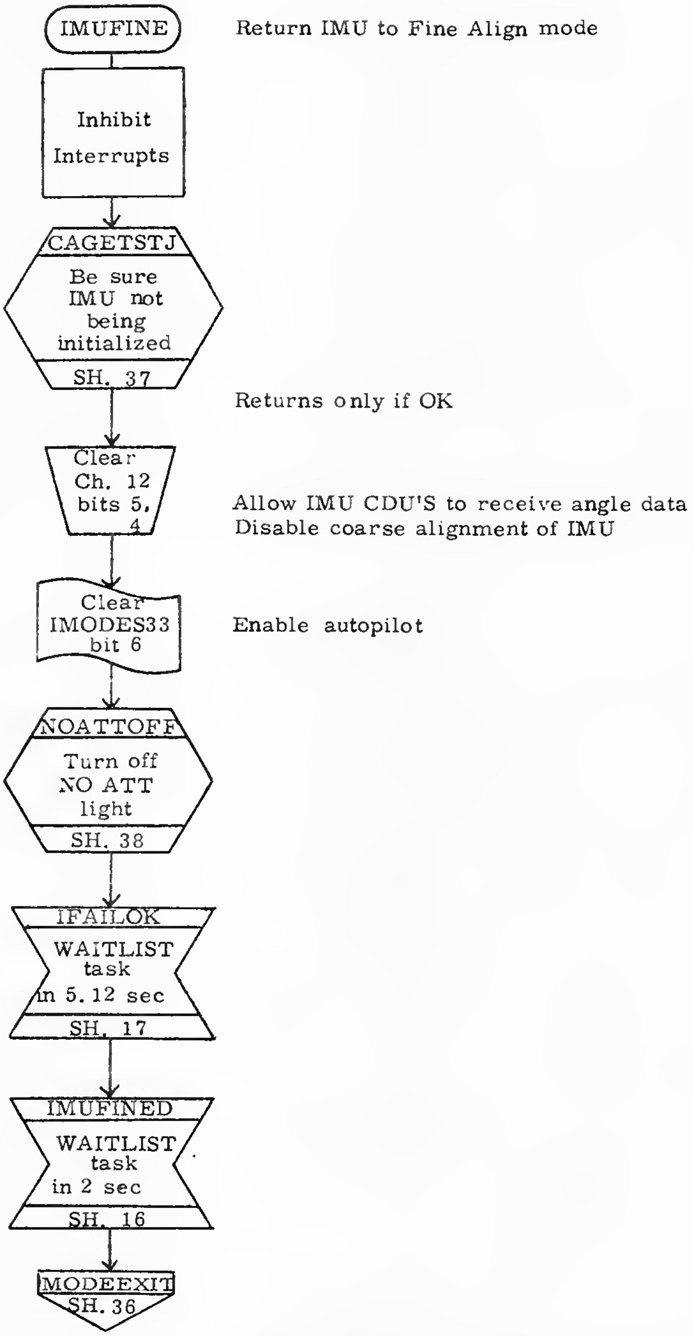
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO. FC-3220

REV 2

SHEET 14 OF 41



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IMU Mode Switching Routines

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ANALST
DOCMR 28 Aug 69
APPR'D A. M. 28 Aug 69

LUMINARY 1D

DOCUMENT NO. FC-3220

REV 2

SHEET 15 OF 41

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DRAWN
PRGMR
ANALST
DOCMR
APPR'D

APOLLO GUIDANCE AND NAVIGATION

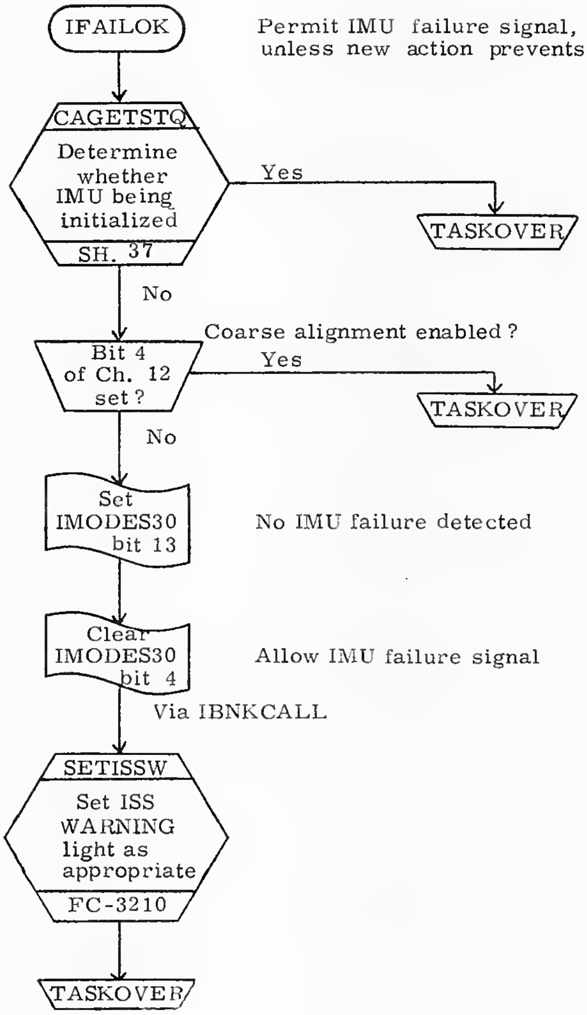
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO.
FC-3220

REV 2

SHEET 16 OF 41



Permit IMU failure signal, unless new action prevents it

No IMU failure detected

Allow IMU failure signal

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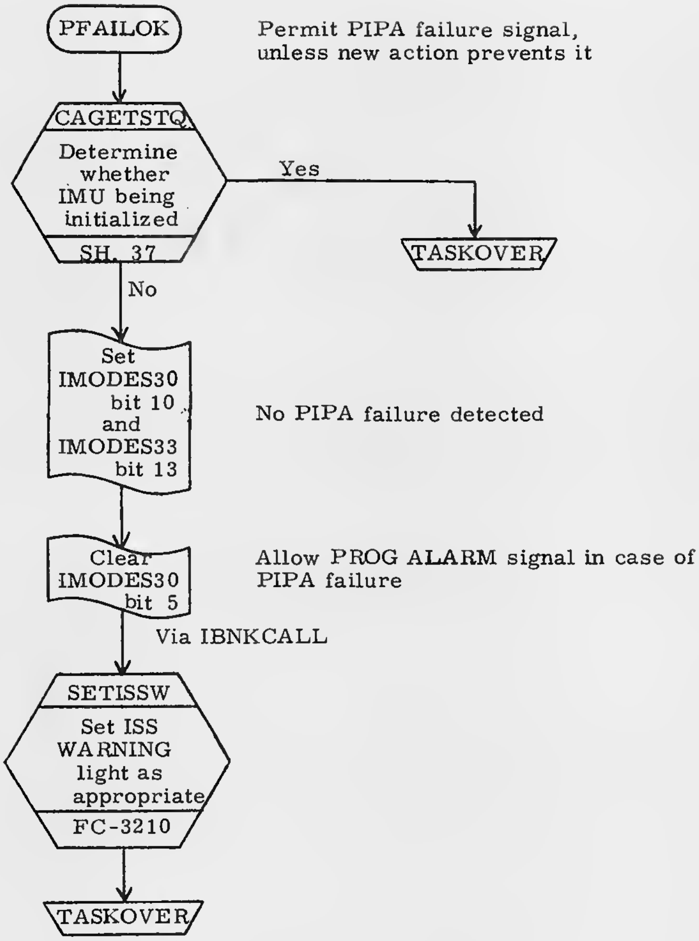
DRAWN	IMU Mode Switching Routines
PRGMR D. Millard 8/28/69	
ANALST	LUMINARY 1D
DOCMR A. M. Sorant 8/28/69	DOCUMENT NO. FC-3220
APPR'D A. M. Sorant 8/28/69	REV 2 SHEET 17 OF 41



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DRAWN
PRGMR D. Millard 8/28/69
ANALST
DOCMR A. M. Grant 8/28/69
APPR'D A. M. Grant 8/28/69

APOLLO GUIDANCE AND NAVIGATION

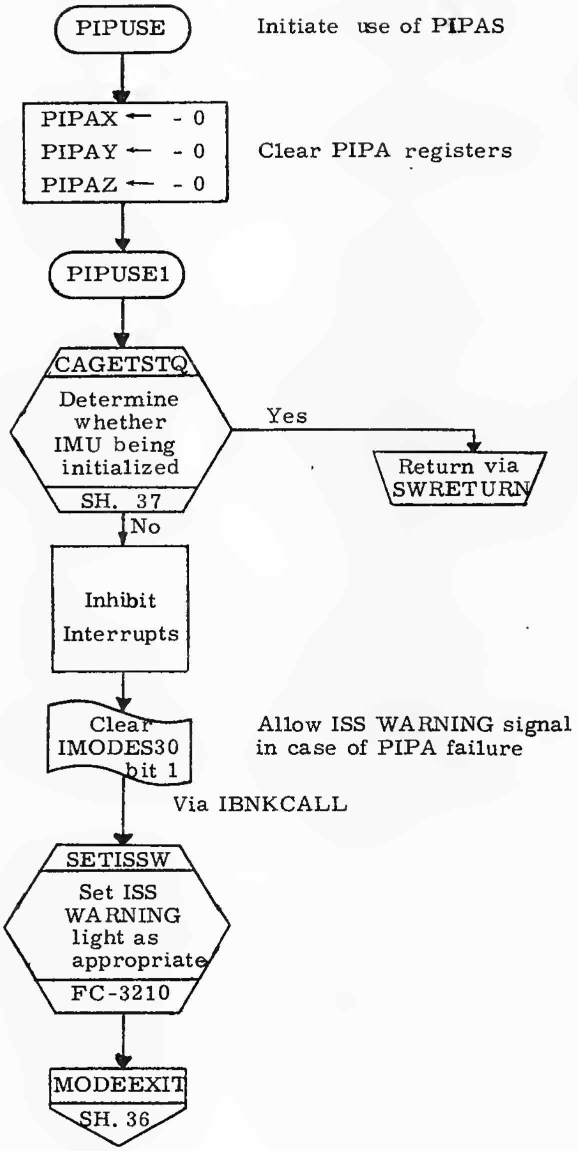
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO.
FC-3220

REV 2

SHEET 18 OF 41



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DRAWN
PRGMR D. Millard
ANALST
DOCMR G. M. Lorant 8/28/69
APPR'D G. M. Lorant 8/28/69

APOLLO GUIDANCE AND NAVIGATION

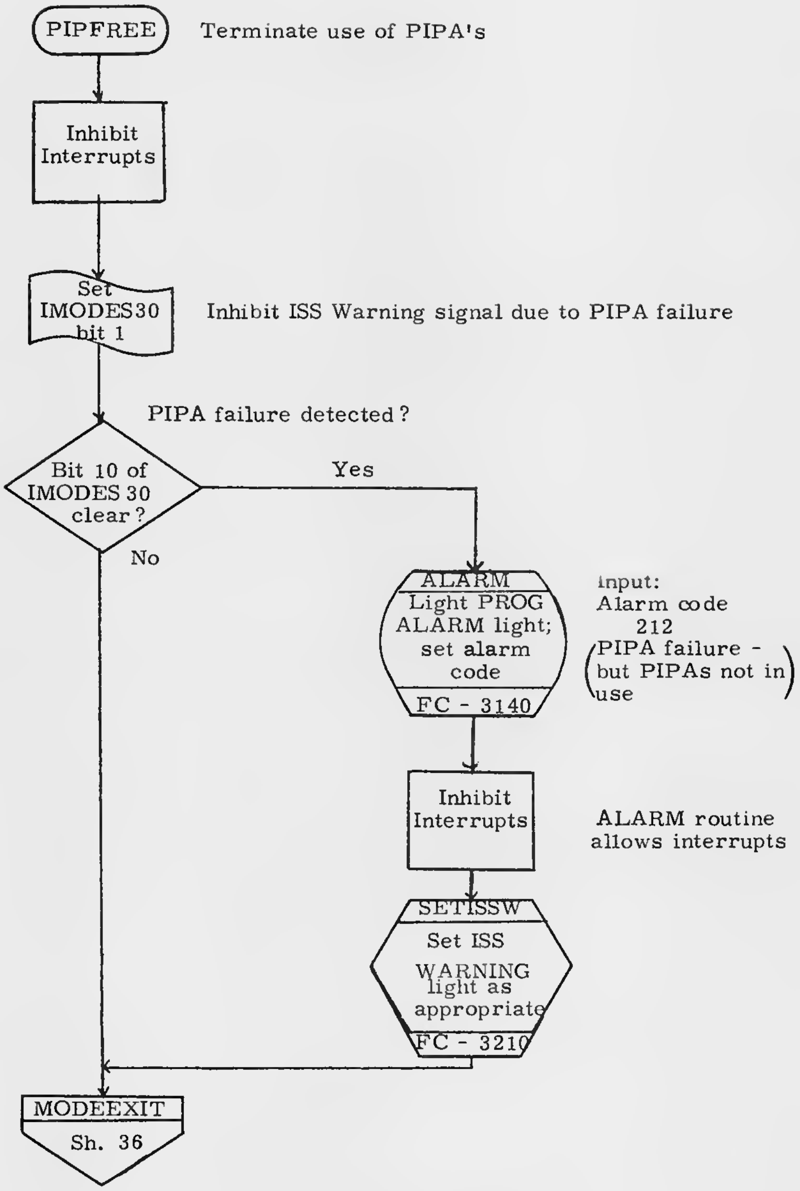
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO. FC-3220

REV 2

SHEET 19 OF 41



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DRAWN
PRGMR D.A. Millard 8/20/69
ANALST
DOCMR A. M. Sorant 8/28/69
APPR'D A. M. Sorant 8/28/69

APOLLO GUIDANCE AND NAVIGATION

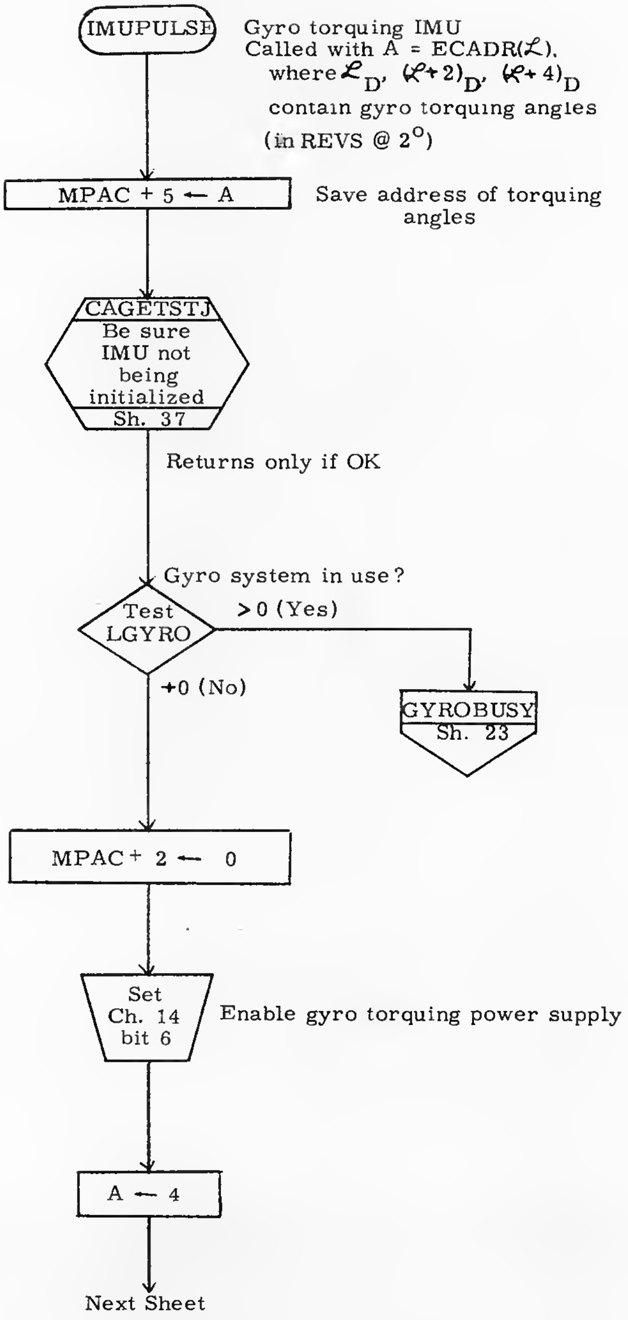
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO. FC-3220

REV 2

SHEET 20 OF 41



Gyro torquing IMU
Called with A = ECADR($\mathcal{L}$), where $\mathcal{L}_D$, $(\mathcal{L}+2)_D$, $(\mathcal{L}+4)_D$ contain gyro torquing angles (in REVS @ 2^0)

Save address of torquing angles

Returns only if OK

Gyro system in use?

Enable gyro torquing power supply

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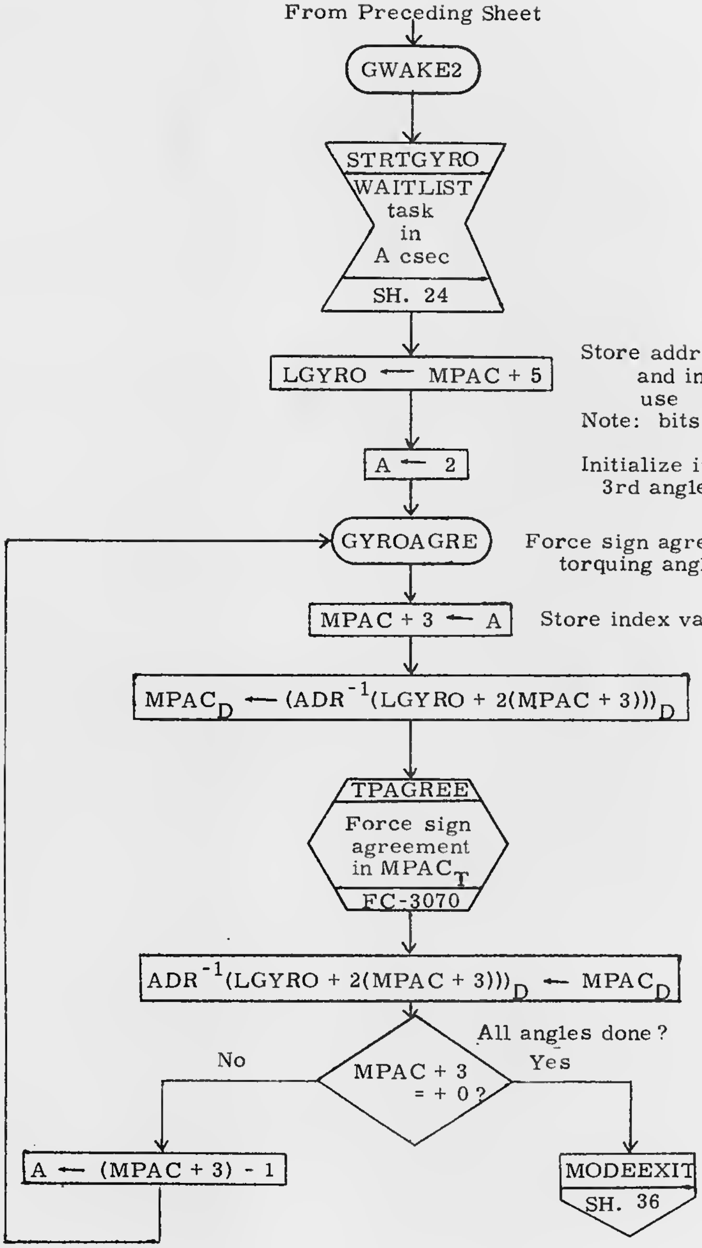
DRAWN		IMU Mode Switching Routines	
PRGMR D. Millard	8/28/69		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3220
DOCMR A. M. Grant	8/28/69	REV 2	SHEET 21 OF 41
APPR'D A. M. Grant	8/28/69		



Store address of torquing angles and indicate gyro system in use

Note: bits 14-12 zero (See sh. 24)

Initialize index value to process 3rd angle first

Force sign agreement in each gyro torquing angle

Store index value for this pass

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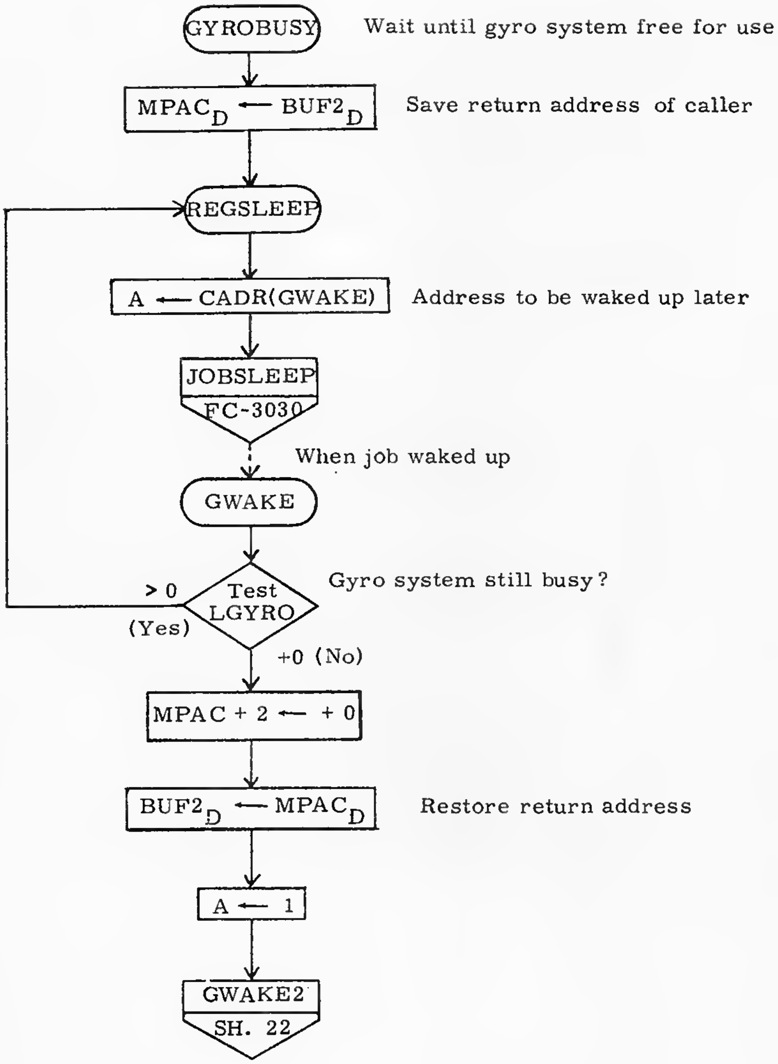
DRAWN		IMU Mode Switching Routines	
PRGMR	8/28/69	LUMINARY 1D	DOCUMENT NO. FC-3220
ANALST			
DOCMR A. M.	8/28/69		
APPR'D A. M.	8/28/69	REV 2	SHEET 22 OF 41



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APOLLO GUIDANCE AND NAVIGATION

DRAWN
PRGMR D. Millard 4/25/67
ANALST
DOCMR A. M. Grant 8/25/68
APPR'D A. M. Grant 8/28/68

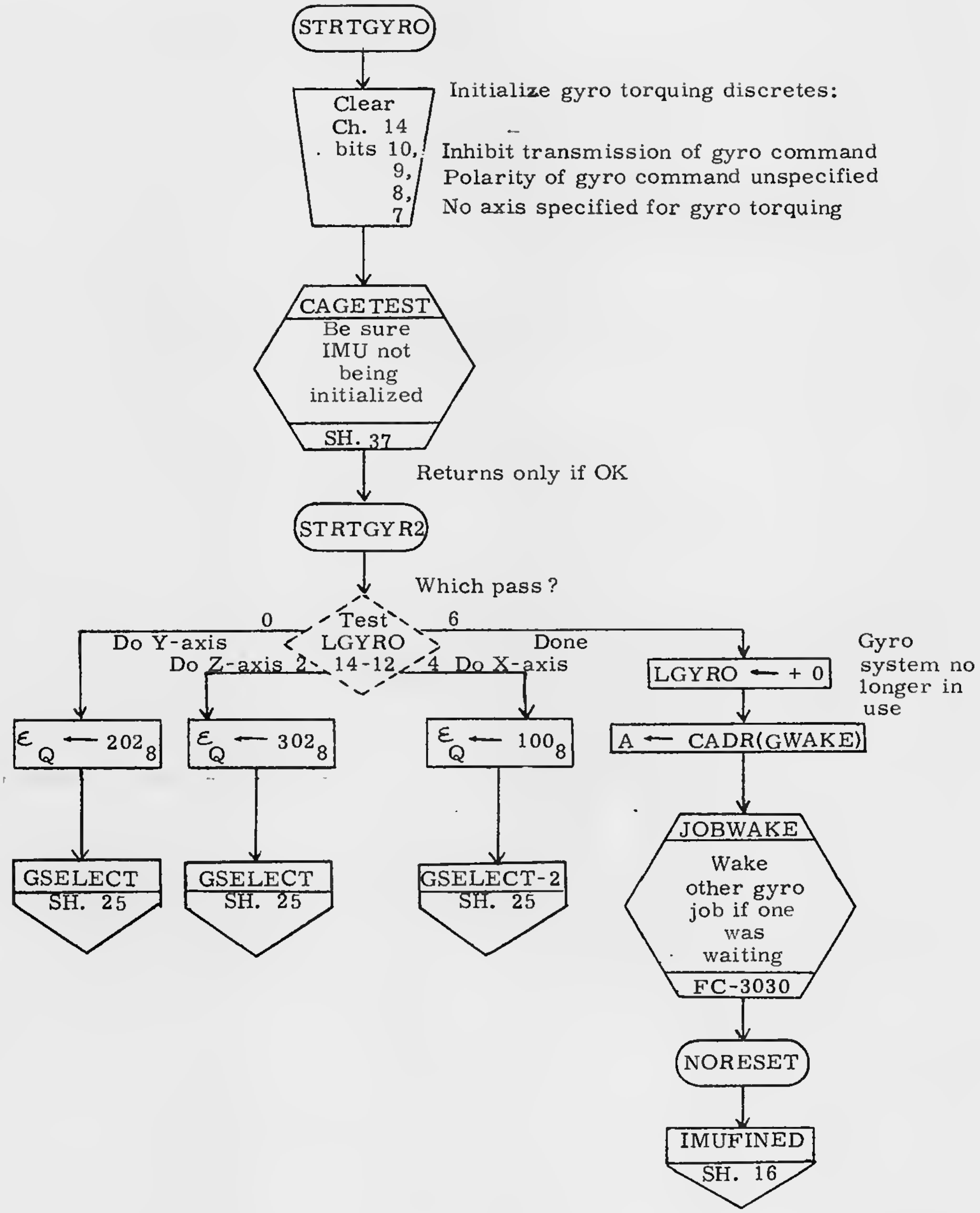
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO. FC-3220

REV 2

SHEET 23 OF 41



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DRAWN
PRGMR D Millard 8/20/69
ANALST
DOCMR AM Grant 8/25/69
APPR'D AM Grant 8/29/69

APOLLO GUIDANCE AND NAVIGATION

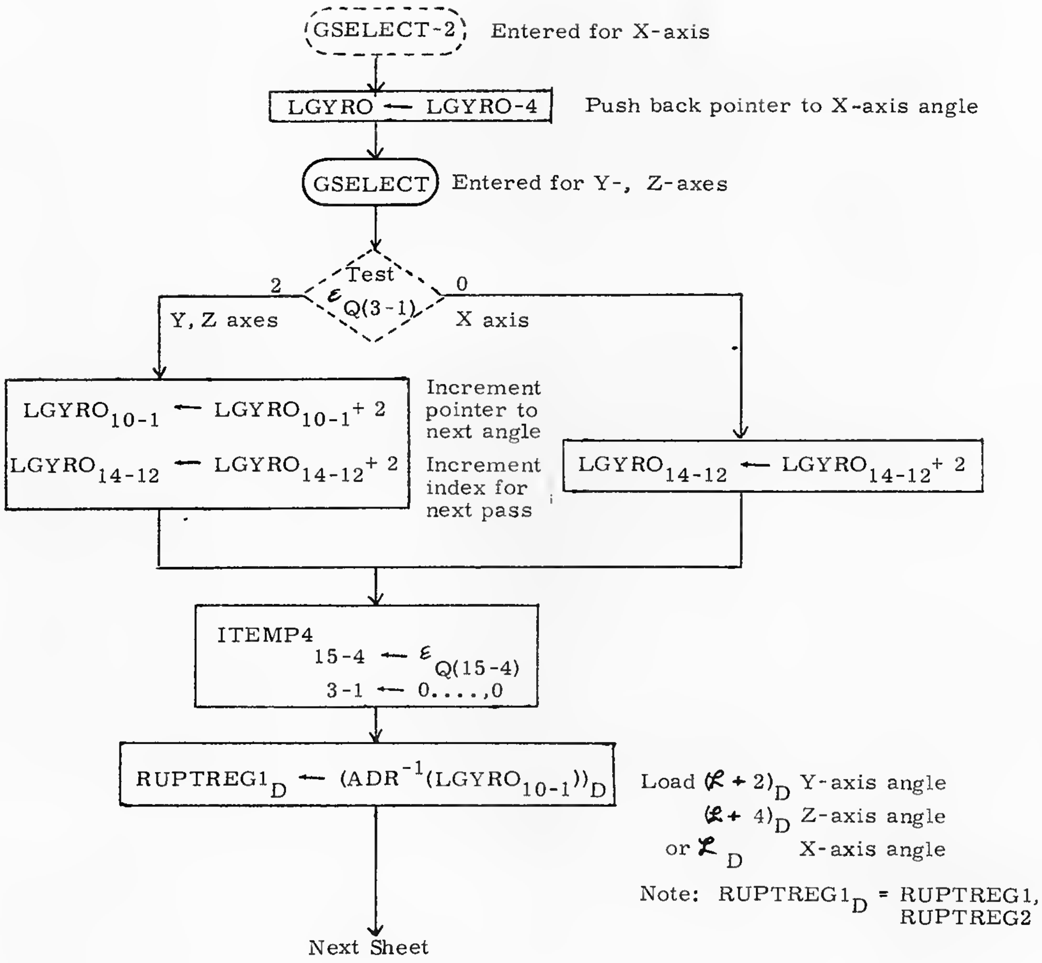
IMU Mode Switching Routines

LUMINARY 1D

DOCUMENT NO.
FC-3220

REV 2

SHEET 24 OF 41



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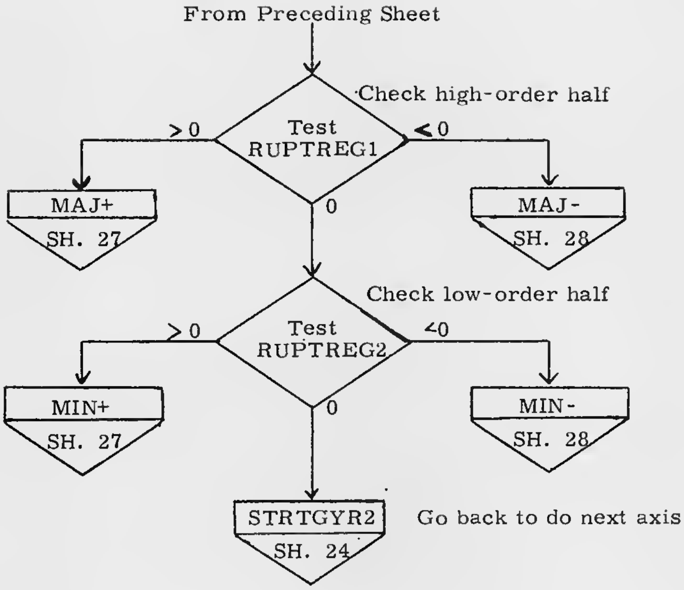
APOLLO GUIDANCE AND NAVIGATION

IMU Mode Switching Routines

DRAWN
PRGMR D Millard [illegible]
ANALST
DOCMR A M Grant 8/28/69
APPR'D A M Grant 8/28/69

LUMINARY 1D
DOCUMENT NO. FC-3220
REV 2
SHEET 25 OF 41



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APOLLO GUIDANCE AND NAVIGATION

IMU Mode Switching Routines

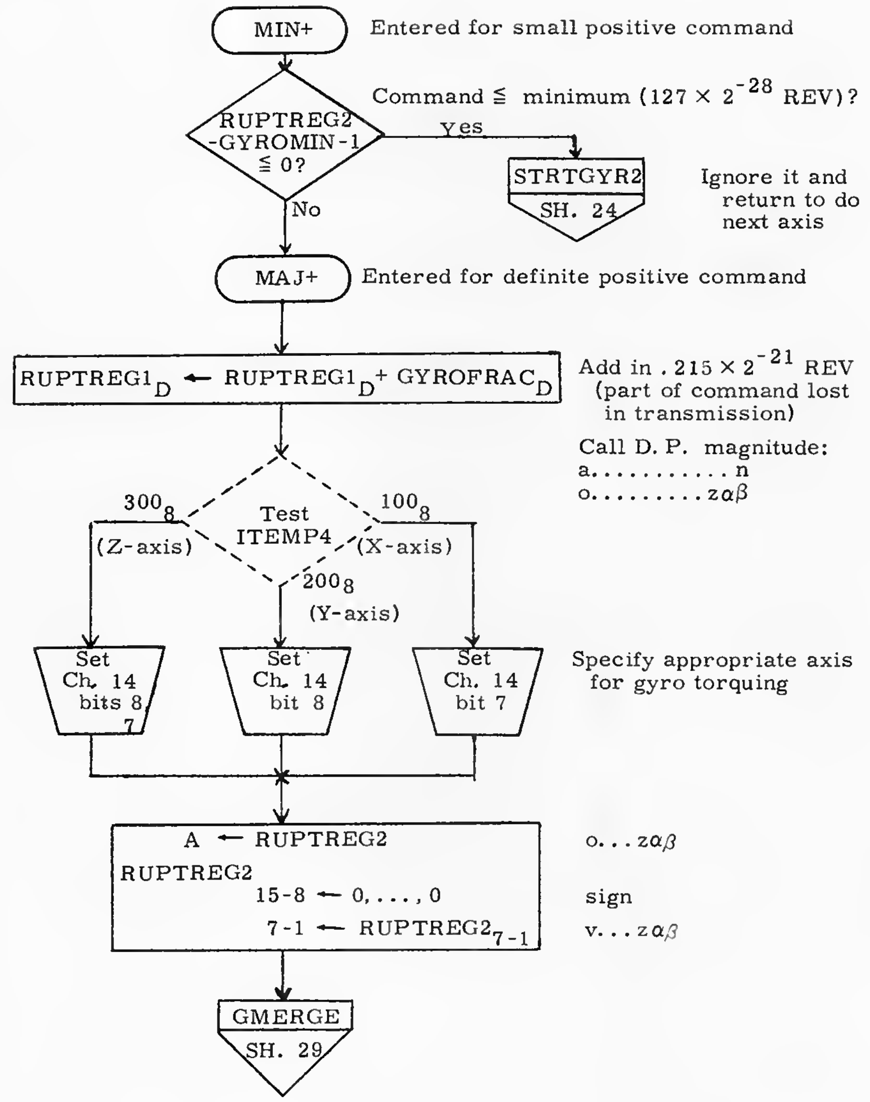
DRAWN
PRGMR D.A. Millard
ANALST
DOCMR A.M. Sorant 8/28/69
APPR'D A.M. Sorant

LUMINARY 1D

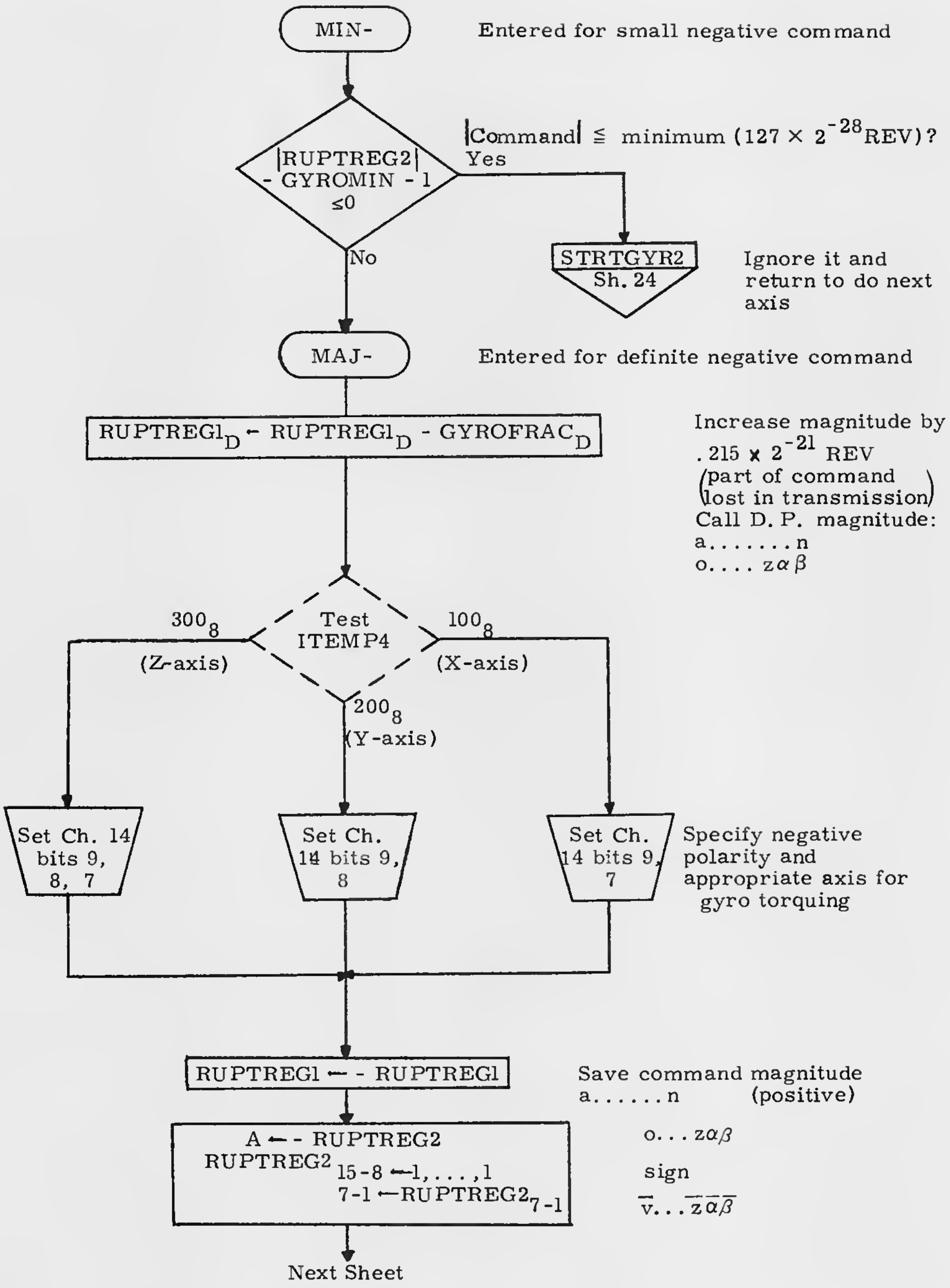
DOCUMENT NO. FC-3220

REV 2

SHEET 26 OF 41



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
DRAWN	IMU Mode Switching Routines
PRGMR	
ANALST	LUMINARY 1D
DOCMR	DOCUMENT NO. FC-3220
APPR'D 8/28/69	REV 2 — SHEET 27 OF 41



Entered for small negative command

|Command| ≤ minimum (127 × 2^{-28}REV)?

Ignore it and return to do next axis

Entered for definite negative command

Increase magnitude by .215 x 2^{-21} REV (part of command lost in transmission)
Call D. P. magnitude:
a. . . . . . . n
o. . . . zαβ

Specify negative polarity and appropriate axis for gyro torquing

Save command magnitude
a. . . . . . n (positive)
o. . . zαβ
sign
$\bar{v}$. . . $\bar{z}\bar{\alpha}\bar{\beta}$

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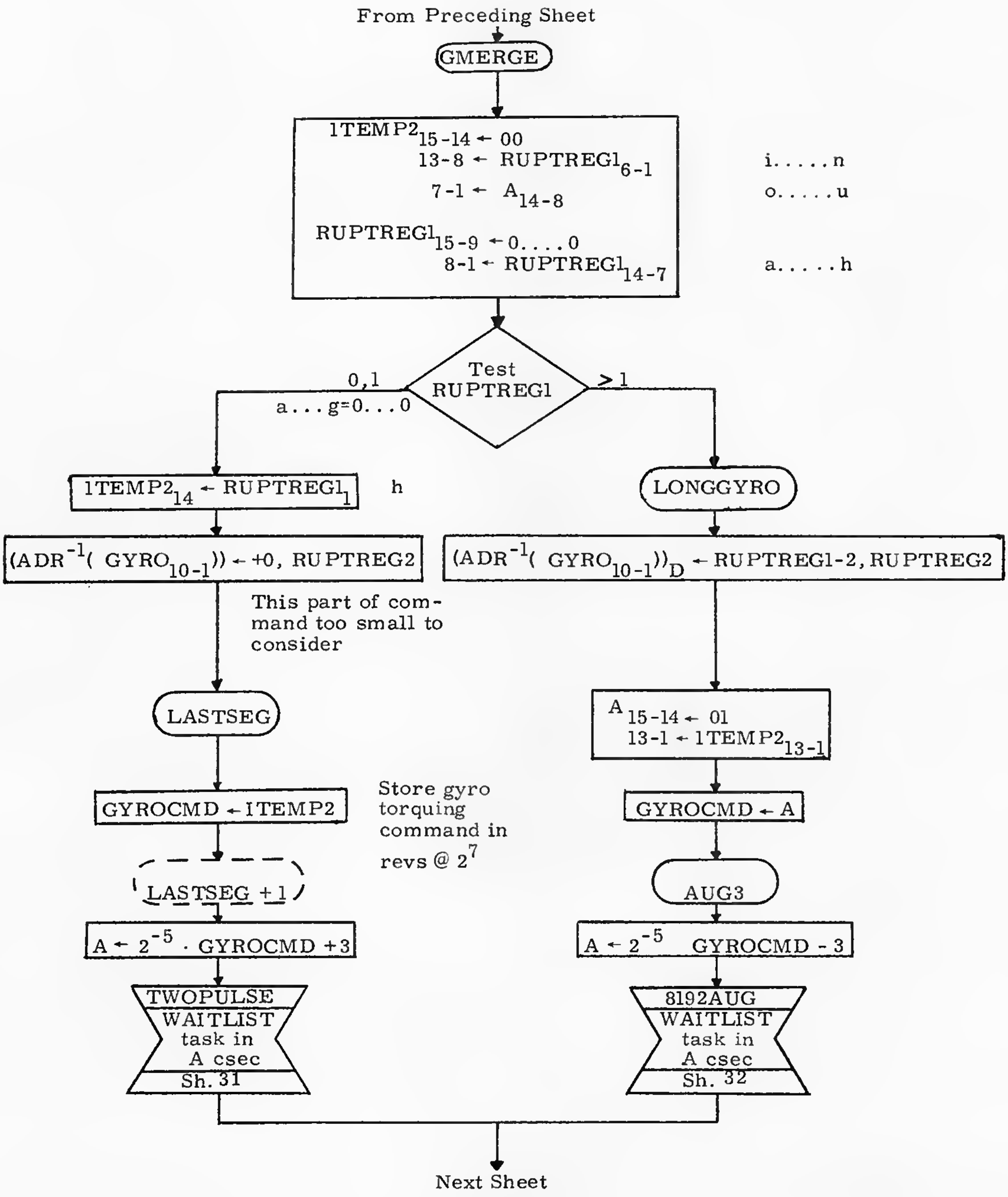
DRAWN		IMU Mode Switching Routines	
PRGMR	8/28/69		DOCUMENT NO.
ANALST			
DOCMR	8/28/69	LUMINARY 1D	FC-3220
APPR'D	8/28/69	REV 2	SHEET 28 OF 41



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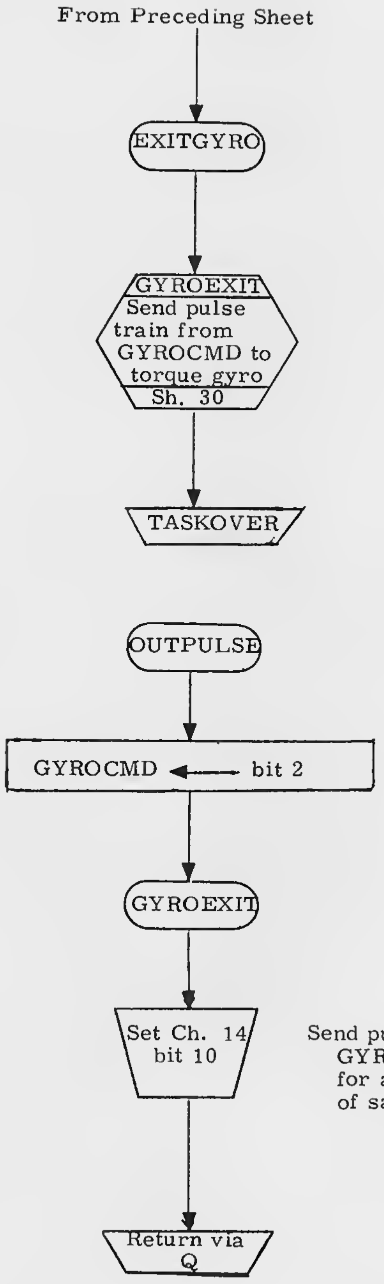
DRAWN		IMU Mode Switching Routines	
PRGMR	[illegible]	LUMINARY 1D	DOCUMENT NO. FC-3220
ANALST			
DOCMR	8/28/69		
APPR'D	8/28/69	REV 2	SHEET 29 OF 41



Send pulse train from
GYROCMD to torque gyro
for axis specified by bits 8-7
of same channel.

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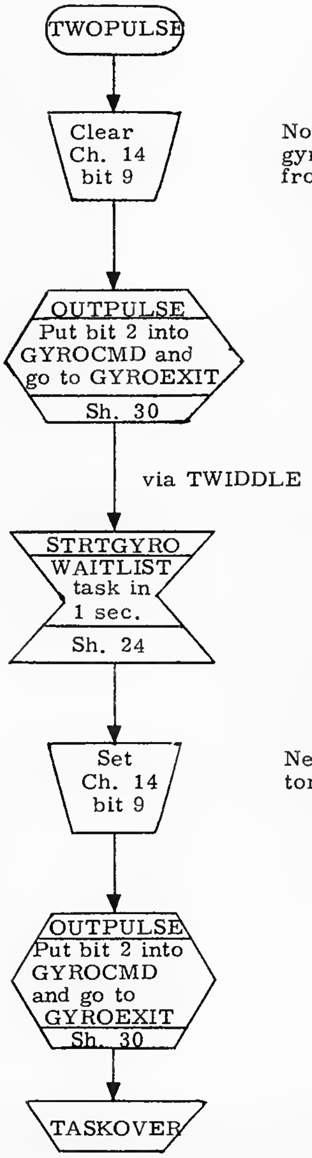
DRAWN		IMU Mode Switching Routines	
PRGMR	D P Millard	8/[illegible]/69		
ANALST			DOCUMENT NO.
DOCMR	AM Sorant	8/28/69	LUMINARY 1D	FC-3220
APPR'D	AM Sorant	8/28/69	REV 2	SHEET 30 OF 41



Not a negative-polarity gyro torquing output from GYROCMD

Negative-polarity gyro torquing output from GYROCMD

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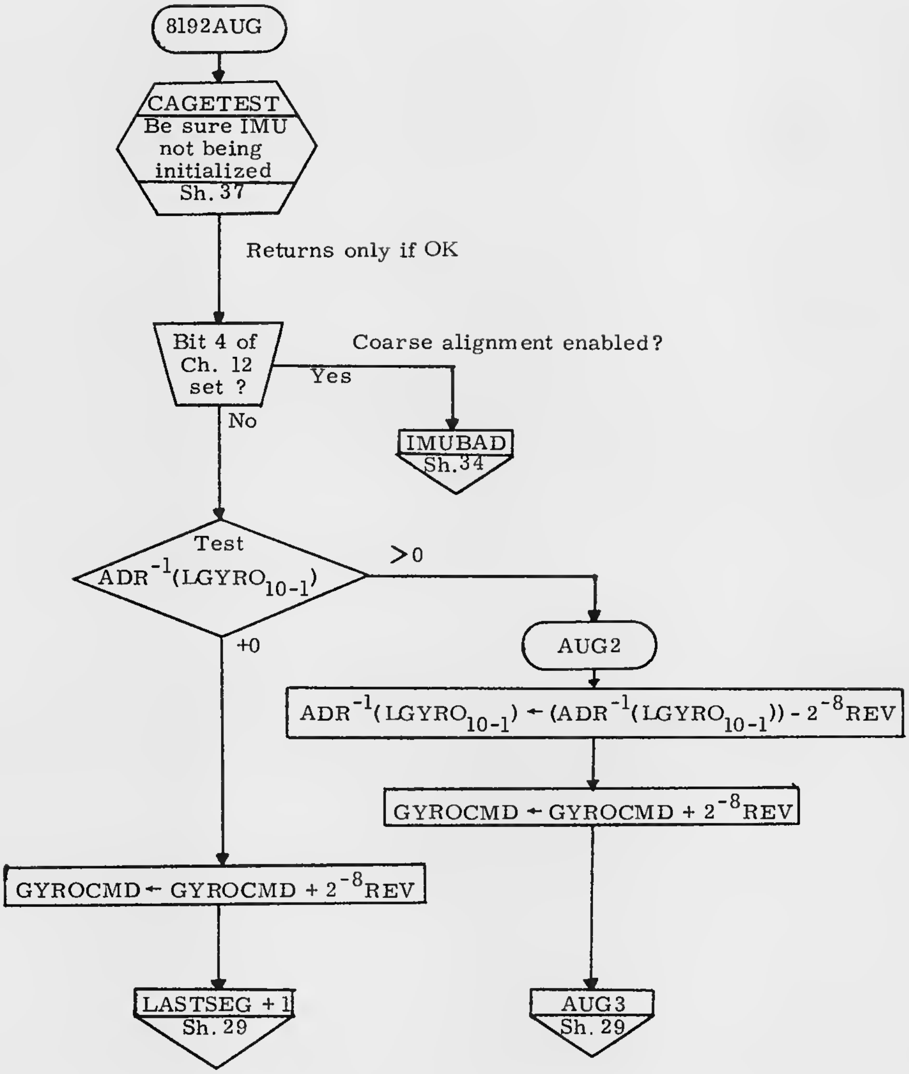
PRGMR D. Millard	6/22/70	LUMINARY 1D	DOCUMENT NO. FC-3220
ANALST			
DOCMR R M Estes	6/22/70		
APPR'D R M Estes	6/22/70	REV 2	SHEET 31 OF 41



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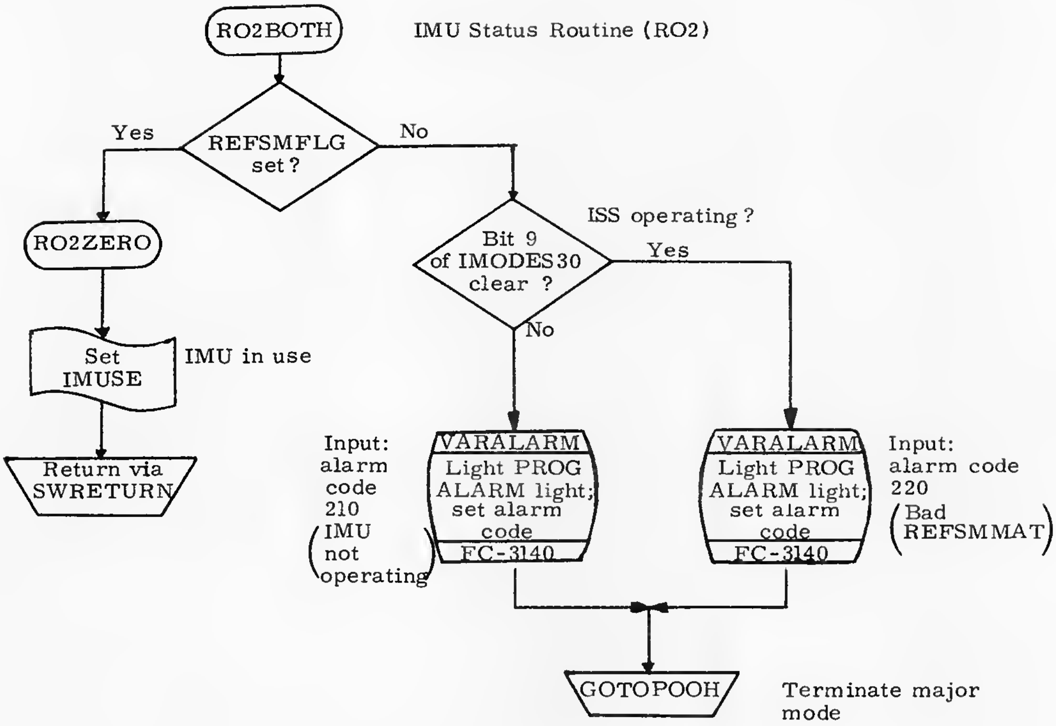

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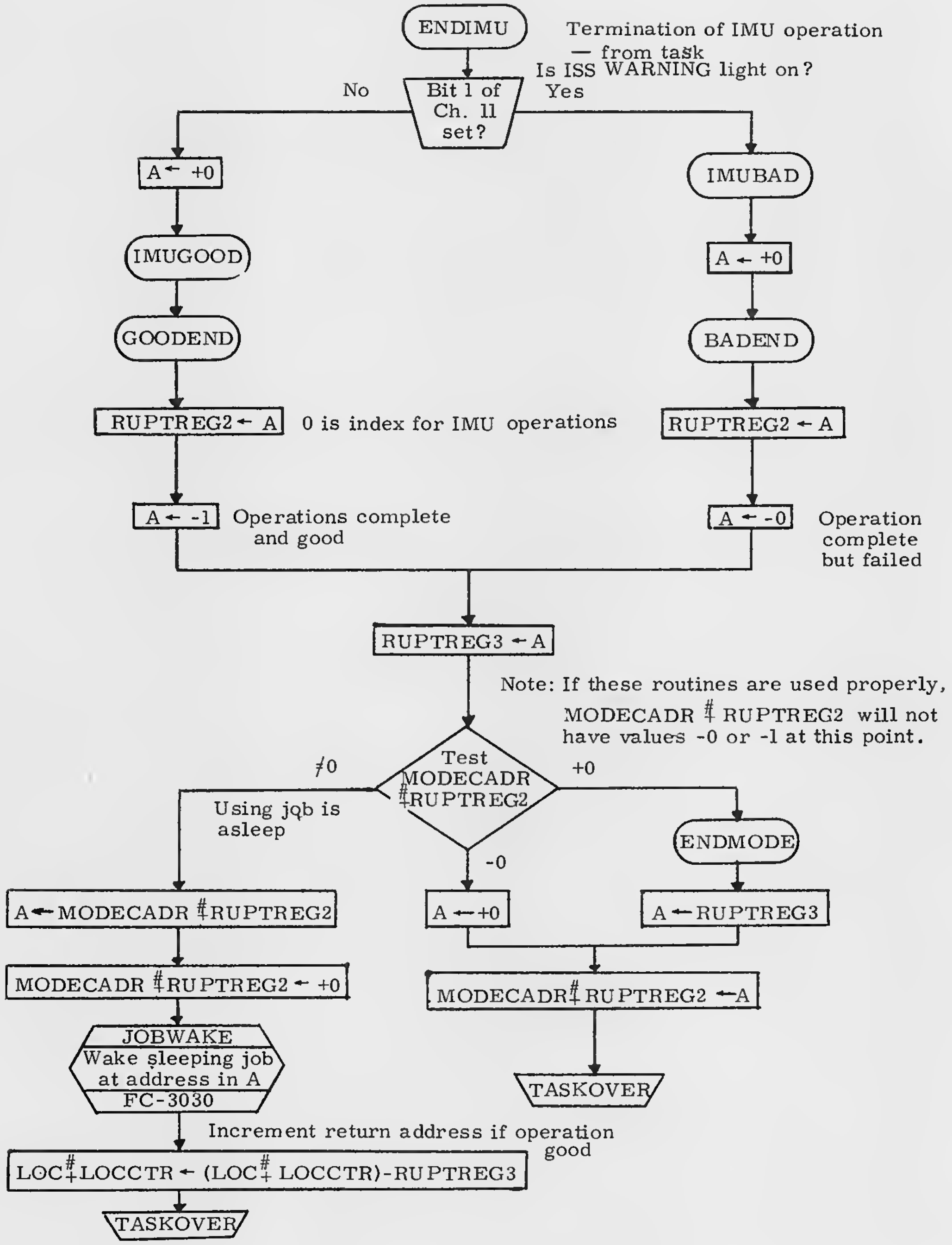
SHEET 33 OF 41



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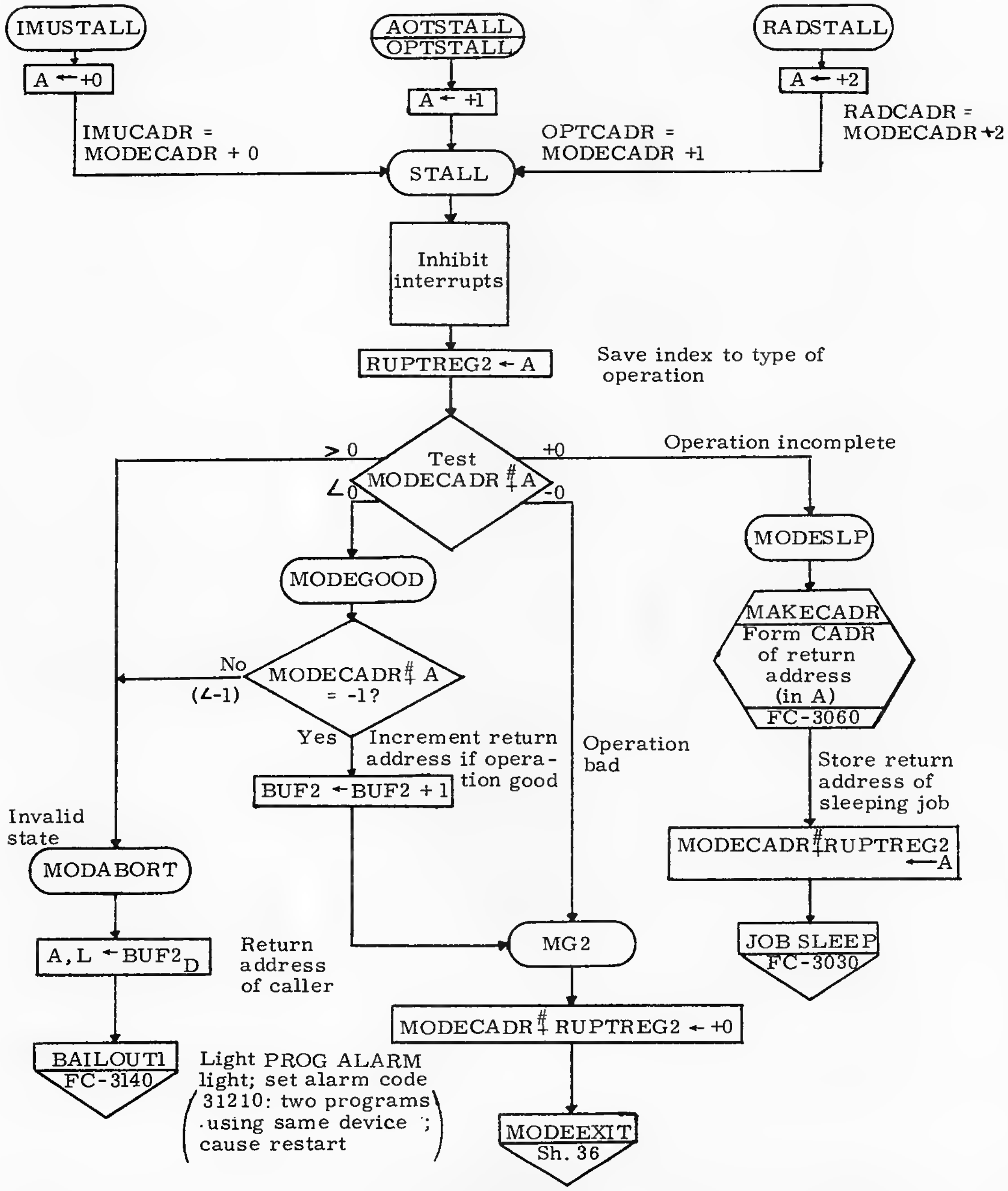
SHEET 34 OF 41



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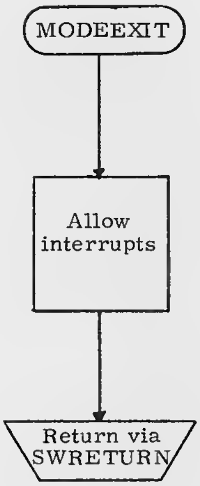

Common return from subroutines

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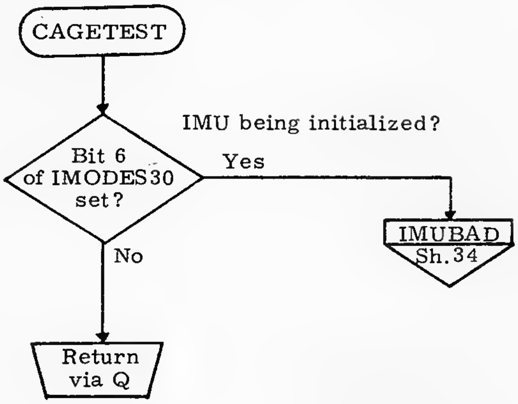
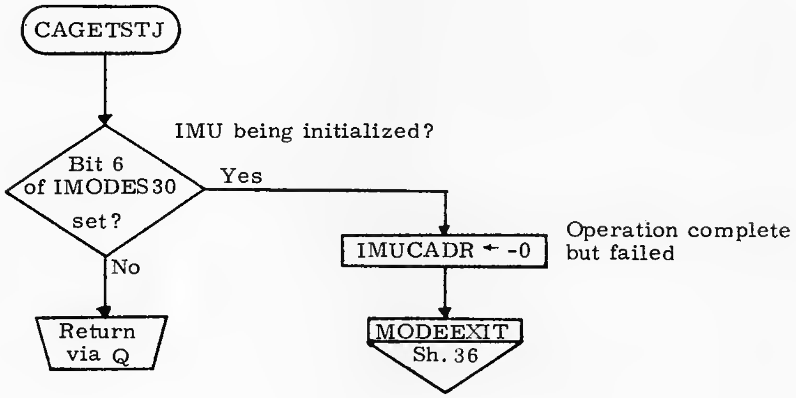
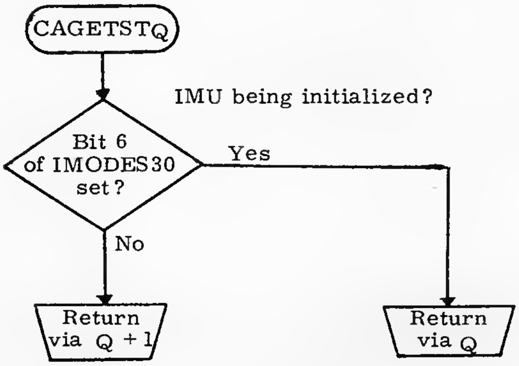
Cage Test Subroutines







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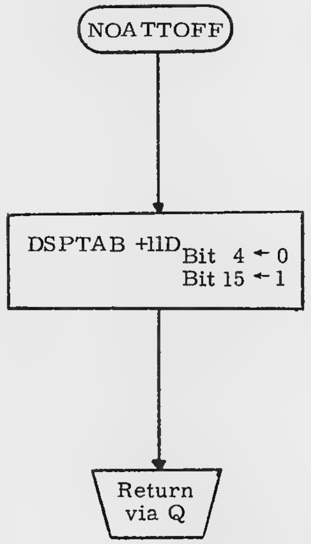

Request NO ATT lamp off
Cause request to be processed

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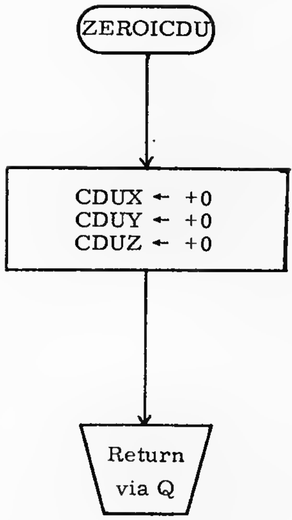

Zero IMU gimbal angle input registers

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SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
ALARM	FC-3140	Light program alarm light; set alarm code	Sh. 2, 3, 13, 20
BAILOUT1	FC-3140	Light program alarm light; set alarm code	Sh. 35
FIXDELAY	FC-3040	Wait specified time	Sh. 12
JOBSLEEP	FC-3030	Put job to sleep	Sh. 23, 35
JOBWAKE	FC-3030	Wake waiting job	Sh. 24, 34
MAKECADR	FC-3060	Form CADR of return address	Sh. 35
SETISSW	FC-3210	Set ISS warning lamp as appropriate	Sh. 5, 17, 18, 19, 20
TPAGREE	FC-3070	Force sign agreement in $MPAC_T$	Sh. 22
VARALARM	FC-3140	Light program alarm light; set alarm code	Sh. 33
VARDELAY	FC-3040	Wait specified time	Sh. 4, 9, 12

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FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	When Tested
DRIFTFLG Flag 2 bit 15	T3RUPT calls gyro compensation	T3RUPT does no gyro compensation		Sh. 8	
IMUSE Flag 0 bit 8	IMU in use	IMU not in use	Sh. 33		
REFSMFLG Flag 3 bit 13	REFSMMAT good	REFSMMAT no good		Sh. 8	Sh. 33
TRACKFLG Flag 1 bit 5	Tracking allowed	Tracking not allowed		Sh. 8	

IMU COMPENSATION PACKAGE

1/PIPA	Sh. 2
GCOMPSUB	Sh. 10
DRIFTSUB	Sh. 11
1/GYRO	Sh. 12
NBDONLY	Sh. 14
LASTBIAS	Sh. 15
IRIGX	Sh. 5
IRIGY	Sh. 7
IRIGZ	Sh. 8

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IMU Compensation Package

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FC-3230

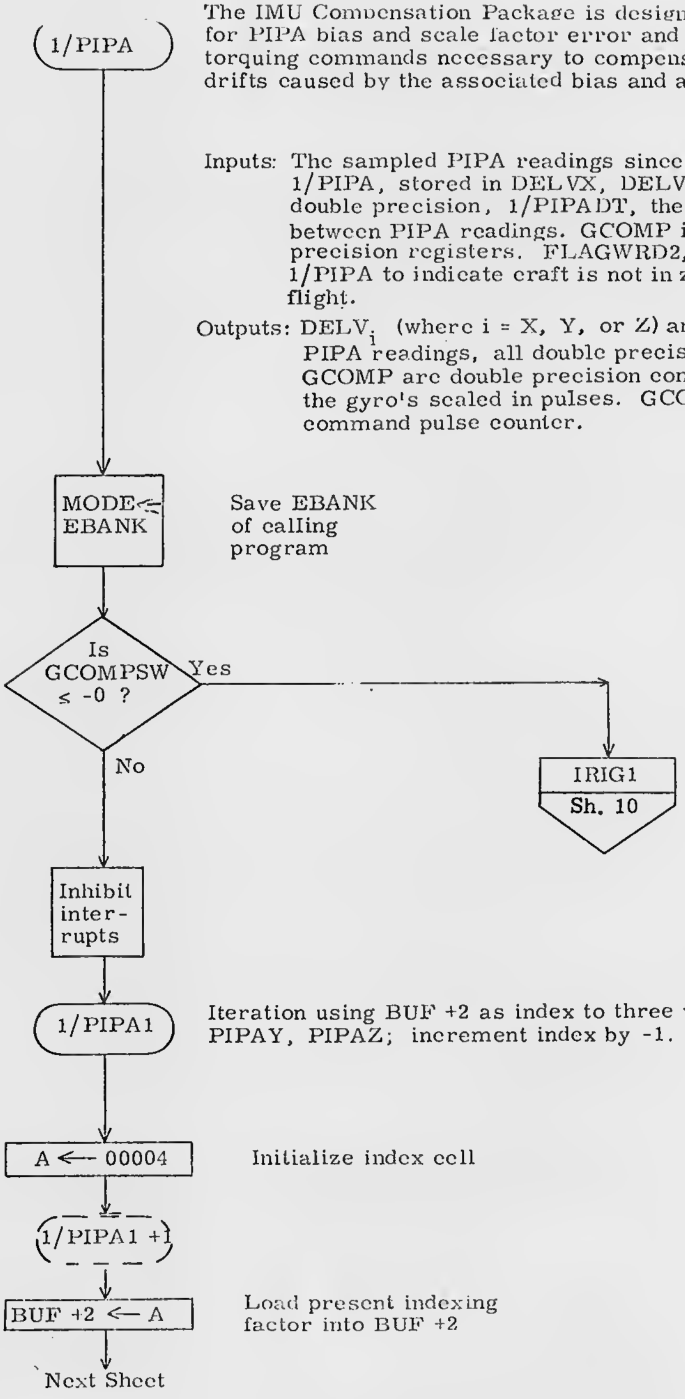
REV 0

SHEET 1 OF 18

The IMU Compensation Package is designed to compensate for PIPA bias and scale factor error and accumulate gyro torquing commands necessary to compensate for the gyro drifts caused by the associated bias and acceleration.

Inputs: The sampled PIPA readings since the last call to 1/PIPA, stored in DELVX, DELVY, and DELVZ in double precision, 1/PIPADT, the time elapsed between PIPA readings. GCOMP is three double precision registers. FLAGWRD2, (bit 15), = 0 during 1/PIPA to indicate craft is not in zero G portion of flight.

Outputs: $DELV_i$ (where i = X, Y, or Z) are the compensated PIPA readings, all double precision quantities. GCOMP are double precision compensation for the gyro's scaled in pulses. GCOMPSW is a command pulse counter.



Save EBANK of calling program

Return if switch is negative.

Iteration using BUF +2 as index to three word table, PIPAX, PIPAY, PIPAZ; increment index by -1.

Initialize index cell

Load present indexing factor into BUF +2

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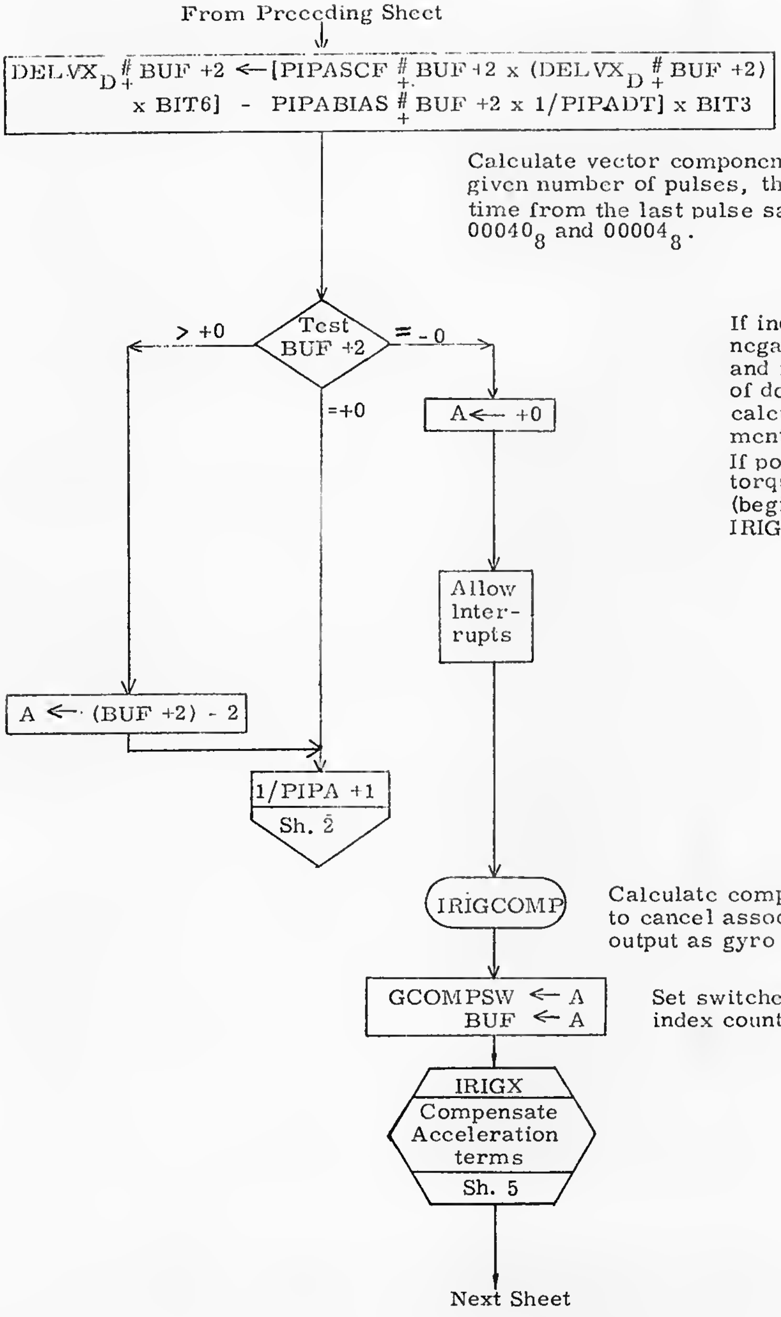
ANALST			LUMINARY 1D	DOCUMENT NO. FC-3230
DOCMR	JBSmith Jr	5/6/70		
APPR'D	Roberta M Estes	5/6/70	REV 0	SHEET 2 OF 18



Calculate vector component changes from a given number of pulses, the bias, and the time from the last pulse sample, scaled by 00040_8 and 00004_8.

If index register is not negative, decrement and return for next set of double-words with calculations of incremental values.

If positive, compute torquing biases (beginning at IRIGCOMP).

Calculate compensation vectors to cancel associated biases to be output as gyro commands.

Set switches and index counter.

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IMU Compensation Package
LUMINARY 1D
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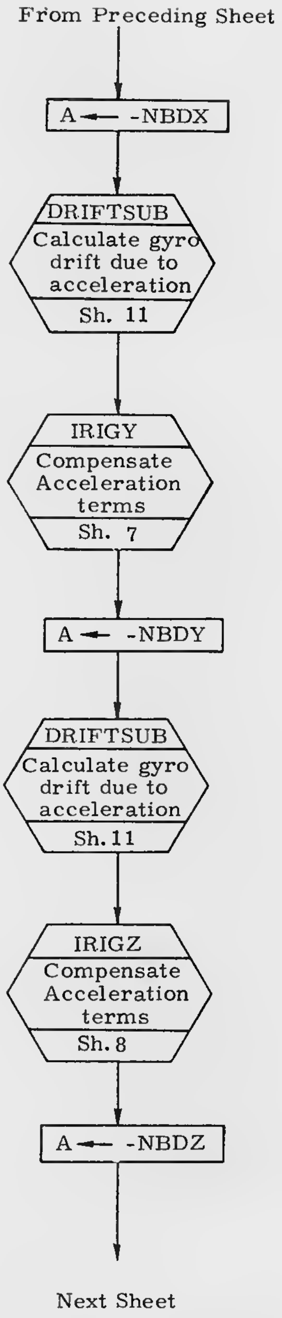

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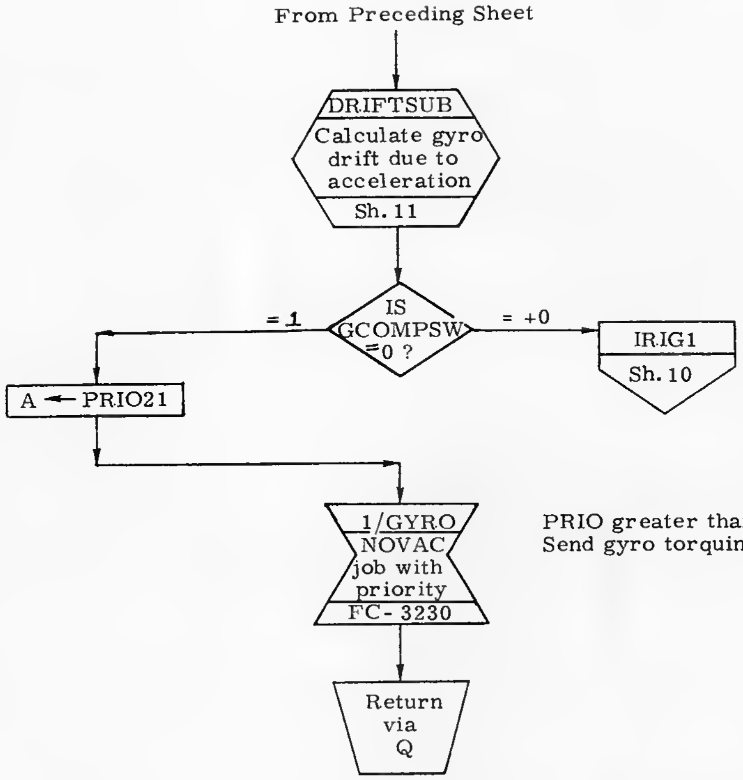
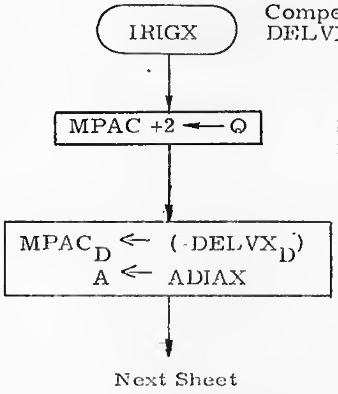
ANALST				
DOCMR	JBSmith Jr	5/6/70	LUMINARY 1D	FC-3230
APPR'D	Robertson M Este	5/6/70	REV 0	SHEET 4 OF 18



PRIO greater than service
Send gyro torquing commands



Compensated PIPAX value is in DELVX scaling ?

Store return address from Q

ADIAX is the positive angular displacement of the gyro case about the input axis (X gyro component due to gravity acting on its input axis).

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ANALST				DOCUMENT NO.
DOCMR	JB Smith Jr	5/6/70	LUMINARY 1D	FC-3230
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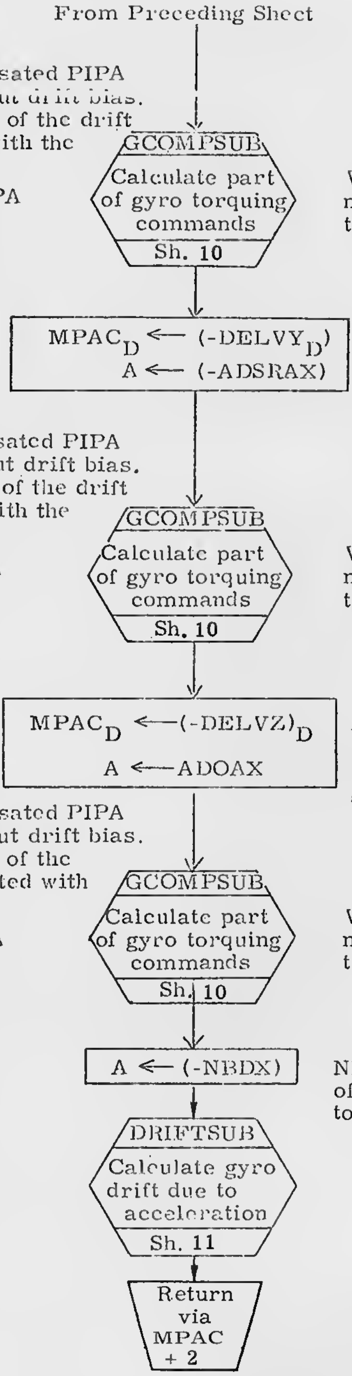

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Output: Drift compensated PIPA pulse in MPAC.

Vector components needed to cancel the associated bias.

ADSRAX is the x-component of the displacement of the acceleration sensitive drift due to a case acceleration drift of one g along the positive spin reference axis.

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Output: Drift compensated PIPA pulse in MPAC.

Vector components needed to cancel the associated bias.

ADOAX is the X-component of the displacement of the gyro output axis due to gravity.

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Output: Drift compensated PIPA pulse in MPAC.

Vector components needed to cancel the associated bias.

NBDX is the X-component of the normal excitation total bias drift

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IMU Compensation Package

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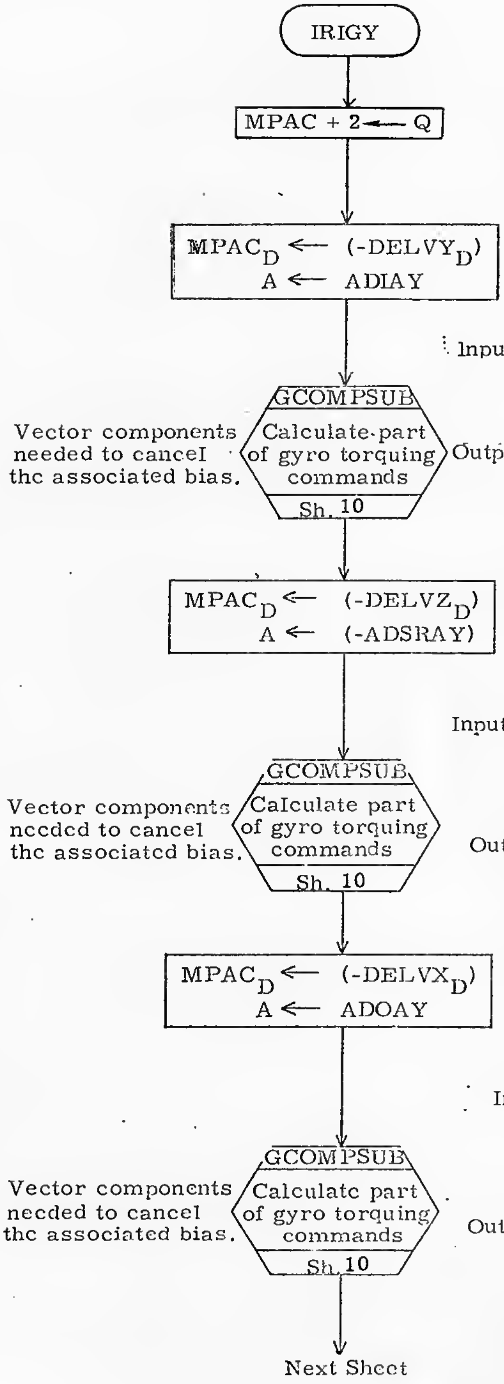

Store return address from Q

ADIAY is the Y-component of the displacement of the acceleration sensitive drift due to a case acceleration drift of one g along the positive input axis.

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Output: Drift compensated PIPA pulse in MPAC.

ADSRAY is the Y-component of the displacement of the acceleration sensitive drift due to a case acceleration drift of one g along the positive spin reference axis.

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Output: Drift compensated PIPA pulse in MPAC

ADOAY is the Y-component of the displacement of the acceleration sensitive drift due to a case acceleration drift of one g along the positive outer axis.

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Output: Drift compensated PIPA pulse in MPAC

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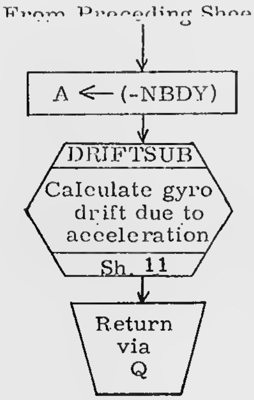
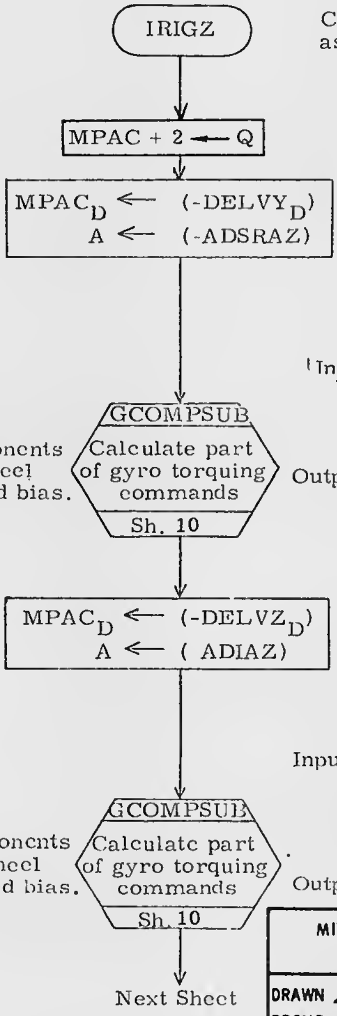


NBDY is Y-component of the displacement of the normal excitation total bias drift.



Compute Z-vector (compensation for associated bias) to go out as a gyro command.

Store return address from Q

Compensated PIPAZ values are in DELVZ.

ADSRAZ is the Z-component of the displacement of the acceleration sensitive drift due to a case acceleration drift of one g along the positive spin reference axis.

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Vector components needed to cancel the associated bias.

Output: Drift compensated PIPA pulse in MPAC

ADIAZ is the Z-component of the displacement of the acceleration sensitive drift due to a case acceleration drift of one g along the positive input axis.

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Vector components needed to cancel the associated bias.

Output: Drift compensated PIPA pulse in MPAC

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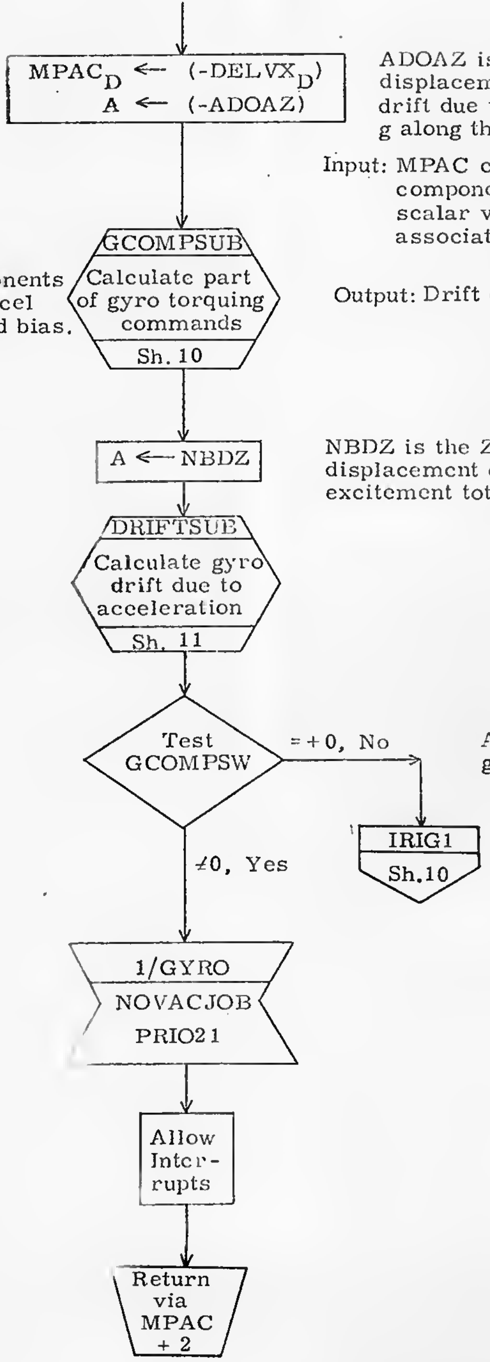
From Preceding Sheet



ADOAZ is the Z-component of the displacement of the acceleration sensitive drift due to a case acceleration drift of one g along the positive outer axis.

Input: MPAC contains compensated PIPA vector component without drift bias. A contains scalar value of the drift component associated with the PIPA component.

Vector components needed to cancel the associated bias.

Output: Drift compensated PIPA pulse in MPAC.

NBDZ is the Z-component of the displacement of the normal excitement total bias drift.

Are gyro commands greater than 2 pulses?

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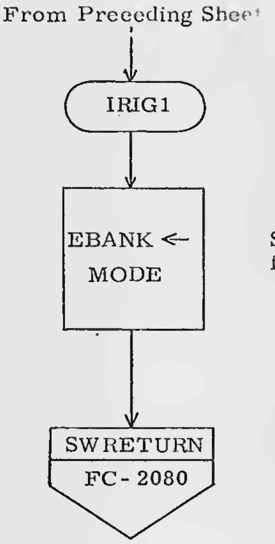
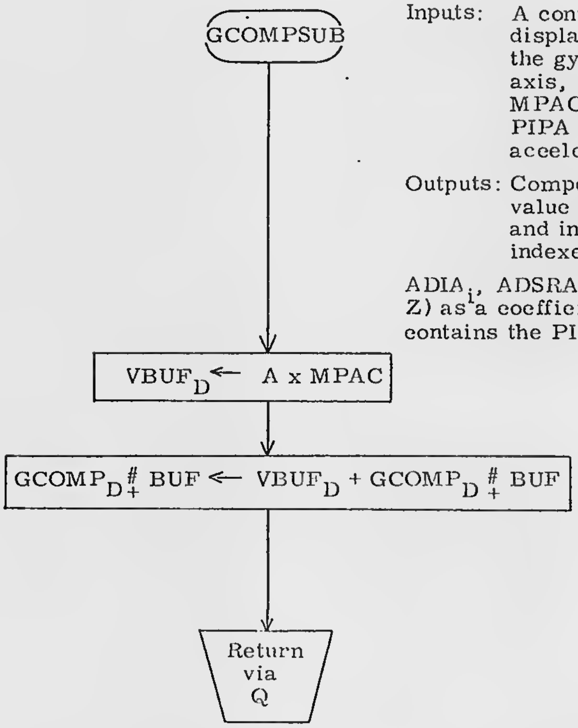


Set up EBANK for return.



Inputs: A contains a component of the displacement vector along the gyro input axis, output axis, or spin reference axis. MPAC contains the compensated PIPA component values less the acceleration torquing bias.

Outputs: Compensate PIPA component value in two words of VBUF and in two words of GCOMP indexed by BUF.

$ADIA_i$, $ADSRA_i$, or $ADOA_i$ (where i = X, Y, or Z) as a coefficient is in A register. MPAC contains the $PIPA_i$ pulse @ 2^{14}).

Contents of GCOMP @ 2^{12}

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DOCMGR J B Smith Jr	5/6/70	LUMINARY 1D	FC-3230
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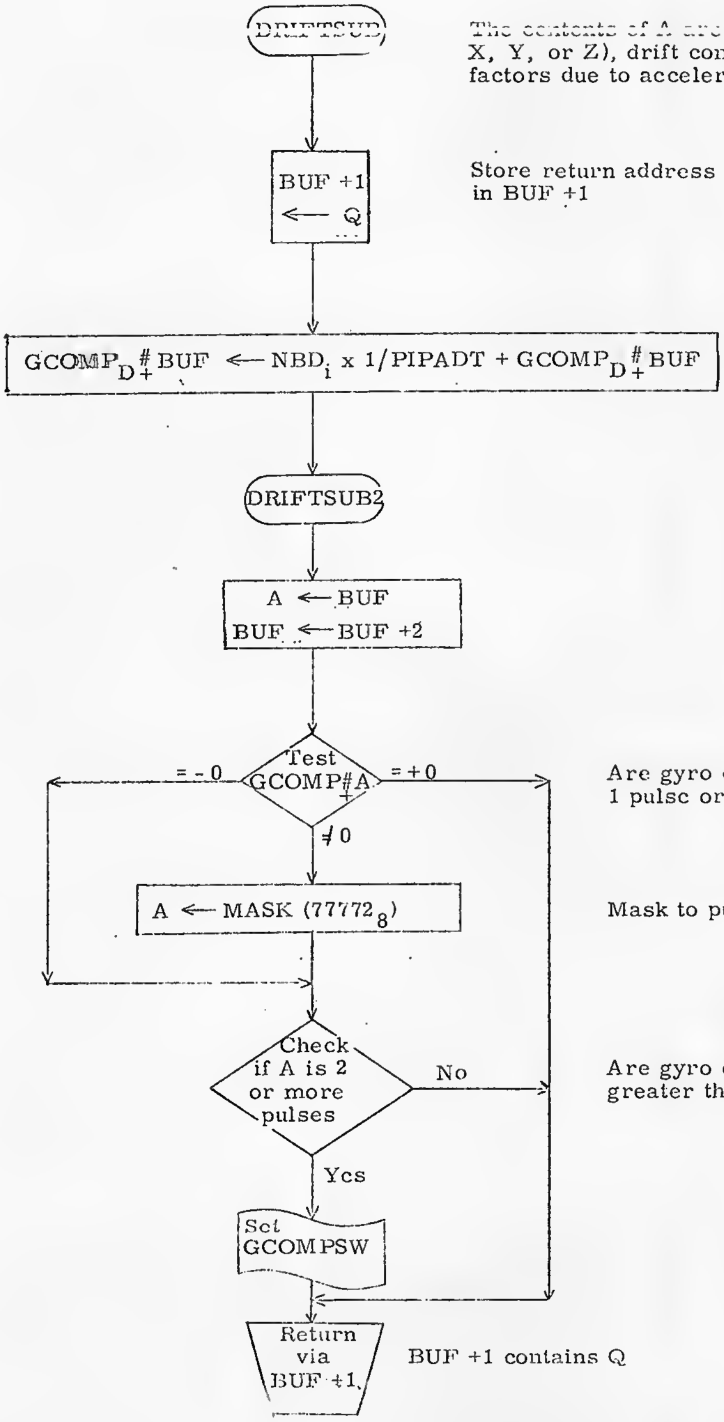

The contents of A are NBD$_i$, (where i = X, Y, or Z), drift compensation bias factors due to acceleration.

Store return address in BUF +1

Add drift compensation to previously compensated PIPAs

Are gyro commands 1 pulse or greater ?

Mask to put in a 2.

Are gyro commands greater than 2 pulses ?

BUF +1 contains Q

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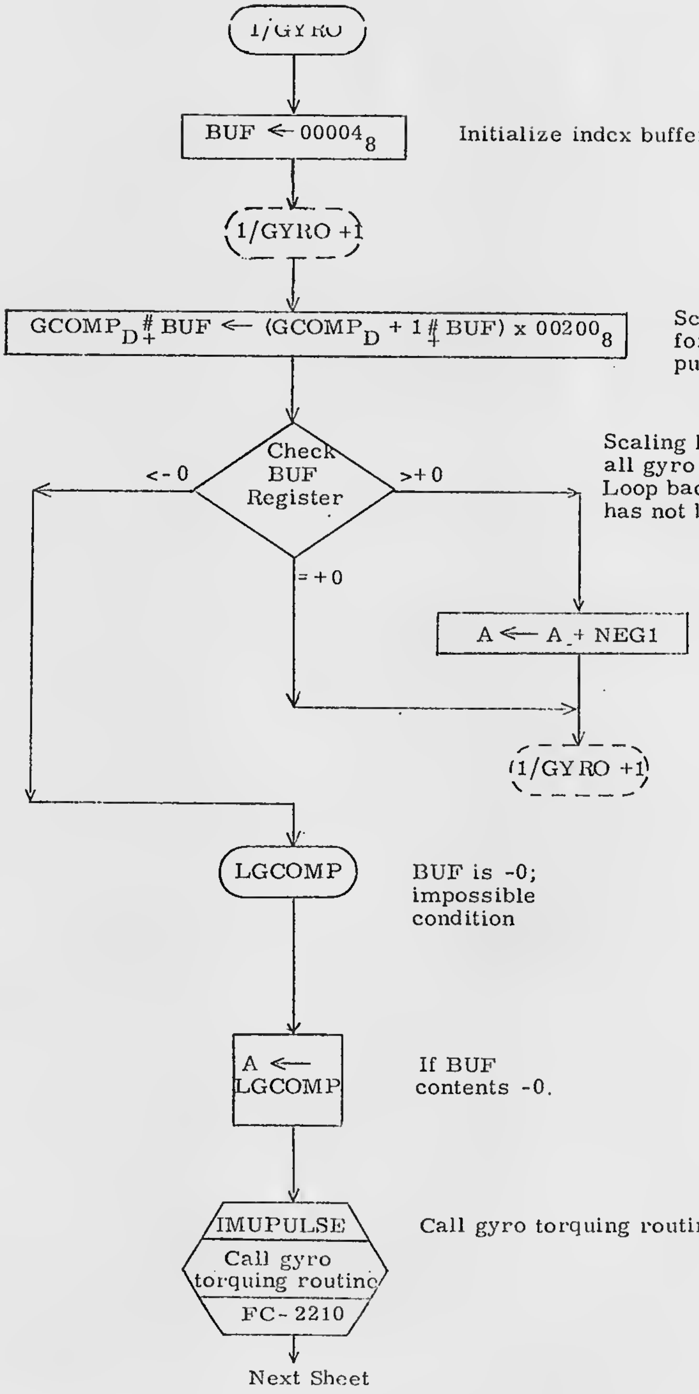

Initialize index buffer

Scales gyro commands for IMUPULSE fractional pulses.

Scaling has been done for all gyro command pulses. Loop back if 1 = X, Y, or Z has not been exhausted.

BUF is -0; impossible condition

If BUF contents -0.

Call gyro torquing routine

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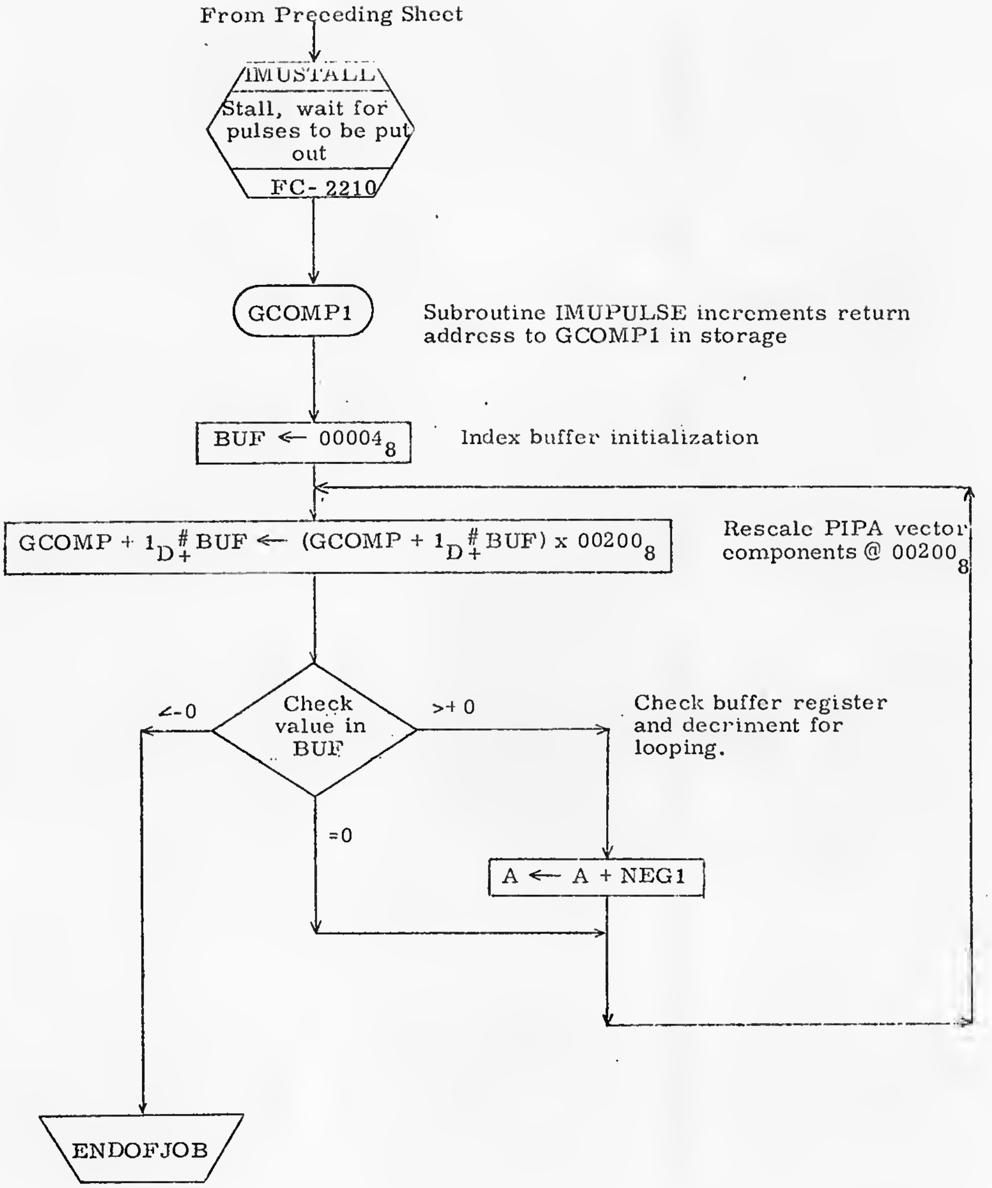

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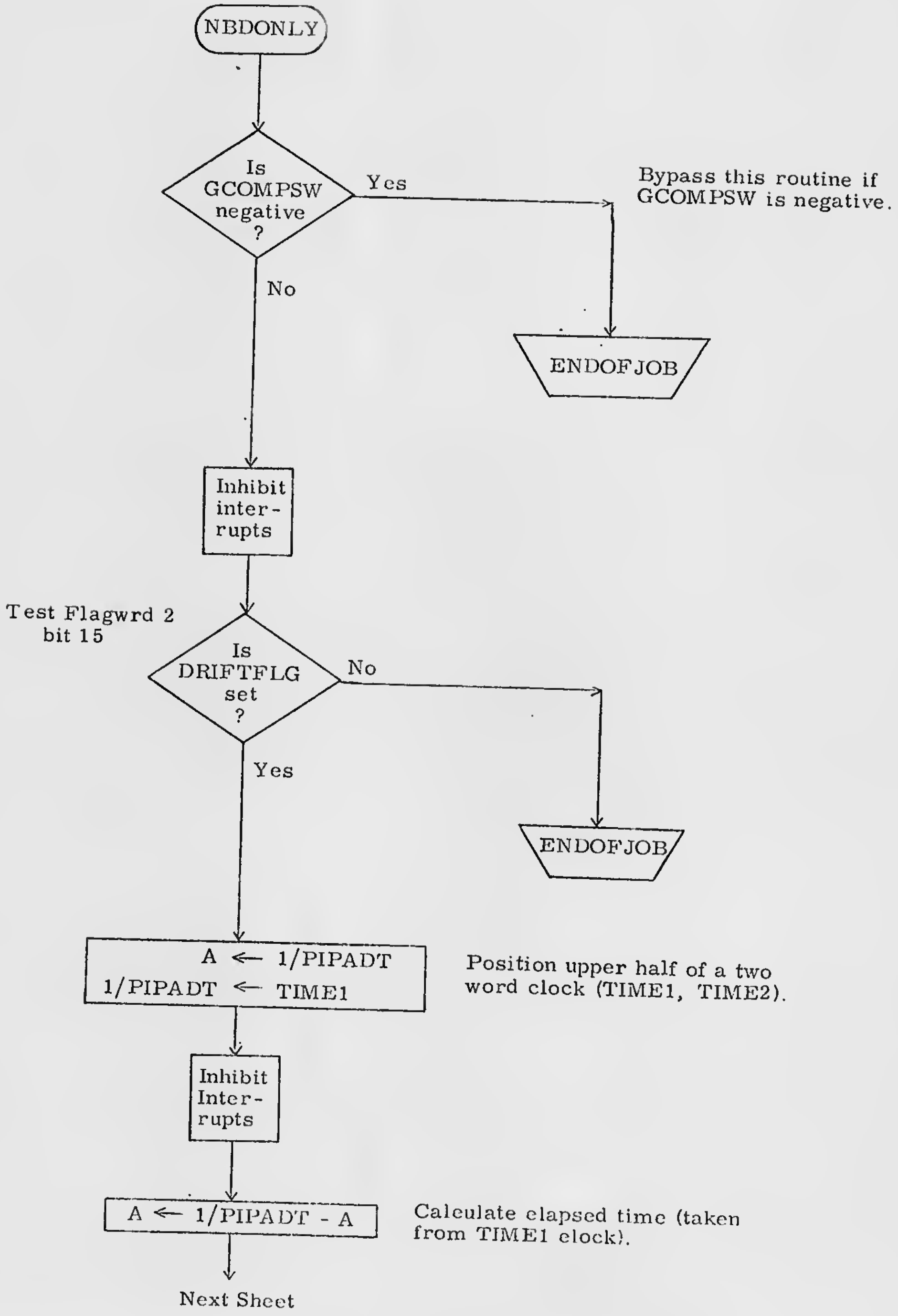

Bypass this routine if GCOMPSW is negative.

Position upper half of a two word clock (TIME1, TIME2).

Calculate elapsed time (taken from TIME1 clock).

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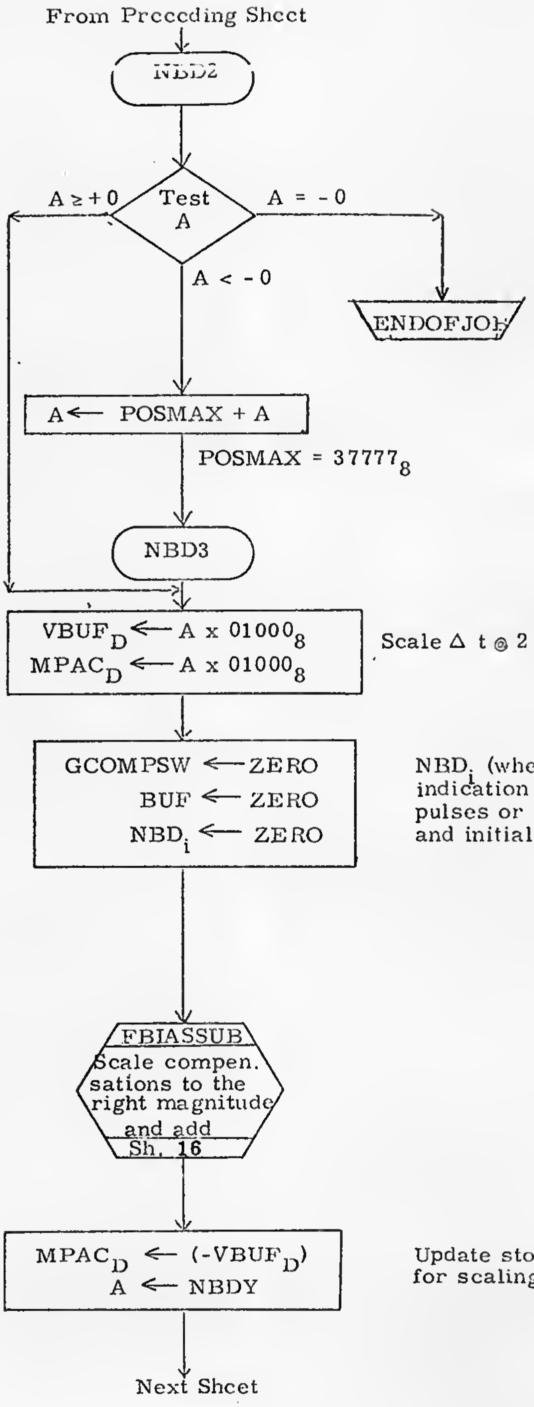
ANALST			LUMINARY 1D
CHCKR	JB Smith Jr	5/6/70	DOCUMENT NO. FC-3230
APPR'D	Robert M Eiste	5/6/70	REV 0 PAGE 14 OF 18



What is elapsed time in first level clock ? Is there a TIME1 clock overflow ?

Calculate absolute time difference (in TIME1 clock).

Scale Δ t @ 2^{19} and store

NBD$_i$ (where i = X, Y, or Z), indication commands are two pulses or less. Set switches and initialize buffer registers.

Update storage and work areas for scaling and adding routine.

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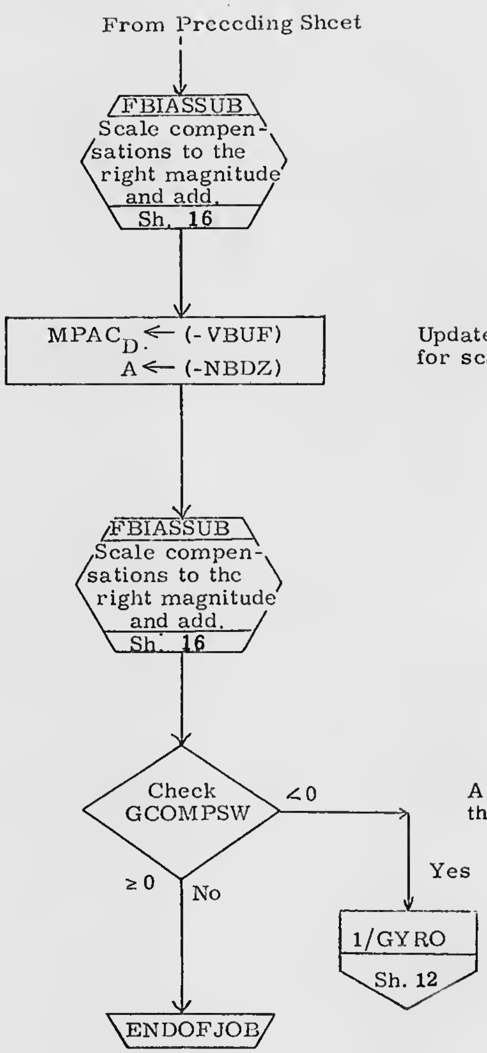
APOLLO GUIDANCE AND NAVIGATION

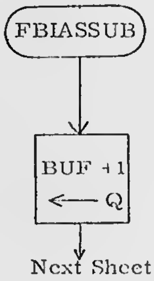
DRAWN	D Lutkevich	2/24/70	IMU Compensation Package
PROGMR	E. J. Grace	5/6/70	
ANALST			LUMINARY 1D
DOCMR	JBSmith Jr	5/6/70	DOCUMENT NO. FC-3230
APPR'D	Roberta M Entes	5/6/70	REV 0

SHEET 15 OF 18



Update storage and work areas for scaling and adding routine.

Are gyro commands greater than or equal to two pulses?



Scale compensations to right magnitude and add to get compensated PIPAs (without drift biases).

Store return address in index register.

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DRAWN D Lutkewich 2/24/70
PROGMR E. J Gray 5/6/70
ANALST
DOCMR JB Smith Jr 5/6/70
APPROVED Roberta M Evans 5/6/70

APOLLO GUIDANCE AND NAVIGATION

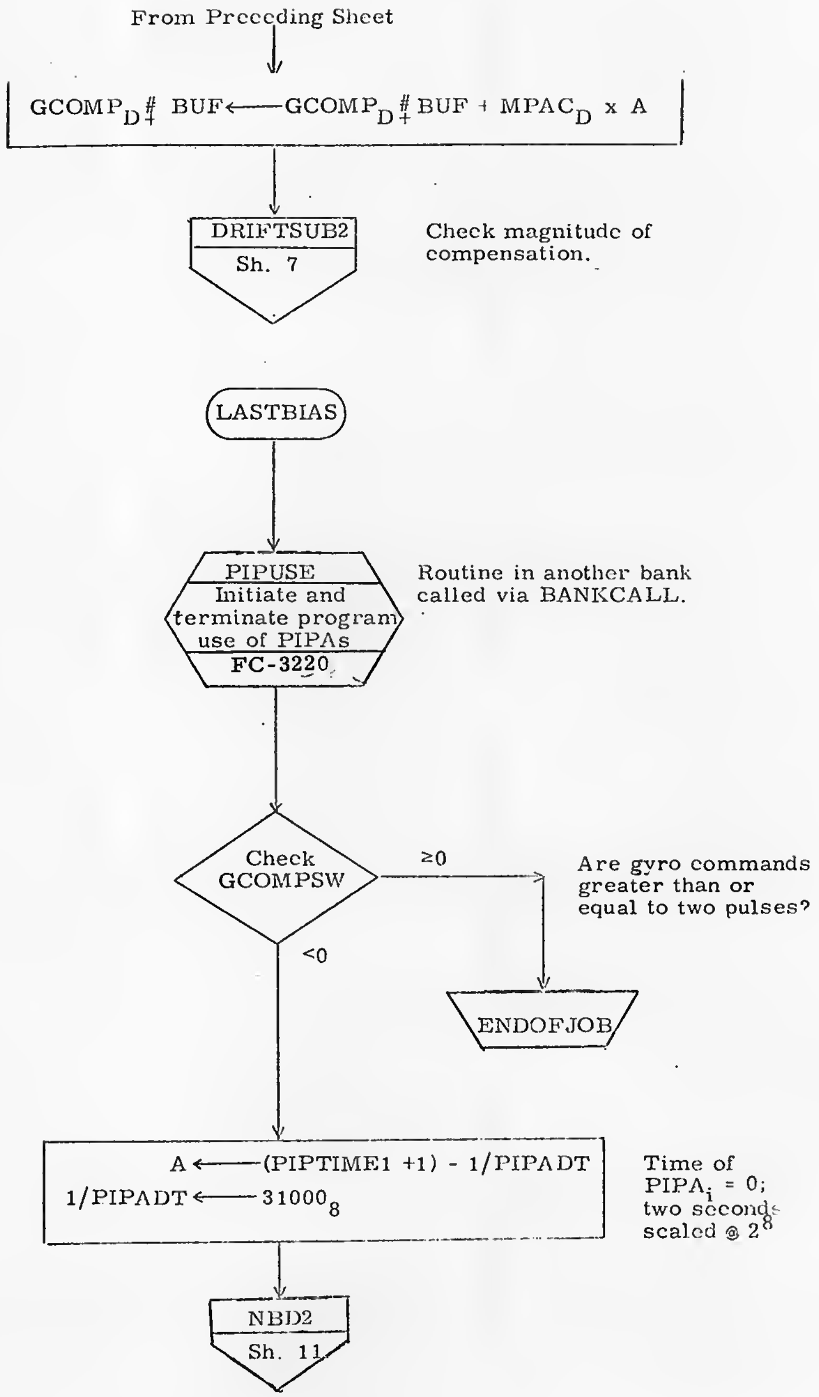
IMU Compensation Package

LUMINARY 1D

DOCUMENT NO. FC-3230

REV 0

SHEET 16 OF 18



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D Lutkewich	2/24/7	IMU Compensation Package	
PRGMR E. J. Grace	5/6/70		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3230
DOCMR J B Smith Jr	5/6/70		
APPR'D Roberta M Cutes	5/6/70	REV 0	SHEET 17 OF 18

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
IMUPULSE	FC-3220	Call gyro torquing routine	Sh. 10
IMUSTALL	FC-3220	Stall, wait for pilses to be put out	Sh. 11
SWRETURN	FC-3060	Return and enter program on switch setting	Sh. 8

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
DRIFTFLG	T3RUPT calls gyro compensation	T3RUPT does no gyro compensation			Sh. 12

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DRAWN	D Lutkewil	4/24/70	IMU Compensation Package
PRGMR	E. J. Gray	5/6/70	
ANALST			DOCUMENT NO.
DOCMR	JB Smith Jr	5/6/70	LUMINARY 1D	FC-3230
APPR'D	Roberta M Estes	5/6/70	REV 0	SHEET 18 OF 18

CMC/LGC Clock Synchronization
(R33, V55)

ALINTIME	Sh. 2
R33	Sh. 2

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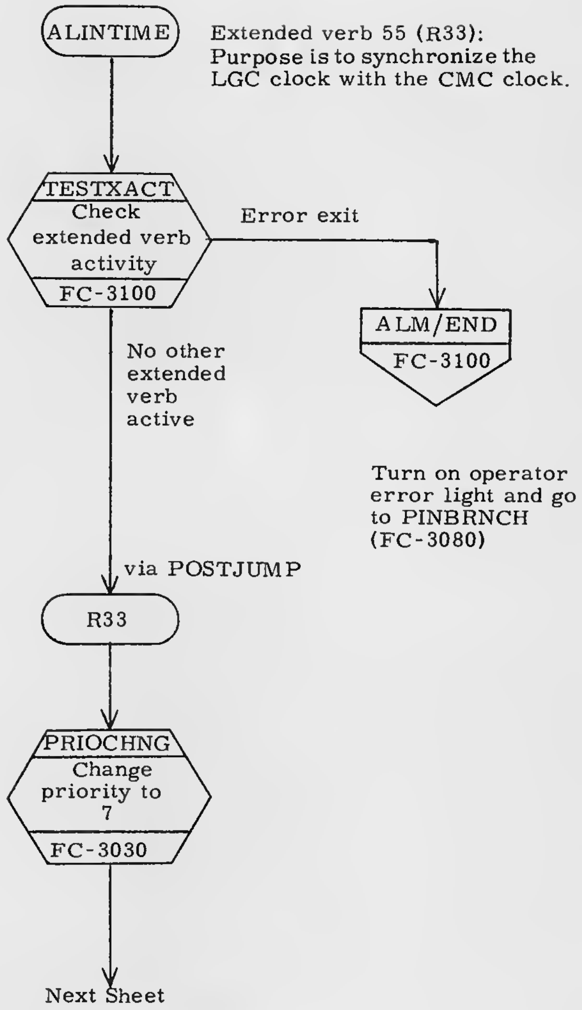
CAMBRIDGE, MASS.

DRAWN	J. Flaherty	
PRGMR	Densmore	9 JUN 70
ANALST		
DOCMR	R.M. Eiten	6/9/70
APPR'D	R.M. Eiten	6/9/70

APOLLO GUIDANCE AND NAVIGATION

CMC/LGC Clock Synchronization (R33, V55)

LUMINARY 1D	DOCUMENT NO. FC-3240
REV	SHEET 1 OF 5



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CAMBRIDGE, MASS.

APOLLO GUIDANCE AND NAVIGATION

CMC/LGC Clock Synchronization (R33, V55)

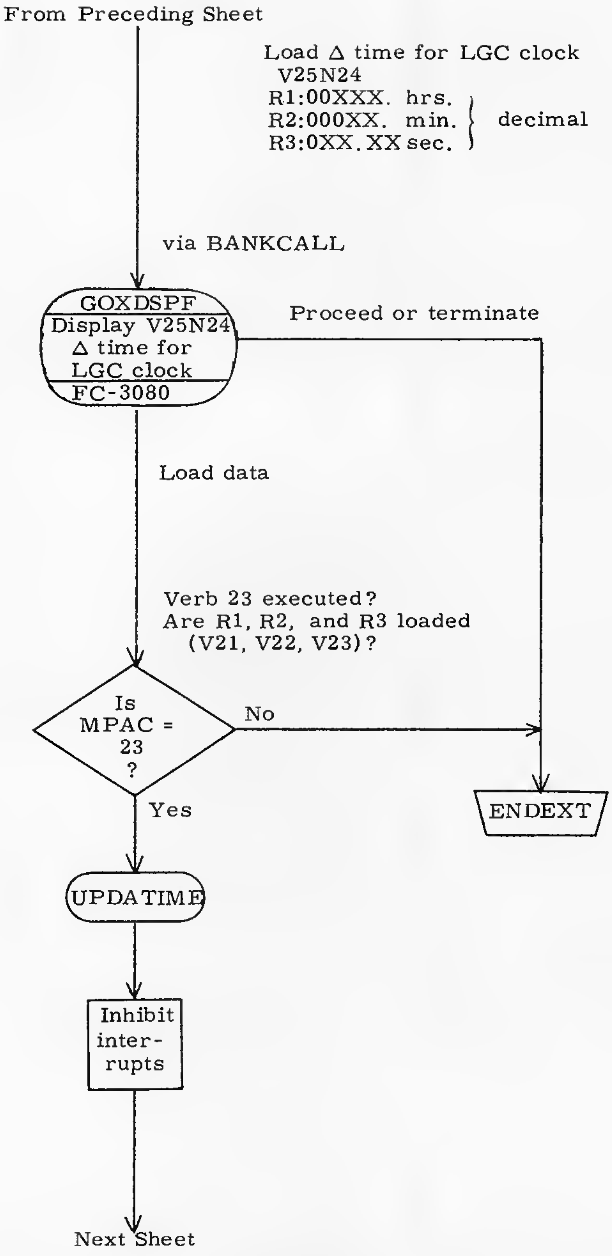
DRAWN	J. Flaherty	
PRGMR	Densmore	9 JUN 70
ANALST		
DOCMR	R.M. Estes	6/9/70
APPR'D	R.M. Estes	6/9/70

LUMINARY 1D

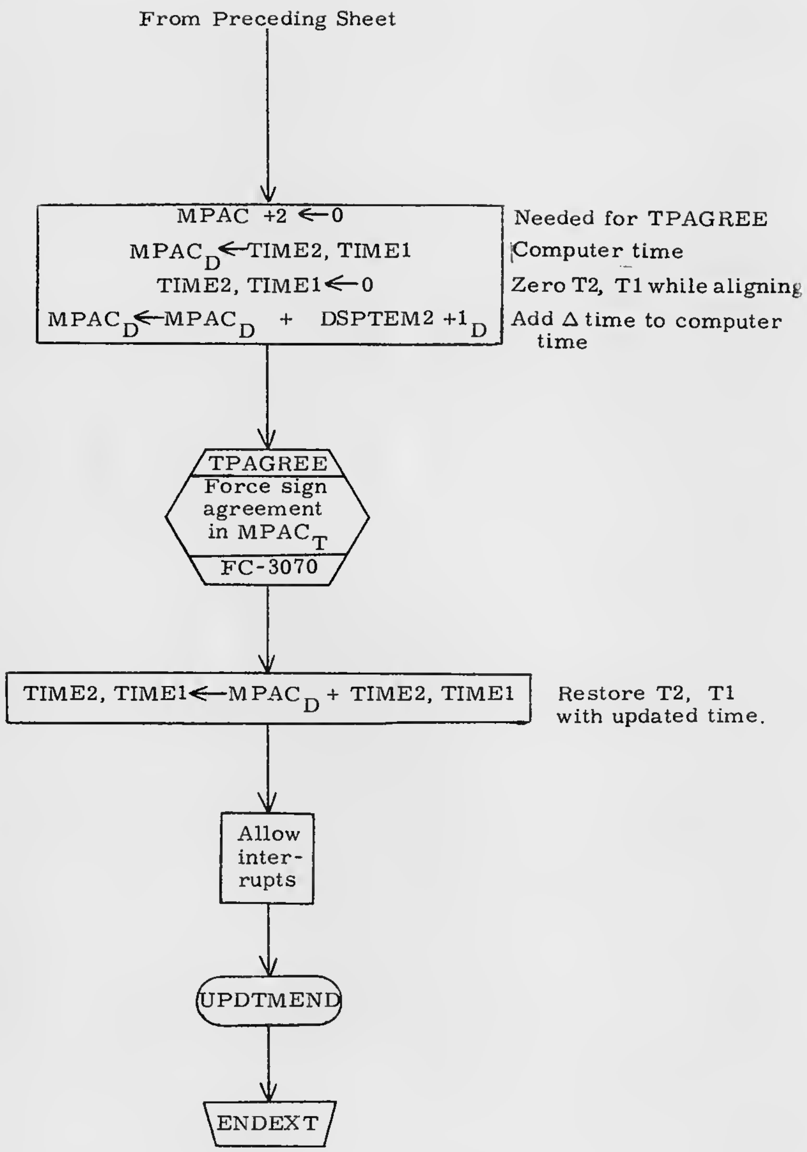
DOCUMENT NO. FC-3240

REV

SHEET 2 OF 5



MIT INSTRUMENTATION LAB **CAMBRIDGE, MASS.**			**APOLLO GUIDANCE AND NAVIGATION**	
DRAWN	J. Flaherty		CMC/LGC Clock Synchronization (R33, V55)	
PRGMR	Densmore	9 JUN 70	LUMINARY 1D	**DOCUMENT NO.** FC-3240
ANALST				
DOCMR	R.M. Enter	6/9/70		
APPR'D	R.M. Enter	6/9/70	**REV**	**SHEET** 3 **OF** 5



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty		CMC/LGC Clock Synchronization (R33, V55)	
PRGMR Densmore	9 JN 70		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3240
DOCMR R.M. Ester	1/9/70		
APPR'D R.M. Ester	1/9/70	REV	SHEET 4 OF 5

ROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Routine Named	Where Flowed	Description	Where Called
GOXDSPF (=GOMARKF)	FC-3080	Flash mark V/N.	Sh. 3
PRIOCHNG	FC-3030	Change priority of job in execution.	Sh. 2
TESTXACT	FC-3100	Check extended verb activity.	Sh. 2
TPAGREE	FC-3070	Force sign agreement in $MPAC_T$	Sh. 4

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DRAWN J. Flaherty		CMC/LGC Clock Synchronization (R33, V55)	
PRGMR Densmore	9 JUN 70	LUMINARY 1D	DOCUMENT NO. FC-3240
ANALST			
DOCMR R.M. Eston	6/9/70		
APPR'D R.M. Eston	6/9/70	REV	SHEET 5 OF 5

R47 – AGS INITIALIZATION

MAJOR SUBROUTINES ON THIS CHART

EXTENDED VERB 47	V47TXACT	START AGS INITIALIZATION	SH 2
	AGSINIT	AGS INITIALIZATION	SH 2

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DRAWN		16MAY69
PRGMR	P. Kys	10JLY69
ANALST		
DOCMR		4JLY69
APPR'D		31JULY69

APOLLO
GUIDANCE AND NAVIGATION

R47 AGS INITIALIZATION

LUMINARY 1C 1D

DOCUMENT NO. FC-3250

REV 2

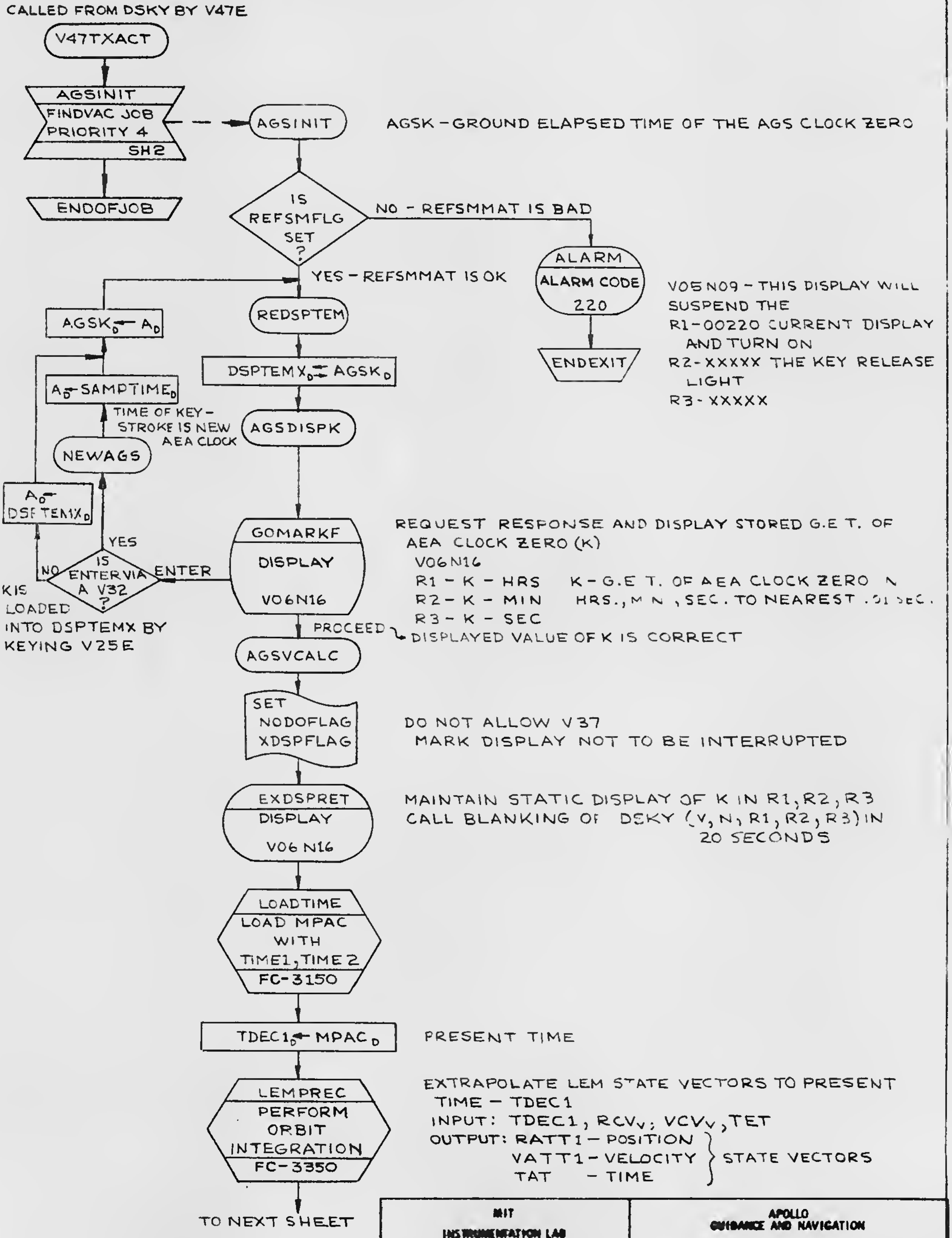
SHEET 1 OF 6

PURPOSE

1) IS TO PROVIDE THE AGS ABORT ELECTRONICS ASSEMBLY (AEA) WITH THE LM AND CSM STATE VECTORS (POSITION, VELOCITY, TIME) IN LM STABLE MEMBER COORDINATES BY MEANS OF THE LGC DIGITAL DOWNLINK.

2) ZERO THE ICDU, LGC, AND AEA GIMBAL ANGLE COUNTERS SIMULTANEOUSLY IN ORDER TO ESTABLISH A COMMON ZERO REFERENCE FOR MEASUREMENT OF GIMBAL (EULER) ANGLES WHICH DEFINE LM ATTITUDE WITH RESPECT TO THE IMU STABLE MEMBER.

3) TO ESTABLISH THE GROUND ELAPSED TIME OF AEA CLOCK ZERO IF THE AEA CLOCK IS ZEROED DURING THIS ROUTINE.



AGSK - GROUND ELAPSED TIME OF THE AGS CLOCK ZERO

V05 N09 - THIS DISPLAY WILL SUSPEND THE
R1-00220 CURRENT DISPLAY AND TURN ON
R2-XXXXX THE KEY RELEASE LIGHT
R3-XXXXX

K IS LOADED INTO DSPTEMX BY KEYING V25E

REQUEST RESPONSE AND DISPLAY STORED G.E.T. OF AEA CLOCK ZERO (K)
V06 N16
R1 - K - HRS K - G.E.T. OF AEA CLOCK ZERO IN
R2 - K - MIN HRS., MIN, SEC. TO NEAREST .01 SEC.
R3 - K - SEC

DISPLAYED VALUE OF K IS CORRECT

DO NOT ALLOW V37
MARK DISPLAY NOT TO BE INTERRUPTED

MAINTAIN STATIC DISPLAY OF K IN R1, R2, R3
CALL BLANKING OF DSKY (V, N, R1, R2, R3) IN 20 SECONDS

PRESENT TIME

EXTRAPOLATE LEM STATE VECTORS TO PRESENT TIME - TDEC1
INPUT: TDEC1, RCV_V; VCV_V, TET
OUTPUT: RATT1 - POSITION
VATT1 - VELOCITY
TAT - TIME
STATE VECTORS

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R47
AGS INITIALIZATION

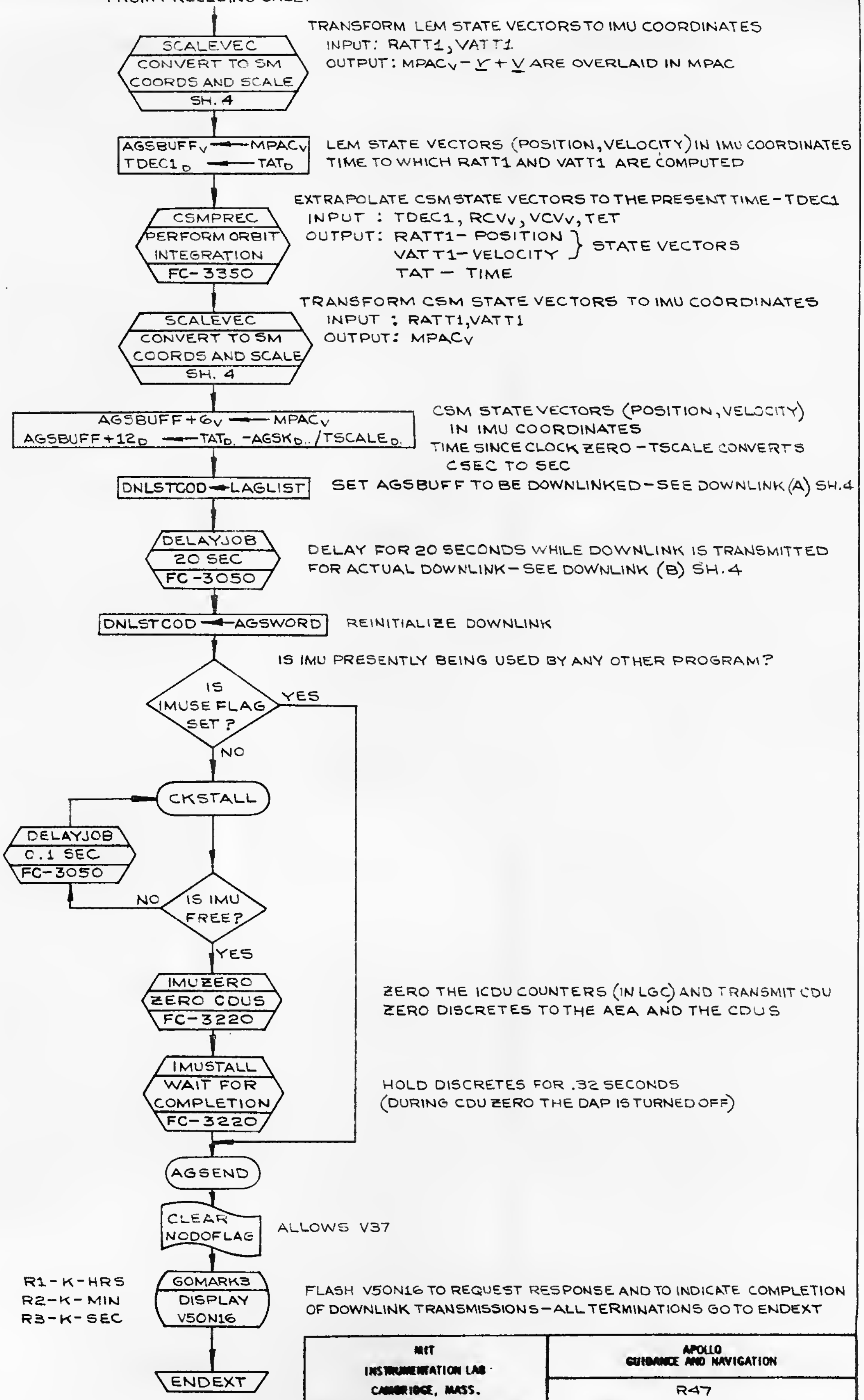
DRAWN	F Pearson	9 JUL 68
PRGMR	P Rye	10 JUL 69
ANALST		
DOCMR	G Nelly	7 OCT 69
APPR'D	John R. Moore	7 OCT 69

LUMINARY 1D

DOCUMENT NO. FC-3250

REV 2

SHEET 2 OF 6



TRANSFORM LEM STATE VECTORS TO IMU COORDINATES
INPUT: RATT1, VATT1
OUTPUT: MPAC$_V$ - $\underline{r}$ + $\underline{V}$ ARE OVERLAID IN MPAC

LEM STATE VECTORS (POSITION, VELOCITY) IN IMU COORDINATES
TIME TO WHICH RATT1 AND VATT1 ARE COMPUTED

EXTRAPOLATE CSM STATE VECTORS TO THE PRESENT TIME - TDEC1
INPUT : TDEC1, RCV$_V$, VCV$_V$, TET
OUTPUT: RATT1 - POSITION } STATE VECTORS
VATT1 - VELOCITY }
TAT - TIME

TRANSFORM CSM STATE VECTORS TO IMU COORDINATES
INPUT : RATT1, VATT1
OUTPUT: MPAC$_V$

CSM STATE VECTORS (POSITION, VELOCITY) IN IMU COORDINATES
TIME SINCE CLOCK ZERO - TSCALE CONVERTS CSEC TO SEC

SET AGSBUFF TO BE DOWNLINKED - SEE DOWNLINK (A) SH.4

DELAY FOR 20 SECONDS WHILE DOWNLINK IS TRANSMITTED FOR ACTUAL DOWNLINK - SEE DOWNLINK (B) SH.4

REINITIALIZE DOWNLINK

IS IMU PRESENTLY BEING USED BY ANY OTHER PROGRAM?

ZERO THE ICDU COUNTERS (IN LGC) AND TRANSMIT CDU ZERO DISCRETES TO THE AEA AND THE CDUS

HOLD DISCRETES FOR .32 SECONDS
(DURING CDU ZERO THE DAP IS TURNED OFF)

ALLOWS V37

FLASH V50N16 TO REQUEST RESPONSE AND TO INDICATE COMPLETION OF DOWNLINK TRANSMISSIONS - ALL TERMINATIONS GO TO ENDEXT

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DRAWN	H.G. Scott.	30 July 68
PRGMR	P. Kye	10 Jul 69
ANALST		
DOCMR	G. Nelly	2 Oct 68
APPR'D	John A. More	2 Oct 68

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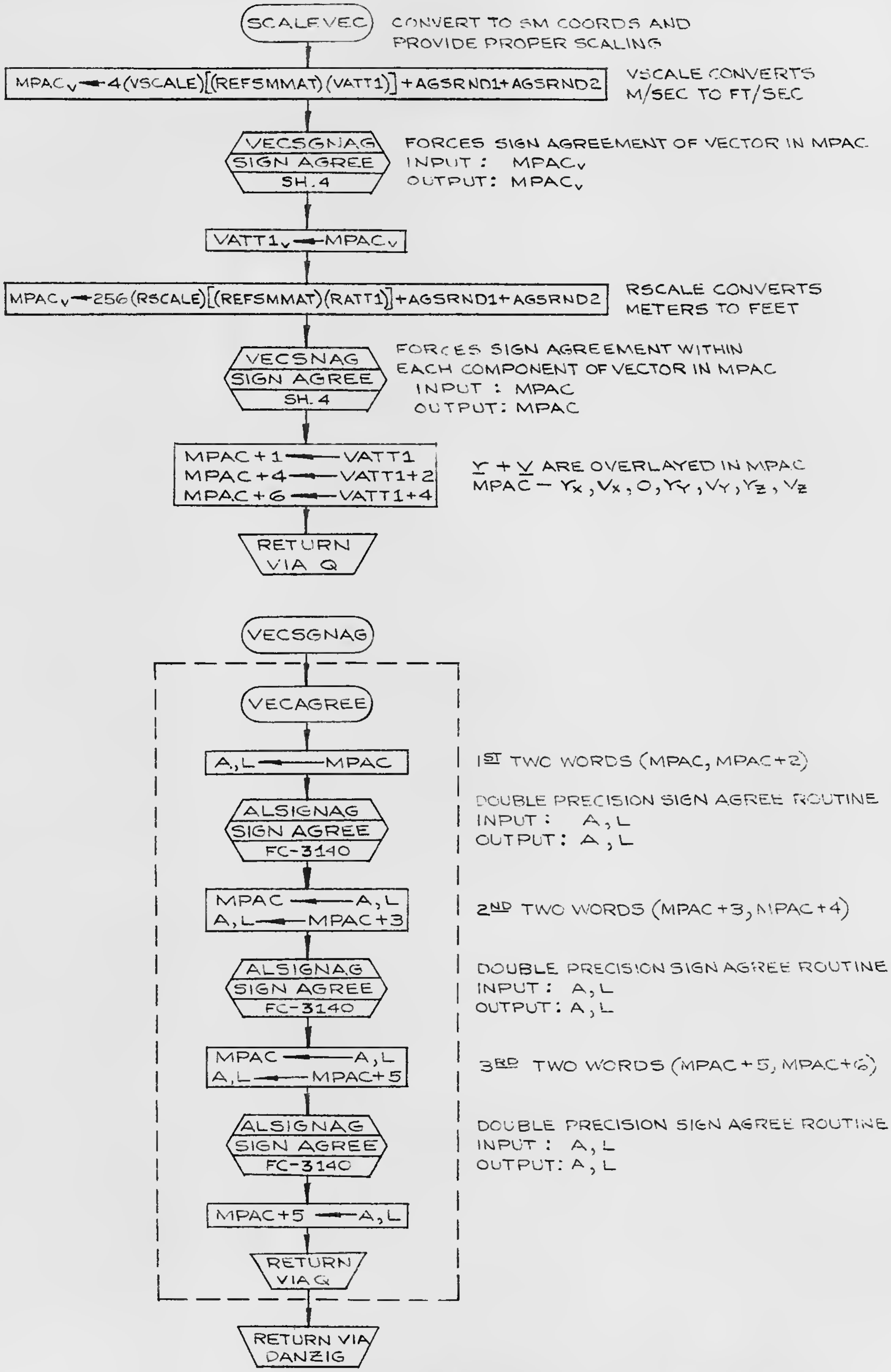
GUIDANCE AND NAVIGATION

R47
AGS INITIALIZATION

LUMINARY 1D
DOCUMENT NO. FC-3250
REV 2
SHEET 3 OF 6



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AGS INITIALIZATION

DRAWN		16 July 68
PRGMR	P. Rye	10 JULY 67
ANALST		
DOCMR	Nelly	7 OCT 68
APPR'D	John	7 OCT 68

LUMINARY 1D
REV 2

DOCUMENT NO. FC-3250
SHEET 4 OF 6

DOWNLINK

(A)

AGSBUFF		UNITS	LUNAR	EARTH ORBITAL
+0	X POSITION LEM	FT.	$\times 2^{-23}$	$\times 2^{-25}$
1	X VELOCITY LEM	FT./SEC.	$\times 2^{-13}$	$\times 2^{-15}$
2	Y POSITION LEM	FT.	$\times 2^{-23}$	$\times 2^{-25}$
3	Y VELOCITY LEM	FT./SEC	$\times 2^{-13}$	$\times 2^{-15}$
4	Z POSITION LEM	FT.	$\times 2^{-23}$	$\times 2^{-25}$
5	Z VELOCITY LEM	FT./SEC.	$\times 2^{-13}$	$\times 2^{-15}$
6	X POSITION CSM	FT.	$\times 2^{-23}$	$\times 2^{-25}$
7	X VELOCITY CSM	FT./SEC.	$\times 2^{-13}$	$\times 2^{-15}$
8	Y POSITION CSM	FT.	$\times 2^{-23}$	$\times 2^{-25}$
9	Y VELOCITY CSM	FT./SEC.	$\times 2^{-13}$	$\times 2^{-15}$
10	Z POSITION CSM	FT.	$\times 2^{-23}$	$\times 2^{-25}$
11	Z VELOCITY CSM	FT./SEC.	$\times 2^{-13}$	$\times 2^{-15}$
12 13	TIME OF STATE VECTORS$_{DP}$	SECS SINCE AGS CLOCK ZERO	$\times 2^{-18}$	$\times 2^{-18}$

(B.) ORDER OF COMPONENTS SENT ON THE DOWNLIST — SCALING IS THE SAME AS AGSBUFF

1	ID WORD (77777)
2	AGSBUFF +0
3	AGSBUFF + 2
4	AGSBUFF + 4
5	AGSBUFF +12
6	AGSBUFF+ 1
7	AGSBUFF + 3
8	AGSBUFF + 5
9	AGSBUFF +13
10	AGSBUFF +6
11	AGSBUFF + 8
12	AGSBUFF +10
13	AGSBUFF +12
14	AGSBUFF + 7
15	AGSBUFF + 9
16	AGSBUFF +11
17	AGSBUFF +13

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DRAWN	J.W. Scott.	16 Jul 6
PROGMR	P. Rye	10 JULY 6
ANALST		
DOCMR	G. Nelly	7 OCT 68
APPR'D	John A. Moore	7 OCT 68

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R47
AGS INITIALIZATION

LUMINARY 1D

DOCUMENT NO. FC-3250

REV 2

SHEET 5 OF 6

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
ALSIGNAG	FC-3140	FORCE A AND L SIGN AGREEMENT	SH. 4
CSMPREC	FC-3350	KEPLER INTEGRATION OF CSM STATE VECTOR	SH. 3
DELAYJOB	FC-3050	DELAY ACTIVE JOB	SH. 3
IMUSTALL	FC-3220	WAIT FOR IMU SUBROUTINE COMPLETION	SH. 3
IMUZERO	FC-3220	ZERO ICDU COUNTERS	SH. 3
LEMPREC	FC-3350	ENCKE INTEGRATION OF LM STATE VECTORS	SH. 2
LOADTIME	FC-3150	LOAD PRESENT TIME INTO MPAC_D	SH. 2

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
IMUSE FLAG 0 BIT 8	IMU IN USE	IMU NOT IN USE			SH. 3
NODOFLAG FLAG 2 BIT 1	V37 NOT PERMITTED	V37 PERMITTED	SH. 2	SH. 3	
REFSMFLG FLAG 3 BIT 13	REFSMMAT GOOD	REFSMMAT NO GOOD			SH. 2
XDSPFLAG FLAG 4 BIT 1	MARK DISPLAY NOT TO BE INTERRUPTED	NO SPECIAL MARK INFORMATION	SH. 2		

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
V06N16	REQUEST RESPONSE	R1 } K { 00XXX. - HRS R2, } K { 000XX. - MIN R3 } K { 0XX.XX - SEC G.E.T. OF AEA CLOCK ZERO	SH. 2
V50N16	PLEASE PERFORM	INDICATES COMPLETION OF DOWNLINK TRANSMISSIONS	SH. 3

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DRAWN
PRGMR P. Rye 10 JULY 69
ANALST
DOCMR 9 JULY 69
APPR'D

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R47
AGS INITIALIZATION

LUMINARY 1D

DOCUMENT NO.
FC-3250

REV 2

SHEET 6 OF 6

4.0 SYSTEM TEST ROUTINES

R04, R77 RADAR TEST ROUTINES

MAJOR ROUTINES ON THIS CHART

EXTENDED VERB 63		
R04	SAMPLE RADAR ONCE PER SECOND	SH2
EXTENDED VERB 78		
R77	START LR SPURIOUS RETURN TEST	SH2
EXTENDED VERB 79		
R77END	TERMINATE LR SPURIOUS RETURN TEST	SH5

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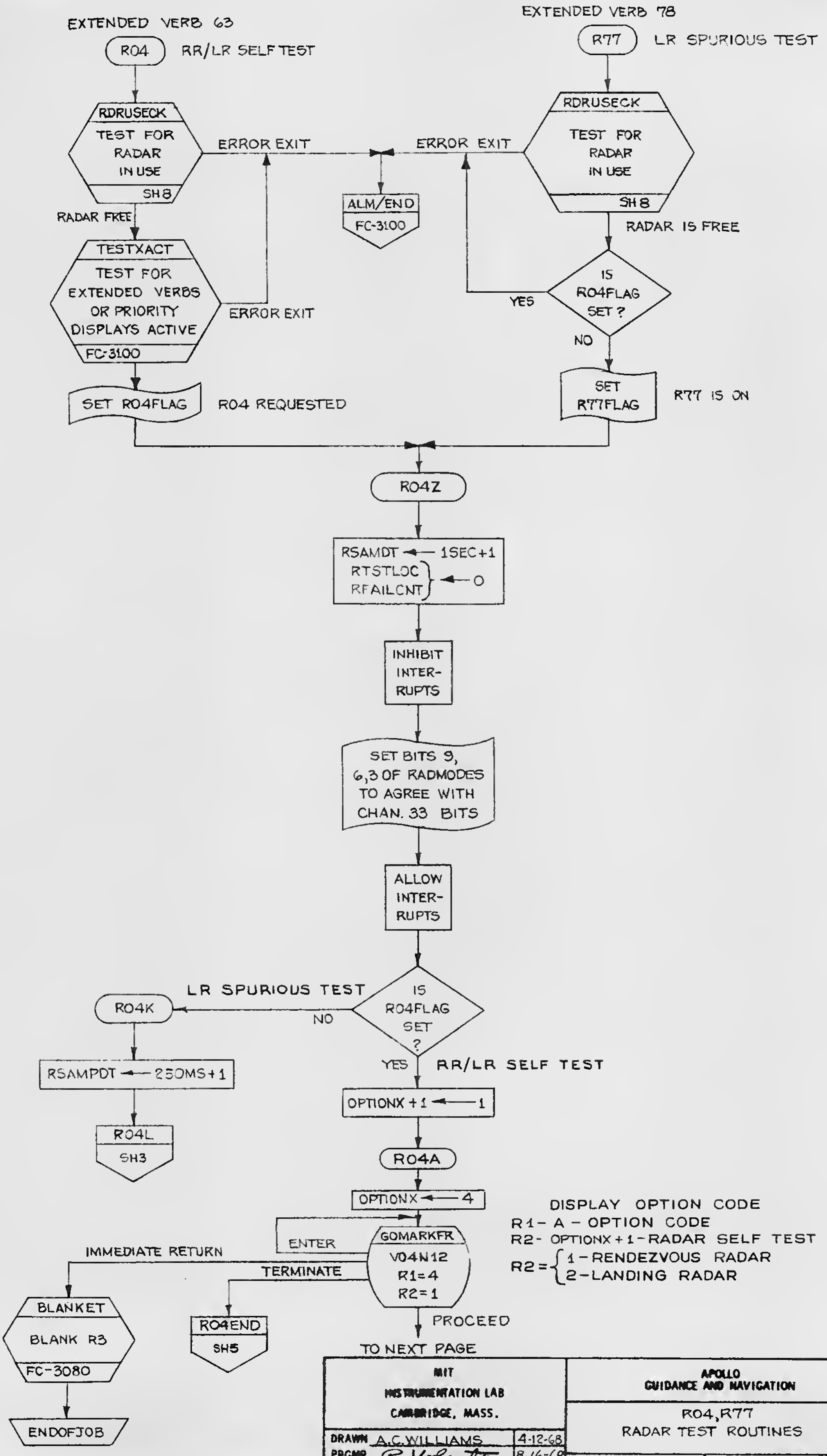
DRAWN	12/8/69	R04, R77 RADAR TEST ROUTINES	
PRGMR P. Volante	12/8/69	LUMINARY 1D	DOCUMENT NO. FC-3280
ANALST			
DOCMR W. Danforth	12/8/69		
APPR'D Roberta M. Eaton		REV 2	SHEET 1 OF 9



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R04,R77
RADAR TEST ROUTINES

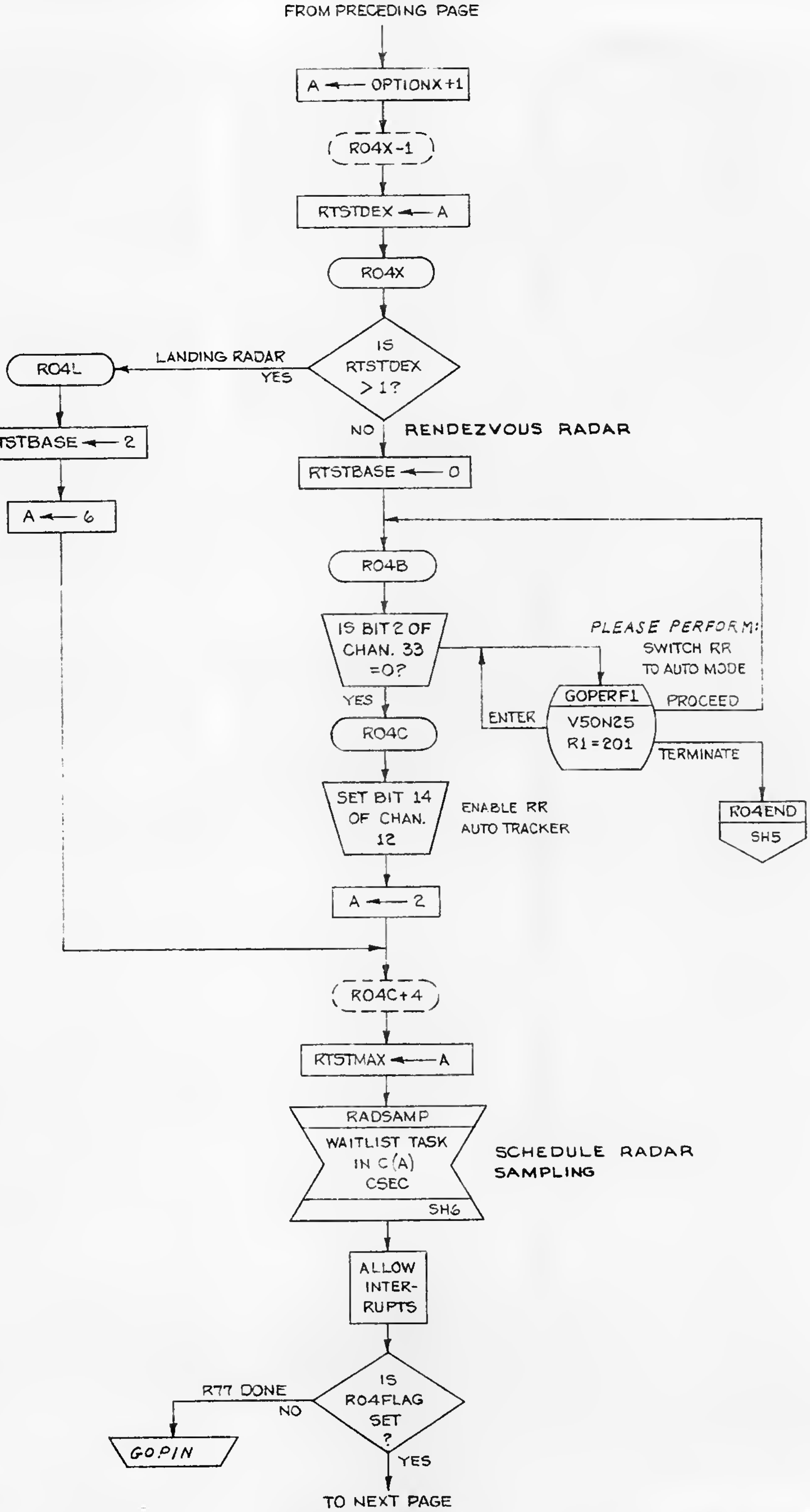
DRAWN	A.C.WILLIAMS	4-12-68
PRGMR	P. Volante	8-16-68
ANALST		
DOCMR		6-6-68
APPR'D	John A. Morse	11/19/68

LUMINARY 1D

DOCUMENT NO.
FC-3280

REV 2

SHEET 2 OF 9



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DRAWN A.C.WILLIAMS 4-12-68
PRGMR P. Volante 8-16-68
ANALST
DOCMR W. Tuckett 6-6-6
APPR'D John A. Morse 11/19/68

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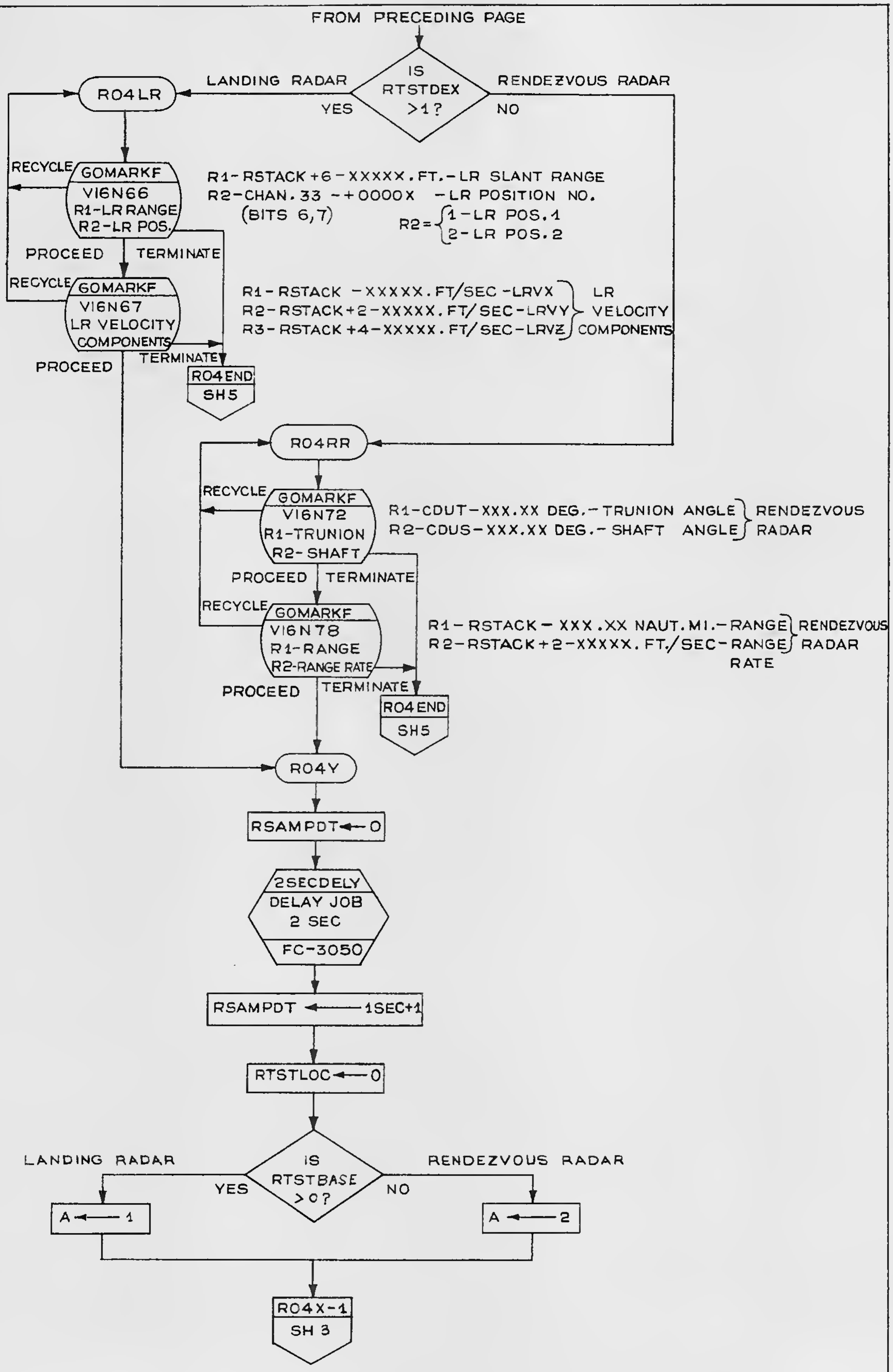
R04, R77
RADAR TEST ROUTINES

LUMINARY 1D

DOCUMENT NO.
FC-3280

REV 2

SHEET 3 OF 9



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DRAWN P.M. Dietrich 26JUL68
PRGMR P. Volante 16AUG68
ANALST
DOCMR 14AUG68
APPR'D John A. Morse 11/19/68

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GUIDANCE AND NAVIGATION

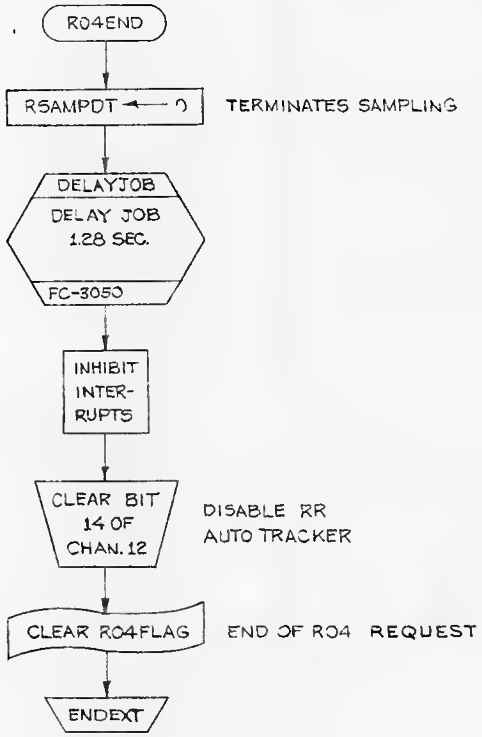
R04, R77
RADAR TEST ROUTINES

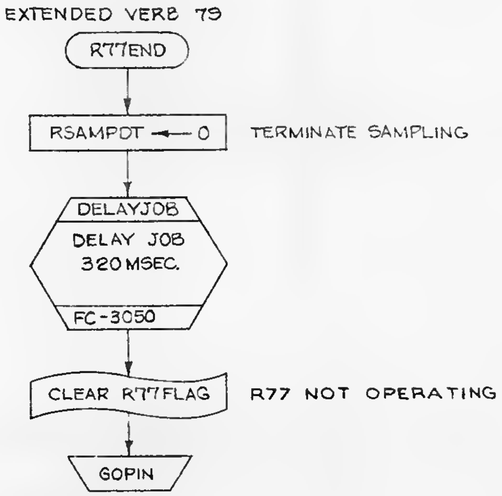
LUMINARY 1D

DOCUMENT NO.
FC-3280

REV 2

SHEET 4 OF 9





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INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN	A.C.WILLIAMS	4-15-68
PRGMR	P. Volante	8-16-68
ANALST		
DOCMR		6-6-68
APPR'D	John A. Moore	11/19/68

APOLLO
GUIDANCE AND NAVIGATION

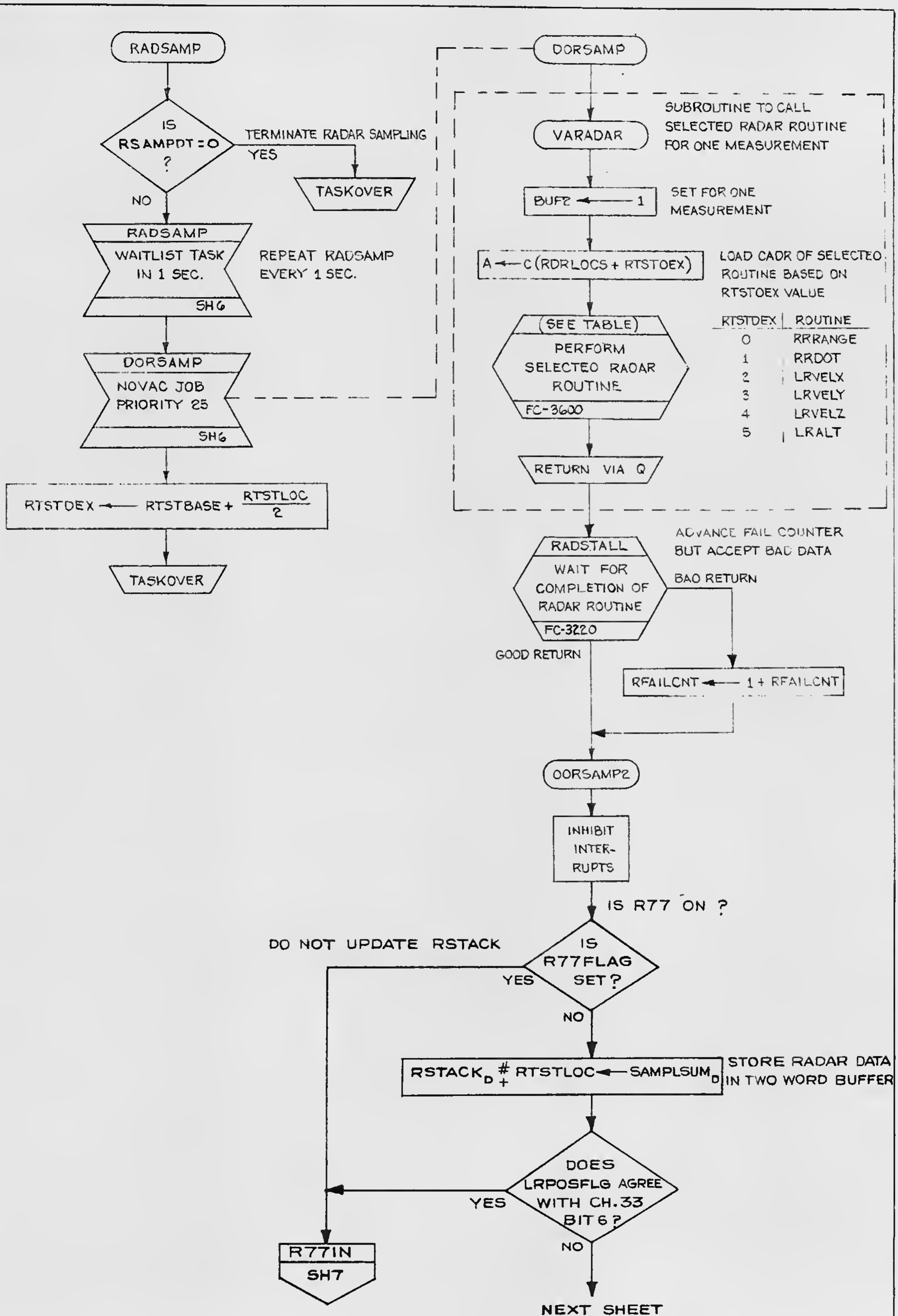
R04, R77
RADAR TEST ROUTINES

LUMINARY 1D

DOCUMENT NO.
FC-3280

REV 2

SHEET 5 OF 9



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN	A.C.WILLIAMS	6-5-68
PRGMR	P. Volante	8-16-68
ANALST		
DOCMR		6-6-68
APPR'D	John A. Morse	11/15/68

APOLLO
GUIDANCE AND NAVIGATION

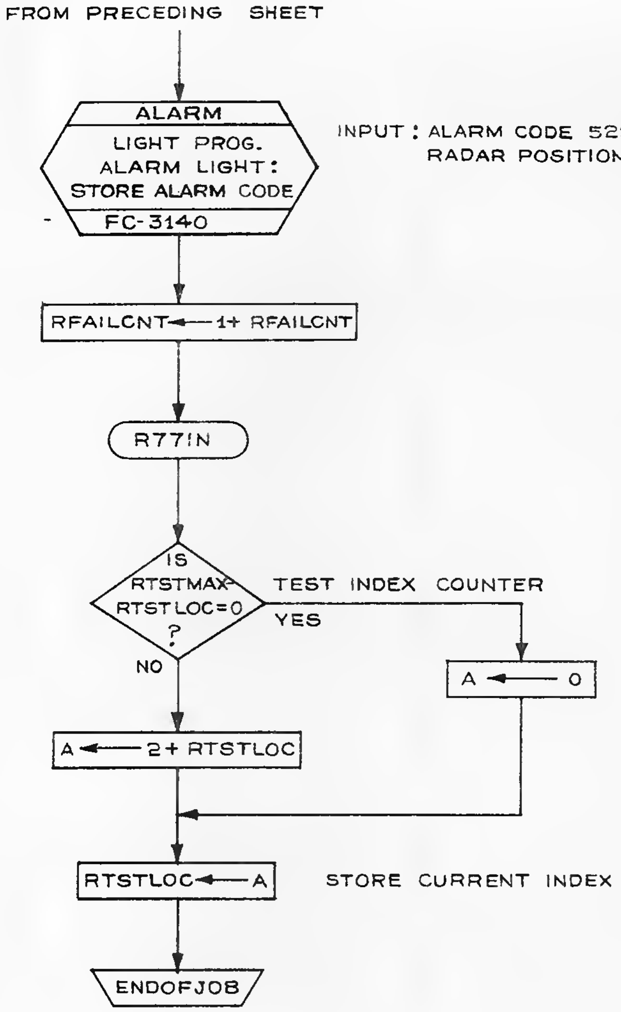
R04, R77
RADAR TEST ROUTINES

LUMINARY 1D

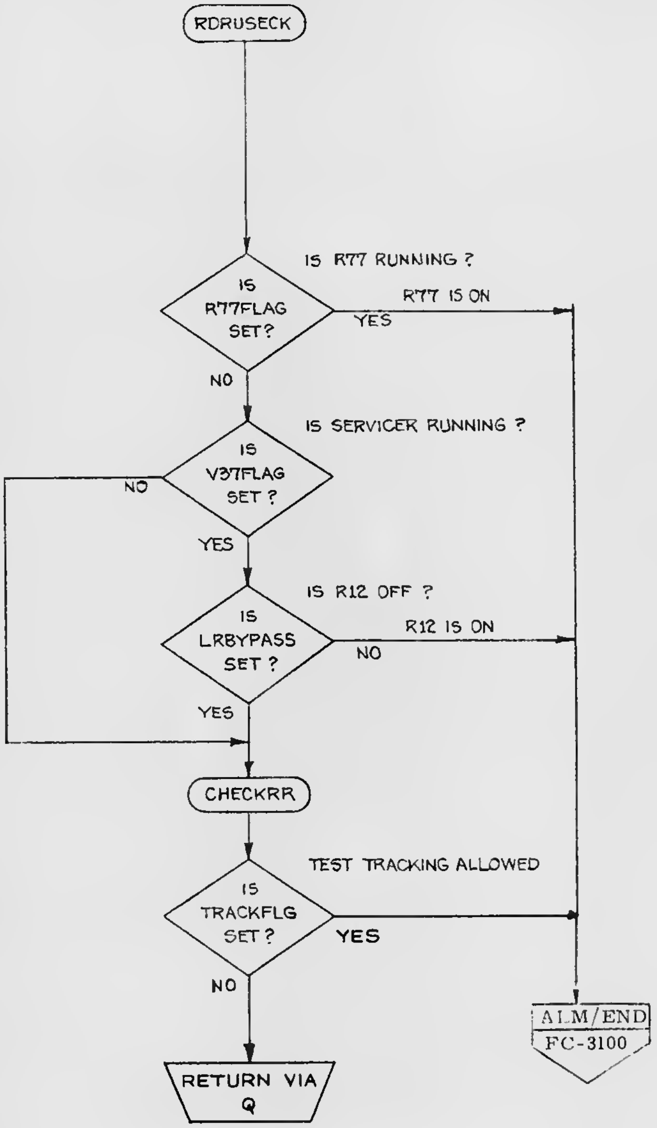
DOCUMENT NO.
FC-3280

REV 2

SHEET 6 OF 9



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN P. M. Dietz Jr	01SEP6	R04, R77 RADAR TEST ROUTINES
PRGMR R. Volante		
ANALST		LUMINARY 1D
DOCMR W C Dayforth	16SEP69	DOCUMENT NO. FC-3280
APPR'D Roberta M. Estes	10/21/69	REV 2 SHEET 7 OF 9



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DRAWN A.C.WILLIAMS 15MAY69
PRGMR
ANALST
DOCMR 18JULY69
APPR'D 10/21/67

APOLLO
GUIDANCE AND NAVIGATION

R04, R77
RADAR TEST ROUTINES

LUMINARY 1D

DOCUMENT NO.
FC-3280

REV 2

SHEET 8 OF 9

SUBROUTINES
ON OTHER CHARTS

		WHERE CALLED
TESTXACT	TEST FOR EXTENDED VERBS OR PRIORITY DISPLAYS ACTIVE	SH 2
DELAYJOB	DELAY ACTIVE JOB	SH 4,5
RADSTALL	WAIT FOR COMPLETION OF RADAR ROUTINE	SH 6

DISPLAYS	MEANING	USED
V04N12	R1-A-OPTION CODE R2-OPTION 2-RADAR SELF TEST R2 = {1-RENDEZVOUS RADAR, 2-LANDING RADAR}	SH 2
V16N66	R1-RSTACK+6-XXXXX.FT.-LR. SLANT RANGE R2-CHAN 33 (BITS 6,7) -0000X -LR. POSITION NO. R2 = {1-LR. POS. 1, 2-LR. POS. 2}	SH 4
V16N67	R1-RSTACK -XXXXX.FT/SEC-LRVX R2-RSTACK+2-XXXXX.FT/SEC-LRVY R3-RSTACK+4-XXXXX.FT/SEC-LRVZ } LANDING RADAR VELOCITY COMPONENTS	SH 4
V16N72	R1-CDUT -XXX.XX DEG.-TRUNION ANGLE R2-CDUS -XXX.XX DEG.-SHAFT ANGLE } RENDEZVOUS RADAR	SH 4
V16N78	R1-RSTACK -XXX.XX NAUT. MILES-RANGE R2-RSTACK+2-XXXXX. FT/SEC -RANGE RATE } RENDEZVOUS RADAR	SH 4
V50N25	R1 - 201 - PLEASE PERFORM: SWITCH RR TO AUTO MODE	SH 3

FLAGS

NAME	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
LRBYPASS FLAG11 BIT 15	BYPASS ALL LANDING RADAR UPDATES	DO NOT BYPASS LANDING RADAR UPDATES			SH. 8
R04FLAG FLAG3 BIT 9	R04 IS ON	R04 IS NOT ON	SH. 2	SH. 5	SH. 2, 3
R77FLAG FLAG5 BIT 11	R77 IS ON	R77 IS NOT ON	SH. 2	SH. 5	SH. 6, 8
TRACKFLG FLAG1 BIT 5	TRACKING ALLOWED	TRACKING NOT ALLOWED			SH. 8
V37FLAG FLAG7 BIT 6	AVERAGE G (SERVICER) RUNNING	AVERAGE G (SERVICER) OFF			SH. 8

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DRAWN A.C.WILLIAMS	6-5-68	LUMINARY 1D
[illegible]	8-16-68	DOCUMENT NO. FC-3280
ANALYST		
[illegible]	14 AUG 68	
APPR'D	11/13/68	REV 2 SHEET 9 OF 9

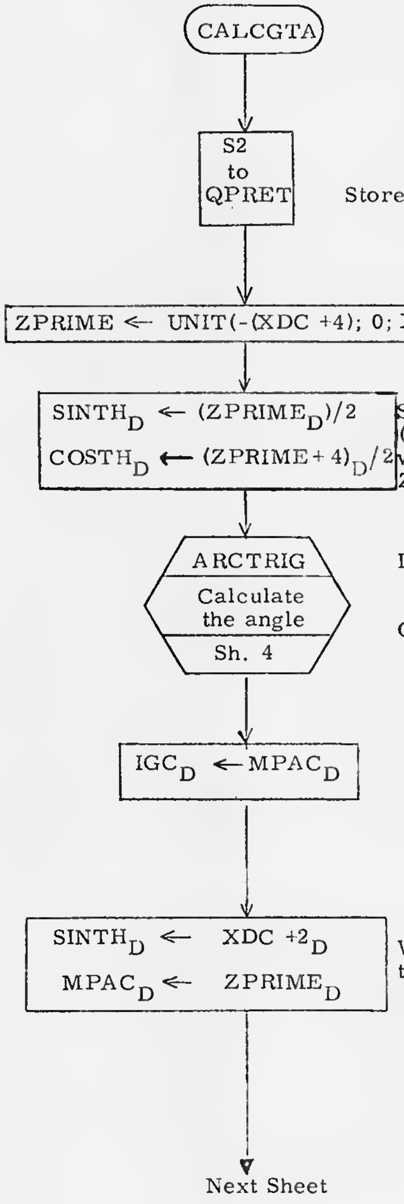
5.0 GEOMETRY TRANSFORMATIONS

INFLIGHT ALIGNMENT ROUTINES

CALCGTA	Sh. 2
ARCTRIG	Sh. 4
CALCGA	Sh. 5
AXISGEN	Sh. 8

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	J. Lutkevich	[illegible]	Inflight Alignment Routines
PRGMR	D Millard	5/14/70	
ANALST			
			LUMINARY 1D
DOCMR	J B Smith Jr	5/14/70	DOCUMENT NO. FC-3310
APPR'D	Roberta M Estes	5/14/70	REV
			SHEET 1 OF 11

This routine computes the gyro torquing angles required to bring the stable member into the desired orientation. Inputs are the half-unit vectors stored at XDC, YDC, ZDC. Outputs are the three gyro torquing angles applied to the X, Y, Z gyros and is stored at OGC, IGC, MGC, respectively.



Store return address

Store the vector components

Scale the vector functions to 2^1 so that functions (angular) entered to routine calculating the angle will have functions factored by 1/4. COS (IGC) = ZP3 and SIN (IGC) = ZP1

Input: Sine and cosine of the angle stored at SINTH and COSTH.

Output: Y gyro torquing angle in MPAC and THETA, between +0.5 and -0.5 revolutions.

Store gyro torquing angle

With XDC +2 scaled to 2^1, this sets SIN (MGC) = XD2.

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Inflight Alignment Routines

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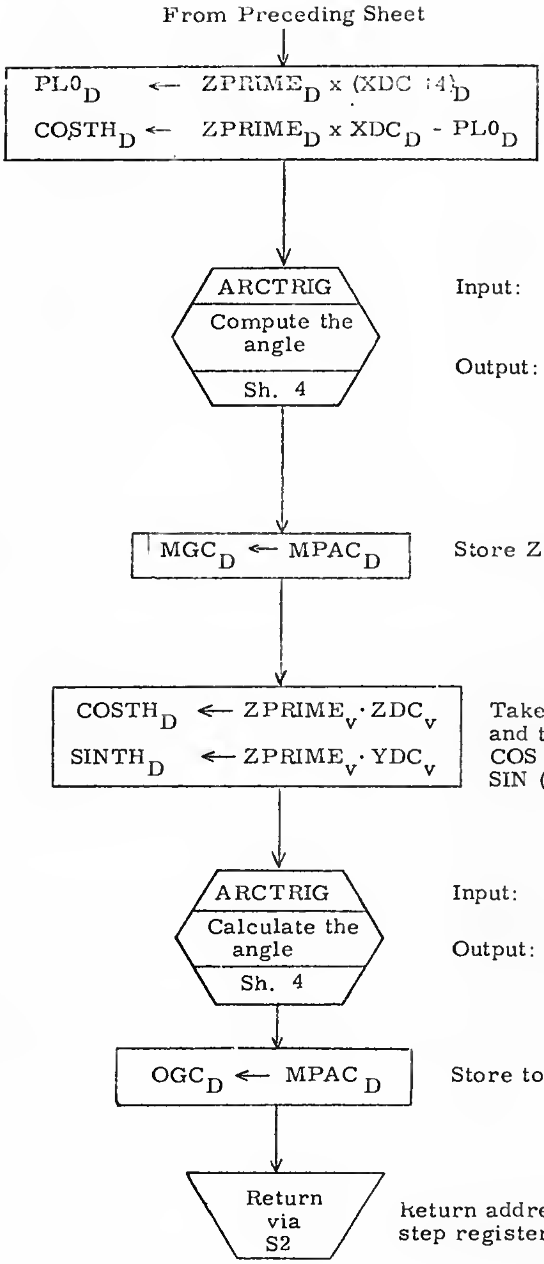
SHEET 2 OF 11



$\mathrm{COS(MGC)} = (\mathrm{ZP3})^2 - (\mathrm{ZP1})(\mathrm{XD3})$

Input: Sine and cosine of the angle is stored at SINTH and COSTH

Output: Z gyro torquing angle in MPAC; THETA, between +0.5 and -0.5 revolutions.

Store Z gyro torquing angle

Take the dot products to get the cosine and the sine of the angle.

$\mathrm{COS\ (OGC)} = \underline{\mathrm{ZP}} \cdot \underline{\mathrm{ZDC}}$

$\mathrm{SIN\ (OGC)} = \underline{\mathrm{ZP}} \cdot \underline{\mathrm{YDC}}$

Input: Sine and cosine of the angle stored in SINTH and COSTH.

Output: X gyro torquing angle (between +0.5 and -0.5 revolutions). Stored in MPAC and THETA.

Store torquing angle.

Return address was stored in step register number 2.

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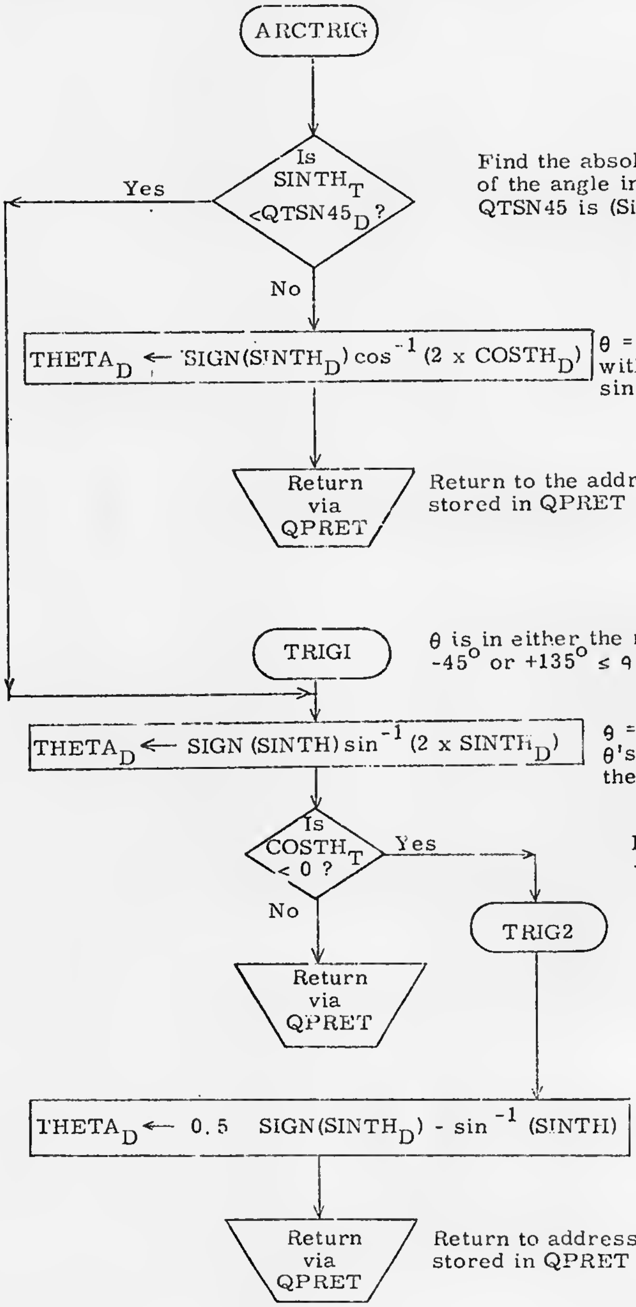
LUMINARY 1D	DOCUMENT NO. FC-3310
REV	SHEET 3 OF 11

This routine (ARCTRIG) computes an angle from its sine and cosine functions. The input values are (sin)/4 and (cos)/4 stored in double precision at SINTH and COSTH, respectively. The output is the calculated angle between +0.5 and -0.5 revolutions. It is stored in MPAC and THETA.



Find the absolute relative value of the angle in terms of its sine. QTSN45 is (Sin (45°))/4.

θ = Arc cosine θ (scaled by 2^1) with the sign determined by the sin θ. θ is in MPAC and THETA.

Return to the address stored in QPRET

θ is in either the range $+45^\circ \leq \theta \leq -45^\circ$ or $+135^\circ \leq \theta \leq -135^\circ$.

θ = Arc sine θ (scaled by 2^1) with θ's sign tentatively determined by the sign of the sin θ.

Is θ in the range $135^\circ \leq \theta \leq -135^\circ$?

Return to the address stored in QPRET

Set θ within $\pm$ 0.5 revolutions

Return to address stored in QPRET

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Inflight Alignment Routines

LUMINARY 1D

DOCUMENT NO. FC-3310

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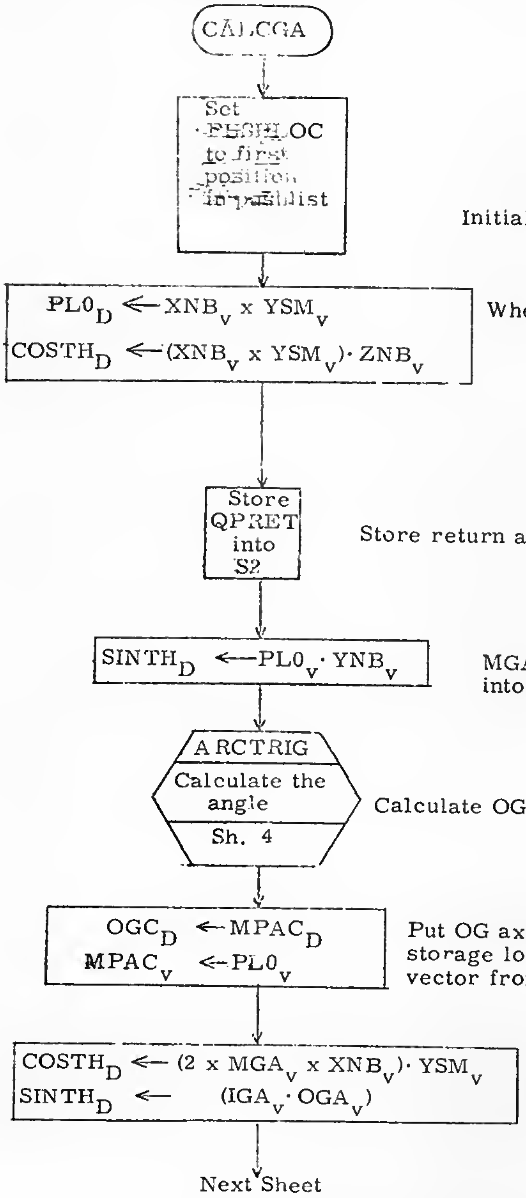
This routine computes the coupled data unit (CDU) driving angles required to bring the stable member into the desired orientation. The inputs are:

1. The navigation base coordinates referred to any coordinate system. The three half-unit vectors are stored at XNB, YNB, and ZNB.
2. The desired stable member coordinates referred to the same coordinate system are stored at XSM, YSM, and ZSM.

The outputs are the three CDU driving angles stored in single precision at THETAD, THETAD +1, and THETAD +2.



Initialize pushdown pointer

Where XNB = Outer gimbal axis (OGA)
YSM = Inner gimbal axis (IGA)
PL0 = UNIT (OGA x IGA) = MGA
COS(OG) = MGA · ZNB

Store return address

MGA has been reset from PL0 into MPAC. Sin(OG) = MGA · YNB

Calculate OGA angle

Put OG axis angle into its storage location. Push up vector from PL0 into $MPAC_v$.

COS(MG) = IGA · (MGA x OGA) scaled @ 2^1.
SIN(MG) = IGA · OGA

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Inflight Alignment Routines
LUMINARY 1D
DOCUMENT NO. FC-3310
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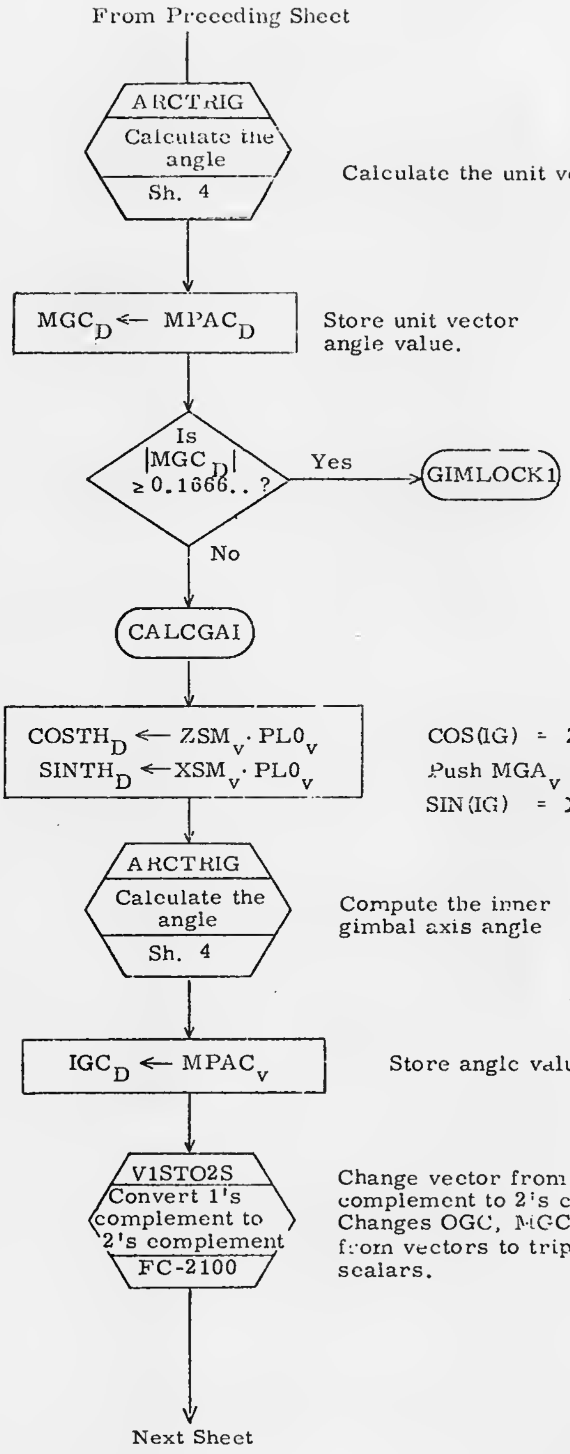

Calculate the unit vector angle

Store unit vector angle value.

$COS(IG) = ZSM \cdot MGA$

Push MGA_v into $MPAC_v$

$SIN(IG) = XSM \cdot MGA$

Compute the inner gimbal axis angle

Store angle value

Change vector from 1's complement to 2's complement. Changes OGC, MGC, and IGC from vectors to triple precision scalars.

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Inflight Alignment Routine

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APPR'D Roberta M Entwistle 5/14/70

LUMINARY 1D

DOCUMENT NO.
FC-3310

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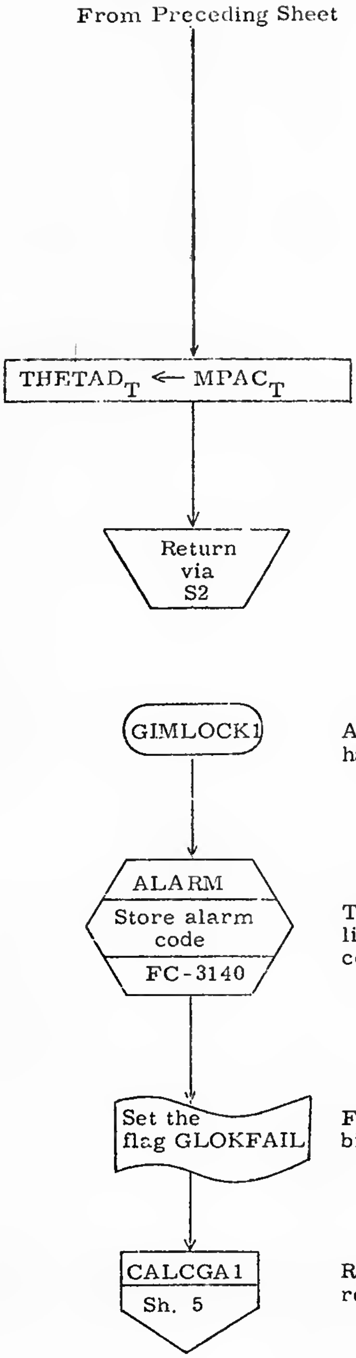

Store three single precision values into THETAD, THETAD +1, THETAD +2.

A gimbal lock has occurred.

Turn on program alarm light and store alarm code into register.

Flagword 3 bit 14

Via subroutine UPFLAG

Return to subroutine re-entry point.

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Inflight Alignment Routines

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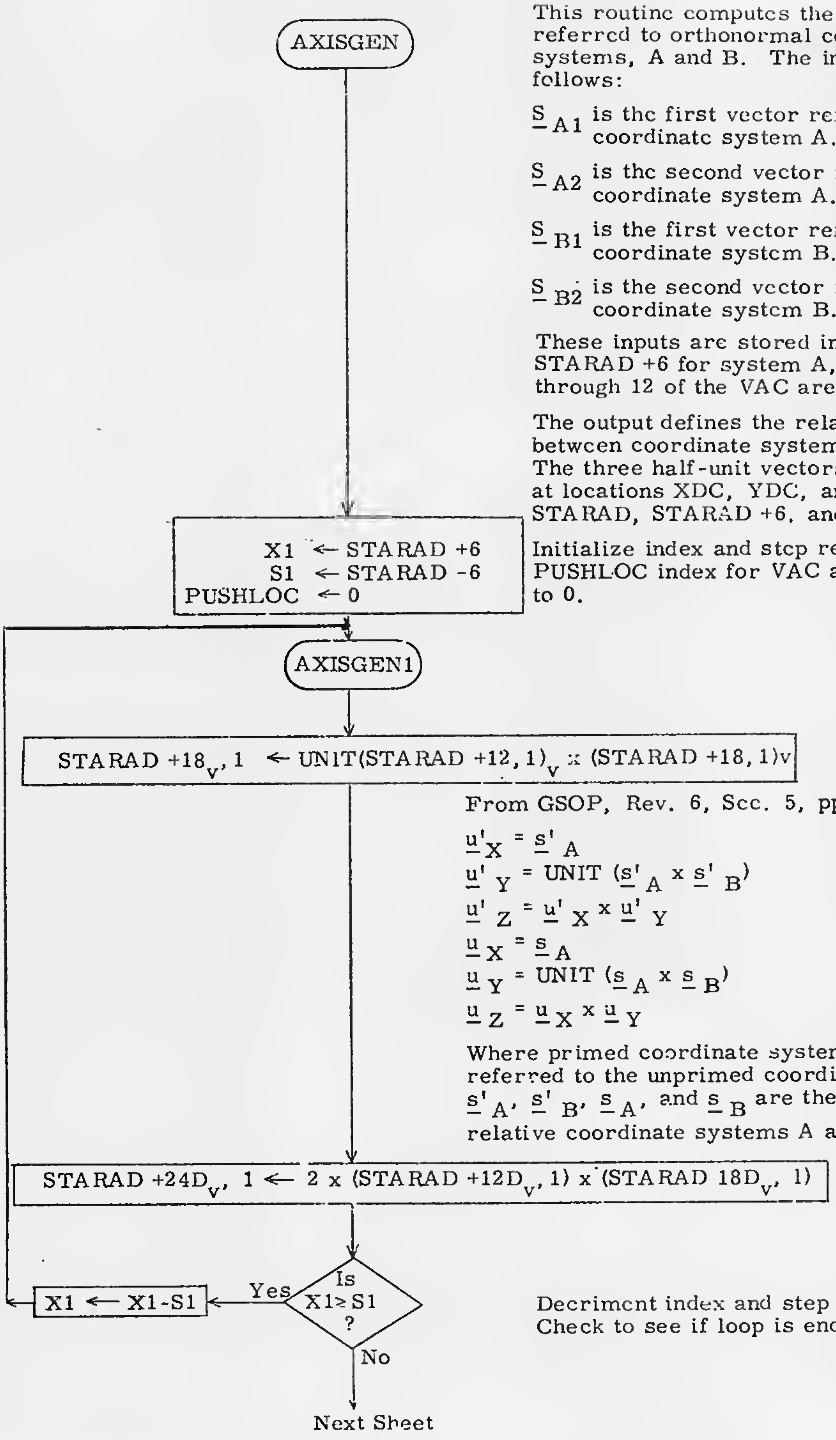


This routine computes the unit vectors referred to orthonormal coordinate systems, A and B. The inputs are as follows:

$\underline{S}_{A1}$ is the first vector referred to coordinate system A.

$\underline{S}_{A2}$ is the second vector referred to coordinate system A.

$\underline{S}_{B1}$ is the first vector referred to coordinate system B.

$\underline{S}_{B2}$ is the second vector referred to coordinate system B.

These inputs are stored in STARAD through STARAD +6 for system A, and locations 6 through 12 of the VAC area for system B.

The output defines the relationship between coordinate systems A and B. The three half-unit vectors are stored at locations XDC, YDC, and ZDC and STARAD, STARAD +6, and STARAD +2.

Initialize index and step registers. Set PUSHLOC index for VAC area indexing to 0.

From GSOP, Rev. 6, Sec. 5, pp 5.6-22,23.

$\underline{u}'_X = \underline{s}'_A$

$\underline{u}'_Y = \text{UNIT}\ (\underline{s}'_A \times \underline{s}'_B)$

$\underline{u}'_Z = \underline{u}'_X \times \underline{u}'_Y$

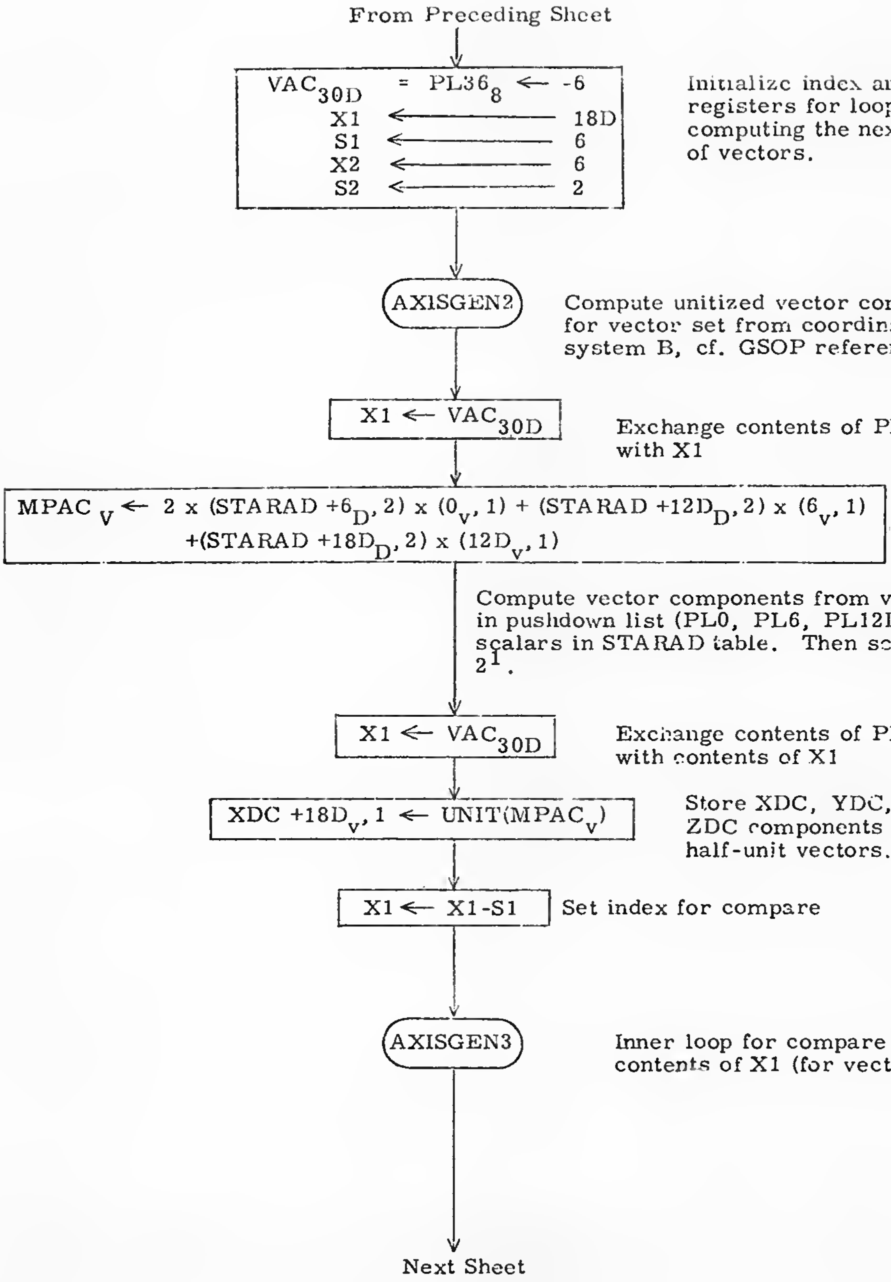
$\underline{u}_X = \underline{s}_A$

$\underline{u}_Y = \text{UNIT}\ (\underline{s}_A \times \underline{s}_B)$

$\underline{u}_Z = \underline{u}_X \times \underline{u}_Y$

Where primed coordinate system axes are referred to the unprimed coordinate system. $\underline{s}'_A$, $\underline{s}'_B$, $\underline{s}_A$, and $\underline{s}_B$ are the vectors in relative coordinate systems A and B.

Decrement index and step registers. Check to see if loop is ended.



Initialize index and step registers for loop for computing the next set of vectors.

Compute unitized vector components for vector set from coordinate system B, cf. GSOP reference above.

Exchange contents of $PL36_8$ with X1

Compute vector components from vectors in pushdown list (PL0, PL6, PL12D) and scalars in STARAD table. Then scale @ 2^1.

Exchange contents of $PL36_8$ with contents of X1

Store XDC, YDC, or ZDC components as half-unit vectors.

Set index for compare

Inner loop for compare on contents of X1 (for vectors)

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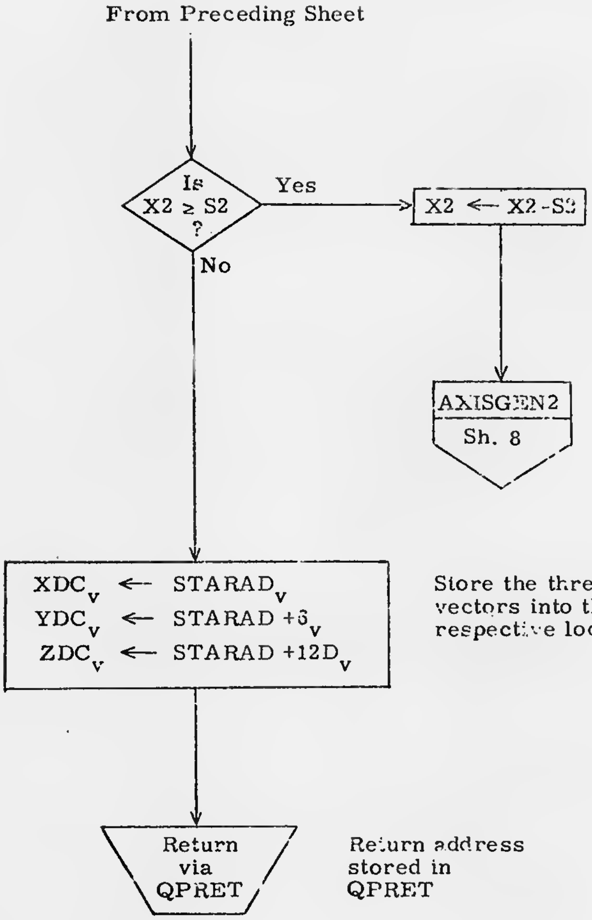

Decrement index and step registers and check if scalar portion of loop is finished. When X2 ≥ S2 the loop is not complete

Store the three half-unit vectors into their respective locations.

Return address stored in QPRET

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APPR'D Roberta M Eaton	5/14/70	REV	SHEET 10 OF 11

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
CPHIFLAG	Output of CALCGA is CPHIX	Output of CALCGA is THETAD	Sh. 7		Sh. 7
GLOKFAIL	Gimbal Lock has occurred	Not in gimbal lock	Sh. 7		

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
V1STO2S	FC-2100	Convert 1's complement to 2's complement	Sh. 6
ALARM	FC-3140	Store alarm code	Sh. 7

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POWERED FLIGHT SUBROUTINES

CDUTRIG	Sh. 2
CD*TR*GS	Sh. 2
CD*TR*G	Sh. 2
CDUTRIGS	Sh. 2
QTPROLOG	Sh. 5
QUICTRIG	Sh. 6
NBSM	Sh. 8
TRG*SMNB	Sh. 9
CDU*SMNB	Sh. 9
TRG*NBSM	Sh. 10
CDU*NBSM	Sh. 10
SMNB	Sh. 11
NBSM	Sh. 11
AX*SR*T	Sh. 12
CALCSMC	Sh. 16

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DOCMR R M Estes 6/19/70
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Powered Flight Subroutines

LUMINARY 1D

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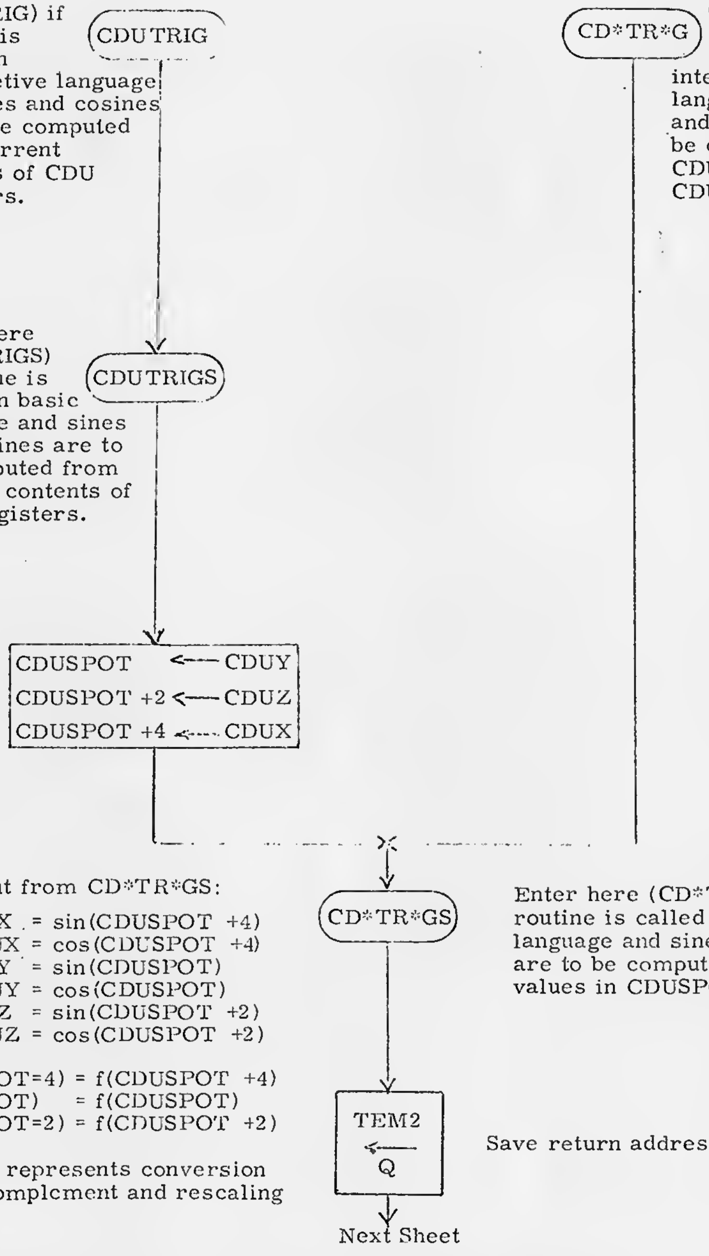

Enter here (CDUTRIG) if routine is called in interpretive language and sines and cosines are to be computed from current contents of CDU registers.

Enter here (CD*TR*G) if routine is called in interpretive language and sines and cosines are to be computed from CDU values in CDUSPOT.

Enter here (CDUTRIGS) if routine is called in basic language and sines and cosines are to be computed from current contents of CDU registers.

Enter here (CD*TR*GS) if routine is called in basic language and sines and cosines are to be computed from CDU values in CDUSPOT.

Save return address

Output from CD*TR*GS:

SINCDUX = sin(CDUSPOT +4)
COSCDUX = cos(CDUSPOT +4)
SINCDUY = sin(CDUSPOT)
COSCDUY = cos(CDUSPOT)
SINCDUZ = sin(CDUSPOT +2)
COSCDUZ = cos(CDUSPOT +2)

(CDUSPOT=4) = f(CDUSPOT +4)
(CDUSPOT) = f(CDUSPOT)
(CDUSPOT=2) = f(CDUSPOT +2)

Where f represents conversion to 1's complement and rescaling to 2π

NOTE:

SINCDUX is SINCDU +4
SINCDUY is SINCDU
SINCDUZ is SINCDU +2
COSCDUX is COSCDU +4
COSCDUY is COSCDU
COSCDUZ is COSCDU +2

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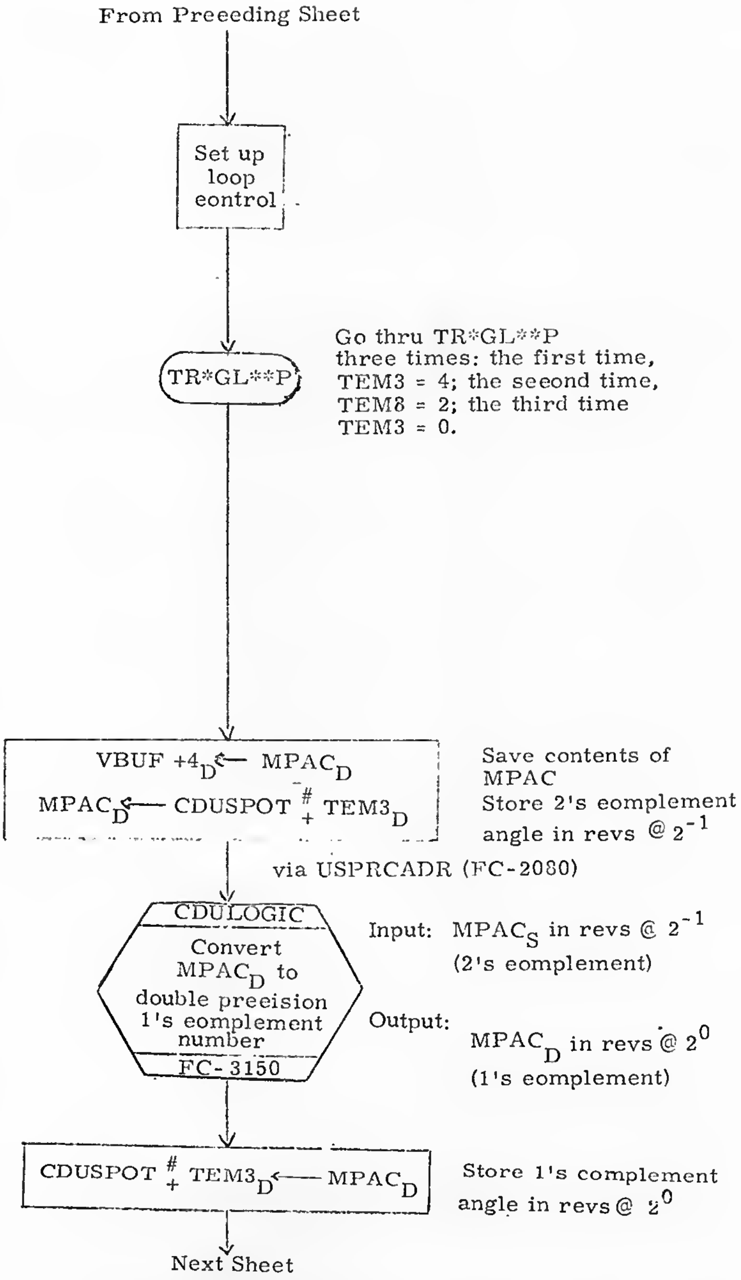
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3320	
DOCMR R M Estes	6/19/70			
APPR'D R M Estes	6/19/70	REV	SHEET 2 OF 22	



Go thru TR*GL**P three times: the first time, TEM3 = 4; the second time, TEM8 = 2; the third time TEM3 = 0.

Save contents of MPAC

Store 2's complement angle in revs @ 2^{-1}

via USPRCADR (FC-2080)

Input: MPAC$_S$ in revs @ 2^{-1} (2's complement)

Output: MPAC$_D$ in revs @ 2^0 (1's complement)

Store 1's complement angle in revs @ 2^0

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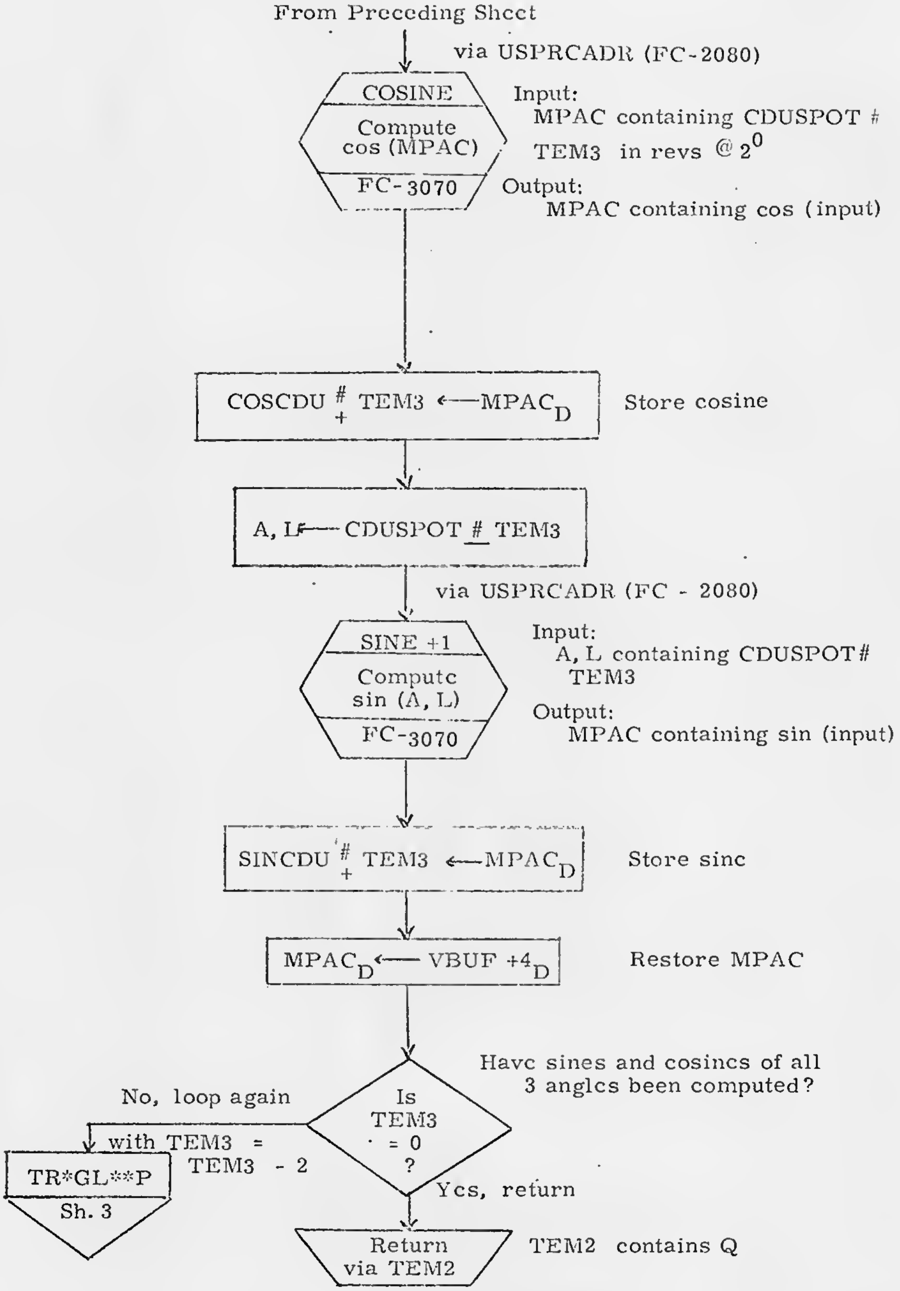

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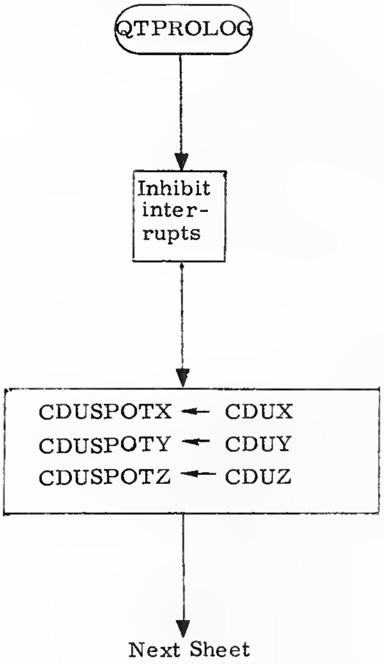
DOCMR RM Eutes	6/19/70		
APPR'D RM Eutes	6/19/70	REV	SHEET 4 OF 22



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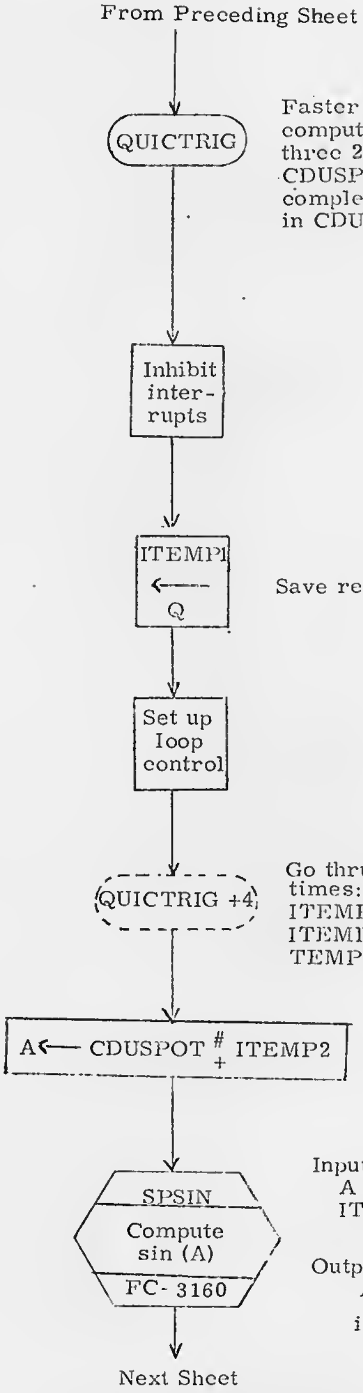
ANALST			LUMINARY 1D	DOCUMENT NO. FC-3320
DOCMR	R M Estes	6/19/70		
APPR'D	R M Estes	6/19/70	REV	SHEET 5 OF 22



Faster version of CD*TR*GS: computes sines and cosines of three 2's complement angles at CDUSPOT, but does not leave 1's complement versions of angles in CDUSPOT.

Save return address

Go thru QUICTRIG +4 three times: the first time, ITEMP2 = 4; the second time, ITEMP2 = 2; the third time, TEMP2 = 0.

Input:
A containing CDUSPOT # ITEMP2 in revs @ 2^{-1}

Output:
A containing sin (input) in revs @ 2^0

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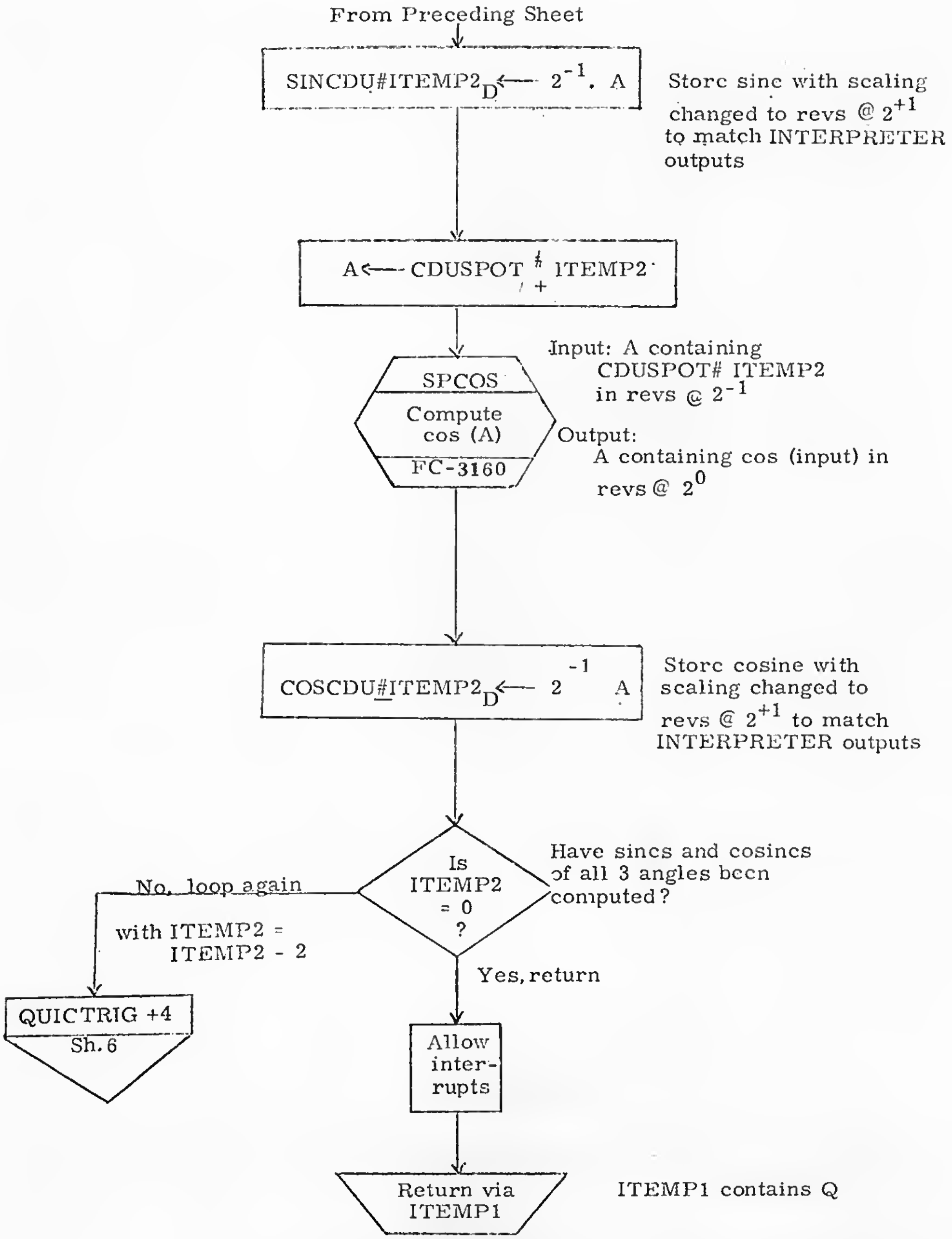

Store sine with scaling changed to revs @ 2^{+1} to match INTERPRETER outputs

Input: A containing CDUSPOT# ITEMP2 in revs @ 2^{-1}

Output: A containing cos (input) in revs @ 2^0

Store cosine with scaling changed to revs @ 2^{+1} to match INTERPRETER outputs

Have sines and cosines of all 3 angles been computed?

ITEMP1 contains Q

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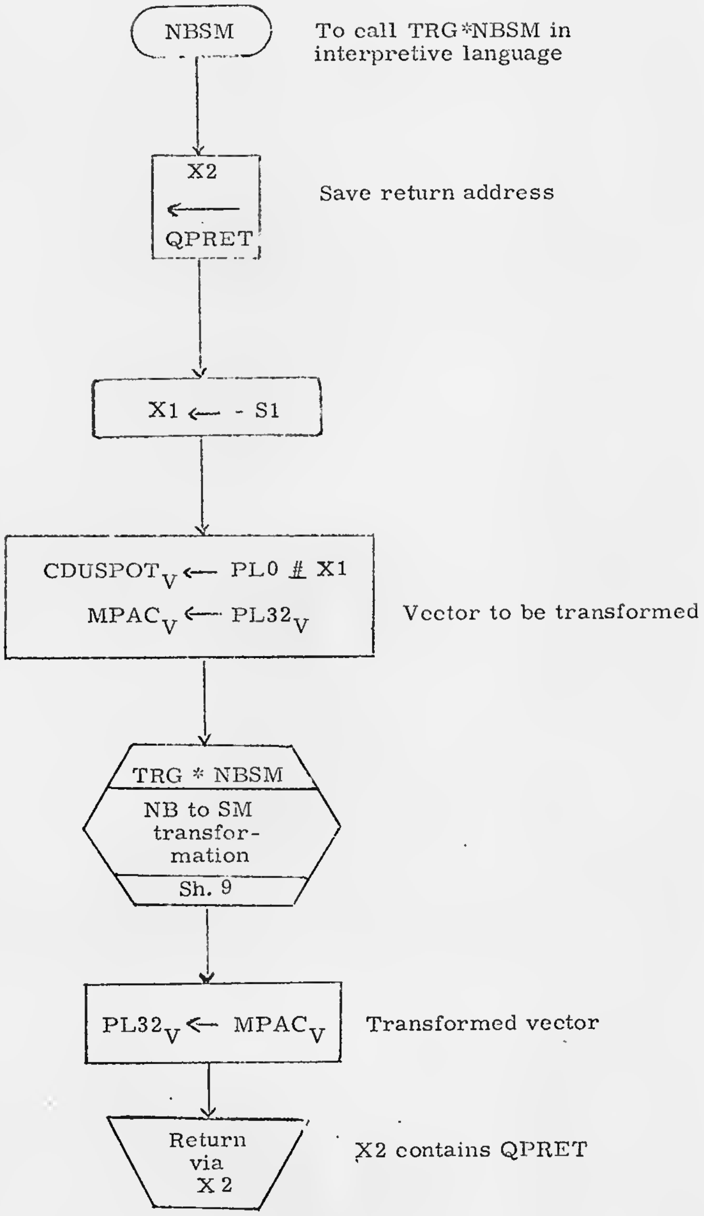
DOCMR RmEntes	6/19/70		
APPR'D RmEntes	6/19/70	REV	SHEET 7 OF 22



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ANALST
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APPR'D 6/19/70

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Powered Flight Subroutines

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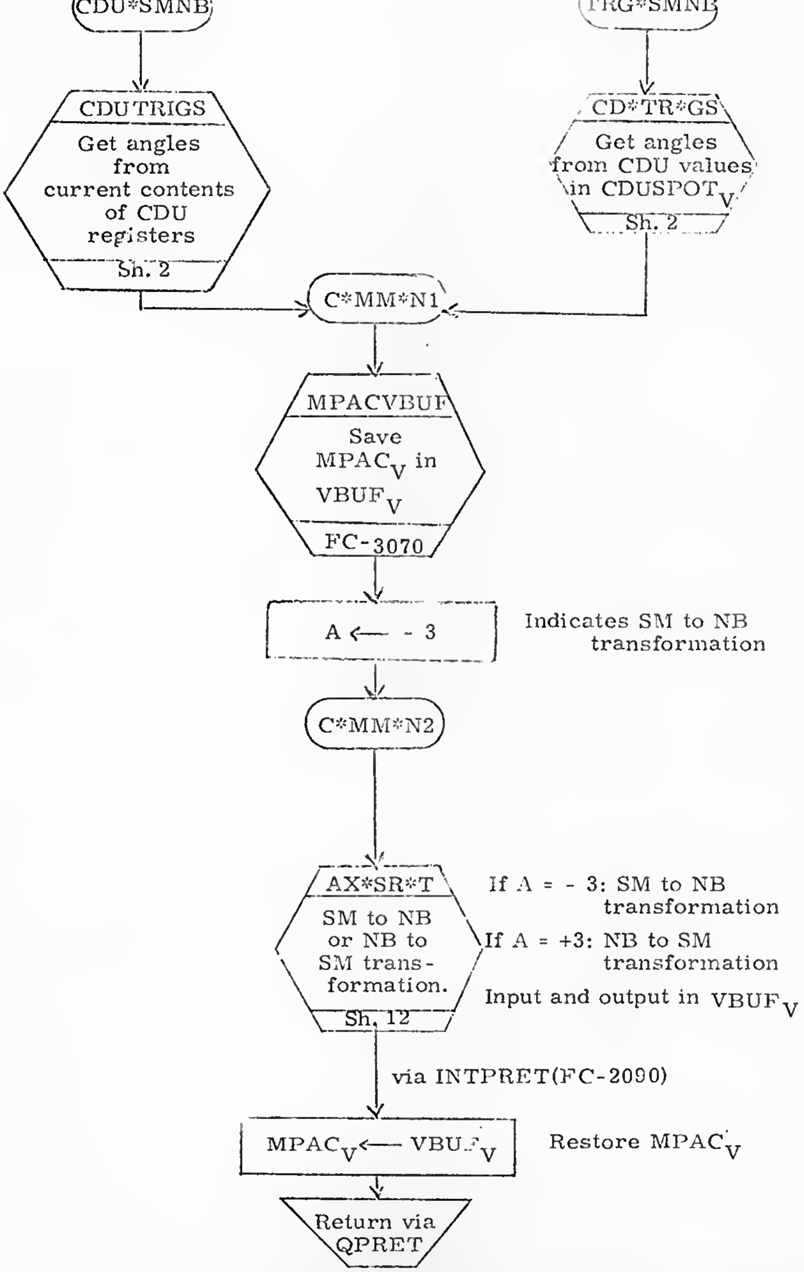

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APPR'D R M Estes 6/19/70

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Powered Flight Subroutines

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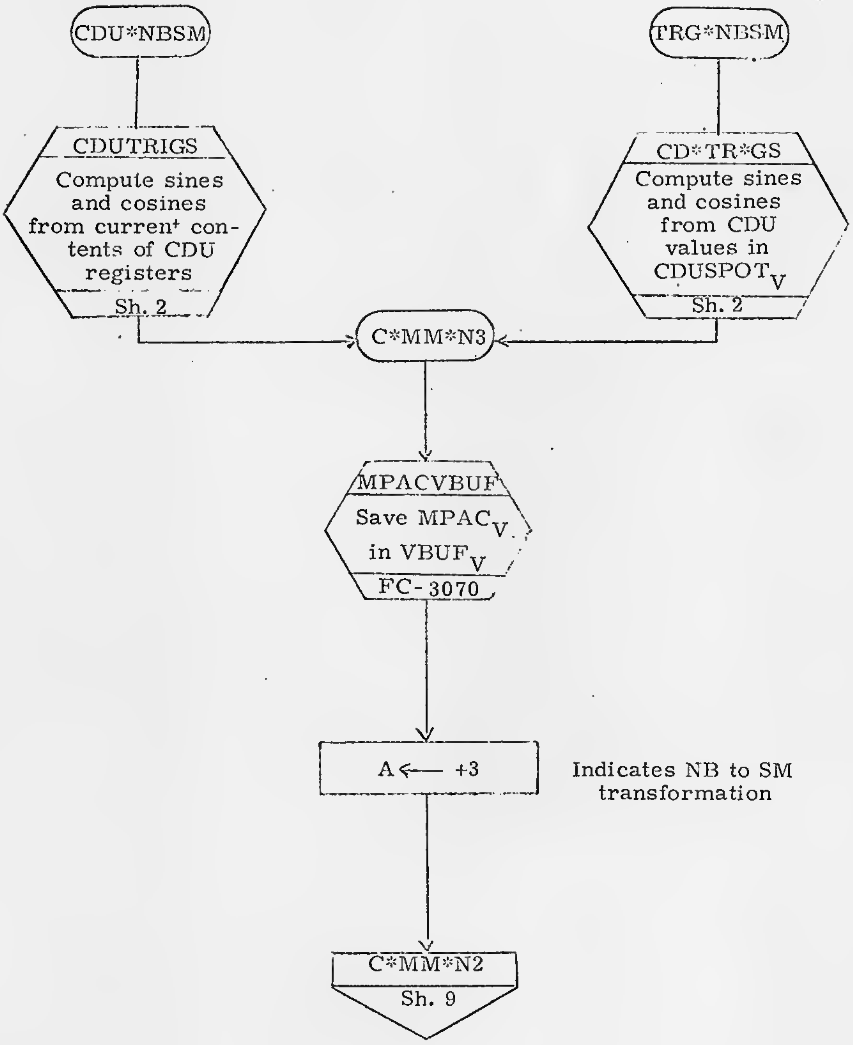

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DRAWN [illegible]
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ANALST
DOCMR R M Estes 6/19/70
APPR'D R M Estes 6/19/70

APOLLO GUIDANCE AND NAVIGATION

Powered Flight Subroutines

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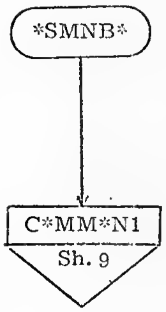
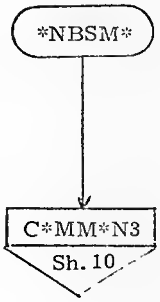


Enter with sines and cosines
at SINCDU and COSCDU.



Enter with sines and cosines
at SINCDU and COSCDU.

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DRAWN [illegible] [illegible]
PRGMR
ANALST
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APPR'D R M Estes 6/19/70

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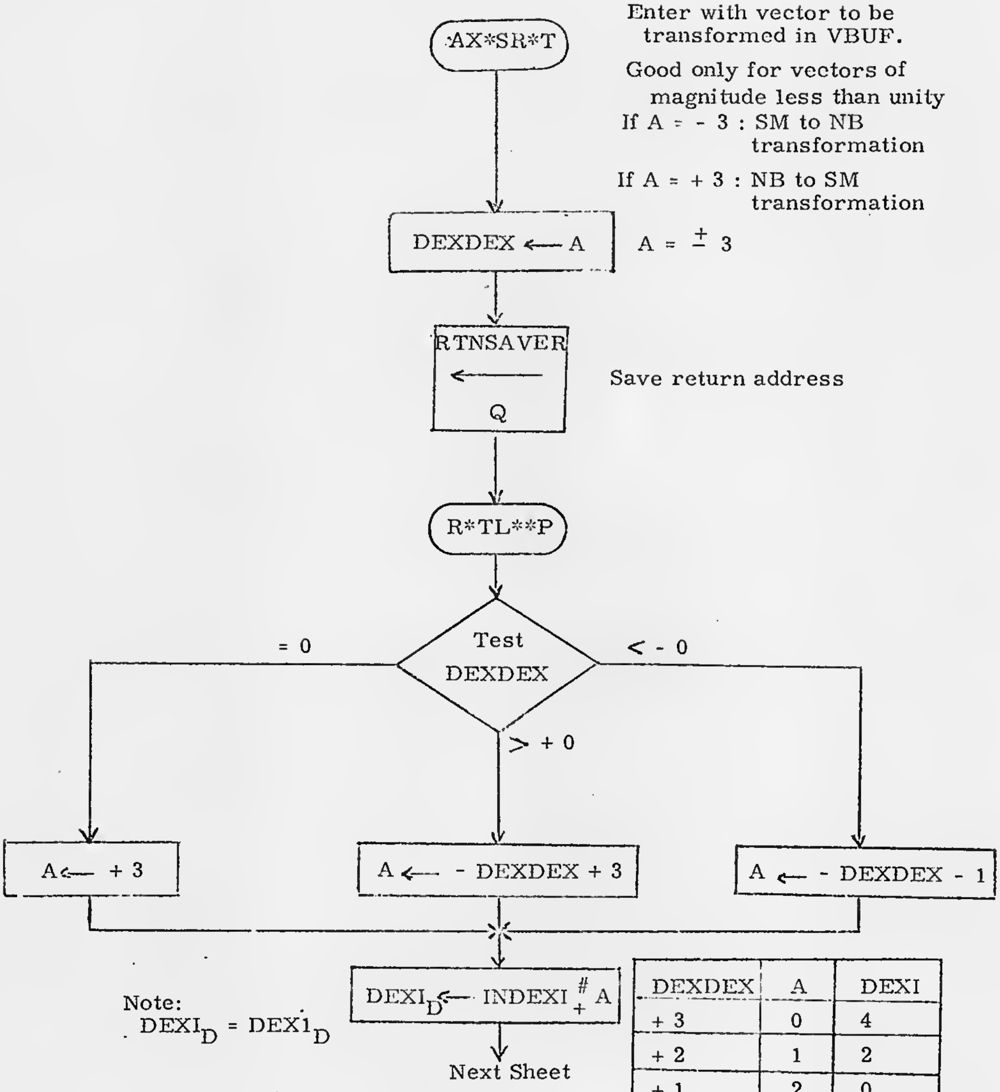

DEXDEX	A	DEXI
+ 3	0	4
+ 2	1	2
+ 1	2	0
- 3	2	0
- 2	1	2
- 1	0	4

Note: when DEXDEX = 0, A = + 3, DEXI = 4.

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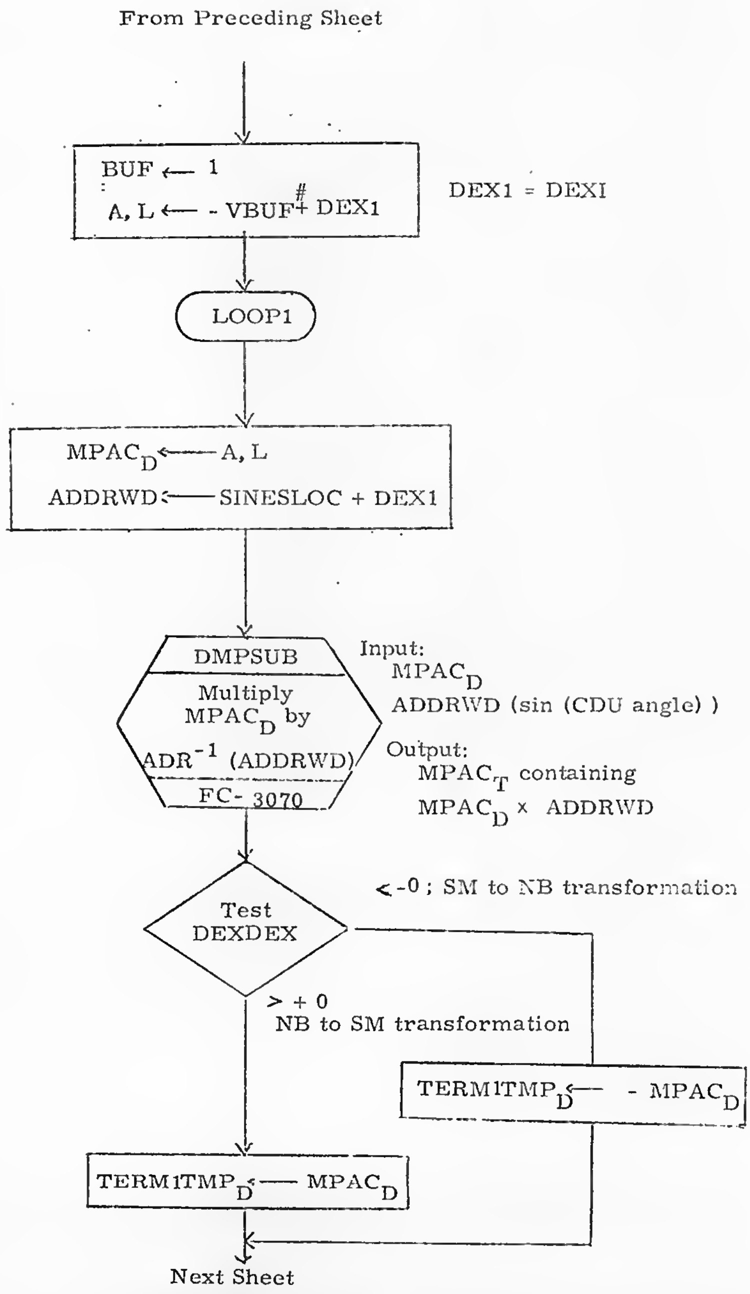
APOLLO GUIDANCE AND NAVIGATION
Powered Flight Subroutines
LUMINARY 1D
DOCUMENT NO. FC-3320
REV
SHEET 12 of 22



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ANALST		
DCCMR	RM Enter	6/19/70
APPR'D	RM Enter	6/19/70

APOLLO GUIDANCE AND NAVIGATION

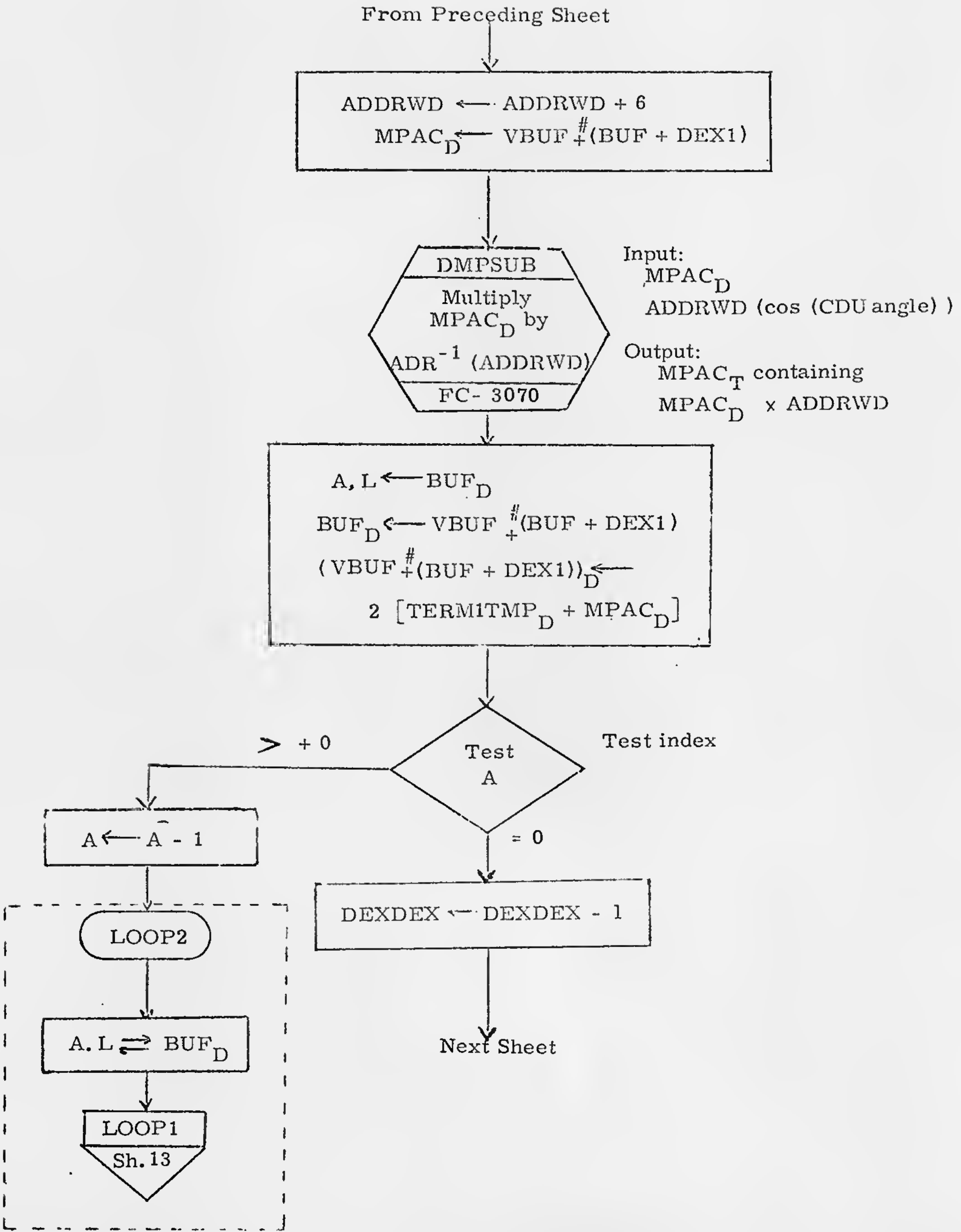
Powered Flight Subroutines -

LUMINARY 1D

DOCUMENT NO. FC- 3320

REV

SHEET 13 OF 22



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DRAWN [illegible] [illegible]
PRGMR
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DOCMR RM Estes 6/19/70
APPR'D RM Estes 6/19/70

APOLLO GUIDANCE AND NAVIGATION

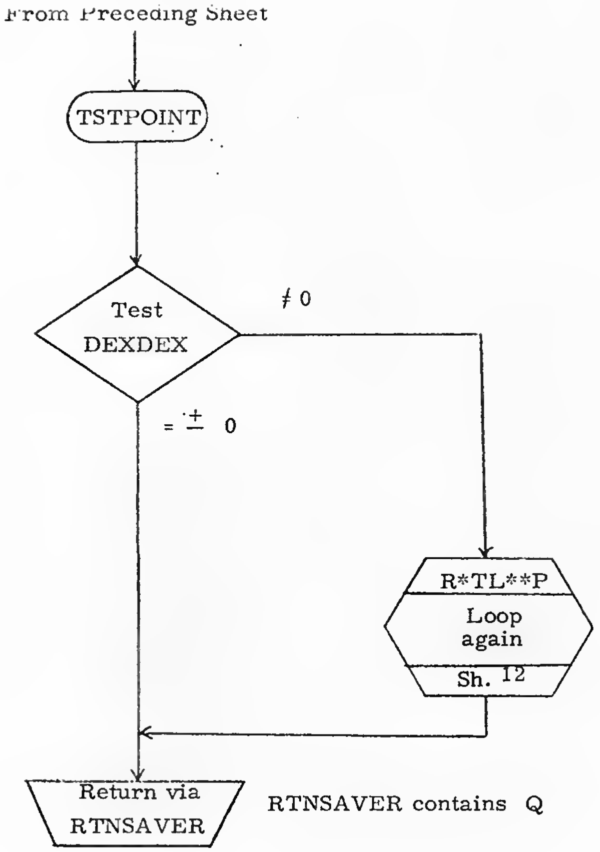
Powered Flight Subroutines

LUMINARY 1D

DOCUMENT NO.
FC-3320

REV

SHEET 14 OF 22



RTNSAVER contains Q

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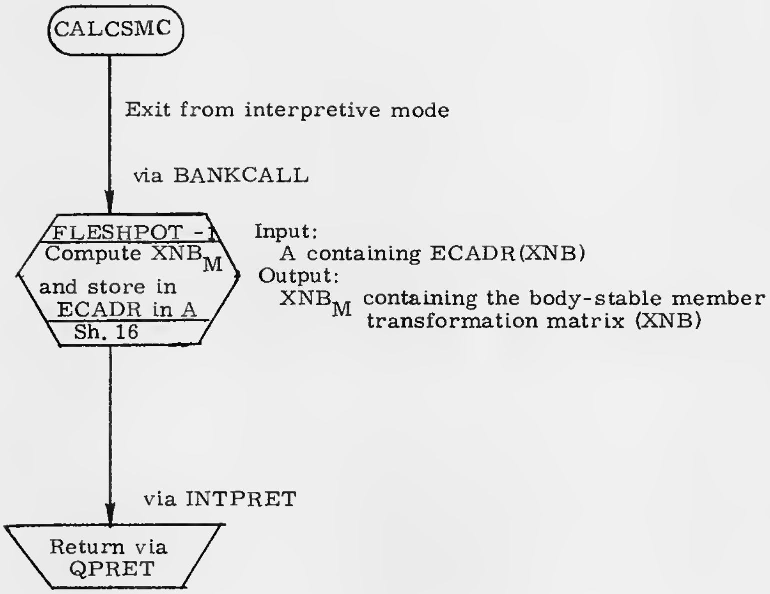
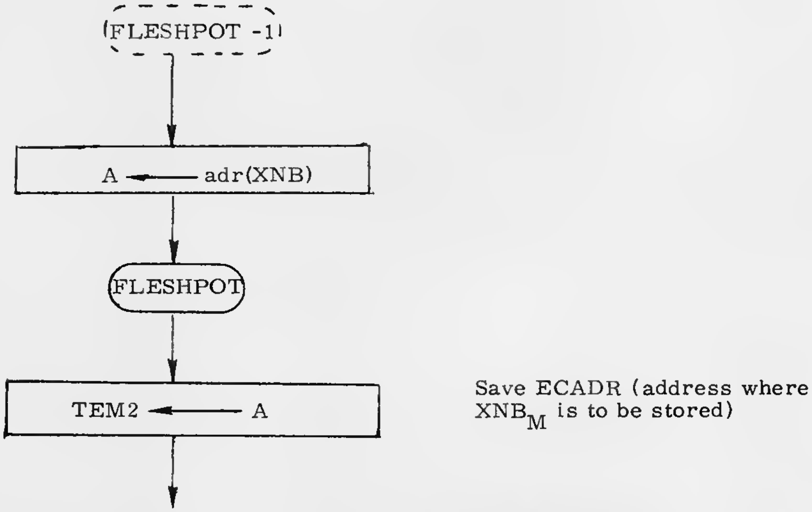
DRAWN	[illegible]	Powered Flight Subroutines	
PRGMR		LUMINARY 1D	DOCUMENT NO. FC-3320
ANALST			
DOCMR R M Estes	6/19/70		
APPR'D R M Estes	6/19/70	REV	SHEET 15 OF 22



Input:
A containing ECADR(XNB)
Output:
XNB_M containing the body-stable member transformation matrix (XNB)



Save ECADR (address where XNB_M is to be stored)

Next Sheet

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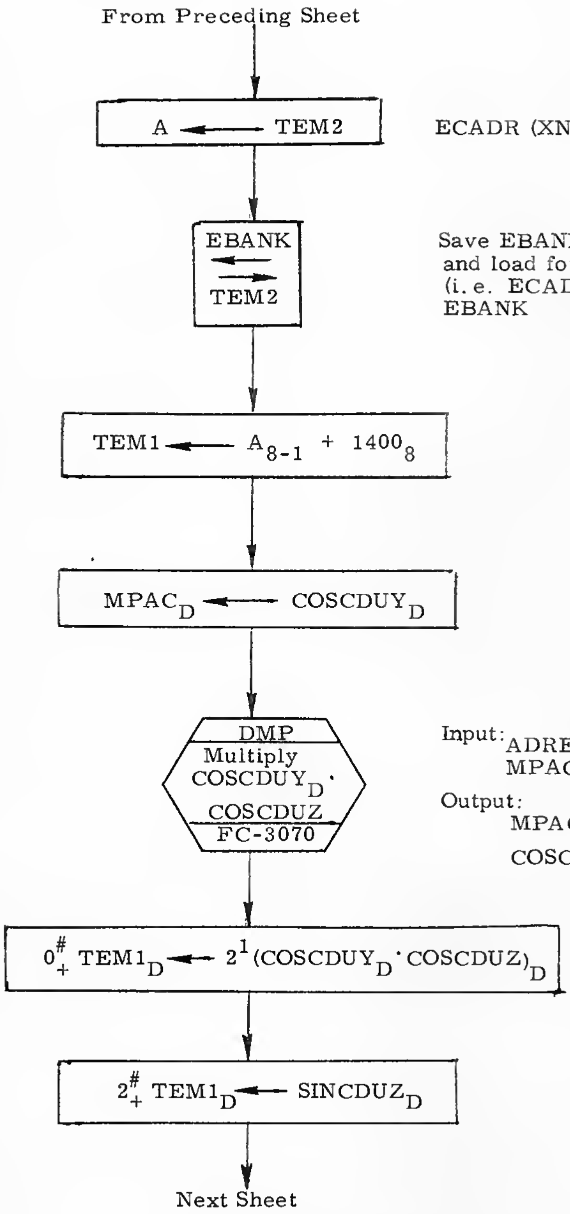
APOLLO GUIDANCE AND NAVIGATION
Powered Flight Subroutines
LUMINARY 1D
DOCUMENT NO. FC-3320
REV
SHEET 16 OF 22



ECADR (XNB)

Save EBANK in TEM2 and load former TEM2 (i.e. ECADR in A) into EBANK

Input: ADRES(COSCDUZ)
$MPAC_D$ containing $COSCDUY_D$
Output:
$MPAC_T$ containing
$COSCDUY_D \cdot$ COSCDUZ

cos X · cos Y

sin Z

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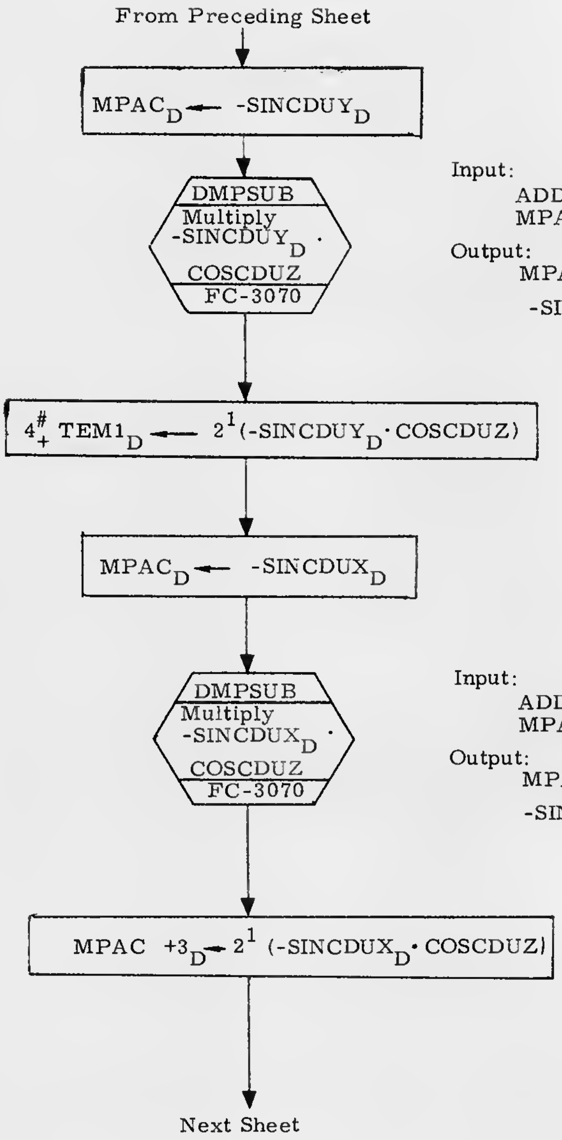
APPR'D RMM Estes 6/19/70
Powered Flight Subroutines
LUMINARY 1D
DOCUMENT NO. FC-3320
REV
SHEET 17 OF 22



Input:
ADDRWD set to COSCDUZ
$MPAC_D$ containing $-SINCDUY_D$
Output:
$MPAC_T$ containing
$-SINCDUY_D \cdot COSCDUZ$

-sin Y cos Z

Input:
ADDRWD set to COSCDUZ
$MPAC_D$ containing $-SINCDUX_D$
Output:
$MPAC_T$ containing
$-SINCDUX_D \cdot COSCDUZ$

-sin X cos Z

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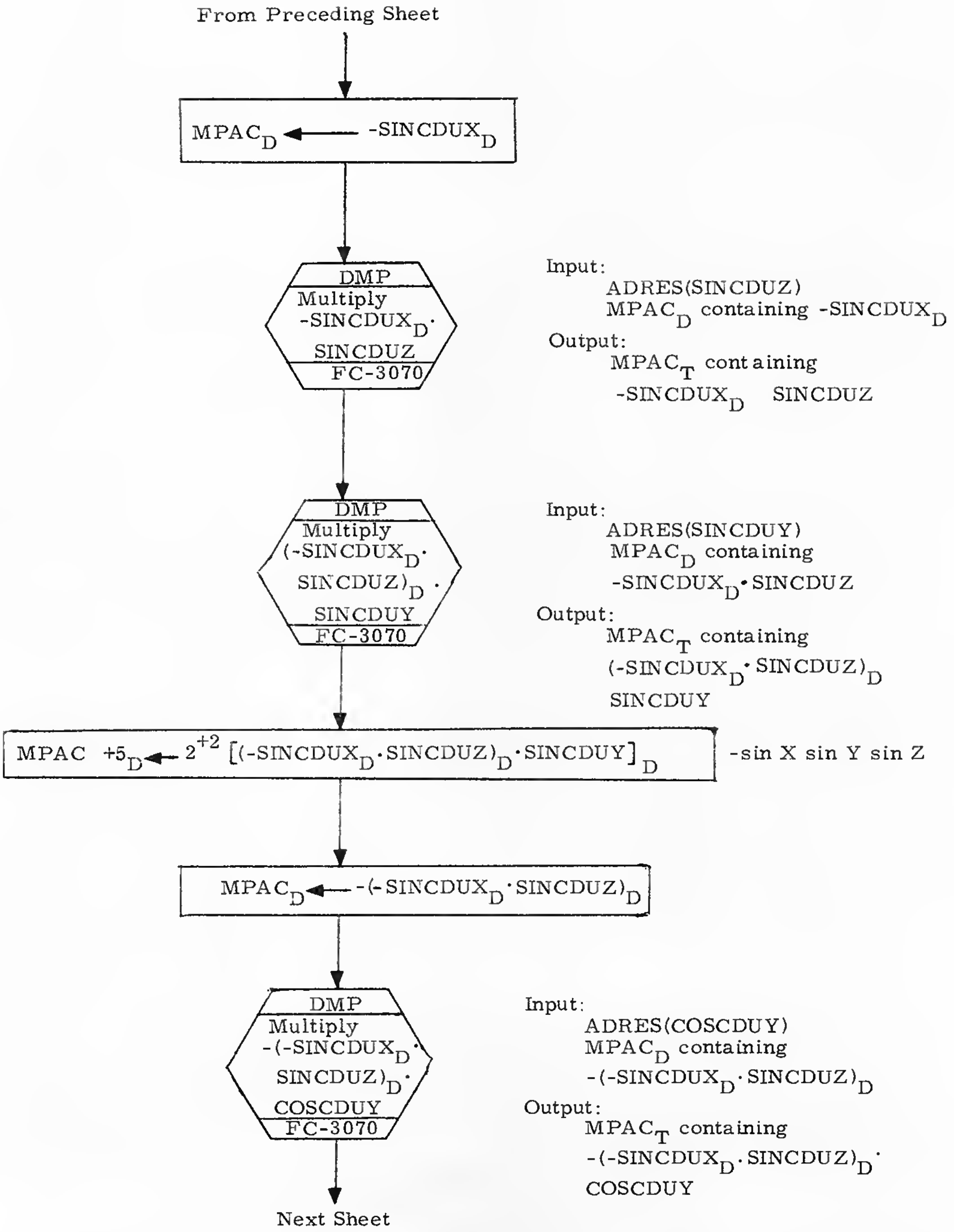
APOLLO GUIDANCE AND NAVIGATION

Powered Flight Subroutines

LUMINARY 1D

DOCUMENT NO. FC-3320

REV



Input:
ADRES(SINCDUZ)
$MPAC_D$ containing $-SINCDUX_D$
Output:
$MPAC_T$ containing
$-SINCDUX_D$ SINCDUZ

Input:
ADRES(SINCDUY)
$MPAC_D$ containing
$-SINCDUX_D \cdot SINCDUZ$
Output:
$MPAC_T$ containing
$(-SINCDUX_D \cdot SINCDUZ)_D$
SINCDUY

-sin X sin Y sin Z

Input:
ADRES(COSCDUY)
$MPAC_D$ containing
$-(-SINCDUX_D \cdot SINCDUZ)_D$
Output:
$MPAC_T$ containing
$-(-SINCDUX_D \cdot SINCDUZ)_D \cdot$
COSCDUY

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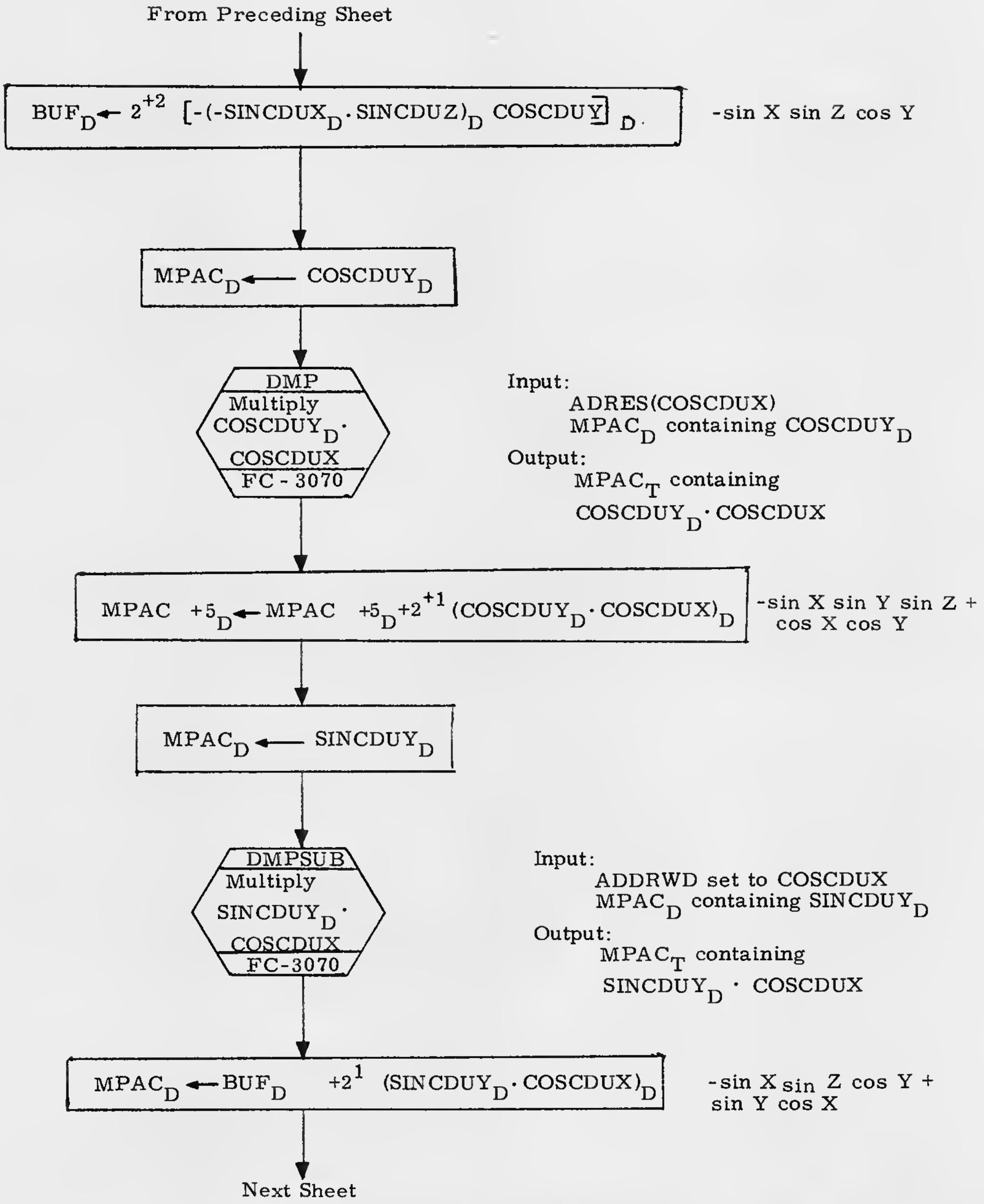
DRAWN [illegible] 5/29/70	Powered Flight Subroutines	
PRGMR	LUMINARY 1D	DOCUMENT NO. FC-3320
ANALST		
DOCMR RM Estes 6/19/70		
APPR'D RM Estes 6/19/70	REV	SHEET 19 OF 22



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ANALST
DOCMR R M Estes 6/19/70
APPR'D R M Estes 6/19/70

APOLLO GUIDANCE AND NAVIGATION

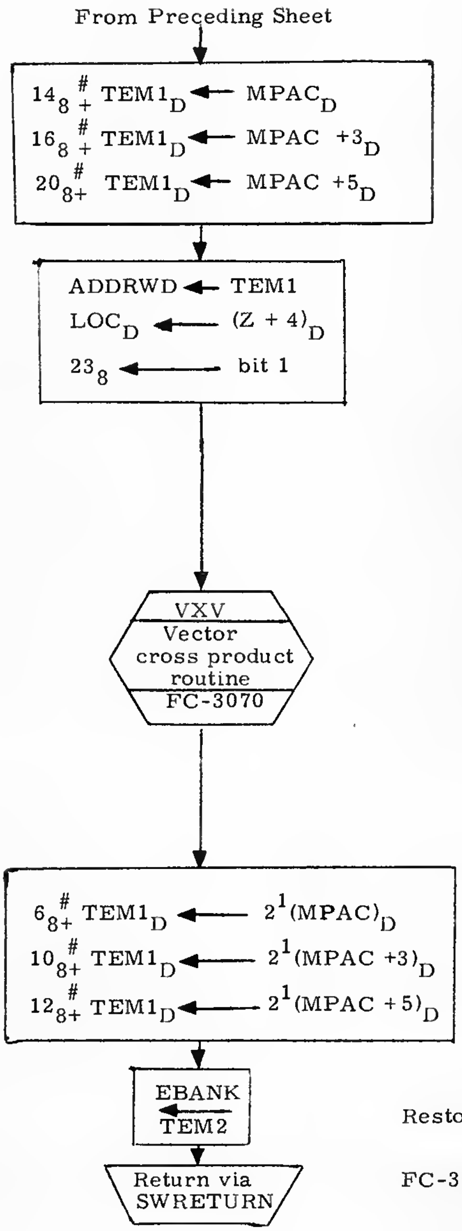
Powered Flight Subroutines

LUMINARY 1D

DOCUMENT NO. FC-3320

REV

SHEET 20 **OF** 22



sin Y cos X - sin X sin Z cos Y

-sin X cos Z

cos X cos Y - sin X sin Y sin Z

Input:
MPAC$_V$ containing

$$\begin{pmatrix} \text{sin Y cos X - sin X sin Z cos Y} \\ \text{-sin X cos Z} \\ \text{cos X cos Y - sin X sin Y sin Z} \end{pmatrix}$$

$0^{\#}_{+}$ TEM1_V containing

$$\begin{pmatrix} \text{cos X cos Y} \\ \text{sin Z} \\ \text{-sin Y cos Z} \end{pmatrix}$$

Output:
MPAC$_V$ containing TEM1_V x MPAC$_V$

1st component of MPAC$_V$

2nd component of MPAC$_V$

3rd component of MPAC$_V$

Restore EBANK

FC-3060

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DRAWN D. Lutkevich	5/29/70	Powered Flight Subroutines	
PRGMR			
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3320
DOCMR RMM Estes	6/19/70		
APPR'D RMM Estes	6/19/70	REV	SHEET 21 OF 22

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
CDULOGIC	FC-3150	Converts s. p. 2's complement number to d. p. 1's complement	Sh. 3
COSINE	FC-3070	Computes cosine	Sh. 4
DMPSUB	FC-3070	Double precision multiplication	Sh. 13, 14, 18, 20
INTPRET	FC-3070	Interpretive language	Sh. 9
MPACVBUF	FC-3070	Saves $MPAC_V$ in $VBUF_V$	Sh. 9, 10
SINE	FC-3070	Computes sine	Sh. 4
SPCOS	FC-3160	Computes cosine	Sh. 7
SPSIN	FC-3160	Computes sine	Sh. 6
USPRCADR	FC-3060	Allows access to F-bank other than user's	Sh. 3, 4
DMP	FC-3070	Double precision multiplication	Sh. 17, 19, 20
VXV	FC-3070	Vector cross product routine	Sh. 21

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APOLLO GUIDANCE AND NAVIGATION
PoweredFlight Subroutines
LUMINARY 1D
DOCUMENT NO. FC-3320
REV
SHEET 22 OF 22

LATITUDE LONGITUDE SUBROUTINES

LAT-LONG Sh. 2
LALOTORV Sh. 7
GETERAD Sh. 9

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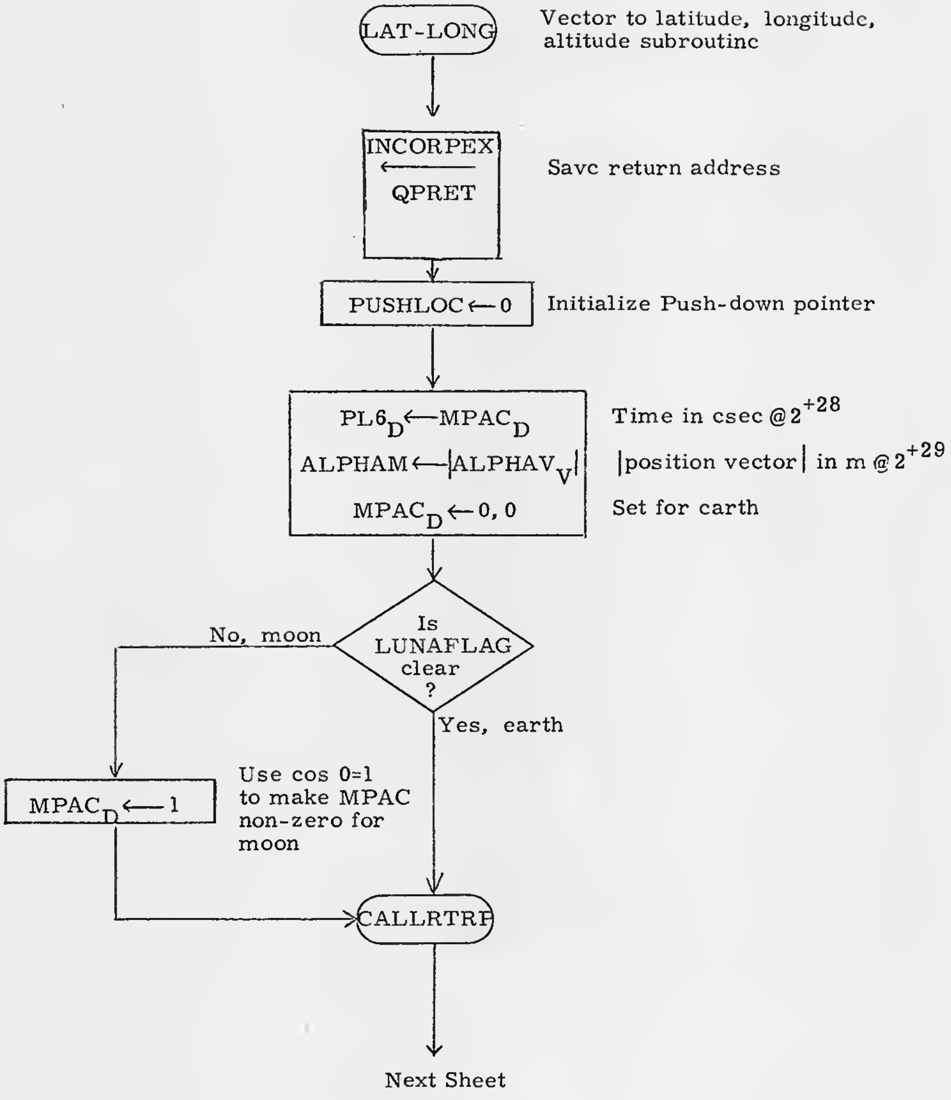
DRAWN	D Lutkewich	1/14/70	Latitude Longitude Subroutines	
PRGMR				DOCUMENT NO.
ANALST	J. M. Reber	1-16-70		
DOCMR	Roberta M. Estes	1/16/70	LUMINARY 1D	FC-3330
APPR'D	Roberta M. Estes	1/16/70	REV 1.	SHEET 1 OF 13



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APOLLO GUIDANCE AND NAVIGATION

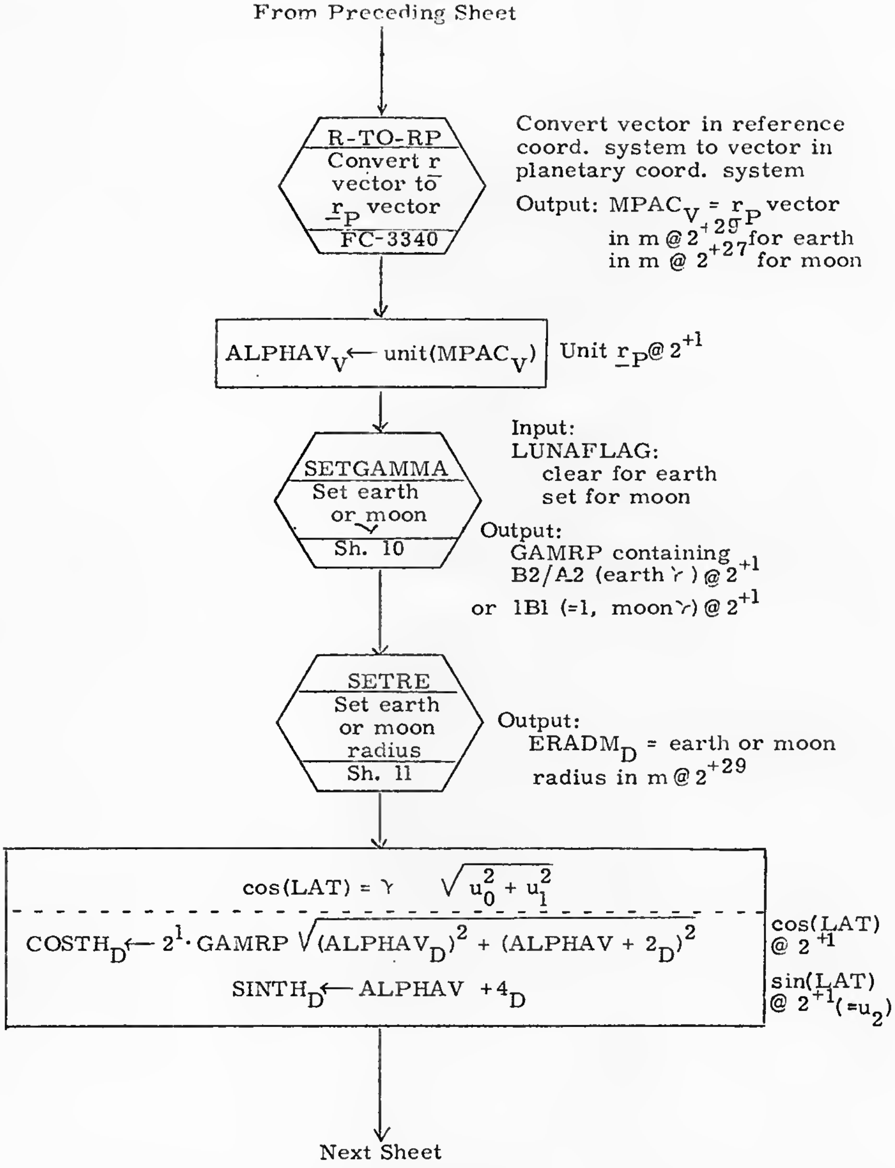
Latitude Longitude Subroutines

LUMINARY 1D

DOCUMENT NO.
FC-3330

REV 1

SHEET 2 OF 13



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DOCMR Roberta M. Estes 1/14/70
APPR'D Roberta M. Estes 1/14/70

APOLLO GUIDANCE AND NAVIGATION

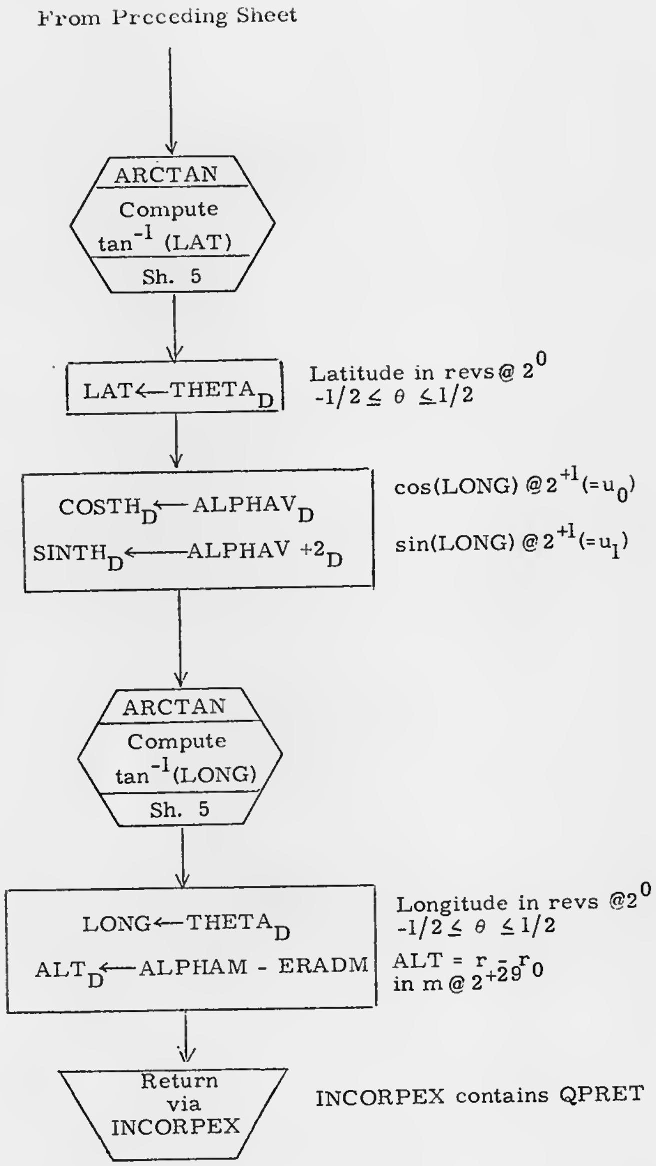
Latitude Longitude Subroutines

LUMINARY 1D

DOCUMENT NO.
FC-3330

REV 1

SHEET 3 OF 13



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ANALST J M Reber
DOCMR Roberta M. Eaton 1/16/70
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APOLLO GUIDANCE AND NAVIGATION

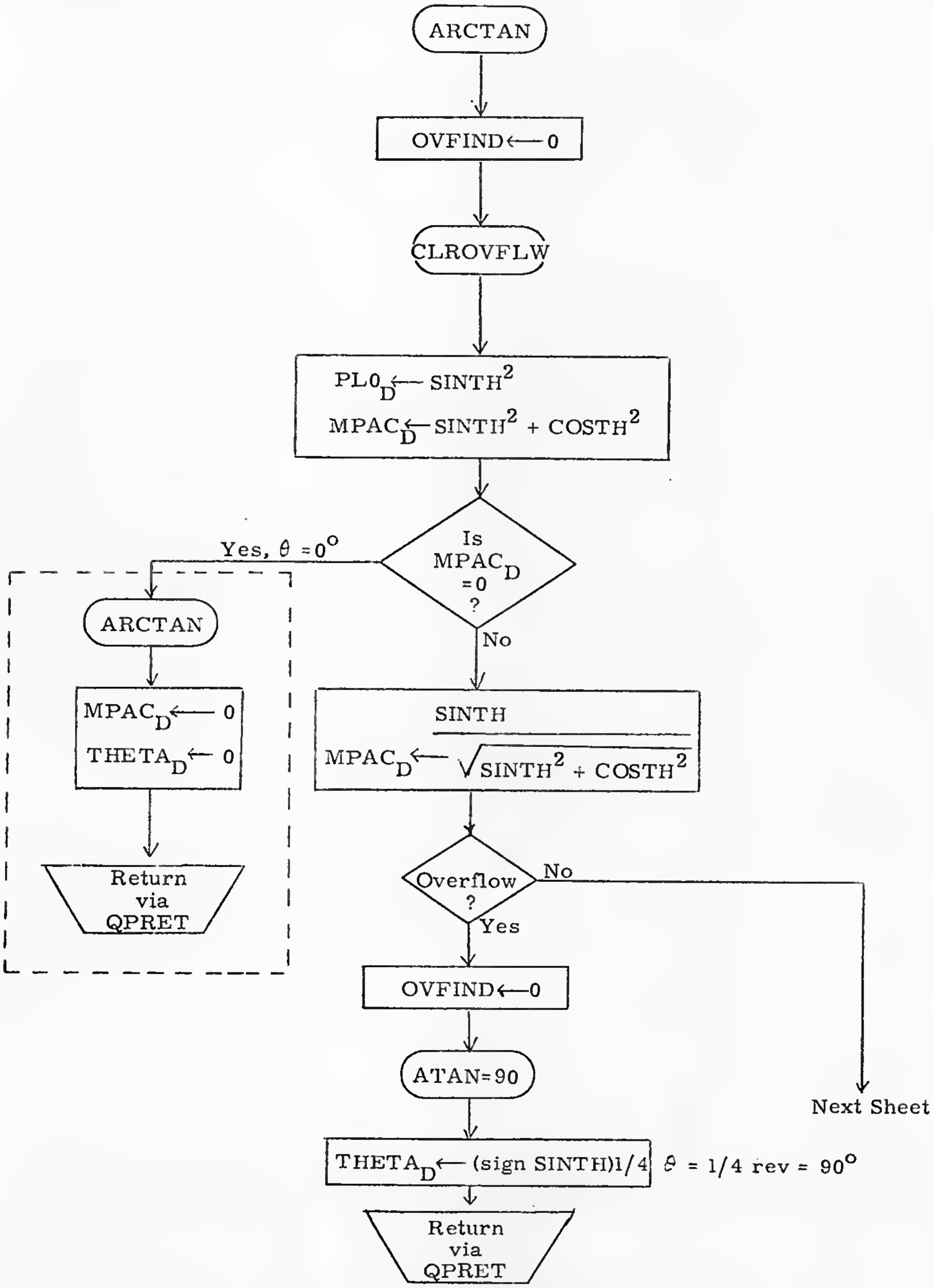
Latitude Longitude Subroutines

LUMINARY 1D

DOCUMENT NO. FC-3330

REV 1

SHEET 4 OF 13



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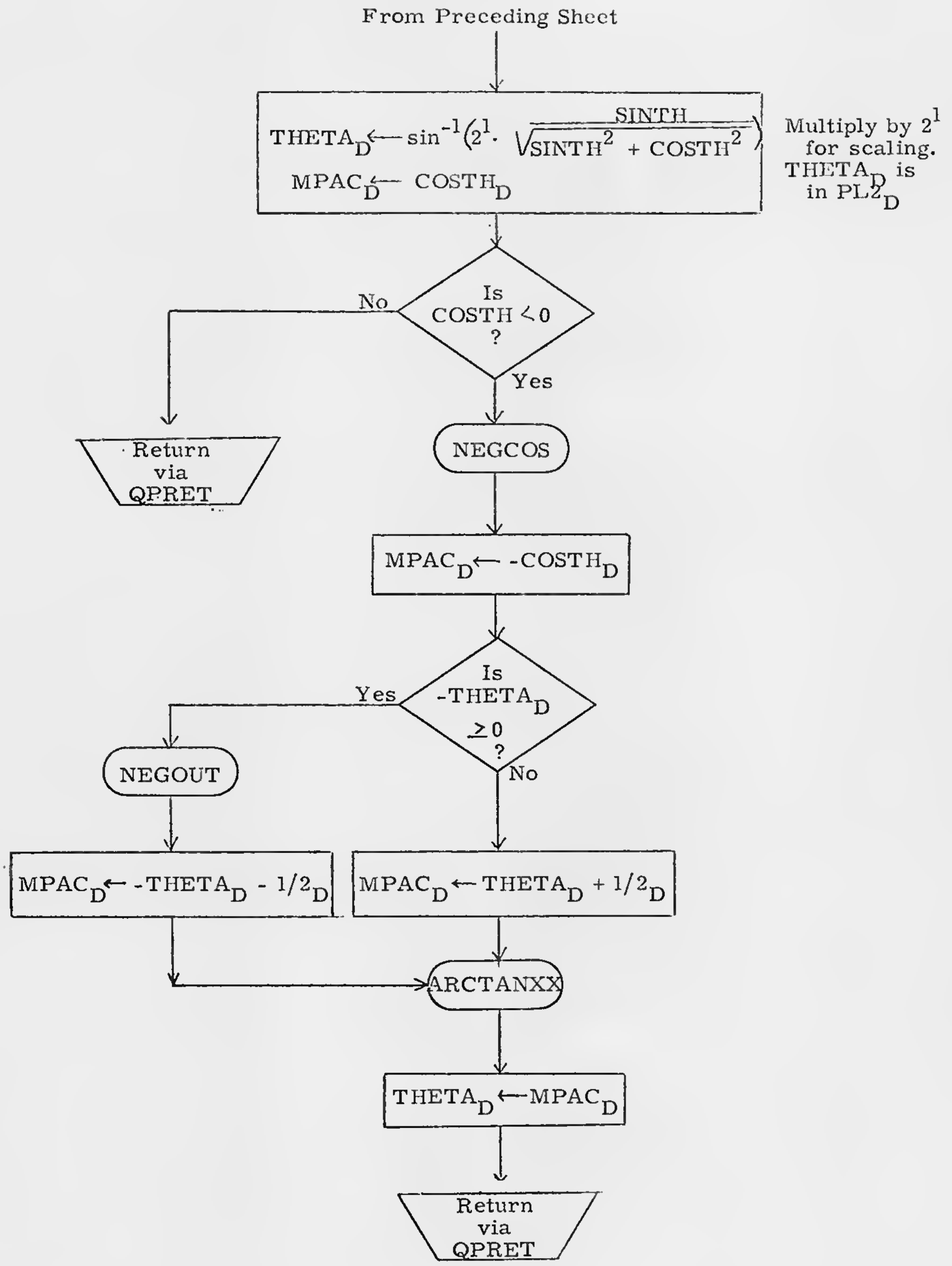
DRAWN D Lutkevich 1/14/70 PROGMR ANALST J. M. Reber DOCMR Roberta M. Estes 1/16/70 APPR'D Roberta M. Estes 1/16/70	Latitude Longitude Subroutines
LUMINARY 1D	DOCUMENT NO. FC-3330
REV 1	SHEET 5 OF 13



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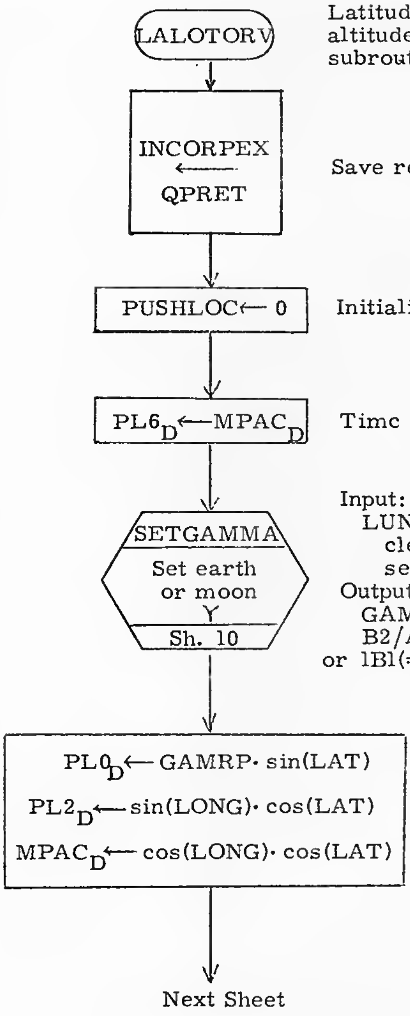
DRAWN	D. Lutkevich	1/14/70	Latitude Longitude Subroutines	
PRGMR				
ANALST	J. M. Reber			DOCUMENT NO.
DOCMR	Roberta M. Estes	1/16/70	LUMINARY 1D	FC-3330
APPR'D	Roberta M. Estes	1/16/70	REV 1	SHEET 6 OF 13



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
B2/A2 (earth Υ) @ 2^{+1}
or 1B1(=1, moon Υ) @ 2^{+1}

Υ sin(LAT) @ 2^{+2}

@ 2^{+2}

@ 2^{+2}

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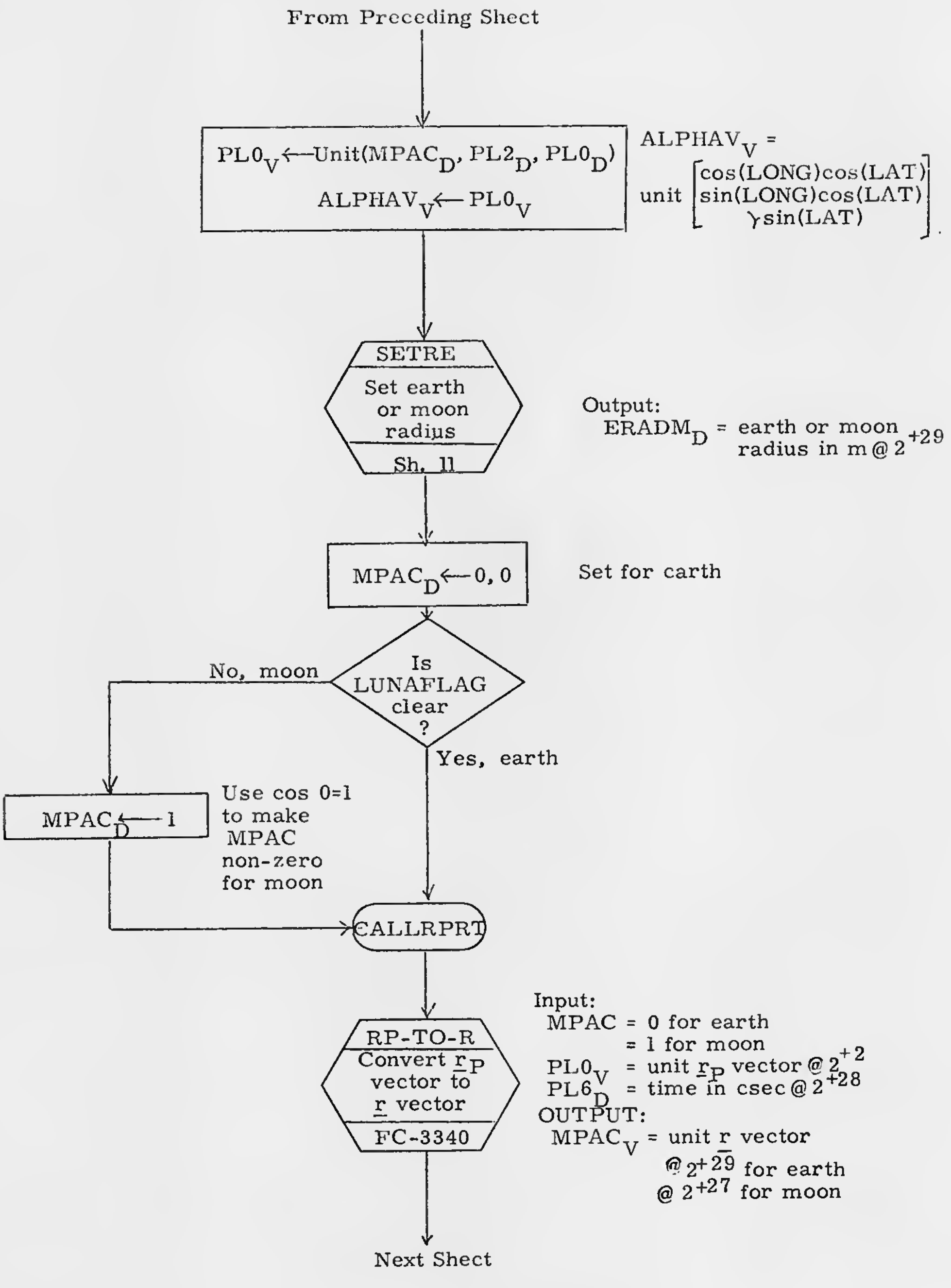
DRAWN D Lutkewied	1/14/70	Latitude Longitude Subroutines
PRGMR		DOCUMENT NO.
ANALST J. M. Reber		
DOCMR Roberta M. Estes	1/16/70	LUMINARY 1D FC-3330
APPR'D Roberta M. Estes	1/16/70	REV 1 SHEET 7 OF 13



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DOCMR Roberta M. Eaton 1/14/70
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APOLLO GUIDANCE AND NAVIGATION

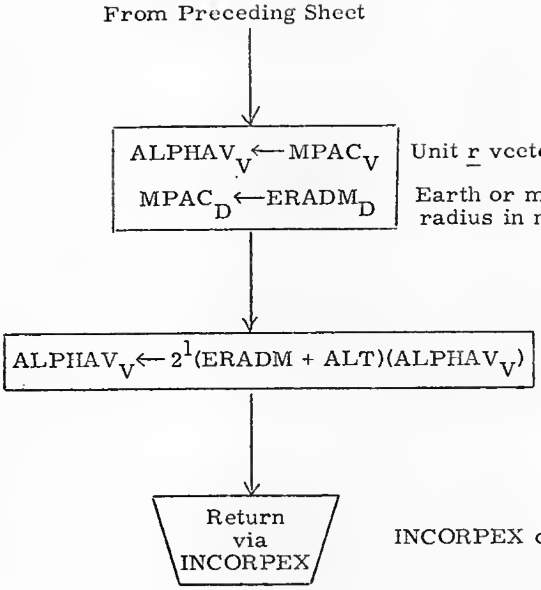
Latitude Longitude Subroutines

LUMINARY 1D

DOCUMENT NO.
FC-3330

REV 1

SHEET 8 OF 13

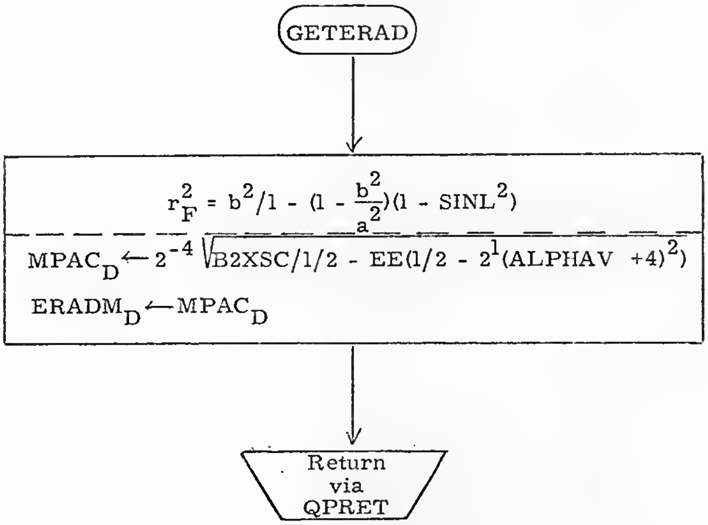


Unit r vector @ 2^{+2}

Earth or moon radius in m @ 2^{+29}

Shift left (multiply by 2^{+1}) for scaling: r vector in m @ 2^{+29}

INCORPEX contains QPRET



Radius of Fischer ellipsoid.

a: semi-ma axis

b: semi-mino axis

Earth radius in m @ 2^{+29}

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APOLLO GUIDANCE AND NAVIGATION

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APPR'D Roberta M. Estes 1/14/70

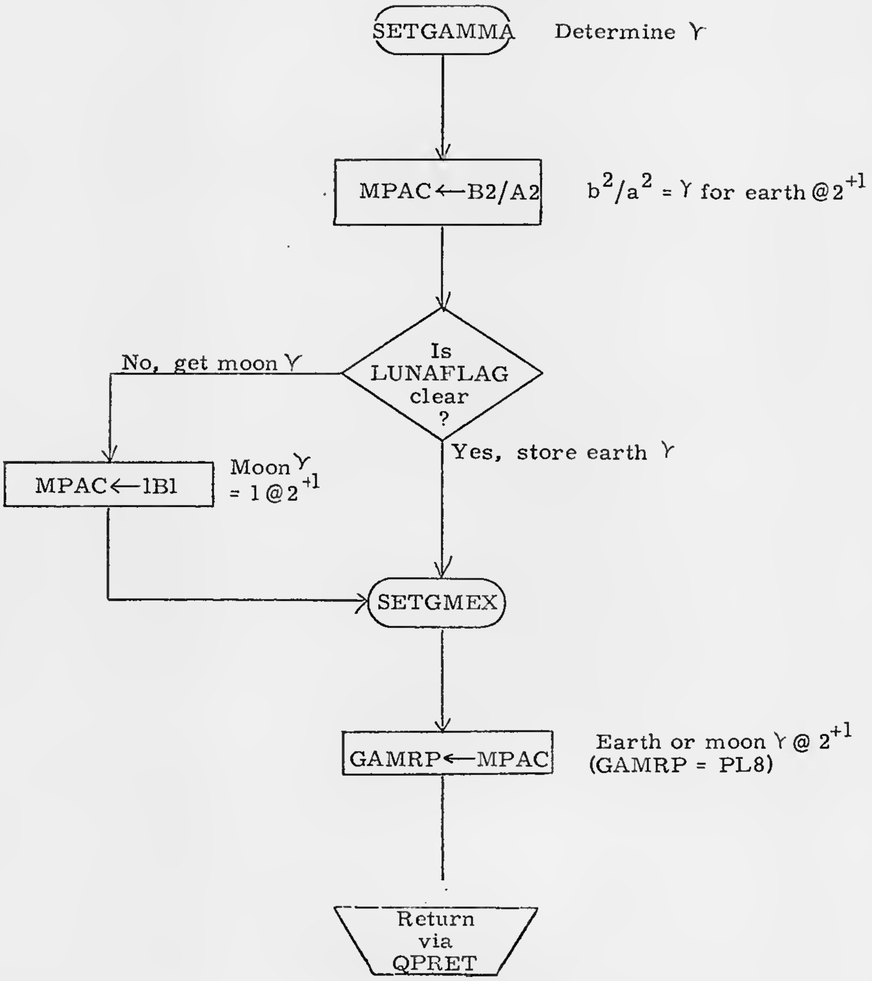
Latitude Longitude Subroutines

LUMINARY 1D

DOCUMENT NO. FC-3330

REV 1

SHEET 9 OF 13



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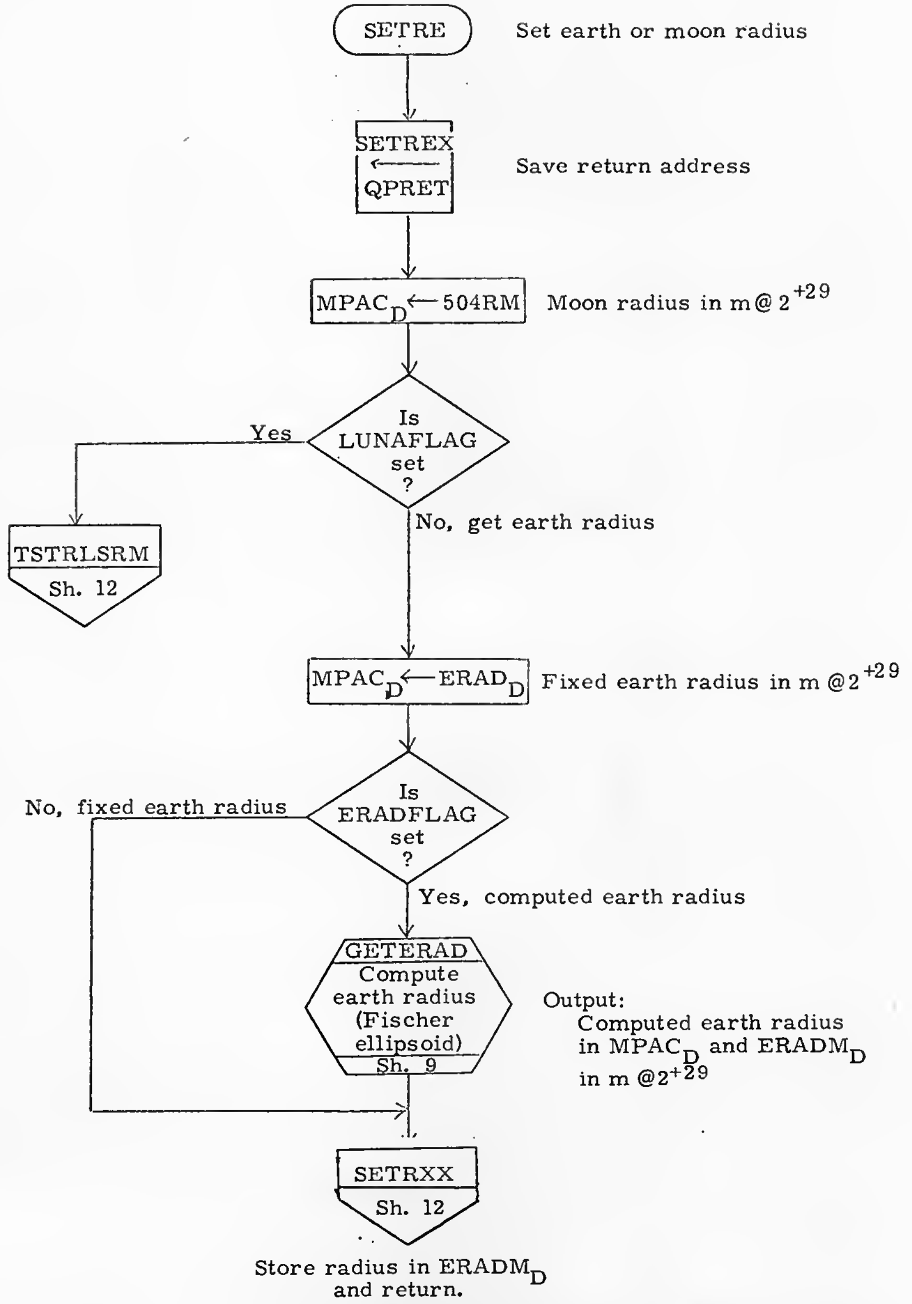
DRAWN D. Lutkewich	11/4/70	Latitude Longitude Subroutines	
PRGMR			
ANALST J. M. Reber			DOCUMENT NO.
DOCMR Roberta M Estes	11/6/70	LUMINARY 1D	FC-3330
APPR'D Roberta M. Estes	11/6/70	REV 1	SHEET 10 OF 13



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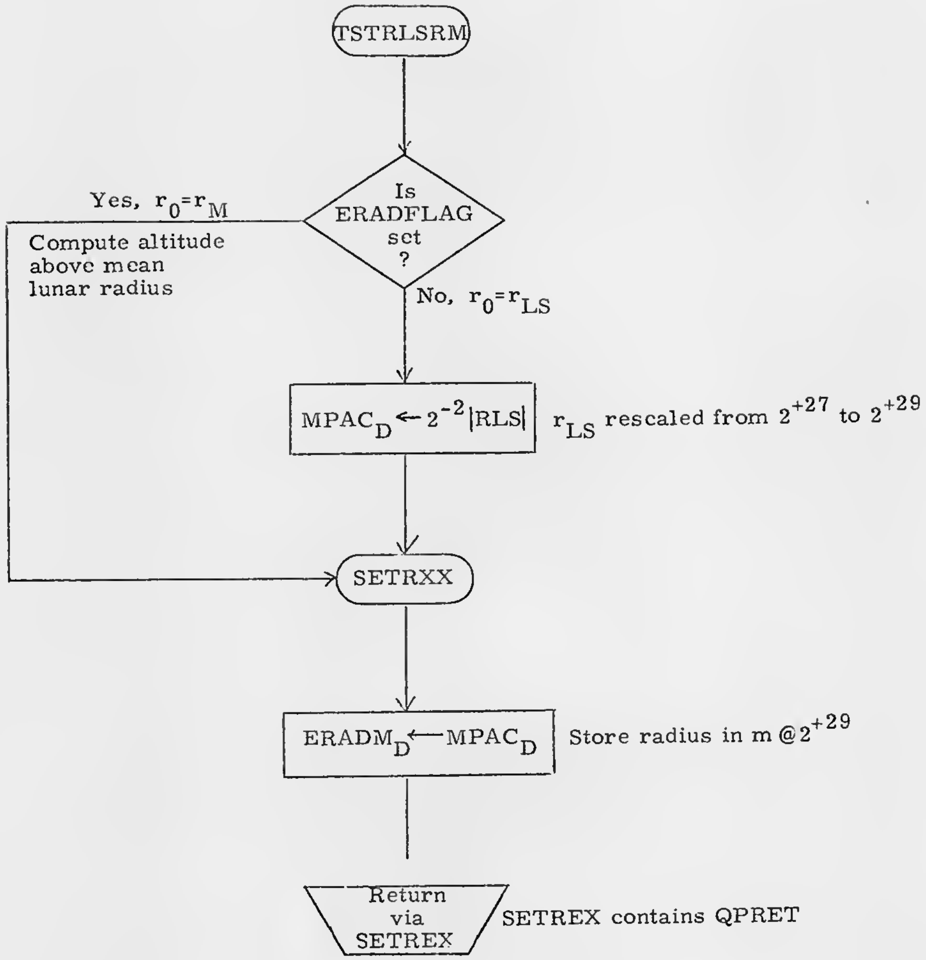
DRAWN D Lutkevich	1/14/70	Latitude Longitude Subroutines
PRGMR		
ANALST J. M. Kober		DOCUMENT NO.
DOCMR Roberta M. Eides	1/16/70	LUMINARY 1D — FC-3330
APPR'D Roberta M. Eides	1/16/70	REV 1 — SHEET 11 OF 13



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DRAWN	D Lutkewich	1/14/70	Latitude Longitude Subroutines	
PRGMR				DOCUMENT NO.
ANALST	J. M. Reber			
DOCMR	Roberta M. Estes	1/14/70	LUMINARY 1D	FC-3330
APPR'D	Roberta M. Estes	1/16/70	REV 1	SHEET 12 OF 13

SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
R-TO-RP	FC-2283	Converts $\underline{r}$ vector to $\underline{r}_P$ vector	Sh. 3
RP-TO-R	FC-2283	Converts $\underline{r}_P$ vector to $\underline{r}$ vector	Sh. 8

FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
ERADFLAG flag 1 bit 13	Earth: compute Fischer ellipsoid radius Moon: use fixed radius	Earth: use fixed radius Moon: use r_{LS} for lunar radius			Sh. 11, 12
LUNAFLAG flag 3 bit 12	Lunar LAT-LONG	Earth LAT-LONG			Sh. 2, 8, 10, 11

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DRAWN D Lutkewitt	1/14/70	Latitude Longitude Subroutines	
PRGMR			DOCUMENT NO.
ANALST J. M. Reber			
DOCMR Roberta M. Estes	1/16/70	LUMINARY 1D	FC-3330
APPR'D Roberta M. Estes	1/16/70	REV 1	SHEET 13 OF 13

PLANETARY INERTIAL ORIENTATION SUBROUTINE (PIOS)

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

RP-TO-R	Sh. 2
R-TO-RP	Sh. 3
EARTHMX	Sh. 4
MOONMX	Sh. 5

1. GUIDANCE SYSTEM OPERATIONS PLAN USING PROGRAM LUMINARY 1D (GSOP), R-567, SECTION 5, GUIDANCE EQUATIONS, (REV. 8)

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DRAWN D Lutkewich	2/26/7	PIOS	
PRGMR			
ANALST J. M. Reber	3/70	LUMINARY 1D	**DOCUMENT NO.** FC-3340
DOCMR Roberta M. Estes	3/19/70		
APPR'D Roberta M. Estes	3/19/70	**REV** 1	**SHEET** 1 **OF** 10

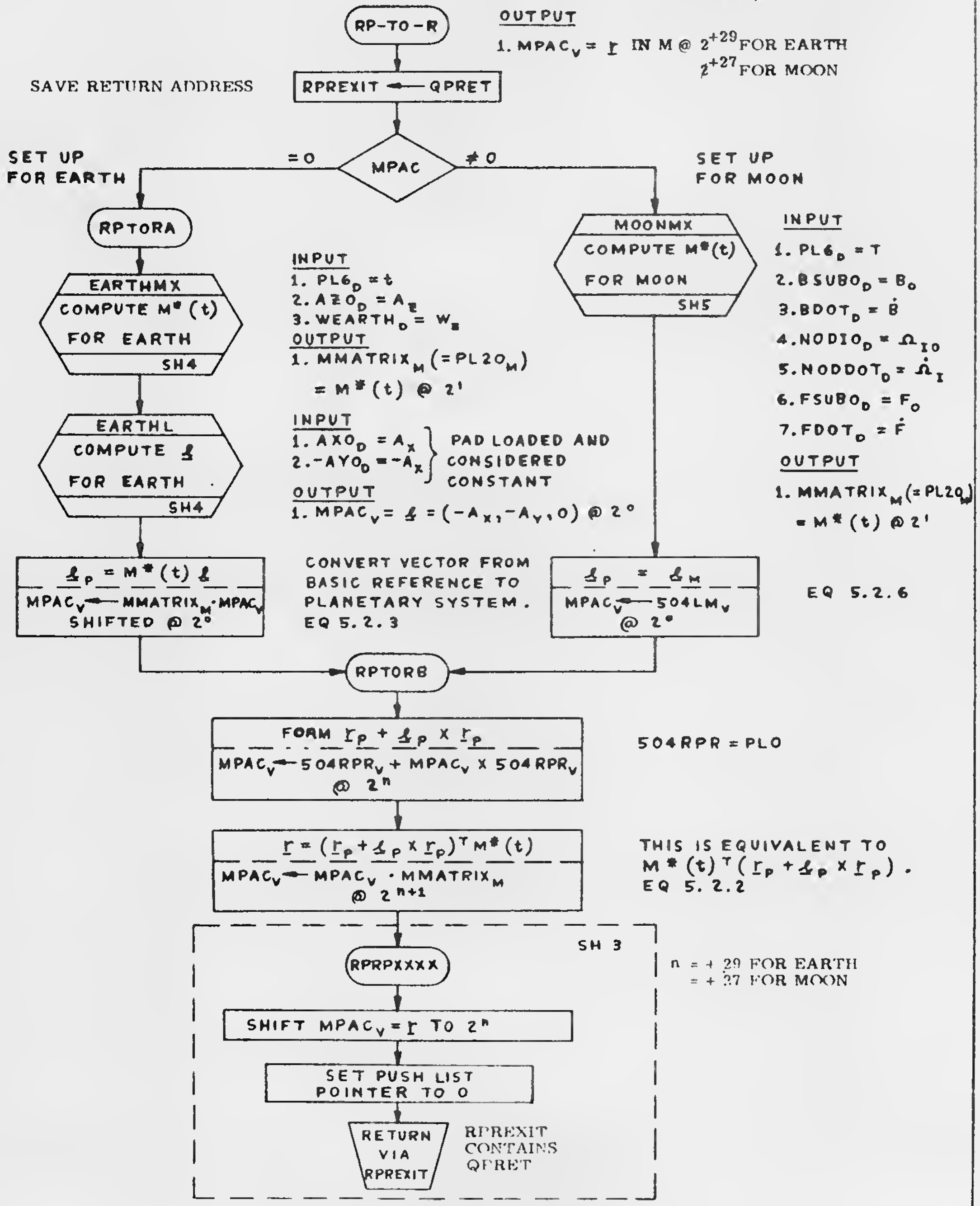
RP-TO-P CONVERTS $\underline{r}_p$, A VECTOR EXPRESSED IN THE PLANETARY (EARTH FIXED OR MOON FIXED) COORDINATE SYSTEM TO $\underline{r}$, THE SAME VECTOR EXPRESSED IN THE BASIC REFERENCE COORDINATE SYSTEM

INPUT:

1. $MPAC = \begin{cases} = 0 & \text{FOR EARTH} \\ \neq 0 & \text{FOR MOON} \end{cases}$
2. $PLO_V = \underline{r}_p$ @ 2^n
3. $PL6_D = t$, TIME OF $\underline{r}_p$, IN CSEC AT 2^{28}

OUTPUT

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



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D Lutkewich	2/24/70	PIOS	
PRGMR			
ANALST J. M. Rebor	3/70	Luminary 1D	DOCUMENT NO. FC-3340
DOCMR R.M. Estes	3/70		
APPR'D R.M. Estes	3/70	REV 1	SHEET 2 OF [illegible]

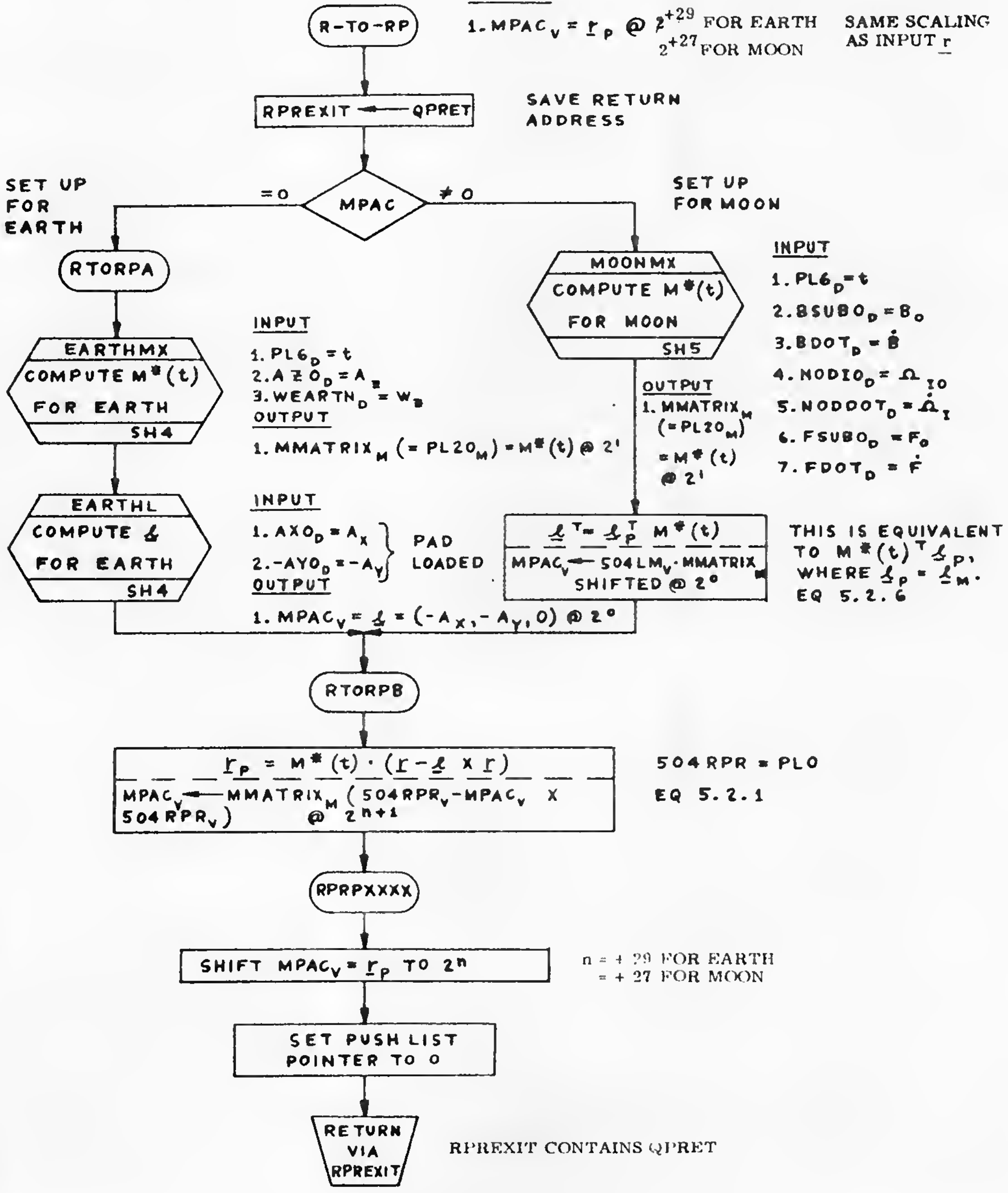
R-TO-RP CONVERTS $\underline{r}$, A VECTOR EXPRESSED IN THE BASIC REFERENCE COORDINATE SYSTEM TO $\underline{r}_p$, THE SAME VECTOR EXPRESSED IN THE PLANETARY (EARTH FIXED OR MOON FIXED) COORDINATE SYSTEM.

INPUT

1. $MPAC = \begin{cases} = 0 \text{ FOR EARTH} \\ \neq 0 \text{ FOR MOON} \end{cases}$
2. $PL0_V = \underline{r} @ 2^n$
3. $PL6_D = t$, TIME OF $\underline{r}$, IN CSEC, AT 2^{28}

OUTPUT

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



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DRAWN D. Lutkewicz 3/70
PRGMR
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PIOS

Luminary 1D

DOCUMENT NO. FC-3340

REV 1

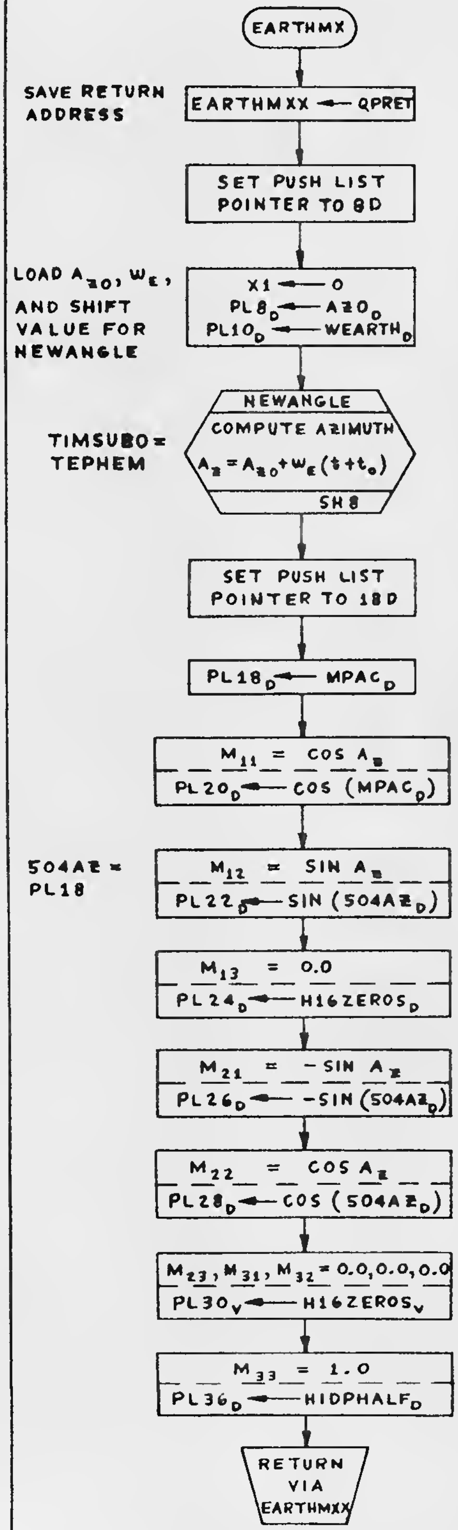
SHEET 3 OF 10

EARTHMX COMPUTES THE TRANSFORMATION MATRIX $M^*(t)$ FOR THE EARTH, WHERE $M^*(t)$ DESCRIBES A ROTATION OF THE COORDINATES SYSTEM ABOUT THE POLAR AXIS (Z-AXIS) OF THE EARTH.

INPUT
1. $PL6_D = t$, TIME SINCE AGC CLOCK WAS ZEROED, IN CSEC AT 2^{28}.
2. $AZ0_D = A_{Z0}$, ANGLE BETWEEN X-AXIS OF BASIC SYSTEM AND X-AXIS OF EARTH SYSTEM AT JULY 1.0, 1968
3. $WEARTH_D = w_E$, ANGULAR VELOCITY OF EARTH IN REVS/CSEC AT 2^{-23}
4. $TIMSUBO_T = t_o$, ELAPSED TIME FROM JULY 1.0, 1968 TO ZEROING OF AGC CLOCK, IN CSEC AT 2^{28}

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

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



INPUT
1. $PL8_D = A_{Z0}$ IN REVS AT 2^0
2. $PL10_D = w_Z$ IN REVS/CSEC AT 2^{-23}
3. $X1 = 0$, SHIFT VALUE
4. $PL6_D = t$ IN CSEC AT 2^{28}
5. $TIMSUBO_D = t_o$ IN CSEC A 2^{28}

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

STORE A_Z IN TEMPORARY STORAGE

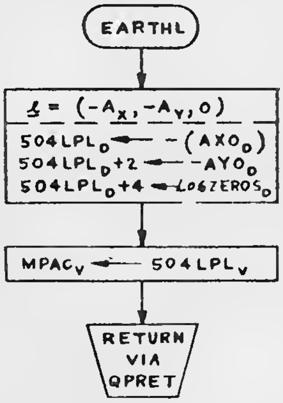
M_{11} THROUGH M_{33} ARE THE ELEMENTS OF MATRIX $M^*(t)$

EARTHMXX CONTAINS QPRET

EARTHL COMPUTES THE ROTATION VECTOR $\underline{\ell}$ FOR EARTH IN THE BASIC REFERENCE COORDINATE SYSTEM.

INPUT
1. $AXO_D = A_X$ IN REVS AT 2^0
2. $-AYO_D = -A_Y$ IN REVS AT 2^0

OUTPUT
1. $MPAC_V = \underline{\ell} = (-A_X, A_Y, 0)$ AT 2^0



EQ 5.2.3
A_X AND A_Y (AND HENCE $\underline{\ell}$) ARE CONSIDERED CONSTANT THROUGHOUT THE MISSION

LOAD $\underline{\ell}$

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REV
SHEET 4 OF 10

MOONMX COMPUTES THE TRANSFORMATION MATRIX $M^*(t)$ FOR THE MOON. $M^*(t)$ ACCOUNTS FOR DIFFERENCE IN ORIENTATION OF BASIC SYSTEM AND MOON SYSTEM ACCORDING TO CASSINI'S LAWS

INPUT

1. $PL6_D = t$, TIME SINCE AGC CLOCK WAS ZEROED, IN CSEC AT 2^{28}
2. $TIMSUBO_T = t_o$, ELAPSED TIME FROM JULY 1.0, 1968 TO ZEROING OF AGC CLOCK, IN CSEC AT 2^{28}
3. $BSUBO_D = B_o$
4. $BDOT_D = \dot{B}$

$\}$ ANGLE AND IT'S DERIVATIVE BETWEEN EARTH'S EQUATORIAL PLANE AND THE ECLIPTIC AT JULY 1.0, 1968.

5. $NODIO_D = \Omega_{Io}$
6. $NODDOT_D = \dot{\Omega}_I$

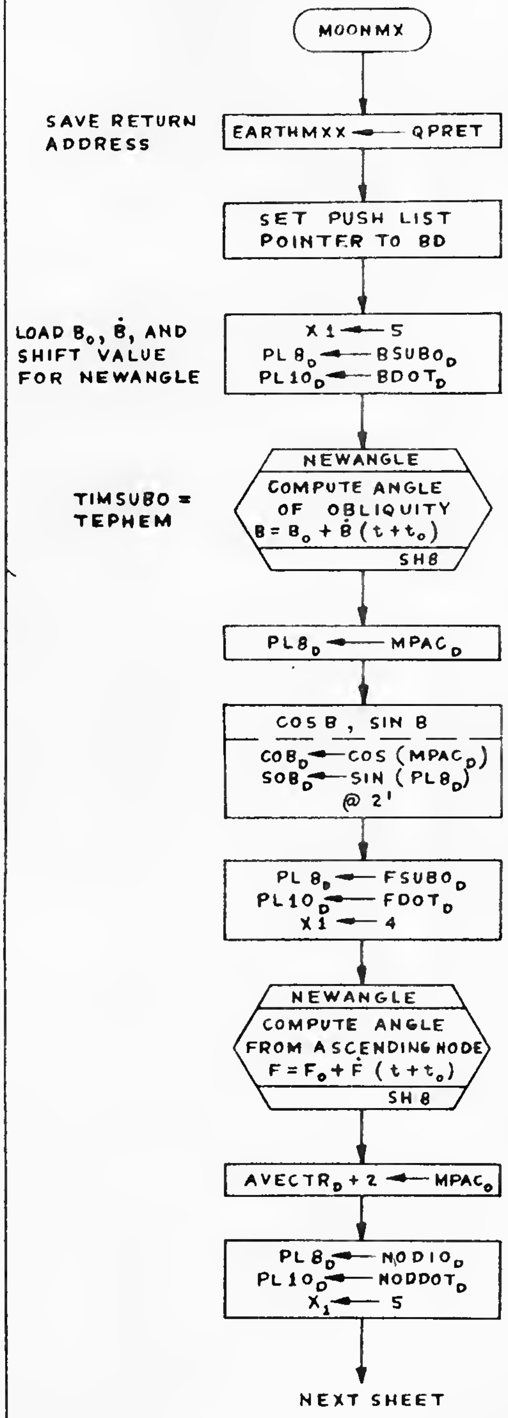
$\}$ LONGITUDE OF NODE OF MOONS ORBIT AND DERIVATIVE, IN BASIC SYSTEM AT JULY 1.0, 1969

7. $FSUBO_D = F_o$
8. $FDOT_D = \dot{F}$

$\}$ ANGLE MEAN ASCENDING NODE OF MOON'S ORBIT AND DERIVATIVE AT JULY 1.0, 1968

OUTPUT

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



INPUT

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

OUTPUT

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

STORE B IN TEMPORARY STORAGE

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

INPUT

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

OUTPUT

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

SAVE F IN TEMPORARY STORAGE.
AVECTR +2 = PL22

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

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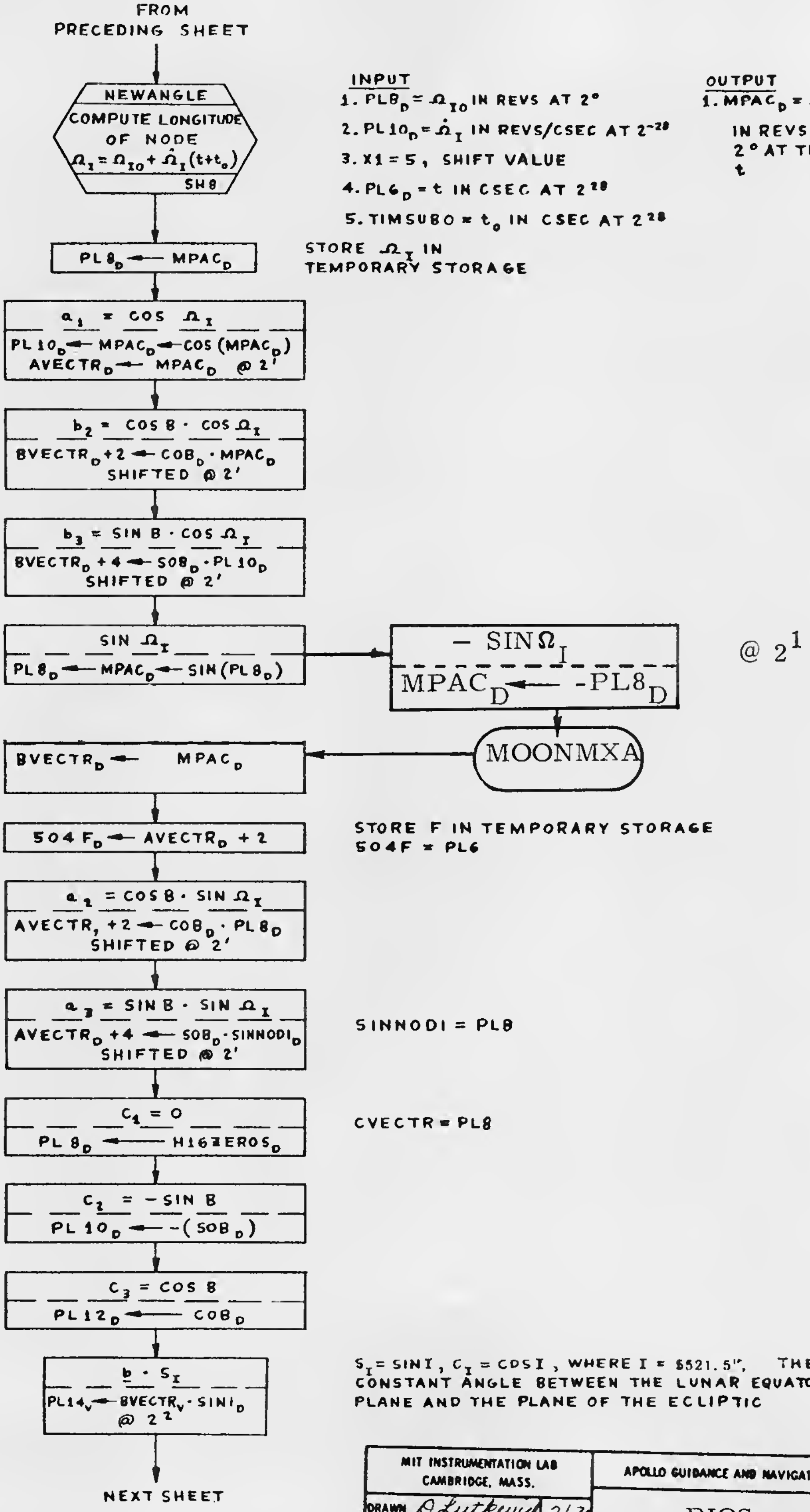
SHEET 5 OF 10



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

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

STORE Ω_I IN TEMPORARY STORAGE

STORE F IN TEMPORARY STORAGE
504F = PL6

SINNODI = PL8

CVECTR = PL8

$S_I = \sin I$, $C_I = \cos I$, WHERE I = $5521.5", THE CONSTANT ANGLE BETWEEN THE LUNAR EQUATORIAL PLANE AND THE PLANE OF THE ECLIPTIC

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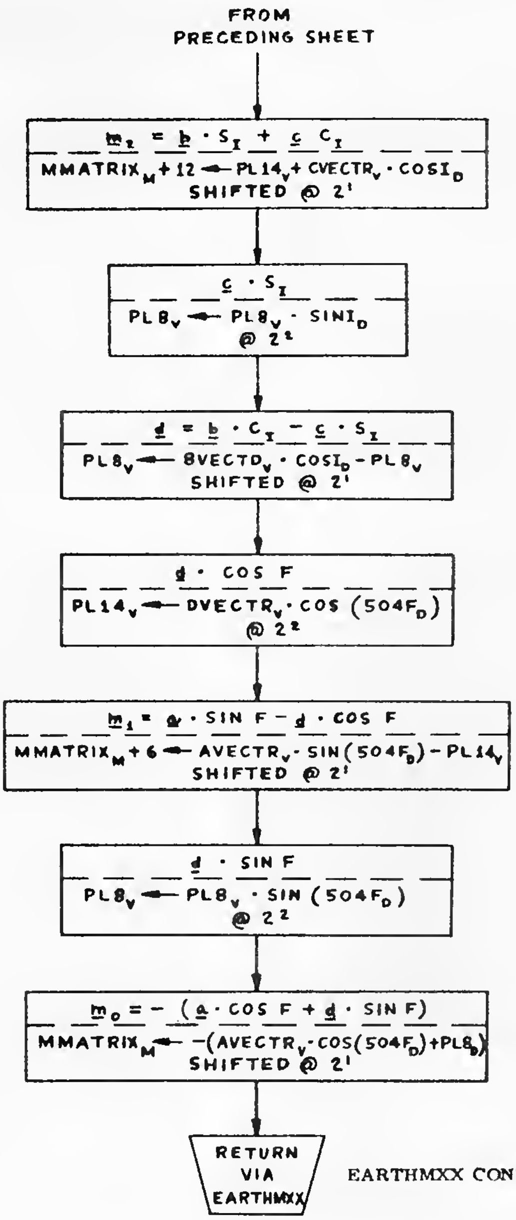
SHEET 6 OF 10



ROW 3 OF $M^*(t)$
EQ 5.2.6

DVECTR = PL8

ROW 2 OF $M^*(t)$
EQ 5.2.6

ROW 1 OF $M^*(t)$
EQ 5.2.6

EARTHMXX CONTAINS QPRET

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NEWANGLE IS A GENERAL PURPOSE SUBROUTINE FOR EVALUATING THE FUNCTION:

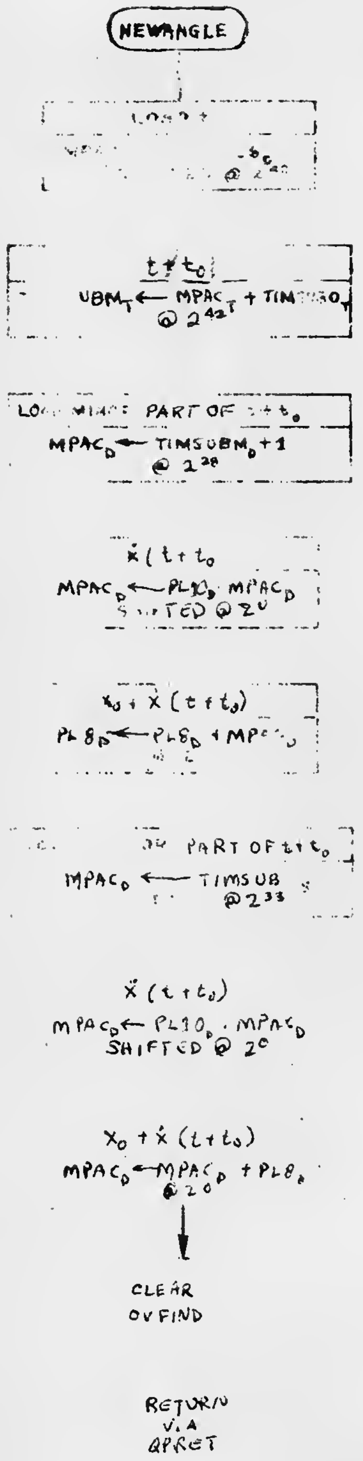
$$x = x_0 + \dot{x}\,(t + t_0)$$

INPUT

1. $PL8_D = x_0$ IN REVS AT 2^0
2. $PL10_D = \dot{x}$ IN REVS/CSEC AT $2^{-22}/2^{-28}/2^{-27}$
3. X1 = SHIFT VALUE OF 0/5/4 CORRESPONDING TO $\dot{x}$ SCALING
4. $PL6_D = t$, TIME IN CSEC AT 2^{28}
5. $TIMSUB0_T = t_0$, TIME IN CSEC AT 2^{42}

OUTPUT

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



TIMSUBM = PL14

MINOR PART OF $\dot{x}\,(t + t_0)$

FROM x_0 PLUS MINOR PART OF $\dot{x}\,(t + t_0)$

MAJOR PART OF $\dot{x}\,(t + t_0)$

FORM x_0 PLUS MAJOR AND MINOR PARTS OF $\dot{x}\,(t + t_0)$

OFF THE ERFLOW INDICATOR

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R.M. Eaton	3/70		
R.M. Eaton	3/70	REV	SHEET 8 OF 10

PROGRAM CONSTANTS

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$H16ZEROS_V$		THE VECTOR (0, 0, 0)	(0, 0, 0)	(0, 0, 0)	2^0
$HIDPHALF_D$		THE NUMBER 1	1.0	0.5	2^1
$NODIO_D$	Ω_{IO}	LONGITUDE OF NODE OF LUNAR ORBIT IN BASIC REFERENCE SYSTEM, AT JULY 1.0, 1970	5.859196887 RADS	.932520147 REVS	2^0
$NODDOT_D$	Ω_I	DERIVATIVE OF LONGITUDE OF NODE	-1.070470151 E-8 RAD/SEC	-1.70370616 E-11 REV/CSEC	2^{-28}
$FSUBO_D$	F_O	ANGLE FROM MEAN ASCENDING NODE OF LUNAR ORBIT TO THE MOON, AT JULY 1.0, 1970	1.5216749598 RADS	2.42182092 E-1 REVS	2^0
$FDOT_D$	$\dot{F}$	DERIVATIVE OF ANGLE F	2.6724042552 E-6 RAD/SEC	4.25326347 E-9 REV/CSEC	2^{-27}
$BSUBO_D$	B_O	OBLIQUITY, ANGLE BETWEEN MEAN EARTH EQUATORIAL PLANE AND ECLIPTIC, AT JULY 1.0, 1970	4.0915963316 E-1 RADS	6.51197781 E-2 REVS	2^0
$BDOT_D$	B	DERIVATIVE OF OBLIQUITY B	-7.1975797907 E-14 RAD/SEC	-1.14553040 E-16 REV/CSEC	2^{-28}
$WEARTH_D$	ω_E	ANGULAR VELOCITY OF THE EARTH	7.292115147 E-5 RAD/SEC	1.16057617 E-7 REV/CSEC	2^{-23}
$COSI_D$	C_I	COS I } WHERE I IS ANGLE BETWEEN MEAN LUNAR EQUATORIAL PLANE AND ECLIPTIC 5521.5'	.999641732	SAME	2^1
SINI	S_I	SIN I	.0267657905	SAME	2^1

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APPR'D R.M. Enter	6/11/70	REV 1	SHEET 9 OF 10

PROGRAM CONSTANTS (CONT.)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
AZO_D	A_Z	ANGLE BETWEEN X-AXIS OF BASIC SYSTEM AND EARTH SYSTEM, JULY 1.0, 1970	4.8631512705 RADS	$7.739945637 \times 10^{-1}$ REVS	2^0

REPRESENTATIVE PAD LOADS

AGC TAG	GSOP TAG	MEANING	ENGINEERING VALUE AND UNITS	AGC VALUE AND UNITS	AGC SCALING
$504LM_V$	$\underline{l}_M$	VECTOR LIBRATION $\underline{l}_P$ IN MOON SYSTEM	$-3.98466794 \times 10^{-4}$ RADS $-2.98927218 \times 10^{-6}$ RADS $-3.79924699 \times 10^{-4}$ RADS	RADS	2^0
AXO_D	A_X	ANGLES ABOUT X- AND Y- AXES OF BASIC SYSTEM DESCRIBING PRECESSION AND NUTATION	$3.962911018 \times 10^{-5}$ RADS	RADS	2^0
$-AYO_D$	$-A_Y$		$-5.58111439 \times 10^{-6}$ RADS	RADS	2^0

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DOCMR RMM Exton	6/11/70		
APPR'D RMM Exton	6/11/70	REV 1	SHEET 10 OF 10

LUNAR AND SOLAR EPHEMERIDES

LSPOS Sh. 2

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APOLLO GUIDANCE AND NAVIGATION

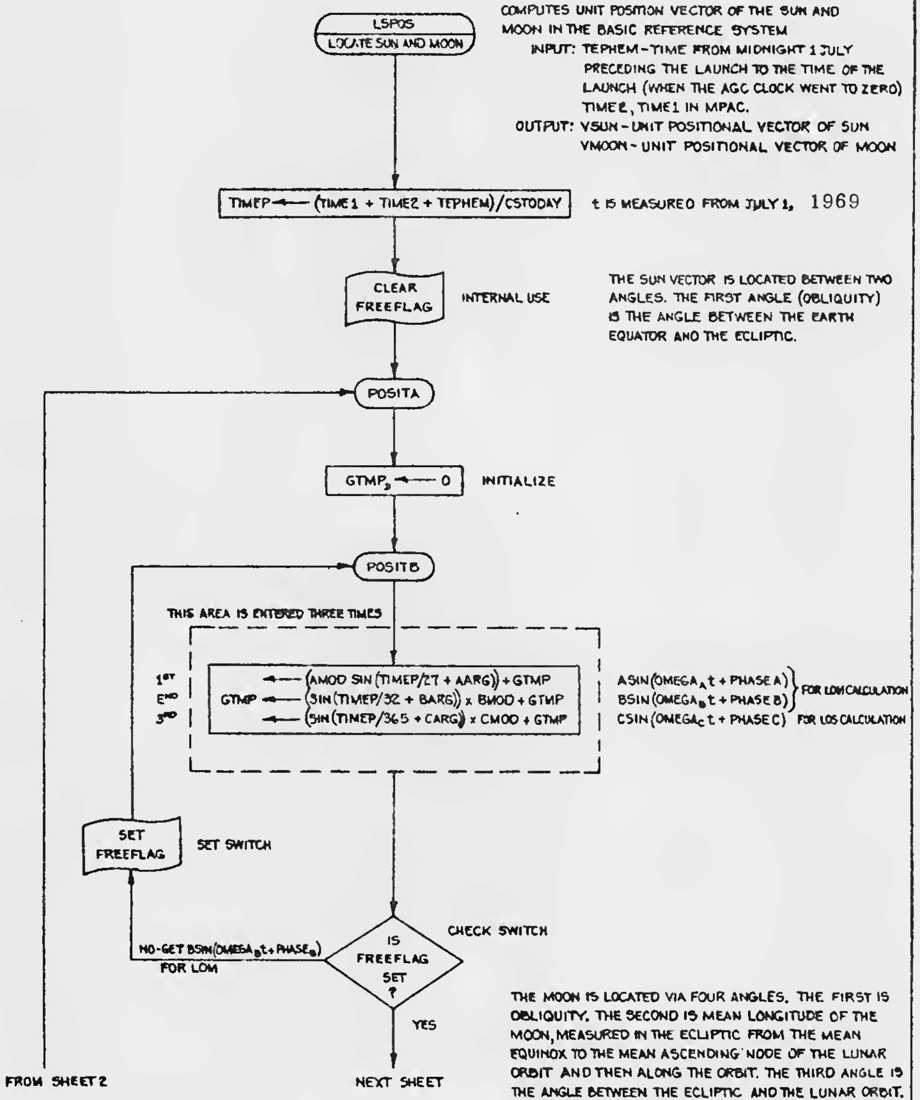
LSPOS
Locate sun and moon

LUMINARY 1D

DOCUMENT NO.
FC-3345

REV 2

SHEET 1 OF 5



COMPUTES UNIT POSITION VECTOR OF THE SUN AND MOON IN THE BASIC REFERENCE SYSTEM

INPUT: TEPHEM - TIME FROM MIDNIGHT 1 JULY PRECEDING THE LAUNCH TO THE TIME OF THE LAUNCH (WHEN THE AGC CLOCK WENT TO ZERO) TIME2, TIME1 IN MPAC.

OUTPUT: VSUN - UNIT POSITIONAL VECTOR OF SUN
VMOON - UNIT POSITIONAL VECTOR OF MOON

t IS MEASURED FROM JULY 1, 1969

THE SUN VECTOR IS LOCATED BETWEEN TWO ANGLES. THE FIRST ANGLE (OBLIQUITY) IS THE ANGLE BETWEEN THE EARTH EQUATOR AND THE ECLIPTIC.

THE MOON IS LOCATED VIA FOUR ANGLES. THE FIRST IS OBLIQUITY. THE SECOND IS MEAN LONGITUDE OF THE MOON, MEASURED IN THE ECLIPTIC FROM THE MEAN EQUINOX TO THE MEAN ASCENDING NODE OF THE LUNAR ORBIT AND THEN ALONG THE ORBIT. THE THIRD ANGLE IS THE ANGLE BETWEEN THE ECLIPTIC AND THE LUNAR ORBIT. THE FOURTH ANGLE IS THE LONGITUDE OF THE NODE OF THE MOON, MEASURED IN THE LUNAR ORBIT. THESE ANGLES ARE OBL, LOM, IM AND LON RESPECTIVELY.

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LSPOS
LOCATE SUN AND MOON

LUMINARY 1D FC-3345
2
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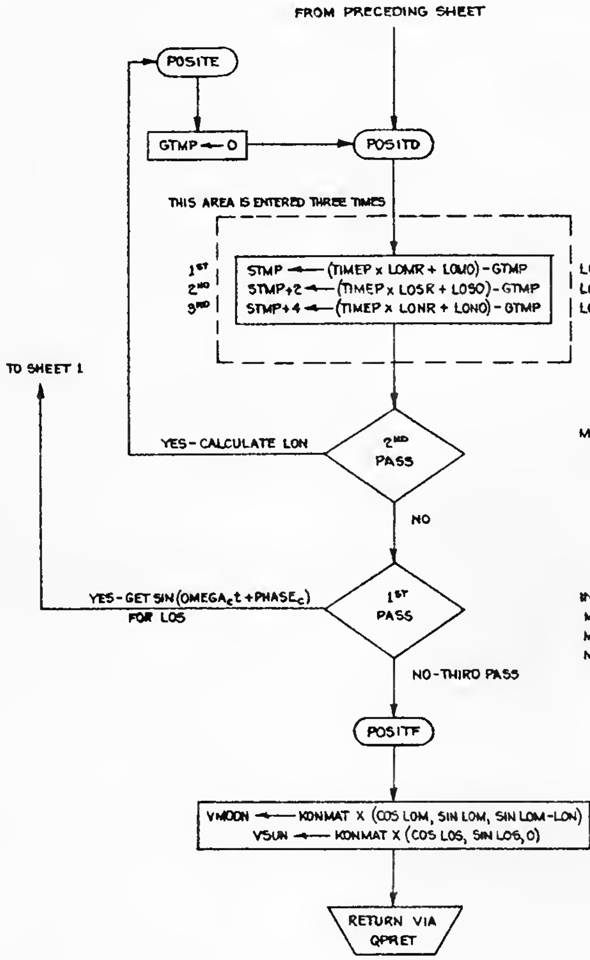

LOM $LOM = LOM_0 + LOM_R t - [ASIN(OMEGA_A t + PHASE_A) + BSIN(OMEGA_B t + PHASE_B)]$

LOS $LOS = LOS_0 + LOS_R t - CSIN(OMEGA_C t + PHASE_C)$

LON $LON = LON_0 + LON_R t$

MATRIX KONMAT

1.0	0	0
0	COS(OBL)	SIN(OBL)
0	SIN(OBL)SIN(IM)	COS(OBL) SIN(IM)

INTERIM MOON VECTOR	INTERIM SUN VECTOR
MPAC - COS LOM	MPAC - COS LOS
MPAC+2 - SIN LOM	MPAC+2 - SIN LOS
MPAC+4 - SIN(LOM - LON)	MPAC+4 - 0

UNIT POSITIONAL VECTOR OF THE MOON
COS(LOM), COS(OBL) X SIN(LOM) - SIN(OBL) X SIN(IM) X SIN(LOM-LON), SIN(OBL) X SIN(LOM) + COS(OBL) X SIN(IM) X SIN(LOM-LON)

UNIT POSITIONAL VECTOR OF THE SUN
COS(LOS), COS(OBL) X SIN(LOS), SIN(OBL) X SIN(LOS)

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PRGMR [illegible]
ANALST
DPGMR [illegible]
APPR'D 10/31/69

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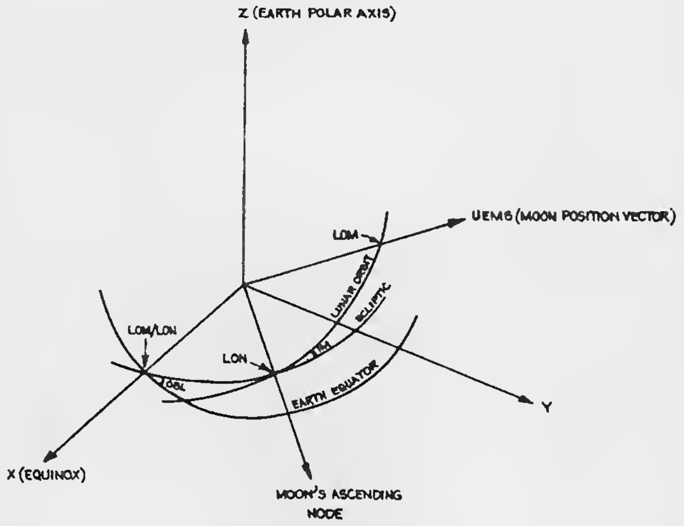
GUIDANCE AND NAVIGATION

LSPOS
LOCATE SUN AND MOON

LUMINARY 1D
DOCUMENT NO. FC-3345
REV 2
SHEET 3 OF 5



THIS IS AN ILLUSTRATION OF THE ANGLES AND TERMS USED TO COMPUTE THE UNIT POSITIONAL VECTORS OF THE SUN AND MOON

OBL = OBLIQUITY; THE ANGLE BETWEEN THE EARTH EQUATOR AND THE ECLIPTIC.
IM = INCLINATION; THE ANGLE BETWEEN THE MOON EQUATOR AND THE ECLIPTIC.
LOM = LONGITUDE OF THE MOON.
LON = LONGITUDE OF THE MOON'S NODE.

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PRGMR
ANALST
DOCMR
APP'D

APOLLO
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LSPOS
LOCATE SUN AND MOON

LUMINARY 1D
DOCUMENT NO. FC-3345
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SHEET 4 OF 5

FLAGS

Name	Where Set	Where Cleared	Where Tested
FREEFLAG Flag 0 bit 3	Sh. 2	Sh. 2	Sh. 2

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APOLLO GUIDANCE AND NAVIGATION

LSPOS
Locate sun and moon

LUMINARY 1D

DOCUMENT NO. FC-3345

REV 2

SHEET 5 OF 5

6.0 CONIC AND INTEGRATION ROUTINES

INTEGRATION INITIALIZATION
MAJOR ENTRY POINTS ON THIS FLOWCHART

STATEINT	Sh. 2
STATINT1	Sh. 2
ATOPCSM	Sh. 7
PTOACSM	Sh. 8
ATOPLEM	Sh. 9
PTOALEM	Sh. 10
CSMPREC	Sh. 12
LEMPREC	Sh. 12
CSMCONIC	Sh. 13
LEMCONIC	Sh. 13
INTEGRVS	Sh. 14
INTEGRV	Sh. 15
INTSTALL	Sh. 17
INTWAKE	Sh. 18
INTWAKE0	Sh. 18
INTWAKEU	Sh. 20
AVETOMID	Sh. 23
MIDTOAV1	Sh. 26
MIDTOAV2	Sh. 26

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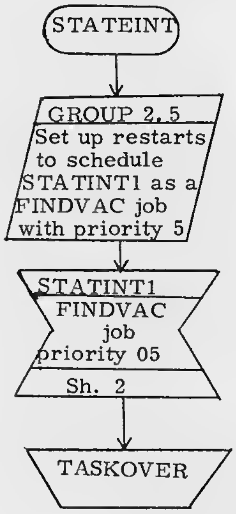
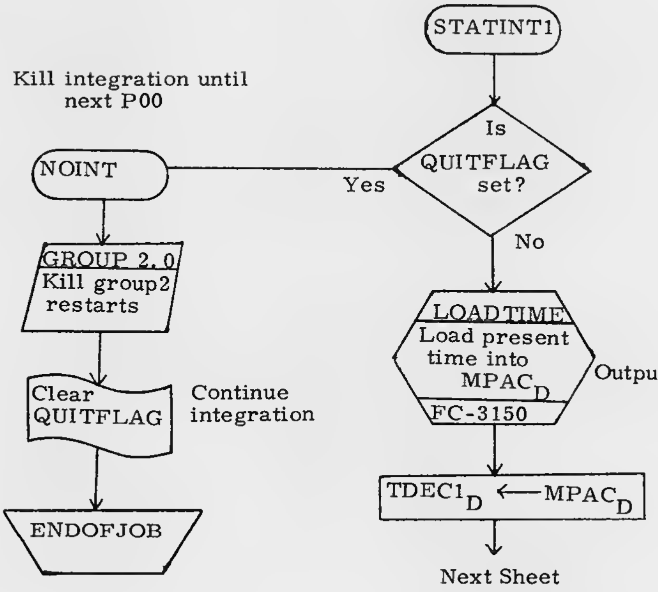
ANALST		
DOCMR W Daybrith	10/20/69	
APPR'D Robert M. Sut		REV 1 — SHEET 1 OF 32

STATEINT is scheduled every 600 seconds during the idling program P00.





Kill integration until next P00

Continue integration

Output: $MPAC_D$=TIME2, TIME1

Store time

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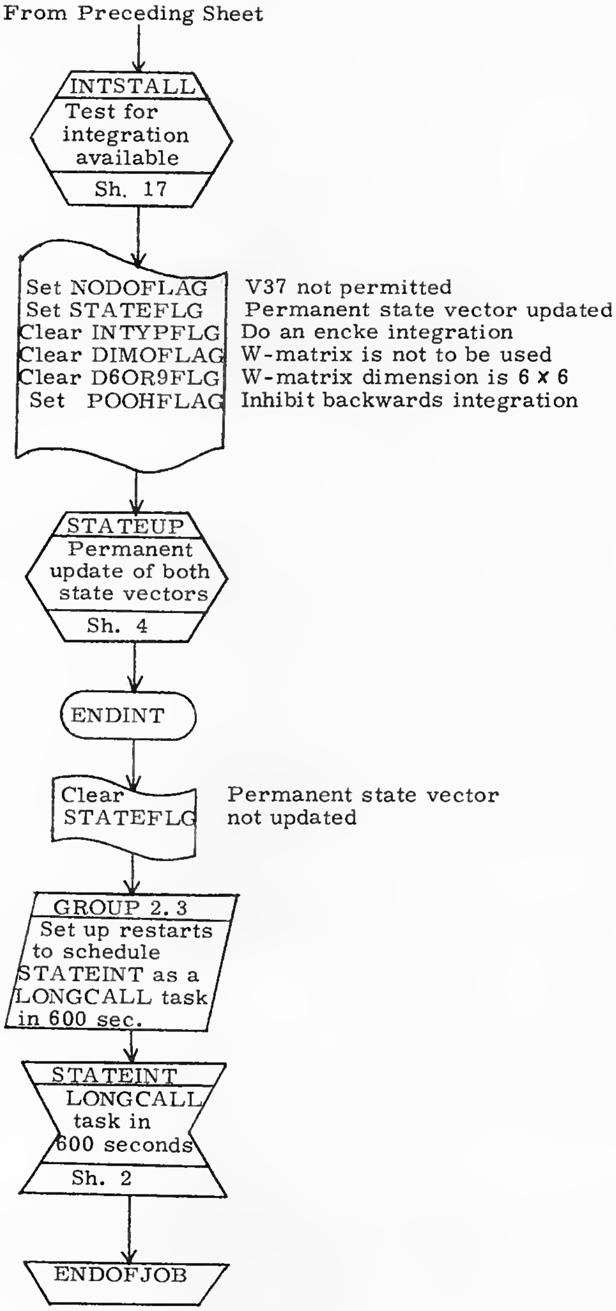
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3350
DOCMR W Dagbert	10/24/69		
APPR'D RM Estes		REV 1	SHEET 2 OF 32



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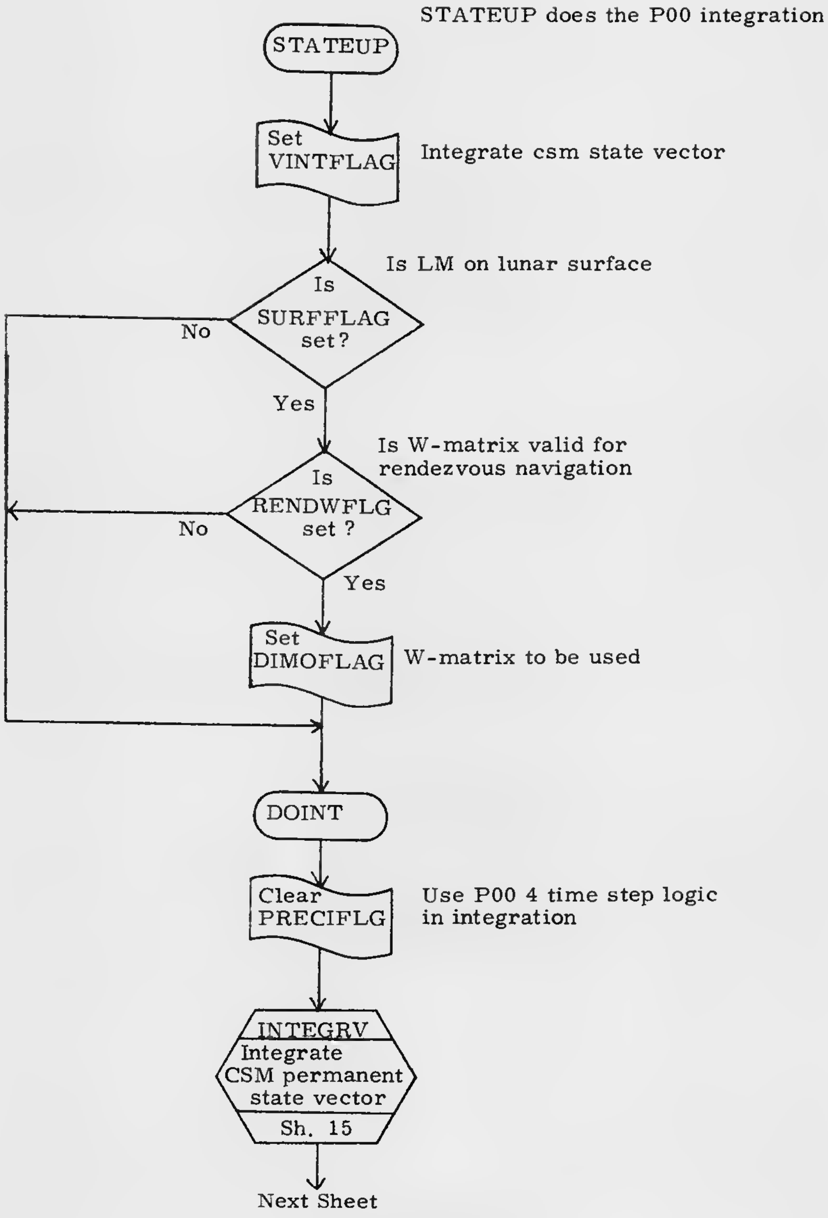
PRGMR Frances Rivers	12/8/69		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3350
DOCMR W Daybeck	10/29/69		
APPR'D RDM Cates		REV 1	SHEET 3 OF 32



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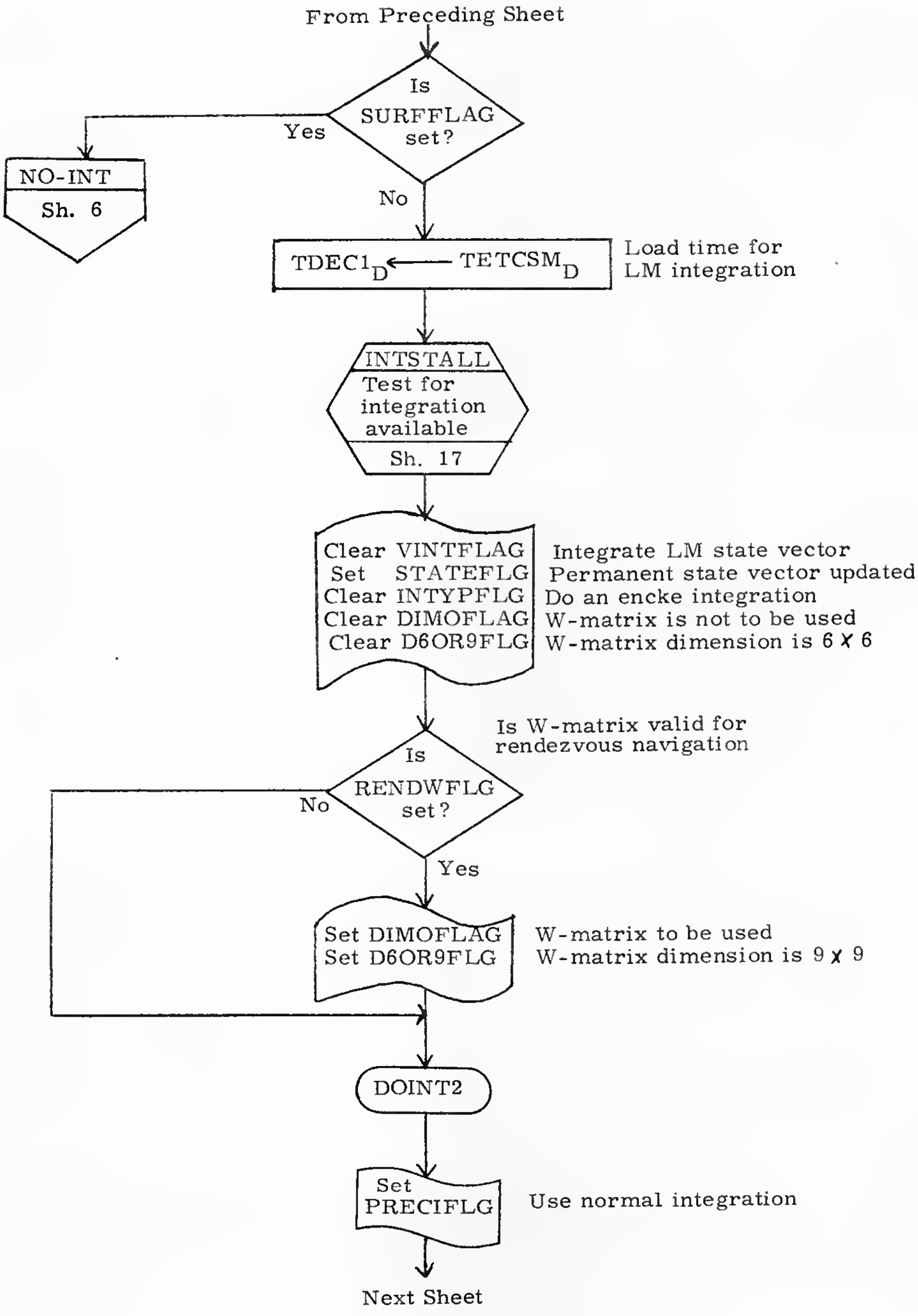
PRGMR	Frances Kiven	12/8/69		
ANALST			LUMINARY 1D	DOCUMENT NO. FC-3350
DOCMR	W Dayboat	10/29/69		
APPR'D	R M Eustis		REV 1	SHEET 4 OF 32



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APOLLO GUIDANCE AND NAVIGATION

DRAWN L. Duncan 10/15/69
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ANALST
DOCMR 10/29/69
APPR'D

Integration
Initialization

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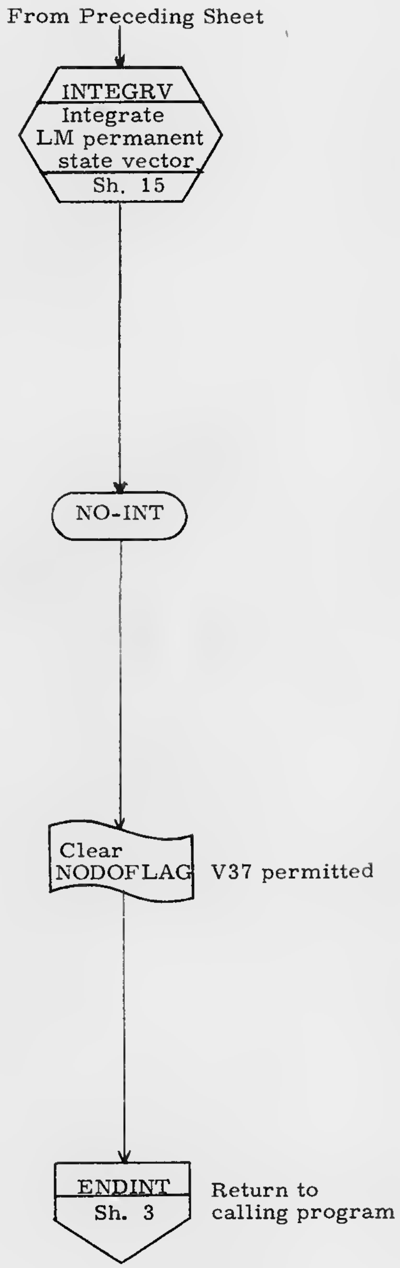
REV 1

SHEET 5 OF 32



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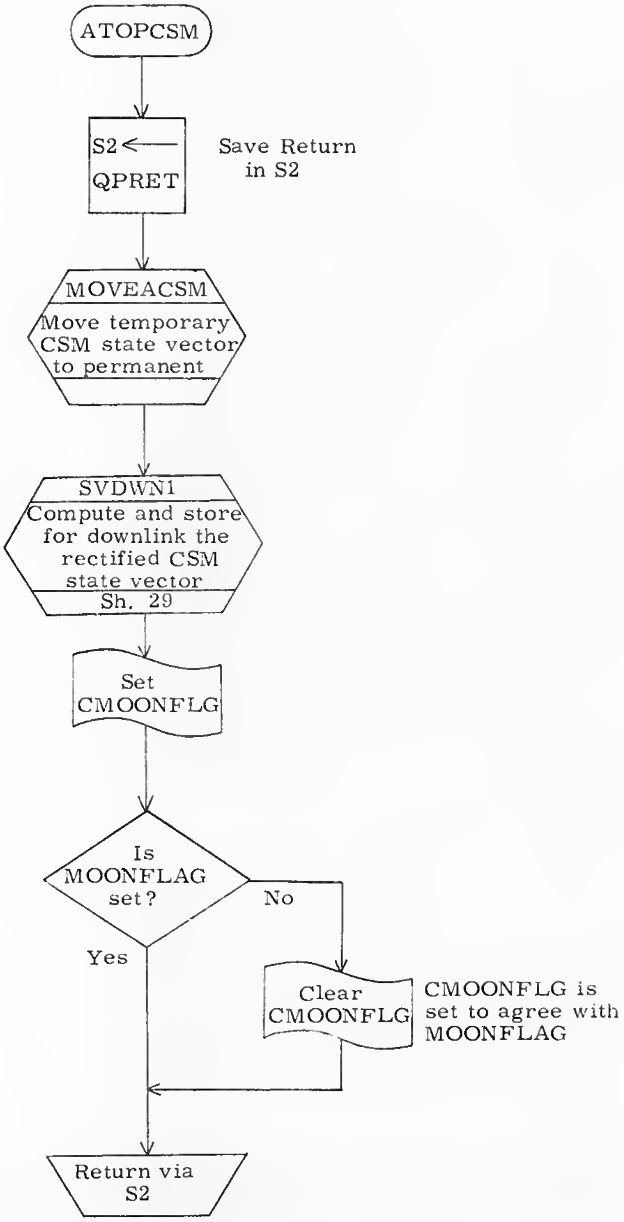
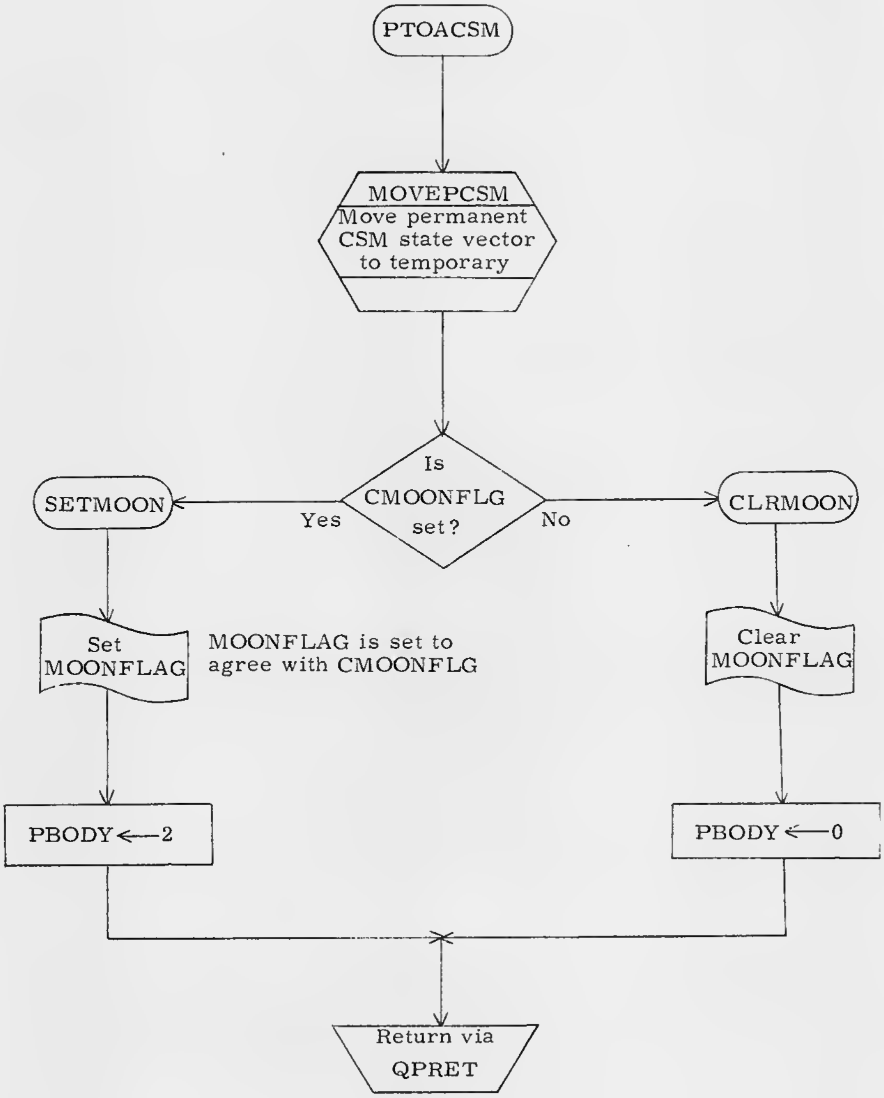
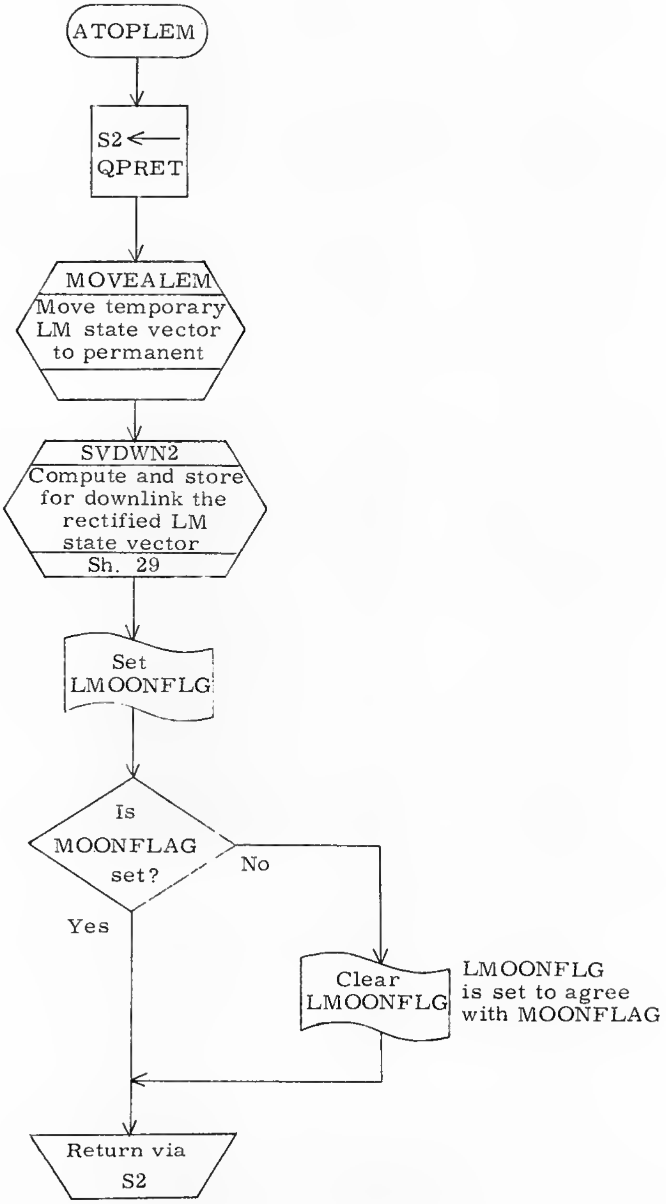
ANALST			
DOCMR W Danforth	10/24/69		
APPR'D R M Estes		REV 1	SHEET 6 OF 32



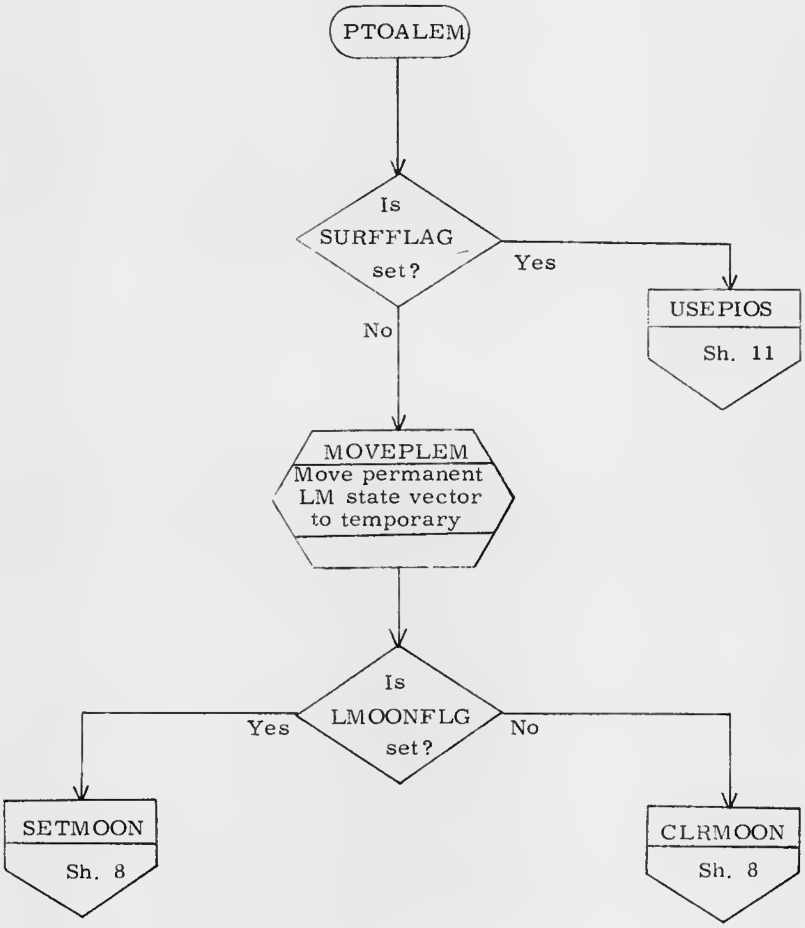
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty	11/22/69	Integration Initialization	
PRGMR Frances Kiwen	12/8/69	LUMINARY 1D	DOCUMENT NO. FC-3350
ANALST			
DOCMR W. Dagbrith	12/8/69		
APPR'D R M Estes		REV 1	SHEET 7 OF 32



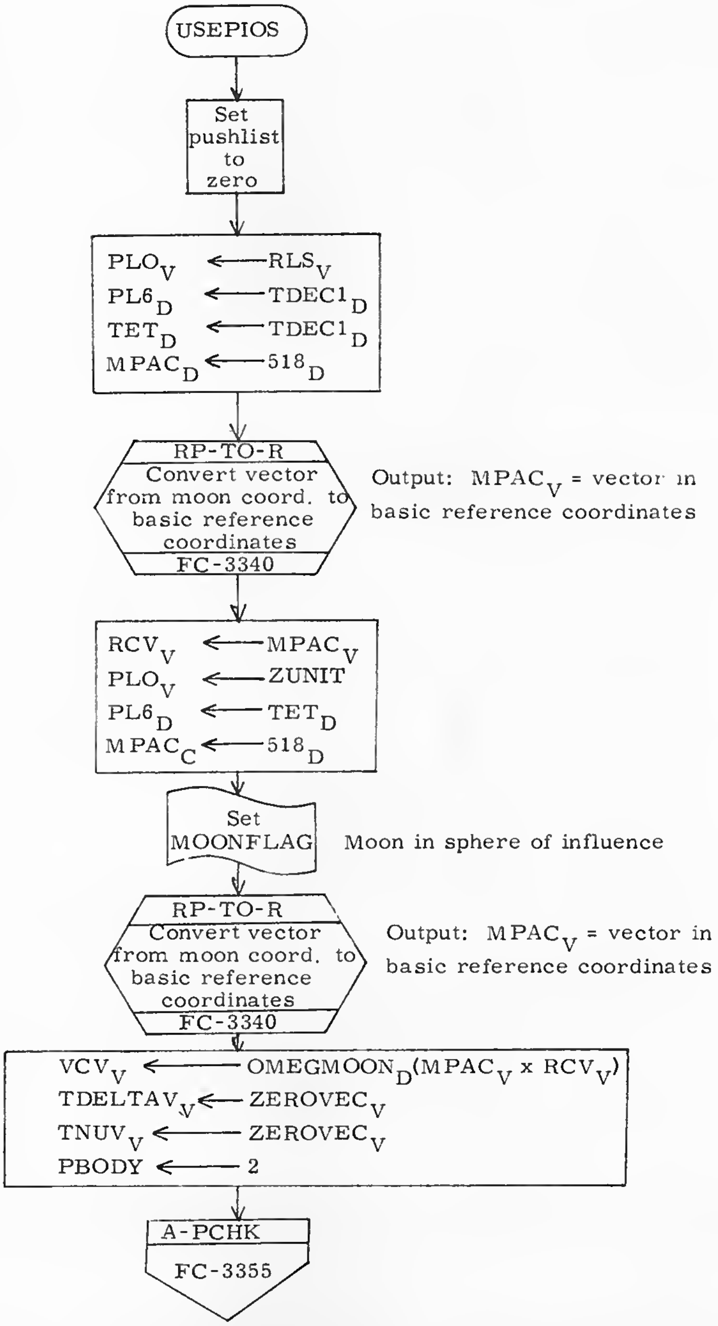
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty	11/22/69	Integration Initialization	
PRGMR Frances Kirwen	12/8/69		DOCUMENT NO.
ANALST		LUMINARY 1D	FC-3350
DOCMR W. Dayhith	12/8/69		
APPR'D R. M. Estes		REV 1	SHEET 8 OF 32



MIT INSTRUMENTATION LAB **CAMBRIDGE, MASS.**		**APOLLO GUIDANCE AND NAVIGATION**		
DRAWN	J. Flaherty	11/22/69	Integration Initialization	
PRGMR	Frances Kirven	12/8/69		
ANALST				**DOCUMENT NO.**
DOCMR	W. Danforth	12/8/69	LUMINARY 1D	FC-3350
APPR'D	R. M. Estes		**REV** 1	**SHEET** 9 **OF** 32



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty	11/22/69	Integration Initialization	
PRGMR Frances Kirven	12/8/69		DOCUMENT NO.
ANALST			
DOCMR W. Danforth	12/8/69	LUMINARY 1D	FC-3350
APPR'D R. M. Cates		REV 1	SHEET 10 OF 32



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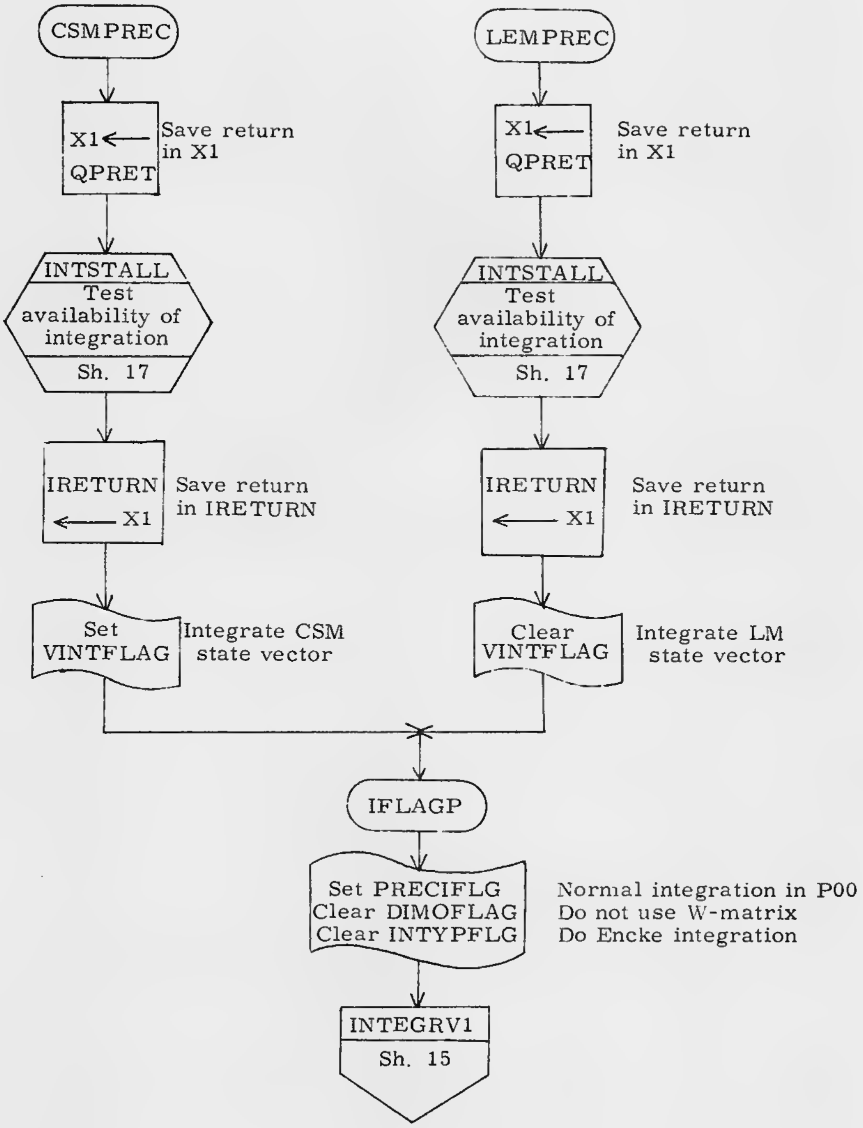
DRAWN J. Flaherty	11/22/69	Integration Initialization	
PRGMR Frances Keiven	12/8/69		DOCUMENT NO.
ANALST			
DOCMR W. Dogbrts	12/8/69	LUMINARY 1D	FC-3350
APPR'D R.M. Cutes		REV 1	SHEET 11 OF 32



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ANALST
DOCMR W. Dofroth 12/8/69
APPR'D R. M. Sutes

APOLLO GUIDANCE AND NAVIGATION

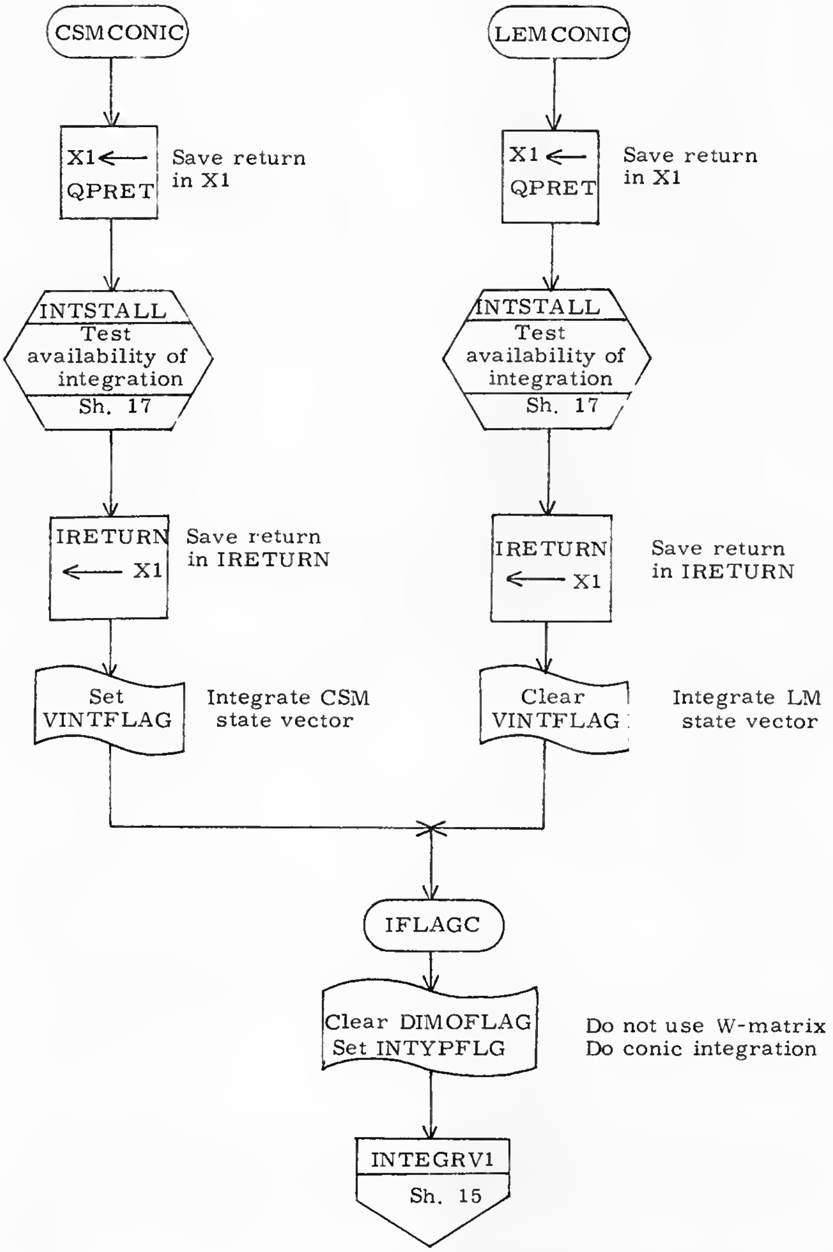
Integration
Initialization

LUMINARY 1D

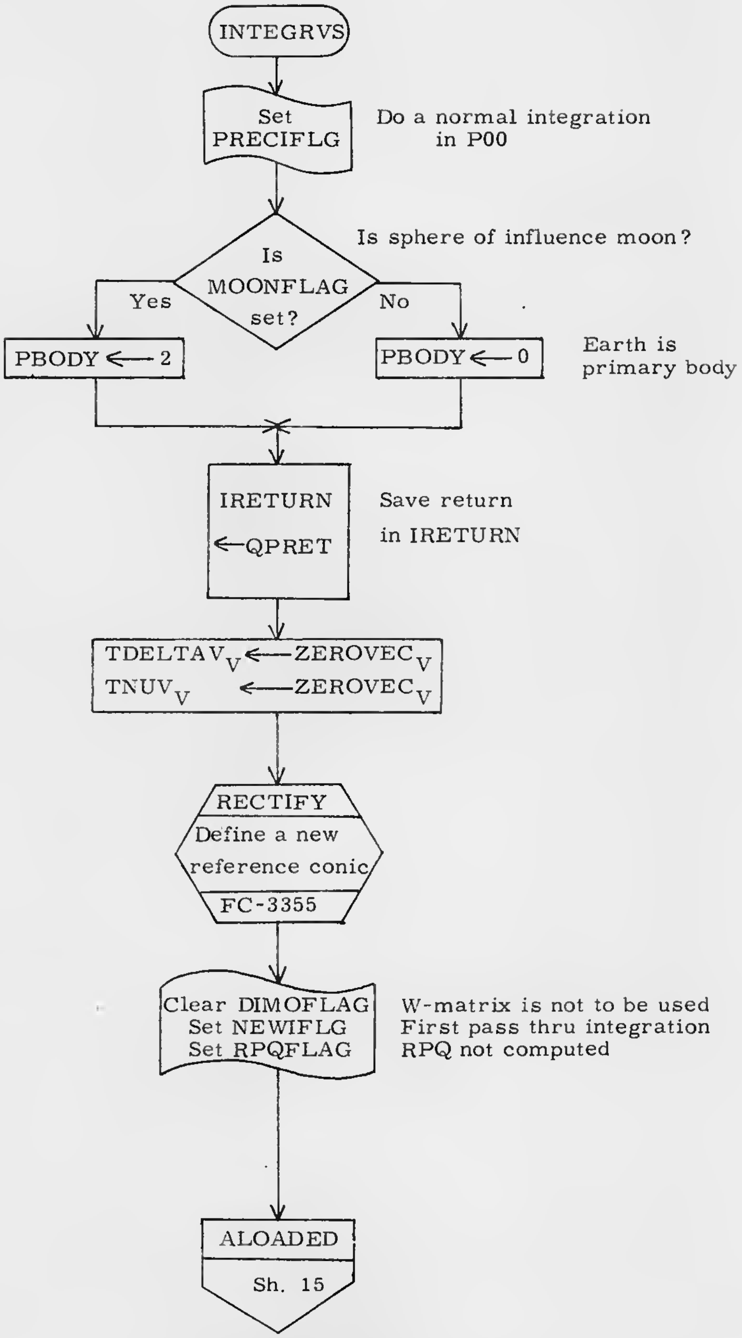
DOCUMENT NO. FC-3350

REV 1

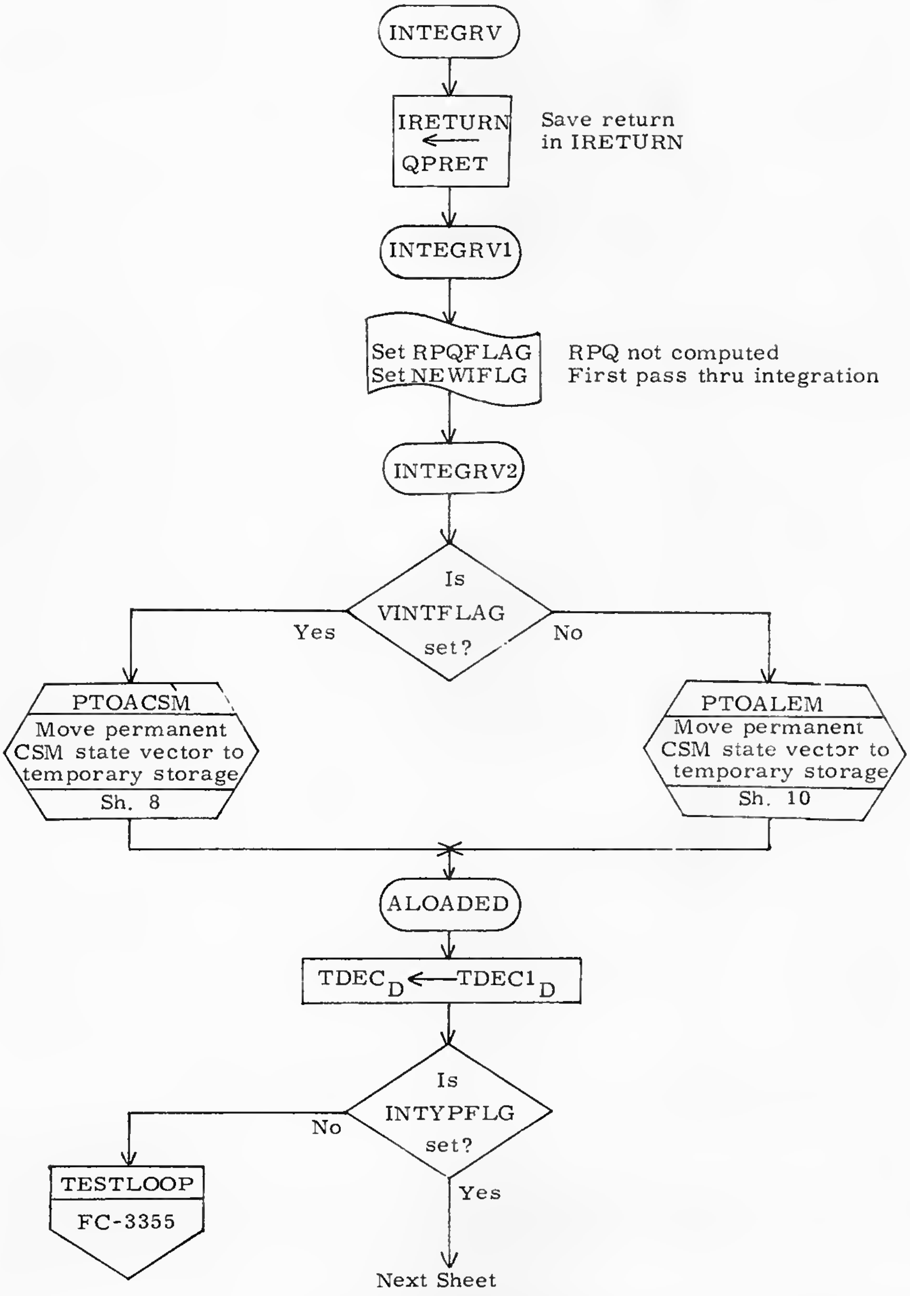
SHEET 12 **OF** 32



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN J.Flaherty 11/22/69	Integration Initialization	
PRGMR Frances Kirven 12/8/69		DOCUMENT NO.
ANALST		
DOCMR W. Dougherty 12/8/69	LUMINARY 1D	FC-3350
APPR'D R. M. Estes	REV 1	SHEET 13 OF 32



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN J. Flaherty	11/22/68	Integration Initialization	
PRGMR Frances Rivers	12/8/69		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3350
DOCMR W. Danforth	12/8/69		
APPR'D R.M. Estes		REV 1	SHEET 14 OF 32



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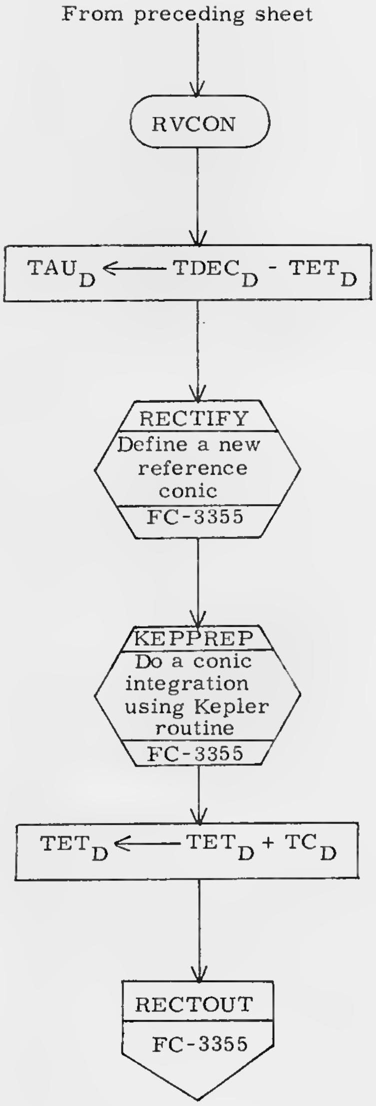
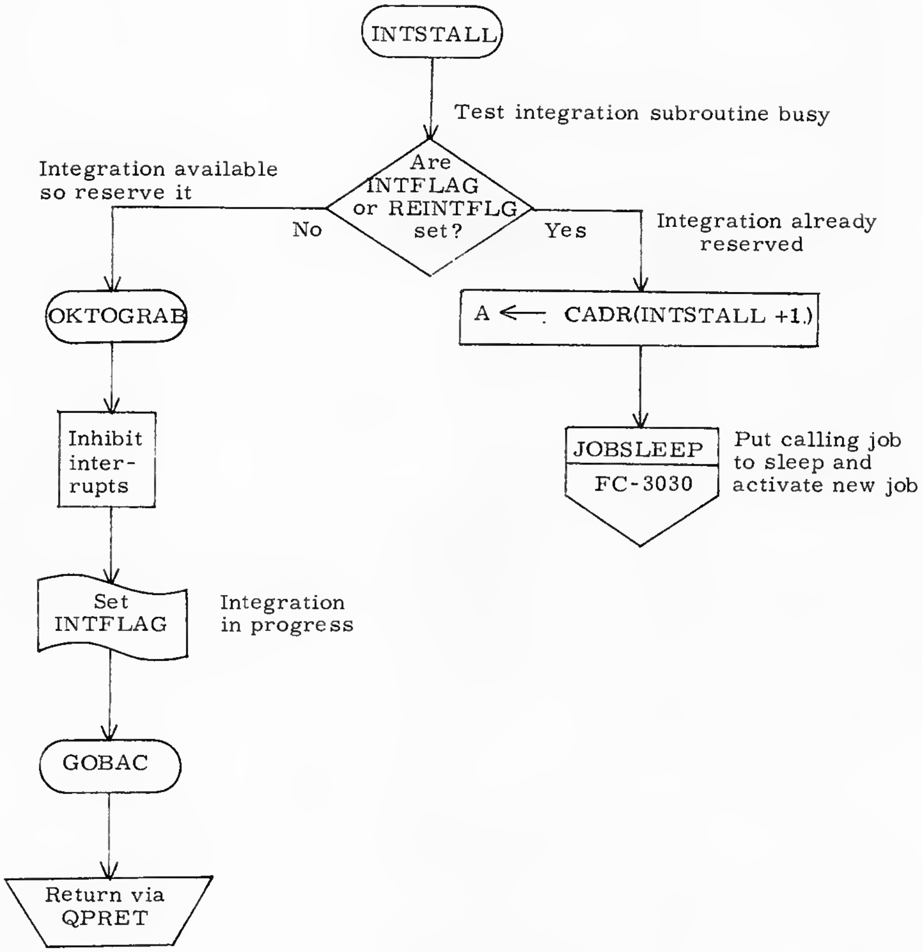
DRAWN J. Flaherty	11/22/69	Integration Initialization
PRGMR Frances Kirven	12/8/69	
ANALST		LUMINARY 1D
DOCMR W. Danforth	12/8/69	DOCUMENT NO. FC-3350
APPR'D R. M. Estes		REV 1
		SHEET 15 OF 32



MIT INSTRUMENTATION LAB **CAMBRIDGE, MASS.**		**APOLLO GUIDANCE AND NAVIGATION**	
DRAWN J. Flaherty	11/22/69	Integration Initialization	
PRGMR Frances Kirwen	12/8/69		
ANALST			**DOCUMENT NO.**
DOCMR W. Dagforth	12/8/69	LUMINARY 1D	FC-3350
APPR'D R. M. Estes		**REV** 1	**SHEET** 16 **OF** 32



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DRAWN J. Flaherty 11/22/69
PRGMR Frances Kirwen 12/8/69
ANALST
DOCMR W. Dayhitt 12/8/69
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APOLLO GUIDANCE AND NAVIGATION

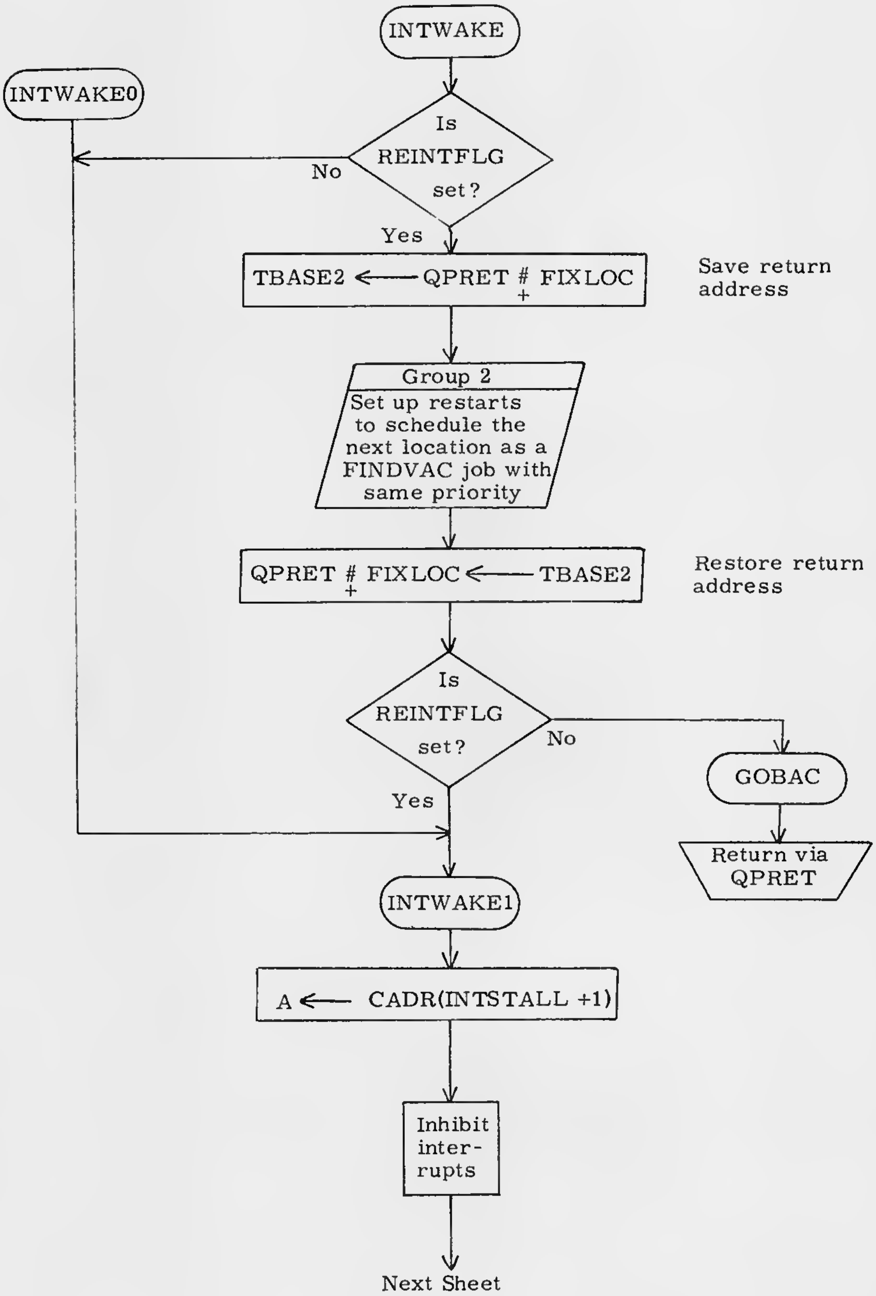
Integration
Initialization

LUMINARY 1D

DOCUMENT NO.
FC-3350

REV 1

SHEET 17 OF 32



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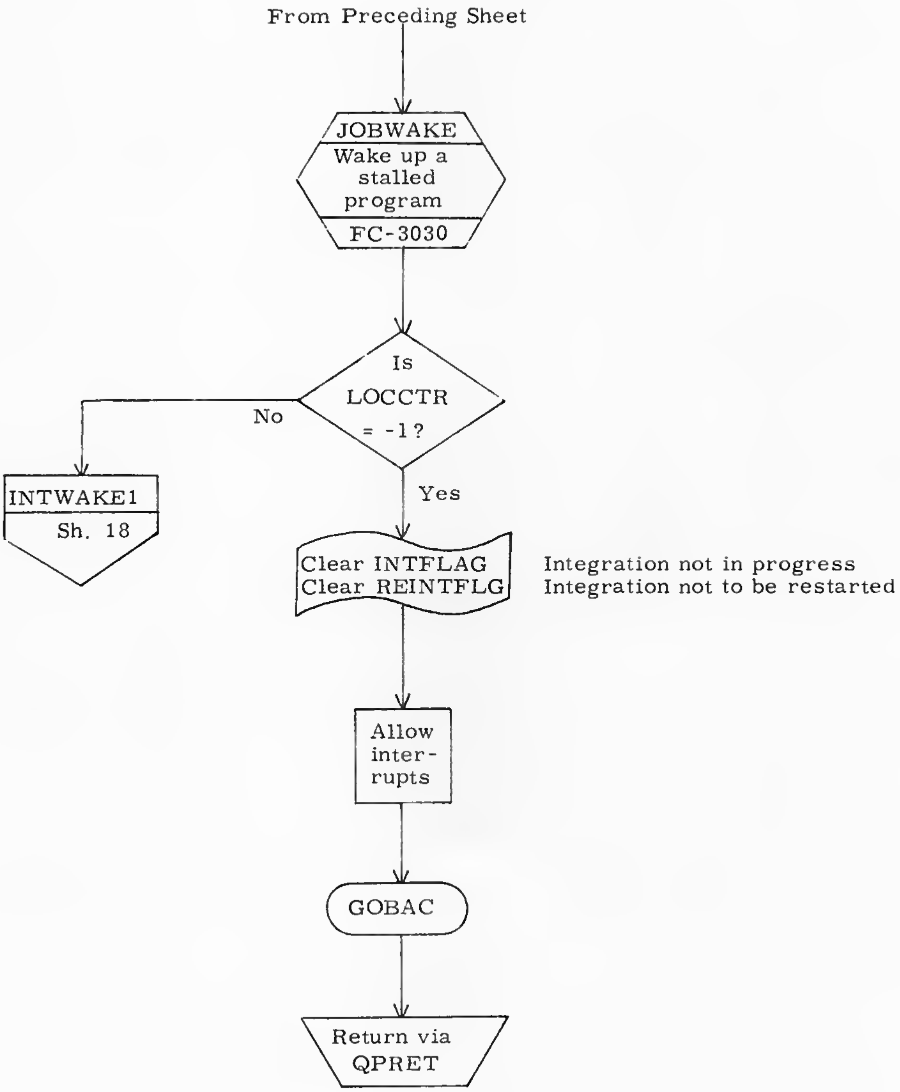
DRAWN J. Flaherty	11/22/69	Integration Initialization	
PRGMR Francis Kirwen	12/8/69		DOCUMENT NO.
ANALST			
DOCMR W. Goforth	12/8/69	LUMINARY 1D	FC-3350
APPR'D R. M. Entes		REV 1	SHEET 18 OF 32



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PRGMR Frances Kirven 12/8/69
ANALST
DOCMR 12/8/69
APPR'D R.M. Estes

APOLLO GUIDANCE AND NAVIGATION

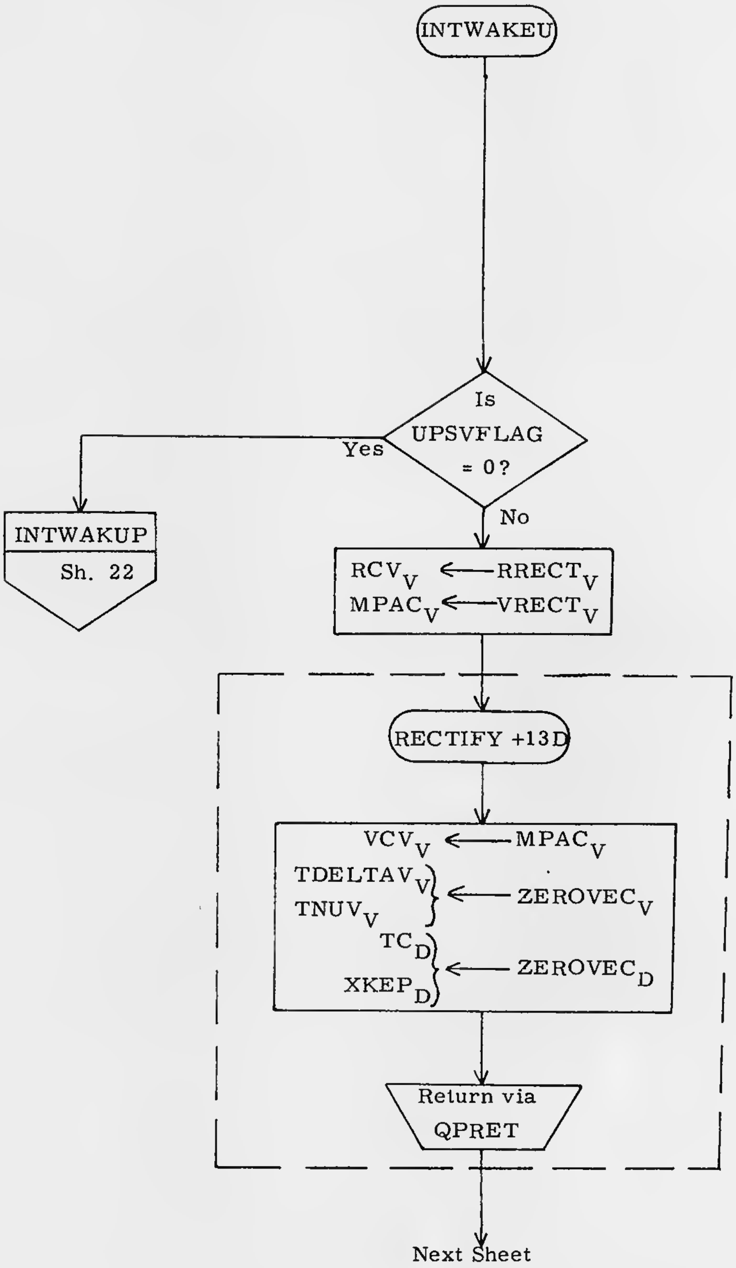
Integration
Initialization

LUMINARY 1D

DOCUMENT NO.
FC-3350

REV 1

SHEET 19 OF 32



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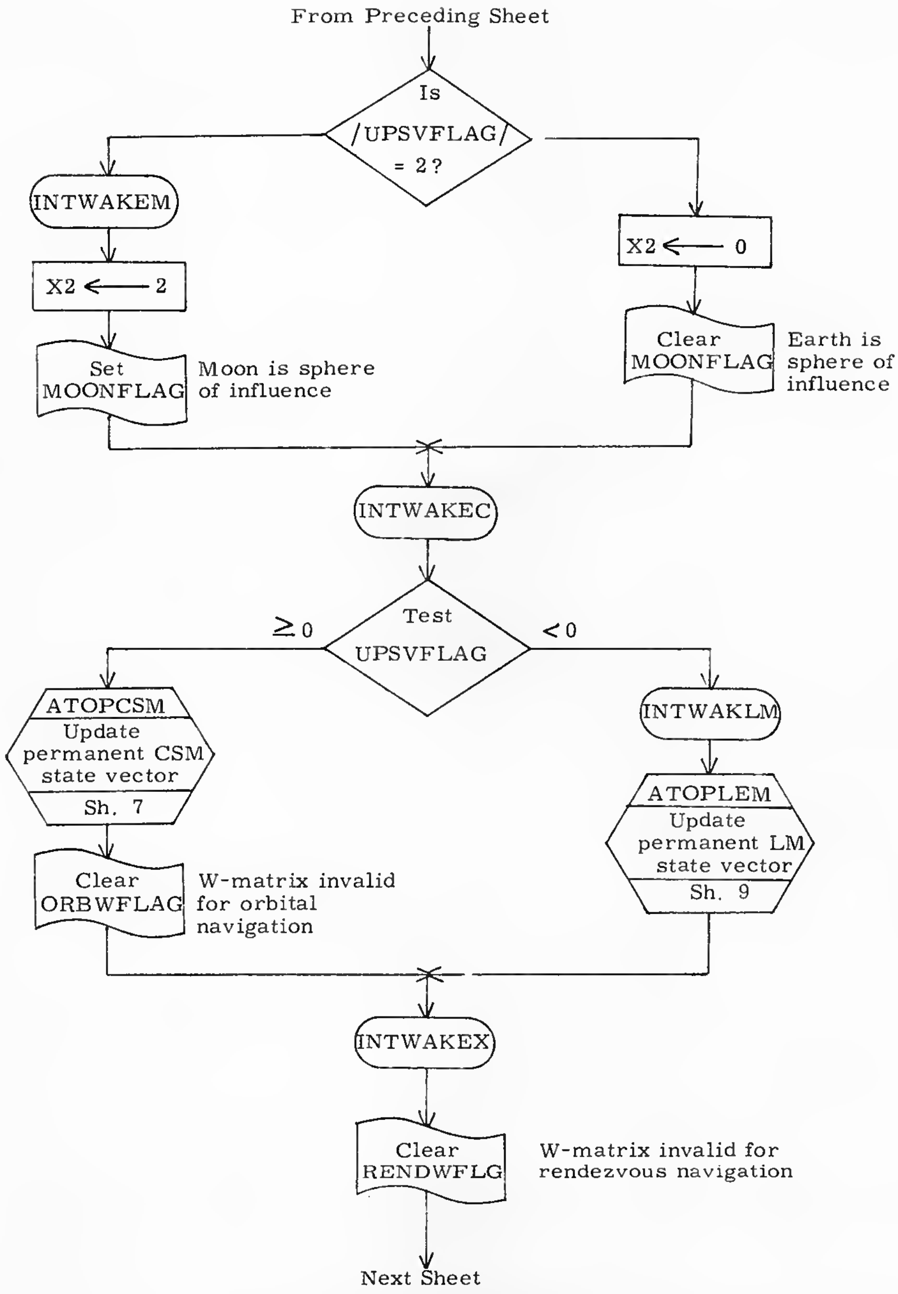
DRAWN	J. Flaherty	11/22/69	Integration Initialization	
PRGMR	Frances Kirven	12/8/69		**DOCUMENT NO.**
ANALST				
DOCMR	W. Danforth	12/8/69	LUMINARY 1D	FC-3350
APPR'D	R. M. Entus		**REV** 1	**SHEET** 20 **OF** 32



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APOLLO GUIDANCE AND NAVIGATION

Integration
Initialization

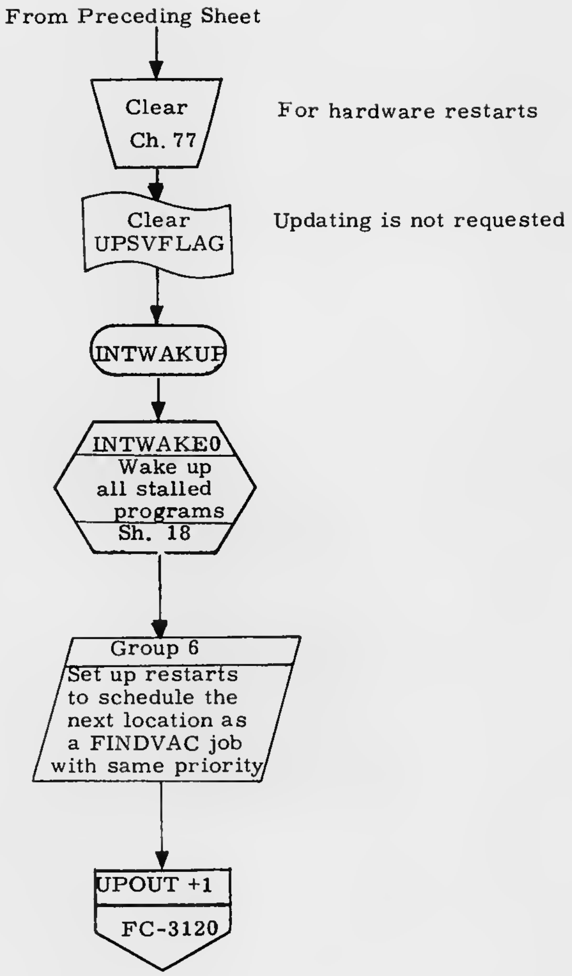
DRAWN J. Flaherty 11/22/69
PRGMR Frances Kirven 12/8/69
ANALST
DOCMR W. Dofort 12/8/69
APPR'D R. M. Entes

LUMINARY 1D

DOCUMENT NO. FC-3350

REV 1

SHEET 21 OF 32



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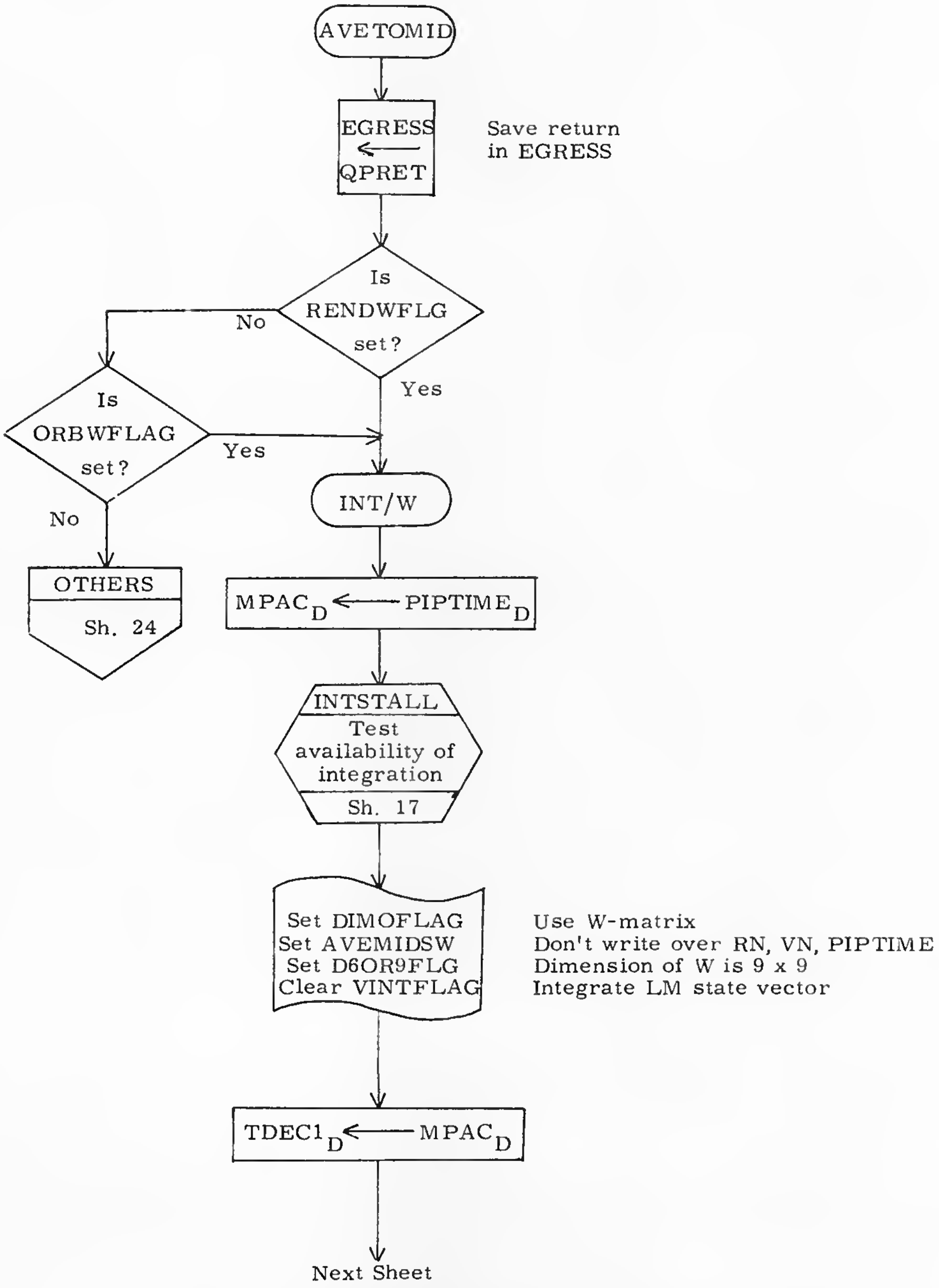
DRAWN J. Flaherty	11/22/69	Integration Initialization	
PRGMR Frances Kirwen	12/8/69		**DOCUMENT NO.**
ANALST		LUMINARY 1D	FC-3350
DOCMR W. Dayton	12/8/69		
APPR'D R. M. Estes		**REV** 1	**SHEET** 22 **OF** 32



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APOLLO GUIDANCE AND NAVIGATION

DRAWN J. Flaherty 11/22/69
PRGMR Frances Kirwen 12/8/69
ANALST
DOCMR W. Dyforth 12/8/69
APPR'D R. M. Este

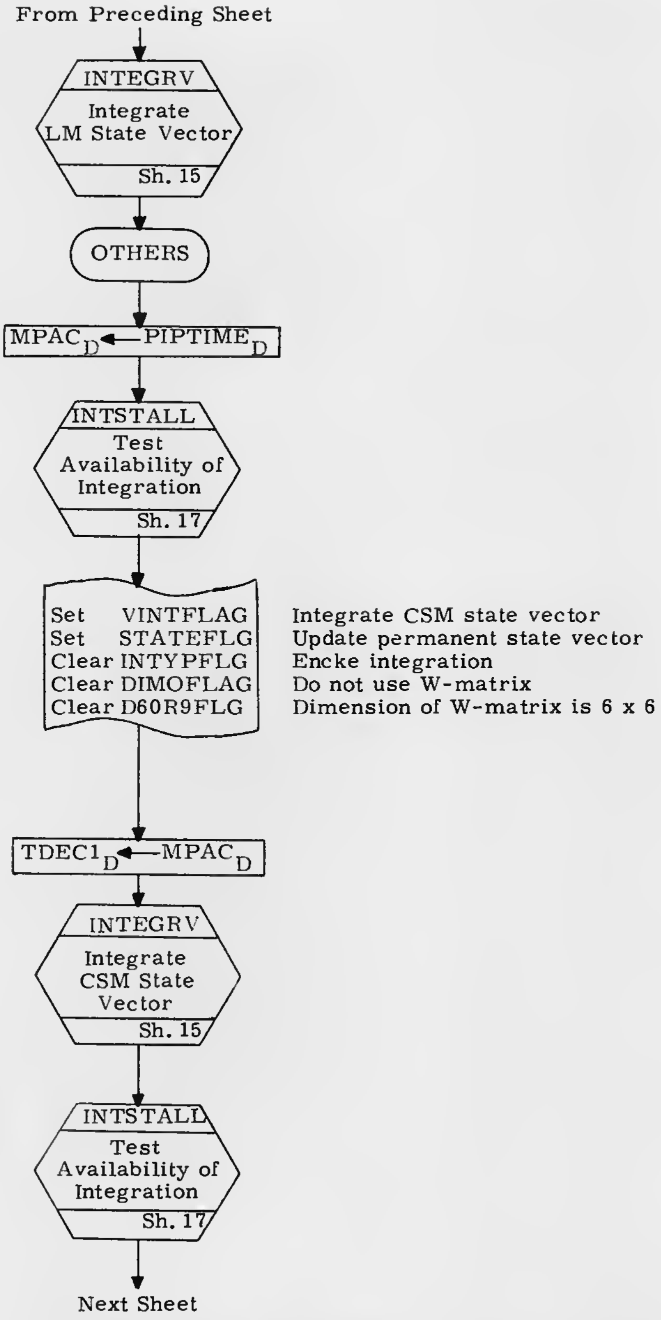
Integration
Initialization

LUMINARY 1D

DOCUMENT NO. FC-3350

REV 1

SHEET 23 **OF** 32



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DRAWN D. Zucholke 12-4-69
PRGMR Frances Perrin 12/8/69
ANALST
DOCMR W. Dorfort 12/8/69
APPR'D R. M. Estes

APOLLO GUIDANCE AND NAVIGATION

Integration
Initialization

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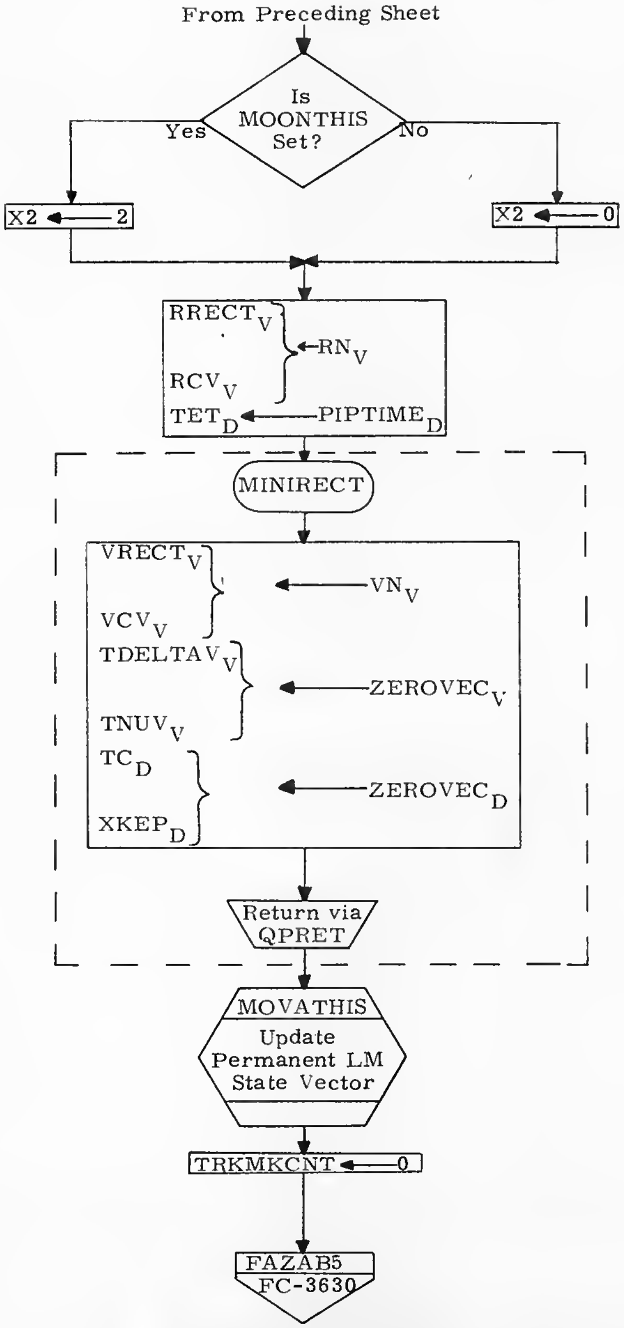
DOCUMENT NO.
FC-3350

REV 1
SHEET 24 **OF** 32



MIT INSTRUMENTATION LAB
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DRAWN		12-4-69
PRGMR	Frances Kirven	12/8/69
ANALST		
DOCMR	W.	12/8/69
APPR'D	R. M. Estes	

APOLLO GUIDANCE AND NAVIGATION

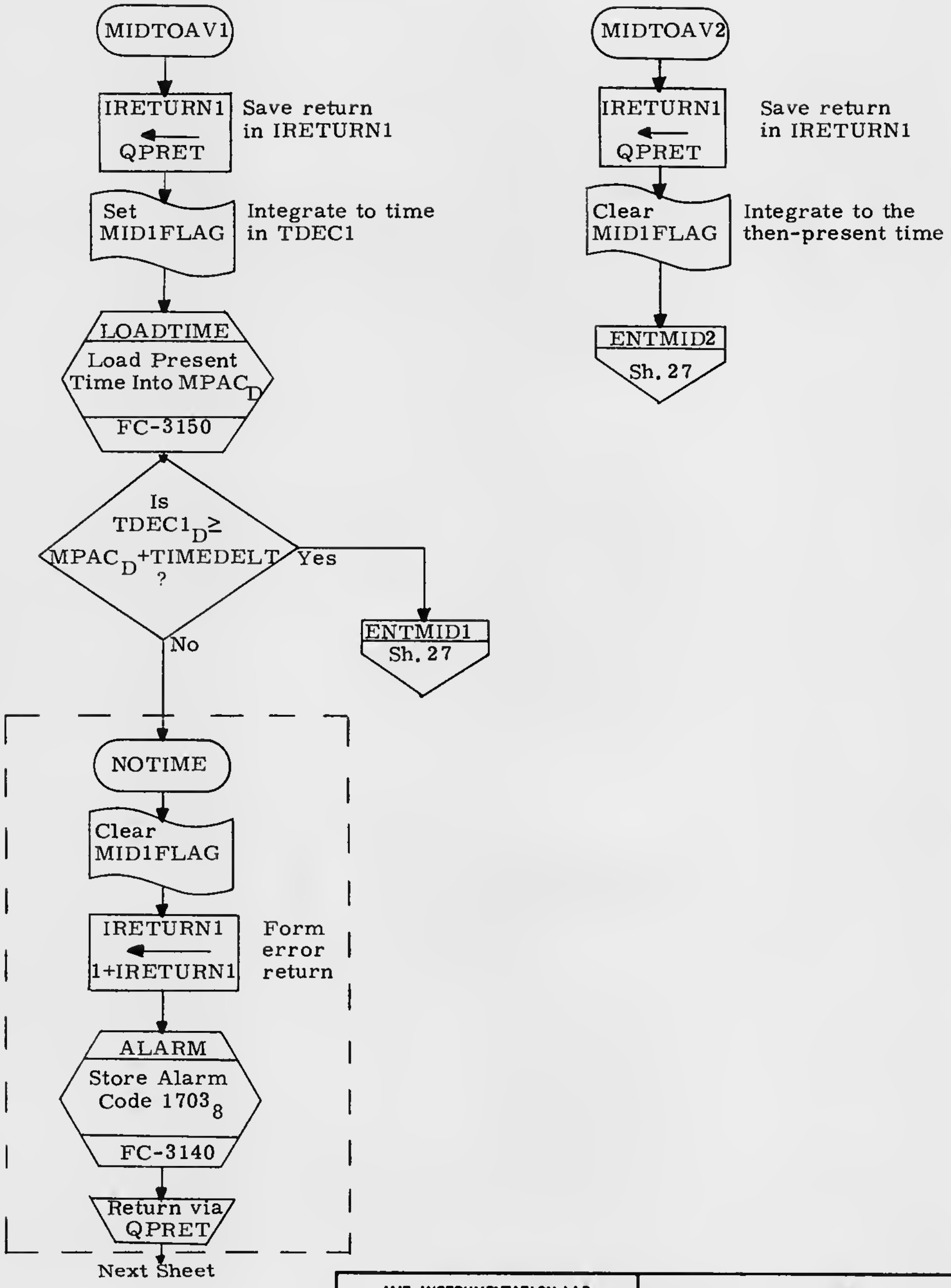
Integration
Initialization

LUMINARY 1D

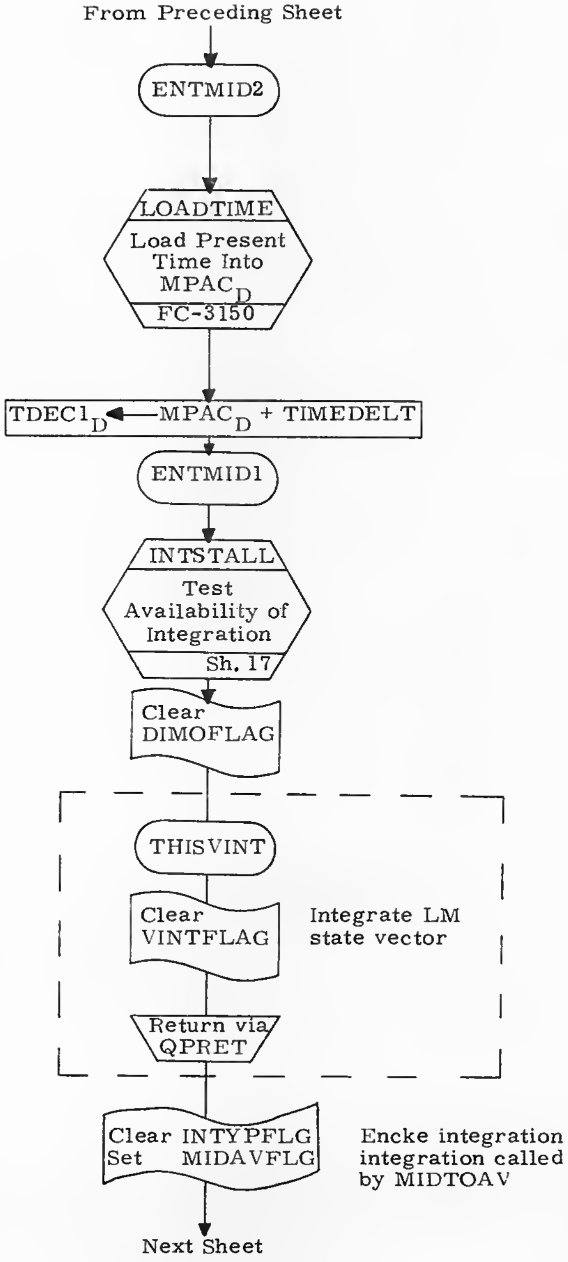
DOCUMENT NO. FC-3350

REV 1

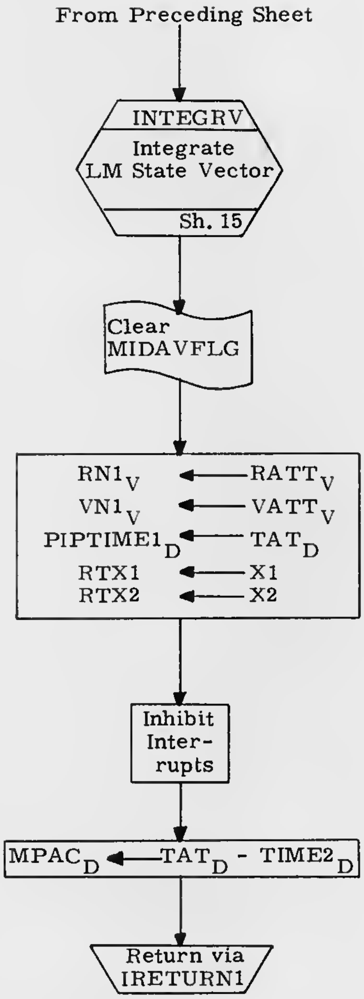
SHEET 25 OF 32



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A. Tucholke	1.24.69	Integration Initialization	
PRGMR Frances Peiven	12/8/69		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3350
DOCMR W. [illegible]	12/8/69		
APPR'D R.M. Estes		REV 1	SHEET 26 OF 32



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN D. Zucholke	12-4-69	Integration Initialization	
PRGMR Frances Kirwen	12/8/69		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3350
DOCMR W. Danforth	12/8/69		
APPR'D R. M. Estes		REV 1	SHEET 27 OF 32



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DRAWN 12-4-69
PRGMR Frances Kirven 12/8/69
ANALST
DOCMR 12/8/69
APPR'D

APOLLO GUIDANCE AND NAVIGATION

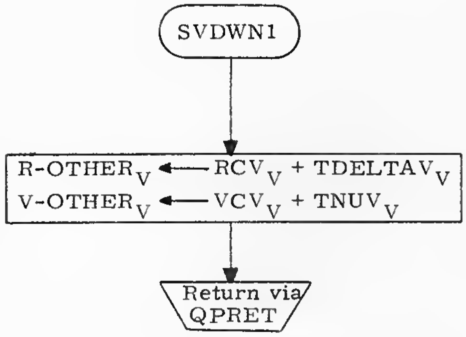
Integration
Initialization

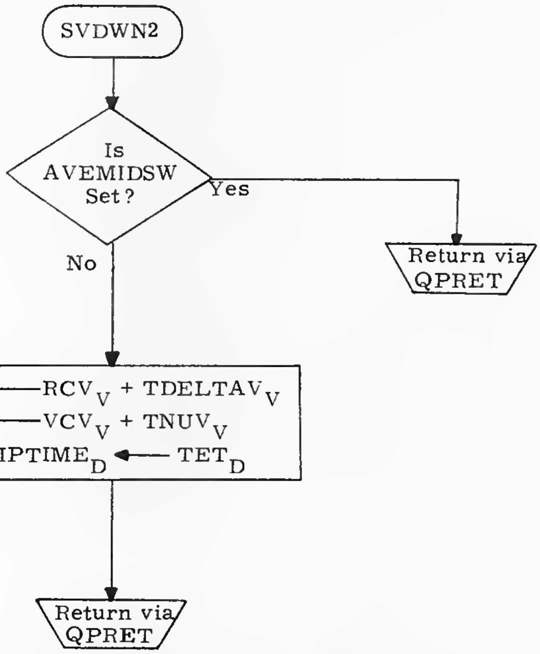
LUMINARY 1D

DOCUMENT NO.
FC-3350

REV 1

SHEET 28 OF 32





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DRAWN 12-4-69
PRGMR Frances Kiven 12/8/69
ANALST
DOCMR 12/9/69
APPR'D

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Integration
Initialization

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DOCUMENT NO.
FC-3350

REV 1

SHEET 29 OF 32

Routines Called On Other Flowcharts

Routine	Flowchart	Description	Where Called
LOADTIME	FC-3150	Load present time into $MPAC_D$	Sh. 2, 26, 27
RP-TO-R	FC-3340	Convert vector from moon coordinates to basic reference coordinates	Sh. 11
RECTIFY	FC-3355	Define a new reference conic	Sh. 14, 16
KEPPREP	FC-3355	Do a conic integration using Kepler routine	Sh. 16
JOBWAKE	FC-3030	Wake up a stalled program	Sh. 19
UPOUT	FC-3120	Normal finish of P27 (Update Program)	Sh. 22

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DRAWN	12.4.69	Integration Initialization	
PRGMR Frances Kiwen	12/8/69		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3350
DOCMR W.	12/8/69		
APPR'D R. M. Estes		REV 1	SHEET 30 OF 32

FLAGS

Name	Meaning When Set	Meaning When Cleared	Where Set	Where Cleared	Where Tested
QUITFLAG Flag 9, Bit 5	Discontinue Integration	Continue Integration		Sh. 2	Sh. 2
NODOFLAG Flag 2 Bit 1	V37 not permitted	V37 permitted	Sh. 3	Sh. 6	
STATEFLG Flag 3 Bit 5	Permanent state vector updated	Permanent state vector not updated	Sh. 3, 5, 24	Sh. 3	
INTYPFLG Flag 3 Bit 4	Conic integration	Encke integration	Sh. 13	Sh. 3, 5, 12, 24, 27	Sh. 15
DIMOFLAG Flag 3 Bit 1	W-matrix is to be used	W-matrix is not to be used	Sh. 4, 23	Sh. 3, 5, 12, 13, 14, 24, 27	
D60R9FLG Flag 3 Bit 2	Dimension of W-matrix is 9 x 9	Dimension of W-matrix is 6 x 6	Sh. 23	Sh. 3, 5, 24	
POOHFLAG Flag 3 Bit 15	Inhibit backwards integration	Allow backwards integration	Sh. 3		
VINTFLAG Flag 3 Bit 3	CSM state vector being integrated	LM state vector being integrated	Sh. 4, 12, 13, 24	Sh. 5, 12, 13, 23, 27	
SURFFLAG Flag 8 Bit 8	LM on lunar Surface	LM not on lunar Surface			Sh. 4, 5, 10
RENDWFLG Flag 5 Bit 1	W-matrix valid for rendezvous navigation	W-matrix invalid for rendezvous navigation		Sh. 21	Sh. 4, 5, 23
PRECIFLG Flag 3 Bit 8	Normal integration in POO	Engages 4-time step logic in integration	Sh. 5, 12	Sh. 4	
CMOONFLG Flag 8 Bit 12	Permanent CSM state in lunar sphere	Permanent CSM state in earth sphere	Sh. 7	Sh. 7	Sh. 8
MOONFLAG Flag 0 Bit 12	Moon is sphere of influence	Earth is sphere of influence	Sh. 8, 11, 21	Sh. 8, 21	Sh. 7, 9, 14

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PRGMR Frances Rizzen 12/4/69
ANALST
DOCMR W. Forsyth 12/9/69
APPR'D R. M. Estes

APOLLO GUIDANCE AND NAVIGATION

Integration Initialization

LUMINARY 1D

DOCUMENT NO. FC-3350

REV 1

SHEET 31 OF 32

FLAGS (Cont.)

Name	Meaning When Set	Meaning When Cleared	Where Set	Where Cleared	Where Tested
LMOONFLG Flag 8 Bit 11	Permanent LM state in lunar sphere	Permanent LM state in earth sphere	Sh. 9	Sh. 9	Sh. 10
NEWIFLG Flag 8 Bit 13	First pass through integration	Succeeding iteration of integration	Sh. 14		
RPQFLAG Flag 8 Bit 15	RPQ not computed	RPQ computed	Sh. 14		
INTFLAG Flag 10 Bit 14	Integration in progress	Integration not in progress		Sh. 19	Sh. 17
REINTFLG Flag 10 Bit 7	Integration routine to be restarted	Integration routine not to be restarted	Sh. 17	Sh. 19	Sh. 17, 18
ORBWFLAG Flag 3 Bit 6	W-matrix valid for orbital navigation	W-matrix invalid for orbital navigation		Sh. 21	Sh. 23
AVEMIDSW Flag 9 Bit 1	AVETOMID calling for W-matrix integration	No AVETOMID W-matrix integration	Sh. 23		Sh. 29
MID1FLAG Flag 9 Bit 3	Integrate to TDEC	Integrate to then present time	Sh. 26	Sh. 26	
MIDAVFLG Flag 9 Bit 2	Integration entered from MIDTOAV	Integration was not entered from MIDTOAV	Sh. 27	Sh. 28	

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DRAWN	D. Tucholski	12-4-69	Integration Initialization	
PRGMR	Frances Kriven	12/8/69		
ANALST			LUMINARY 1D	DOCUMENT NO. FC-3350
DOCMR	W. Dzybeth	12/3/69		
APPR'D	R. M. Estes		REV 1	SHEET 32 OF 32

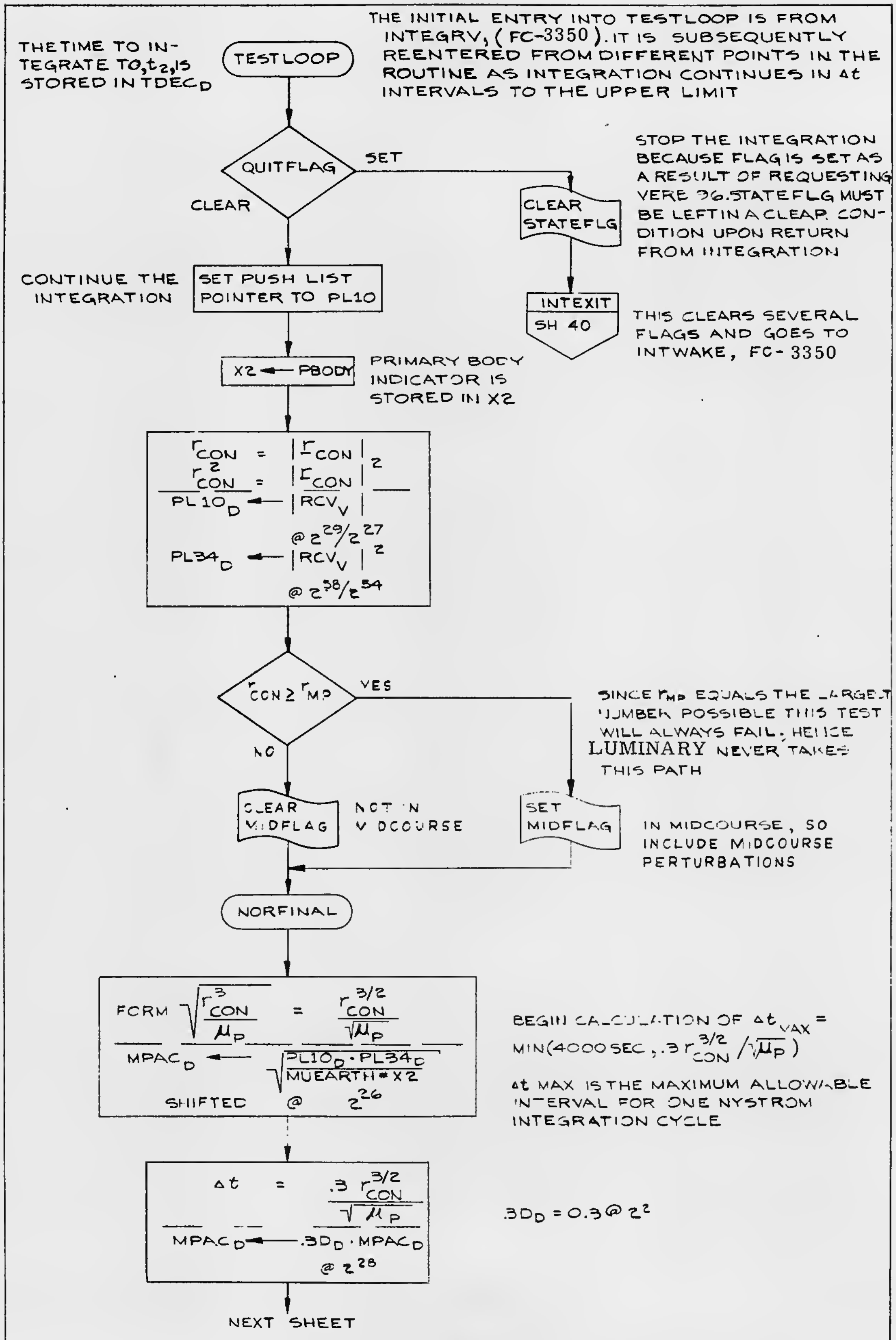
ORBITAL INTEGRATION

MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS		
TESTLOOP	ENTRY TO ACTUAL INTEGRATION LOOP	SH. 2
TIMESTEP	INTERMEDIATE ENTRY POINT IN INTEGRATION LOOP	SH. 5
INTGRATE	INTERMEDIATE ENTRY POINT IN INTEGRATION LOOP THAT INITIALIZES LOCATIONS FOR FIRST PASS THROUGH LOOP	SH. 9
ACCOMP	COMPUTES THE ACCELERATION COMPONENTS FOR EARTH AND MOON	SH. 10
GAMCOMP	SUBROUTINE THAT COMPUTES ACCELERATION $\underline{a}_p$ DUE TO THE ATTRACTION OF THE PRIMARY BODY	SH. 24
DIFEQ+0	EVALUATE $\underline{\psi}$ AND $\underline{\phi}$ AT THE LEFT HAND POINT	SH. 28
DIFEQ+1	EVALUATE $\underline{\dot{\psi}}$ AND $\underline{\phi}$ AT THE MID-POINT	SH. 28
FBR3	CALCULATE TIME AND CONIC STATE VECTOR AT MIDPOINT AND RIGHT HAND POINT	SH. 29
KEPPREP	SUBROUTINE COMPUTES ESTIMATE OF x AND THEN CALLS KEPLER SUBROUTINE TO CALCULATE CONIC STATE VECTOR	SH. 30
DIFEQ+2	EVALUATE $\underline{\psi}$ AND $\underline{\phi}$ AT THE RIGHT HAND POINT AND THEN CALCULATE THE FUNCTION $\underline{y}$ AND ITS DERIVATIVE $\underline{z}$ AT RIGHT HAND POINT	SH. 33
NEXTCOL	INTERMEDIATE ENTRY POINT FOR INTEGRATING A COLUMN OF THE W-MATRIX	SH. 36
CKMID2	ROUTINE ENTERED BY INTEGRATION IF CALLED BY MIDTOAV	SH. 37
A-PCHK	WRAPS UP THE INTEGRATION ROUTINE WITH A STATE VECTOR UPDATE IF REQUESTED AND A RECTIFICATION	SH. 39
RECTOUT	DOES RECTIFICATION AND STORES OUTPUT IN PUSHLIST	SH. 40
DOW..	ROUTINE THAT CONTROLS THE CALCULATION OF THE ACCELERATION TERMS USED FOR INTEGRATING THE W-MATRIX	SH. 41
DOW..1	SUBROUTINE THAT CALCULATES THE ACCELERATIONS $\underline{a}_p$ AND $\underline{a}_q$	SH. 42
RECTIFY	DEFINE A NEW REFERENCE CONIC AND ZERO THE DEVIATIONS	SH. 43
MINIRECT	ENTRY POINT IN RECTIFY IF $\underline{\delta}$, $\underline{\nu}$ MUST BE INITIALLY ZERO	SH. 43
RECTIFY +13D	ENTRY POINT IN MINIRECT IF VRECT$_V$. ALREADY STORED	SH. 43
ORIGCHNG	CHANGE ORIGIN OF COORDINATE SYSTEM	SH. 44

REFERENCES FOR ORBITAL INTEGRATION

1. GUIDANCE SYSTEM OPERATIONS PLAN USING PROGRAM LUMINARY (GSOP), R-567, SECTION 5. GUIDANCE EQUATIONS. NOVEMBER, 1969.
2. OSTANEK. W. F.. USER'S GUIDE FOR ORBITAL INTEGRATION ROUTINE FOR FLIGHT 504. FLIGHT 504 MEMO 5. REV 1. JUNE. 1967.
3. OSTANEK AND KEFAUVER. LEVEL II TEST PACKAGE FOR COASTING INTEGRATION SUBROUTINE. MIT/IL. NOVEMBER. 1967.

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Matis	6/9/70	Orbital Integration	
PRGMR W. Ostanek	6/16/70	LUMINARY 1D	DOCUMENT NO. FC-3355
ANALST			
DOCMR R M Estes	6/17/70		
APPR'D R M Estes	6/17/70	REV	SHEET 1 OF 49



THE INITIAL ENTRY INTO TESTLOOP IS FROM INTEGRV, (FC-3350). IT IS SUBSEQUENTLY REENTERED FROM DIFFERENT POINTS IN THE ROUTINE AS INTEGRATION CONTINUES IN Δt INTERVALS TO THE UPPER LIMIT

THE TIME TO INTEGRATE TO, t_2, IS STORED IN $TDEC_D$

STOP THE INTEGRATION BECAUSE FLAG IS SET AS A RESULT OF REQUESTING VERB 96. STATEFLG MUST BE LEFT IN A CLEAR CONDITION UPON RETURN FROM INTEGRATION

THIS CLEARS SEVERAL FLAGS AND GOES TO INTWAKE, FC-3350

CONTINUE THE INTEGRATION

PRIMARY BODY INDICATOR IS STORED IN X2

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

NOT IN MIDCOURSE

IN MIDCOURSE, SO INCLUDE MIDCOURSE PERTURBATIONS

BEGIN CALCULATION OF $\Delta t_{MAX} = MIN(4000\,SEC, .3\, r^{3/2}_{CON}/\sqrt{\mu_P})$

Δt MAX IS THE MAXIMUM ALLOWABLE INTERVAL FOR ONE NYSTROM INTEGRATION CYCLE

$.3D_D = 0.3 @ 2^2$

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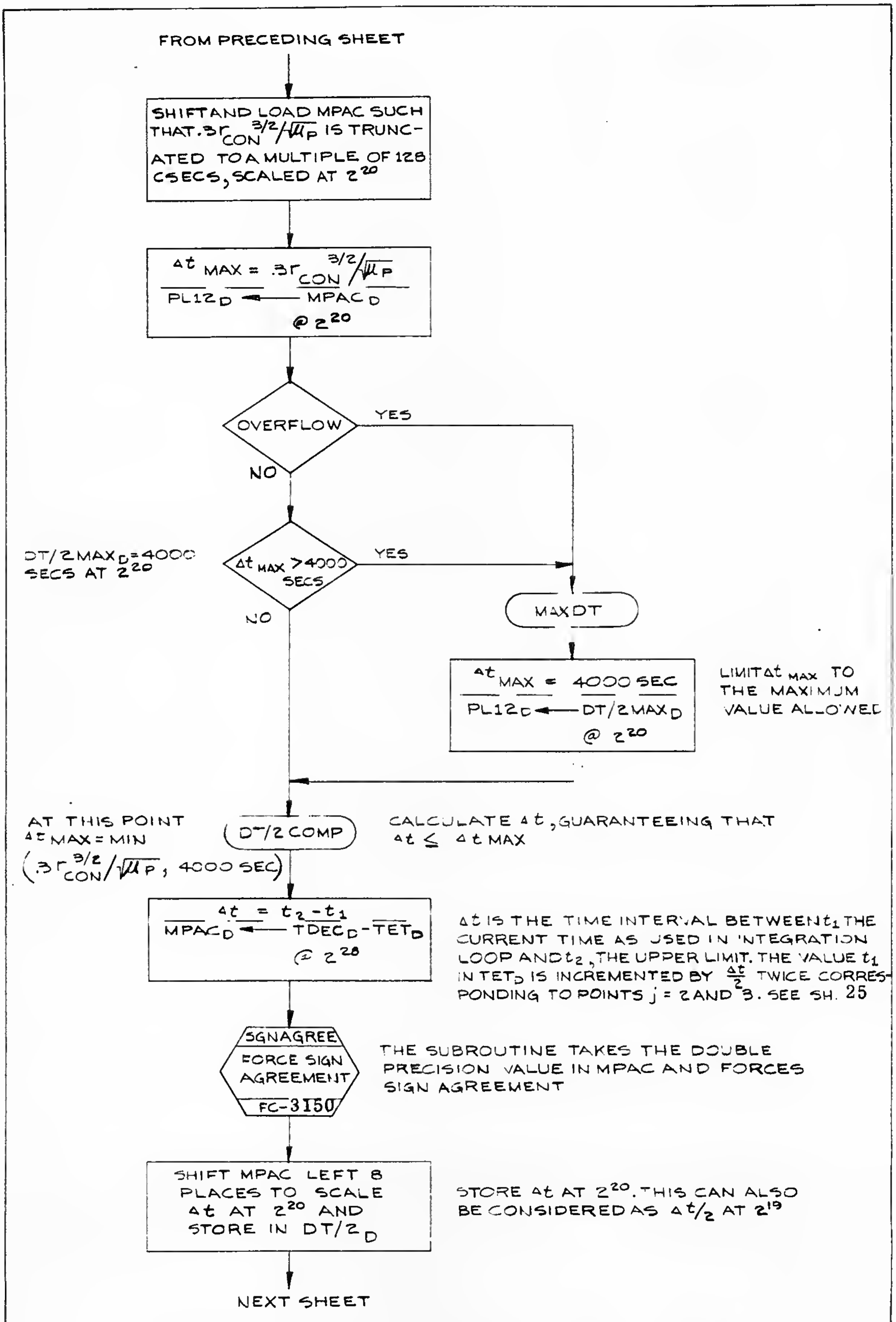

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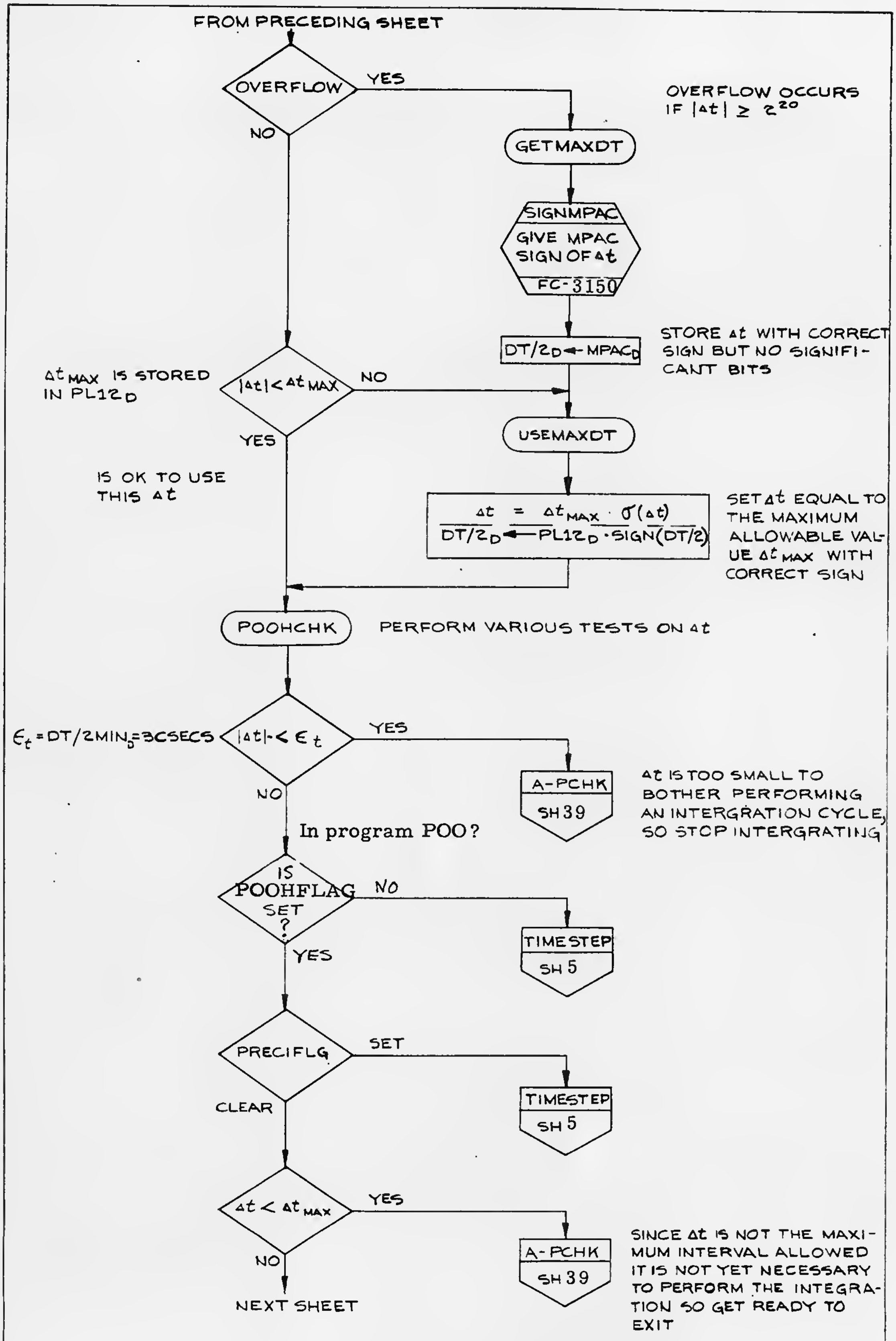

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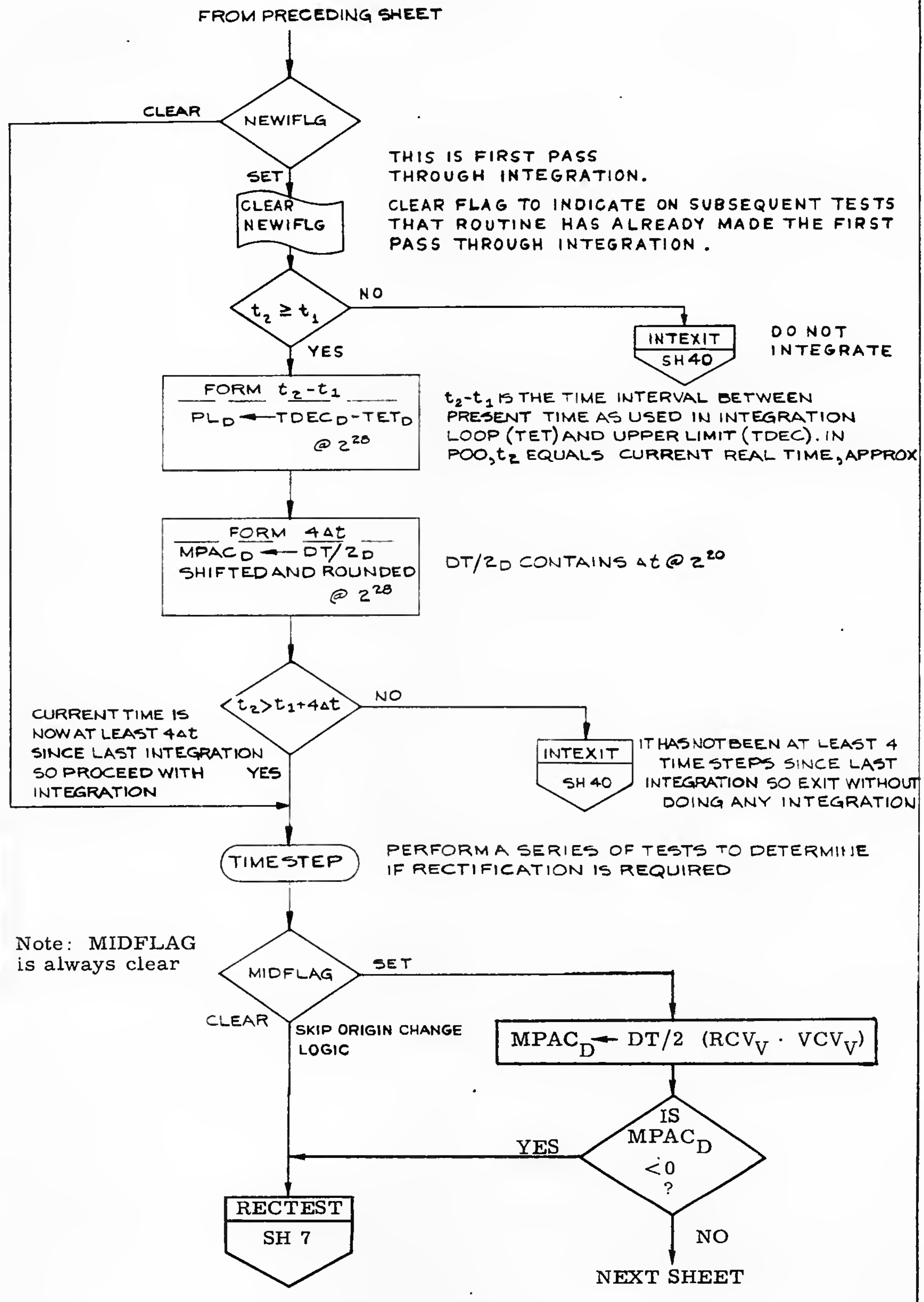

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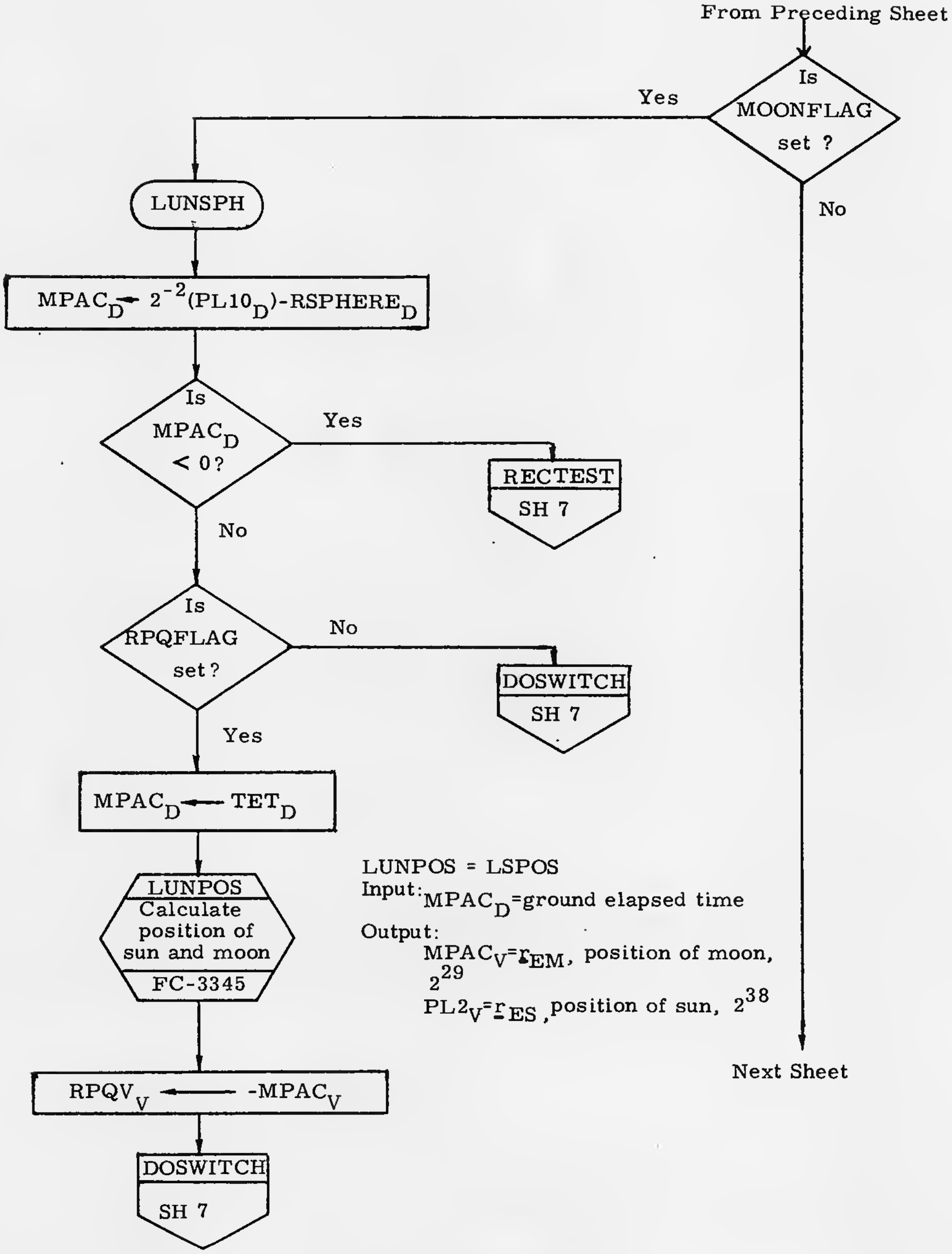

LUNPOS = LSPOS

Input: $MPAC_D$=ground elapsed time

Output:

$MPAC_V = \underline{r}_{EM}$, position of moon, 2^{29}

$PL2_V = \underline{r}_{ES}$, position of sun, 2^{38}

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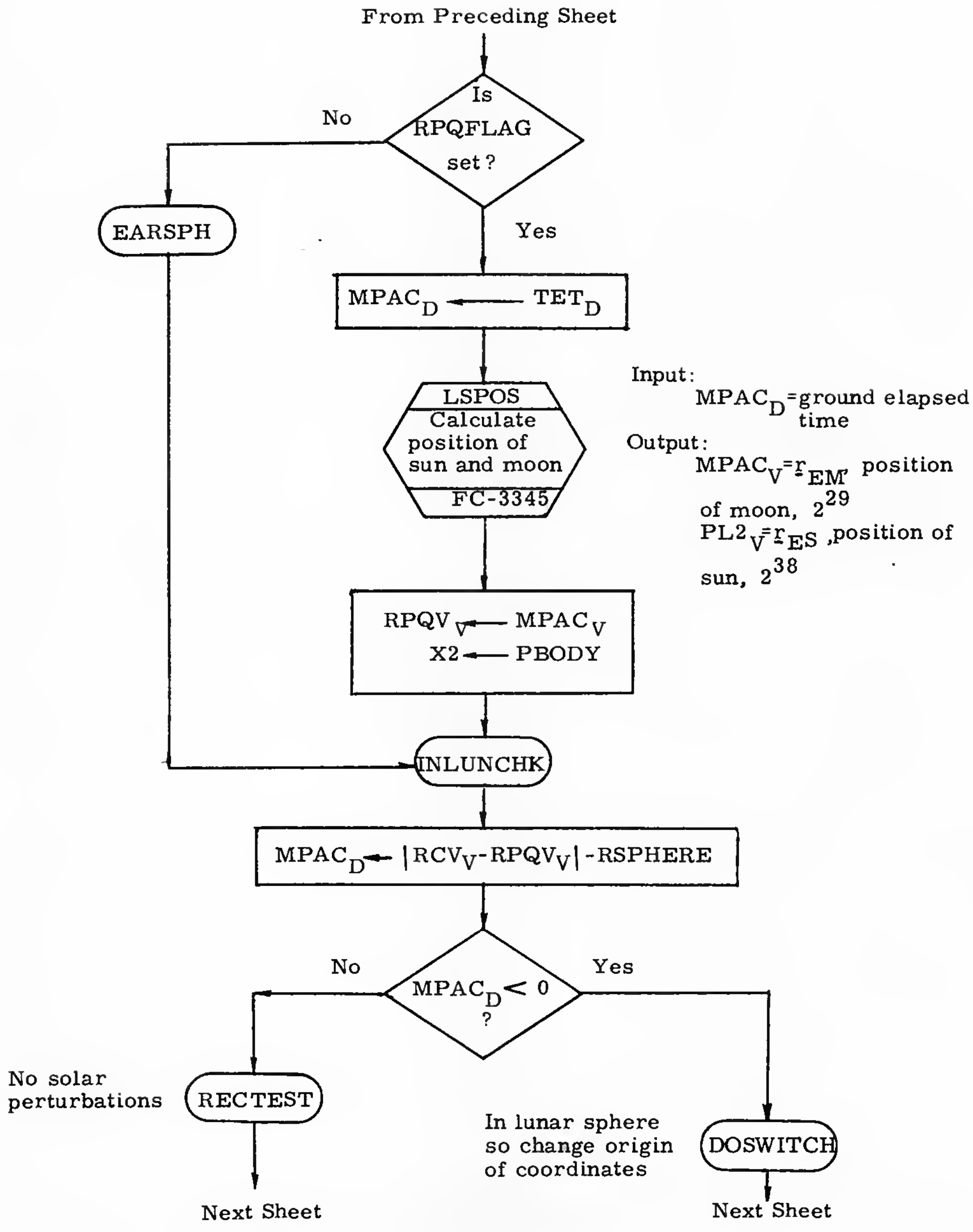

Input:
$MPAC_D$=ground elapsed time

Output:
$MPAC_V = r_{EM}$, position of moon, 2^{29}
$PL2_V = r_{ES}$,position of sun, 2^{38}

No solar perturbations

In lunar sphere so change origin of coordinates

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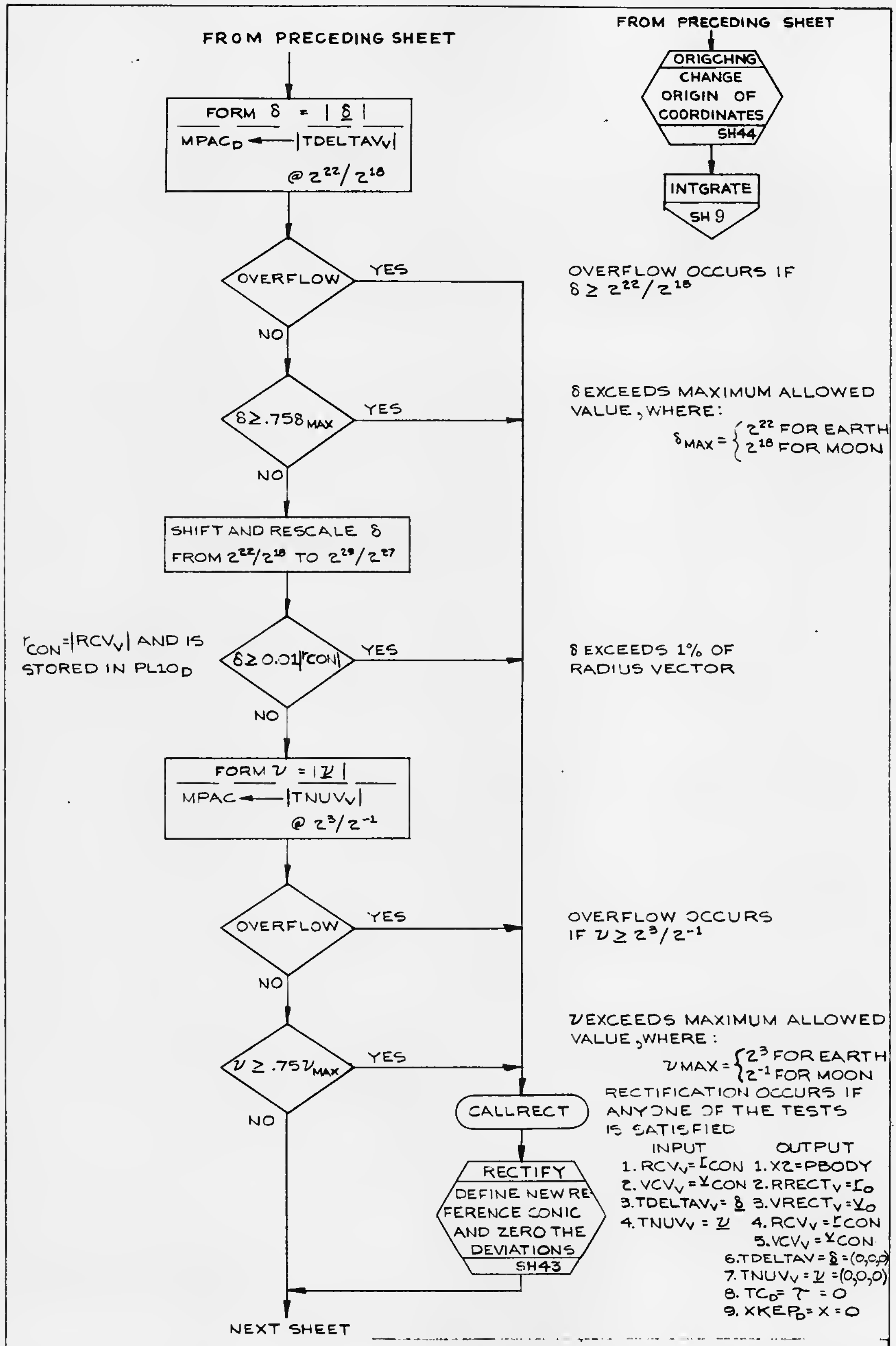

$r_{CON} = |RCV_V|$ AND IS STORED IN $PL10_D$

OVERFLOW OCCURS IF $\delta \geq 2^{22}/2^{18}$

δ EXCEEDS MAXIMUM ALLOWED VALUE, WHERE:

$$\delta_{MAX} = \begin{cases} 2^{22} \text{ FOR EARTH} \\ 2^{18} \text{ FOR MOON} \end{cases}$$

δ EXCEEDS 1% OF RADIUS VECTOR

OVERFLOW OCCURS IF $\nu \geq 2^3/2^{-1}$

ν EXCEEDS MAXIMUM ALLOWED VALUE, WHERE:

$$\nu MAX = \begin{cases} 2^3 \text{ FOR EARTH} \\ 2^{-1} \text{ FOR MOON} \end{cases}$$

RECTIFICATION OCCURS IF ANYONE OF THE TESTS IS SATISFIED

INPUT	OUTPUT
1. $RCV_V = \underline{r}_{CON}$	1. X2 = PBODY
2. $VCV_V = \underline{v}_{CON}$	2. $RRECT_V = \underline{r}_0$
3. $TDELTAV_V = \underline{\delta}$	3. $VRECT_V = \underline{v}_0$
4. $TNUV_V = \underline{\nu}$	4. $RCV_V = \underline{r}_{CON}$
	5. $VCV_V = \underline{v}_{CON}$
	6. $TDELTAV = \underline{\delta} = (0,0,0)$
	7. $TNUV_V = \underline{\nu} = (0,0,0)$
	8. $TC_D = \tau = 0$
	9. $XKEP_D = X = 0$

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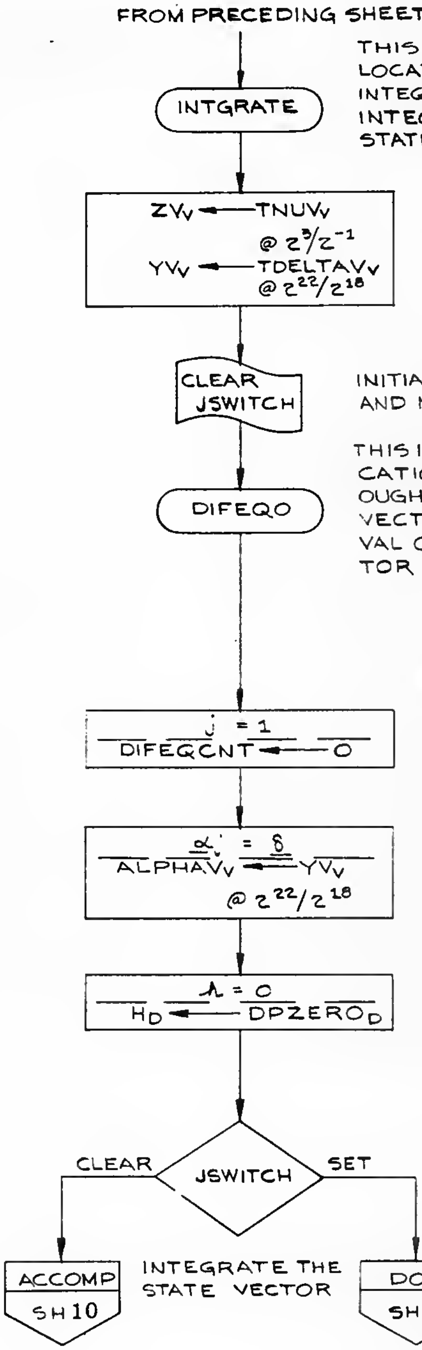

THIS IS THE ENTRY SEQUENCE FOR INITIALIZING LOCATIONS FOR THE FIRST PASS THROUGH THE INTEGRATION LOOP. LOCATIONS ARE SET UP FOR INTEGRATING THE STATE VECTOR SINCE THE STATE VECTOR IS ALWAYS INTEGRATED FIRST

STORE ν, δ 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 $j = 1, 2, 3$). THE VECTOR BEING INTEGRATED OVER A TIME INTERVAL OF Δt IS EITHER A STATE VECTOR OR A VECTOR IN THE W-MATRIX

INITIALIZE j
j TAKES ON THE VALUES 1, 2, 3 CORRESPONDING TO THE LEFT POINT, MIDPOINT, AND RIGHT POINT OF AN INTERVAL OF LENGTH Δt. DIFEQCNT TAKES ON THE VALUES 0, -12D, -24D

INITIALIZE α_j
α_j IS THE ESTIMATE OF $\underline{\delta}$ USED ON EACH OF THE THREE PASSES THROUGH THE INTEGRATION LOOP

INITIALIZE h.
h TAKES ON THE VALUES 0, $\frac{\Delta t}{2}$, Δt CORRESPONDING TO THE LEFT POINT, MID POINT, AND RIGHT POINT VALUE OF THE INTERVAL Δt.

INTEGRATE THE STATE VECTOR

INTEGRATE A VECTOR FROM THE W-MATRIX

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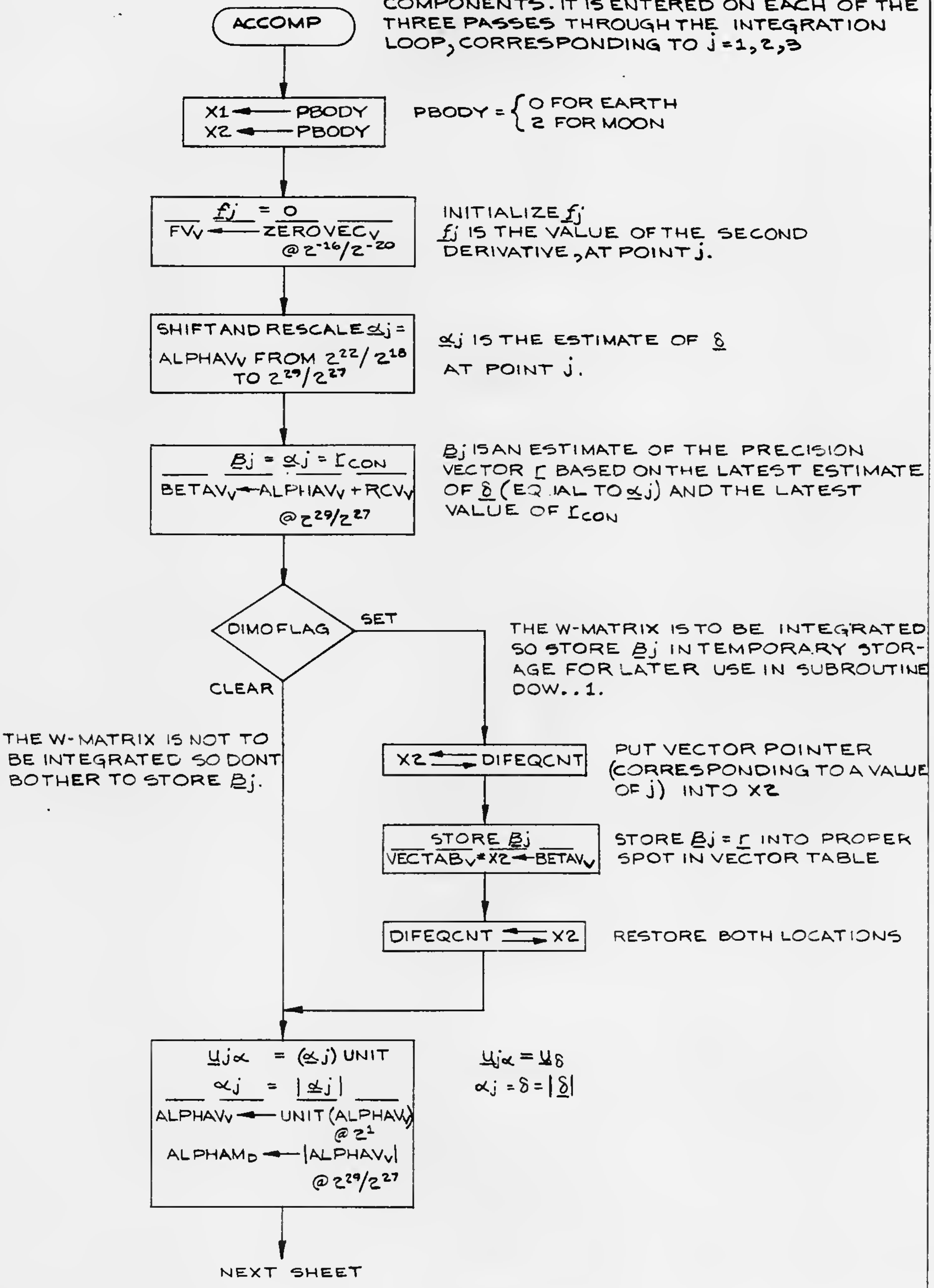
ACCOMP COMPUTES THE ACCELERATION COMPONENTS. IT IS ENTERED ON EACH OF THE THREE PASSES THROUGH THE INTEGRATION LOOP, CORRESPONDING TO $j = 1, 2, 3$



PBODY = { 0 FOR EARTH / 2 FOR MOON

INITIALIZE $\underline{f}_j$

$\underline{f}_j$ IS THE VALUE OF THE SECOND DERIVATIVE, AT POINT j.

$\underline{\alpha}_j$ IS THE ESTIMATE OF $\underline{\delta}$ AT POINT j.

$\underline{\beta}_j$ IS AN ESTIMATE OF THE PRECISION VECTOR $\underline{r}$ BASED ON THE LATEST ESTIMATE OF $\underline{\delta}$ (EQUAL TO $\underline{\alpha}_j$) AND THE LATEST VALUE OF $\underline{r}_{CON}$

THE W-MATRIX IS TO BE INTEGRATED SO STORE $\underline{\beta}_j$ IN TEMPORARY STORAGE FOR LATER USE IN SUBROUTINE DOW..1.

THE W-MATRIX IS NOT TO BE INTEGRATED SO DONT BOTHER TO STORE $\underline{\beta}_j$.

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

STORE $\underline{\beta}_j = \underline{r}$ INTO PROPER SPOT IN VECTOR TABLE

RESTORE BOTH LOCATIONS

$\underline{u}_{j\alpha} = \underline{u}_{\delta}$

$\alpha_j = \delta = |\underline{\delta}|$

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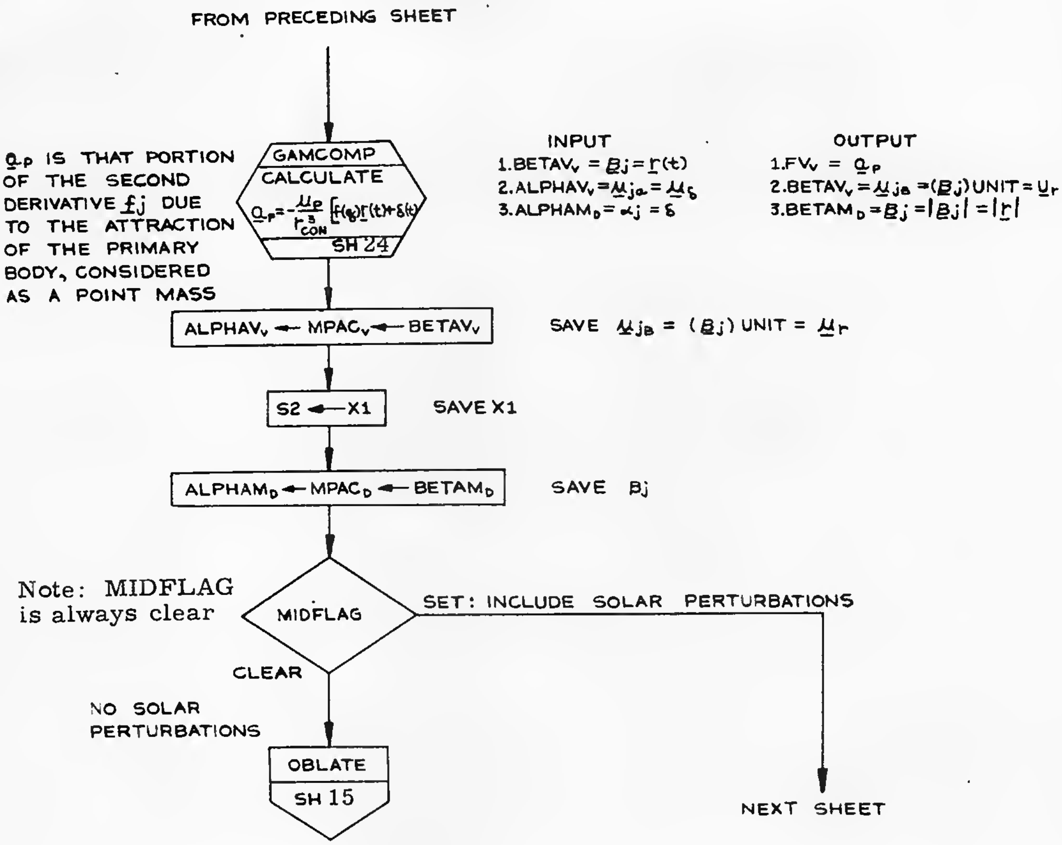

$\underline{a}_P$ IS THAT PORTION OF THE SECOND DERIVATIVE $\underline{f}$j DUE TO THE ATTRACTION OF THE PRIMARY BODY, CONSIDERED AS A POINT MASS

INPUT
1.BETAV$_V$ = $\underline{B}$j = $\underline{r}$(t)
2.ALPHAV$_V$ = $\underline{u}_{ja}$ = $\underline{u}_\delta$
3.ALPHAM$_D$ = αj = δ

OUTPUT
1.FV$_V$ = $\underline{a}_P$
2.BETAV$_V$ = $\underline{u}_{jB}$ = ($\underline{B}$j) UNIT = $\underline{u}_r$
3.BETAM$_D$ = $\underline{B}$j = |$\underline{B}$j| = |$\underline{r}$|

Note: MIDFLAG is always clear

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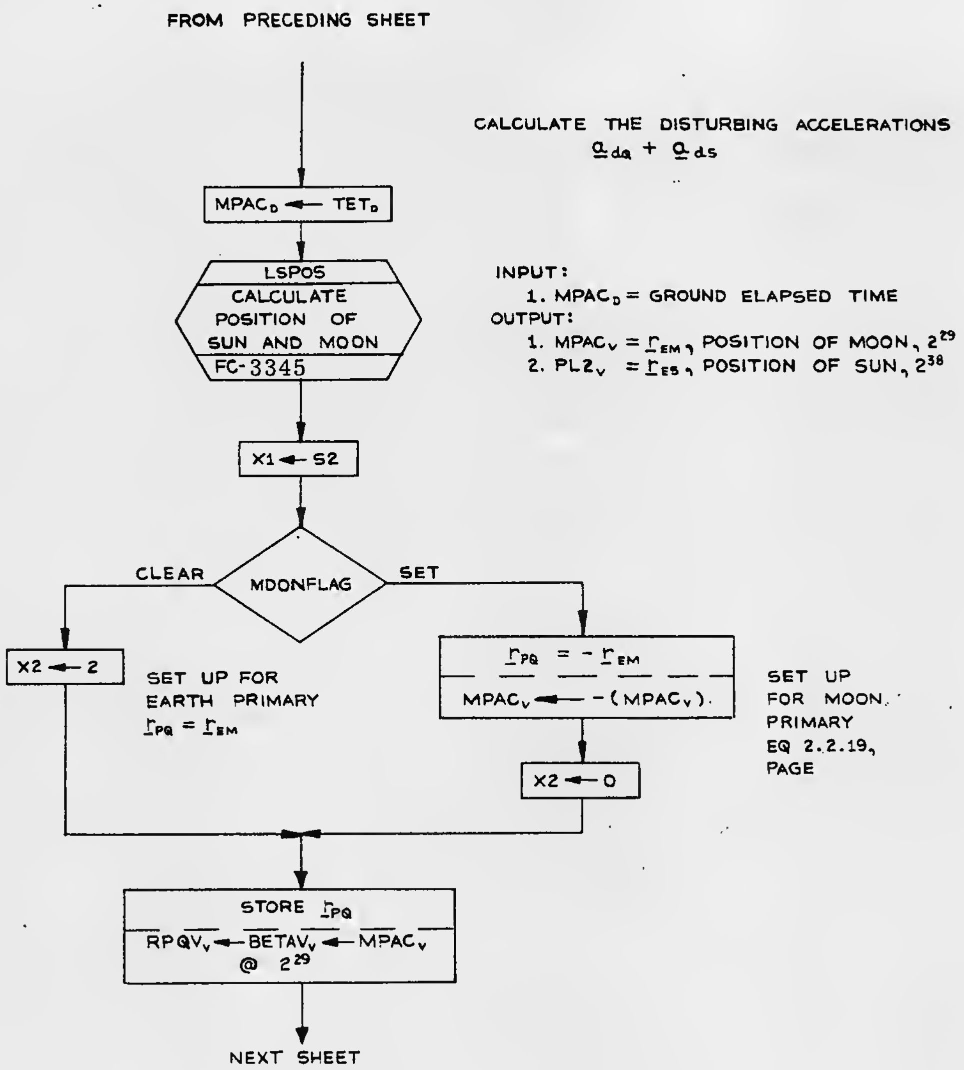

CALCULATE THE DISTURBING ACCELERATIONS
$\underline{a}_{dq} + \underline{a}_{ds}$

INPUT:
1. $MPAC_D$ = GROUND ELAPSED TIME
OUTPUT:
1. $MPAC_V = \underline{r}_{EM}$, POSITION OF MOON, 2^{29}
2. $PL2_V = \underline{r}_{ES}$, POSITION OF SUN, 2^{38}

SET UP FOR
EARTH PRIMARY
$\underline{r}_{PQ} = \underline{r}_{EM}$

SET UP
FOR MOON
PRIMARY
EQ 2.2.19,
PAGE

NEXT SHEET

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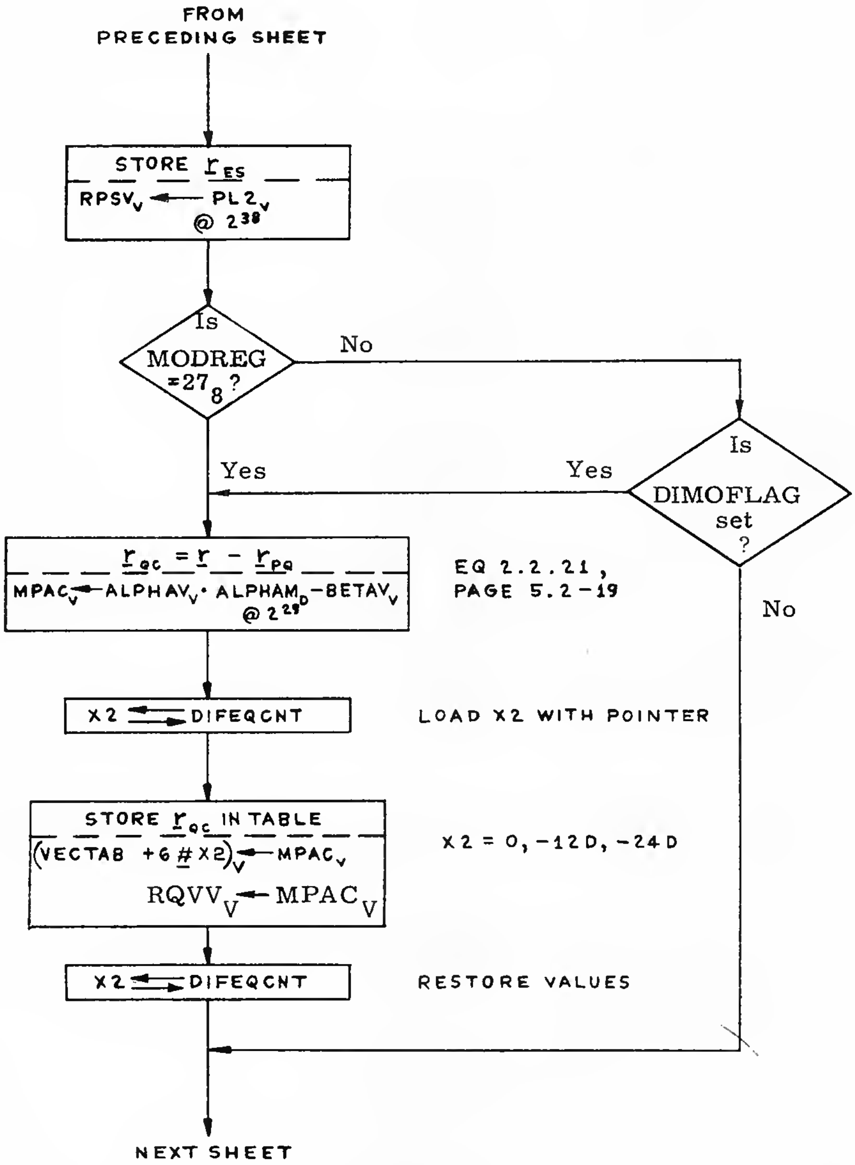

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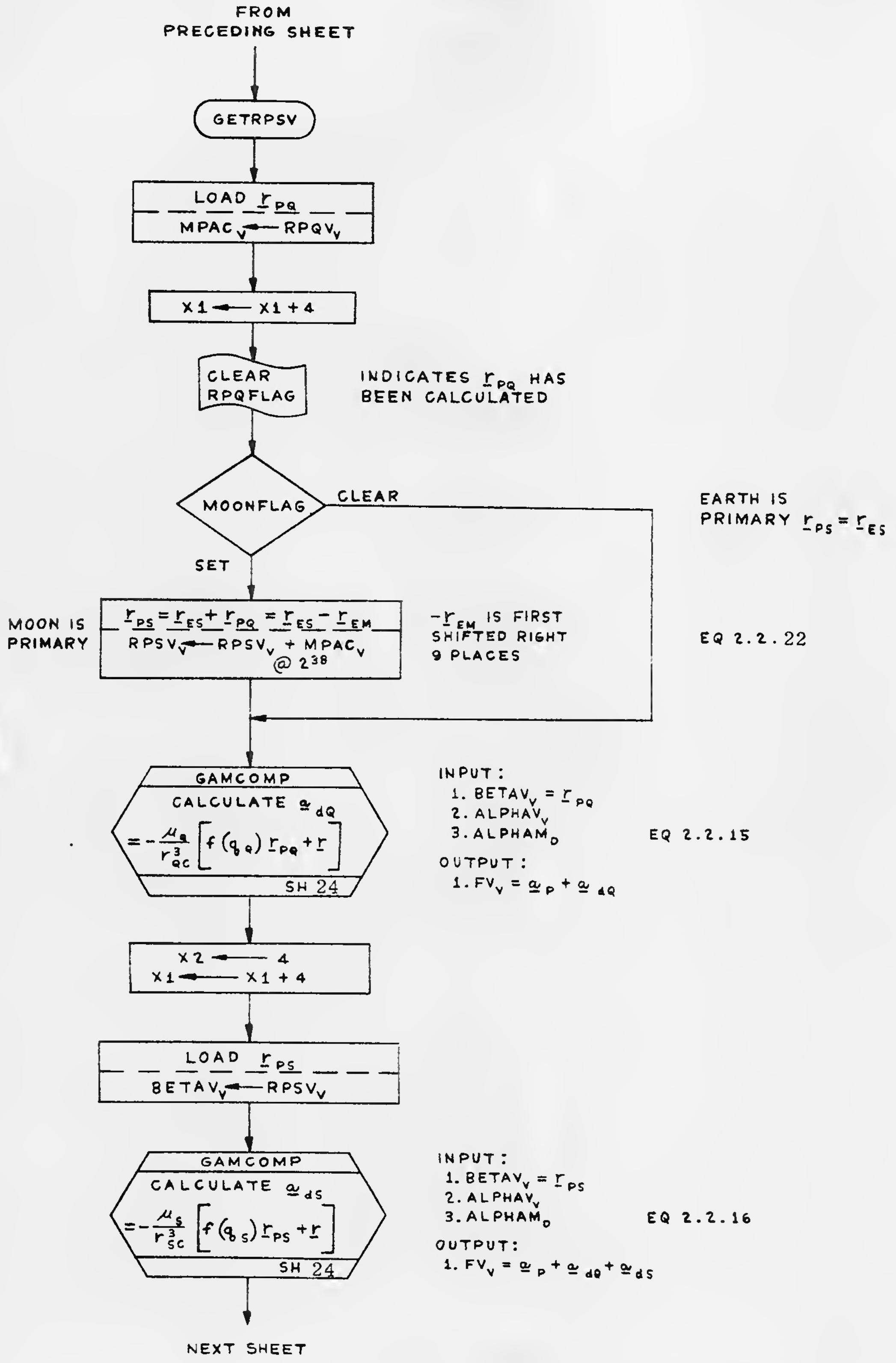

INDICATES $\underline{r}_{PQ}$ HAS BEEN CALCULATED

EARTH IS PRIMARY $\underline{r}_{PS} = \underline{r}_{ES}$

$-\underline{r}_{EM}$ IS FIRST SHIFTED RIGHT 9 PLACES

EQ 2.2.22

INPUT:
1. $BETAV_V = \underline{r}_{PQ}$
2. $ALPHAV_V$
3. $ALPHAM_D$

EQ 2.2.15

OUTPUT:
1. $FV_V = \underline{\alpha}_P + \underline{\alpha}_{dQ}$

INPUT:
1. $BETAV_V = \underline{r}_{PS}$
2. $ALPHAV_V$
3. $ALPHAM_D$

EQ 2.2.16

OUTPUT:
1. $FV_V = \underline{\alpha}_P + \underline{\alpha}_{dQ} + \underline{\alpha}_{dS}$

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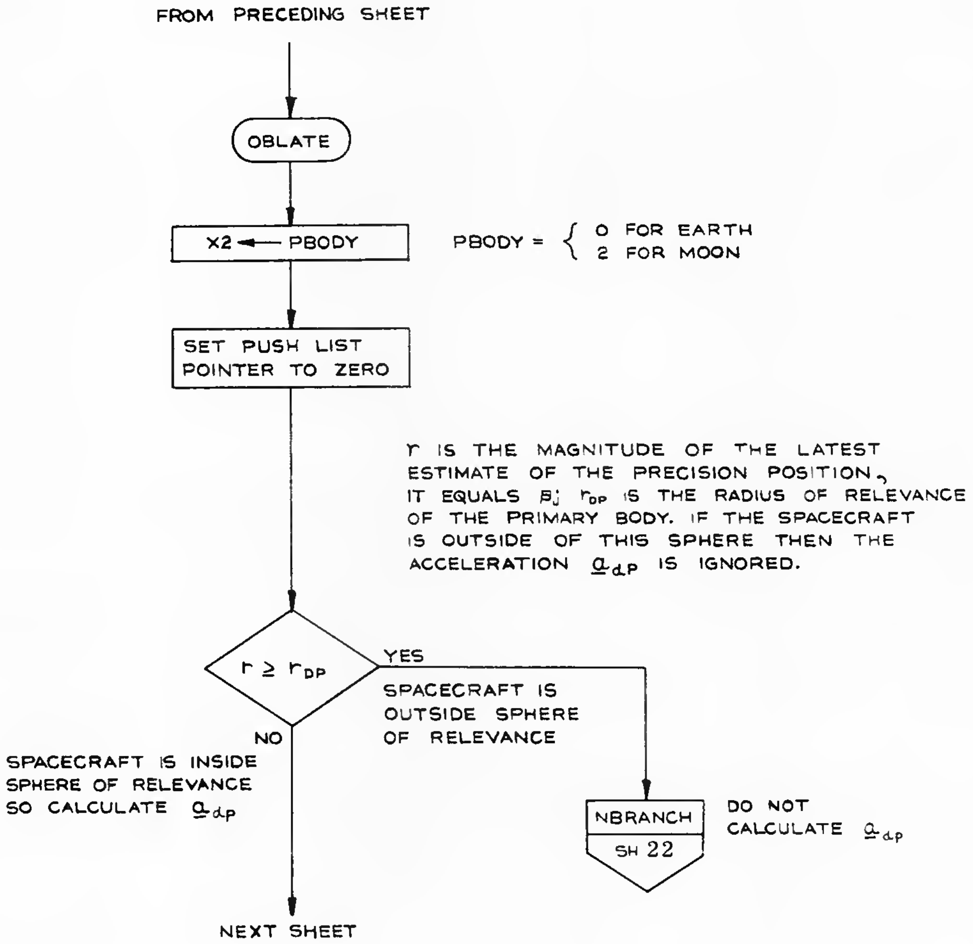

PBODY = { 0 FOR EARTH
2 FOR MOON

r IS THE MAGNITUDE OF THE LATEST ESTIMATE OF THE PRECISION POSITION, IT EQUALS B_j; r_{DP} IS THE RADIUS OF RELEVANCE OF THE PRIMARY BODY. IF THE SPACECRAFT IS OUTSIDE OF THIS SPHERE THEN THE ACCELERATION $\underline{a}_{dP}$ IS IGNORED.

SPACECRAFT IS OUTSIDE SPHERE OF RELEVANCE

SPACECRAFT IS INSIDE SPHERE OF RELEVANCE SO CALCULATE $\underline{a}_{dP}$

DO NOT CALCULATE $\underline{a}_{dP}$

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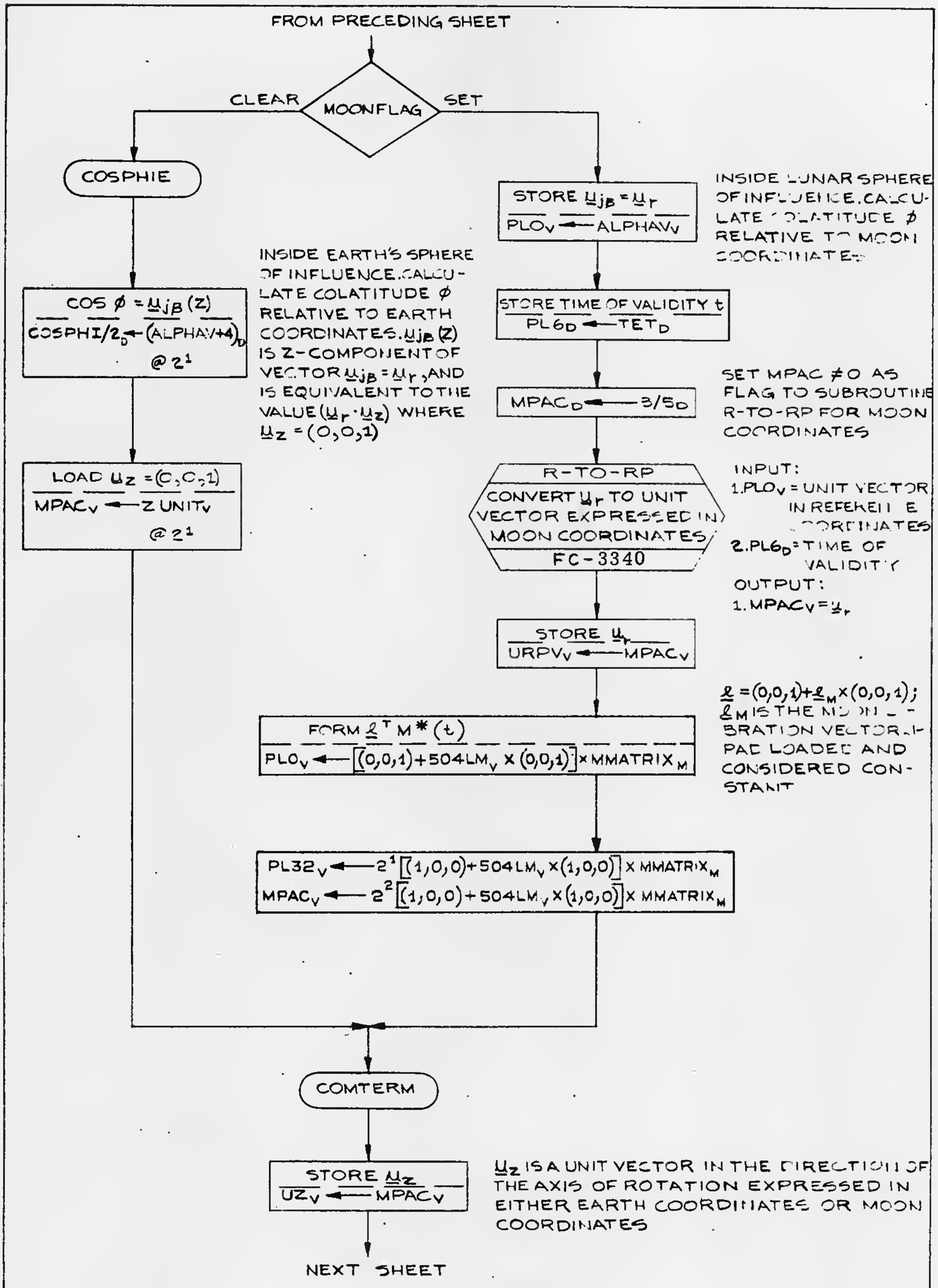

INSIDE EARTH'S SPHERE OF INFLUENCE. CALCULATE COLATITUDE ϕ RELATIVE TO EARTH COORDINATES. $\underline{u}_{jB}(Z)$ IS Z-COMPONENT OF VECTOR $\underline{u}_{jB} = \underline{u}_r$, AND IS EQUIVALENT TO THE VALUE $(\underline{u}_r \cdot \underline{u}_Z)$ WHERE $\underline{u}_Z = (0,0,1)$

INSIDE LUNAR SPHERE OF INFLUENCE. CALCULATE COLATITUDE ϕ RELATIVE TO MOON COORDINATES

SET MPAC ≠ 0 AS FLAG TO SUBROUTINE R-TO-RP FOR MOON COORDINATES

INPUT:

1. PLO_V = UNIT VECTOR IN REFERENCE COORDINATES
2. PL6_D = TIME OF VALIDITY

OUTPUT:

1. $\text{MPAC}_V = \underline{u}_r$

$\underline{\ell} = (0,0,1) + \underline{\ell}_M \times (0,0,1)$; $\underline{\ell}_M$ IS THE MOON LIBRATION VECTOR, PAD LOADED AND CONSIDERED CONSTANT

$\underline{u}_Z$ IS A UNIT VECTOR IN THE DIRECTION OF THE AXIS OF ROTATION EXPRESSED IN EITHER EARTH COORDINATES OR MOON COORDINATES

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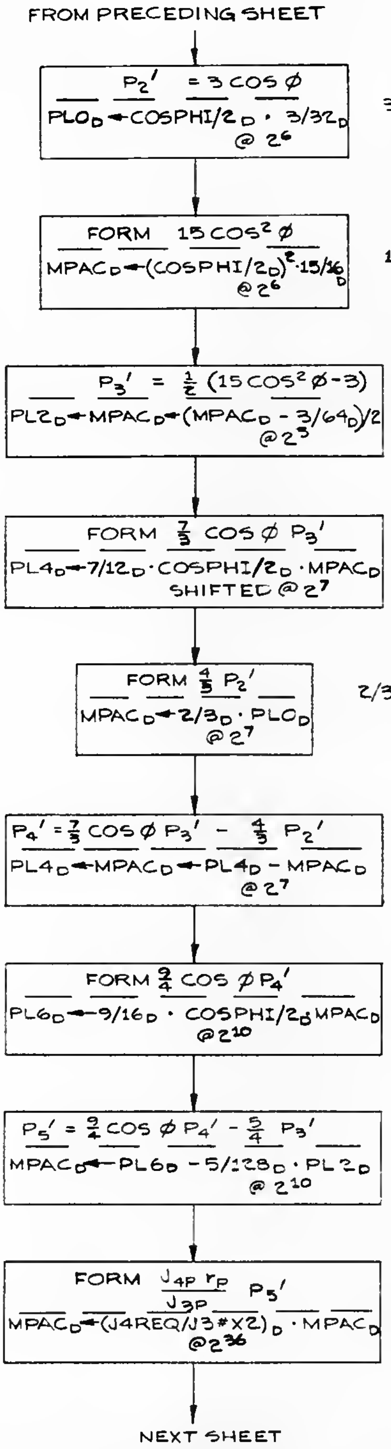

$3/32_D = 3.0 @ 2^5$

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

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

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

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

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

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

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

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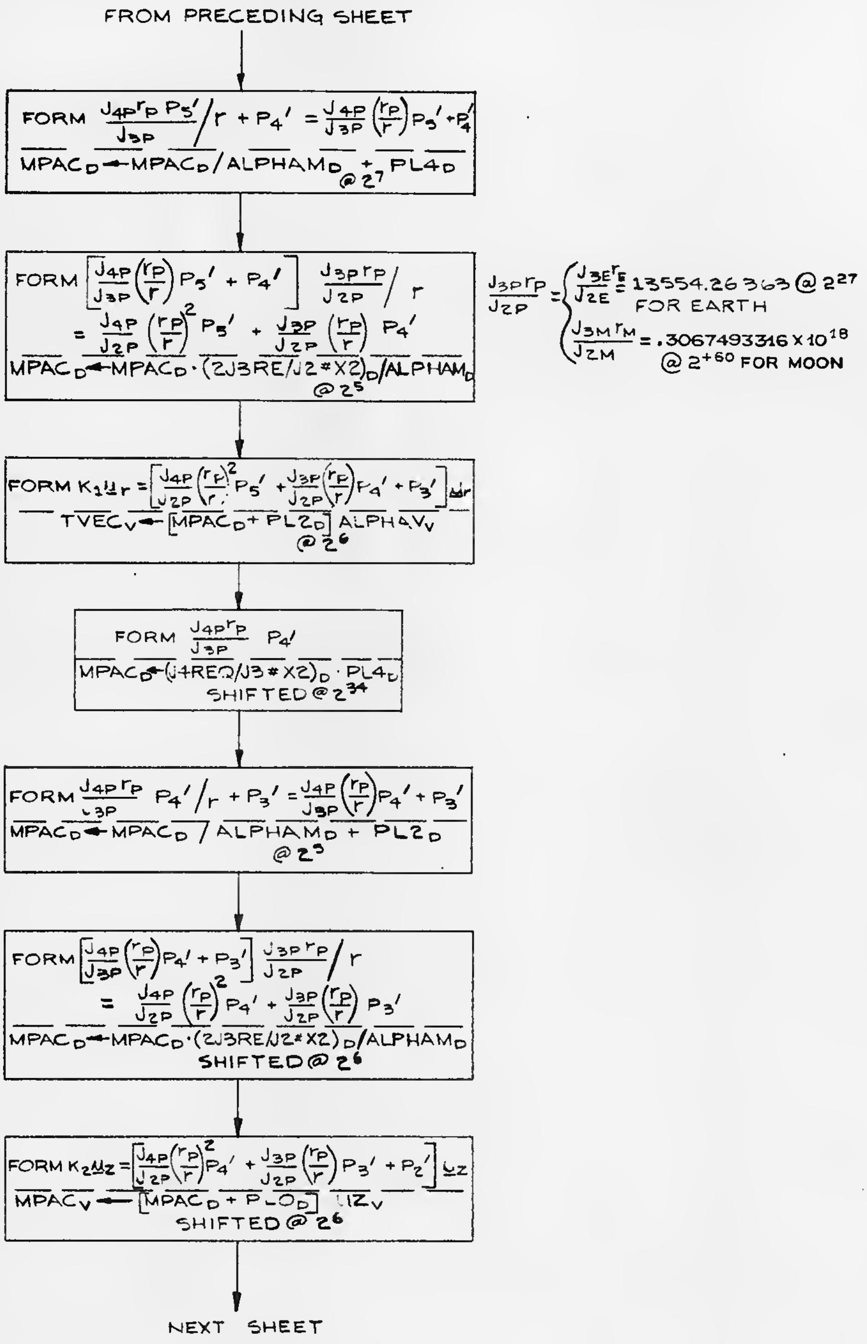

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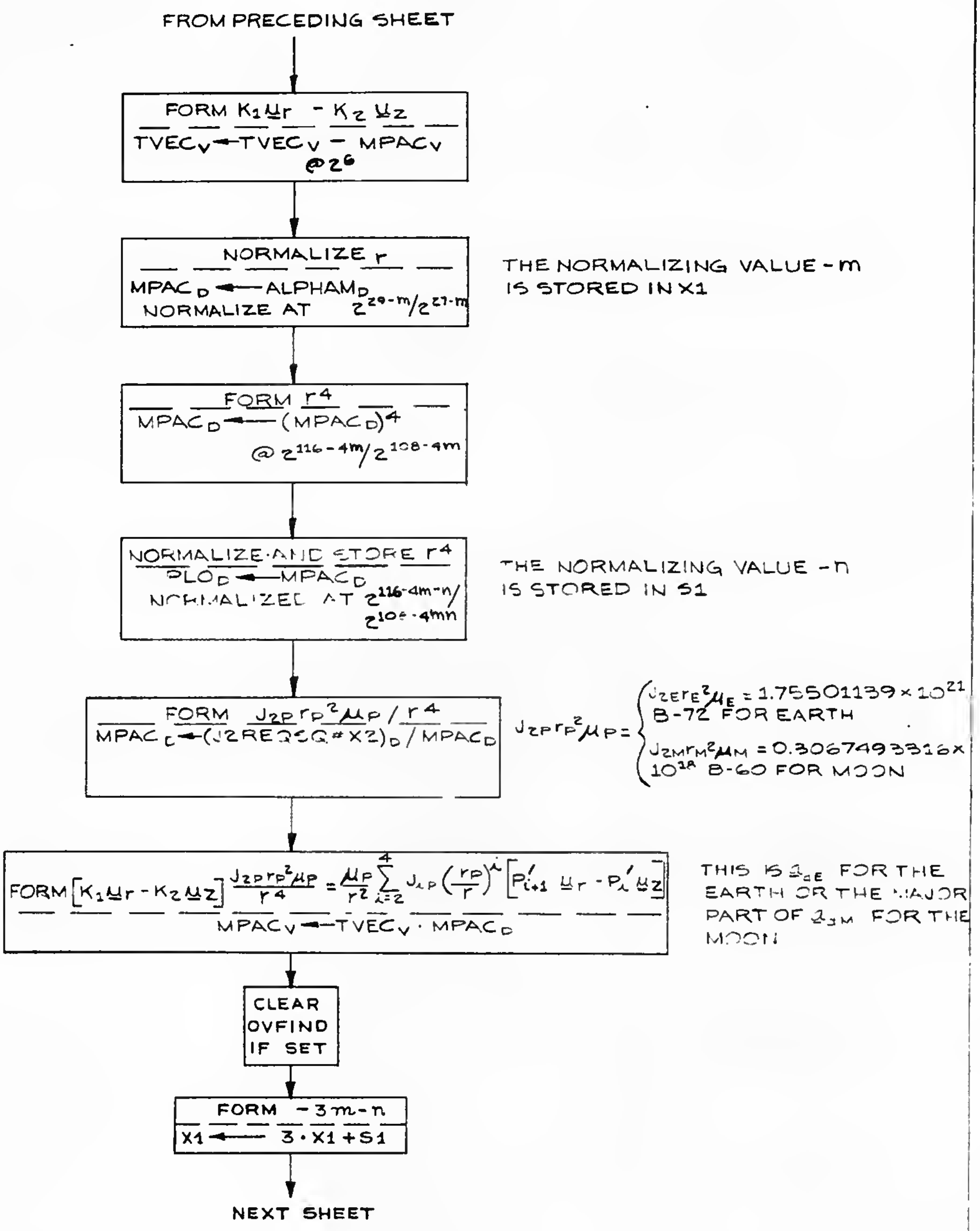

$$\left\{K_1\underline{u}_r - K_2\underline{u}_z\right\}\frac{J_{2P}r_P{}^2\mu_P}{r^4}$$

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

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

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

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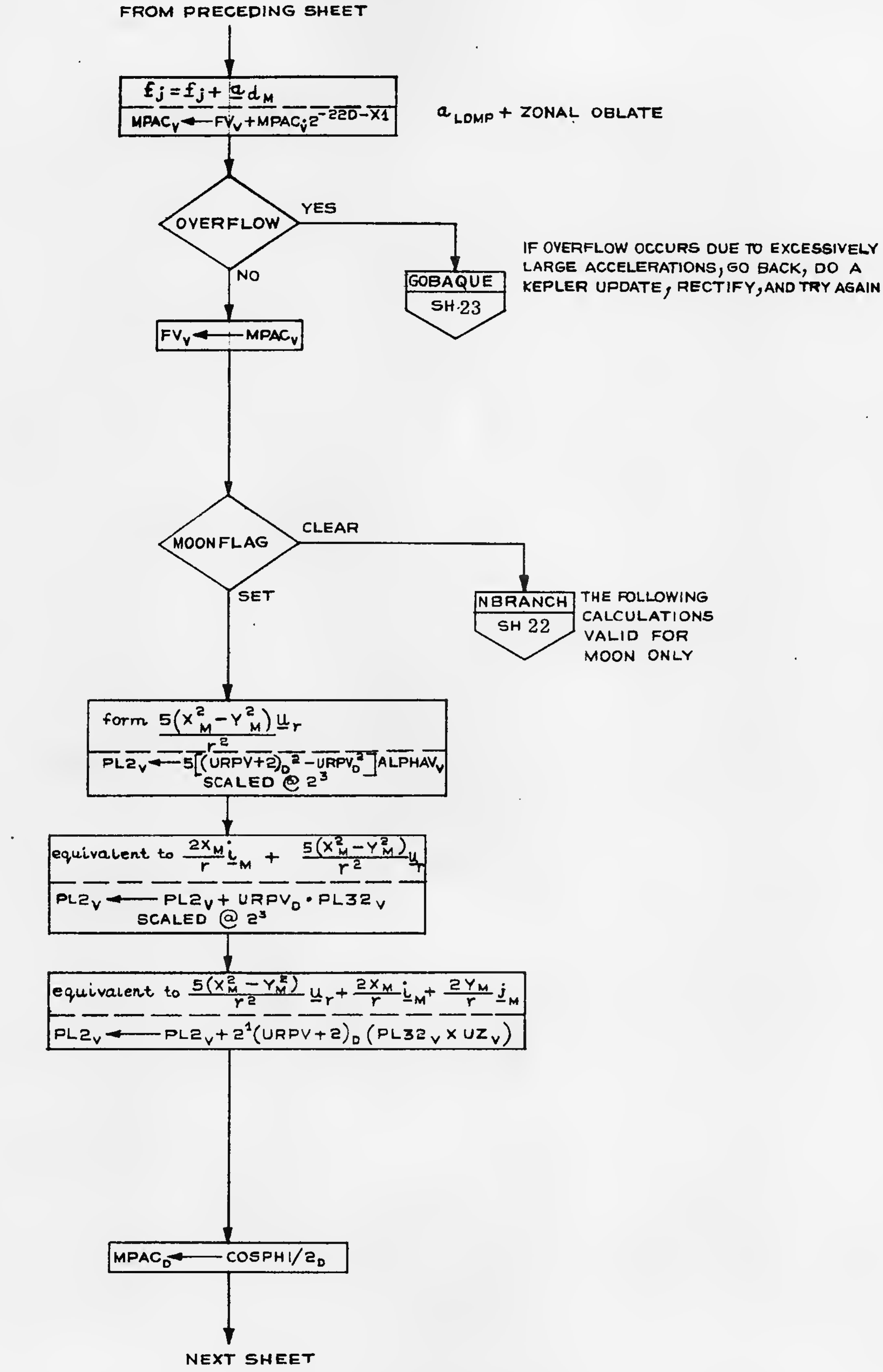

a_{LDMP} + ZONAL OBLATE

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

THE FOLLOWING CALCULATIONS VALID FOR MOON ONLY

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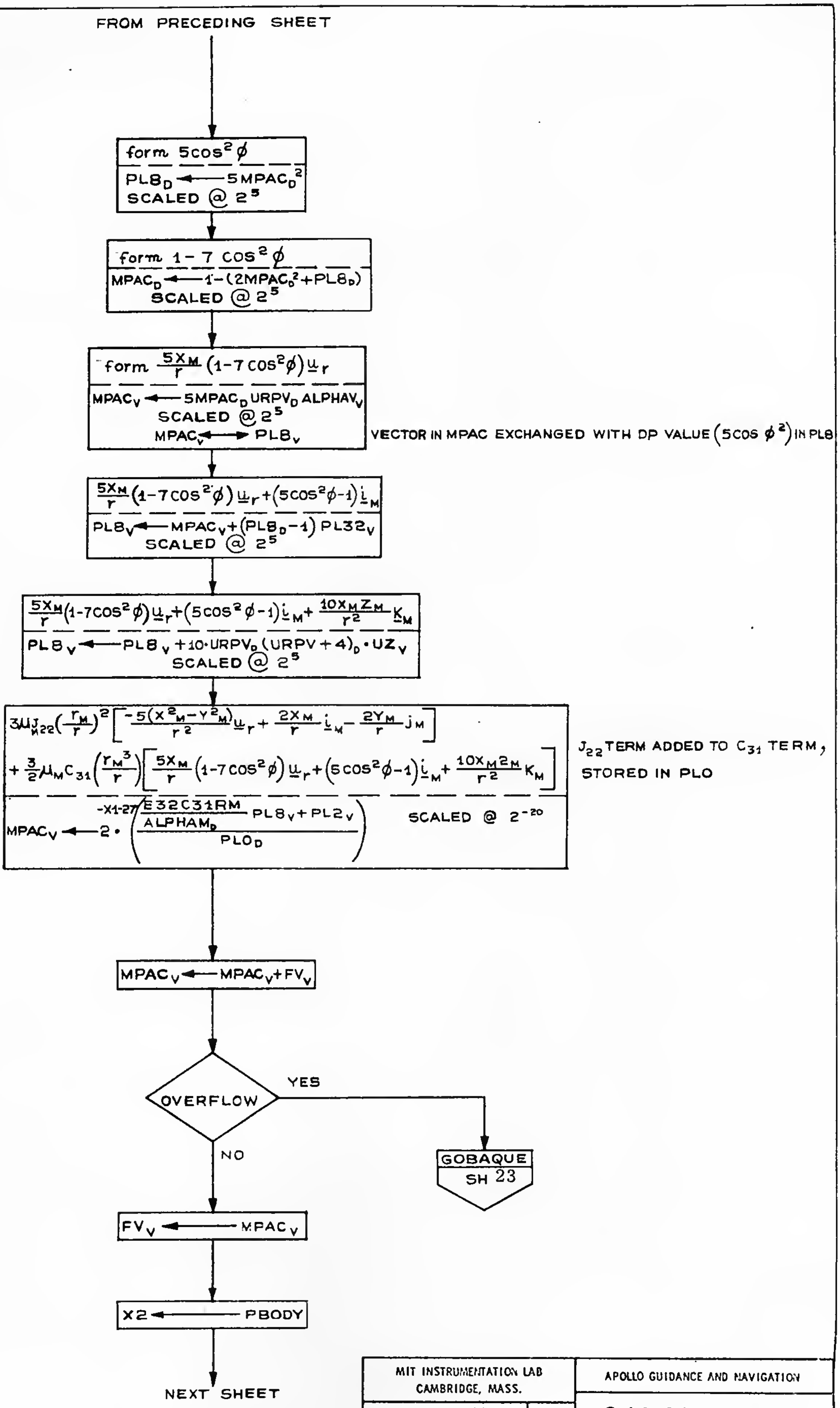

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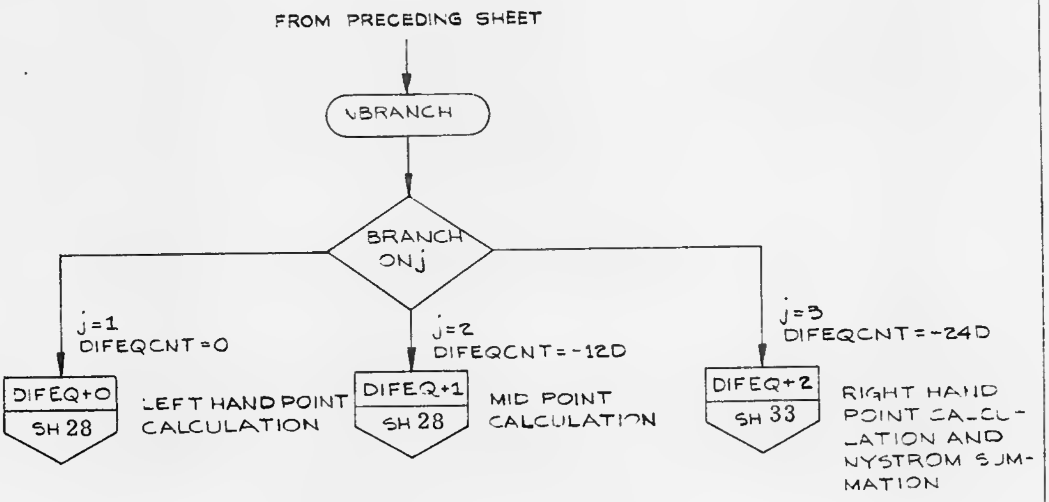

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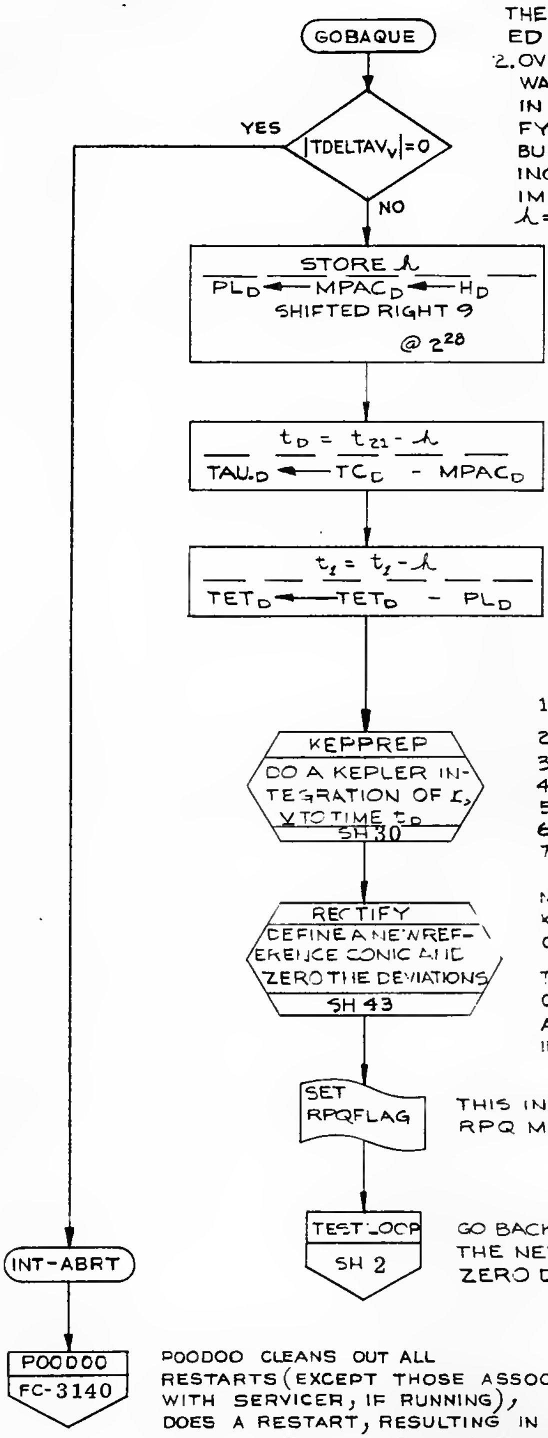

GOBAQUE IS ENTERED IF EITHER:

1. OVERFLOW OCCURED IN GAMCOMP WHEN THE SECOND DERIVATIVE INCREMENT WAS ADDED TO $\underline{f}_j$, OR,
2. OVERFLOW OCCURED IN OBLATE WHEN $\underline{a}_{dp}$ WAS ADDED TO $\underline{a}_p$.

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

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

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

t_D = DESIRED TRANSFER TIME. IT MUST BE REDUCED BY h TO MAKE TIME CORRESPOND TO THE PREVIOUS VALUE OF j SINCE RESULTS WERE VALID FOR THAT VALUE OF j (I.E. THERE WAS NO OVERFLOW)

t_1 IS REDUCED BY h TO MAKE IT AGREE WITH TIME OF VALIDITY OF RCV_V, VCV_V

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

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

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

THIS INDICATES THE VECTOR RPQ MUST BE CALCULATED

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

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

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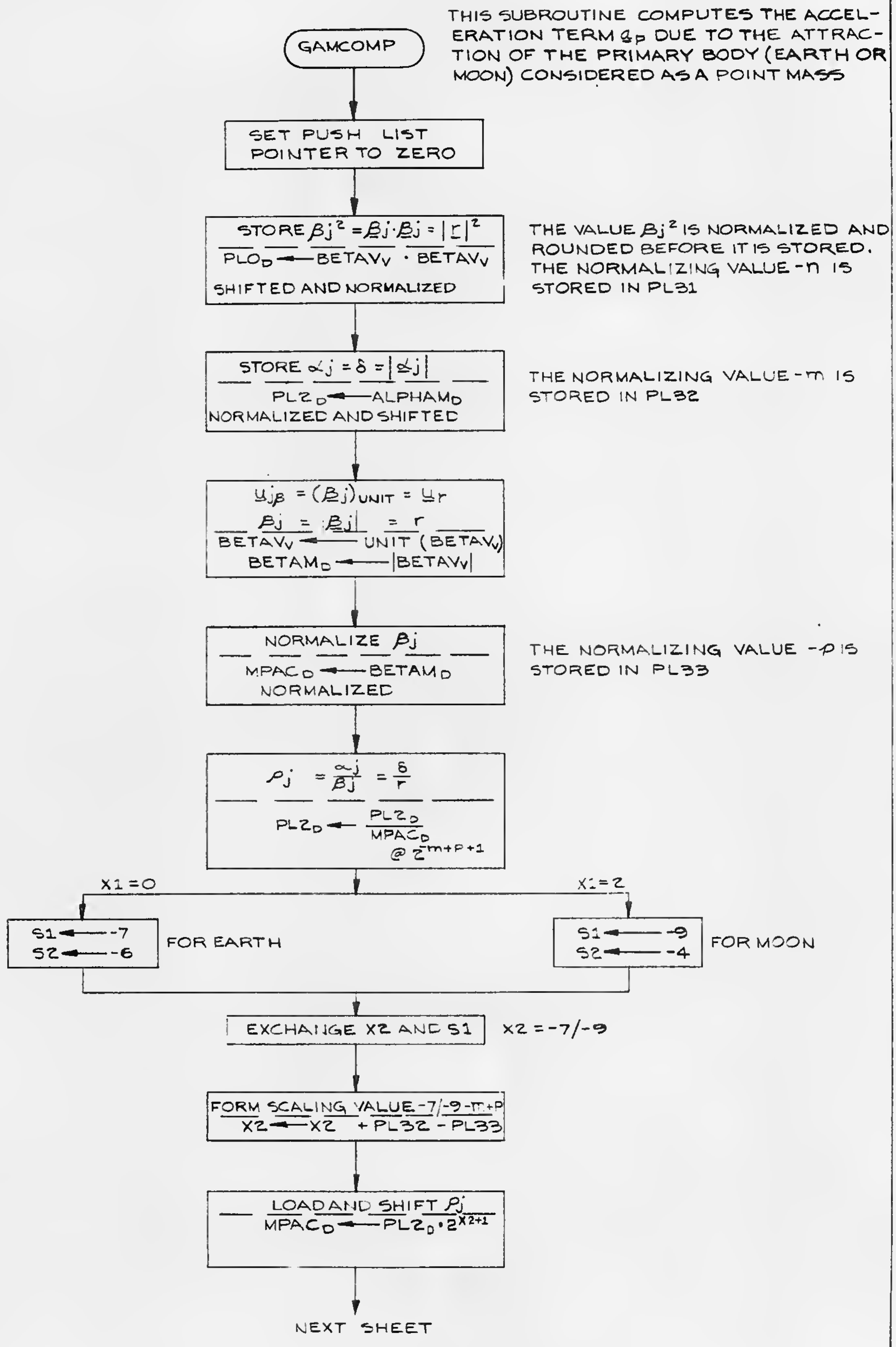

THIS SUBROUTINE COMPUTES THE ACCELERATION TERM g_P DUE TO THE ATTRACTION OF THE PRIMARY BODY (EARTH OR MOON) CONSIDERED AS A POINT MASS

THE VALUE βj^2 IS NORMALIZED AND ROUNDED BEFORE IT IS STORED. THE NORMALIZING VALUE $-n$ IS STORED IN PL31

THE NORMALIZING VALUE $-m$ IS STORED IN PL32

THE NORMALIZING VALUE $-p$ IS STORED IN PL33

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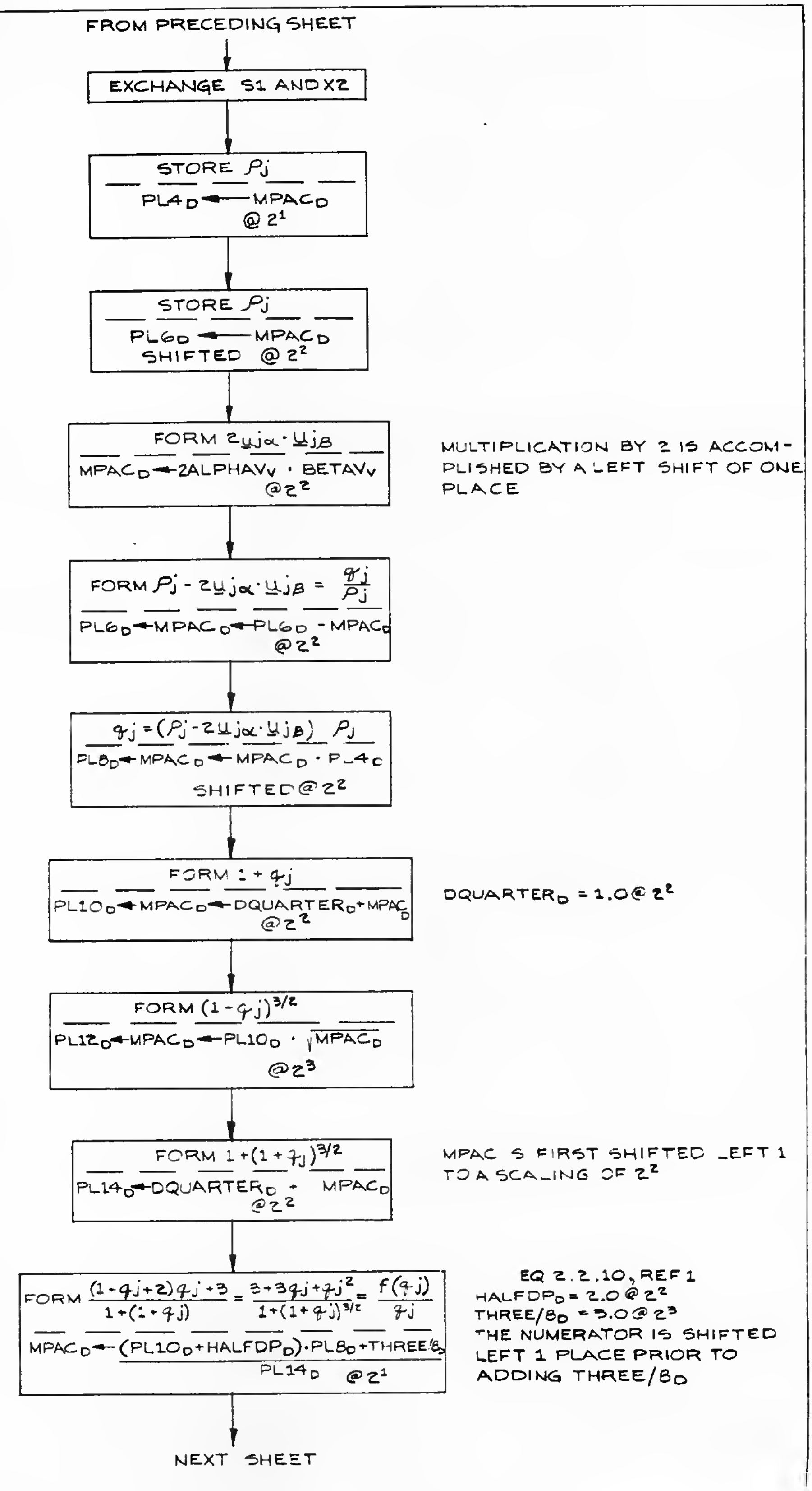

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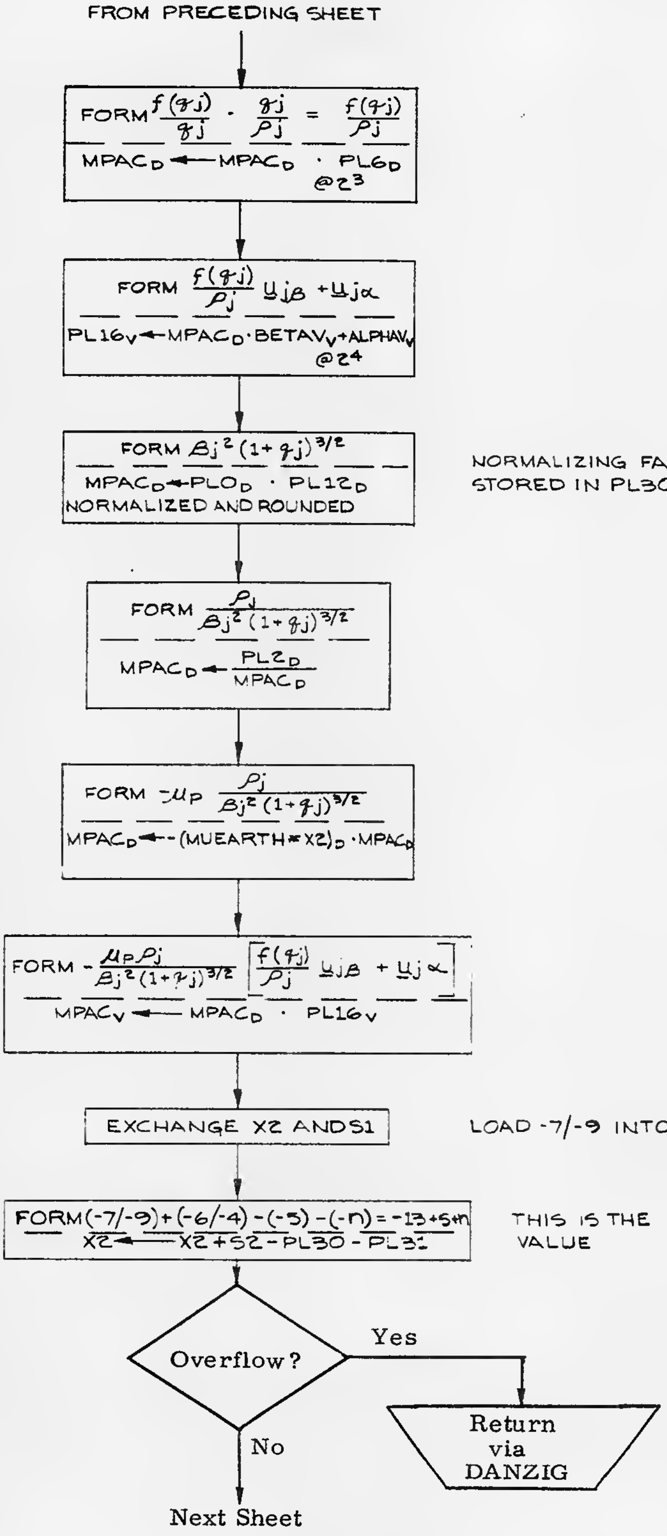

NORMALIZING FACTOR -5 IS STORED IN PL30

LOAD -7/-9 INTO X2

THIS IS THE UNNORMALIZING VALUE

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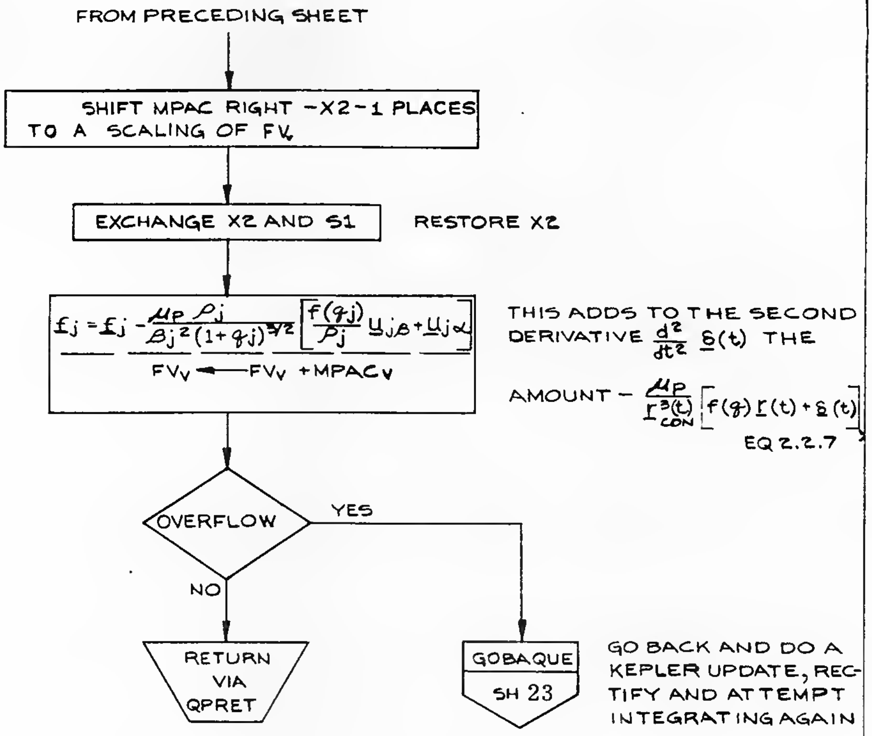

THE DIFFERENTIAL EQUATION FOR THE ENCKE VARIABLE $\underline{\delta}(t)$ CAN BE WRITTEN AS:

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

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

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

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

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

WHERE r^3_{CON} HAS BEEN REPLACED BY $\beta_j^3\ (1+q_j)^{3/2}$. CONTINUING,

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

THE VARIABLE q IS EVALUATED AS,

$$\begin{aligned}q_j &= \frac{(\underline{\alpha}_j-2\underline{\beta}_j)\cdot\underline{\alpha}_j}{\beta_j^2} = \frac{(\alpha_j\underline{u}_{j\alpha}-2\beta_j\underline{u}_{j\beta})\cdot\alpha_j\underline{u}_{j\alpha}}{\beta_j^2}\\ &= \left[\left(\frac{\alpha_j}{\beta_j}\right)\underline{u}_{j\alpha}-2\underline{u}_{j\beta}\right]\left(\frac{\alpha_j}{\beta_j}\right)\underline{u}_{j\alpha} = \rho_j\left[\rho_j-2\underline{u}_{j\alpha}\cdot\underline{u}_{j\beta}\right]\end{aligned}$$

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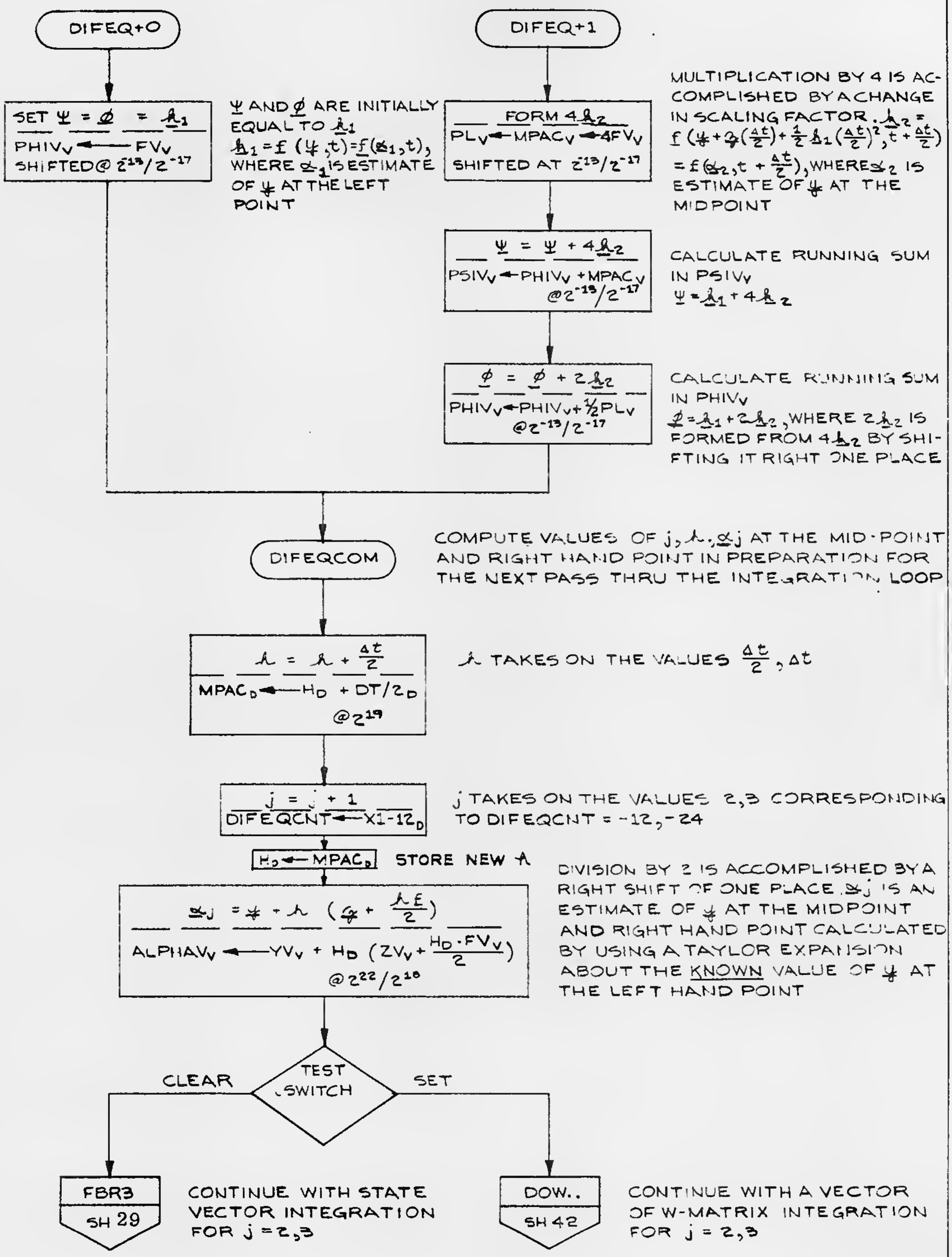
EVALUATE THE RUNNING FUNCTIONS Ψ AND ϕ AT THE LEFT HAND POINT, FOR $j = 1$

EVALUATE THE RUNNING FUNCTIONS Ψ AND ϕ AT THE MID-POINT, FOR $j = 2$



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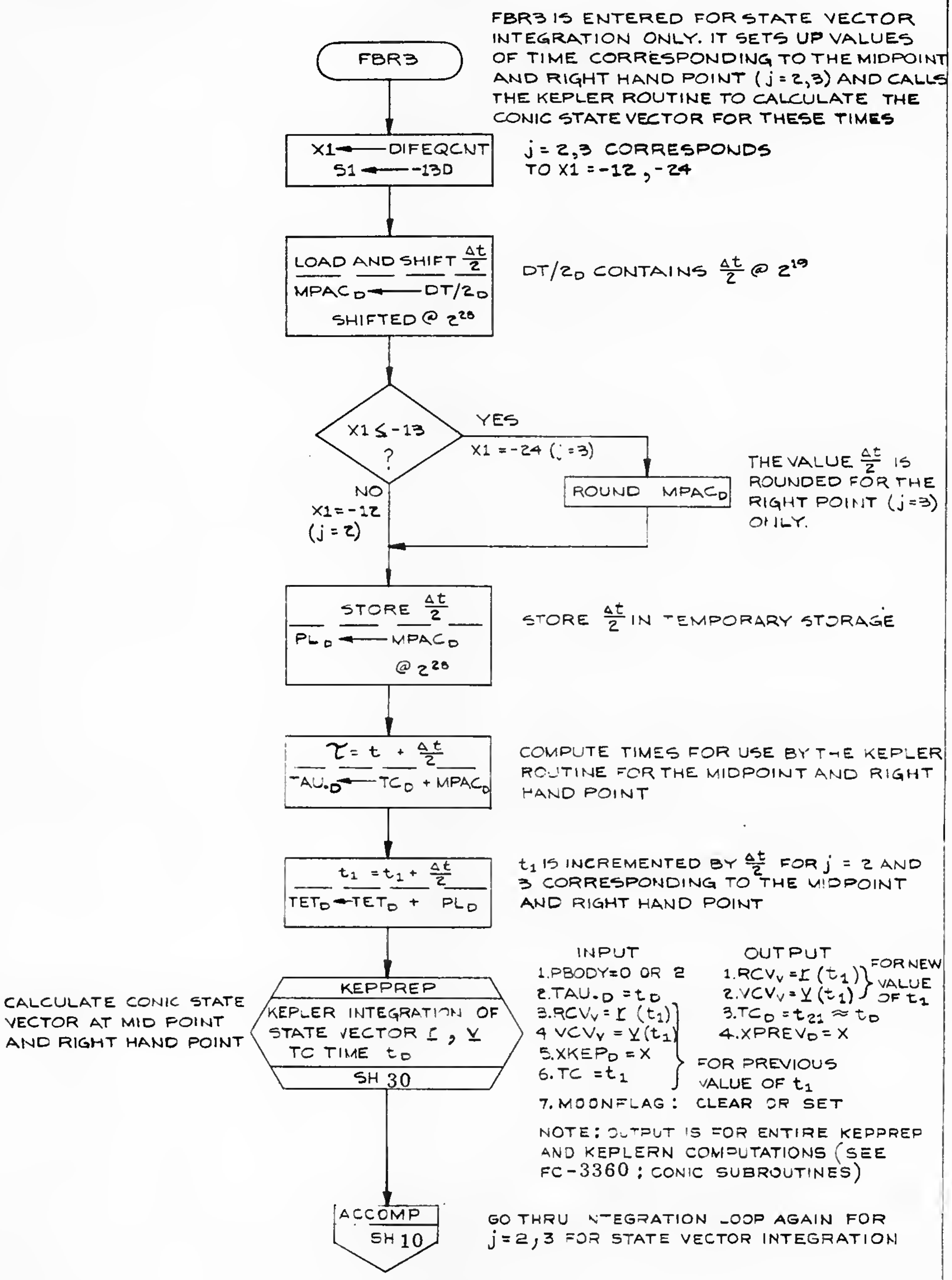

FBR3 IS ENTERED FOR STATE VECTOR INTEGRATION ONLY. IT SETS UP VALUES OF TIME CORRESPONDING TO THE MIDPOINT AND RIGHT HAND POINT (j = 2,3) AND CALLS THE KEPLER ROUTINE TO CALCULATE THE CONIC STATE VECTOR FOR THESE TIMES

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

DT/2$_D$ CONTAINS $\frac{\Delta t}{2}$ @ 2^{19}

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

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

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

t_1 IS INCREMENTED BY $\frac{\Delta t}{2}$ FOR j = 2 AND 3 CORRESPONDING TO THE MIDPOINT AND RIGHT HAND POINT

CALCULATE CONIC STATE VECTOR AT MID POINT AND RIGHT HAND POINT

INPUT
1. PBODY = 0 OR 2
2. TAU.$_D$ = t_D
3. RCV$_V$ = $\underline{r}$ (t_1)
4 VCV$_V$ = $\underline{v}(t_1)$
5. XKEP$_D$ = X
6. TC = t_1
FOR PREVIOUS VALUE OF t_1
7. MOONFLAG : CLEAR OR SET

OUTPUT
1. RCV$_V$ = $\underline{r}$ (t_1)
2. VCV$_V$ = $\underline{v}$ (t_1)
FOR NEW VALUE OF t_1
3. TC$_D$ = $t_{21} \approx t_D$
4. XPREV$_D$ = X

NOTE: OUTPUT IS FOR ENTIRE KEPPREP AND KEPLERN COMPUTATIONS (SEE FC-3360 ; CONIC SUBROUTINES)

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

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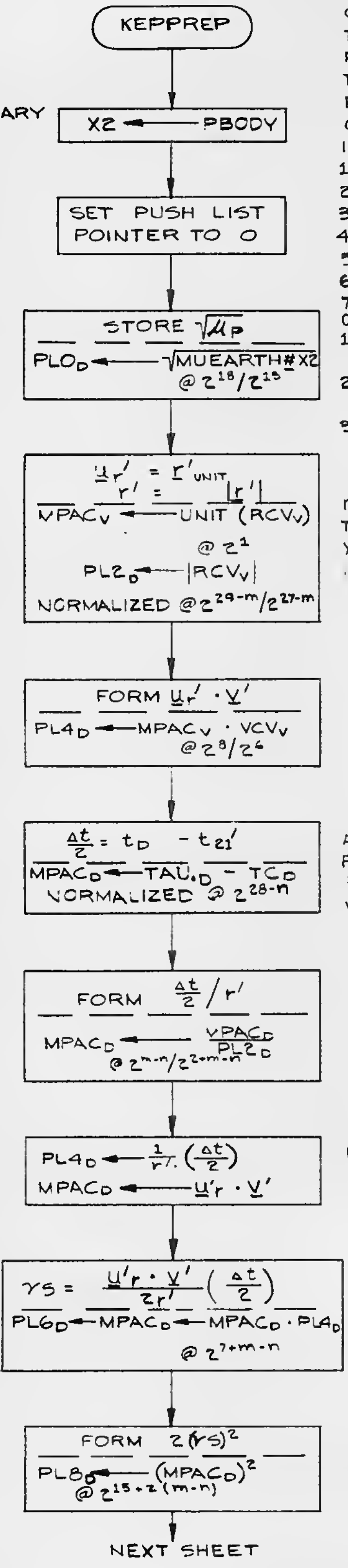
THIS SUBROUTINE COMPUTES AN ESTIMATE OF THE VARIABLE X AT TIME t_D BASED ON THE VALUES X', $\underline{r}'(t_{21}')$, $\underline{V}'(t_{21}')$ AT TIME t_{21}' FROM THE PREVIOUS COMPUTATION CYCLE. THIS INITIAL ESTIMATE OF X IS USED AS INPUT TO KEPLER TO SPEED UP CONVERGENCE.

INPUT:

1. PBODY = 0 FOR EARTH PRIMARY, 2 FOR MOON
2. $RCV_V = \underline{r}' = \underline{r}_{CON}(\tau - \frac{\Delta t}{2})$ } THE STATE VECTOR CORRESPONDING TO PREVIOUS CYCLE
3. $VCV_V = \underline{V}' = \underline{V}_{CON}(\tau - \frac{\Delta t}{2})$ }
4. $XKEP_D = X' = X(\tau - \frac{\Delta t}{2})$
5. $TAU._D = t_D$, DESIRED TRANSFER TIME
6. $TC_D = t_{21}' = \tau - \frac{\Delta t}{2}$, PREVIOUS TRANSFER TIME
7. MOONFLAG: CLEAR FOR EARTH, SET FOR MOON

OUTPUT: (OUTPUT FOR KEPPREP ONLY)

1. $XKEPNEW = X_t$, FIRST ESTIMATE OF X CORRESPONDING TO THE TRANSFER TIME t_D
2. X1 = μ-TABLE POINTER, -2 FOR EARTH, -10D FOR MOON
3. PUSH LIST POINTER AT PL4



LOAD X2 WITH PRIMARY BODY INDICATOR

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

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

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

EXCHANGE MPAC AND PL4

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

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

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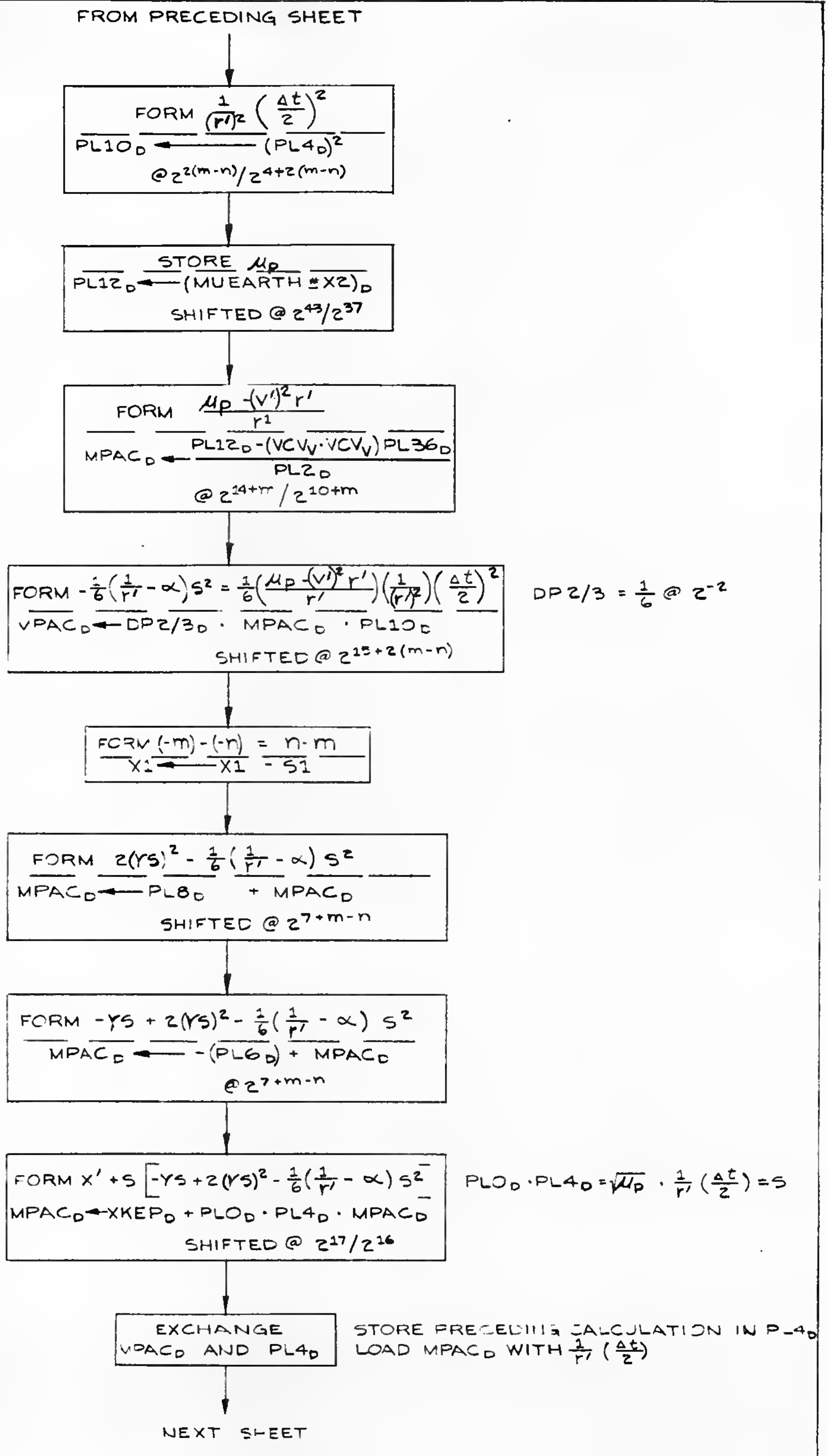

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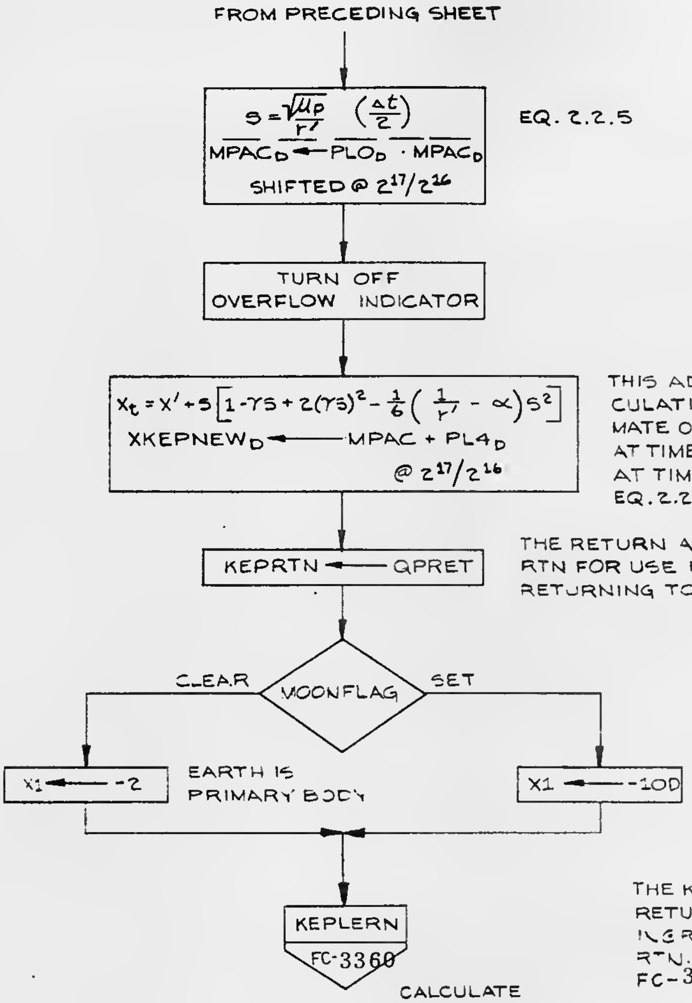


EQ. 2.2.5

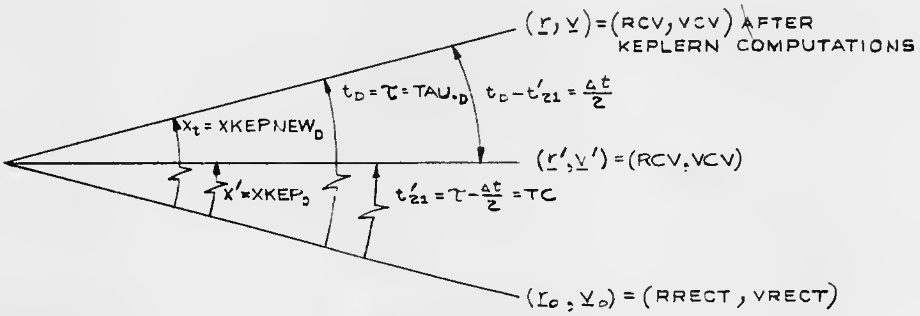
THIS ADDS S TO INTERMEDIATE CALCULATION IN $PL4_D$. X_t IS AN ESTIMATE OF THE CORRECT VALUE OF X AT TIME $t_D = \tau$ BASED ON $X', \underline{r}', \underline{v}'$ AT TIME $t'_{21} = \tau - \frac{\Delta t}{2}$
EQ. 2.2.4

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

MOON IS PRIMARY BODY

THE KEPLER ROUTINE KEPLERN RETURNS CONTROL TO THE CALLING ROUTINE DIRECTLY VIA KEPRTN. SEE CONIC SUBROUTINES, FC-3360

CALCULATE CONIC STATE VECTOR AT TIME $TAU._D = t_D = \tau$



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

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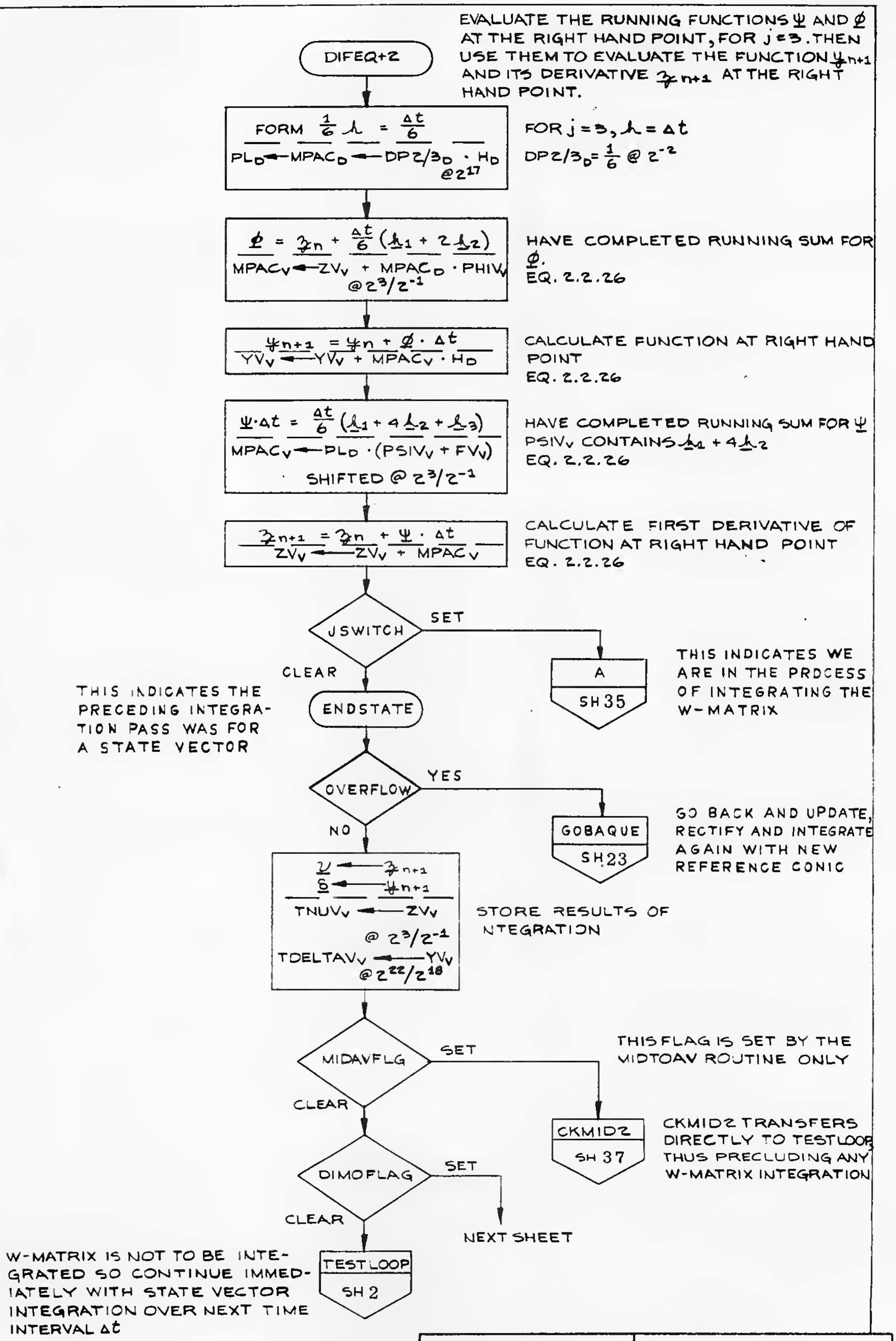

EVALUATE THE RUNNING FUNCTIONS Ψ AND Φ AT THE RIGHT HAND POINT, FOR j = 3. THEN USE THEM TO EVALUATE THE FUNCTION ψ_{n+1} AND ITS DERIVATIVE z_{n+1} AT THE RIGHT HAND POINT.

FOR j = 3, $h = \Delta t$
$DP2/3_D = \frac{1}{6}$ @ 2^{-2}

HAVE COMPLETED RUNNING SUM FOR Φ.
EQ. 2.2.26

CALCULATE FUNCTION AT RIGHT HAND POINT
EQ. 2.2.26

HAVE COMPLETED RUNNING SUM FOR Ψ
$PSIV_V$ CONTAINS $h_1 + 4h_2$
EQ. 2.2.26

CALCULATE FIRST DERIVATIVE OF FUNCTION AT RIGHT HAND POINT
EQ. 2.2.26

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

THIS INDICATES THE PRECEDING INTEGRATION PASS WAS FOR A STATE VECTOR

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

STORE RESULTS OF INTEGRATION

THIS FLAG IS SET BY THE MIDTOAV ROUTINE ONLY

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

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

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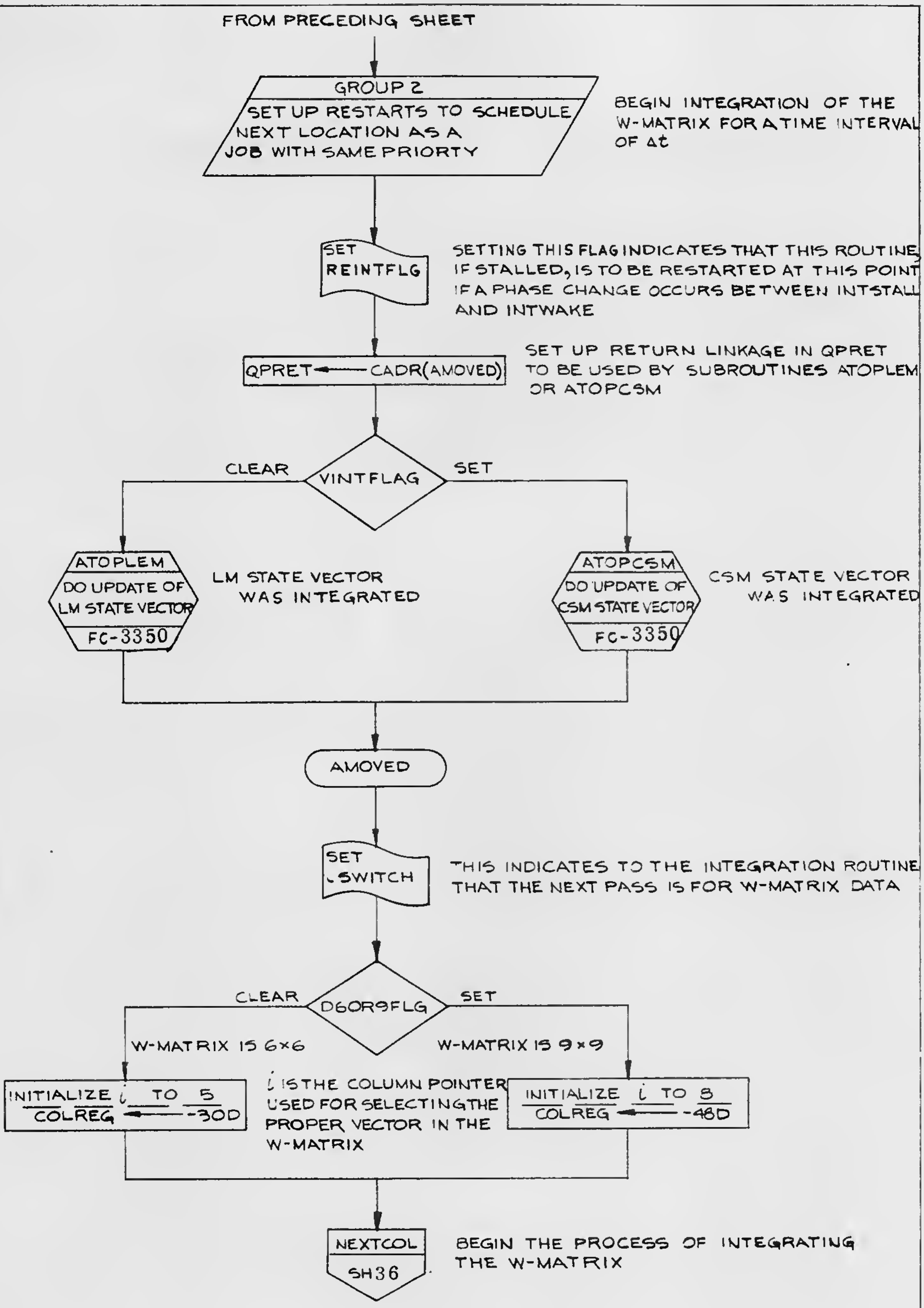

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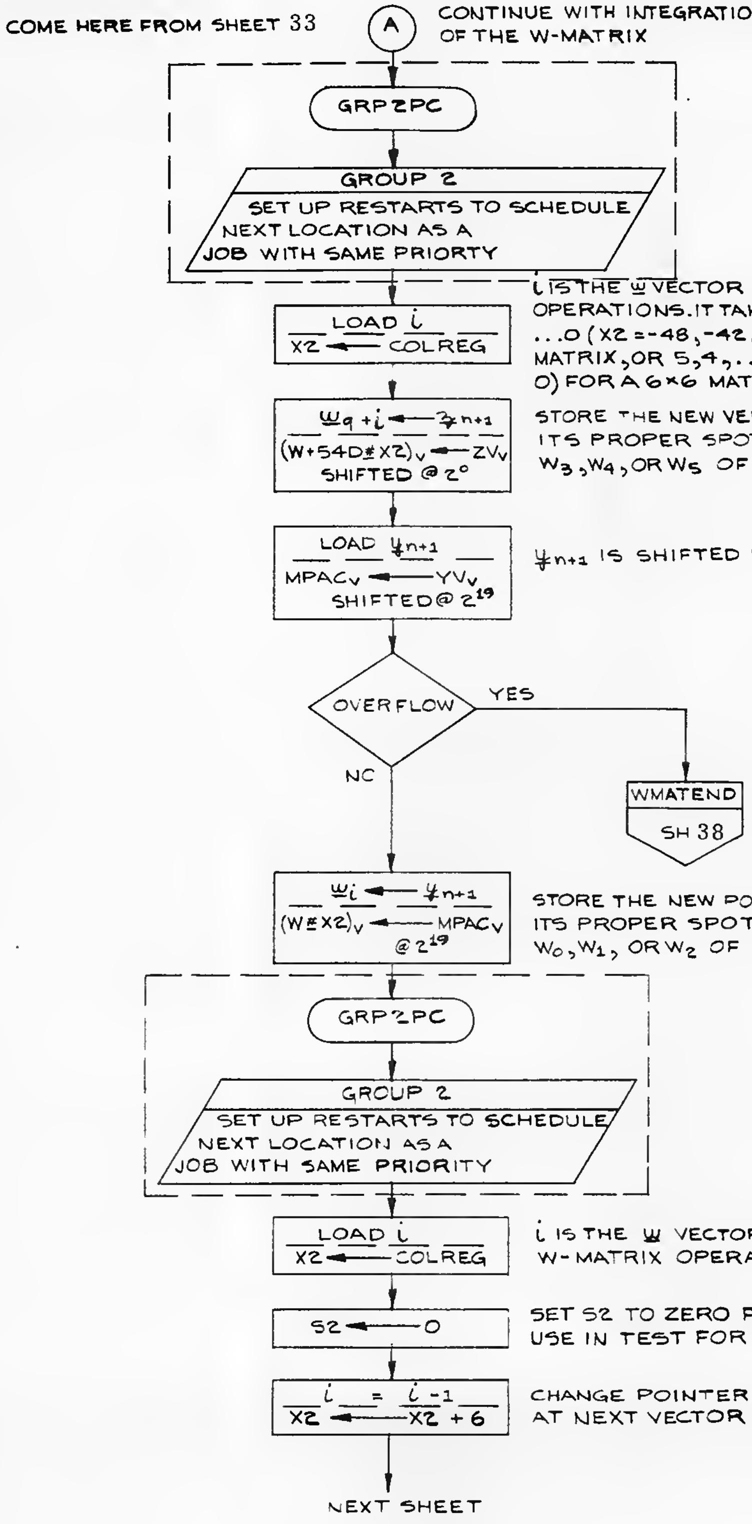

i IS THE $\underline{w}$ VECTOR POINTER FOR W-MATRIX OPERATIONS. IT TAKES ON THE VALUES 8, 7, ... 0 (X2 = -48, -42, ... -6, 0) FOR A 9×9 MATRIX, OR 5, 4, ... 0 (X2 = -30, -24, ... -6, 0) FOR A 6×6 MATRIX

STORE THE NEW VELOCITY VECTOR INTO ITS PROPER SPOT IN EITHER SUBMATRIX W_3, W_4, OR W_5 OF W-MATRIX

y_{n+1} IS SHIFTED FROM 2^{22} TO 2^{19}

IF OVERFLOW OCCURS AS A RESULT OF SHIFTING LEFT THEN AT LEAST ONE COMPONENT OF y_{n+1} IS $\geq 2^{19}$

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

i IS THE $\underline{w}$ VECTOR POINTER FOR W-MATRIX OPERATIONS

SET S2 TO ZERO FOR SEBSEQUENT USE IN TEST FOR $i = 0$

CHANGE POINTER TO POINT AT NEXT VECTOR $\underline{w}_{i-1}$

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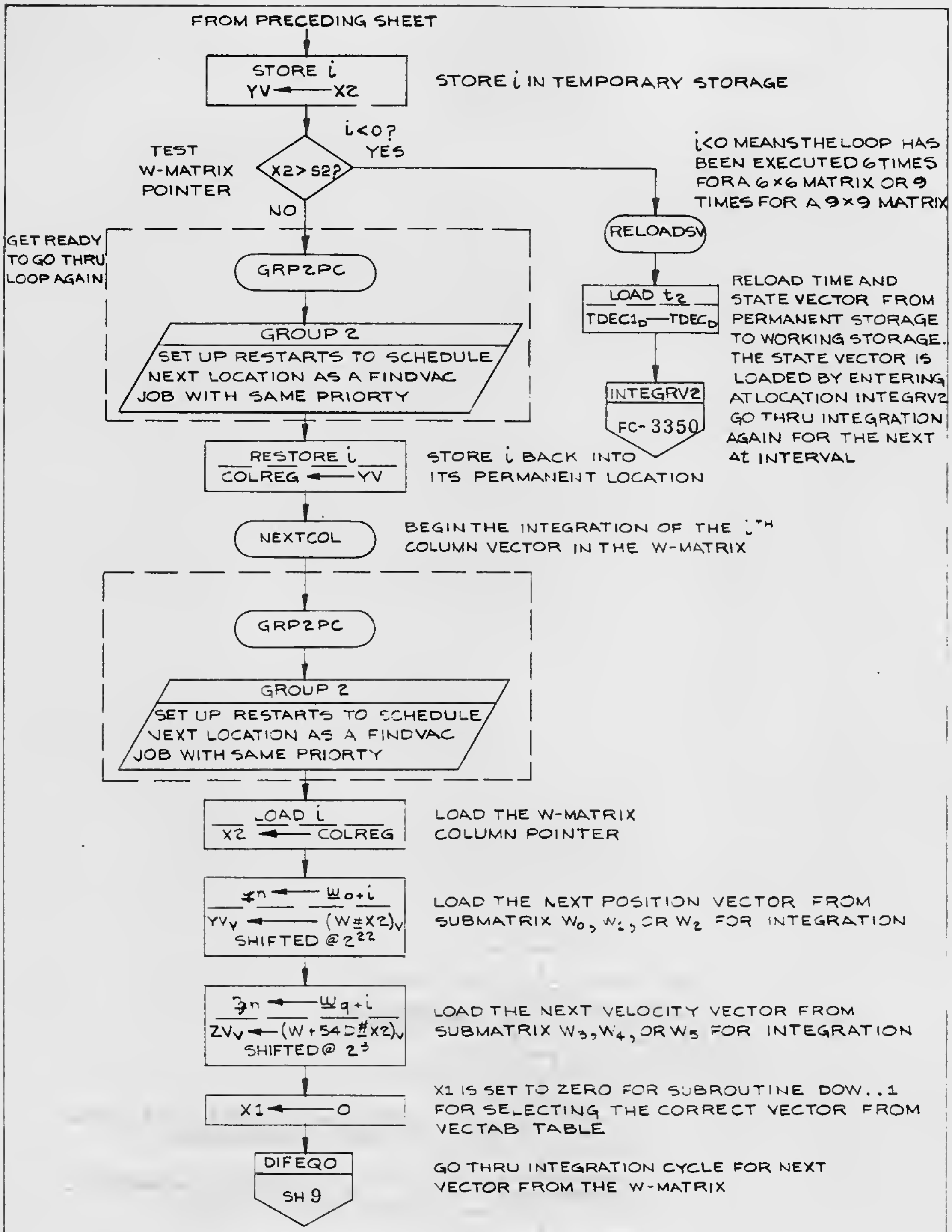

STORE i IN TEMPORARY STORAGE

i<0 MEANS THE LOOP HAS BEEN EXECUTED 6 TIMES FOR A 6×6 MATRIX OR 9 TIMES FOR A 9×9 MATRIX

RELOAD TIME AND STATE VECTOR FROM PERMANENT STORAGE TO WORKING STORAGE. THE STATE VECTOR IS LOADED BY ENTERING AT LOCATION INTEGRV2 GO THRU INTEGRATION AGAIN FOR THE NEXT Δt INTERVAL

STORE i BACK INTO ITS PERMANENT LOCATION

BEGIN THE INTEGRATION OF THE i^TH COLUMN VECTOR IN THE W-MATRIX

LOAD THE W-MATRIX COLUMN POINTER

LOAD THE NEXT POSITION VECTOR FROM SUBMATRIX W_0, W_1, OR W_2 FOR INTEGRATION

LOAD THE NEXT VELOCITY VECTOR FROM SUBMATRIX W_3, W_4, OR W_5 FOR INTEGRATION

X1 IS SET TO ZERO FOR SUBROUTINE DOW..1 FOR SELECTING THE CORRECT VECTOR FROM VECTAB TABLE

GO THRU INTEGRATION CYCLE FOR NEXT VECTOR FROM THE W-MATRIX

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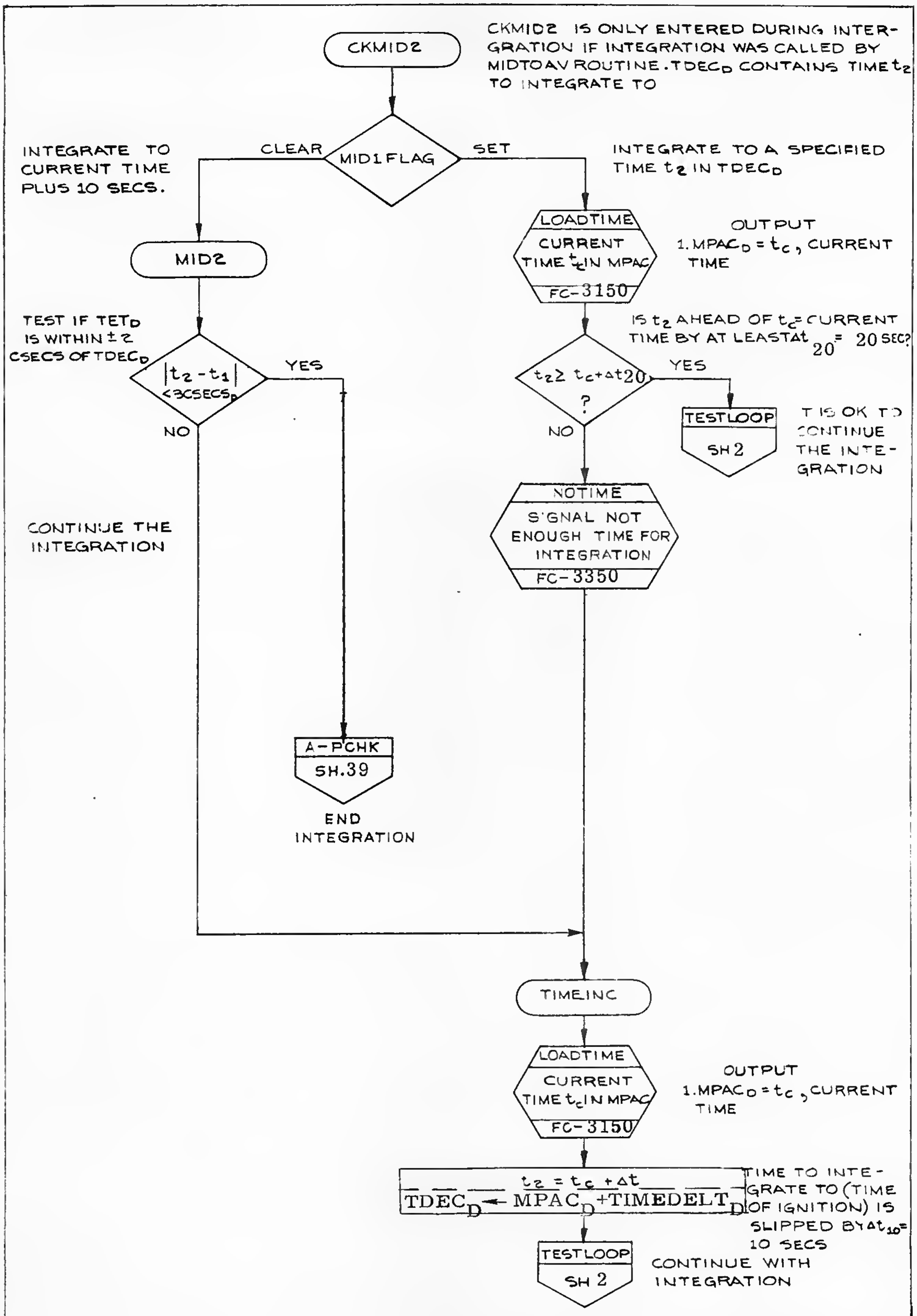

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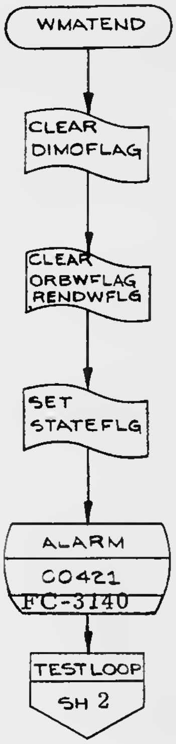

THIS ROUTINE IS ENTERED FROM DIFEQ+2 IF OVERFLOW OCCURRED DURING INTEGRATION OF THE W-MATRIX. THIS ROUTINE ENDS W-MATRIX INTEGRATION.

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

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

SET FLAG TO FORCE A STATE VECTOR UPDATE IN A-PCHK, SHEET 35

ALARM 00421 INDICATES A W-MATRIX OVERFLOW

CONTINUE INTEGRATING WITHOUT THE W-MATRIX

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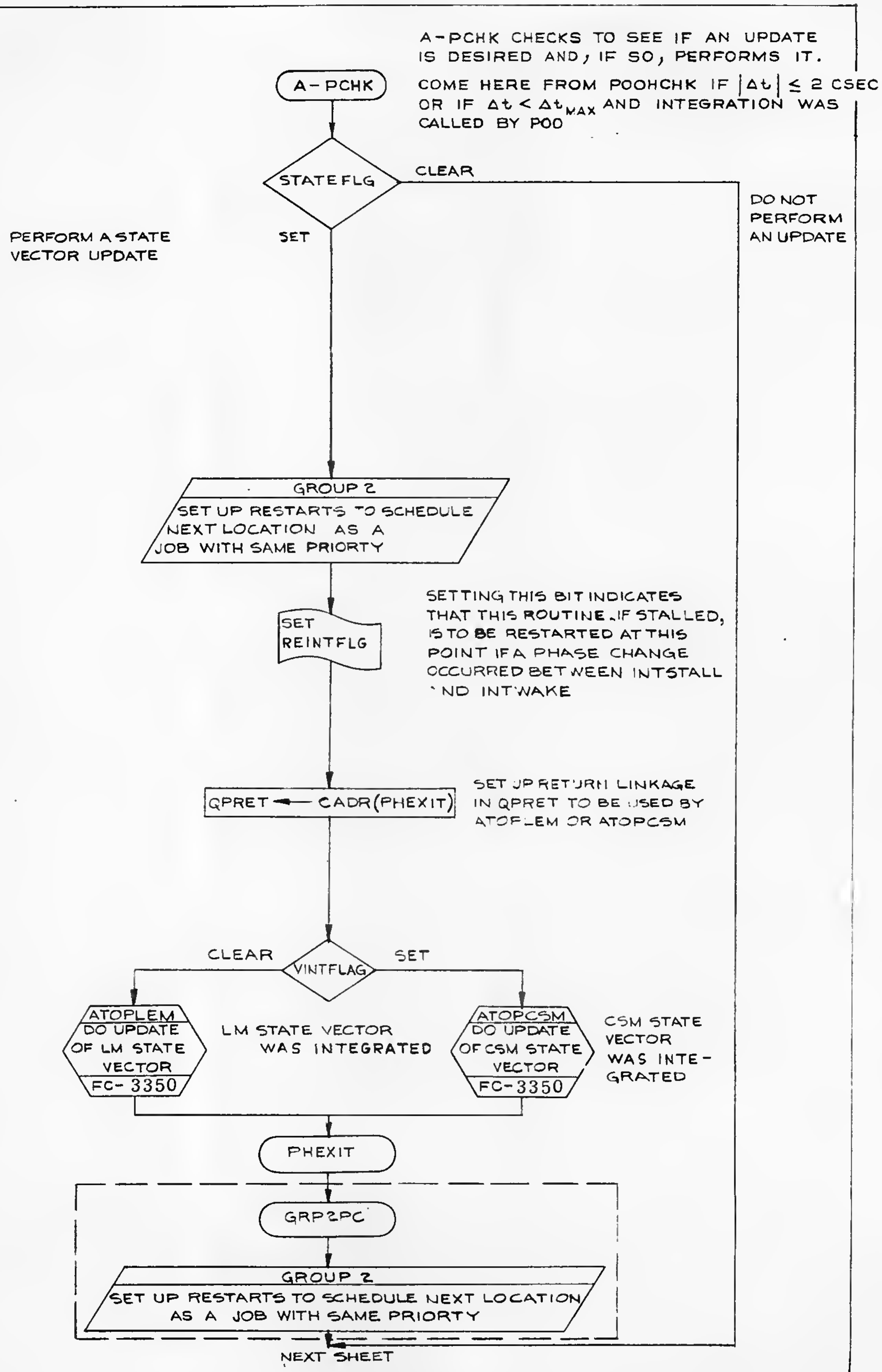

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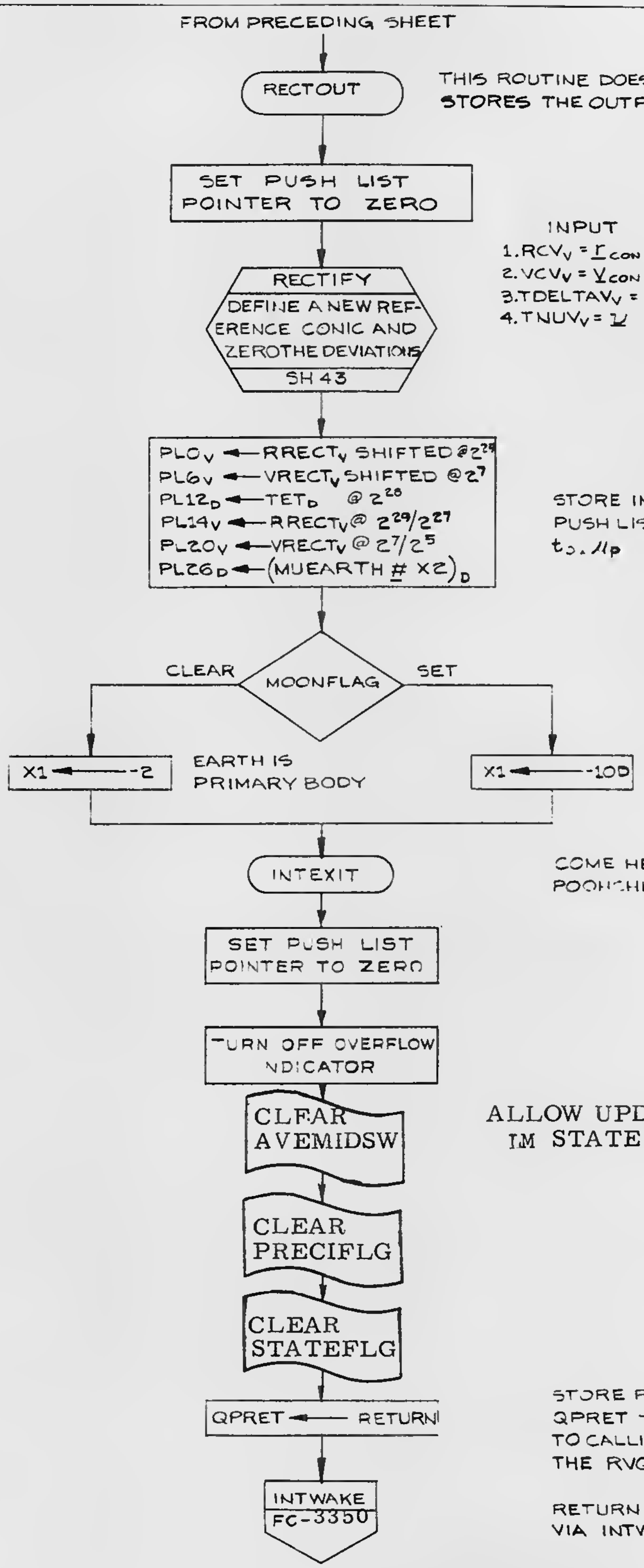

THIS ROUTINE DOES A RECTIFICATION AND STORES THE OUTPUT IN THE PUSH LIST

INPUT

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

OUTPUT

1. $X2 = PBODY$
2. $RRECT_V = \underline{r}_0 = \underline{r}_{CON} + \underline{\delta}$
3. $VRECT_V = \underline{v}_0 = \underline{v}_{CON} + \underline{\nu}$
4. $RCV_V = \underline{r}_{CON} = NEW\ \underline{r}_0$
5. $RCV_V = \underline{v}_{CON} = NEW\ \underline{v}_0$
6. $TDELTAV_V = \underline{\delta} = (0,0,0)$
7. $TNUV_V = \underline{\nu} = (0,0,0)$
8. $TC_D = \tau = 0$
9. $XKEP_D = x = 0$

STORE INTEGRATION OUTPUT IN PUSH LIST. THIS INCLUDES $\underline{r}_0, \underline{v}_0, t_0, \mu_p$

COME HERE DIRECTLY FROM POODCHK IF $t_2 > t_1 + 4\Delta t$

ALLOW UPDATE OF DOWNLINK
LM STATE VECTOR

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

RETURN TO CALLING ROUTINE VIA INTWAKE

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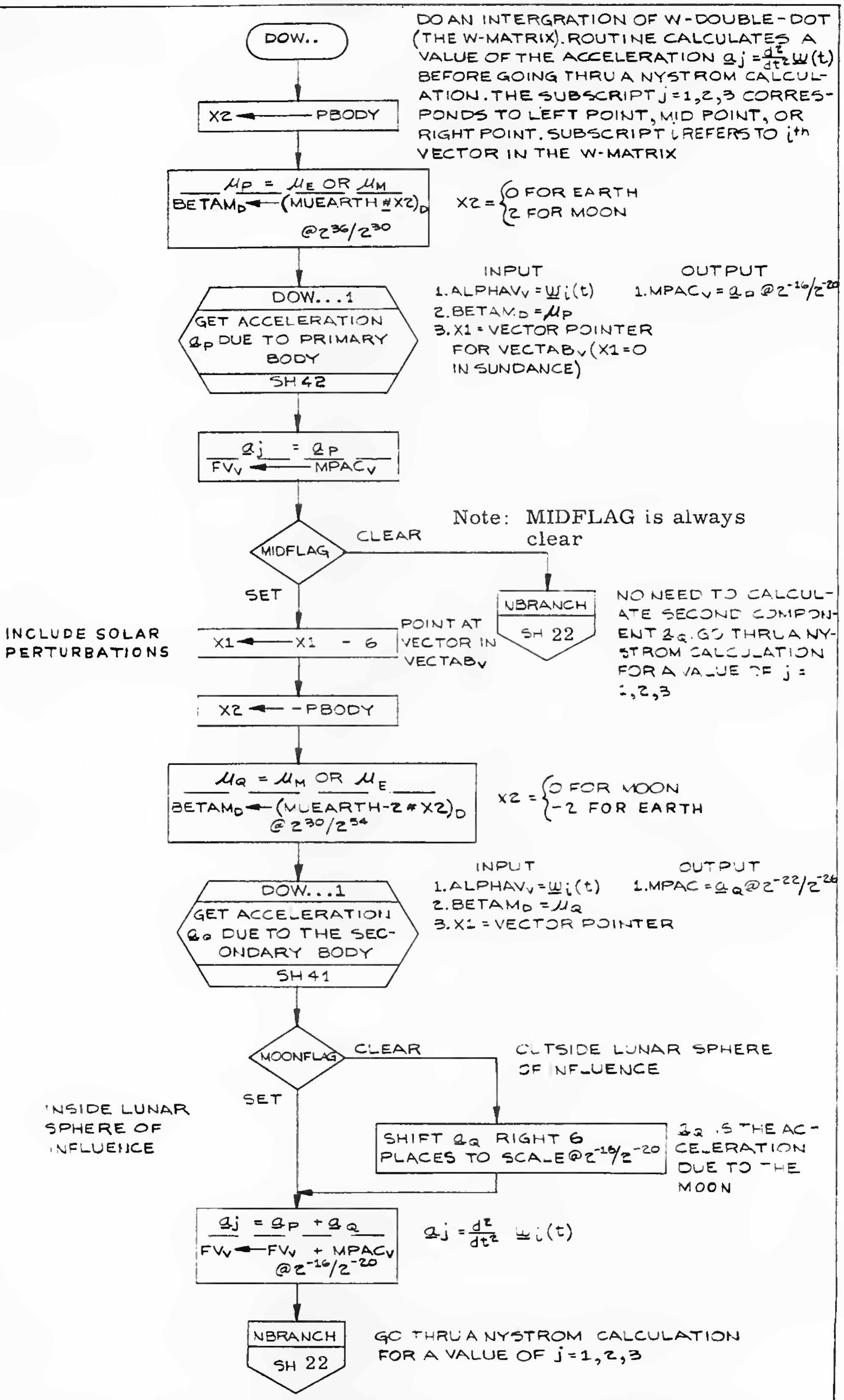

DO AN INTERGRATION OF W-DOUBLE-DOT (THE W-MATRIX). ROUTINE CALCULATES A VALUE OF THE ACCELERATION $a_j = \frac{d^2}{dt^2} w(t)$ BEFORE GOING THRU A NYSTROM CALCULATION. THE SUBSCRIPT j = 1,2,3 CORRESPONDS TO LEFT POINT, MID POINT, OR RIGHT POINT. SUBSCRIPT i REFERS TO i^{th} VECTOR IN THE W-MATRIX

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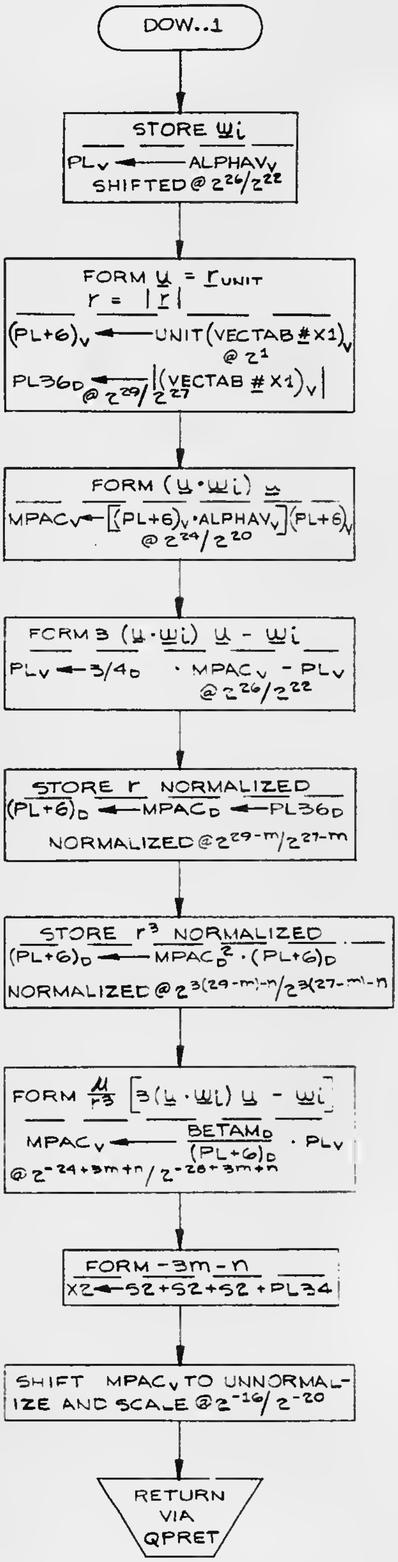

CALCULATE THE ACCELERATION COMPONENT a_p OR a_q FOR A GIVEN $\underline{w}_i$

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

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

$3/4 = 3.0 @ 2^2$

THE NORMALIZING COUNT $-m$ IS STORED IN S2

THE NORMALIZING COUNT $-r$ IS STORED IN PL34.

THIS IS THE ACCELERATION COMPONENT

$-3m-n$ IS THE UNNORMALIZING COUNT

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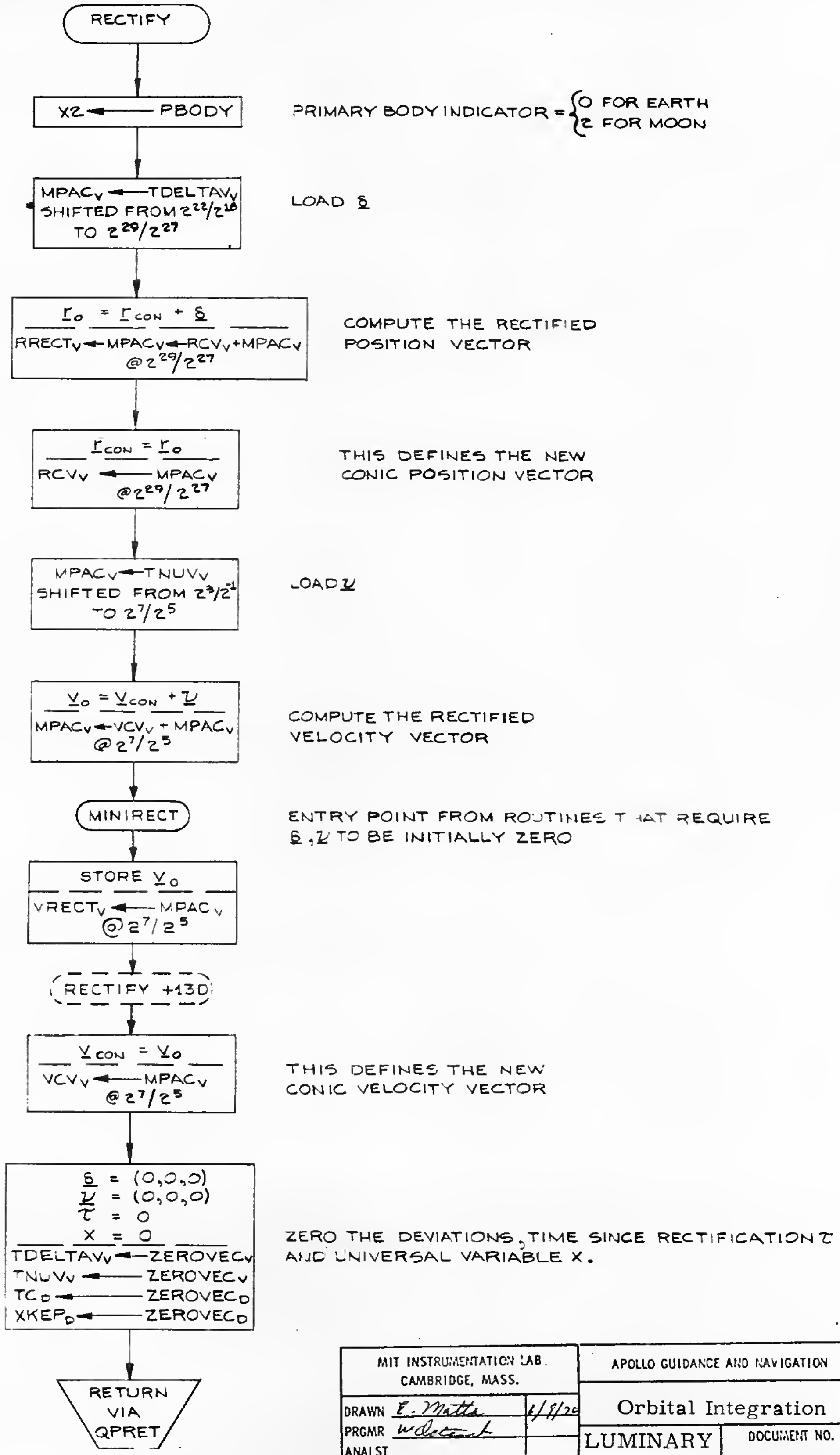
THE RECTIFY SUBROUTINE IS CALLED BY THE INTEGRATION ROUTINE AND OCCASIONALLY BY THE MEASUREMENT INCORPORATION ROUTINES TO DEFINE A NEW REFERENCE CONIC.



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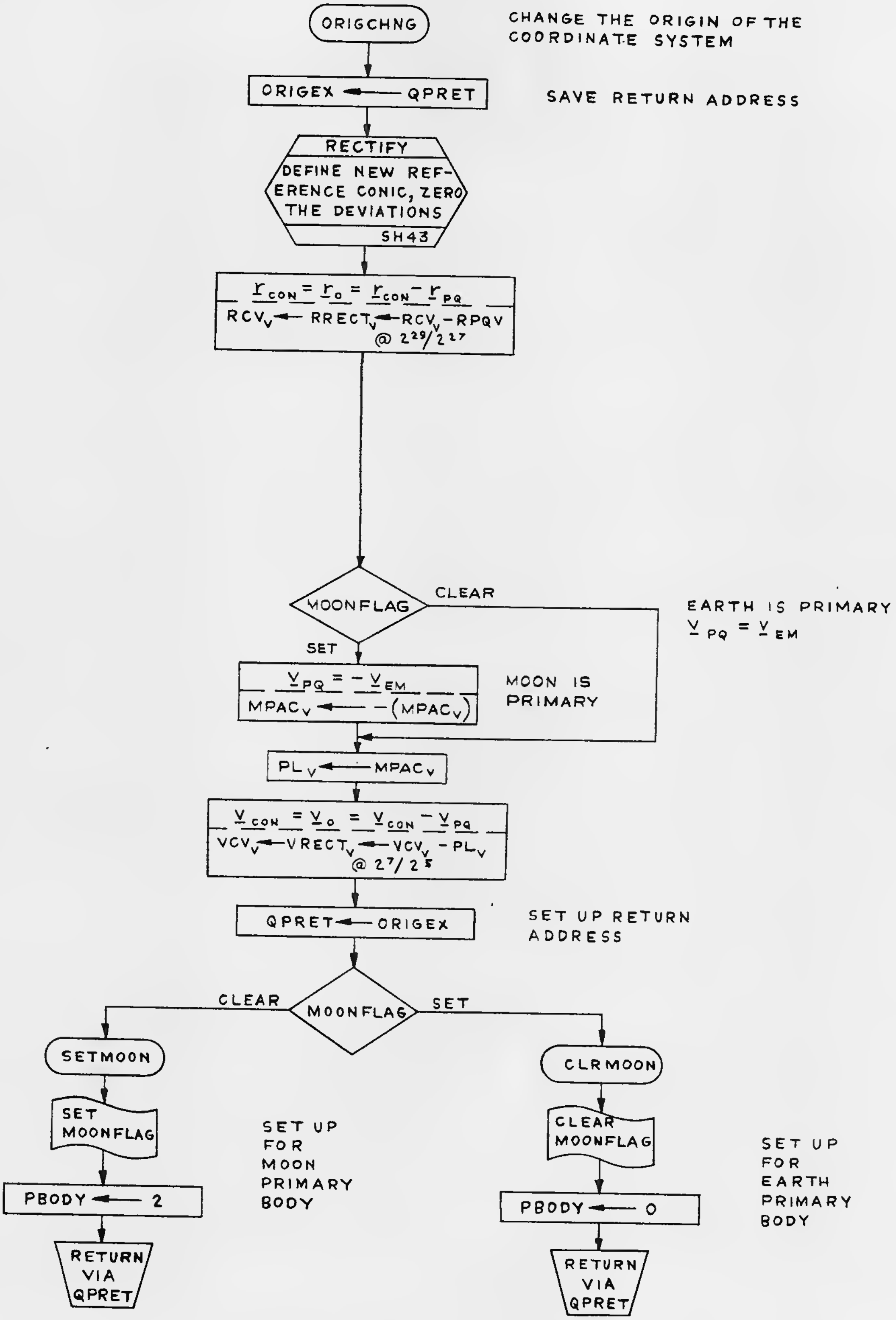

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ANALST		LUMINARY 1D
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APPR'D R M Entes	4/17/70	REV — SHEET 44 OF 49

SUBROUTINES CALLED WHICH ARE
FLOWED ON OTHER FLOW CHARTS

SUBROUTINE NAME	FLOW CHART	DESCRIPTION	WHERE CALLED
SGNAGREE	FC-3150	FORCE SIGN AGREEMENT OF NUMBER IN MPAC	SH. 3
SIGNMPAC	FC-3150	LOAD MPAC WITH SIGNUM (MPAC)	SH. 4
R-TO-RP	FC-3340	CONVERT A VECTOR FROM BASIC REFERENCE COORDINATES TO MOON COORDINATES	SH. 16
NOTIME	FC-3350	SIGNAL NOT ENOUGH TIME FOR INTEGRATION	SH. 37
KEPLERN	FC-3360	KEPLER ROUTINE COMPUTES THE NEW CONIC STATE VECTOR	SH. 32
ATOPLEM	FC-3350	DO UPDATE OF PERMANENT LM STATE VECTOR	SH. 34,39
ATOPCSM	FC-3350	DO UPDATE OF PERMANENT CSM STATE VECTOR	SH. 34,39
INTEGRV2	FC-3350	ENTRY POINT IN INTEGRATION INITIALIZATION FOR NEXT PASS THROUGH INTEGRATION WITH NEXT t VALUE	SH. 36
LOADTIME	FC-3150	LOAD TIME1 AND TIME2 (CURRENT TIME) INTO MPAC	SH. 37
INTWAKE	FC-3350	ENTRY POINT FOR WAKING UP ALL INTEGRATION STALLED PROGRAMS, WHEN PRESENT INTEGRATION IS COMPLETED	SH. 40
LSPOS	FC-3345	CALCULATE POSITION OF SUN, MOON	SH. 7,12
LUNPOS	FC-3345	CALCULATE POSITION OF MOON	SH. 6
ALARM	FC-3140	LIGHT PROGRAM ALARM LIGHT	SH. 38
POODOO	FC-3140	TERMINATE MAJOR MODE IN RESTART	SH. 23

FLAGS

NAME (BIT, FLAGWORD)	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
VINTFLAG (3, 3)	INTEGRATE THE CSM STATE VECTOR	INTEGRATE THE LM STATE VECTOR			SH. 34, 39
DIMOFLAG (1, 3)	INTEGRATE THE W-MATRIX	DO NOT INTEGRATE THE W-MATRIX		SH. 38	SH.10,13 33
D6OR9FLG (2, 3)	W-MATRIX IS 9X9	W-MATRIX IS 6X6			SH. 34
STATEFLG (5, 3)	UPDATE PERMANENT CSM/LM STATE VECTOR	DO NOT UPDATE PERMANENT CSM/LM STATE VECTOR	SH. 37	SH. 2, 40	SH. 39
QUITFLAG (5, 9)	DISCONTINUE INTEGRATION AT START OF NEXT TIMESTEP	CONTINUE INTEGRATION			SH 2
MIDFLAG (13, 0)	INTEGRATE WITH SOLAR PERTURBATIONS	INTEGRATE WITHOUT SOLAR PERTURBATIONS	SH.2	SH. 2	SH.5,11, 41
PRECIFLG (8, 3)	CSMPREC OR LEMPREC CALLED	INTEGRV OR INTEGRVS CALLED		SH. 40	SH. 4
NEWIFLG (13, 8)→	FIRST PASS THROUGH INTEGRATION LOOP	SUBSEQUENT PASS THROUGH INTEGRATION LOOP		SH. 5	SH. 5
JSWITCH (14, 0)	INTEGRATE A VECTOR FROM THE W-MATRIX	INTEGRATE THE STATE VECTOR	SH. 34	SH. 9	SH. 9,28 33
POOHFLAG (15,3)	IN PROGRAM P00	NOT IN PROGRAM P00			SH.4

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FLAGS (CONTINUED)

NAME (BIT, FLAGWORD)	MEANING WHEN SET	MEANING WHEN CLEAR	WHERE SET	WHERE CLEARED	WHERE TESTED
MOONFLAG (12, 0)	INSIDE LUNAR SPHERE OF INFLUENCE	OUTSIDE LUNAR SPHERE OF INFLUENCE	SH. 44	SH. 44	SH. 6, 12, 14, 20, 32, 40, 41, 44
RPQFLAG (15, 8)	CALCULATE THE VECTOR RPQ	DO NOT CALCULATE THE VECTOR RPQ	SH. 23	SH. 14	SH. 6, 7
MIDAVFLG (2, 9)	INTEGRATION CALLED BY THE MIDTOAV ROUTINE	INTEGRATION NOT CALLED BY THE MIDTOAV ROUTINE			SH. 33
REINTFLG (7, 10)	RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS	DO NOT RESTART THIS ROUTINE IF STALLED AND RESTART OCCURS	SH. 34, 39		
MID1FLAG (3, 9)	INTEGRATE TO A SPECIFIED TIME t_2 STORED IN TDEC	INTEGRATE TO CURRENT TIME PLUS 10 SECONDS			SH. 37
ORBWFLAG (6, 3)	W-MATRIX IS VALID FOR ORBITAL NAVIGATION	W-MATRIX IS INVALID FOR ORBITAL NAVIGATION		SH. 38	
RENDWFLG (1, 5)	W-MATRIX IS VALID FOR RENDEZVOUS NAVIGATION	W-MATRIX IS INVALID FOR RENDEZVOUS NAVIGATION		SH 38	
AVEMIDSW (1, 9)	PREVENT UPDATING THE CSM DOWNLINK DATA RN, VN, PIPTIME	ALLOW UPDATING THE CSM DOWNLINK DATA RN, VN, PIPTIME		SH. 40	

DISPLAYS

VERB-NOUN	TYPE OF DISPLAY	DESCRIPTION OF EACH REGISTER	WHERE EXECUTED
	ALARM	PROG ALARM LIGHT ON; R1, R2, R3, NOT AFFECTED	SH. 38

ERASABLE LOCATIONS USED

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
$DT/2_D$	t	TIME INTERVAL FOR ONE INTEGRATION CYCLE	CSEC	CSEC	2^{20}
$TDEC1_D$	t_2	TIME TO INTEGRATE TO	CSEC	CSEC	2^{28}
RCV_V	$\underline{r}_{con}$	CONIC POSITION VECTOR	M	M	$2^{29}/2^{27}$
VCV_V	$\underline{v}_{con}$	CONIC VELOCITY VECTOR	M/CSEC	M/CSEC	2^{7} 2^{5}
TET_D	t	TIME OF VALIDITY OF STATE VECTOR	CSEC	CSEC	2^{28}
$RRECT_V$	$\underline{r}_o$	POSITION VECTOR AT RECTIFICATION	M	M	$2^{29} \cdot 2^{27}$

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DOCMR RM Estes	6/17/70		
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ERASABLE LOCATIONS USED (CONTINUED)

AGC TAG	GSOP SYMBOL	MEANING	ENGINEERING UNITS	AGC UNITS	AGC SCALING
VRECT$_V$	$\underline{v}_o$	VELOCITY VECTOR AT RECTIFICATION	M/CSEC	M/CSEC	$2^7/2^5$
TDELTAV$_V$	$\underline{\delta}$	POSITION DEVIATION VECTOR	M	M	$2^{22}/2^{18}$
TNUV$_V$	$\underline{\nu}$	VELOCITY DEVIATION VECTOR	M/CSEC	M/CSEC	$2^3/2^{-4}$
TC$_D$	t_{21}	TIME SINCE RECTIFICATION	CSEC	CSEC	2^{28}
XKEP$_D$	x	UNIVERSAL VARIABLE	$M^{1/2}$	$M^{1/2}$	$2^{17}/2^{16}$
YV$_V$	$\underline{\delta}$	INTERMEDIATE VALUE OF $\underline{\delta}$	M	M	$2^{22}/2^{18}$
ZV$_V$	$\underline{\nu}$	INTERMEDIATE VALUE OF $\underline{\nu}$	M/CSEC	M/CSEC	$2^3/2^{-4}$
DIFEQCNT	j	SUBSCRIPT FOR LEFT, MID, AND RIGHT POINTS	INTEGER	INTEGER	
ALPHAV$_V$	$\underline{\alpha}_j$	INTERMEDIATE VALUE OF $\underline{\delta}$	M	M	$2^{22}/2^{18}$
H$_D$	h	RUNNING TIME INCREMENT EQUALS 0, Δ 1/2, Δt	CSEC	CSEC	2^{19}
EV$_V$	$\underline{f}_j$	VALUE OF SECOND DERIVATIVE AT POINT j	M/(CSEC)^2	M/(CSEC)^2	$2^{-16}, 2^{-20}$
BETAV$_V$	$\underline{\beta}_j$	INTERMEDIATE VALUE OF r$_o$	M	M	$2^{29}, 2^{27}$
VECTAB$_V$	$\underline{\beta}_j$	WORKING STORAGE FOR $\underline{\beta}_j$	M	M	$2^{29}/2^{27}$
ALPHAM$_D$	α_j	$\lvert\underline{\alpha}_j\rvert$, MAGNITUDE OF $\underline{\alpha}_j$	M	M	$2^{29}/2^{27}$
BETAM$_D$	β_j	$\lvert\underline{\beta}_j\rvert$, MAGNITUDE OF $\underline{\beta}_j$	M	M	$2^{29}/2^{27}$
UZ$_V$	$\underline{u}_z$	UNIT VECTOR IN DIRECTION OF ROTATION AXIS			2^1
COSPHI/2$_D$	COS φ	COSINE OF COALTITUDE φ			2^1
URPV$_V$	$\underline{u}_r$	UNIT VECTOR OF POSITION IN MOON COORDINATES			2^1
TVEC$_V$	$\underline{a}_v$	THE DISTURBING ACCELERATION	M/(CSEC)^2	M/(CSEC)^2	
TAU.$_D$	t_D	DESIRED TRANSFER TIME	CSEC	CSEC	2^{28}
PHIV$_V$	$\underline{\varphi}$	RUNNING SUM OF $\underline{k}_1 + 2k_2$	M/(CSEC)^2	M/(CSEC)^2	$2^{-13}, 2^{-17}$
PSIV$_V$	$\underline{\psi}$	RUNNING SUM OF $\underline{k}_1 + \underline{k}_2 + \underline{k}_3$	M/(CSEC)^2	M/(CSEC)^2	$2^{-13}, 2^{-17}$
PBODY	P	PRIMARY BODY INDICATOR	INTEGER	INTEGER	
XKEPNEW$_D$	x	INITIAL ESTIMATE OF NEW VALUE OF x	$M^{1/2}$	$M^{1/2}$	$2^{17}/2^{16}$
W$_M$	W	W-MATRIX	M, M/CSEC	M, M/CSEC	2^{19}, 2^0

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PROGRAM CONSTANTS

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

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PROGRAM CONSTANTS (CONTINUED)

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

PAD LOADS

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

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CONIC SUBROUTINES

KEPLERN	SH. 3
LAMBERT	SH. 11
TIMETHET	SH. 23
TIMERAD	SH. 24
DELTIME	SH. 26
GETX	SH. 27
PARAM	SH. 34
GEOM	SH. 35
NEWSTATE	SH. 36
LAMENTER	SH. 36
ITERATOR	SH. 37
APSIDES	SH. 39

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CONIC SUBROUTINES

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FLOW CHART CONVENTIONS FOR THE CONIC SUBROUTINES

1. $c_1 = \sqrt{p_N r_1(t)} \cot\gamma$

KEPC1 ← $\sqrt{\text{P} \cdot \text{R1}}$ · COGA

SCALED AT $2^{17}/2^{16}$

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In boxes divided by a broken line, the upper half represents the mathematical formulation of the statement and the lower half represents how the statement was coded in the computer. The arrow implies that the quantity computed on the right side of the arrow was stored into the location specified on the left side, or mathematically the quantity on the left was set equal to the quantity on the right. Where possible, equations are referenced by equation, page and reference number.

2. All values are considered to be double-precision numbers (28 bits of precision plus sign) unless subscripted with an $_s$ for single-precision (14 bits plus sign) or subscripted with a $_v$ for a vector quantity (3 double-precision components). All flags are considered to be one-bit indicators unless shown otherwise.

3. Double-precision numbers are considered to be scaled fractions lying in the range between -1.0 and 1.0. The scaling factor included in the box is the value by which the number as stored internally must be multiplied to obtain its true value. It can also be interpreted as defining the binary point. Thus a scaling of 2^5 means that the binary point lies to the right of bit -5, where bit positions are labeled 0, -1, -2 ... going from left to right, starting with the sign bit. In cases where a pair of scaling factors are included, the first applies to the nominal situation and the second-applies to the off-nominal situation. A scaling of 2^{28} indicates the double-precision number is an integer. Thus, all values of time are given as an integral number of centiseconds.

4. A push list is available for temporary storage of data and for storage of data common to several subroutines. Locations within the push list are referred to relative to its initial location and are given as decimal numbers. Thus 6D refers to location 6 in the push list, counting from zero. The values can range from 0D to 42D. For a general location within the push list the name PL is used.

5. MPAC The name MPAC refers to the multipurpose accumulator used by the interpreter routine. It consists of seven consecutive locations within erasable memory and holds the results of interpretive arithmetic operations. It is functionally equivalent to the actual accumulator register within the AGC.

6. $\underline{r}(t_1)_{\text{UNIT}}$

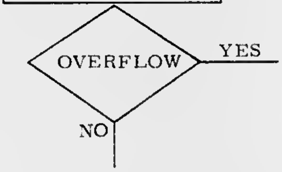
UNIT (R1VEC_v)

The unit operation, corresponding to the subscript unit, computes a vector of unit length parallel to the specified vector, and leaves the result in MPAC with a scaling of 2^1. It also automatically stores the magnitude as double-precision in push list location 36D.

7. $|\underline{r}(t_1)|$

$|\text{R1VEC}_v|$

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

8. 

Testing the overflow indicator automatically turns it off.

REFERENCES FOR CONIC SUBROUTINES

1. Battin, R. H., Astronautical Guidance, McGraw-Hill Inc., New York, 1964.

2. Hildebrand, F. B., Introduction to Numerical Analysis, McGraw-Hill Inc., New York, 1956.

3. Guidance System Operations Plan Using Program COLOSSUS II, (GSOP), R-577, Section 5, Guidance Equations, March 1969.

4. Marscher, W. F., A Unified Method of Generating Conic Sections, R-479, MIT/IL, February 1965.

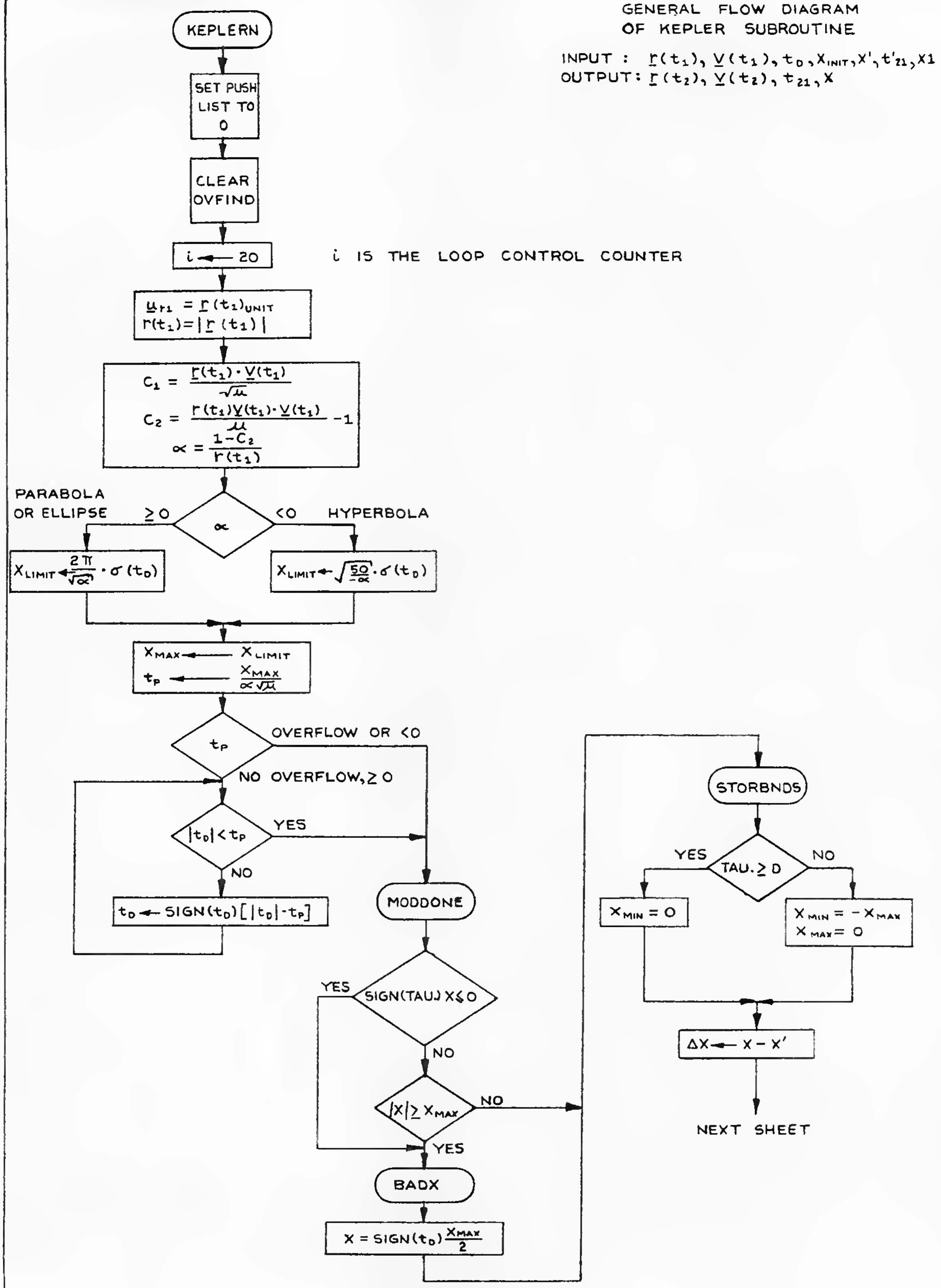
5. Robertson, W. M., Explicit Universal Series Solutions for the Universal Variable X, MIT/IL, SGA Memo 8-67, May 1967.

6. Newman, C. M., Power Series Economization, MIT/IL, SGA Memo 11-67, August 1967.

7. Krause, K., Generalized Slope Iterator, MIT/IL, SGA Memo 4-67, February 1967.

GENERAL FLOW DIAGRAM OF KEPLER SUBROUTINE

INPUT : $\underline{r}(t_1)$, $\underline{V}(t_1)$, t_D, X_{INIT}, X', t'_{21}, $X1$
OUTPUT: $\underline{r}(t_2)$, $\underline{V}(t_2)$, t_{21}, X



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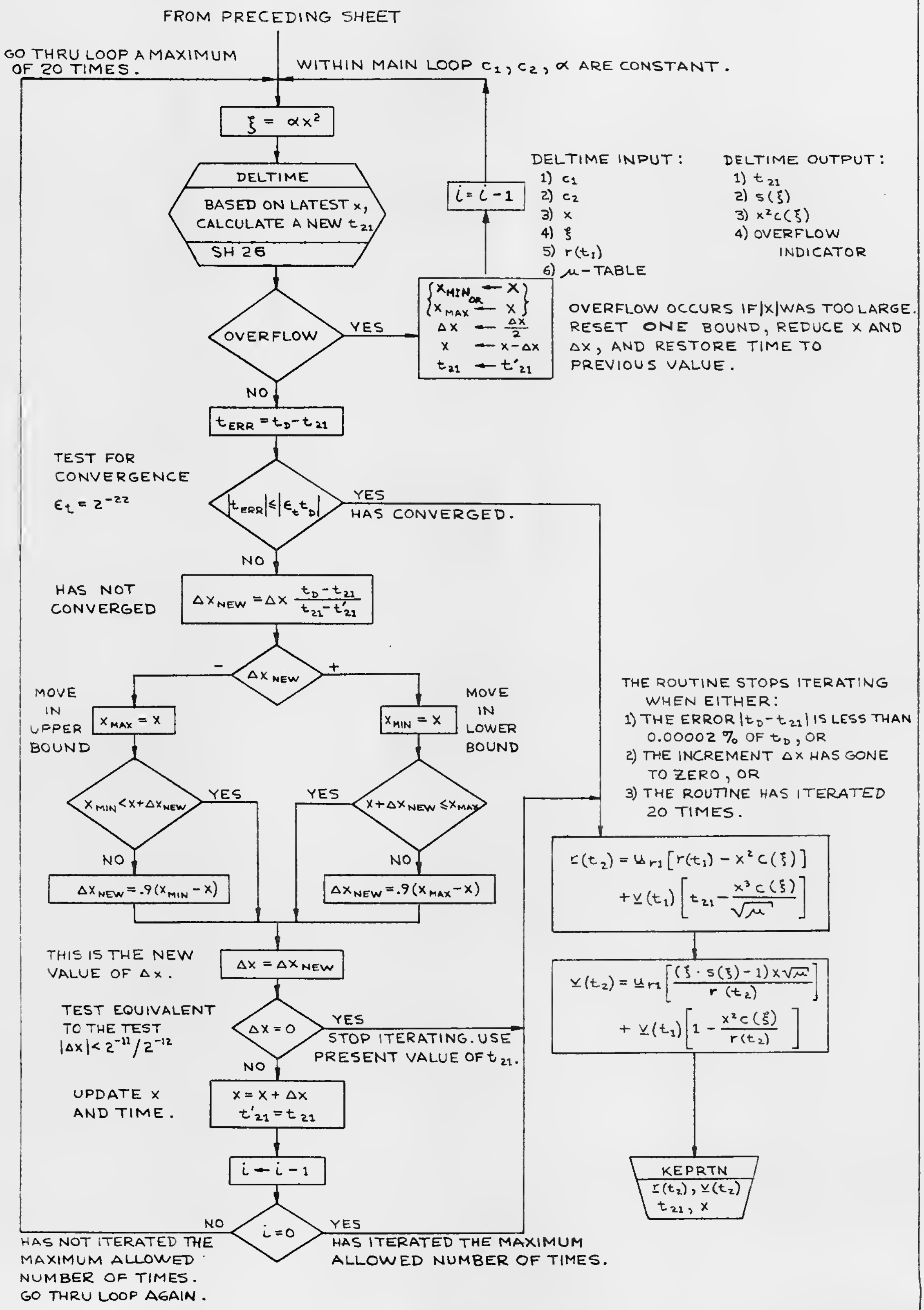

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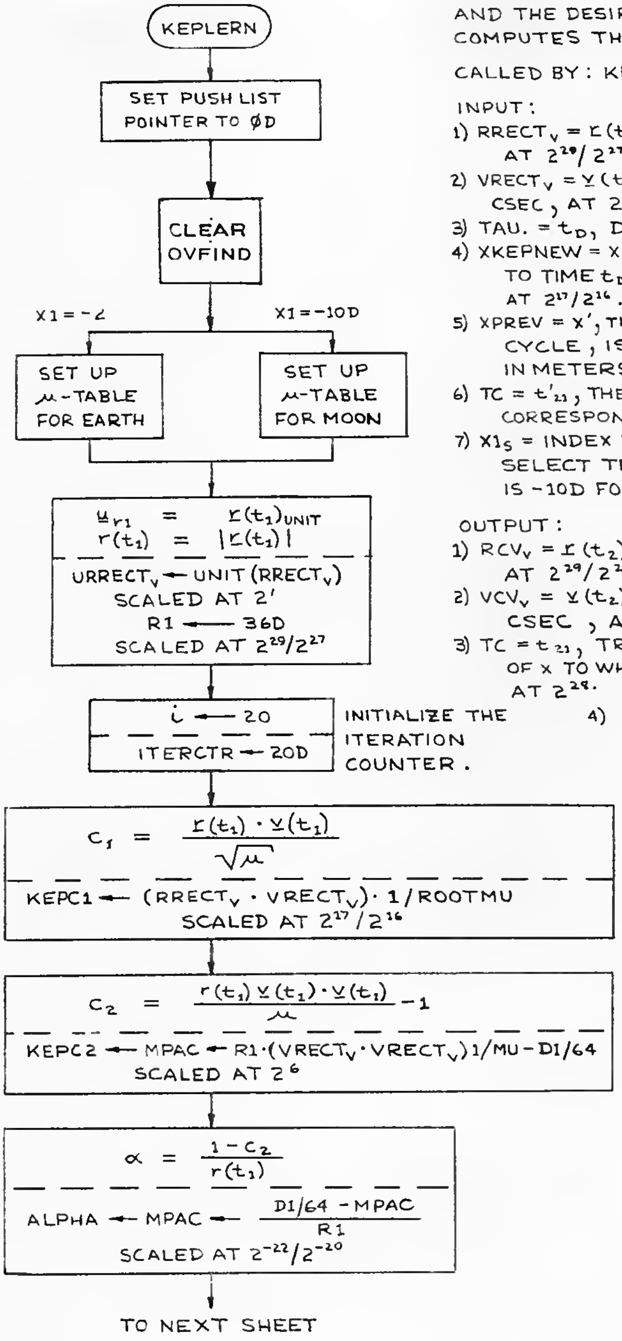

GIVEN THE INITIAL STATE VECTOR $\underline{r}(t_1)$ AND $\underline{v}(t_1)$, AND THE DESIRED TRANSFER TIME t_D, THIS ROUTINE COMPUTES THE NEW STATE VECTOR $\underline{r}(t_2)$ AND $\underline{v}(t_2)$.

CALLED BY: KEPPREP

INPUT:

1) RRECT$_V$ = $\underline{r}(t_1)$, INITIAL POSITION VECTOR, IN METERS, AT $2^{29}/2^{27}$.
2) VRECT$_V$ = $\underline{v}(t_1)$, INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7/2^5$.
3) TAU. = t_D, DESIRED TRANSFER TIME, IN CSECS, AT 2^{28}.
4) XKEPNEW = X_{INIT}, THE FIRST GUESS OF X CORRESPONDING TO TIME t_D, IS THE OUTPUT OF KEPPREP, IN METERS$^{1/2}$, AT $2^{17}/2^{16}$.
5) XPREV = x', THE VALUE OF x FROM A PREVIOUS COMPUTATION CYCLE, IS USED ONLY TO CALCULATE AN INITIAL Δx, IN METERS$^{1/2}$, AT $2^{17}/2^{16}$.
6) TC = t'_{21}, THE PREVIOUS VALUE OF TRANSFER TIME CORRESPONDING TO x', IN CSECS, AT 2^{28}.
7) X1$_S$ = INDEX REGISTER 1 CONTAINING A VALUE USED TO SELECT THE PROPER μ-TABLE, IS −2 FOR EARTH, IS −10D FOR MOON.

OUTPUT:

1) RCV$_V$ = $\underline{r}(t_2)$, TERMINAL POSITION VECTOR, IN METERS, AT $2^{29}/2^{27}$.
2) VCV$_V$ = $\underline{v}(t_2)$, TERMINAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7/2^5$.
3) TC = t_{21}, TRANSFER TIME CORRESPONDING TO THE VALUE OF x TO WHICH KEPLER ROUTINE CONVERGED, IN CSECS, AT 2^{28}.
4) XPREV = MPAC = x, THE VALUE OF x TO WHICH KEPLER CONVERGED, IN METERS$^{1/2}$, AT $2^{17}/2^{16}$.
5) PUSH LIST POINTER IS AT ØD.

NOTE: IF x_i IS CONSIDERED TO BE THE i^{th} ITERATE OF x, THEN x' AND x_{INIT} CAN BE CONSIDERED TO BE X_{-1} AND x_0 RESPECTIVELY.

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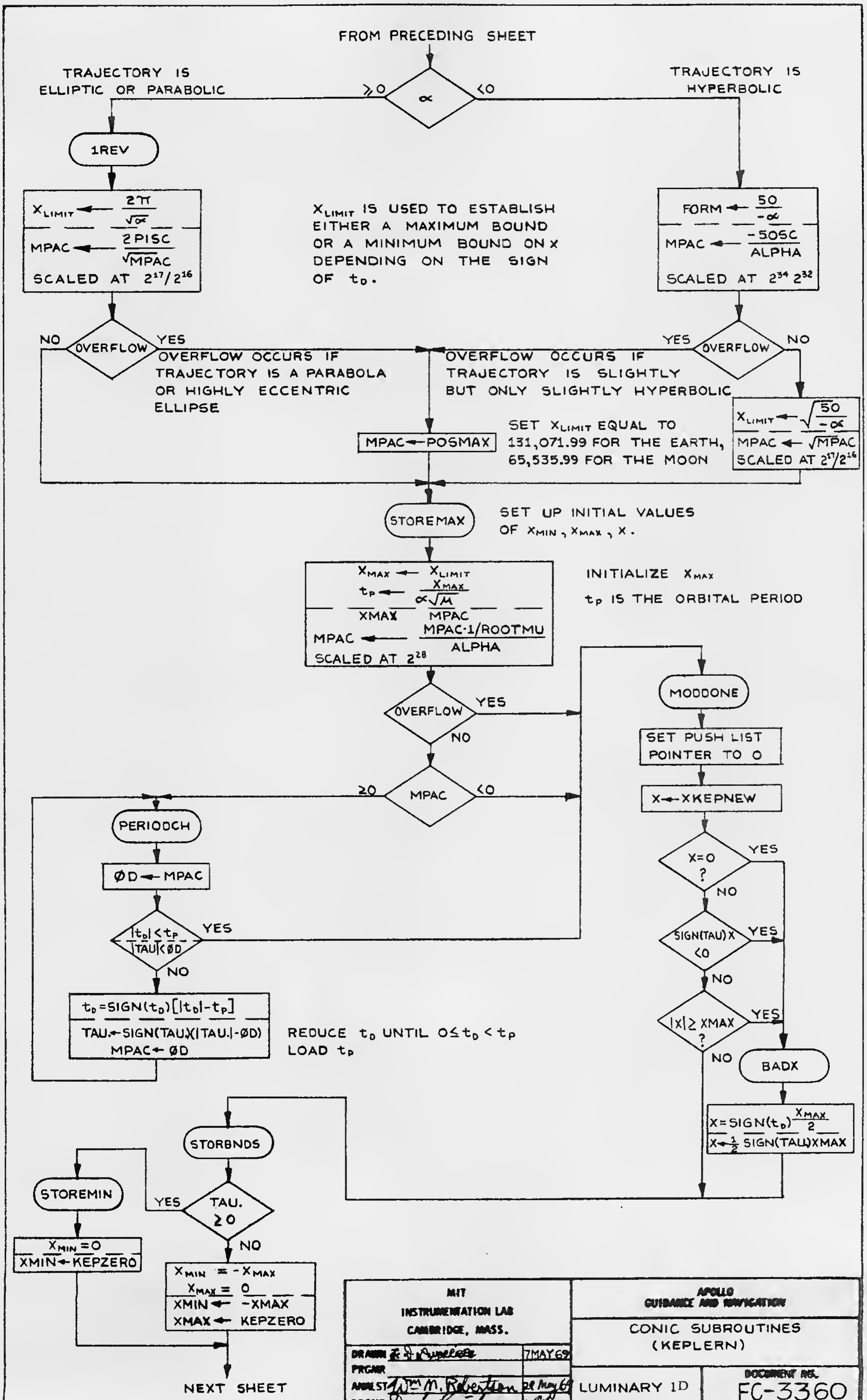

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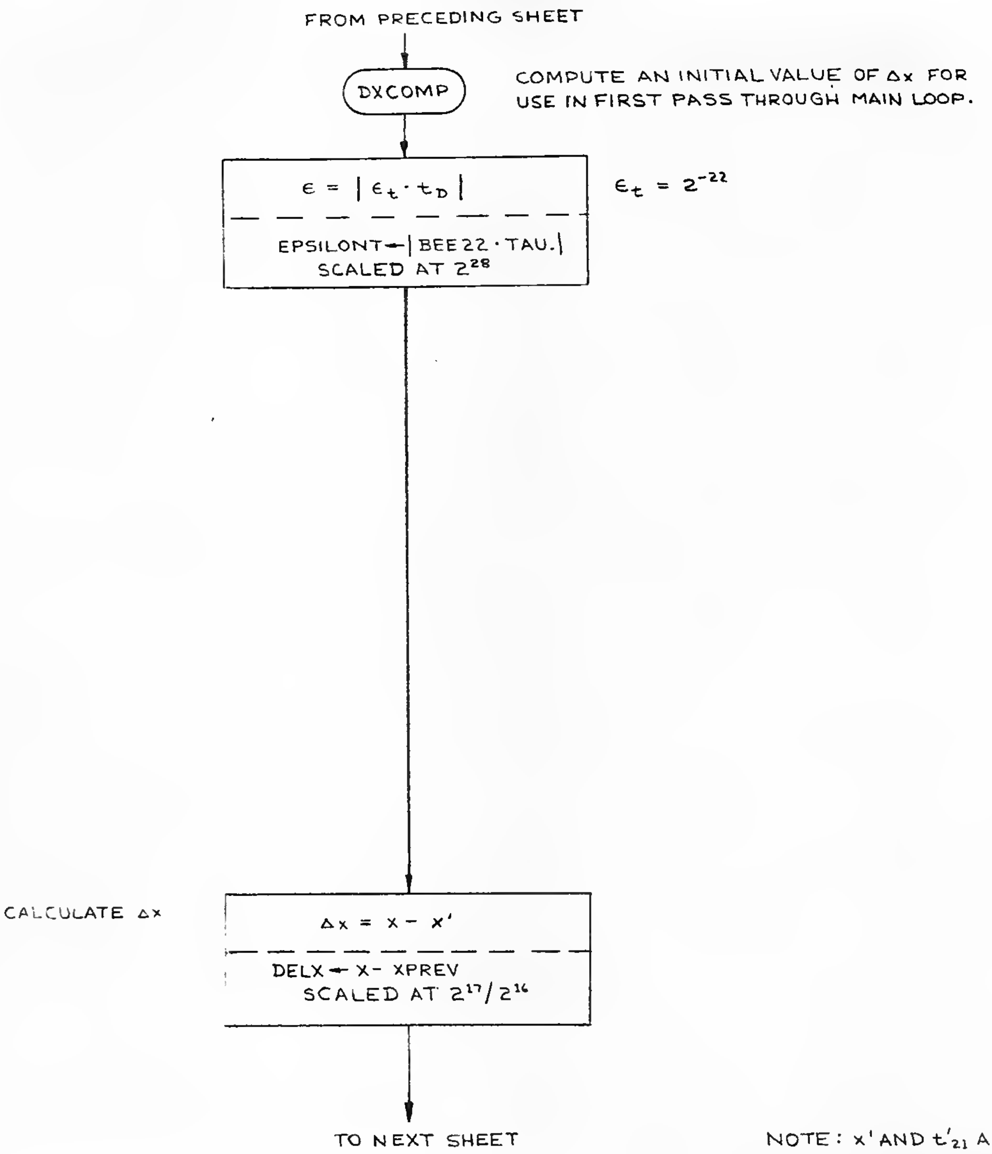

NOTE: x' AND t'_{21} ARE NON-ZERO ONLY IF THE SUBROUTINE IS BEING USED REPETITIVELY.

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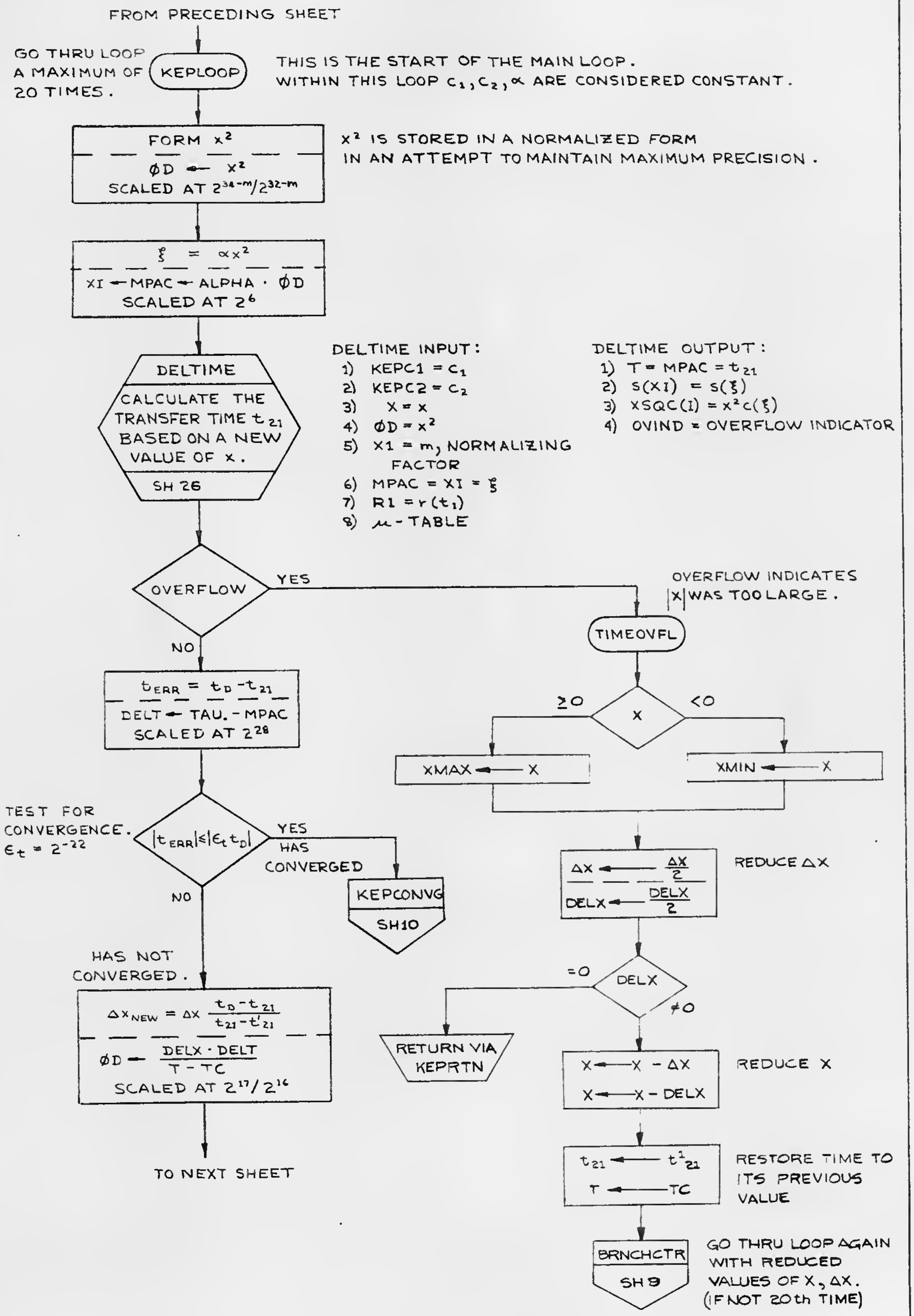

GO THRU LOOP A MAXIMUM OF 20 TIMES.

THIS IS THE START OF THE MAIN LOOP. WITHIN THIS LOOP c_1, c_2, α ARE CONSIDERED CONSTANT.

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

DELTIME INPUT:
1) KEPC1 = c_1
2) KEPC2 = c_2
3) X = x
4) ØD = x^2
5) X1 = m, NORMALIZING FACTOR
6) MPAC = XI = ξ
7) R1 = $r(t_1)$
8) μ - TABLE

DELTIME OUTPUT:
1) T = MPAC = t_{21}
2) S(XI) = $s(\xi)$
3) XSQC(I) = $x^2 c(\xi)$
4) OVIND = OVERFLOW INDICATOR

OVERFLOW INDICATES $|x|$ WAS TOO LARGE.

TEST FOR CONVERGENCE. $\epsilon_t = 2^{-22}$

HAS NOT CONVERGED.

GO THRU LOOP AGAIN WITH REDUCED VALUES OF X, ΔX. (IF NOT 20th TIME)

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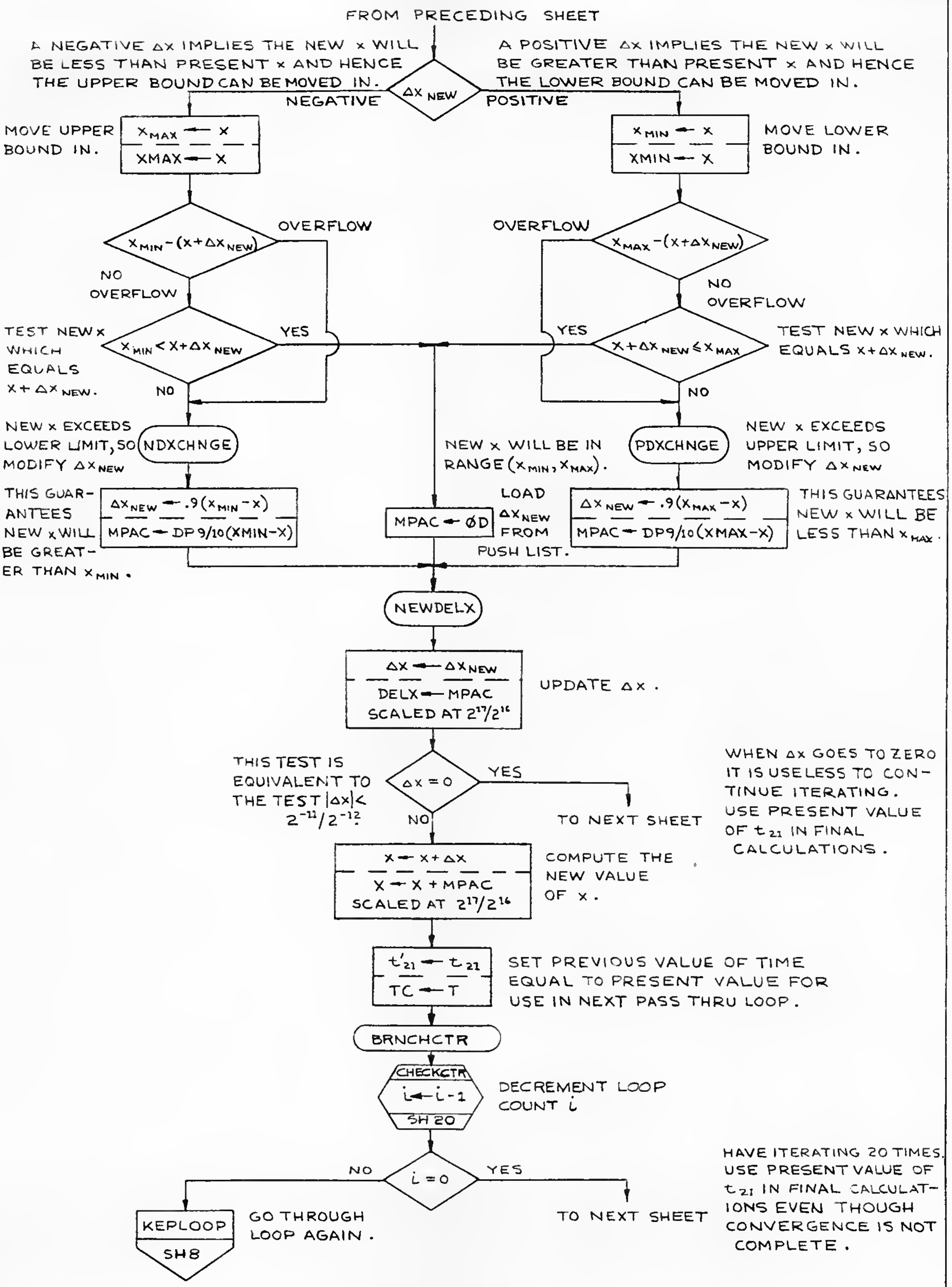

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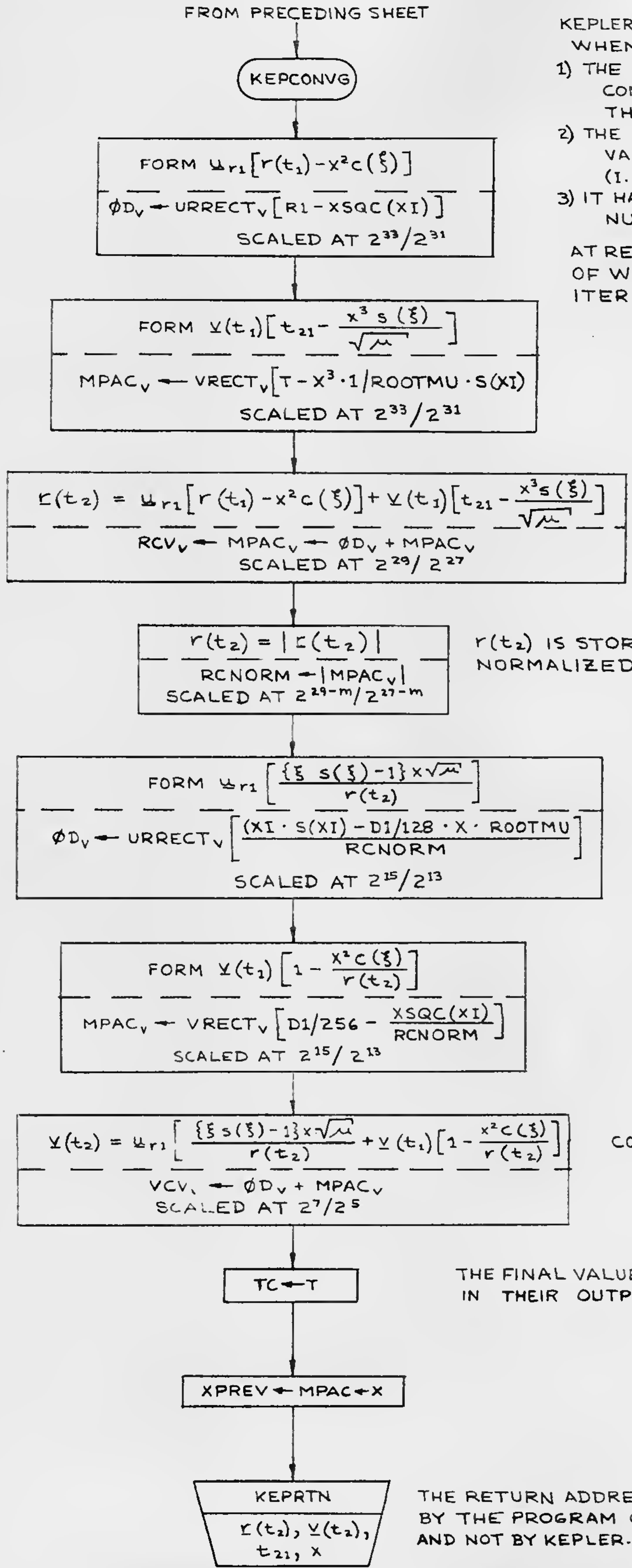

KEPLER TERMINATES THE ITERATION WHEN EITHER:

1) THE INDEPENDENT VARIABLE t_{21} HAS CONVERGED TO WITHIN 0.00002 % OF THE DESIRED TIME t_D, OR
2) THE CHANGE IN THE DEPENDENT VARIABLE x HAS GONE TO ZERO (I.E. LESS THAN $2^{-11}/2^{12}$), OR
3) IT HAS ITERATED THE MAXIMUM (20) NUMBER OF TIMES.

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

COMPUTE $\underline{r}(t_2)$

$r(t_2)$ IS STORED IN NORMALIZED FORM.

COMPUTE $\underline{v}(t_2)$.

THE FINAL VALUES OF t_{21} AND x ARE STORED IN THEIR OUTPUT LOCATIONS

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

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LAMBERT

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

1) RECTILINEAR TRAJECTORIES CAN NOT BE COMPUTED.
2) ACCURACY DEGRADATION OCCURS AS $\cos\theta$ APPROACHES 1.0.
3) THE ANGLE γ BETWEEN ANY POSITION VECTOR AND ITS VELOCITY VECTOR MUST BE IN THE RANGE $(1° 47.5', 178° 12.5')$.
4) A NEGATIVE TRANSFER TIME IS AMBIGUOUS AND WILL RESULT IN NO SOLUTION.

CALLED BY: INITVEL

INPUT:

1) $R1VEC_v = \underline{r}(t_1)$, INITIAL POSITION VECTOR, IN METERS, AT $2^{29}/2^{27}$.
2) $R2VEC_v = \underline{r}(t_2)$, TERMINAL POSITION VECTOR, IN METERS, AT $2^{29}/2^{27}$.
3) TDESIRED $= t_{D21}$, DESIRED TRANSFER TIME, IN CSEC, AT 2^{28}.
4) GEOMSGN $= S_G$, A FLAG, IS POSITIVE IF THE DESIRED TRANSFER ANGLE θ IS $\leq 180°$, IS NEGATIVE IF $\theta > 180°$.
5) $VTARGTAG_s = n_1$, A FLAG, IS CLEAR IF THE TERMINAL VELOCITY VECTOR $\underline{v}(t_2)$ IS TO BE CALCULATED, IS SET IF $\underline{v}(t_2)$ IS NOT TO BE CALCULATED.

6) GUESSW $= f_1$, A FLAG, IS CLEAR IF AN INITIAL GUESS OF $\cot\gamma$ IS INCLUDED AS INPUT, IS SET IF AN INITIAL GUESS IS NOT INPUT BUT MUST BE CALCULATED BY THE LAMBERT ROUTINE.
7) COGA $= \cot\gamma$, AN INITIAL GUESS OF VALUE IF f_1 IS CLEAR, IS IGNORED IF f_1 IS SET, AT 2^5.
8) NORMSW $= f_2$, A FLAG, IS CLEAR IF $\underline{u}_N$ IS TO BE COMPUTED BY THE GEOM SUBROUTINE CALLED BY LAMBERT, IS SET IF $\underline{u}_N$ IS INCLUDED AS INPUT TO LAMBERT.
9) $UN_v = \underline{u}_N$, A UNIT VECTOR NORMAL TO THE DESIRED ORBIT PLANE IN THE DIRECTION OF THE RESULTING ANGULAR MOMENTUM VECTOR, IS IGNORED IF f_2 IS CLEAR, AT $2'$.
10) X1 = INDEX REGISTER 1 CONTAINING VALUE USED TO SELECT PROPER μ-TABLE, IS -2 IF EARTH IS CENTRAL BODY, IS $-10D$ IF MOON IS CENTRAL BODY.
11) $ITERCTR_s = i_{MAX}$, MAXIMUM NUMBER OF ITERATIONS.

OUTPUT

1) $VVEC_v = \underline{v}(t_1)$, INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7/2^5$.
2) $VTARGET_v = \underline{v}(t_2)$, TERMINAL VELOCITY VECTOR, IS COMPUTED ONLY IF n_1 IS CLEAR, IN METERS/CSEC, AT $2^7/2^5$.
3) $MPAC_v = VVEC_v$ IF n_1 IS SET, IS $VTARGET_v$ IF n_1 IS CLEAR.
4) COGA $= \cot\gamma$, COTANGENT OF FLIGHT PATH ANGLE MEASURED FROM THE VERTICAL, CORRESPONDS TO LAST CALCULATED VALUE OF TIME t_{21}, AT 2^5.
5) SOLNSW $= f_5$, A FLAG, IS CLEAR IF LAMBERT WAS ABLE TO CALCULATE A VALID SOLUTION, IS SET IF NO SOLUTION WAS POSSIBLE DUE TO A TRANSFER ANGLE TOO CLOSE TO 0° OR 360°, OR A TIME t_{21} TOO SMALL.
6) PUSH LIST POINTER IS LEFT AT ØD.

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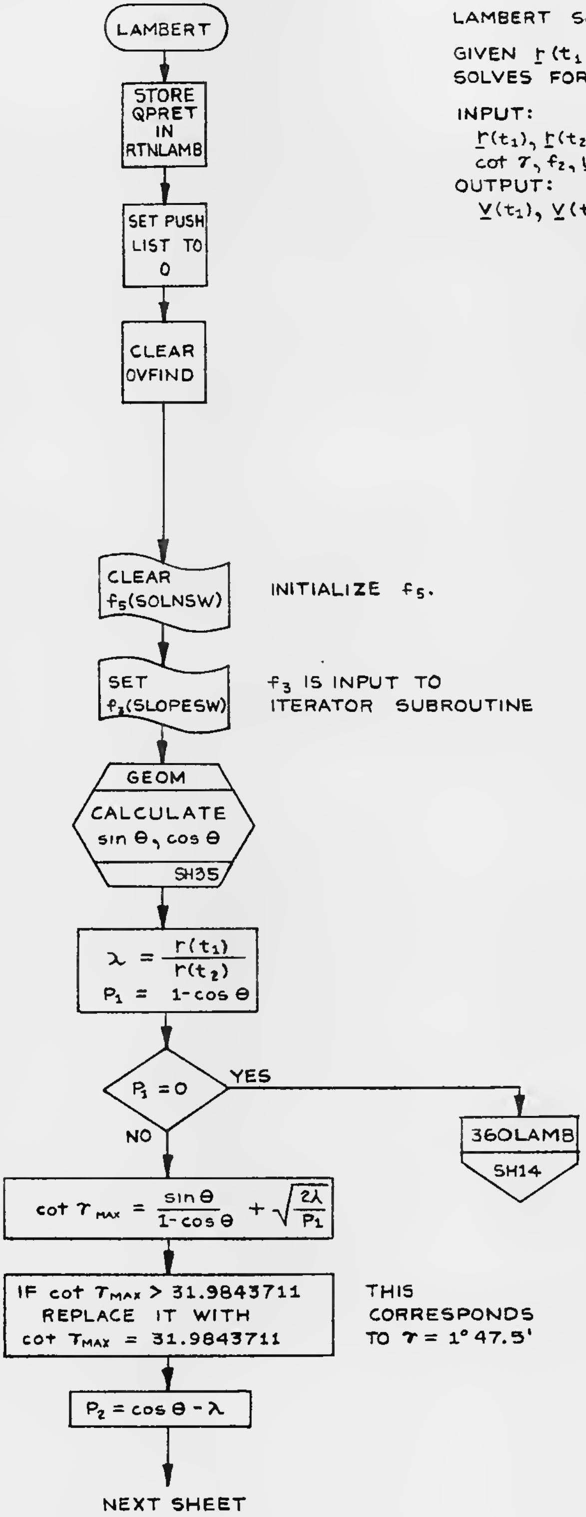
GENERAL FLOW DIAGRAM OF LAMBERT SUBROUTINE

GIVEN $\underline{r}(t_1)$, $\underline{r}(t_2)$, t_{D21}, SOLVES FOR $\underline{V}(t_1)$, $\underline{V}(t_2)$.

INPUT:
$\underline{r}(t_1)$, $\underline{r}(t_2)$, t_{D21}, S_G, n_1, f_1, $\cot \gamma$, f_2, $\underline{U}_N$, X1, i_{MAX}.

OUTPUT:
$\underline{V}(t_1)$, $\underline{V}(t_2)$, $\cot \gamma$, f_5.



INITIALIZE f_5.

f_3 IS INPUT TO ITERATOR SUBROUTINE

SET f_5 AND RETURN

THIS CORRESPONDS TO $\gamma = 1° 47.5'$

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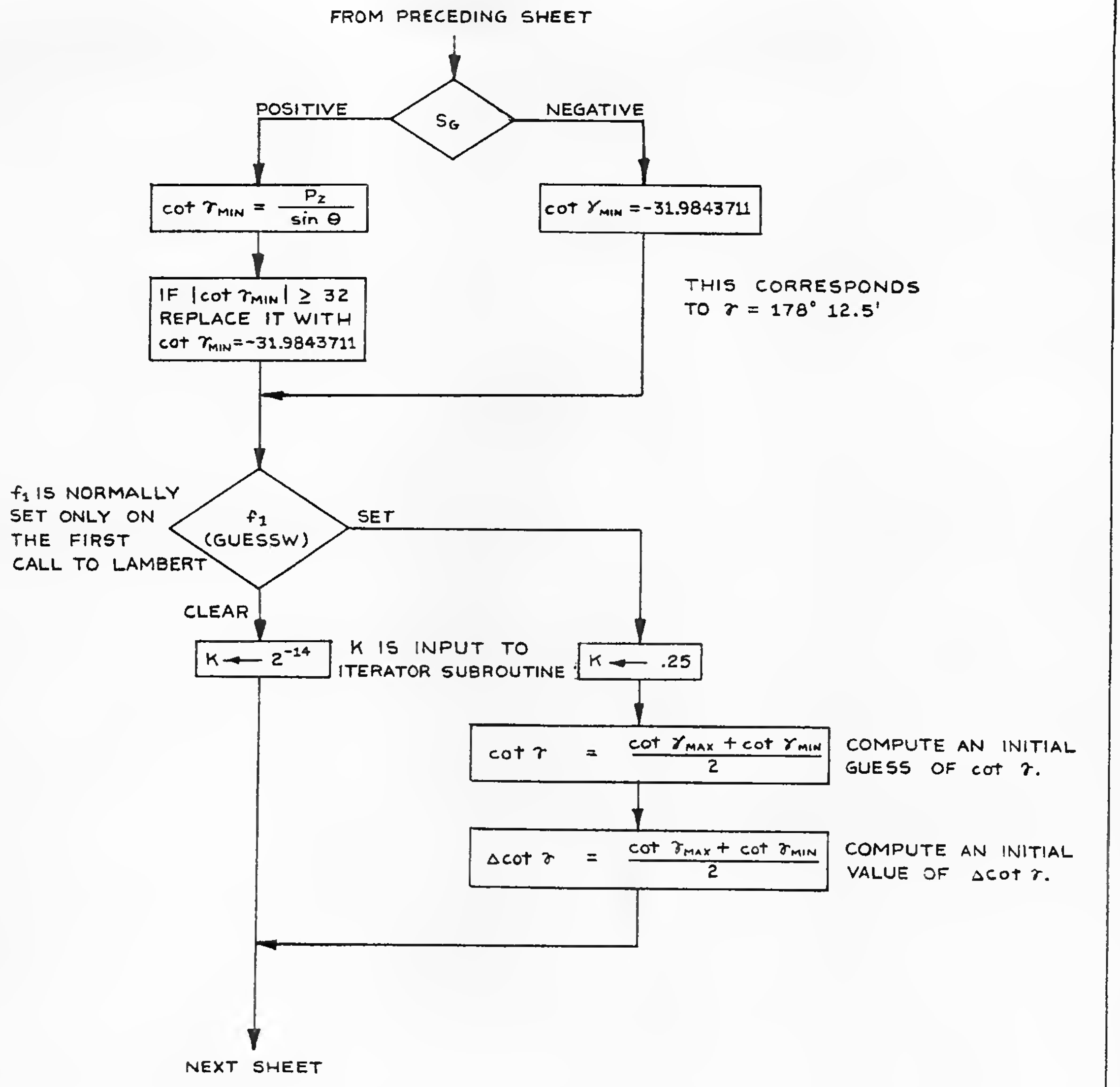

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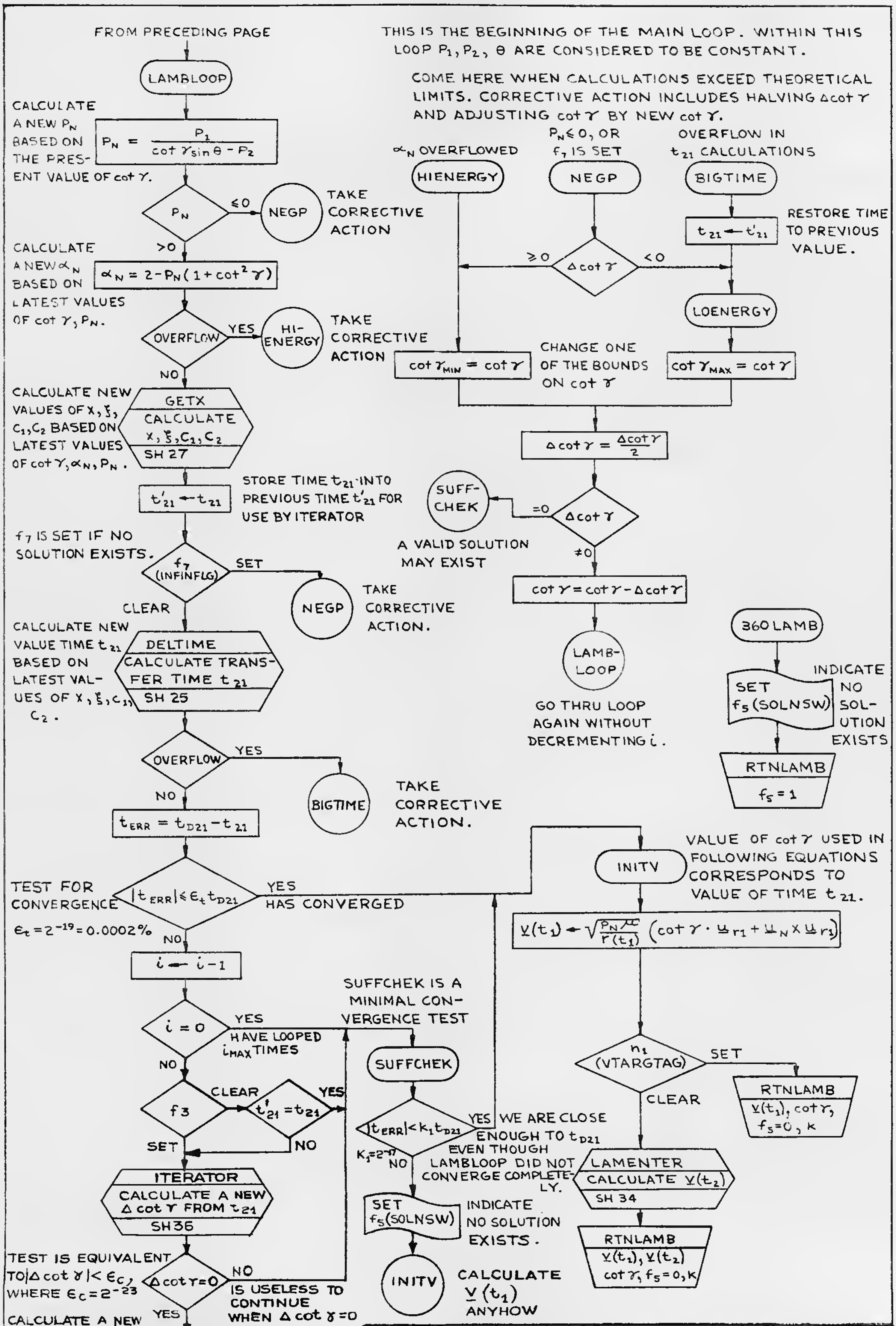

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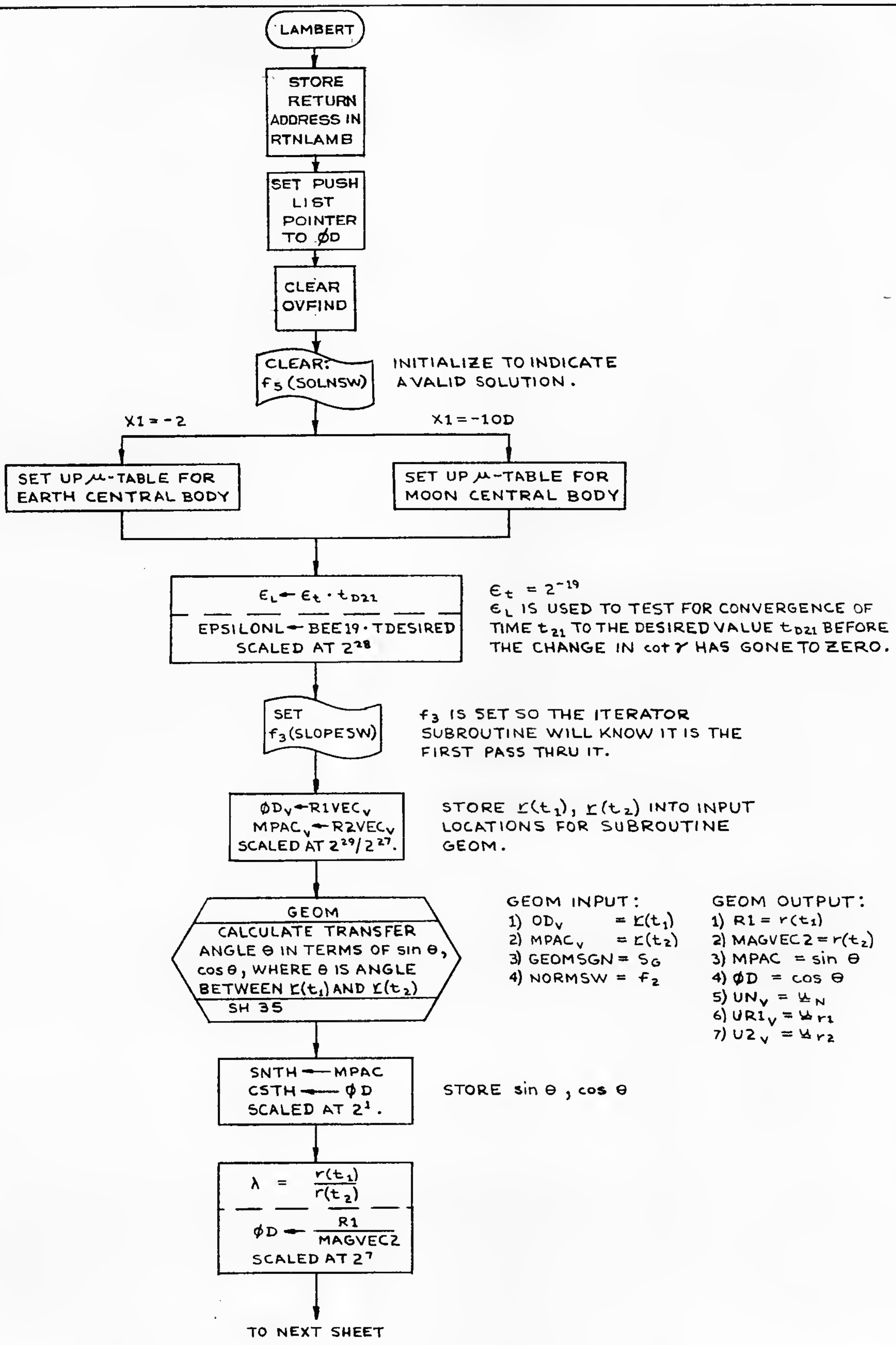

INITIALIZE TO INDICATE A VALID SOLUTION.

$\epsilon_t = 2^{-19}$

ϵ_L IS USED TO TEST FOR CONVERGENCE OF TIME t_{21} TO THE DESIRED VALUE t_{D21} BEFORE THE CHANGE IN $\cot\gamma$ HAS GONE TO ZERO.

f_3 IS SET SO THE ITERATOR SUBROUTINE WILL KNOW IT IS THE FIRST PASS THRU IT.

STORE $\underline{r}(t_1)$, $\underline{r}(t_2)$ INTO INPUT LOCATIONS FOR SUBROUTINE GEOM.

GEOM INPUT:

1) $OD_V = \underline{r}(t_1)$
2) $MPAC_V = \underline{r}(t_2)$
3) GEOMSGN = S_G
4) NORMSW = f_2

GEOM OUTPUT:

1) R1 = $r(t_1)$
2) MAGVEC2 = $r(t_2)$
3) MPAC = $\sin\theta$
4) ØD = $\cos\theta$
5) $UN_V = \underline{u}_N$
6) $UR1_V = \underline{u}_{r1}$
7) $U2_V = \underline{u}_{r2}$

STORE $\sin\theta$, $\cos\theta$

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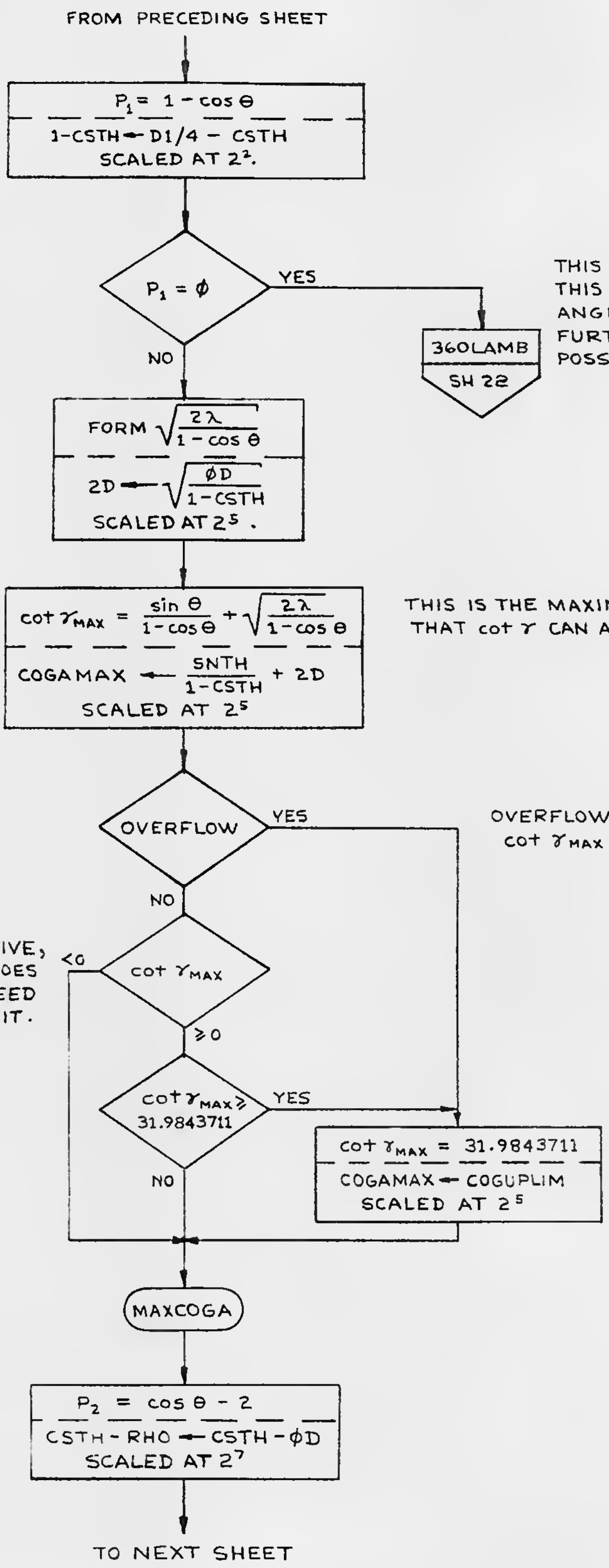

THIS TEST IS EQUIVALENT TO $P_1 < 2^{-26}$. THIS CORRESPONDS TO A TRANSFER ANGLE θ WITHIN 35 ARC-SECONDS 70° OR 360° FURTHER CALCULATIONS ARE POSSIBLE. SET f_5 AND RETURN.

THIS IS THE MAXIMUM THEORETICAL VALUE THAT $\cot\gamma$ CAN ACHIEVE BASED ON θ, λ, P_1 .

OVERFLOW IMPLIES $|\gamma| < 1° 47.5'$ AND HENCE $\cot\gamma_{MAX}$ EXCEEDS UPPER LIMIT.

IF NEGATIVE, $\cot\gamma_{MAX}$ DOES NOT EXCEED UPPER LIMIT.

SET $\cot\gamma_{MAX}$ EQUAL TO UPPER LIMIT. THIS IS THE LARGEST VALUE POSSIBLE FOR $\cot\gamma$ THAT WILL NOT PRODUCE OVERFLOW IN α_N CALCULATIONS.

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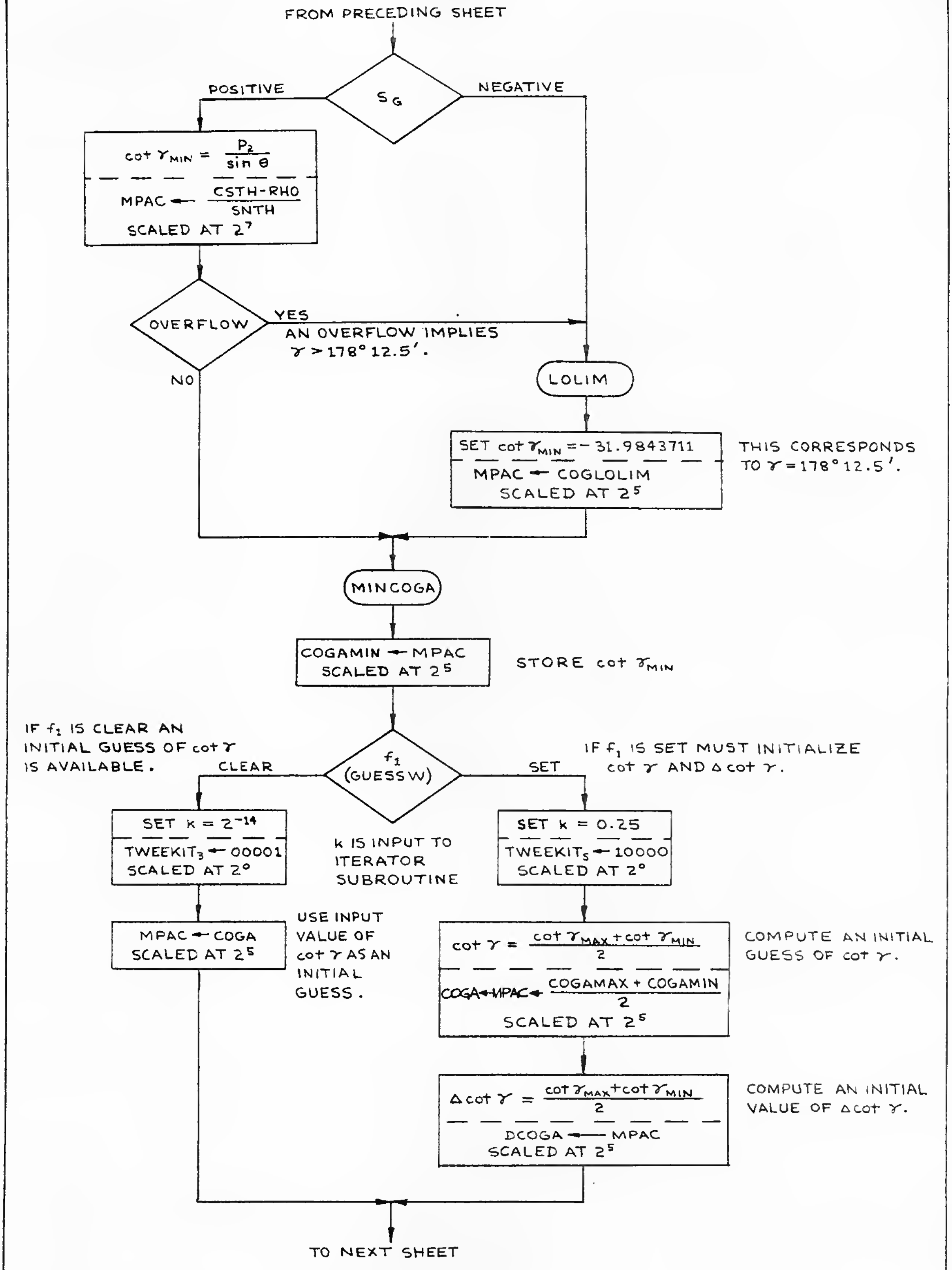

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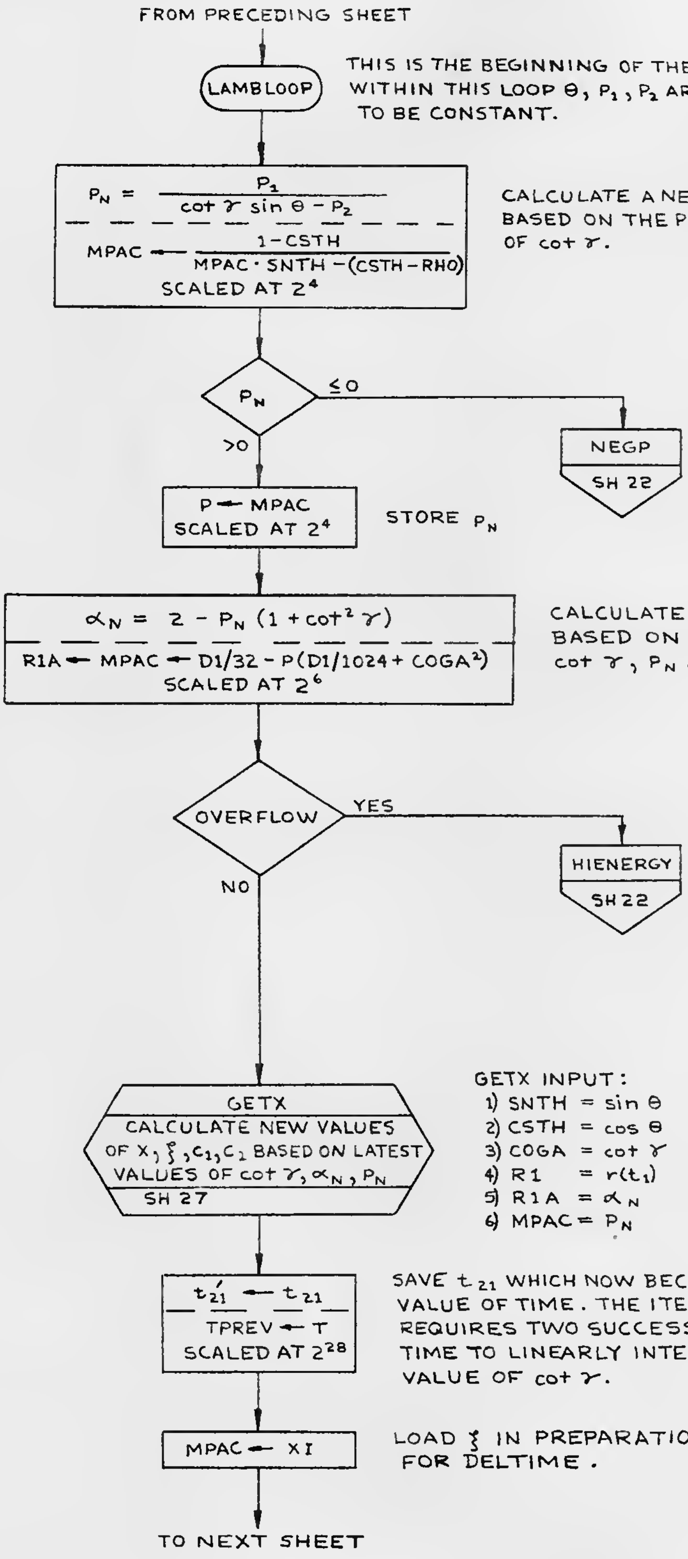

THIS IS THE BEGINNING OF THE MAIN LOOP. WITHIN THIS LOOP θ, P_1, P_2 ARE CONSIDERED TO BE CONSTANT.

CALCULATE A NEW VALUE OF P_N BASED ON THE PRESENT VALUE OF cot γ.

HAVE EXCEEDED THEORETICAL LIMITS. TAKE CORRECTIVE ACTION.

STORE P_N

CALCULATE A NEW VALUE OF α_N BASED ON LATEST VALUES OF cot γ, P_N.

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

GETX INPUT:

1) SNTH = sin θ
2) CSTH = cos θ
3) COGA = cot γ
4) R1 = $r(t_1)$
5) R1A = α_N
6) MPAC = P_N

GETX OUTPUT:

1) X = x
2) XI = ξ
3) KEPC1 = c_1
4) KEPC2 = c_2
5) ΦD = x^2
6) INFINFLG = f_7

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

LOAD ξ IN PREPARATION FOR DELTIME.

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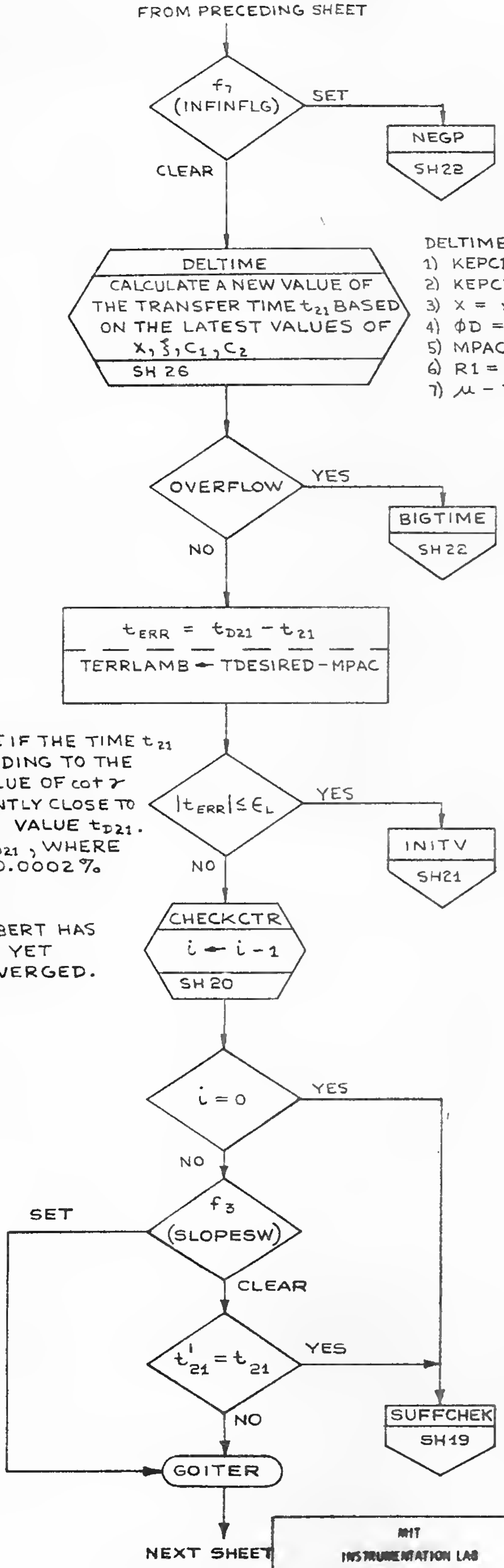

f_7 IS SET IN SUBROUTINE GETX IF CONIC IS REQUIRED TO PASS THROUGH INFINITY. TAKE CORRECTIVE ACTION.

DELTIME INPUT:
1) KEPC1 = C_1
2) KEPC2 = C_2
3) X = x
4) ΦD = x^2
5) MPAC = XI = ξ
6) R1 = $r(t_1)$
7) μ − TABLE

DELTIME OUTPUT:
1) T = MPAC = t_{21}
2) S(XI) = $S(\xi)$
3) XSQC(XI) = $x^2 c(\xi)$
4) OVIND = OVERFLOW INDICATOR

OVERFLOW MAY HAVE OCCURED DURING CALCULATION OF t_{21} IN DELTIME. TAKE CORRECTIVE ACTION.

TEST TO SEE IF THE TIME t_{21} CORRESPONDING TO THE LATEST VALUE OF $\cot \gamma$ IS SUFFICIENTLY CLOSE TO THE DESIRED VALUE t_{D21}. $\epsilon_L = \epsilon_t \cdot t_{D21}$, WHERE $\epsilon_t = 2^{-19} = 0.0002\%$

LAMBERT HAS SUCCESSFULLY CONVERGED. GO TO FINAL CALCULATIONS.

LAMBERT HAS NOT YET CONVERGED.

EVEN THOUGH i HAS GONE TO ZERO THE TIME t_{21} MAY HAVE CONVERGED IN A MINIMAL SENSE.
GO TO SUFFCHEK FOR THIS MINIMAL CONVERGENCE TEST.

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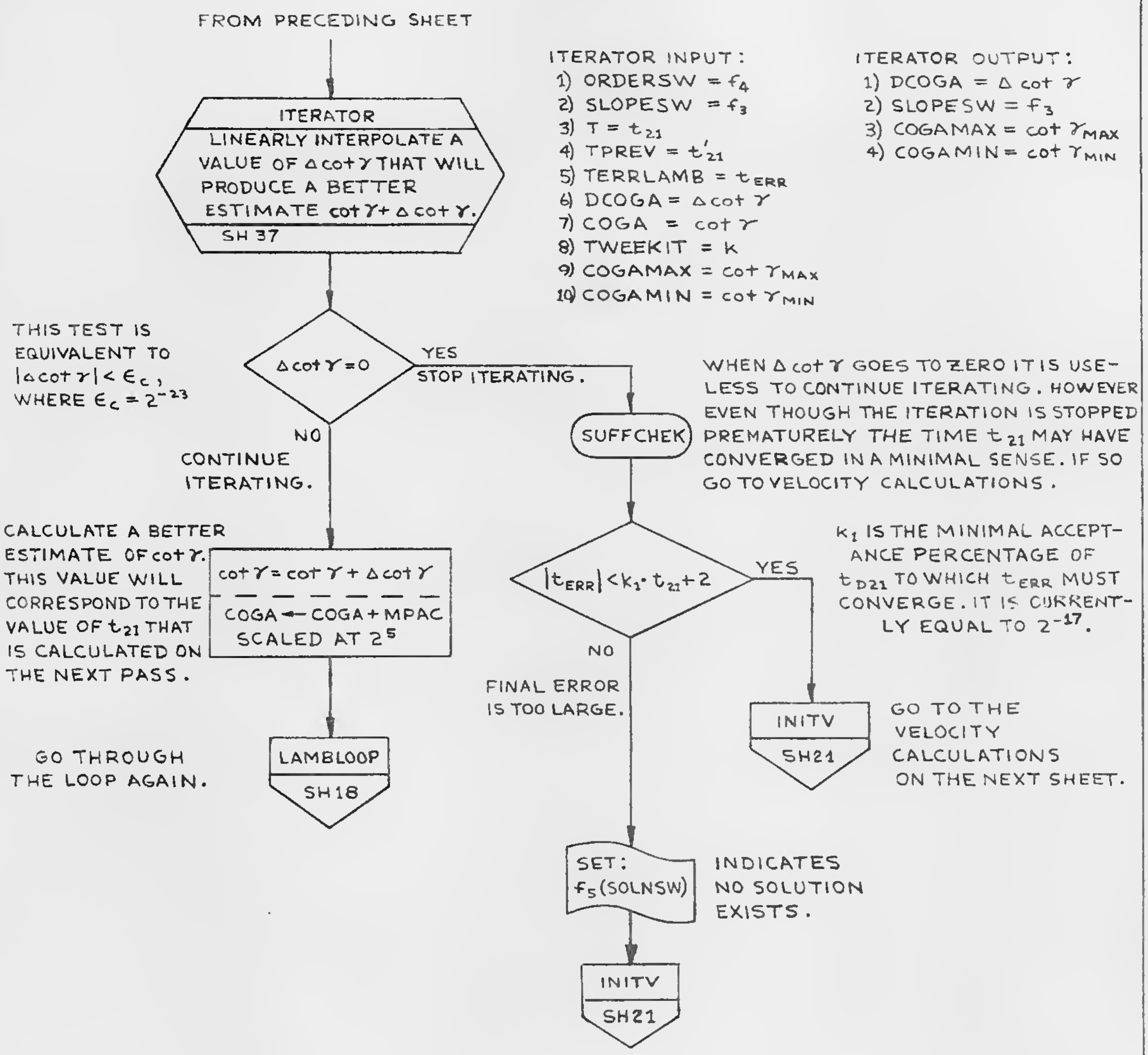
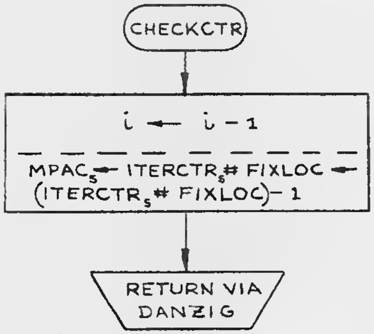


ITERATOR INPUT:
1) ORDERSW $= f_4$
2) SLOPESW $= f_3$
3) $T = t_{21}$
4) TPREV $= t'_{21}$
5) TERRLAMB $= t_{ERR}$
6) DCOGA $= \Delta\cot\gamma$
7) COGA $= \cot\gamma$
8) TWEEKIT $= k$
9) COGAMAX $= \cot\gamma_{MAX}$
10) COGAMIN $= \cot\gamma_{MIN}$

ITERATOR OUTPUT:
1) DCOGA $= \Delta\cot\gamma$
2) SLOPESW $= f_3$
3) COGAMAX $= \cot\gamma_{MAX}$
4) COGAMIN $= \cot\gamma_{MIN}$



THIS SUBROUTINE IS CODED IN BASIC LANGUAGE.

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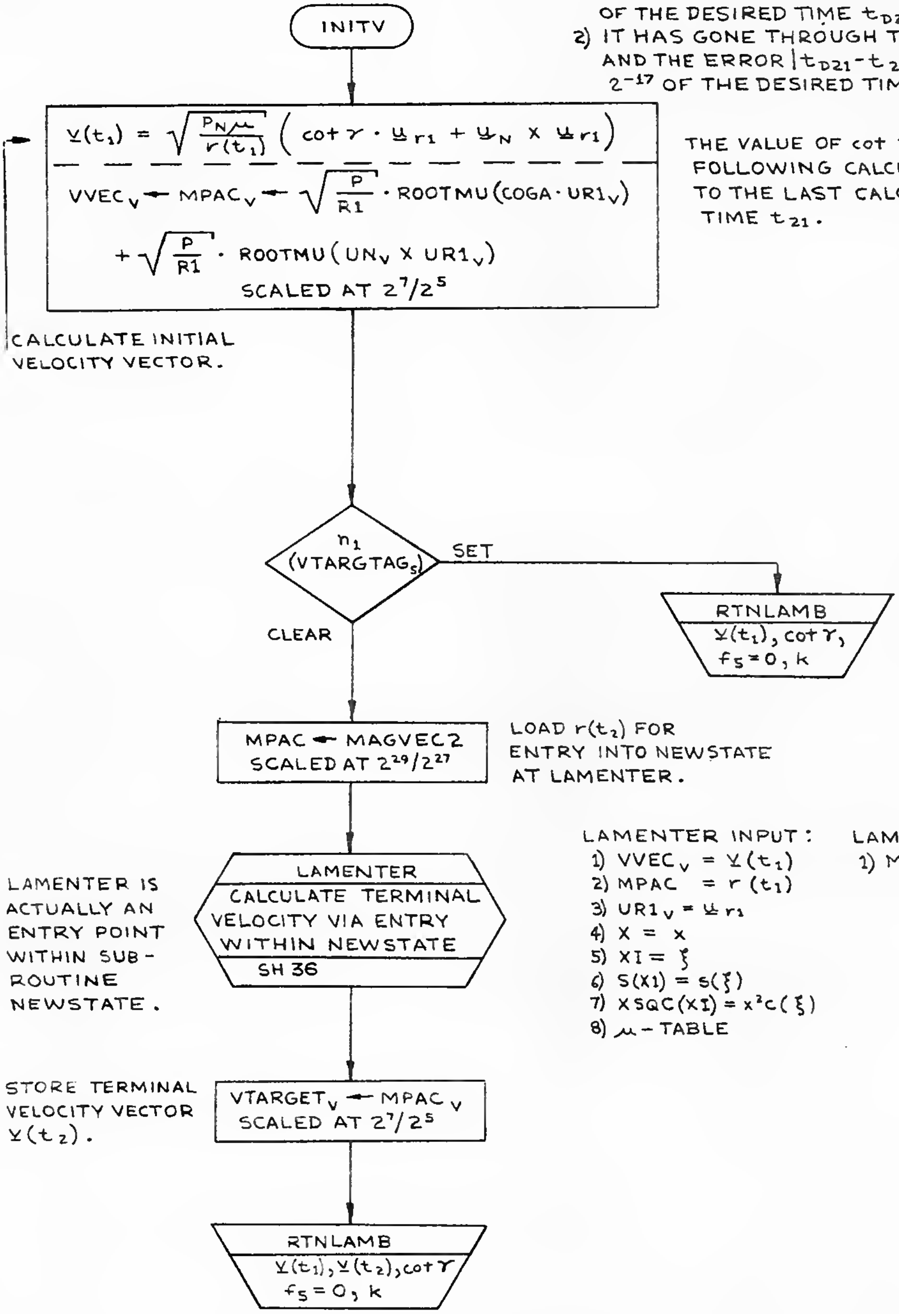
LAMBERT TERMINATES ITERATING AND COMES HERE FOR THE FINAL CALCULATIONS IF EITHER:

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



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

CALCULATE INITIAL VELOCITY VECTOR.

IF n_1 IS SET DO NOT CALCULATE TERMINAL VELOCITY.

LOAD $r(t_2)$ FOR ENTRY INTO NEWSTATE AT LAMENTER.

LAMENTER IS ACTUALLY AN ENTRY POINT WITHIN SUBROUTINE NEWSTATE.

LAMENTER INPUT:

1) $VVEC_v = \underline{v}(t_1)$
2) $MPAC = r(t_1)$
3) $UR1_v = \underline{u}_{r1}$
4) $X = x$
5) $XI = \xi$
6) $S(XI) = s(\xi)$
7) $XSQC(XI) = x^2c(\xi)$
8) μ - TABLE

LAMENTER OUTPUT:

1) $MPAC_v = \underline{v}(t_2)$

STORE TERMINAL VELOCITY VECTOR $\underline{v}(t_2)$.

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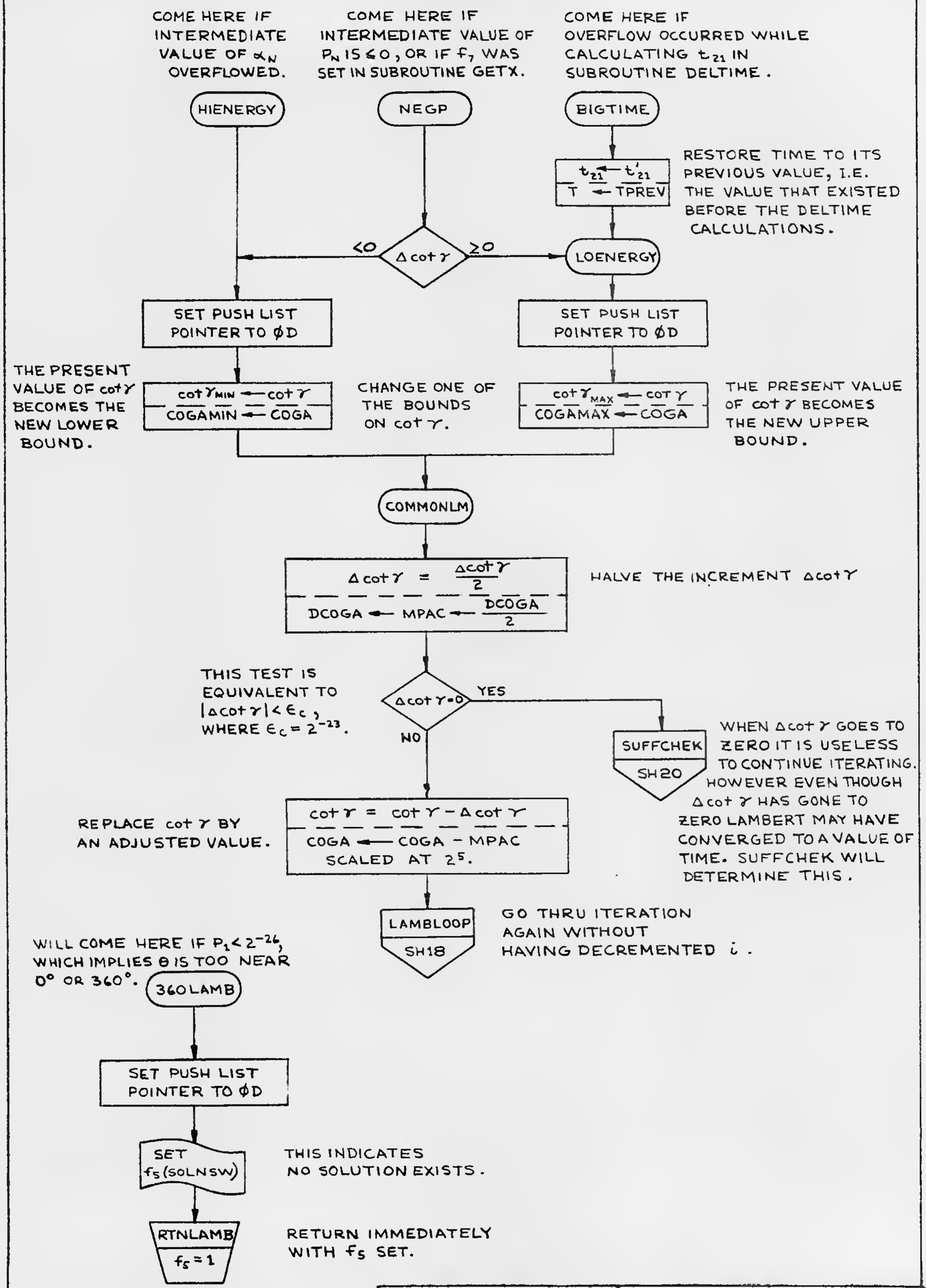
PROGRAM COMES TO ONE OF THESE ENTRIES WHENEVER THE CALCULATIONS EXCEED THE THEORETICAL BOUNDS. CORRECTIVE ACTION IS TAKEN BY HALVING THE INCREMENT $\Delta \cot \gamma$ AND THEN ADJUSTING THE VALUE OF $\cot \gamma$ WITH THE NEW $\Delta \cot \gamma$.



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GIVEN THE INITIAL STATE VECTOR $\underline{r}(t_1)$ AND $\underline{v}(t_1)$ AND THE DESIRED TRUE ANOMALY DIFFERENCE θ, THIS SUBROUTINE CALCULATES THE CORRESPONDING TIME OF FLIGHT t_{21} AND OPTIONALLY THE FINAL STATE VECTOR $\underline{r}(t_2)$ AND $\underline{v}(t_2)$.

CALLED BY:

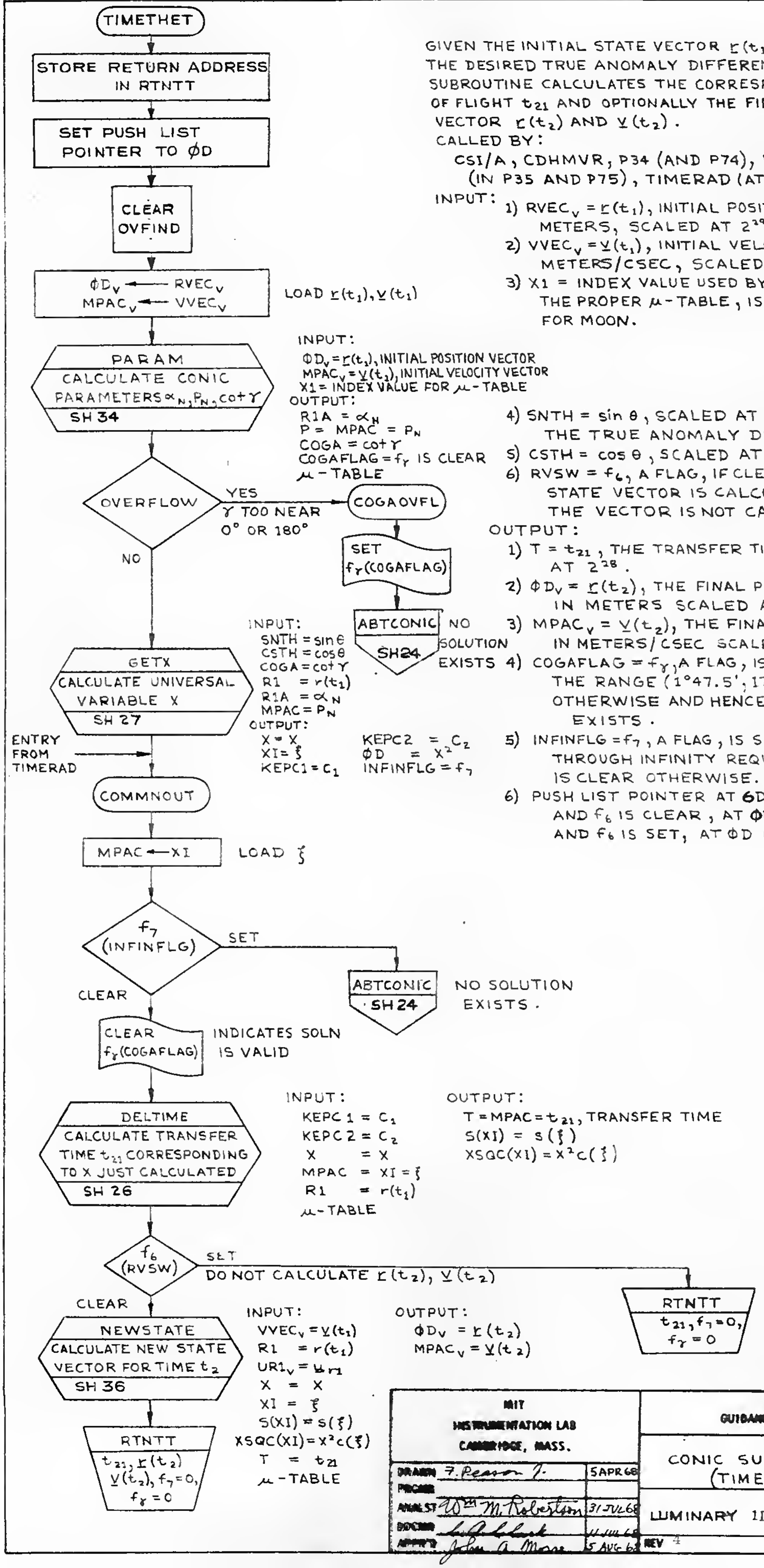
CSI/A, CDHMVR, P34 (AND P74), PREC/TT (IN P35 AND P75), TIMERAD (AT COMMNOUT)

INPUT:

1) $RVEC_V = \underline{r}(t_1)$, INITIAL POSITION VECTOR, IN METERS, SCALED AT $2^{29}/2^{27}$.
2) $VVEC_V = \underline{v}(t_1)$, INITIAL VELOCITY VECTOR, IN METERS/CSEC, SCALED AT $2^7/2^5$.
3) X1 = INDEX VALUE USED BY PARAM TO SET UP THE PROPER μ-TABLE, IS -2 FOR EARTH, -10D FOR MOON.
4) SNTH = sin θ, SCALED AT 2^1, WHERE θ IS THE TRUE ANOMALY DIFFERENCE.
5) CSTH = cos θ, SCALED AT 2^1.
6) RVSW = f_6, A FLAG, IF CLEAR THE FINAL STATE VECTOR IS CALCULATED, IF SET THE VECTOR IS NOT CALCULATED.

OUTPUT:

1) T = t_{21}, THE TRANSFER TIME IN CSEC SCALED AT 2^{28}.
2) $\phi D_V = \underline{r}(t_2)$, THE FINAL POSITION VECTOR, IN METERS SCALED AT $2^{29}/2^{27}$.
3) $MPAC_V = \underline{v}(t_2)$, THE FINAL VELOCITY VECTOR, IN METERS/CSEC SCALED AT $2^7/2^5$.
4) COGAFLAG = f_γ, A FLAG, IS CLEARED IF γ IN THE RANGE (1°47.5', 178°12.5'), IS SET OTHERWISE AND HENCE NO SOLUTION EXISTS.
5) INFINFLG = f_7, A FLAG, IS SET IF CLOSURE THROUGH INFINITY REQUIRED (NO SOLUTION). IS CLEAR OTHERWISE.
6) PUSH LIST POINTER AT 6D IF SOLN EXISTS AND f_6 IS CLEAR, AT ΦD IF SOLN EXISTS AND f_6 IS SET, AT ΦD IF NO SOLN EXISTS.



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GIVEN THE INITIAL STATE VECTOR $\underline{r}(t_1)$ AND $\underline{v}(t_1)$ AND A DESIRED RADIUS $r(t_2)$ TO WHICH THE STATE VECTOR IS TO BE UPDATED, THIS SUBROUTINE CALCULATES THE TRANSFER TIME t_{21} AND OPTIONALLY THE NEW STATE VECTOR.

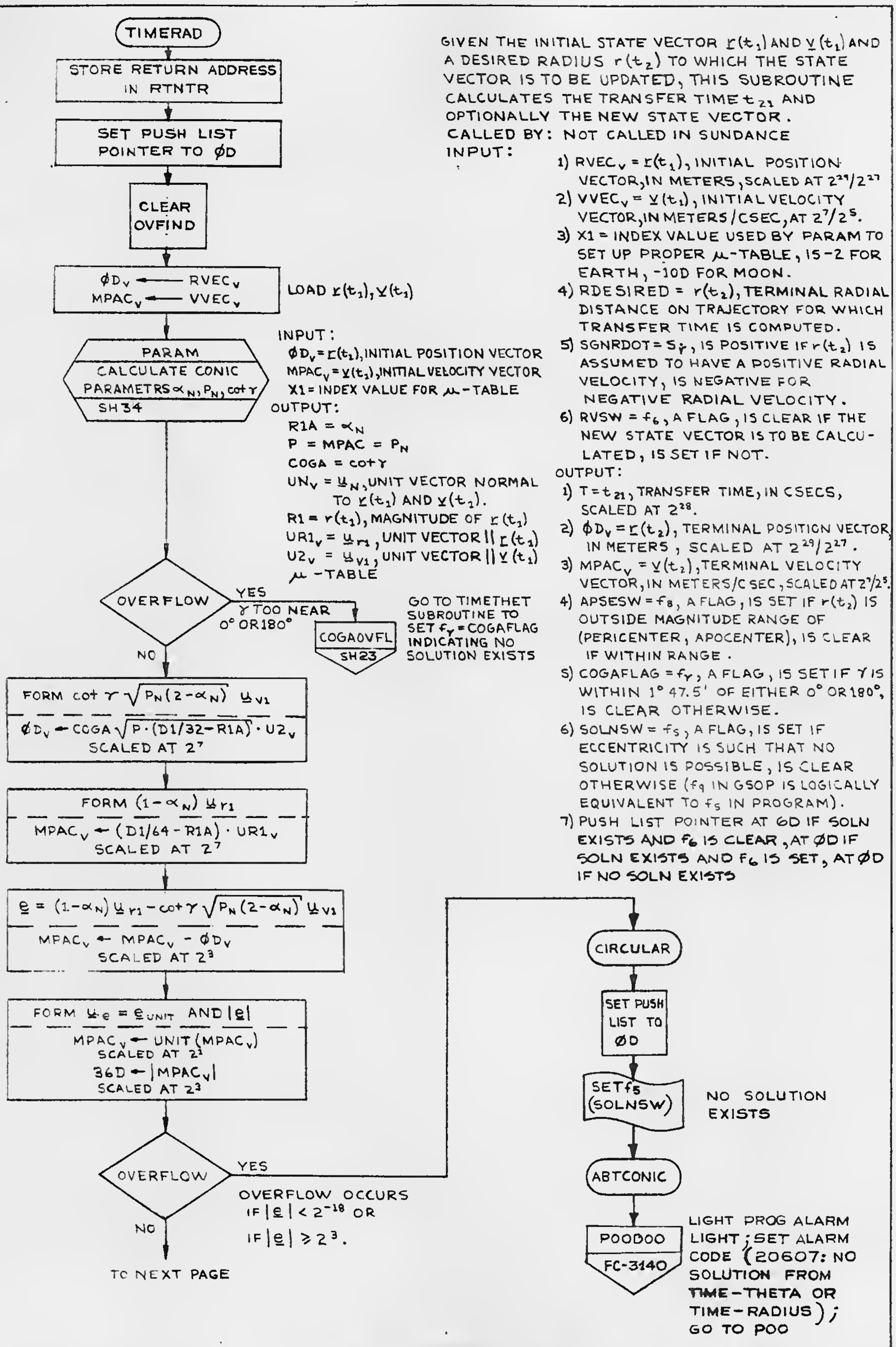
CALLED BY: NOT CALLED IN SUNDANCE

INPUT:

1) $RVEC_v = \underline{r}(t_1)$, INITIAL POSITION VECTOR, IN METERS, SCALED AT $2^{29}/2^{27}$
2) $VVEC_v = \underline{v}(t_1)$, INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7/2^5$.
3) X1 = INDEX VALUE USED BY PARAM TO SET UP PROPER μ-TABLE, 15-2 FOR EARTH, -10D FOR MOON.
4) RDESIRED = $r(t_2)$, TERMINAL RADIAL DISTANCE ON TRAJECTORY FOR WHICH TRANSFER TIME IS COMPUTED.
5) SGNRDOT = $S_{\dot{r}}$, IS POSITIVE IF $r(t_2)$ IS ASSUMED TO HAVE A POSITIVE RADIAL VELOCITY, IS NEGATIVE FOR NEGATIVE RADIAL VELOCITY.
6) RVSW = f_6, A FLAG, IS CLEAR IF THE NEW STATE VECTOR IS TO BE CALCULATED, IS SET IF NOT.

OUTPUT:

1) $T = t_{21}$, TRANSFER TIME, IN CSECS, SCALED AT 2^{28}.
2) $ØD_v = \underline{r}(t_2)$, TERMINAL POSITION VECTOR, IN METERS, SCALED AT $2^{29}/2^{27}$.
3) $MPAC_v = \underline{v}(t_2)$, TERMINAL VELOCITY VECTOR, IN METERS/CSEC, SCALED AT $2^7/2^5$.
4) APSESW = f_8, A FLAG, IS SET IF $r(t_2)$ IS OUTSIDE MAGNITUDE RANGE OF (PERICENTER, APOCENTER), IS CLEAR IF WITHIN RANGE.
5) COGAFLAG = f_γ, A FLAG, IS SET IF γ IS WITHIN 1° 47.5' OF EITHER 0° OR 180°, IS CLEAR OTHERWISE.
6) SOLNSW = f_5, A FLAG, IS SET IF ECCENTRICITY IS SUCH THAT NO SOLUTION IS POSSIBLE, IS CLEAR OTHERWISE (f_9 IN GSOP IS LOGICALLY EQUIVALENT TO f_5 IN PROGRAM).
7) PUSH LIST POINTER AT 6D IF SOLN EXISTS AND f_6 IS CLEAR, AT ØD IF SOLN EXISTS AND f_6 IS SET, AT ØD IF NO SOLN EXISTS



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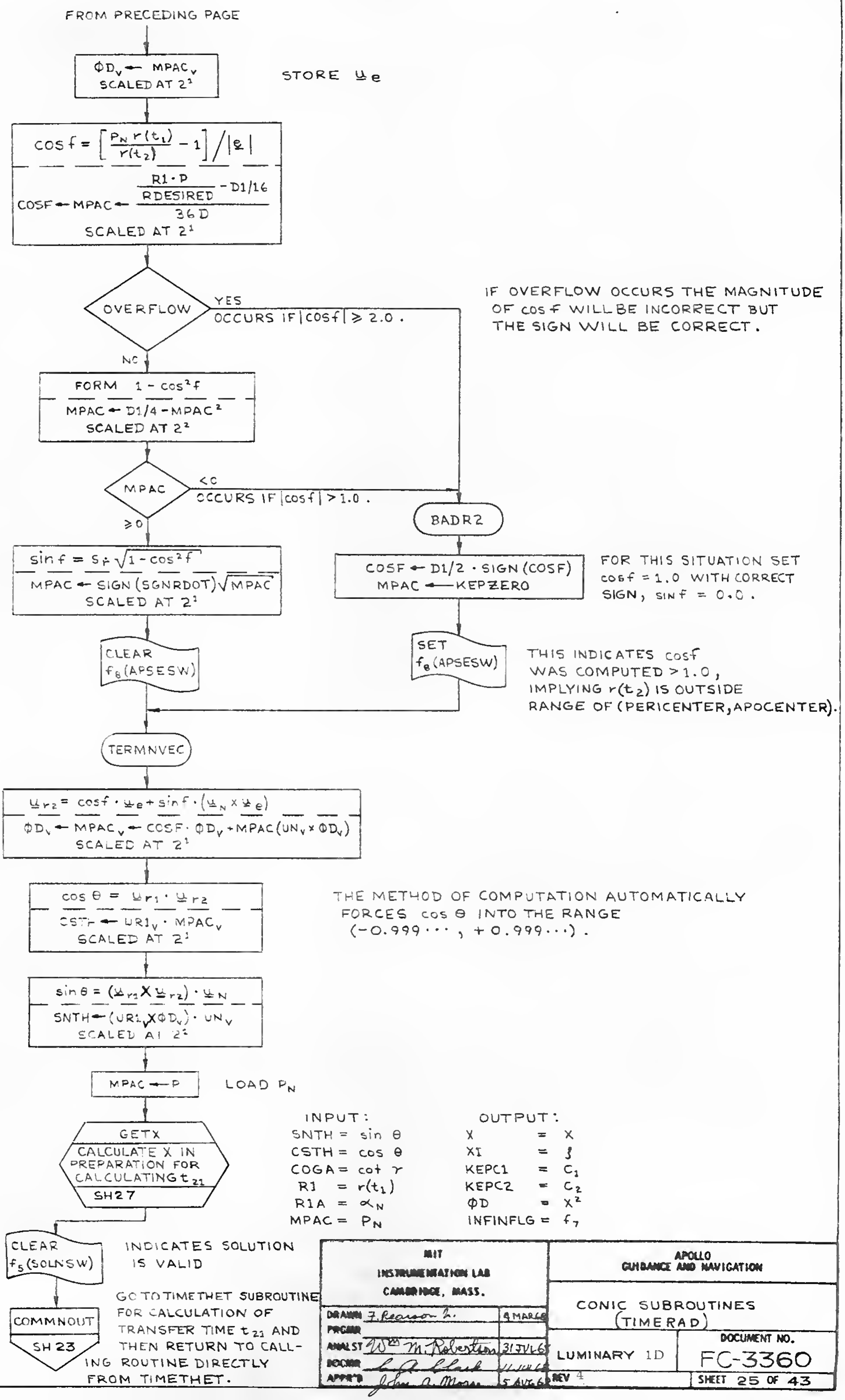

STORE $\underline{u}_e$

IF OVERFLOW OCCURS THE MAGNITUDE OF cos f WILL BE INCORRECT BUT THE SIGN WILL BE CORRECT.

FOR THIS SITUATION SET cos f = 1.0 WITH CORRECT SIGN, sin f = 0.0 .

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

THE METHOD OF COMPUTATION AUTOMATICALLY FORCES cos θ INTO THE RANGE (−0.999··· , +0.999···) .

LOAD P_N

INPUT:

SNTH = sin θ
CSTH = cos θ
COGA = cot γ
R1 = $r(t_1)$
R1A = α_N
MPAC = P_N

OUTPUT:

X = X
XI = ξ
KEPC1 = C_1
KEPC2 = C_2
ΦD = X^2
INFINFLG = f_7

INDICATES SOLUTION IS VALID

GO TO TIMETHET SUBROUTINE FOR CALCULATION OF TRANSFER TIME t_{21} AND THEN RETURN TO CALLING ROUTINE DIRECTLY FROM TIMETHET.

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GIVEN A VALUE OF THE UNIVERSAL VARIABLE x, AND THE VALUES C_1, C_2, AND ξ, THIS SUBROUTINE CALCULATES THE CORRESPONDING TRANSFER TIME t_{21}.

CALLED BY :

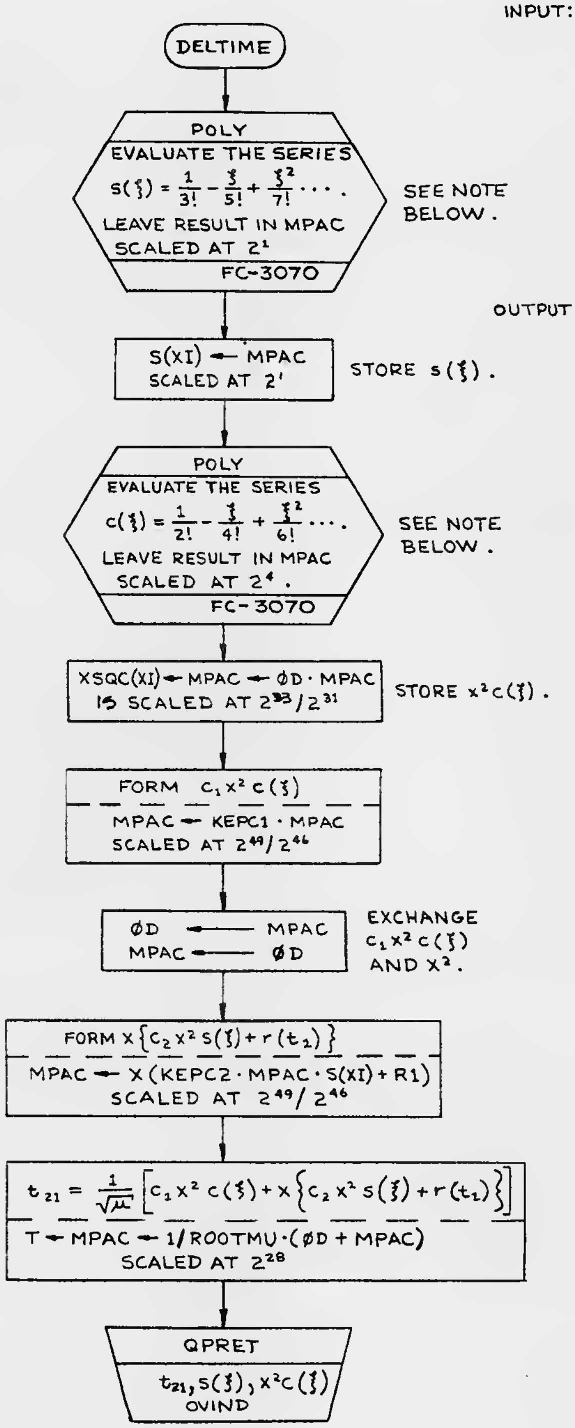
KEPLERN, LAMBERT, TIMETHET.

INPUT:

1) KEPC1 = c_1 AT $2^{17}/2^{16}$.
2) KEPC2 = c_2 AT 2^6.
3) X = x, UNIVERSAL VARIABLE, AT $2^{17}/2^{16}$.
4) 0D = x^2, NORMALIZED AT $2^{34-n}/2^{32-n}$.
5) X1 = INDEX REGISTER CONTAINING THE NORMALIZING VALUE $-n$.
6) MPAC = ξ, AT 2^6 .
7) R1 = $r(t_1)$, THE MAGNITUDE OF $\underline{r}(t_1)$, AT $2^{29}/2^{27}$.
8) μ-TABLE APPROPRIATE FOR EITHER EARTH OR MOON .
9) THE PUSH LIST POINTER IS AT 2D.

OUTPUT:

1) T = MPAC = t_{21}, TRANSFER TIME, IN CSECS, AT 2^{28} .
2) S(XI) = $s(\xi)$, AT 2^1.
3) XSQC(XI) = $x^2 c(\xi)$, AT $2^{33}/2^{31}$.
4) OVFIND = THE OVERFLOW INDICATOR, IT MAY BE TURNED ON AS A RESULT OF t_{21} CALCULATION, IMPLYING THE VALUE OF X AT INPUT WAS TOO LARGE .
5) PUSH LIST POINTER IS LEFT AT 0D .



NOTE:

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

$s(\xi)$	$c(\xi)$
0.083333334×2^1	0.031250001×2^4
$-0.266666684 \times 2^{-5}$	$-0.166666719 \times 2^{-2}$
$0.406349155 \times 2^{-11}$	$0.355555413 \times 2^{-8}$
$-0.361198675 \times 2^{-17}$	$-0.406347410 \times 2^{-14}$
$0.210153242 \times 2^{-23}$	$0.288962094 \times 2^{-20}$
$-0.086221951 \times 2^{-29}$	$-0.140117894 \times 2^{-26}$
$0.026268812 \times 2^{-35}$	$0.049247387 \times 2^{-32}$
$-0.006163316 \times 2^{-41}$	$-0.013081923 \times 2^{-38}$
$0.001177342 \times 2^{-47}$	$0.002806389 \times 2^{-44}$
$-0.000199055 \times 2^{-53}$	$-0.000529414 \times 2^{-50}$

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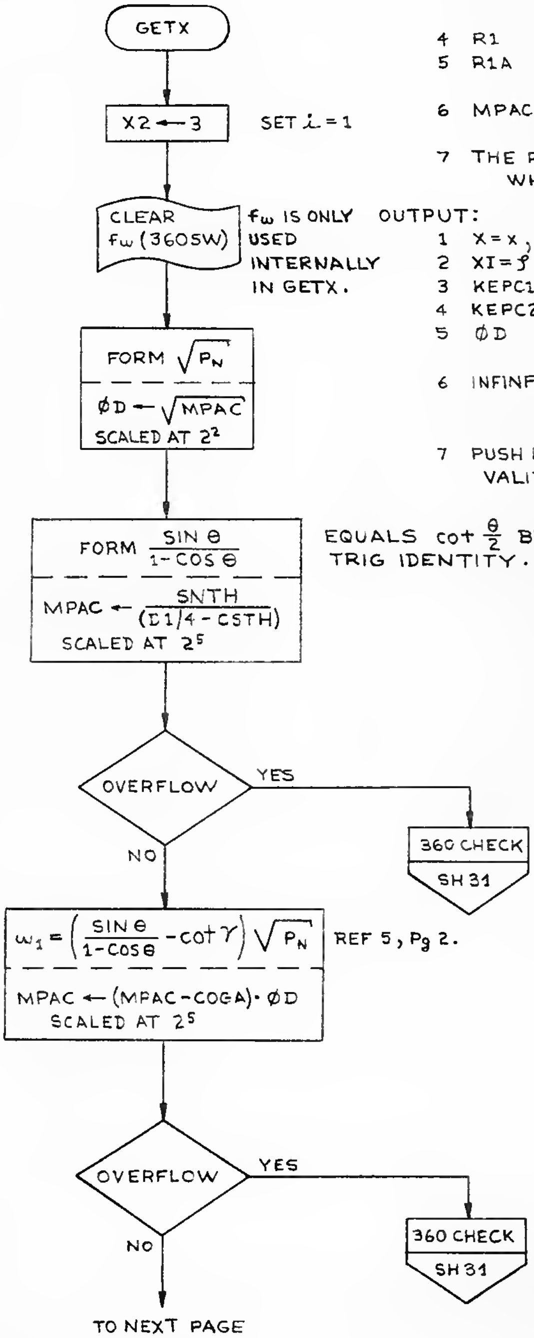
THIS SUBROUTINE COMPUTES THE UNIVERSAL VARIABLE X REQUIRED BY THE TIME EQUATION.
CALLED BY: LAMBERT, TIMERAD, TIMETHET

INPUT:

1 SNTH = sin θ SCALED AT 2^1, WHERE θ IS THE TRANSFER ANGLE.
2 CSTH = cos θ SCALED AT 2^1.
3 COGA = cot γ, THE COTANGENT OF THE FLIGHT PATH ANGLE MEASURED FROM THE VERTICAL, SCALED AT 2^5
4 R1 = $r(t_1)$, THE MAGNITUDE OF $\underline{r}(t_1)$, SCALED AT $2^{29}/2^{27}$.
5 R1A = α_N, THE RATIO OF $r(t_1)$ TO THE SEMI-MAJOR AXIS a, SCALED AT 2^6.
6 MPAC = P_N, THE RATIO OF THE SEMI-LATUS RECTUM TO $r(t_1)$, SCALED AT 2^4.
7 THE PUSH LIST POINTER CAN BE AT ANY VALUE PL, WHERE 0 ≤ PL ≤ 27D; IS NORMALLY AT 0D.

OUTPUT:

1 X = x, THE UNIVERSAL CONIC PARAMETER, SCALED AT $2^{17}/2^{16}$.
2 XI = ξ, WHERE $\xi = \alpha_N x_N^2$, SCALED AT 2^6.
3 KEPC1 = c_1, SCALED AT $2^{17}/2^{16}$
4 KEPC2 = c_2, SCALED AT 2^6.
5 0D = x^2, NORMALIZED SCALED AT $2^{34-N1}/2^{32-N1}$, AND -N1 IS IN X1.
6 INFINFLG = f_7, A FLAG, IS SET IF TRAJECTORY IS REQUIRED TO CLOSE THROUGH INFINITY, IS CLEAR IF SOLUTION IS VALID.
7 PUSH LIST POINTER IS LEFT AT PL+2 IF SOLUTION VALID, IS LEFT AT 0D IF f_7 IS SET.



SET $i = 1$

f_ω IS ONLY USED INTERNALLY IN GETX.

EQUALS cot $\frac{\theta}{2}$ BY TRIG IDENTITY.

OVERFLOW OCCURS IF $\left|\frac{\sin\theta}{1-\cos\theta}\right| = \left|\cot\frac{\theta}{2}\right| \geq 32.0$, CORRESPONDING TO $|\theta| \leq 3°35'$.

REF 5, Pg 2.

OVERFLOW OCCURS IF $|\omega_1| \geq 32.0$.

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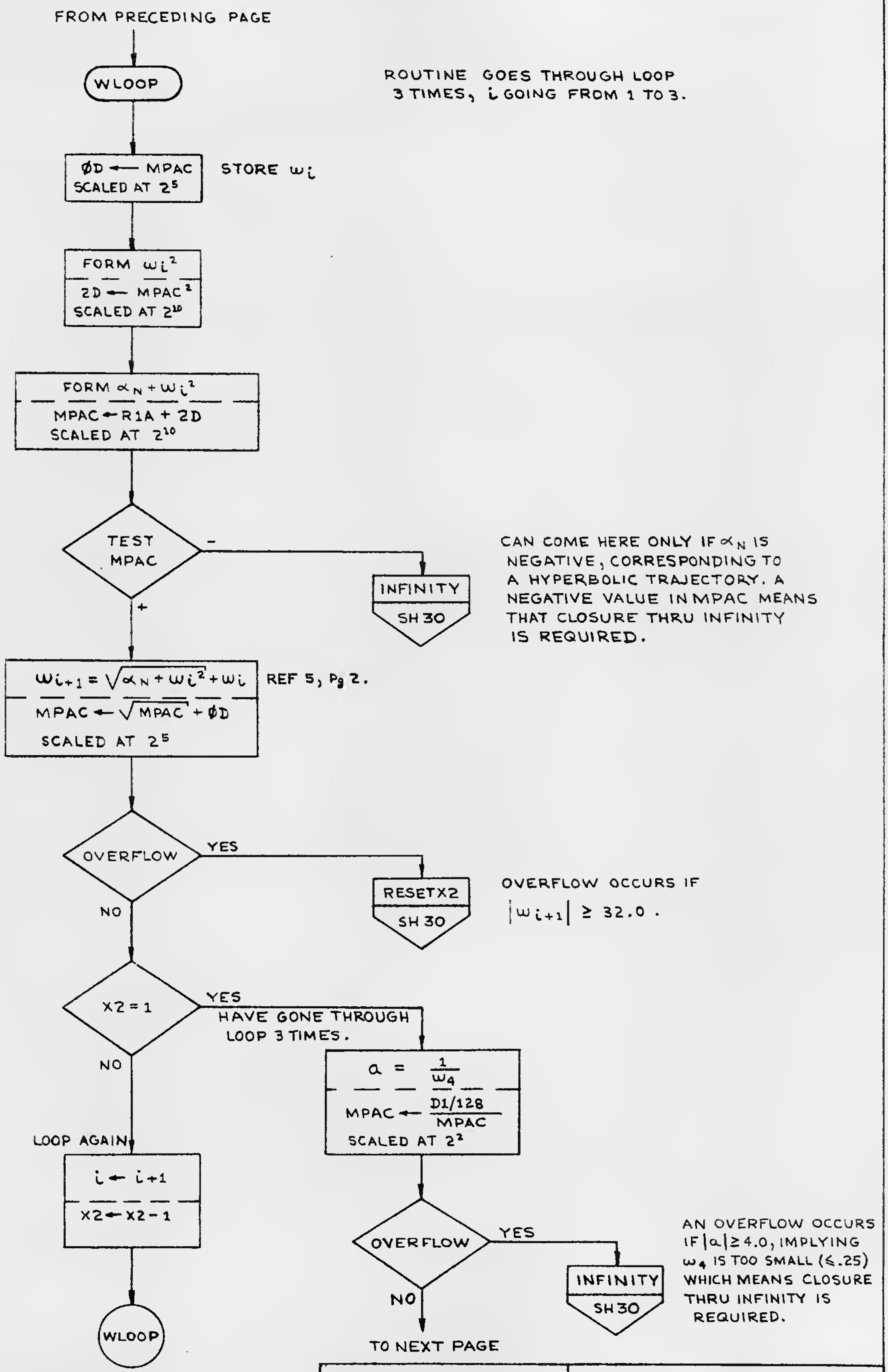

ROUTINE GOES THROUGH LOOP 3 TIMES, i GOING FROM 1 TO 3.

CAN COME HERE ONLY IF α_N IS NEGATIVE, CORRESPONDING TO A HYPERBOLIC TRAJECTORY. A NEGATIVE VALUE IN MPAC MEANS THAT CLOSURE THRU INFINITY IS REQUIRED.

OVERFLOW OCCURS IF $|\omega_{i+1}| \geq 32.0$.

AN OVERFLOW OCCURS IF $|a| \geq 4.0$, IMPLYING ω_4 IS TOO SMALL ($\leq .25$) WHICH MEANS CLOSURE THRU INFINITY IS REQUIRED.

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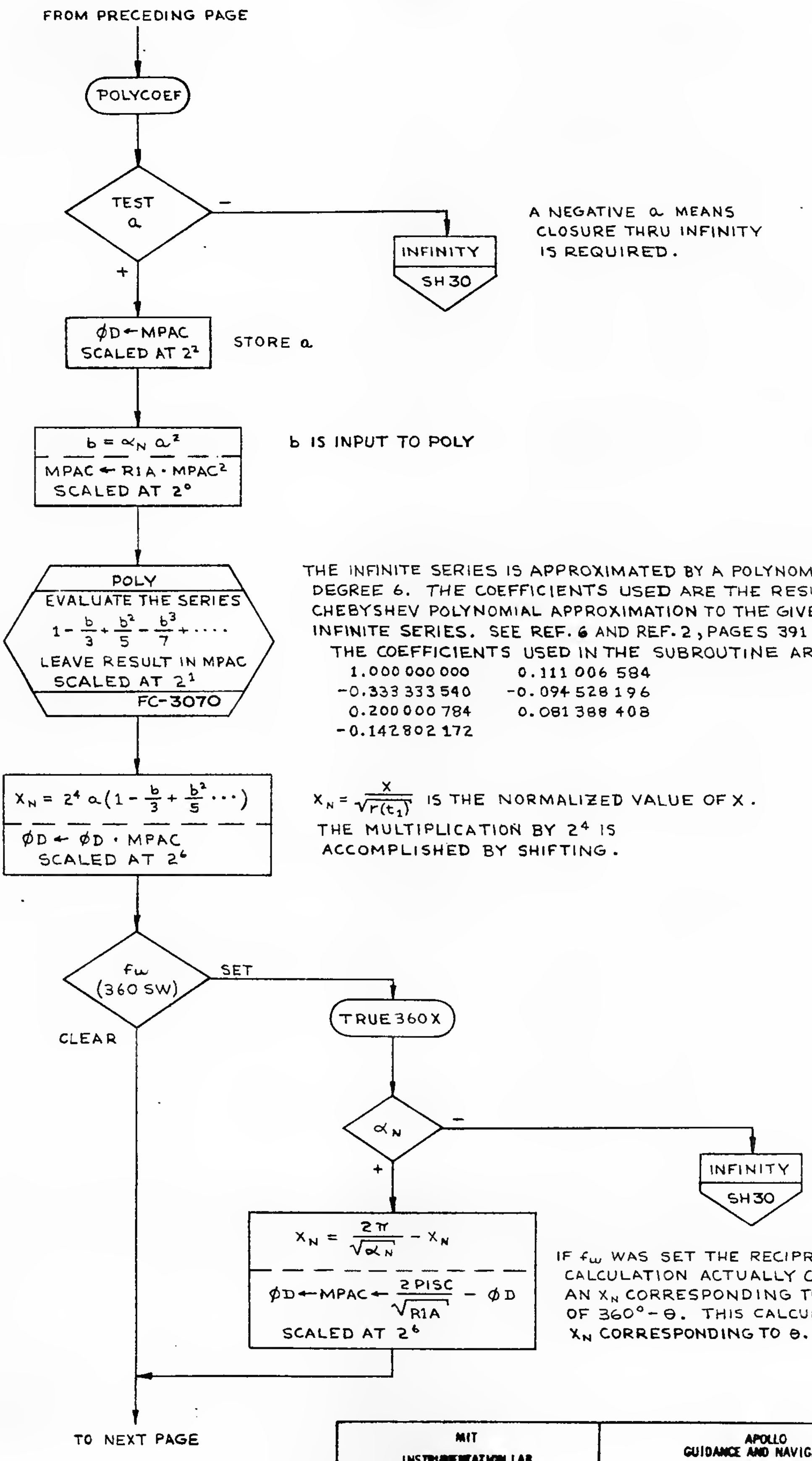

A NEGATIVE a MEANS CLOSURE THRU INFINITY IS REQUIRED.

STORE a

b IS INPUT TO POLY

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1.000 000 000	0.111 006 584
-0.333 333 540	-0.094 528 196
0.200 000 784	0.081 388 408
-0.142 802 172	

$x_N = \frac{x}{\sqrt{r(t_1)}}$ IS THE NORMALIZED VALUE OF X. THE MULTIPLICATION BY 2^4 IS ACCOMPLISHED BY SHIFTING.

IF f_ω WAS SET THE RECIPROCAL CALCULATION ACTUALLY COMPUTED AN X_N CORRESPONDING TO AN ANGLE OF $360° - \theta$. THIS CALCULATES THE X_N CORRESPONDING TO θ.

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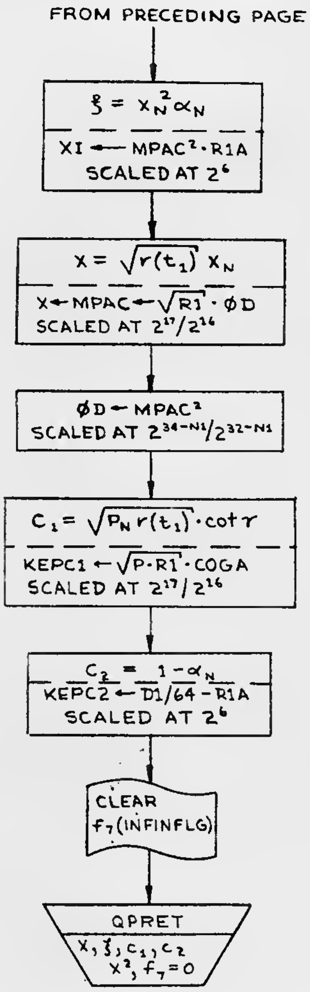
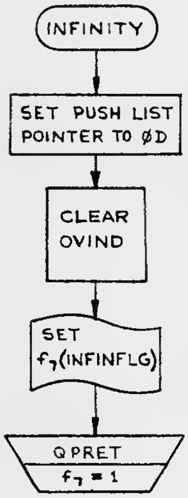


STORE X^2 NORMALIZED, WITH
−N1 IN X1.

INDICATES SOLUTION
IS VALID.



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

CLEAR THE
OVERFLOW INDICATOR

THIS INDICATES CLOSURE
THROUGH INFINITY REQUIRED

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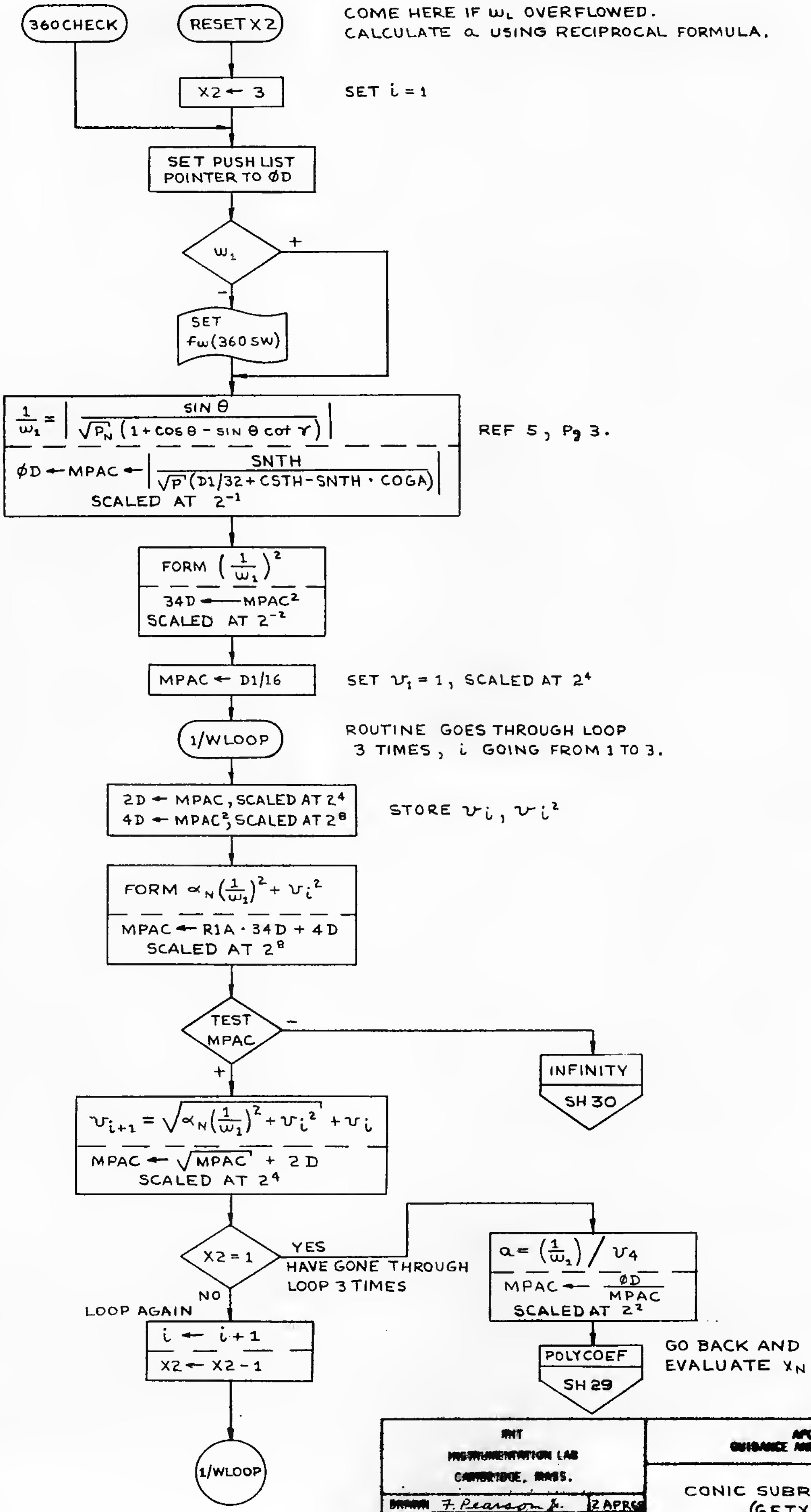

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RELATING EQUATIONS IN SUBROUTINE TO EQUATIONS GIVEN IN REFRENCE 5

THE EQUATIONS USED IN SUBROUTINE GETX FOR CALCULATING THE VARIABLE x ARE NOT IDENTICAL TO THE EQUATIONS GIVEN IN REF. 5, PAGES 2 AND 3, BUT ARE AN EQUIVALENT SET OF NORMALIZED EQUATIONS. THE FOLLOWING DEMONSTRATES THEIR EQUIVALENCE.

NOTATION

r = POSITION VECTOR MAGNITUDE
γ = FLIGHT PATH ANGLE
p = SEMI-LATUS RECTUM
$p_N = p/r$

α = RECIPROCAL OF SEMI-MAJOR AXIS
$\alpha_N = r\alpha$
θ = TRANSFER ANGLE
x = UNIVERSAL VARIABLE
$x_N = x/\sqrt{r}$

THE VARIABLE x CAN BE EXPRESSED EXPLICITLY AS:

$$x = \frac{2^i}{W_i}\left[1 - \frac{1}{3}\left(\frac{\alpha}{W_i^2}\right) + \frac{1}{5}\left(\frac{\alpha}{W_i^2}\right)^2 - \cdots\right],$$

WHERE THE VARIABLE W_i IS THE i^{TH} VALUE IN A SEQUENCE DEFINED RECURSIVELY AS:

$$W_1 = \left(\frac{\sin\theta}{1-\cos\theta} - \cot\gamma\right)\frac{\sqrt{P}}{r},$$

$$W_i = \sqrt{\alpha + W^2_{i-1}} + W_{i-1} \quad \text{FOR} \quad i = 2, 3, \cdots$$

IT HAS BEEN ESTABLISHED THAT IT IS SUFFICIENT TO GO ONLY TO W_4 TO EVALUATE x WITH THE REQUIRED ACCURACY. THUS

$$W_4 = \sqrt{\alpha + W_3^2} + W_3 \quad \text{AND}$$

$$x = \frac{2^4}{W_4}\left[1 - \frac{1}{3}\left(\frac{\alpha}{W_4^2}\right) + \frac{1}{5}\left(\frac{\alpha}{W_4^2}\right)^2 - \cdots\right]$$

THE SUBROUTINE EVALUATES A VARIABLE ω_i RECURSIVELY THROUGH ω_4 AS:

$$\omega_1 = \left(\frac{\sin\theta}{1-\cos\theta} - \cot\gamma\right)\sqrt{\frac{P}{r}},$$

$$\omega_i = \sqrt{\alpha_N + \omega_{i-1}^2} + \omega_{i-1} \quad \text{FOR} \quad i = 2, 3, 4 .$$

THE RELATION BETWEEN ω_i AND W_i IS AS FOLLOWS:

$$\omega_1 = \sqrt{r}\, W_1$$
$$\omega_2 = \sqrt{\alpha_N + \omega_1^2} + \omega_1 = \sqrt{r\alpha + rW_1^2} + \sqrt{r}\,W_1 = \sqrt{r}\,W_2$$
$$\omega_3 = \sqrt{\alpha_N + \omega_2^2} + \omega_2 = \sqrt{r\alpha + rW_2^2} + \sqrt{r}\,W_2 = \sqrt{r}\,W_3$$
$$\omega_4 = \sqrt{\alpha_N + \omega_3^2} + \omega_3 = \sqrt{r\alpha + rW_3^2} + \sqrt{r}\,W_3 = \sqrt{r}\,W_4$$

SUBSTITUTING $\frac{\sqrt{r}}{\omega_4}$ FOR $\frac{1}{W_4}$ IN THE EQUATION FOR x GIVES:

$$x = \frac{2^4\sqrt{r}}{\omega_4}\left[1 - \frac{1}{3}\left(\frac{r\alpha}{\omega_4^2}\right) + \frac{1}{5}\left(\frac{r\alpha}{\omega_4^2}\right)^2 - \cdots\right].$$

REPLACING $r\alpha$ BY α_N GIVES

$$x_N = \frac{x}{\sqrt{r}} = \frac{2^4}{\omega_4}\left[1 - \frac{1}{3}\left(\frac{\alpha_N}{\omega_4^2}\right) + \frac{1}{5}\left(\frac{\alpha_N}{\omega_4^2}\right)^2 - \cdots\right].$$

LET $a = \frac{1}{\omega_4}$ AND $b = \alpha_N a^2 = \frac{\alpha_N}{\omega_4^2}$ AND SUBSTITUTE IN EQUATION TO GET

$$x_N = 2^4 a\left[1 - \frac{1}{3}b + \frac{1}{5}b^2 - \frac{1}{7}b^3 + \cdots\right].$$

THIS IS THE FORM OF THE EQUATION AS IT IS CODED IN THE SUBROUTINE USING THE ABOVE VALUES OF a AND b.

FOR THE RECIPROCAL CASE, THE RECIPROCAL OF W_1 IS GIVEN BY

$$\frac{1}{W_1} = \frac{\sin\theta}{1 + \cos\theta - \sin\theta\cot\gamma}\left(\frac{r}{\sqrt{P}}\right).$$

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A VARIABLE V_i IS DEFINED RECURSIVELY IN REF. 5 AS

$$V_1 = 1$$

$$V_i = \sqrt{\frac{\alpha}{W_1^2} + V_{i-1}^2} + V_{i-1} \quad \text{FOR } i = 2, 3, \cdots .$$

THE RECIPROCAL $\frac{1}{W_4}$ IS DEFINED AS

$$\frac{1}{W_4} = \left(\frac{1}{W_1}\right) \Big/ V_4$$

THE SUBROUTINE EVALUATES INSTEAD THE VARIABLE $\frac{1}{\omega_1}$ AND VARIABLE υ_i RECURSIVELY THROUGH υ_4 AS:

$$\frac{1}{\omega_1} = \frac{\sin\theta}{1 + \cos\theta - \sin\theta \cot\gamma}\left(\frac{1}{\sqrt{P_N}}\right), \quad \text{WHERE } \frac{1}{\sqrt{P_N}} = \sqrt{\frac{r}{p}},$$

$$\upsilon_1 = 1$$

$$\upsilon_i = \sqrt{\frac{\alpha_N}{\omega_1^2} + \upsilon_{i-1}^2} + \upsilon_{i-1} \qquad \text{FOR } i = 2, 3, 4 .$$

THE RELATIONS BETWEEN $\frac{1}{\omega_1}$ AND $\frac{1}{W_1}$, AND υ_i AND V_i ARE AS FOLLOWS:

$$\frac{1}{\omega_1} = \frac{1}{\sqrt{r}}\,\frac{1}{W_1} \quad \text{AND HENCE} \quad \frac{\alpha_N}{\omega_1^2} = \frac{\alpha}{W_1^2},$$

$$\upsilon_1 = V_1$$

$$\upsilon_2 = \sqrt{\frac{\alpha_N}{\omega_1^2} + \upsilon_1^2} + \upsilon_1 = \sqrt{\frac{\alpha}{W_1^2} + V_1^2} + V_1 = V_2$$

$$\upsilon_3 = \sqrt{\frac{\alpha_N}{\omega_1^2} + \upsilon_2^2} + \upsilon_2 = \sqrt{\frac{\alpha}{W_1^2} + V_2^2} + V_2 = V_3$$

$$\upsilon_4 = \sqrt{\frac{\alpha_N}{\omega_1^2} + \upsilon_3^2} + \upsilon_3 = \sqrt{\frac{\alpha}{W_1^2} + V_3^2} + V_3 = V_4$$

SUBSTITUTING THESE VALUES OF $\frac{1}{W_1}$ AND V_4 BACK INTO THE EQUATION FOR $\frac{1}{W_4}$ GIVES

$$\frac{1}{W_4} = \left(\frac{1}{W_1}\right) \Big/ V_4 = \left(\frac{\sqrt{r}}{\omega_1}\right) \Big/ \upsilon_4 = \frac{\sqrt{r}}{\omega_1 \upsilon_4}$$

SUBSTITUTING THIS INTO THE EQUATION FOR X GIVES

$$X = \frac{2^4\sqrt{r}}{\omega_1 \upsilon_4}\left[1 - \frac{1}{3}\alpha\left(\frac{r}{\omega_1^2 \upsilon_4^2}\right) + \frac{1}{5}\alpha^2\left(\frac{r}{\omega_1^2 \upsilon_4^2}\right)^2 - \cdots\right] .$$

LETTING $a = \frac{1}{\omega_1 \upsilon_4}$ AND $b = \alpha_N a^2 = \frac{\alpha_N}{\omega_1^2 \upsilon_4^2}$, AND RECALLING THAT $\alpha_N = \alpha r$, GIVES

$$X_N = \frac{X}{\sqrt{r}} = 2^4 a\left[1 - \frac{1}{3}b + \frac{1}{5}b^2 - \frac{1}{7}b^3 + \cdots\right],$$

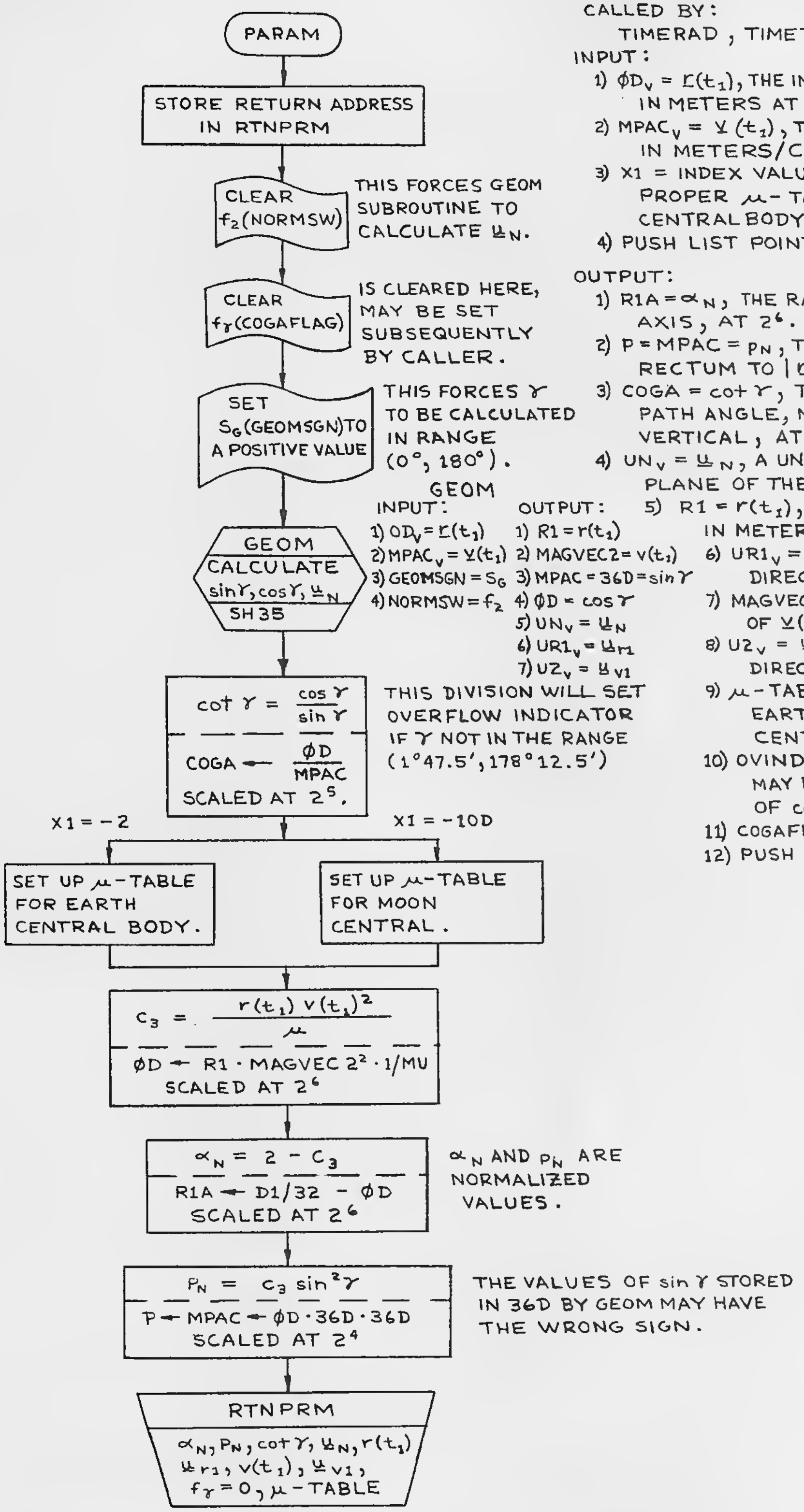
THIS IS EXACTLY THE SAME FORM FOR EVALUATING X_N AS IN THE PREVIOUS CASE, USING THE ABOVE VALUES OF a AND b.

THIS SUBROUTINE COMPUTES THE CONIC PARAMETERS α_N, p_N, $\cot\gamma$ FOR A GIVEN TIME t_1.

CALLED BY:
TIMERAD , TIMETHET

INPUT:
1) $\phi D_v = \underline{r}(t_1)$, THE INITIAL POSITION VECTOR, IN METERS AT $2^{29}/2^{27}$.
2) $MPAC_v = \underline{v}(t_1)$, THE INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7/2^5$.
3) X1 = INDEX VALUE USED TO SET UP THE PROPER μ- TABLE, IS -2 IF EARTH IS CENTRAL BODY, IS $-10D$ FOR THE MOON.
4) PUSH LIST POINTER IS AT 6D.

OUTPUT:
1) $R1A = \alpha_N$, THE RATIO OF $|\underline{r}(t_1)|$ TO SEMI-MAJOR AXIS, AT 2^6.
2) $P = MPAC = p_N$, THE RATIO OF THE SEMI-LATUS RECTUM TO $|\underline{r}(t_1)|$, AT 2^4.
3) $COGA = \cot\gamma$, THE COTAN OF THE FLIGHT PATH ANGLE, MEASURED FROM THE VERTICAL, AT 2^5.
4) $UN_v = \underline{u}_N$, A UNIT VECTOR NORMAL TO PLANE OF THE INPUT VECTORS, AT 2^1.
5) $R1 = r(t_1)$, THE MAGNITUDE OF $\underline{r}(t_1)$, IN METERS, AT $2^{29}/2^{27}$.
6) $UR1_v = \underline{u}_{r1}$, A UNIT VECTOR IN DIRECTION OF $\underline{r}(t_1)$, AT 2^1.
7) $MAGVEC2 = v(t_1)$, THE MAGNITUDE OF $\underline{v}(t_1)$, IN METERS/CSEC, AT $2^7/2^5$.
8) $U2_v = \underline{u}_{v1}$, UNIT VECTOR IN DIRECTION $\underline{v}(t_1)$, AT $2'$.
9) μ-TABLE APPROPRIATE TO EITHER EARTH CENTERED OR MOON CENTERED SYSTEM.
10) OVIND = THE OVERFLOW INDICATOR MAY BE SET IN CALCULATION OF $\cot\gamma$.
11) $COGAFLAG = f_\gamma$ IS CLEARED.
12) PUSH LIST POINTER AT ϕD.



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(PARAM)

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GIVEN TWO VECTORS $\underline{r}_1$ AND $\underline{r}_2$, THIS SUBROUTINE COMPUTES THE SINE AND COSINE OF THE ANGLE ϕ BETWEEN THEM, AND OPTIONALLY A UNIT VECTOR $\underline{u}_N$ NORMAL TO THE PLANE DEFINED BY THE VECTORS.

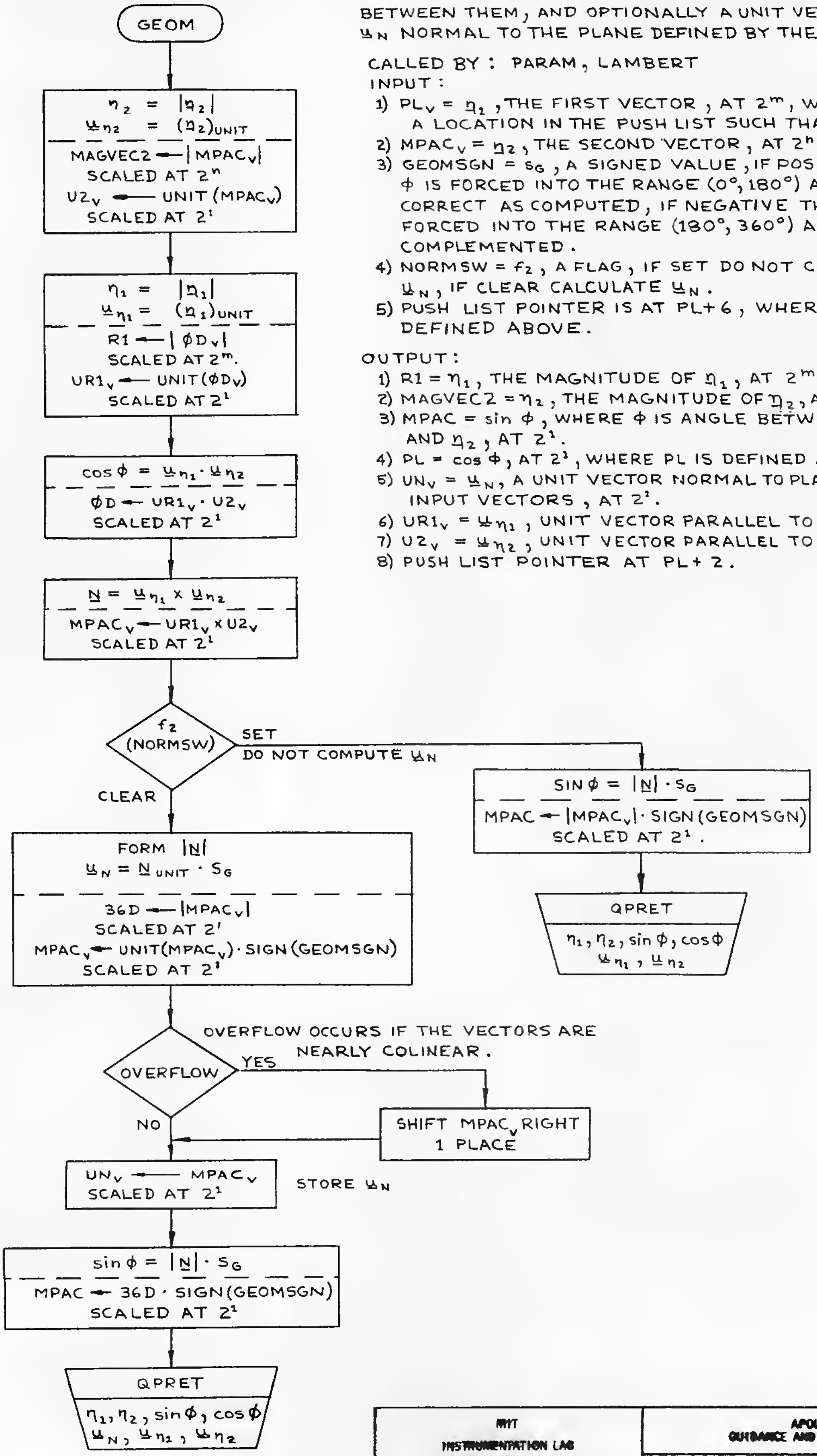
CALLED BY: PARAM, LAMBERT

INPUT:

1) $PL_v = \underline{r}_1$, THE FIRST VECTOR, AT 2^m, WHERE PL IS A LOCATION IN THE PUSH LIST SUCH THAT $0 \leq PL \leq 30D$.
2) $MPAC_v = \underline{r}_2$, THE SECOND VECTOR, AT 2^n.
3) GEOMSGN $= s_G$, A SIGNED VALUE, IF POSITIVE THEN ϕ IS FORCED INTO THE RANGE (0°, 180°) AND $\underline{u}_N$ IS CORRECT AS COMPUTED, IF NEGATIVE THEN ϕ IS FORCED INTO THE RANGE (180°, 360°) AND $\underline{u}_N$ IS COMPLEMENTED.
4) NORMSW $= f_2$, A FLAG, IF SET DO NOT CALCULATE $\underline{u}_N$, IF CLEAR CALCULATE $\underline{u}_N$.
5) PUSH LIST POINTER IS AT PL+6, WHERE PL IS DEFINED ABOVE.

OUTPUT:

1) $R1 = r_1$, THE MAGNITUDE OF $\underline{r}_1$, AT 2^m.
2) $MAGVEC2 = r_2$, THE MAGNITUDE OF $\underline{r}_2$, AT 2^n.
3) $MPAC = \sin\phi$, WHERE ϕ IS ANGLE BETWEEN $\underline{r}_1$ AND $\underline{r}_2$, AT 2^1.
4) $PL = \cos\phi$, AT 2^1, WHERE PL IS DEFINED ABOVE.
5) $UN_v = \underline{u}_N$, A UNIT VECTOR NORMAL TO PLANE OF INPUT VECTORS, AT 2^1.
6) $UR1_v = \underline{u}_{r1}$, UNIT VECTOR PARALLEL TO $\underline{r}_1$, AT 2^1.
7) $U2_v = \underline{u}_{r2}$, UNIT VECTOR PARALLEL TO $\underline{r}_2$, AT 2^1.
8) PUSH LIST POINTER AT PL+2.



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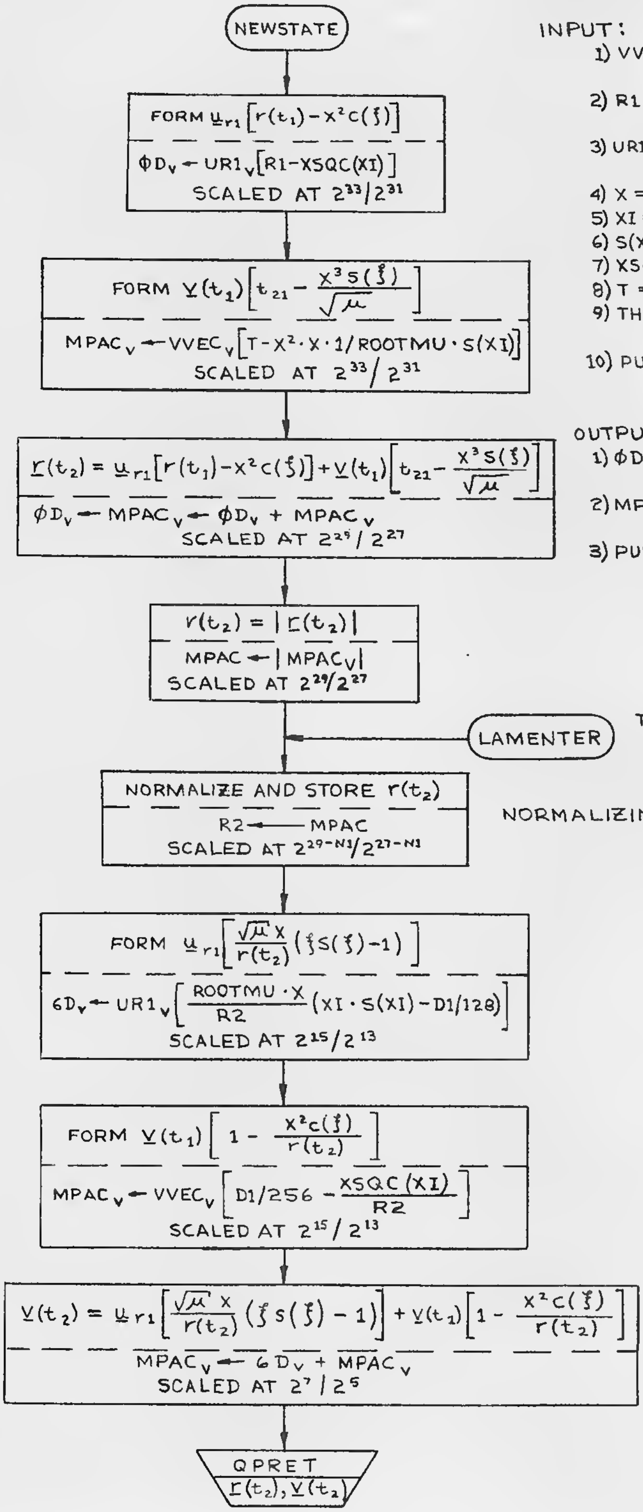
THIS SUBROUTINE CALCULATES THE NEW STATE VECTORS $\underline{r}(t_2)$ AND $\underline{v}(t_2)$.

IT IS CALLED BY: TIMETHET
LAMBERT (AT LOCATION LAMENTER)



INPUT:

1) $VVEC_v = \underline{v}(t_1)$, THE INITIAL VELOCITY VECTOR, IN METERS/CSEC, SCALED AT $2^7/2^5$.
2) $R1 = r(t_1)$, THE MAGNITUDE OF INITIAL POSITION VECTOR, IN METERS, SCALED AT $2^{29}/2^{27}$.
3) $UR1_v = \underline{u}_{r1}$, A UNIT VECTOR IN DIRECTION OF INITIAL POSITION VECTOR $\underline{r}(t_1)$, SCALED AT 2^1.
4) $X = x$, THE UNIVERSAL VARIABLE, SCALED AT $2^{17}/2^{16}$.
5) $XI = \xi = \alpha x^2$, SCALED AT 2^6.
6) $S(XI) = s(\xi)$, SCALED AT 2^1.
7) $XSQC(XI) = x^2c(\xi)$, SCALED AT $2^{33}/2^{31}$.
8) $T = t_{21}$, THE TRANSFER TIME, SCALED AT 2^{28}.
9) THE μ-TABLE APPROPRIATE FOR EITHER THE EARTH OR MOON.
10) PUSH LIST POINTER IS AT THE GENERAL VALUE PL IF ENTRY AT NEWSTATE, AT PL+6 IF ENTRY AT LAMENTER, WHERE $0 \leq PL \leq 8D$.

OUTPUT:

1) $\phi D_v = \underline{r}(t_2)$, THE TERMINAL POSITION VECTOR, IN METERS, SCALED AT $2^{29}/2^{27}$.
2) $MPAC_v = \underline{v}(t_2)$, THE TERMINAL VELOCITY VECTOR, IN METERS/CSEC, SCALED AT $2^7/2^5$.
3) PUSH LIST POINTER AT PL+6 NORMALLY; AT PL IF ROUTINE WAS ENTERED BY LAMBERT AT LOCATION LAMENTER, WHERE PL IS THE ENTRY VALUE.

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

NORMALIZING VALUE IS −N1, STORED IN X1.

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

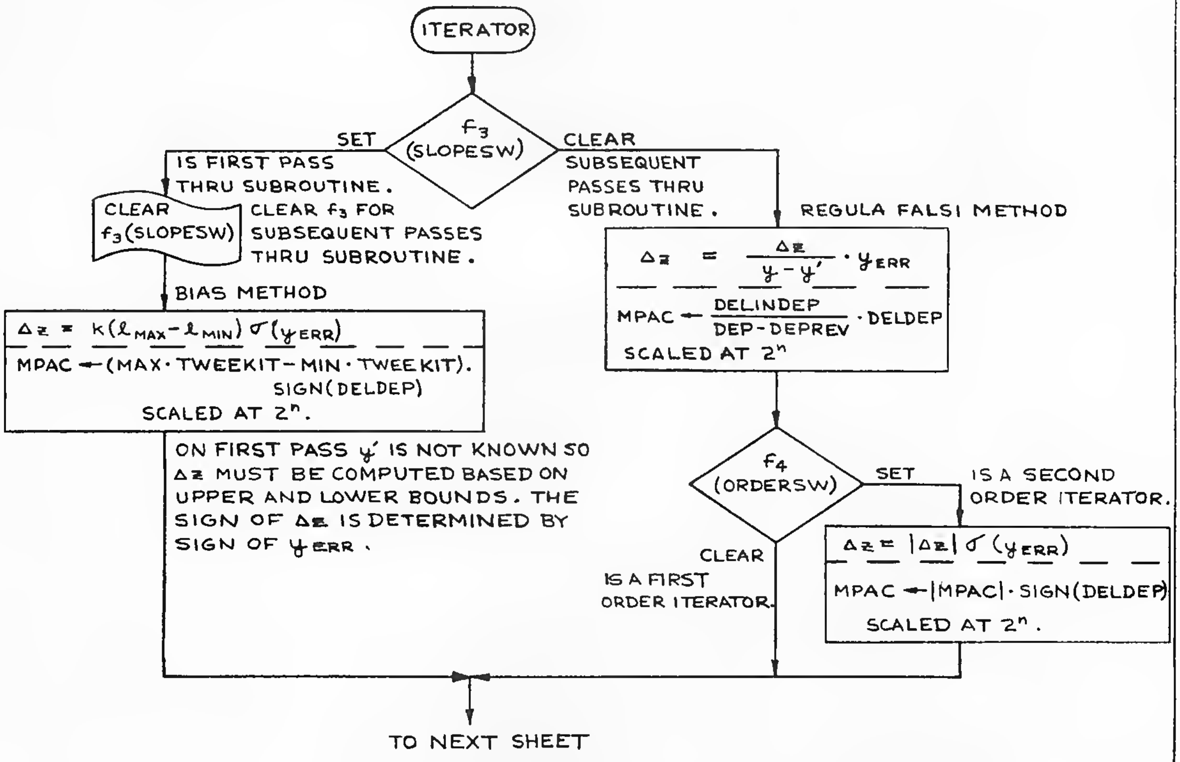
CALLED BY: LAMBERT, P10 AND P11.

INPUT:

1) ORDERSW = f_4, A FLAG, IF CLEAR SUBROUTINE ACTS AS A FIRST ORDER ITERATOR, IF SET ACTS AS SECOND ORDER ITERATOR.
2) SLOPESW = f_3, A FLAG, IF SET IS FIRST PASS THRU AND MUST USE BIAS METHOD TO CALCULATE Δz, IF CLEAR IS SUBSEQUENT PASS AND CAN USE THE REGULA FALSI METHOD TO CALCULATE Δz.
3) DEP = y, PRESENT VALUE OF DEPENDENT VARIABLE, AT 2^m
4) DEPREV = y', PREVIOUS VALUE OF y, AT 2^m
5) DELDEP = y_{ERR}, ERROR IN y, EQUAL TO $y_{FINAL} - y$, AT 2^m.
6) DELINDEP = Δz, INCREMENT IN INDEPENDENT VARIABLE THAT PRODUCED THE PREVIOUS INCREMENT $y - y'$, AT 2^n.
7) INDEP = z, PRESENT VALUE OF INDEPENDENT VARIABLE, AT 2^n.
8) TWEEKIT = K, A FRACTION BETWEEN 0 AND 1, DETERMINES MAGNITUDE OF Δz ON FIRST PASS THROUGH SUBROUTINE, AT 2^0.
9) MAX = ℓ_{MAX}, PRESTABLISHED UPPER BOUND ON z, AT 2^7.
10) MIN = ℓ_{MIN}, PRESTABLISHED LOWER BOUND ON z, AT 2^7.
11) PUSH LIST POINTER MUST BE AT 0D.

OUTPUT:

1) DELINDEP = MPAC = Δz, A NEW INCREMENT IN z SUCH THAT THE NEW VALUE OF z, EQUAL TO $z + \Delta z$, WILL PRODUCE AN ERROR y_{ERR} OF SMALLER MAGNITUDE, AT 2^n.
2) SLOPESW = f_3, A FLAG, IS CLEARED BY SUBROUTINE ON THE FIRST PASS FOR SUBSEQUENT PASSES.
3) MAX = ℓ_{MAX}, IF f_4 IS CLEAR A NEW UPPER BOUND MAY BE ESTABLISHED BY THE SUBROUTINE, AT 2^n.
4) MIN = ℓ_{MIN}, IF f_4 IS CLEAR A NEW LOWER BOUND MAY BE ESTABLISHED BY THE SUBROUTINE, AT 2^n.
5) PUSH LIST POINTER IS AT 0D.



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APOLLO
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CONIC SUBROUTINES
(ITERATOR)

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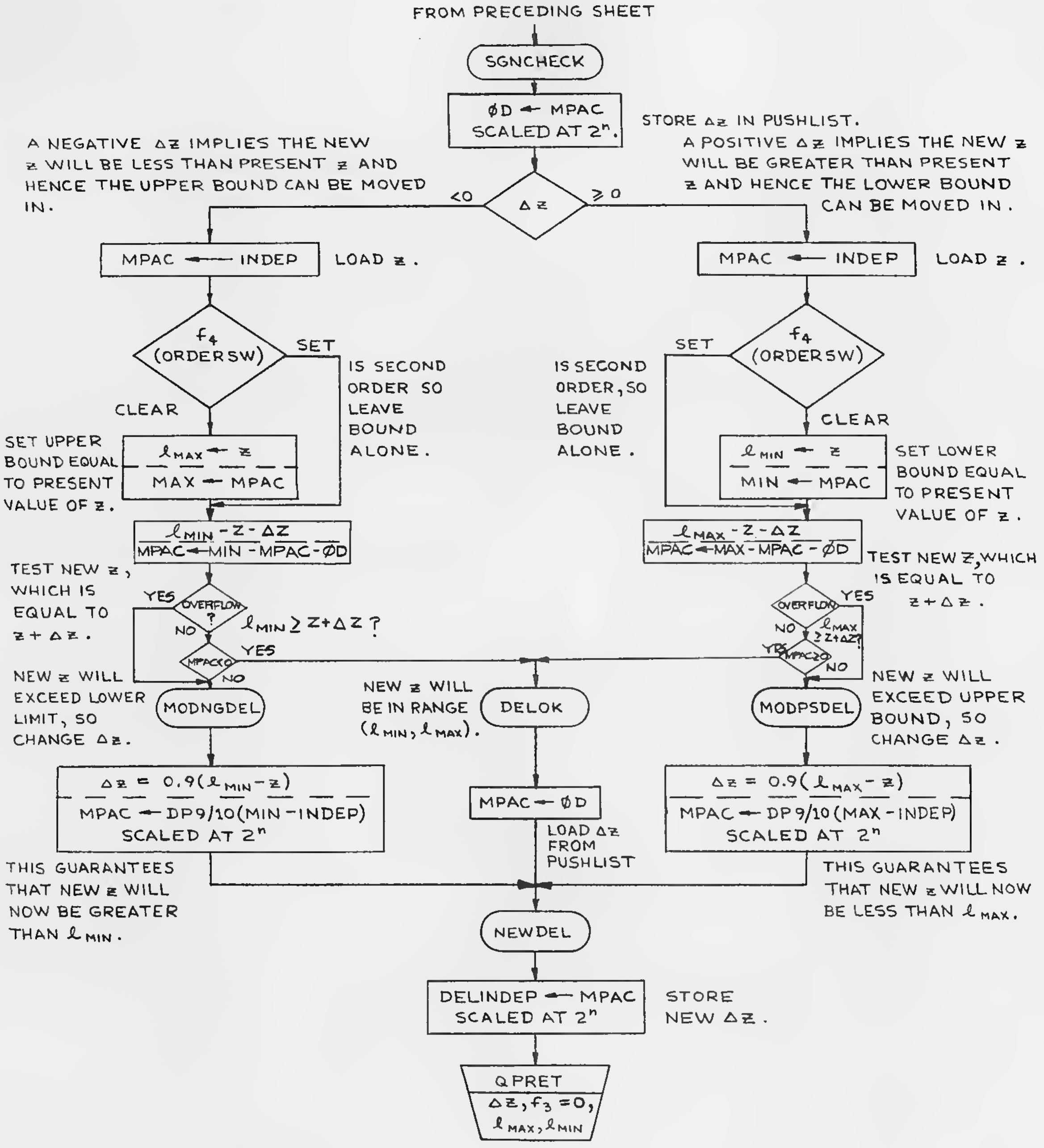

THE ITERATOR SUBROUTINE IS DESIGNED TO BE CALLED ONCE ON EACH PASS THROUGH A LOOP THAT IS ATTEMPTING TO CONVERGE ON A SOLUTION TO AN EQUATION OF THE FORM $y = y(z)$, WHERE A VALUE OF THE DEPENDENT VARIABLE y (CALLED y_{FINAL}) IS GIVEN AND THE PROGRAM IS SOLVING FOR THE CORRESPONDING VALUE OF THE INDEPENDENT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

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

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

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ANALYST Wm M. Robertson	31 JUL67	LUMINARY 1D — DOCUMENT NO. FC-3360
DOCMR C. A. Clark	11JUL68	
APPR'D John A. Morse	5AUG68	REV 4 — SHEET 38 OF 43

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

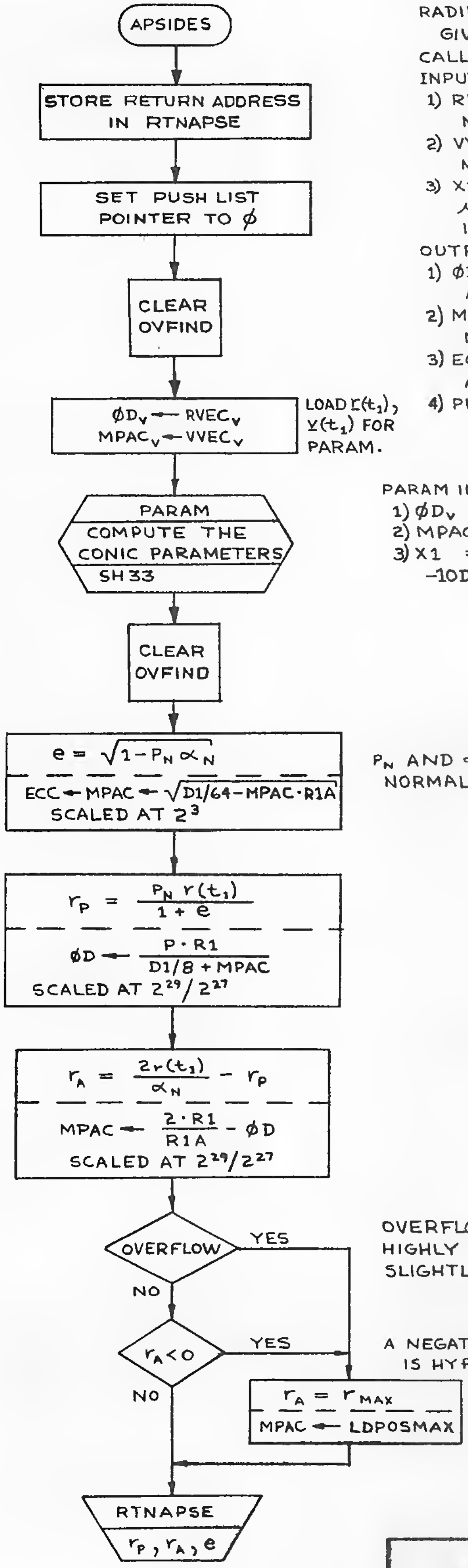
CALLED BY: PERIAPO

INPUT:

1) RVEC$_V$ = $\underline{r}(t_1)$, THE INITIAL POSITION VECTOR, IN METERS, AT $2^{29}/2^{27}$.
2) VVEC$_V$ = $\underline{v}(t_1)$, THE INITIAL VELOCITY VECTOR, IN METERS/CSEC, AT $2^7/2^5$.
3) X1 = INDEX VALUE USED TO SET UP THE PROPER μ-TABLE; IS −2 IF EARTH IS CENTRAL BODY; IS −10D IF MOON IS CENTRAL BODY.

OUTPUT:

1) 0D = r_P, THE RADIUS OF PERICENTER, IN METERS, AT $2^{29}/2^{27}$.
2) MPAC = r_A, THE RADIUS OF APOCENTER, IN METERS AT $2^{29}/2^{27}$.
3) ECC = e, THE ECCENTRICITY OF CONIC TRAJECTORY, AT 2^3.
4) PUSH LIST POINTER AT 0D.



PARAM INPUT:

1) $0D_V = \underline{r}(t_1)$
2) $MPAC_V = \underline{v}(t_1)$
3) X1 = −2 FOR EARTH, −10D FOR MOON

PARAM OUTPUT:

1) R1A = α_N
2) P = MPAC = P_N
3) COGA = cot γ
4) R1 = $r(t_1)$
5) μ-TABLE

P_N AND α_N ARE NORMALIZED VALUES.

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

A NEGATIVE VALUE IMPLIES TRAJECTORY IS HYPERBOLIC.

SET RADIUS OF APOCENTER EQUAL TO r_{MAX}, THE LARGEST VALUE POSSIBLE, WHERE $r_{MAX} = \begin{cases} 2^{29}-2 \text{ FOR THE EARTH.} \\ 2^{27}-.5 \text{ FOR THE MOON.} \end{cases}$

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CONIC SUBROUTINES
(APSIDES)

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GENERAL INFORMATION FOR CONICS

SUBROUTINES CALLED ON OTHER CHARTS

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

FLAGS USED

NAME	MEANING		WHERE SET	WHERE CLEARED	WHERE TESTED
	SET	CLEAR			
GUESSW (f_1)	INITIAL GUESS OF cot γ NOT AVAILABLE	INITIAL GUESS OF cot γ IS AVAILABLE	INITVEL	INITVEL	LAMBERT
NORMSW (f_2)	μ_N IS INPUT TO LAMBERT	μ_N IS COMPUTED BY LAMBERT	INITVEL	PARAM, INITVEL	GEOM, S40.1 S40.9
SLOPESW (f_3)	INITIAL CALL TO ITERATOR	SUBSEQUENT CALL TO ITERATOR	LAMBERT, P10	ITERATOR	ITERATOR
ORDERSW (f_4)	SECOND ORDER ITERATION	FIRST ORDER ITERATION	(NO WHERE)	P10	ITERATOR (3)
SOLNSW (f_5)	NO SOLN POSSIBLE	SOLN VALID	LAMBERT (2)	LAMBERT, TIMERAD	(NO WHERE)
RVSW (f_6)	DO NOT COMPUTE NEW STATE VECTOR	COMPUTE NEW STATE VECTOR	P39, P34, CSI/A (2)	CDHMVR	TIMETHET
INFINFLG (f_7)	CONIC PASSES THRU INFINITY	CONIC SOLN EXISTS	GETX	GETX	LAMBERT, TIMETHET
APSESW (f_8)	POSITION VECTOR OUTSIDE RANGE (PERICENTER, APOCENTER)	POSITION VECTOR WITHIN RANGE (PERICENTER, APOCENTER)	TIMERAD	TIMERAD	(NO WHERE)
360SW (f_ω)	TRANSFER ANGLE NEAR 360°	TRANSFER ANGLE NOT NEAR 360°	GETX	GETX	GETX
COGAFLAG (f_γ)	NO SOLN EXISTS, TOO CLOSE TO RECTILINEAR	SOLN EXISTS	TIMETHET	TIMETHET, PARAM	(NO WHERE)
VTARGTAG$_s$	$\underline{v}(t_2)$ NOT CALCULATED	$\underline{v}(t_2)$ IS CALCULATED	INITVEL	INITVEL	LAMBERT, INITVEL (2)
GEOMSGN$_s$ (s_G)	IS MINUS IF TRANSFER ANGLE > 180°	IS PLUS IF TRANSFER ANGLE ≤ 180°	INITVEL	INITVEL, PARAM	LAMBERT, GEOM (3)
SGNRDOT$_s$ ($s_{\dot{r}}$)	IS MINUS IF RADIAL VELOCITY NEGATIVE	IS PLUS IF RADIAL VELOCITY POSITIVE	(NO WHERE)	(NO WHERE)	TIMERAD

VARIABLES USED (BOTH PUSH LIST AND ERASABLE)

NAME	MEANING	SCALING	LOCATION
ALPHA	RECIPROCAL OF SEMI-MAJOR AXIS	$2^{-22}/2^{-20}$	8D
MIN	LOWER BOUND ON z	2^n	8D
COGAMIN	LOWER BOUND ON cot γ	2^5	8D
XMAX	MAXIMUM VALUE OF x	$2^{17}/2^{16}$	10D
XMIN	MINIMUM VALUE OF x	$2^{17}/2^{16}$	12D
DELINDEP	Δz	2^n	12D
DCOGA	Δcot γ	2^5	12D
MAX	UPPER BOUND ON z	2^n	14D
COGAMAX	UPPER BOUND ON cot γ	2^5	14D
1/MU	$1/\mu$	$2^{-34}/2^{-28}$	14D
ROOTMU	$\sqrt{\mu}$	$2^{18}/2^{15}$	16D

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DRAWN		3JUL68
PRGMR		
ANALST	Wm M. Robertson	31 JUL 68
DOCMR		11JUL6
APPR'D	John A. Morse	5 AUG 6

APOLLO
GUIDANCE AND NAVIGATION

CONIC SUBROUTINES

LUMINARY 1D

DOCUMENT NO.
FC-3360

REV 4

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

NAME	MEANING	SCALING	LOCATION
1/ROOTMU	$1/\sqrt{\mu}$	$2^{-17}/2^{-14}$	18D
X	UNIVERSAL VARIABLE x	$2^{17}/2^{16}$	20D
ITERCTR_s	ITERATION COUNTER	2^{14}	22D
COSF	cos (f)	2^1	24D
XI	$\alpha_N x_N^2$	2^6	24D
S (XI)	s (ζ)	2^1	26D
XSQC (XI)	$x^2 c\ (\zeta)$	$2^{33}/2^{31}$	28D
DEP	PRESENT VALUE OF y	2^m	30D
T	TRANSFER TIME, CSEC	2^{28}	30D
R1	MAGNITUDE OF POSITION VECTOR, METERS	$2^{29}/2^{27}$	32D
RCNORM	NORMALIZED VECTOR MAGNITUDE, METERS	$2^{29-m}/2^{27-m}$	34D
KEPC1	c_1	$2^{17}/2^{16}$	34D
KEPC2	c_2	2^6	36D
TWEEKIT	k, FRACTION BETWEEN 0 AND 1	2^0	40D
RRECT_v	$\underline{r}$ (t), POSITION VECTOR, METERS	$2^{29}/2^{27}$	E3, 1502
VRECT_v	$\underline{v}$ (t), VELOCITY VECTOR, METERS/CSEC	$2^7/2^5$	E3, 1510
RCV_v	$\underline{r}$ (t), POSITION VECTOR, METERS	$2^{29}/2^{27}$	E3, 1534
VCV_v	$\underline{v}$ (t), VELOCITY VECTOR, METERS/CSEC	$2^7/2^5$	E3, 1542
TC	PREVIOUS VALUE OF TIME, CSEC	2^{28}	E3, 1550
XPREV	PREVIOUS VALUE OF x	$2^{17}/2^{16}$	E3, 1552
TAU	DESIRED TRANSFER TIME, CSEC	2^{28}	E4, 1475
KEPRTN_s	RETURN ADDRESS FROM KEPLER		E4, 1514
XKEPNEW	GUESS OF VARIABLE x	$2^{17}/2^{16}$	E4, 1531
EPSILONT	CONVERGENCE CRITERION, CSEC	2^{28}	E4, 1604
DELX	Δx	$2^{17}/2^{16}$	E5, 1642
DELT	t_{ERR}, CSEC	2^{28}	E5, 1644
URRECT_v	UNIT VECTOR	2^1	E5, 1646
R1VEC_v	$\underline{r}$ (t), POSITION VECTOR, METERS	$2^{29}/2^{27}$	E5, 1654
RVEC_v	$\underline{r}$ (t), POSITION VECTOR, METERS	$2^{29}/2^{27}$	E5, 1654
R2VEC_v	$\underline{r}$ (t), POSITION VECTOR, METERS	$2^{29}/2^{27}$	E5, 1662
TDESIRED	DESIRED TRANSFER TIME, CSEC	2^{28}	E5, 1670
GEOMSGN_s	s_G, A FLAG	2^0	E5, 1672
UN_v	$\underline{u}_N$, UNIT NORMAL VECTOR	2^1	E5, 1673
VTARGTAG_s	n_1, A FLAG	2^0	E5, 1701
VTARGET_v	TARGET VELOCITY VECTOR, METERS/CSEC	$2^7/2^5$	E5, 1702
RTNLAMB_s	RETURN ADDRESS FROM LAMBERT		E5, 1710
RTNTT_s	RETURN ADDRESS FROM TIMETHET		E5, 1710

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APPR'D John A. Moore 5 AUG 68

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GUIDANCE AND NAVIGATION

CONIC SUBROUTINES

LUMINARY 1D

DOCUMENT NO.
FC-3360

REV 4

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

NAME	MEANING	SCALING	LOCATION
$RTNTR_s$	RETURN ADDRESS FROM TIMERAD		E5, 1710
$RTNAPSE_s$	RETURN ADDRESS FROM APSIDES		E5, 1710
$U2_v$	UNIT VECTOR	2^1	E5, 1711
MAGVEC2	VECTOR MAGNITUDE, METERS/CSEC	$2^7/2^5$	E5, 1717
R2	NORMALIZED VECTOR MAGNITUDE, METERS/CSEC	$2^{29-m}/2^{27-m}$	E5, 1717
$UR1_v$	UNIT VECTOR	2^1	E5, 1721
SNTH	sin (ϕ)	2^1	E5, 1727
CSTH	cos (ϕ)	2^1	E5, 1731
1-CSTH	1-cos (ϕ)	2^2	E5, 1733
CSTH-RHO	cos (θ) - λ	2^7	E5, 1735
P	$p_N = p/r_1$	2^4	E5, 1737
R1A	$\alpha_N = r_1/a$	2^6	E5, 1741
$VVEC_v$	VELOCITY VECTOR, METERS/CSEC	$2^7/2^5$	E5, 1743
ECC	ECCENTRICITY	2^3	E5, 1751
$RTNPRM_s$	RETURN ADDRESS FROM PARAM		E5, 1753
$SGNRDOT_s$	$s_{\dot{r}}$, SIGN OF RADIAL VELOCITY	2^0	E5, 1754
RDESIRED	RADIAL DISTANCE, METERS	$2^{29}/2^{27}$	E5, 1755
DELDEP	y_{ERR}	2^m	E5, 1757
TERRLAMB	CONVERGENCE CRITERION, CSEC	2^{28}	E5, 1757
DEPREV	PREVIOUS VALUE OF y	2^m	E5, 1761
TPREV	PREVIOUS TIME, CSEC	2^{28}	E5, 1761
EPSILONL	CONVERGENCE CRITERION, CSEC	2^{28}	E5, 1763
COGA	cot γ	2^5	E5, 1765
INDEP	z	2^n	E5, 1765

CONSTANTS USED

NAME	PHYSICAL MEANING	SCALING	COMPUTER VALUE
D1/4	1.0	2^2	1.0 B-2
D1/8	1.0	2^3	1.0 B-3
D1/16	1.0	2^4	1.0 B-4
D1/32	2.0	2^6	1.0 B-5
D1/64	1.0	2^6	1.0 B-6
D1/128	1.0	2^7	1.0 B-7
D1/256	1.0	2^8	1.0 B-8
D1/1024	1.0	2^{10}	1.0 B-10
DP1/4	1.0	2^2	1.0 B-2
BEE19	$\epsilon_t = 2^{-19}$	2^0	0000001000_8
BEE22	$\epsilon_t = 2^{-22}$	2^0	0000000100_8
ONEBIT	2^{-28}	2^0	1.0 B-28
2PISC	2π	2^6	6.28318530 B-6
-50SC	-50.0	2^{12}	-50.0 B-12
DP9/10	0.9	2^0	0.9 BO
COGUPLIM	$\cot \gamma_{max} = 31.9843711$	2^5	0.999511597 BO
COGLOLIM	$\cot \gamma_{min} = -31.9843711$	2^5	-0.999511597 BO
MUTABLE +2	$1/\mu$	2^{-34}	$0.25087606 \times 10^{-10}$ B34
MUTABLE +4	$\sqrt{\mu_E}$	2^{18}	1.99650495×10^{5} B-18
MUTABLE +6	$1/\sqrt{\mu_E}$	2^{-17}	$0.50087529 \times 10^{-5}$ B17
MUTABLE +10D	$1/\mu_M$	2^{-28}	0.203966×10^{-8} B28
MUTABLE +12D	$\sqrt{\mu_M}$	2^{15}	2.21422176×10^{4} B-15
MUTABLE +14D	$1/\sqrt{\mu_M}$	2^{-14}	$0.45162595 \times 10^{-4}$ B14
BEE17	$k_1 = 2^{-17}$	2^0	0000004000_8

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN F. Pearson J.	11 JUL 68	CONIC SUBROUTINES	
PROGMR			
ANALST Wm M. Robertson	31 JUL 68	LUMINARY 1D	DOCUMENT NO. FC-3360
DOCMR C. A. Clark	11 JUL 68		
APPR'D John A. Moore	5 AUG 68	REV 4	SHEET 43 OF 43

TIME OF FREE FALL

TFFCONIC	Sh. 3
TFFCONMU	Sh. 3
TFFRP/RA	Sh. 4
CALCTPER	Sh. 5
CALCTFF	Sh. 5

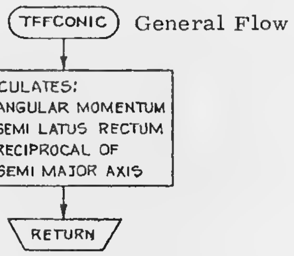
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN E. Welch	2/3/70	Time Of Free Fall	
PRGMR R Bairnfather	3/16/70	LUMINARY 1D	DOCUMENT NO. FC-3370
ANALST			
DOCMR Roberta M Estes	3/17/70		
APPR'D Roberta M Estes	3/17/70	REV	SHEET 1 OF 14

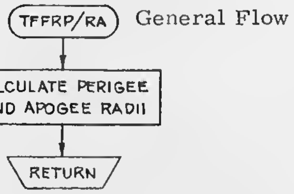
SINCE CONIC CALCULATIONS REQUIRED FLOATING POINT ARITHMETIC, THESE CHARTS ATTEMPT TO INDICATE WHERE SUCH OPERATIONS ARE EMPLOYED. LET REGISTER M BE NORMALIZED SO THAT $1 > M \geq 0.5$. LET THE NUMBER OF LEFT SHIFTS REQUIRED TO BRING THIS ABOUT BE $-X1$. THEN THE CONVENTION USED HEREIN IS THAT THE NORMALIZED CMC VARIABLE TFFM (E.G.) IS RELATED TO THE UNNORMALIZED CMC VARIABLE IN M BY : $TFFM = M2^{-X1}$ AND $M = NORM_{X1}(TFFM)$.

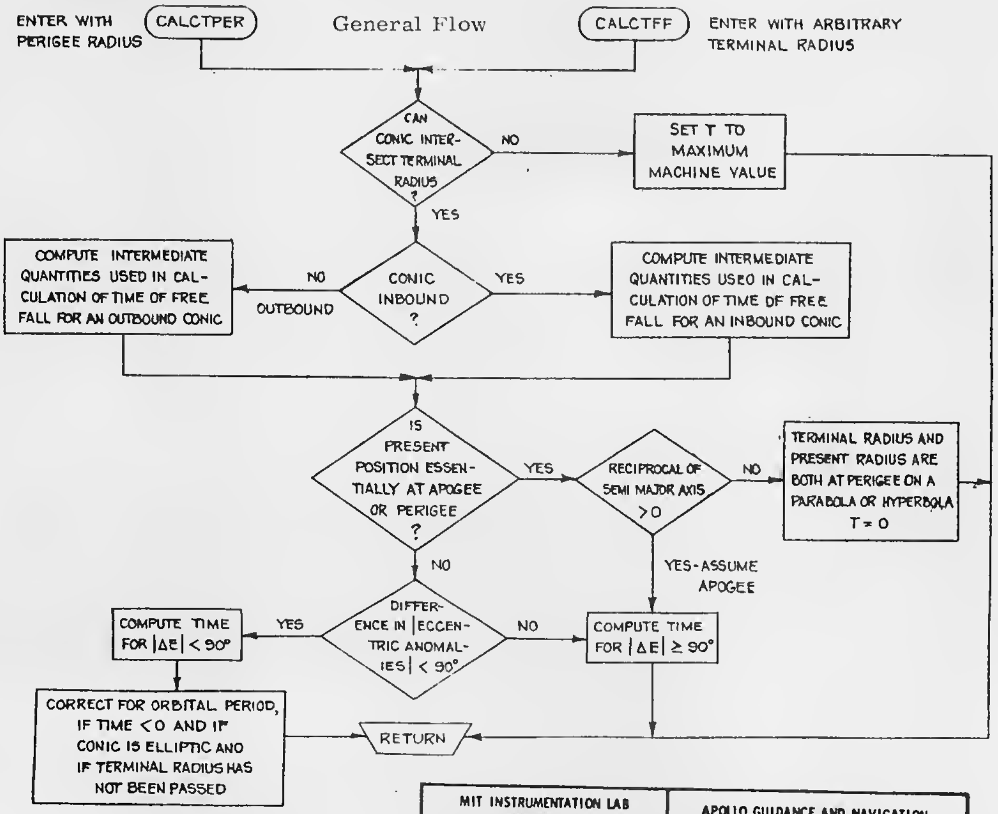
R30 APPLICATION : THE SPHERICAL VALUES OF GRAVITATIONAL CONSTANT μ ARE USED DEPENDING ON EARTH/MOON CENTERED COORDINATES :

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

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







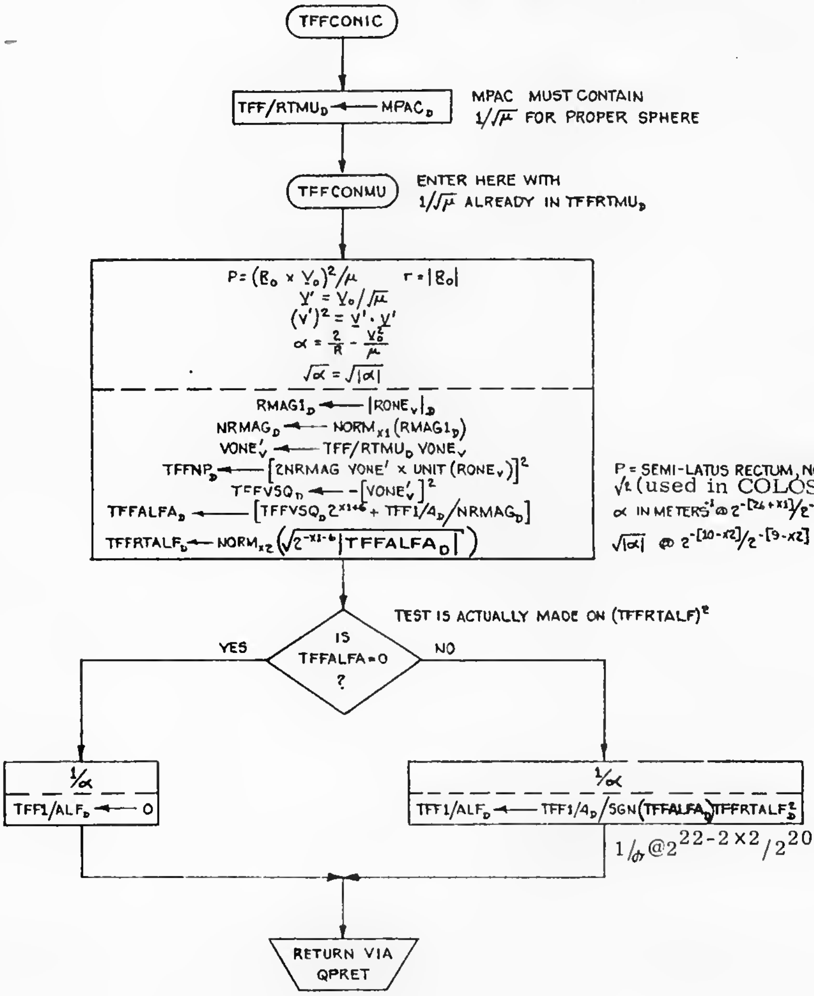
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN R. Welch	3/3/70	Time Of Free Fall
PRGMR	3/16/70	
ANALST		LUMINARY 1D
DOCMR	3/17/70	DOCUMENT NO. FC-3370
APPR'D	3/17/70	REV
		SHEET 2 OF 14

CALLED BY V82 SEQUENCE (FC- 3770)

To compute those conic parameters required by the TFF subroutines and establish them in the push list area.

INPUTS: $RONE_V = \underline{R}_0$ = PRESENT POSITION VECTOR IN METERS @ $2^{27}/2^{29}$
$VONE_V = \underline{V}_0$ = PRESENT VELOCITY VECTOR IN M/CSEC @ $2^5/2^7$
$TFFRTMU_D = 1/\sqrt{\mu}$ FOR MOON OR EARTH

OUTPUTS: $RMAG1_D = |\underline{R}_0|$
$NRMAG_D = (PL32) = RMAG2^{-X1}$
$TFFNP_D$ = PL28D = P = SEMI-LATUS RECTUM
$VONE'_V = V_0/\sqrt{\mu}$
$TFFVSQ_0 = \underline{V}'^2$ = PL20D
TFFALFA = α = (SEMI MAJOR AXIS)$^{-1}$ = PL26D
TFFRTALF = $\sqrt{\alpha}$ = PL24D
TFF1/ALF = $1/\alpha$ = PL22D
X1 = −NORM COUNT OF $RMAG_D$
X2 = −NORM COUNT OF $\sqrt{\alpha}$



MPAC MUST CONTAIN $1/\sqrt{\mu}$ FOR PROPER SPHERE

ENTER HERE WITH $1/\sqrt{\mu}$ ALREADY IN $TFFRTMU_D$

P = SEMI-LATUS RECTUM, NORMALIZED
$\sqrt{t}$ (used in COLOSSUS only)
α IN METERS^{-1} @ $2^{-[26+X1]}/2^{-[24+X1]}$
$\sqrt{|\alpha|}$ @ $2^{-[10-X2]}/2^{-[9-X2]}$

TEST IS ACTUALLY MADE ON $(TFFRTALF)^2$

$1/\alpha$ @ $2^{22-2\times2}/2^{20-2\times2}$

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DRAWN R. Welch 3/5/70
PRGMR R. Bairnsfather 3/16/70
ANALST
DOCMR R M Estes 3/17/70
APPR'D R M Estes 3/17/70

APOLLO GUIDANCE AND NAVIGATION

Time Of Free Fall

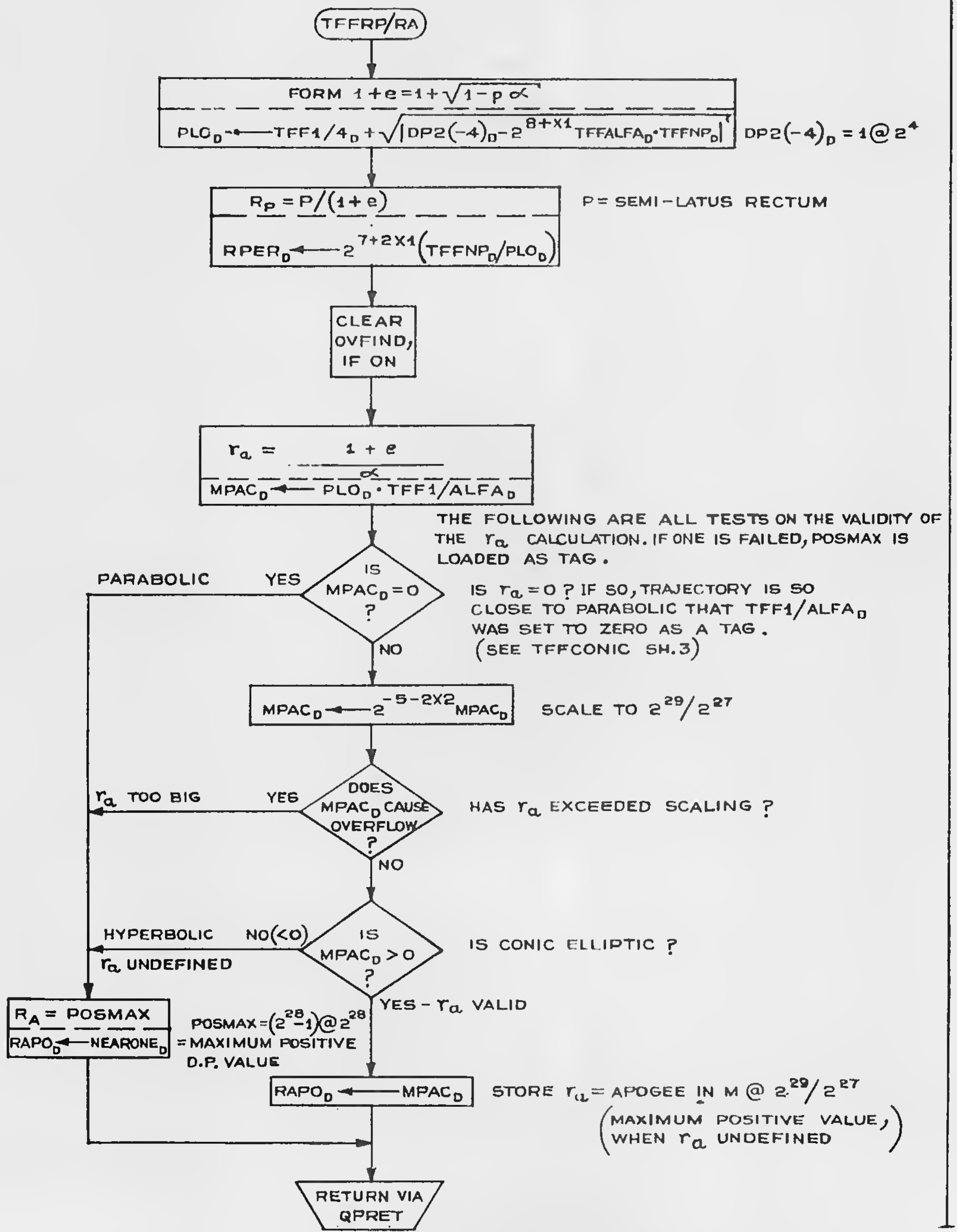
LUMINARY 1D

DOCUMENT NO. FC-3370

REV

SHEET 3 OF 14

CALLED BY V82 SEQUENCE (FC-3770).
CALCULATES APOGEE AND PERIGEE
FOR A GENERAL CONIC.
INPUT: $TFFNP_D$ = SEMI-LATUS RECTUM
$TFFALFA_D$ = RECIPROCAL SEMI-MAJOR AXIS
X1, X2
} FROM TFFCONIC
OUTPUT: $RAPO_D$ = APOGEE
$RPER_D$ = PERIGEE
} IN METERS @ $2^{29}/2^{27}$



THE FOLLOWING ARE ALL TESTS ON THE VALIDITY OF THE r_a CALCULATION. IF ONE IS FAILED, POSMAX IS LOADED AS TAG.

IS $r_a = 0$? IF SO, TRAJECTORY IS SO CLOSE TO PARABOLIC THAT $TFF1/ALFA_D$ WAS SET TO ZERO AS A TAG. (SEE TFFCONIC SH.3)

HAS r_a EXCEEDED SCALING ?

IS CONIC ELLIPTIC ?

STORE r_a = APOGEE IN M @ $2^{29}/2^{27}$ (MAXIMUM POSITIVE VALUE, WHEN r_a UNDEFINED)

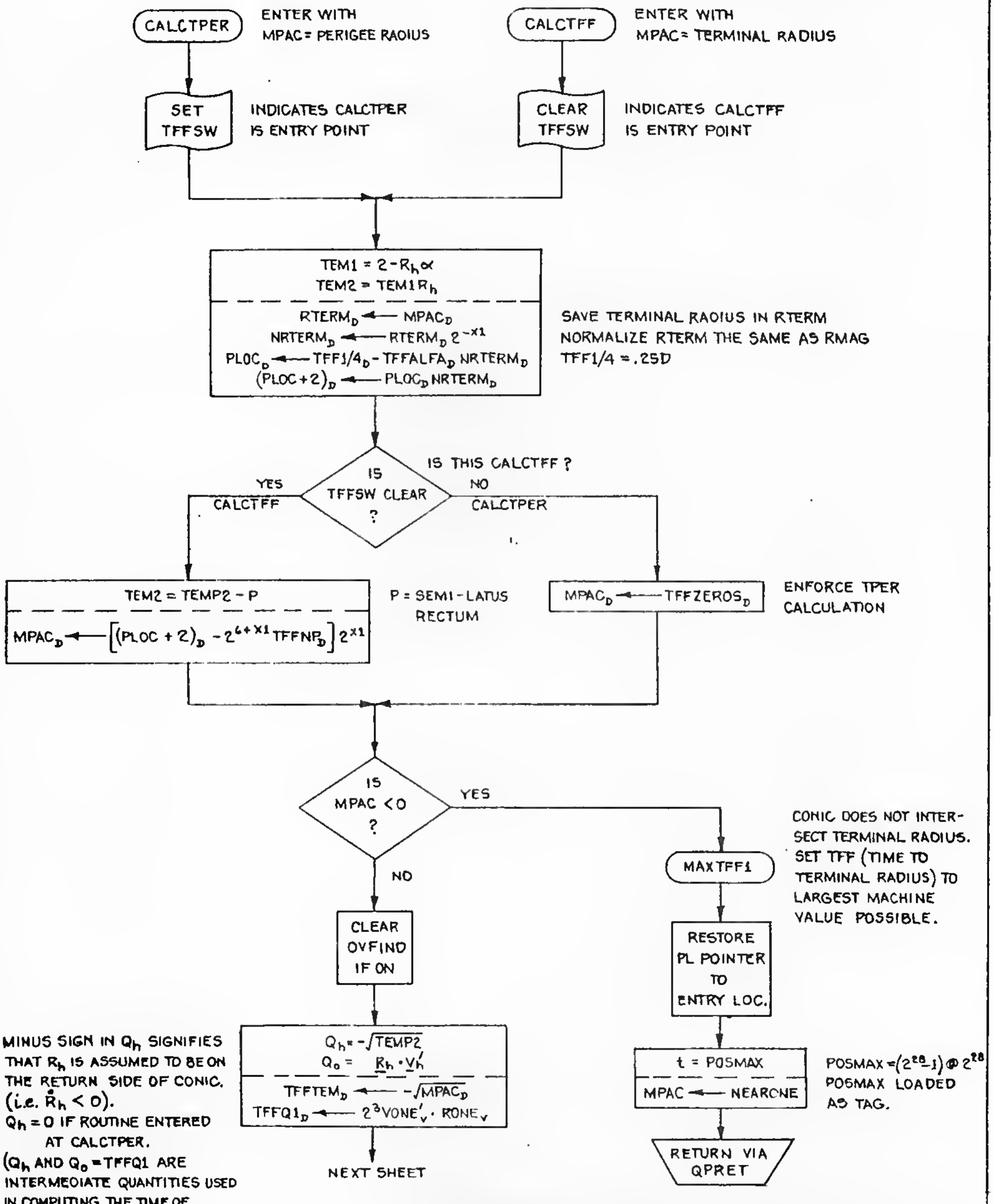
MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
DRAWN	3/3/70	Time Of Free Fall
PRGMR P. Barnisfather	3/16/70	
ANALST		LUMINARY 1D — DOCUMENT NO. FC-3370
DOCMR R M Estes	3/17/70	
APPR'D R M Estes	3/17/70	REV — SHEET 4 OF 14

CALLED BY V82 SEQUENCE (FC-3770)

CALCULATES THE TIME OF FREE FALL FLIGHT FROM PRESENT POSITION(RN) AND VELOCITY(VN) TO A RADIUS LENGTH SPECIFIED BY R_h, SUPPLIED BY THE USER.

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

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



CONIC DOES NOT INTERSECT TERMINAL RADIUS. SET TFF (TIME TO TERMINAL RADIUS) TO LARGEST MACHINE VALUE POSSIBLE.

POSMAX = $(2^{28}-1)$ @ 2^{28}
POSMAX LOADED AS TAG.

MINUS SIGN IN Q_h SIGNIFIES THAT R_h IS ASSUMED TO BE ON THE RETURN SIDE OF CONIC. (i.e. $\dot{R}_h < 0$).
$Q_h = 0$ IF ROUTINE ENTERED AT CALCTPER.
(Q_h AND Q_o = TFFQ1 ARE INTERMEOIATE QUANTITIES USED IN COMPUTING THE TIME OF FREE FALL TO THE SPECIFIED RADIUS.)

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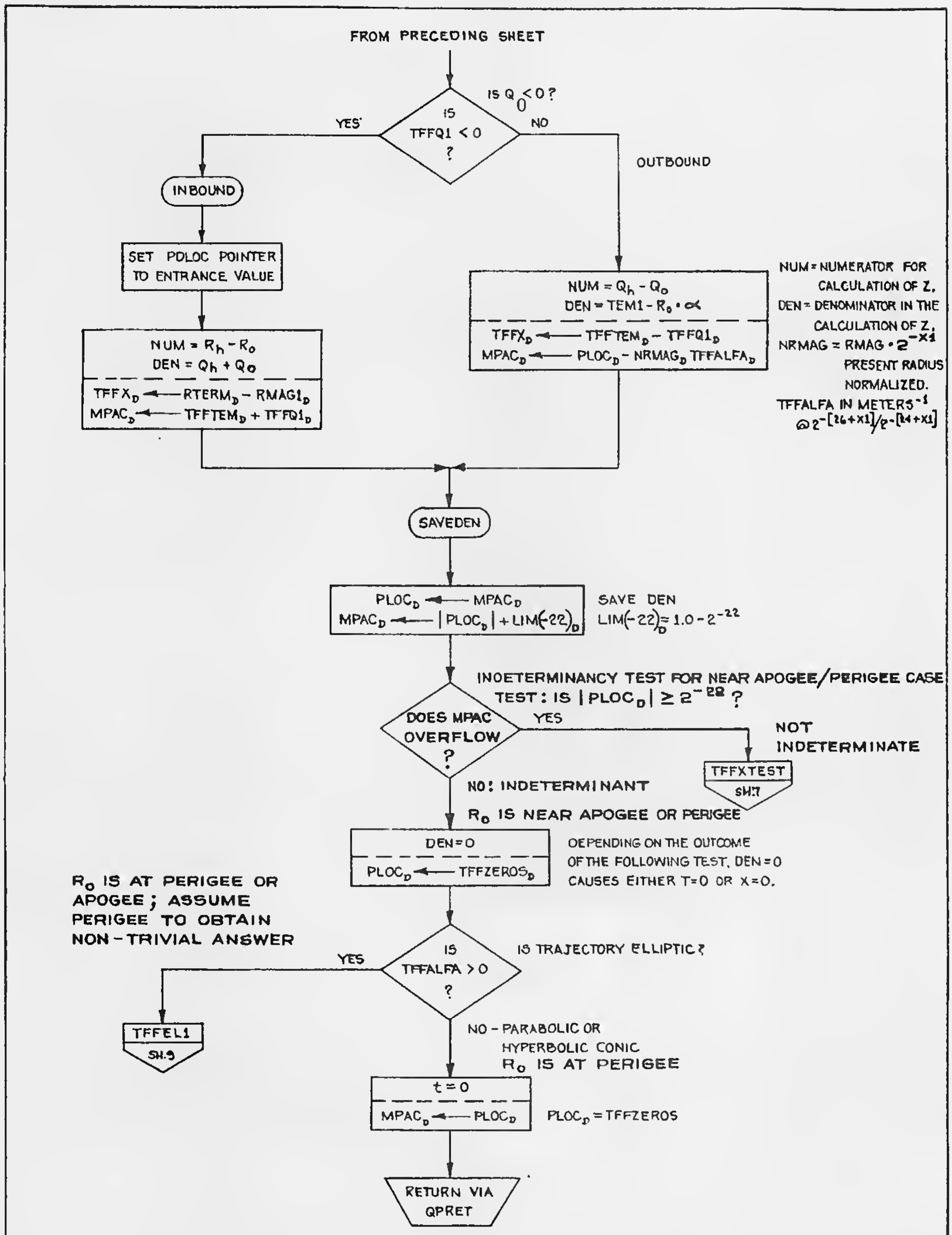
DRAWN R. Welch	3/2/70	Time Of Free Fall	
PRGMR	3/16/70		
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3370
DOCMR RM Estes	3/17/70		
APPR'D RM Estes	3/17/70	REV	SHEET 5 OF 14



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DRAWN A. Welch 3/6/70
PRGMR 3/16/70
ANALST
DOCMR RM Eston 3/17/70
APPR'D RM Eston 3/17/70

APOLLO GUIDANCE AND NAVIGATION

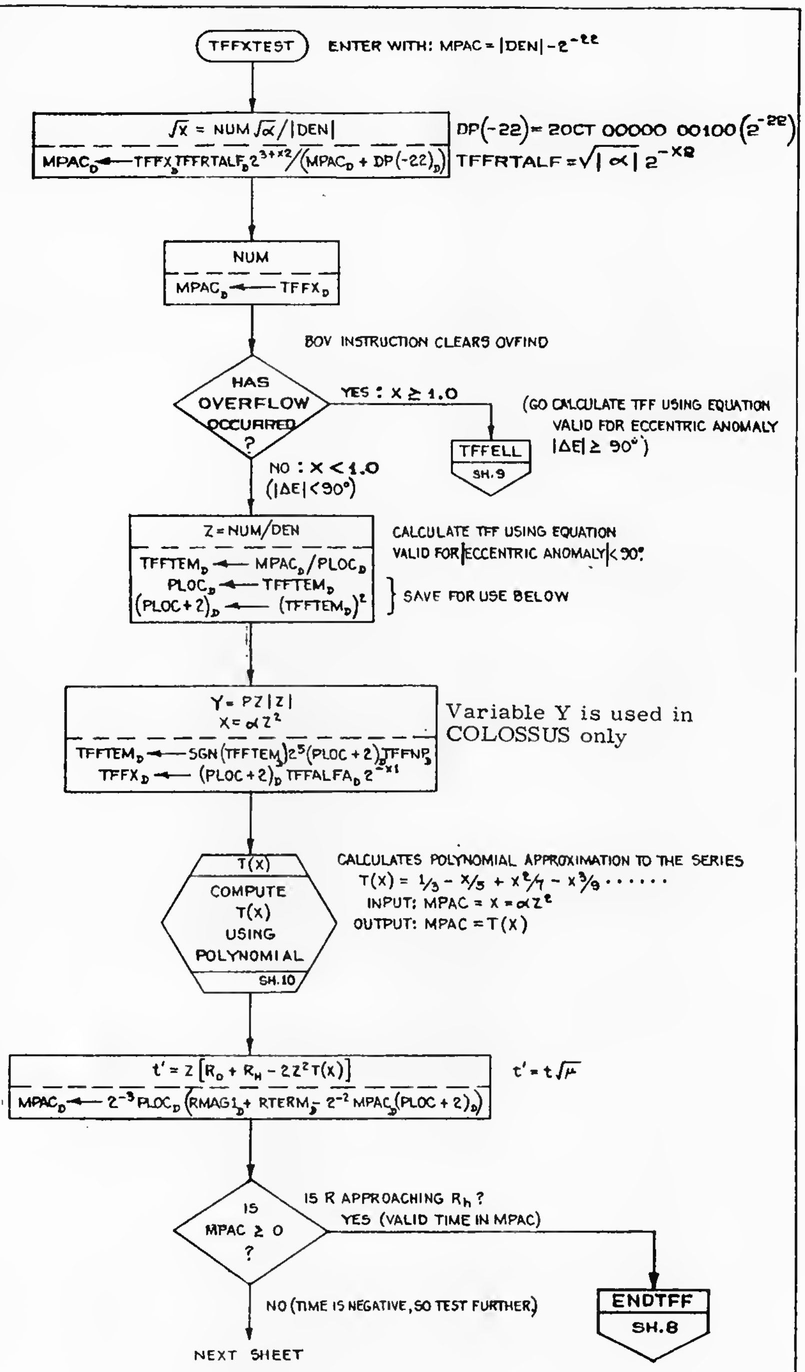
Time Of Free Fall

LUMINARY
1D

DOCUMENT NO.
FC-3370

REV

SHEET 6 OF 14



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DRAWN R. Welch [illegible]
PRGMR R Bairnsfather 3/16/70
ANALST
DOCMR RM Estes 3/17/70
APPR'D RM Estes 3/17/70

APOLLO GUIDANCE AND NAVIGATION

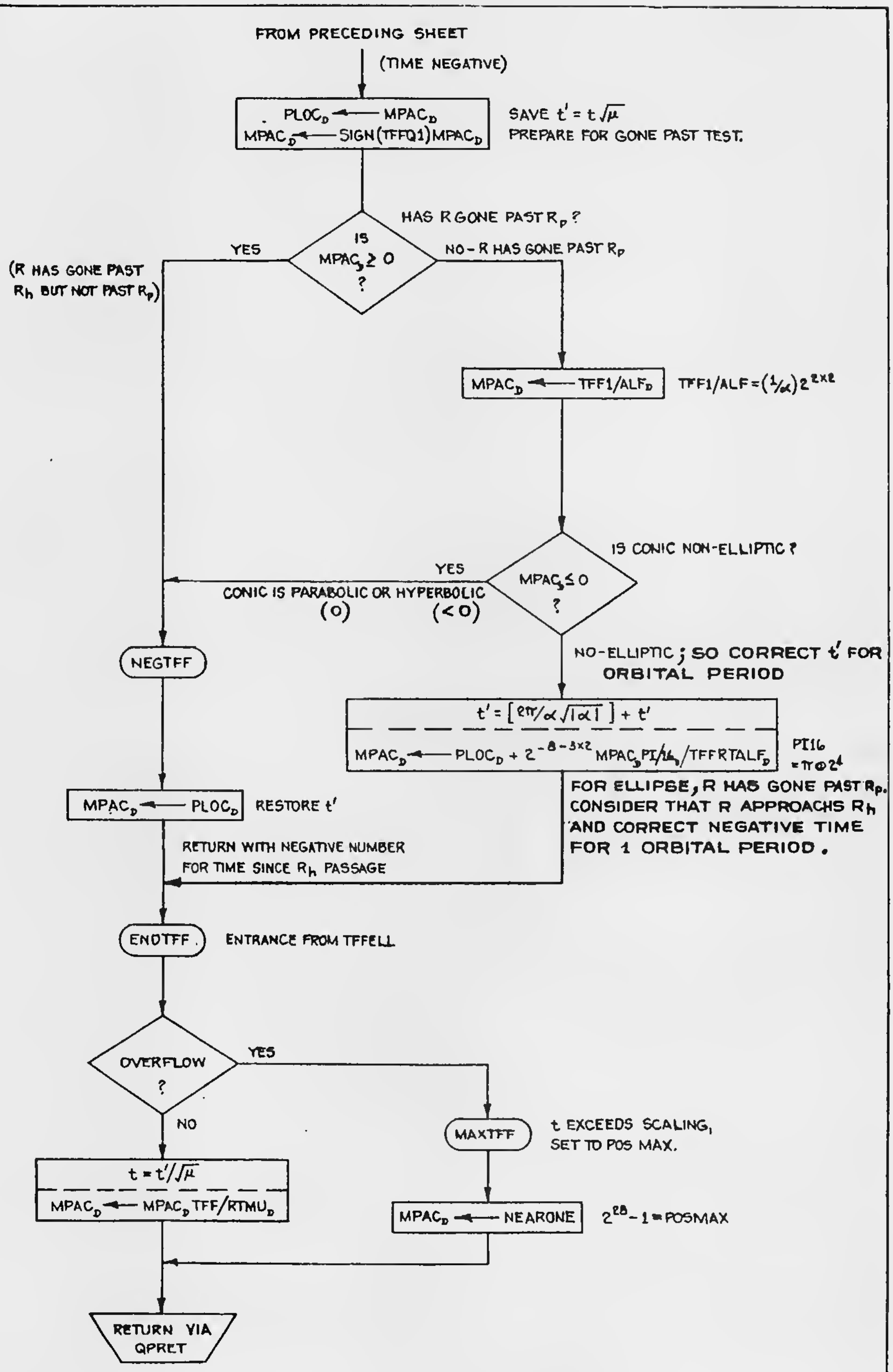
Time Of Free Fall

LUMINARY
1D

DOCUMENT NO.
FC-3370

REV

SHEET 7 OF 14



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DRAWN 3/2/7
PRGMR 3/16/70
ANALST
DOCMR R M Estes 3/17/70
APPR'D R M Estes 3/17/70

APOLLO GUIDANCE AND NAVIGATION

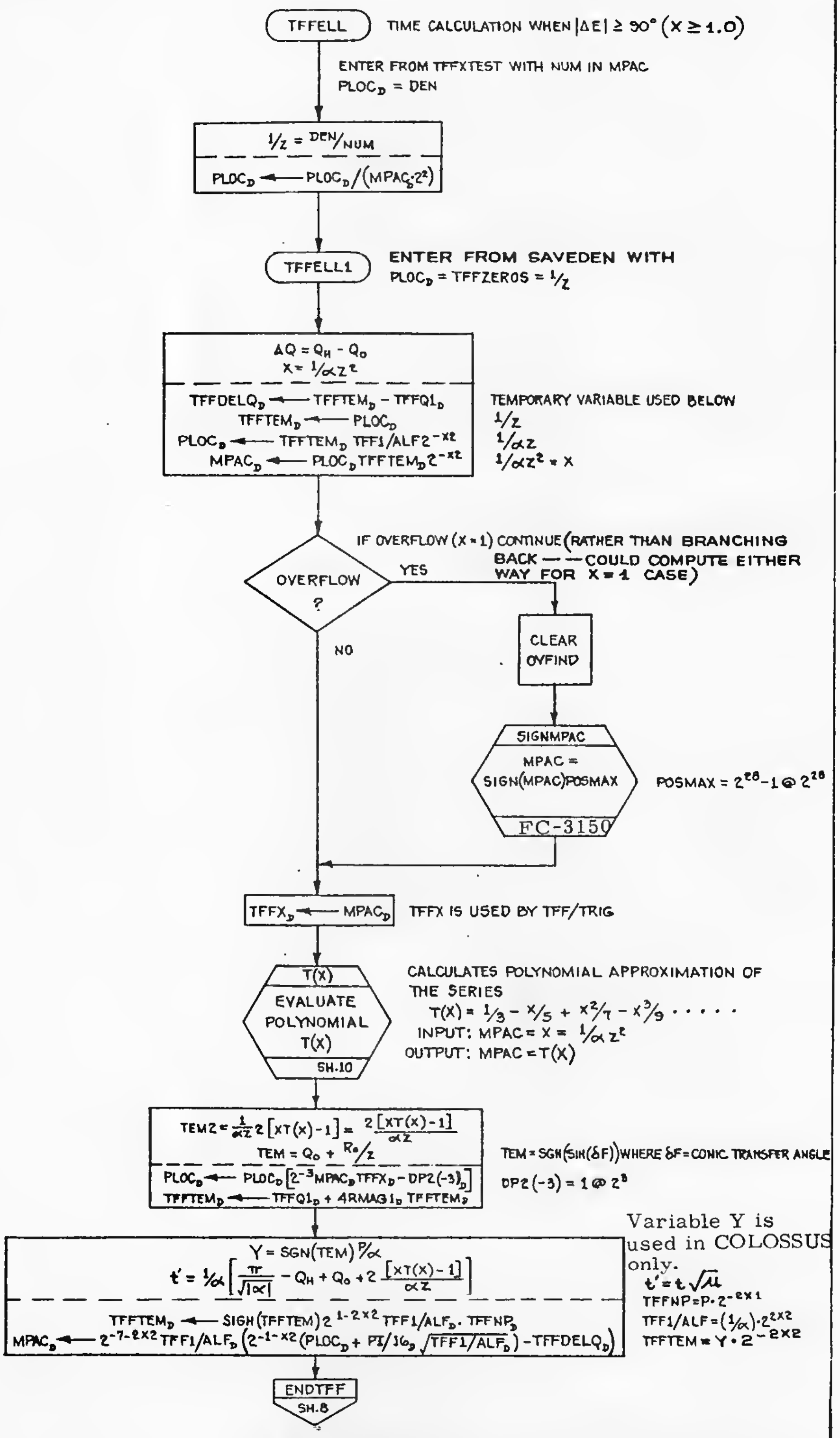
Time Of Free Fall

LUMINARY 1D

DOCUMENT NO. FC-3370

REV

SHEET 8 OF 14



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DRAWN R. Welch 2/13/70
PRGMR Beimpeker 3/16/70
ANALST
DOCMR RMM Easton 3/17/70
APPD RMM Easton 3/17/70

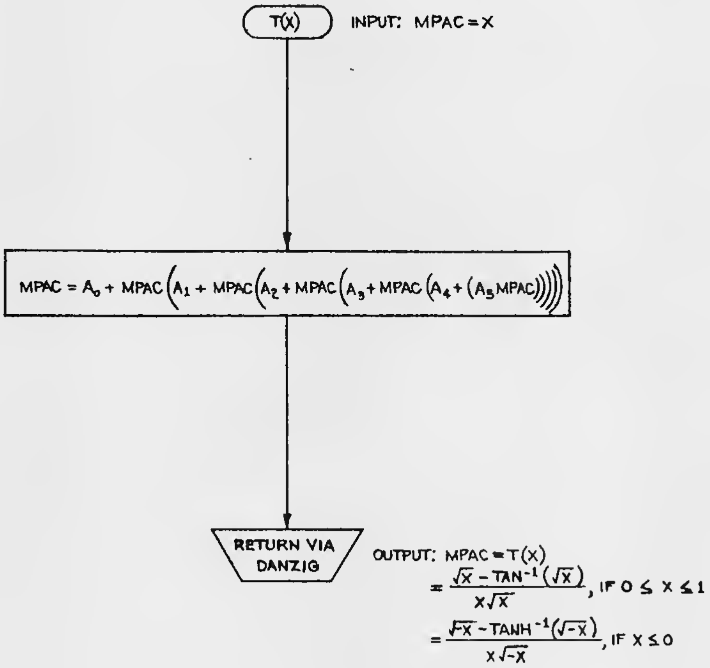
APOLLO GUIDANCE AND NAVIGATION

Time Of Free Fall

LUMINARY
1D

DOCUMENT NO
FC-3370

SHEET 9 OF 14



T(X) = POLYNOMIAL APPROXIMATION TO THE SERIES:

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

POLYNOMIAL IS OF 5TH ORDER, HAVING COEFFICIENTS

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

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

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DRAWN R. Welch 3/3/70
PRGMR 3/16/70
ANALST
DOCMR RM Estes 3/17/70
APPR'D RM Estes 3/17/70

APOLLO GUIDANCE AND NAVIGATION
Time Of Free Fall
LUMINARY 1D
DOCUMENT NO. FC-3770
REV
SHEET 10 OF 14

SUBROUTINE CALLED WHICH IS FLOWED ON OTHER FLOWCHART

Subroutine Name	Where Flowed	Description	Where Called
SIGNMPAC	FC-3150	Puts DPOSMAX into MPAC if MPAC was positive, and-DPOSMAX if MPAC was negative.	Sh. 9

FLAG

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
TFFSW flag 7 bit 1	CALCTPER	CALCTFF	Sh. 5	Sh. 5	Sh. 5

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN R. Welch	2/3/70	Time Of Free Fall	
PRGMR	3/16/70	LUMINARY 1D	DOCUMENT NO. FC-3370
ANALST			
DOCMR RM Eaton	3/17/70		
APPR'D RM Eaton	3/17/70	REV	SHEET 11 OF 14

ERASABLE LOCATIONS USED

AGC Tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
NRMAG_D		Normalized magnitude of $\underline{r}$	feet	meters	$2^{29-X1}/$ 2^{27-X1}
NRTERM_D		Normalized terminal radius	feet	meters	$2^{29-X1}/$ 2^{27-X1}
RMAG1_D	r	Current radius magnitude	feet	meters	$2^{29}/2^{27}$
RONE_V	$\underline{r}$	Current radius state vector	feet	meters	$2^{29}/2^{27}$
RTERM_D	r_h	Terminal radius	feet	meters	$2^{29}/2^{27}$
TFFALFA_D	α	Inverse of semimajor axis of conic	1/feet	1/meters	$2^{-26+X1}/$ 2^{-24+X1}
TFFDELQ_D	$Q_h - Q_0$	Temporary variable	$\text{feet}^{1/2}$	$\text{meters}^{1/2}$	$2^{16}/2^{15}$
TFFNP_D	p	Semi-latus rectum, weighted by X1	feet	meters	$2^{38+2X1}/$ 2^{36+2X1}
TFFQ1_D	Q_0	$(\underline{r}_0 \quad \underline{v}_0)/\sqrt{\mu}$	$\text{feet}^{1/2}$	$\text{meters}^{1/2}$	$2^{16}/2^{15}$
TFFRTALF_D	$\sqrt{\alpha}$	Square root of inverse of semimajor axis	$1/\text{feet}^{1/2}$	$1/\text{meters}^{1/2}$	$2^{-10+X2}/$ 2^{-9+X2}
TFFTEM_D		Temporary variable location			
TFFVSQ_D	$-(v')^2 =$ $-\left(\frac{v}{\mu}\right)^2$	Minus square of velocity over mu	1/feet	1/meters	$2^{-20}/2^{-18}$

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN	3/4/70	Time Of Free Fall	
PRGMR	3/16/70	LUMINARY 1D	DOCUMENT NO. FC-3370
ANALST			
DOCMR	3/17/70		
APPR'D	3/17/70	REV	SHEET 12 OF 14

ERASABLE LOCATIONS USED (CONTINUED)

AGC tag	GSOP Symbol	Meaning	Engineering Units	AGC Units	AGC Scaling
$TFFX_D$	X	$1/\alpha Z^2$ or αZ^2			2^0
$TFF1/ALF_D$	$1/\alpha$	Inverse of alpha: semi-major axis	feet	meters	$2^{22-2X2}/$ 2^{20-2X2}
$URONE_V$	$UNIT(\underline{R}_o)$	Unit vector of current position			2^1
$VONE_V$	$\underline{V}_0$	Current velocity vector	feet/sec	meters/csec	$2^7/2^5$
$VONE'_V$	$\underline{v}'$	Current velocity vector over $mu^{1/2}$	$feet^{-1/2}$	$meters^{-1/2}$	$2^{-10}/2^{-9}$

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DRAWN A. Welch	3/4/70	Time Of Free Fall	
PRGMR R Bairnsfather	3/16/70	LUMINARY 1D	DOCUMENT NO. FC-3370
ANALST			
DOCMR RM Estes	3/17/70		
APPR'D RM Estes	3/17/70	REV	SHEET 13 OF 14

PROGRAM CONSTANTS

AGC Tag	GSOP Symbol	Meaning	Engineering Value and Units	AGC Value and Units	AGC Scaling
$DP(-22)_D$			2^{-22}	1	2^{22}
$DP2(-3)_D$	$1@2^3$	One	$1@2^3$	1	2^3
$DP2(-4)_D$	$1@2^4$	One	$1@2^4$	1	2^4
$HIDPHALF_D$	1/2		1/2	.5	2^0
$HI6ZEROS_D$	0	Zero	00000000.0	00000000.0	2^0
$LIM(-22)_D$	$1-2^{22}$	Test constant for $\|D\|$	$1-2^{22}$	$1-2^{22}$	2^0
$NEARONE_D$	$2^{28}-1$	Machine positive maximum	$2^{28}-1$	.999999999	2^0
$PI/16_D$	π	Pi	π	π	2^4
$TFFZEROS_D$	0	Zero	0	0	
$TFF1/4_D$	2	Two	$2@2^3$	2	2^3

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APOLLO GUIDANCE AND NAVIGATION

Time Of Free Fall

DRAWN B. Welch 3/4/70
PRGMR R. Bairnsfather 3/16/70
ANALST
DOCMR R M Estes 3/17/70
APPR'D R M Estes 3/17/70

LUMINARY 1D

DOCUMENT NO. FC-3370

REV

SHEET 14 OF 14

7.0 MANEUVER ROUTINES

R63 – RENDEZVOUS FINAL ATTITUDE

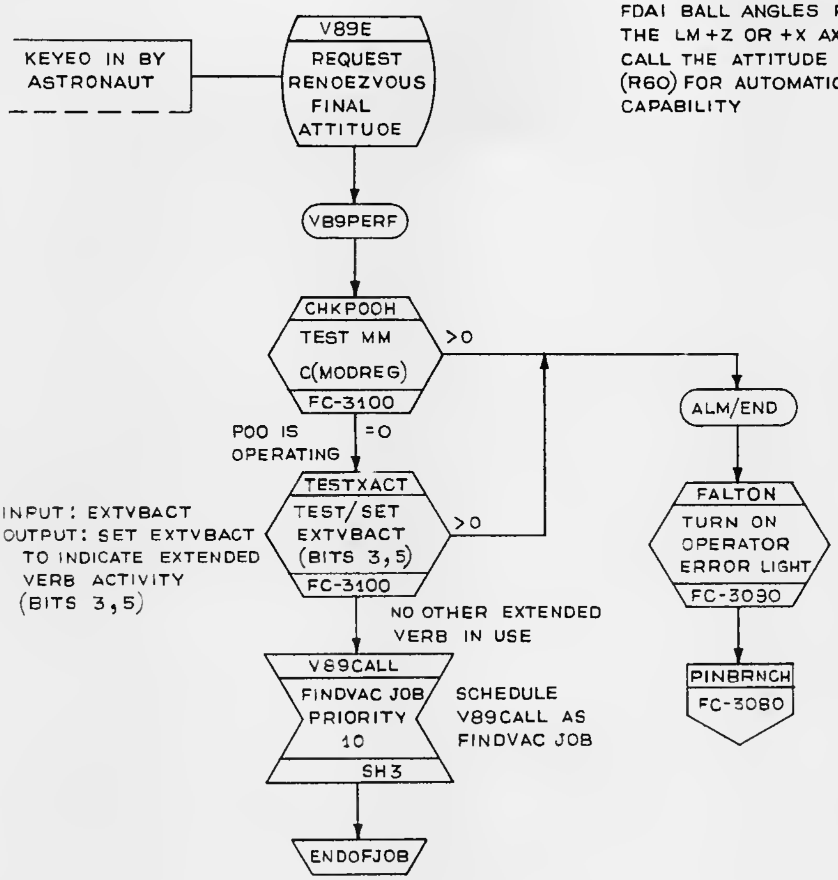
MAJOR SUBROUTINES ON THIS FLOWCHART

EXTENDED VERB – 89	V89PERF	REQUEST RENDEZVOUS FINAL ATTITUDE	SH 2
	V89CALL	ALIGN LM X OR Z AXIS ALONG LOS TO CSM	SH 3

D.M. Dietrich 3JUNE69
10JUNE69
W.C. Dayfort 10JUNE69.
Aleta M. Sorant 10JUNE69

R63
RENDEZVOUS FINAL ATTITUDE
LUMINARY 1D
FC-3400
2
1 5

PURPOSE: TO CALCULATE AND DISPLAY THE FINAL FDAI BALL ANGLES REQUIRED TO POINT THE LM +Z OR +X AXIS AT THE CSM. TO CALL THE ATTITUDE MANEUVER ROUTINE (R60) FOR AUTOMATIC MANEUVER CAPABILITY



R63

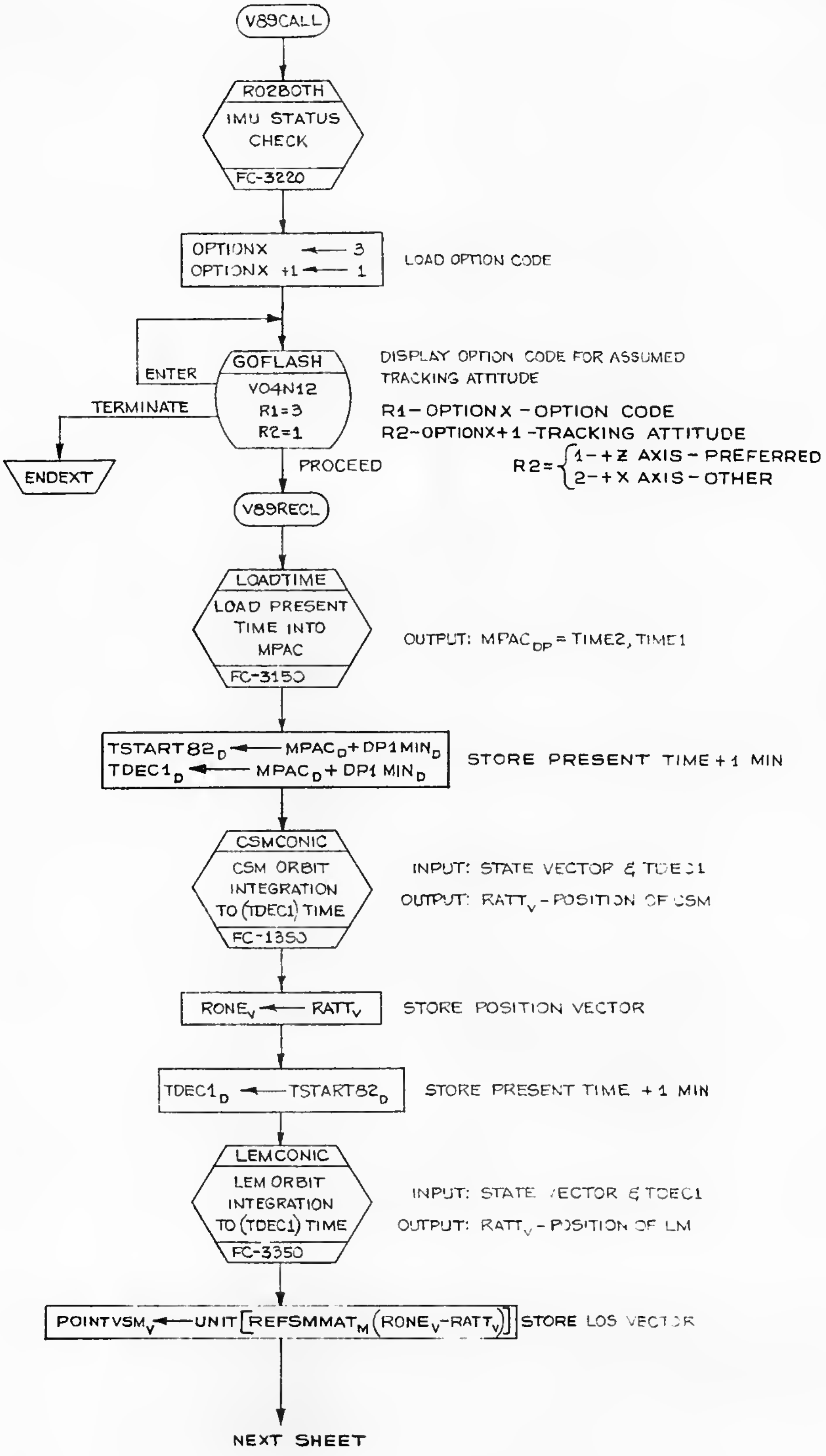
RENDEZVOUS FINAL ATTITUDE

P.M Dietz 8 AUG 68
14 AUG 68
R Werner 14 AUG 68
14 AUG 68
John A. Move 20 AUG 68

LUMINARY 1D

FC-3400

2 2 5



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DRAWN A.C.WILLIAMS 4-11-68
PRGMR K.M. Griggs 8-14-68
ANALST R Werner 1-14-68
DOCMR 5-9-68
APPR'D John A. Morse 20 AUG '68

APOLLO
GUIDANCE AND NAVIGATION

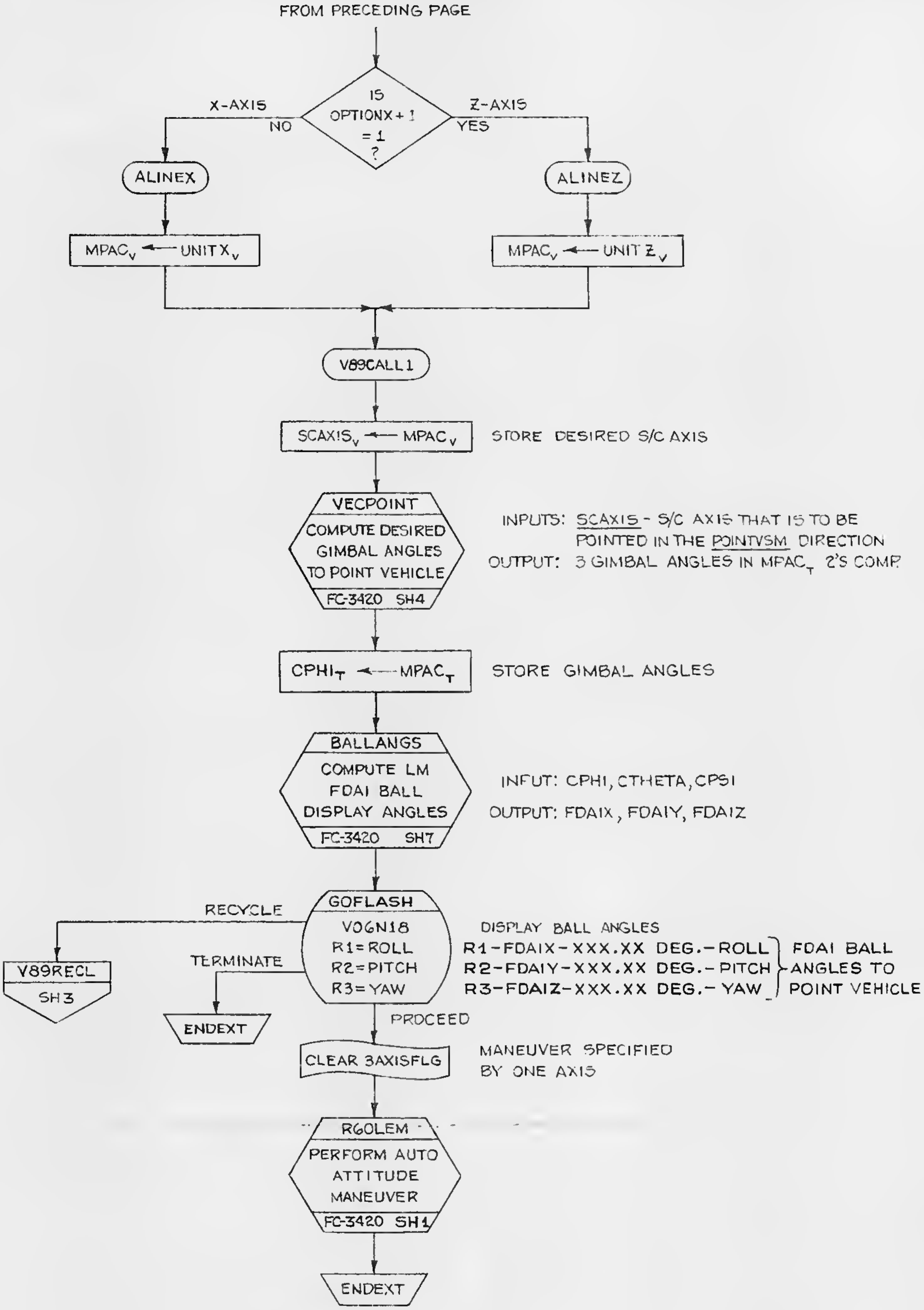
R63
RENDEZVOUS FINAL ATTITUDE

LUMINARY 1D

DOCUMENT NO. FC-3400

REV 2

SHEET 3 OF 5



MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C.WILLIAMS	4-11-68	R63 RENDEZVOUS FINAL ATTITUDE	
PROGMR K.M. Griggs	8-14-68	LUMINARY 1D	DOCUMENT NO. FC-3400
ANALST R. [illegible]	8-14-68		
DOCMR W [illegible]	8-9-68		
APPR'D John A. Morse	20 AUG 68	REV 2	SHEET 4 OF 5

R63 RENDEZVOUS FINAL ATTITUDE

SUBROUTINES
ON OTHER CHARTS

CHKPOOH	TEST CONTENTS OF MODREG
TESTXACT	TEST EXTENDED VERB ACTIVITY
R02BOTH	IMU STATUS CHECK
LOADTIME	LOAD PRESENT TIME INTO MPAC$_{DP}$
CSMCONIC	CSM ORBIT INTEGRATION
LEMCONIC	LM ORBIT INTEGRATION
VECPOINT	COMPUTE DESIRED GIMBAL ANGLES TO POINT VEHICLE
BALLANGS	COMPUTE LM FDAI DISPLAY ANGLES
R60LEM	PERFORM AUTO ATTITUDE MANEUVER
FALTON	TURN ON OPERATOR ERROR LIGHT

FLAGS	MEANING	SET	CLEARED	TESTED
3 AXISFLG	SET-MANEUVER SPECIFIED BY THREE AXES CLEARED-MANEUVER SPECIFIED BY ONE AXIS		SH 4	

DISPLAYS		USED
V04N12	R1-OPTIONX-OPTION CODE FOR ASSUMED TRACKING ATTITUDE R2-OPTIONX+1-TRACKING ATTITUDE R2-{1- +Z AXIS-PREFERRED 2- +X AXIS- OTHER	SH 3
V06N18	R1-FDAIX-XXX.XX DEG.-ROLL R2-FDAIY-XXX.XX DEG.-PITCH R3-FDAIZ-XXX.XX DEG.-YAW } FDAI BALL ANGLES TO POINT VEHICLE	SH 4

ERASABLES	MEANING	UNITS	SCALING
POINTVSM$_{V}$	LINE-OF-SIGHT VECTOR	——	B1
SCAXIS$_{V}$	DESIRED SPACE CRAFT AXIS	——	B1
CPHI CTHETA CPSI	DESIRED GIMBAL ANGLES FOR MANEUVER	REV	B0

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CAMBRIDGE, MASS.

DRAWN	A.C.WILLIAMS	5-7-68
PRGMR	K M Griggs	8-14-68
ANALST	R. Werner	8-14-68
DOCMR	Dogherty	5-9-68
APPR'D	John A. Moore	20 AUG 68

APOLLO
GUIDANCE AND NAVIGATION

R63
RENDEZVOUS FINAL ATTITUDE

LUMINARY 1D

DOCUMENT NO.
FC-3400

REV 2

SHEET 5 OF 5

R62 - CREW DEFINED MANEUVER

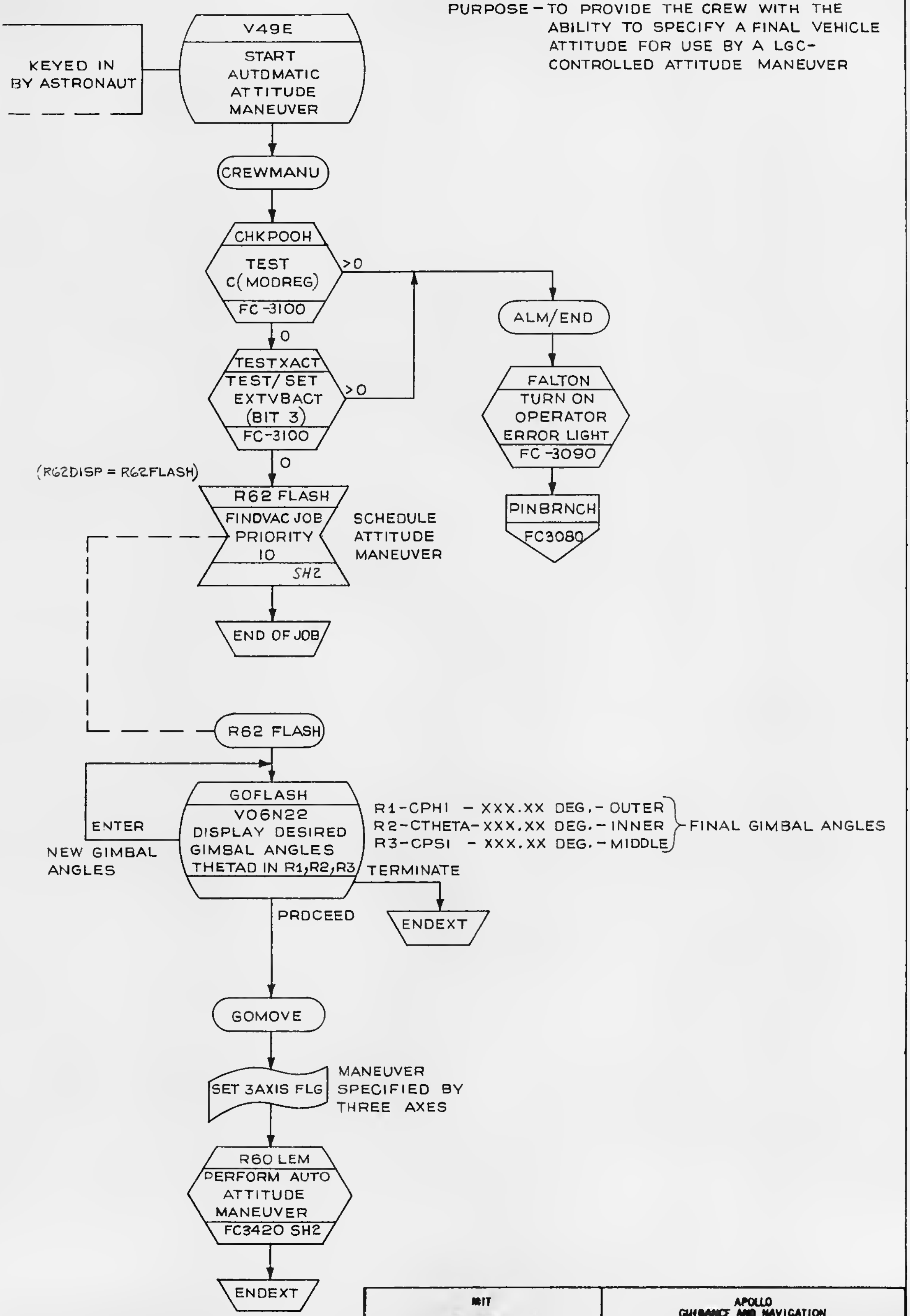
MAJOR SUBROUTINES ON THIS FLOW CHART

EXTENDED VERB - 49	CREWMANU	START AUTOMATIC ATTITUDE MANEUVER	SH2
	R62DISP = R62FLASH	CREW DEFINED MANEUVER	SH2

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION	
DRAWN A.C.WILLIAMS	3JUNE69	CREW DEFINED MANEUVER	
PRGMR		LUMINARY 1D	DOCUMENT NO. FC-3410
ANALST			
DOCMR	4JUNE69		
APPR'D	JUNE69	REV 2	SHEET 1 OF 3

R62 CREW-DEFINED MANEUVER

PURPOSE – TO PROVIDE THE CREW WITH THE ABILITY TO SPECIFY A FINAL VEHICLE ATTITUDE FOR USE BY A LGC-CONTROLLED ATTITUDE MANEUVER



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DRAWN	P.M. Dietrich	23JUL68
PRGMR	D. W. Keene	12AUG68
ANALST	R.E. Weiner	15AUG68
DOCMR	W. C. Dexter	29JUL68
APPR'D	John A. Morse	20AUG 68

APOLLO
GUIDANCE AND NAVIGATION

CREW DEFINED MANEUVER

LUMINARY 1D

DOCUMENT NO. FC-3410

REV 2

SHEET 2 OF 3

R62 CREW DEFINED MANEUVER

SUBROUTINES

ON OTHER CHARTS

CHKPOOH	TEST CONTENTS OF MODREG
TESTXACT	TEST / SET EXTVBACT
FALT ON	TURN ON OPERATOR ERROR LIGHT
R60LEM	PERFORM AUTO ATTITUDE MANEUVER

FLAGS	MEANING	SET	CLEARED	TESTED
3AXISFLG	SET - MANEUVER SPECIFIED BY THREE AXES CLEARED - MANEUVER SPECIFIED BY ONE AXIS	SH2		

DISPLAYS		USED
V06N22	R1-CPHI-XXX.XX DEG. - OUTER R2-CTHETA-XXX.XX DEG.- INNER R3-CPSI -XXX.XX DEG.- MIDDLE } FINAL GIMBAL ANGLES	SH2

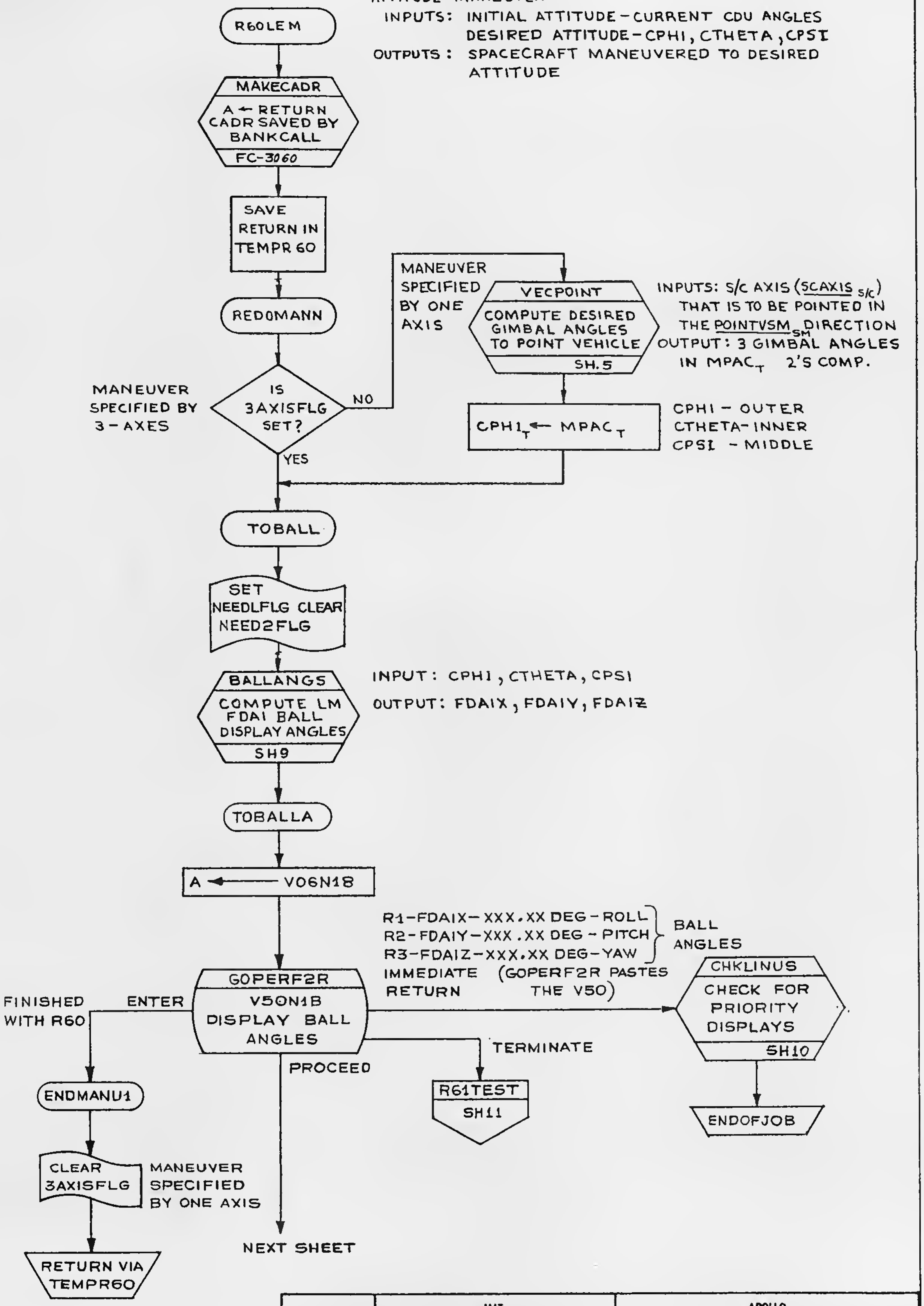
	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.		APOLLO GUIDANCE AND NAVIGATION
	DRAWN	30APR68	CREW DEFINED MANUVER
	PRGMR D. W. Kline	12 AUG 68	
	DOCMR W. Danforth	9 MAY 68	LUMINARY 1D — DOCUMENT NO. FC-3410
	ANALST	15AUG68	
USED ON	APPR'D John G. Morse	20 AUG 68	REV 2 — SHEET 3 OF 3

R60 - Attitude Maneuver

Major Subroutines On This Flowchart

R60LEM	Sh. 2
VECPOINT	Sh. 5
BALLANGS	Sh. 9
CHKLINUS	Sh. 10
RELINUS	Sh. 10
G+N, AUTO	Sh. 11
ISITAUTO	Sh. 11

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION	
DRAWN	12/8/69	ATTITUDE MANEUVER
PRGMR D.W. Keene	12/9/69	
ANALST		LUMINARY 1D
DOCMR W. Danforth	12/8/69	DOCUMENT NO. FC-3420
APPR'D W. Danforth	12/16/69	REV 3
		SHEET 1 OF 12



ATTITUDE MANEUVER
INPUTS: INITIAL ATTITUDE - CURRENT CDU ANGLES
DESIRED ATTITUDE - CPHI, CTHETA, CPSI
OUTPUTS: SPACECRAFT MANEUVERED TO DESIRED ATTITUDE

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DRAWN F. Pearson 7-DEC 67
PRGMR D.W. Keene 26 AUG 68
DOCMR W. Danforth 9 MAY 68
ANALST
APPR'D John A. Morse 5 Sept 69

USED ON

APOLLO
GUIDANCE AND NAVIGATION

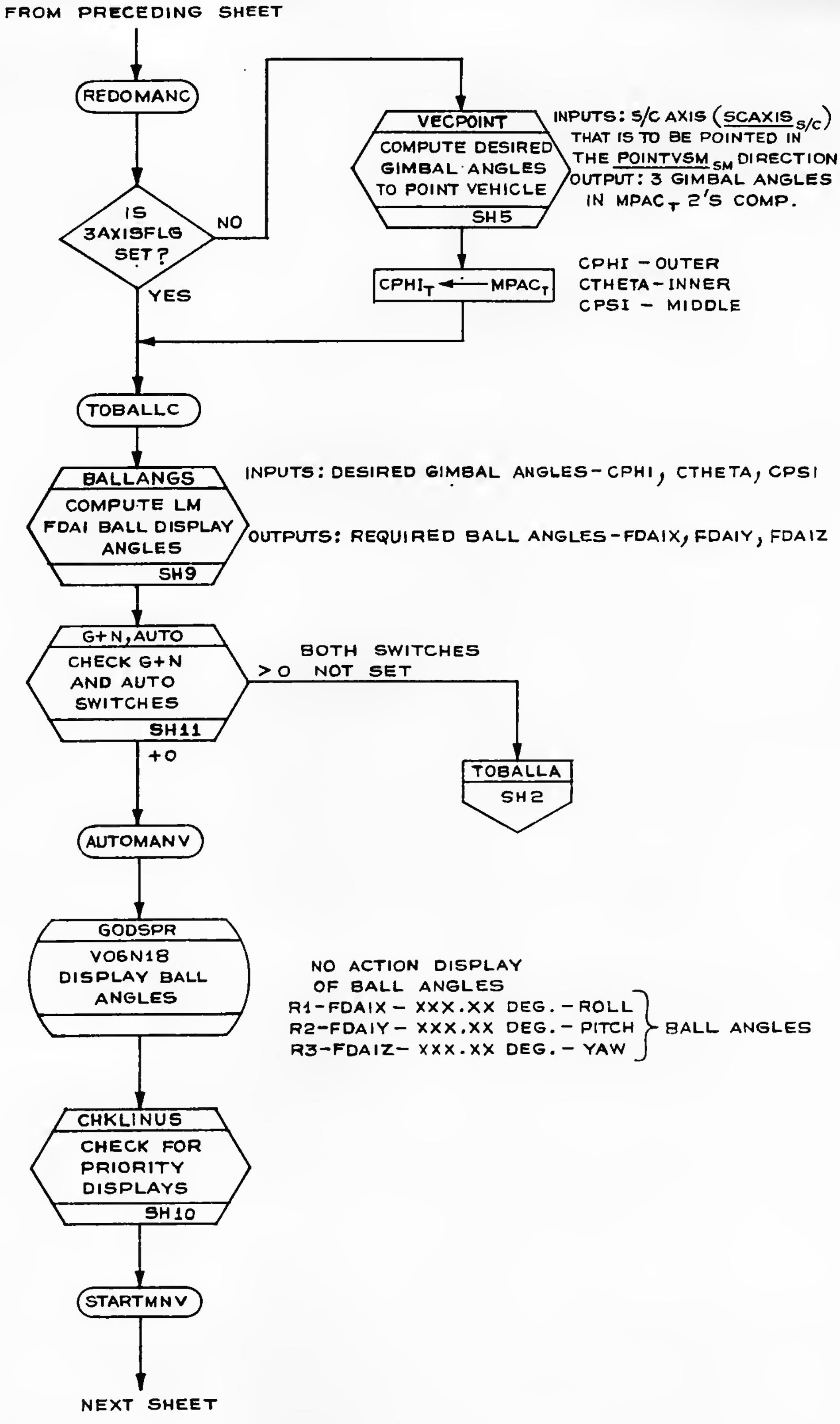
ATTITUDE MANEUVER

LUMINARY
1D

DOCUMENT NO.
FC-3420

REV .3

SHEET 2 OF 12



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DRAWN		4 JUNE 69
PRGMR	D. W. Keene	1 AUG 69
ANALST		
DOCMR		11 JUNE 69
APPR'D		4 AUG 69

APOLLO
GUIDANCE AND NAVIGATION

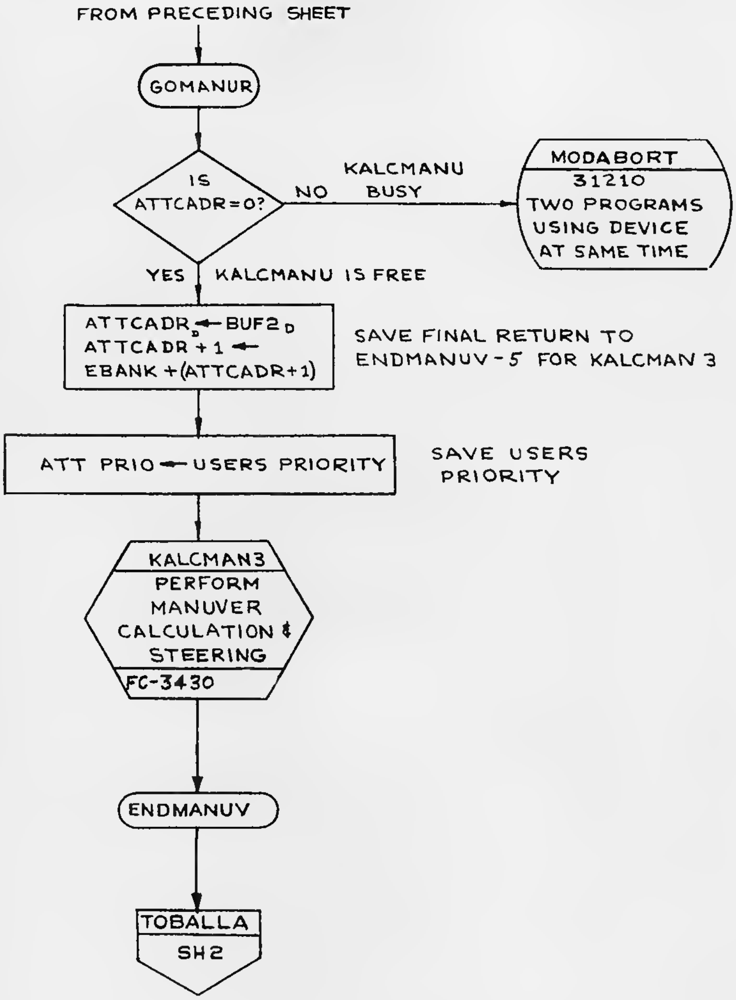
ATTITUDE MANEUVER

LUMINARY
1D

DOCUMENT NO.
FC-3420

REV 3

SHEET 3 OF 12



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DRAWN F. Bensen Jr. 27 JUN 68
PROGMR D. W. Keeny 26 AUG 68
DOCMR W. Doolittle 27 June 6
ANALST
APPR'D John A. Morse 5 Sept. 69

USED ON

APOLLO
GUIDANCE AND NAVIGATION

ATTITUDE MANEUVER

LUMINARY
1D

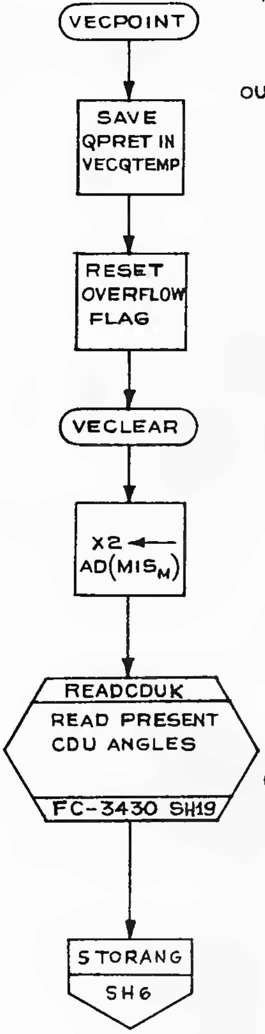
DOCUMENT NO. FC-3420

REV 3.

SHEET 4 OF 12

INPUTS: $SCAXIS_V$ = S/C AXIS TO BE POINTED
$POINTVSM_V$ = DIRECTION S/C IS TO BE POINTED IN SM COORDINATES

OUTPUTS: DESIRED GIMBAL ANGLES IN $MPAC_T$ (2'S COMP.)
MPAC – OUTER
MPAC + 1 – INNER
MPAC + 2 – MIDDLE



OUTPUT: $MPAC_T$ = CURRENT CDU ANGLES

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DRAWN 4 JUNE 69
PRGMR D.W. Keene 1 AUG 69
ANALST
DOCMR 11 JUNE 69
APPR'D 4 AUG 69

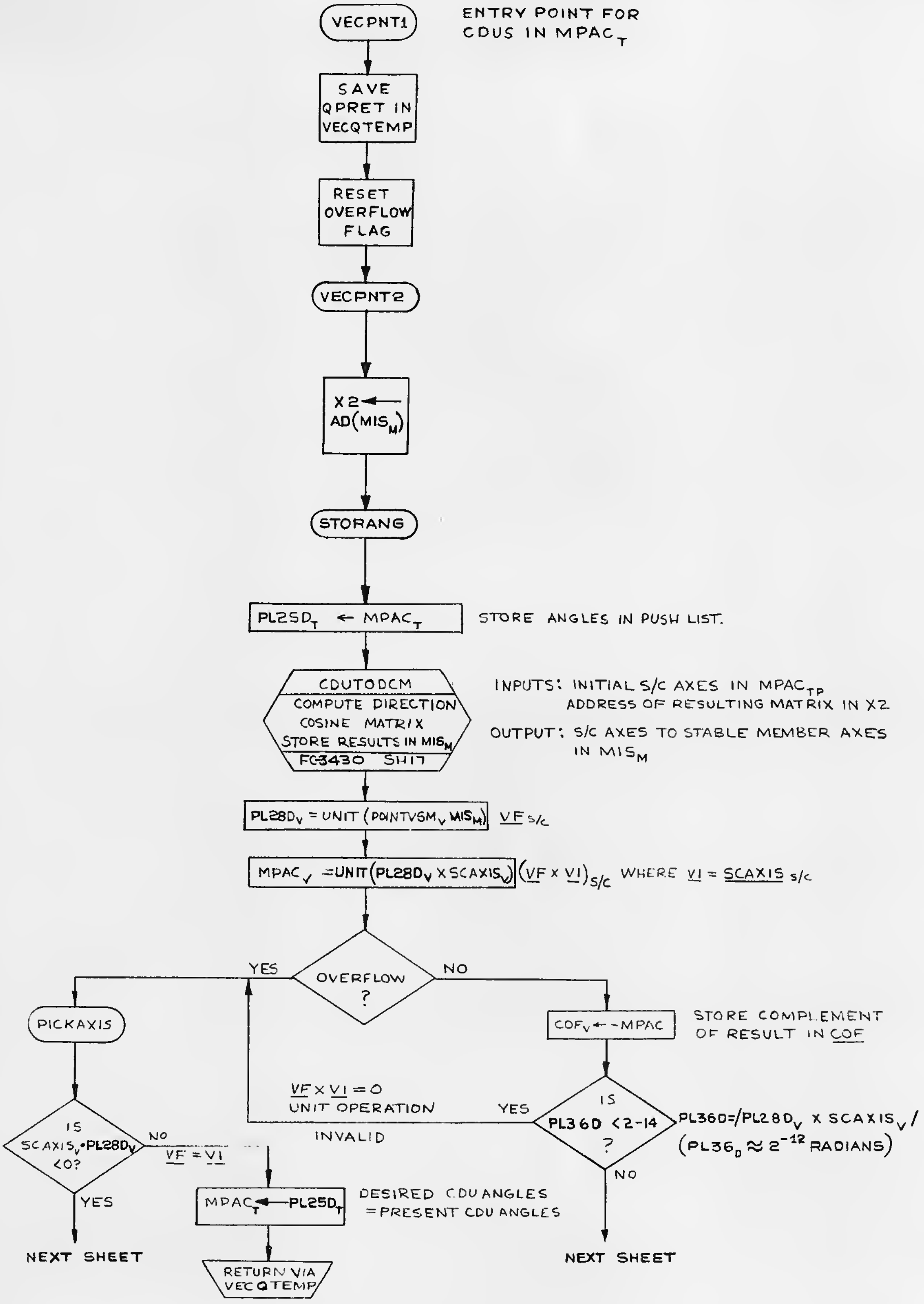
APOLLO
GUIDANCE AND NAVIGATION

ATTITUDE MANEUVER

LUMINARY
1D

DOCUMENT NO.
FC-3420

REV 3
SHEET 5 OF 12



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INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN F. Peterson Jr. I-10-67
PRGMR D.W. Keene 26-AUG 68
DOCMR W. Dayforth Jr. 9-9-68
ANALST
APPR'D John A. Morse 5 Sept. 68

USED ON

APOLLO
GUIDANCE AND NAVIGATION

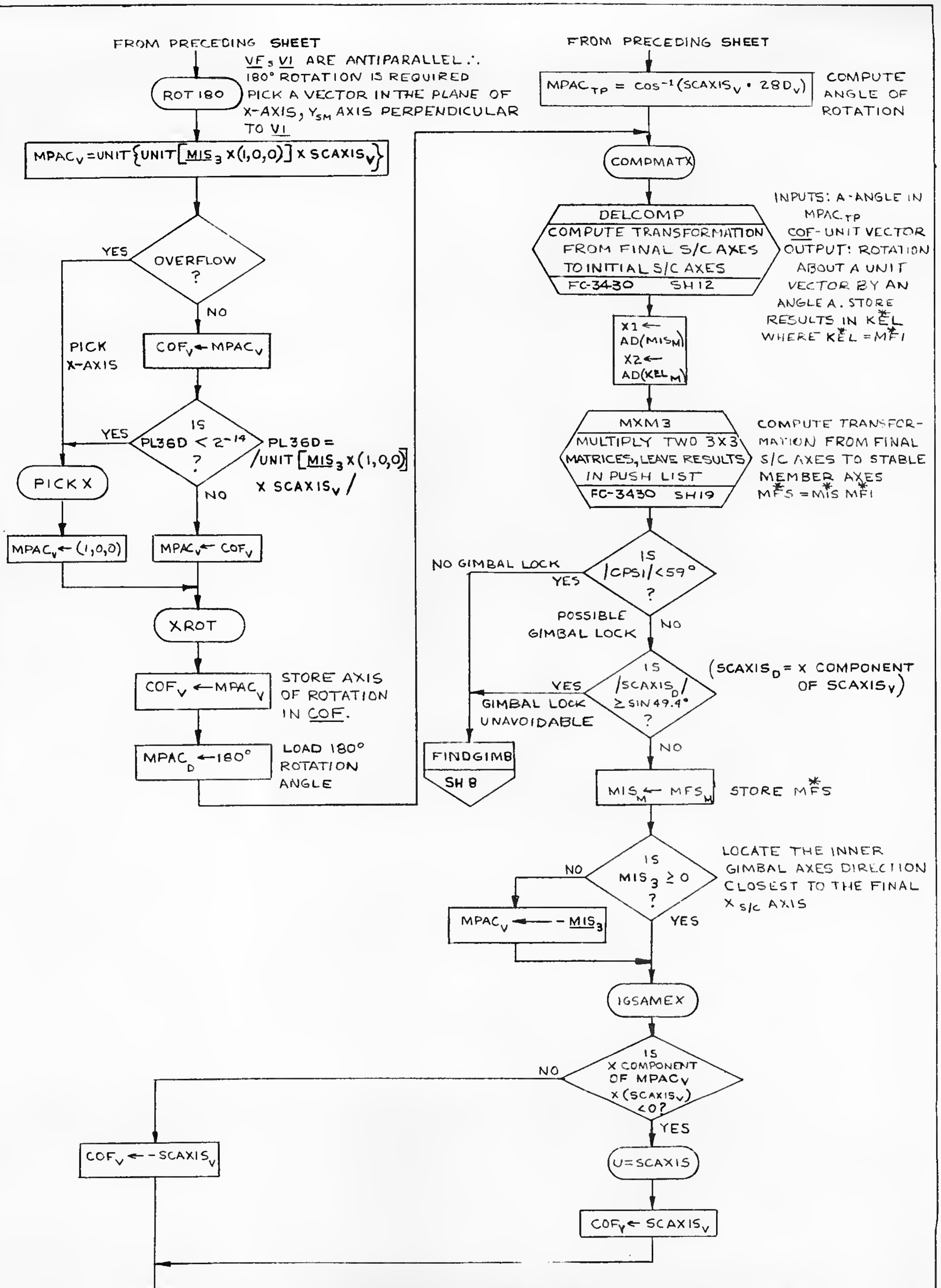
ATTITUDE MANEUVER

LUMINARY
1D

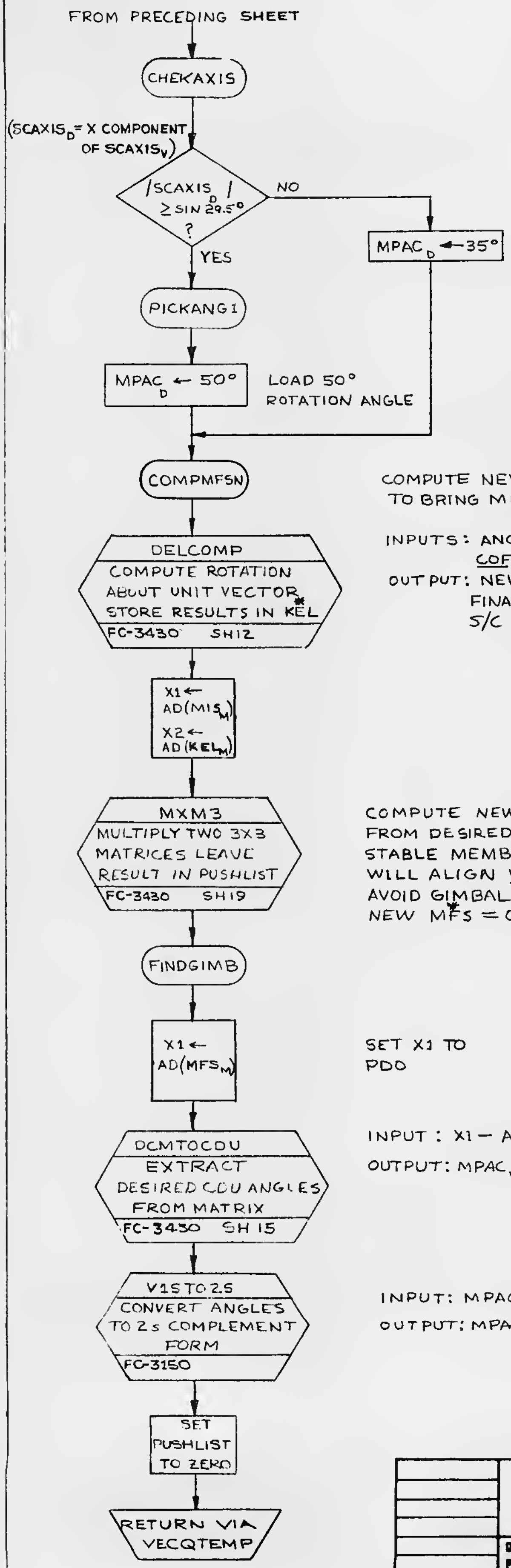
DOCUMENT NO.
FC-3420

REV 3

SHEET 6 OF 12



	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		ATTITUDE MANEUVER
	DRAWN F. Pearson Jr. 11-10-67	
	PROGMR D. W. Keene 26 Aug 68	
	DOCMR W. Dougherty Jr. 5-9-68	LUMINARY 1D — DOCUMENT NO. FC-3420
	ANALST	
USED ON	APPR'D John A. Morse 5 Sept 68	REV 3 — SHEET 7 OF 12



LOAD 35°
ROTATION ANGLE

LOAD 50°
ROTATION ANGLE

COMPUTE NEW ROTATION ABOUT SCAXIS s/c
TO BRING M*FS OUT OF GIMBAL LOCK

INPUTS: ANGLE IN MPAC
COF-UNIT VECTOR
OUTPUT: NEW TRANSFORMATION FROM
FINAL S/C AXES TO INITIAL
S/C AXES.

COMPUTE NEW TRANSFORMATION
FROM DESIRED S/C AXES TO
STABLE MEMBER AXES WHICH
WILL ALIGN VI WITH VF AND
AVOID GIMBAL LOCK.
NEW M*FS = OLD M*FS K*EL

SET X1 TO
PDO

INPUT : X1 — AD(M*FS)
OUTPUT: MPAC$_V$ — DESIRED CDU ANGLES
IN 1'S COMPLEMENT FORM

INPUT: MPAC$_V$ - CDU ANGLES$_D$
OUTPUT: MPAC$_T$ - CDU ANGLES$_S$

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CAMBRIDGE, MASS.

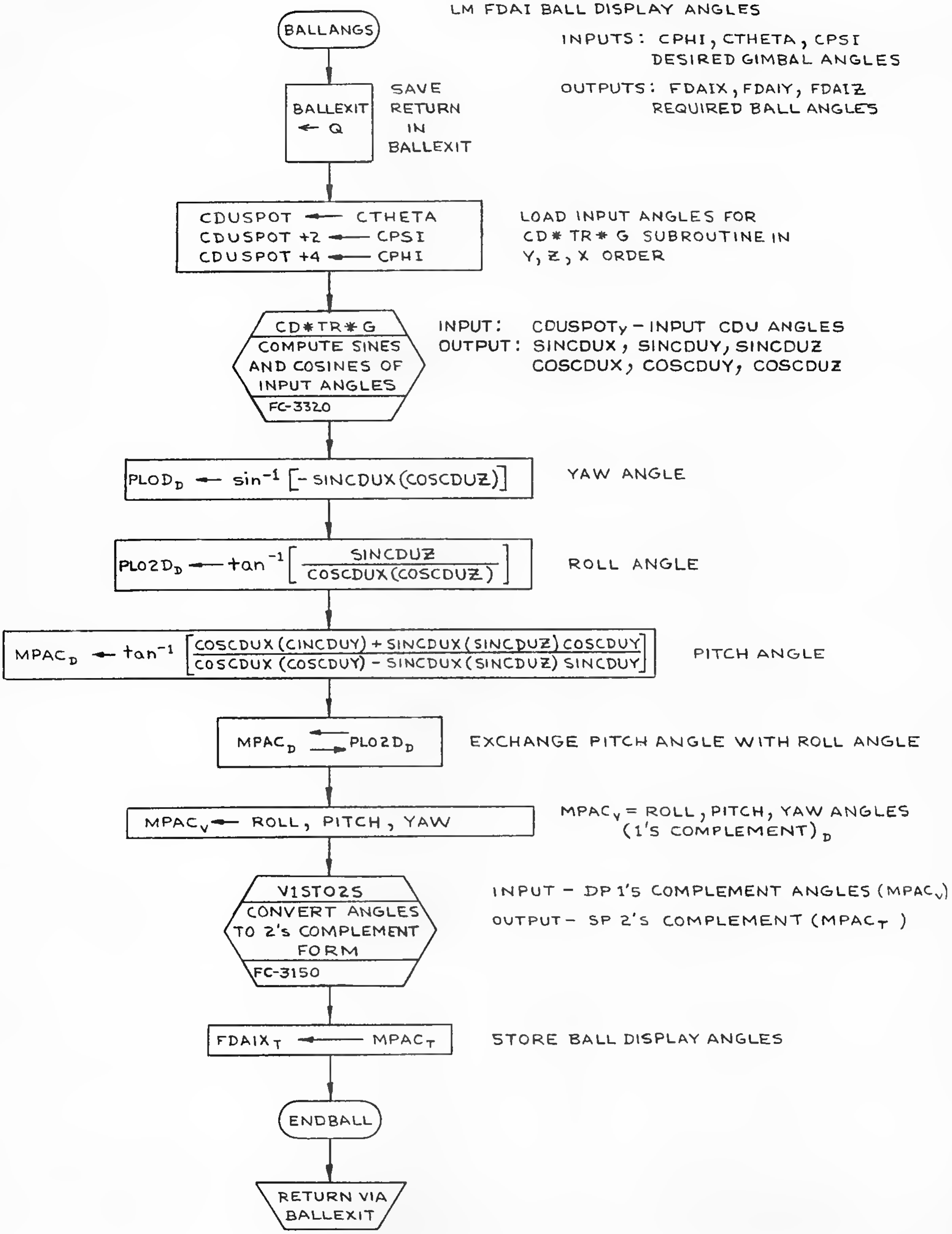
DRAWN F. Pearson Jr. 11-10-67
PRGMR D. W. Keene 26-4-68
DOCMR N. Danforth 5-9-68
ANALST
APPR'D John A. Morse 5 Sept 68
USED ON

APOLLO
GUIDANCE AND NAVIGATION

ATTITUDE MANEUVER

LUMINARY 1D
DOCUMENT NO. FC-3420
REV 3
SHEET 8 OF 12

SUBROUTINE TO COMPUTE
LM FDAI BALL DISPLAY ANGLES



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN F. Pearson Jr. 2 MAY 68
PRGMR W. Keene 26 AUG 68
DOCMR W. Daybitt Jr 9 MAY 68
ANALST
APPR'D John A. Moore 5 Sept 68
USED ON

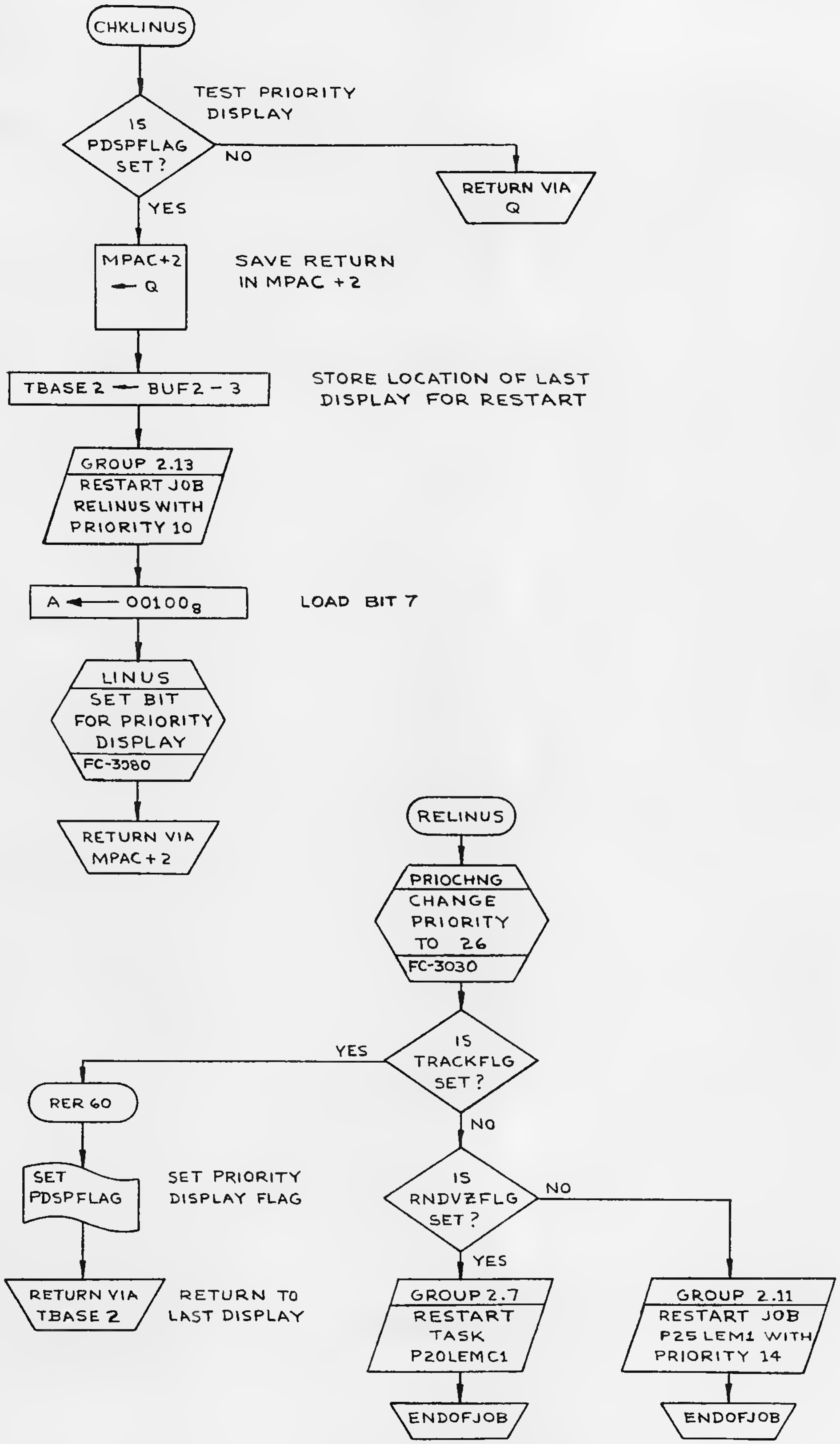
APOLLO
GUIDANCE AND NAVIGATION

ATTITUDE MANEUVER

LUMINARY
1D
REV 3

DOCUMENT NO.
FC-3420

SHEET 9 OF 12



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DRAWN J. Pearson jr. 2 MAY 68
PRGMR P. Volante 4 SEPT 68
DOCMR W. Dufoth Jr. 9 MAY 66
ANALST
APPR'D John A. Morse 5 Sept 68

USED ON

APOLLO
GUIDANCE AND NAVIGATION

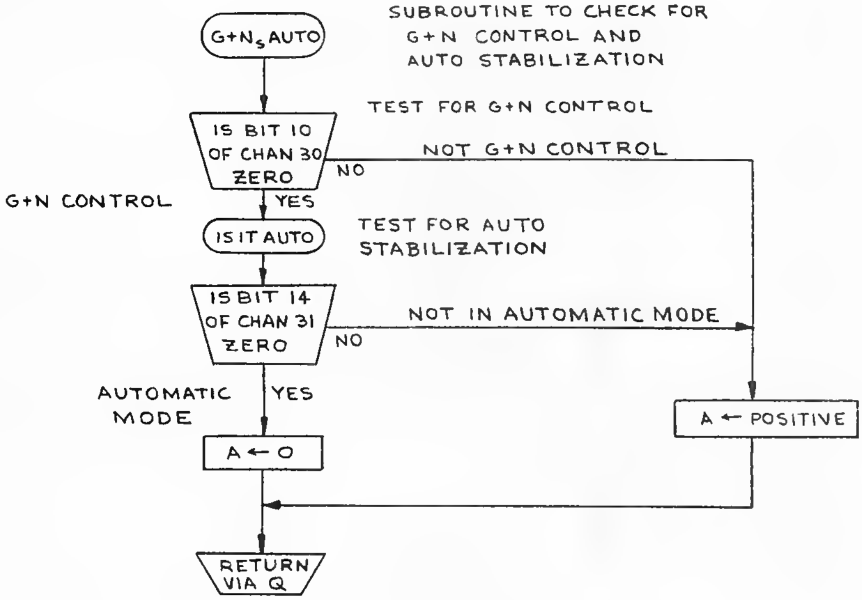
ATTITUDE MANEUVER

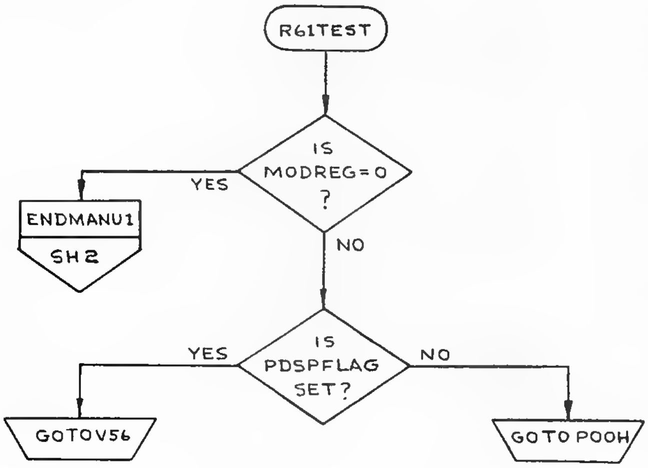
LUMINARY 1D

DOCUMENT NO. FC-3420

REV 3

SHEET 10 OF 12





	MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION
		ATTITUDE MANEUVER
	DRAWN F. Pearson J. — 14DEC67	
	PRGMR P. Volante — 4SEPT68	
	DOCMR — 9MAY68	LUMINARY 1D — DOCUMENT NO. FC-3420
	ANALST	
USED ON	APPR'D John A. Moore — 5 Sept 68	REV 3 — SHEET 11 OF 12

R60 ATTITUDE MANEUVER

SUBROUTINES

IN THIS CHART

VECPOINT	COMPUTE DESIRED GIMBAL ANGLES TO POINT VEHICLE
BALLANGS	COMPUTE LM FDAI BALL DISPLAY ANGLES
CHKLINUS	TEST FOR PRIORITY DISPLAYS
G+N, AUTO	TEST G+N AND AUTO SWITCHES

ON OTHER CHARTS

MAKECADR	LOAD RETURN CADR SAVED BY BANKCALL
READCDUK	READ PRESENT CDU ANGLES
CDUTODCM	COMPUTE DIRECTION COSINE MATRIX
DELCOMP	COMPUTE TRANSFORMATION MATRIX
MXM 3	MULTIPLY TWO 3×3 MATRICES
DCMTOCDU	EXTRACT DESIRED CDU ANGLES FROM MATRIX
V1STO2S	CONVERT 1's COMPLEMENT ANGLES TO 2's COMPLEMENT ANGLES
CD*TR*G	COMPUTE SINES AND COSINES OF 2's COMPLEMENT ANGLES
LINUS	SET BITS FOR PRIORITY DISPLAY
PRIOCHNG	CHANGE PRIORITY OF JOB IN EXECUTION
KALCMAN3	*MANEUVER CALCULATIONS AND STEERING*

FLAGS	MEANING	SET	CLEARED	TESTED
AUTMANSW	SET - DO MANEUVER MANUALLY CLEARED - DO MANEUVER USING KALCMANU		SH2	
3AXISFLG	SET - MANEUVER SPECIFIED BY THREE AXES CLEARED - MANEUVER SPECIFIED BY ONE AXIS		SH 2	SH 2
PDSPFLAG	SET - CANNOT INTERRUPT PRIORITY DISPLAY CLEARED - MAY INTERRUPT NO PRIORITY DISPLAY	SH 10		SH 10,11
TRACKFLG	SET - TRACKING ALLOWED CLEARED - TRACKING NOT ALLOWED			SH 10
RNDVZFLG	SET - P20 RUNNING (RADAR IN USE) CLEARED - P 20 NOT RUNNING (RADAR NOT IN USE)			SH 10

DISPLAYS	MEANING	USED
V50N18 V06N18	R1 - FDAIX - XXX.XX DEG. - ROLL R2 - FDAIY - XXX.XX DEG. - PITCH R3 - FDAIZ - XXX.XX DEG. - YAW } FINAL FDAI BALL ANGLES	SH 2 SH 3

ALARMS	MEANING	USED
31210	TWO PROGRAMS USING DEVICE AT SAME TIME	SH 4

ERASABLES	MEANING	UNITS	SCALING
CPHI CTHETA CPSI	DESIRED GIMBAL ANGLES FOR MANEUVER	REV	2^0

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DRAWN F. Pearson Jr. 5 MAY 68
PRGMR D. W. Kiernan 26 AUG 68
DOCMR W. [illegible] 9 MAY 68
ANALST
APPR'D John A. Moore 5 Sept 68

USED ON

APOLLO
GUIDANCE AND NAVIGATION

ATTITUDE MANEUVER

LUMINARY
1D

DOCUMENT NO.
FC-3420

REV. 3

SHEET 12 OF 12

MANEUVER CALCULATIONS AND STEERING

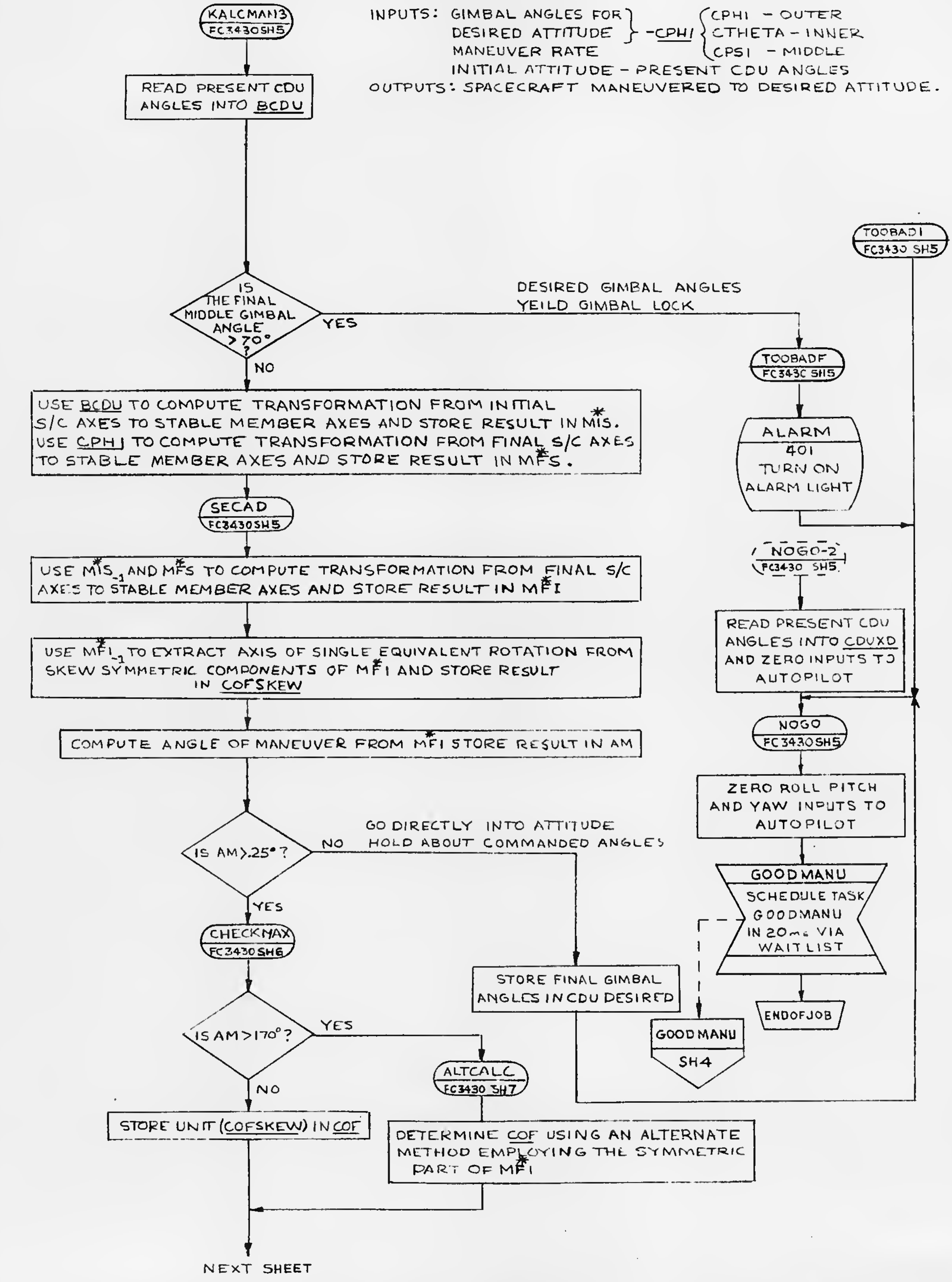
MAJOR SUBROUTINES AND EXTERNAL ENTRY POINTS

KALCMAN3	MANEUVER CALCULATIONS AND STEERING	SH. 5
STOPRATE	ZERO INPUTS TO AUTOPILOT	SH. 14
ZATTEROR	LOAD COMMANDED ANGLES; ZERO INPUTS TO AUTOPILOT	SH. 14
TIMECHK	TEST TIME REMAINING TILL END OF MANEUVER	SH. 15
DELCOMP	COMPUTE TRANSFORMATION MATRIX	SH. 16
DCMTOCDU	EXTRACT DESIRED CDU ANGLES FROM MATRIX	SH. 19
CDUTODCM	COMPUTE DIRECTION COSINE MATRIX	SH. 21
READCDUK	LOAD PRESENT CDU ANGLES INTO MPAC$_T$	SH. 23
TRANSPOS	TRANSPOSE MATRIX	SH. 23
MXM3	MULTIPLY TWO 3 X 3 MATRICES	SH. 23
TRNSPSPD	TRANSPOSE MATRIX IN PUSH LIST	SH. 23

MIT INSTRUMENTATION LAB CAMBRIDGE, MASS.	APOLLO GUIDANCE AND NAVIGATION MANEUVER CALCULATIONS AND STEERING	
DRAWN		
PROGMR D. W. Keene 7-9-69	LUMINARY 1D	DOCUMENT NO. FC-3430
ANALST		
DOCMR 8JLY69		
APPR'D 8JULY69	REV 2	SHEET 1 OF 24

KALCMANU — MANEUVER CALCULATIONS AND STEERING

INPUTS: GIMBAL ANGLES FOR DESIRED ATTITUDE } — CPHI { CPHI — OUTER, CTHETA — INNER, CPSI — MIDDLE
MANEUVER RATE
INITIAL ATTITUDE — PRESENT CDU ANGLES
OUTPUTS: SPACECRAFT MANEUVERED TO DESIRED ATTITUDE.



MIT
INSTRUMENTATION LAB
CAMBRIDGE, MASS.

DRAWN Fisher Pearson 9-19-67
PRGMR D. W. Keene 9-3-68
DOCMR W. Daggett Jr. 9-9-68
ANALST

APOLLO
GUIDANCE AND NAVIGATION

SIMPLIFIED FLOW
MANEUVER CALCULATIONS
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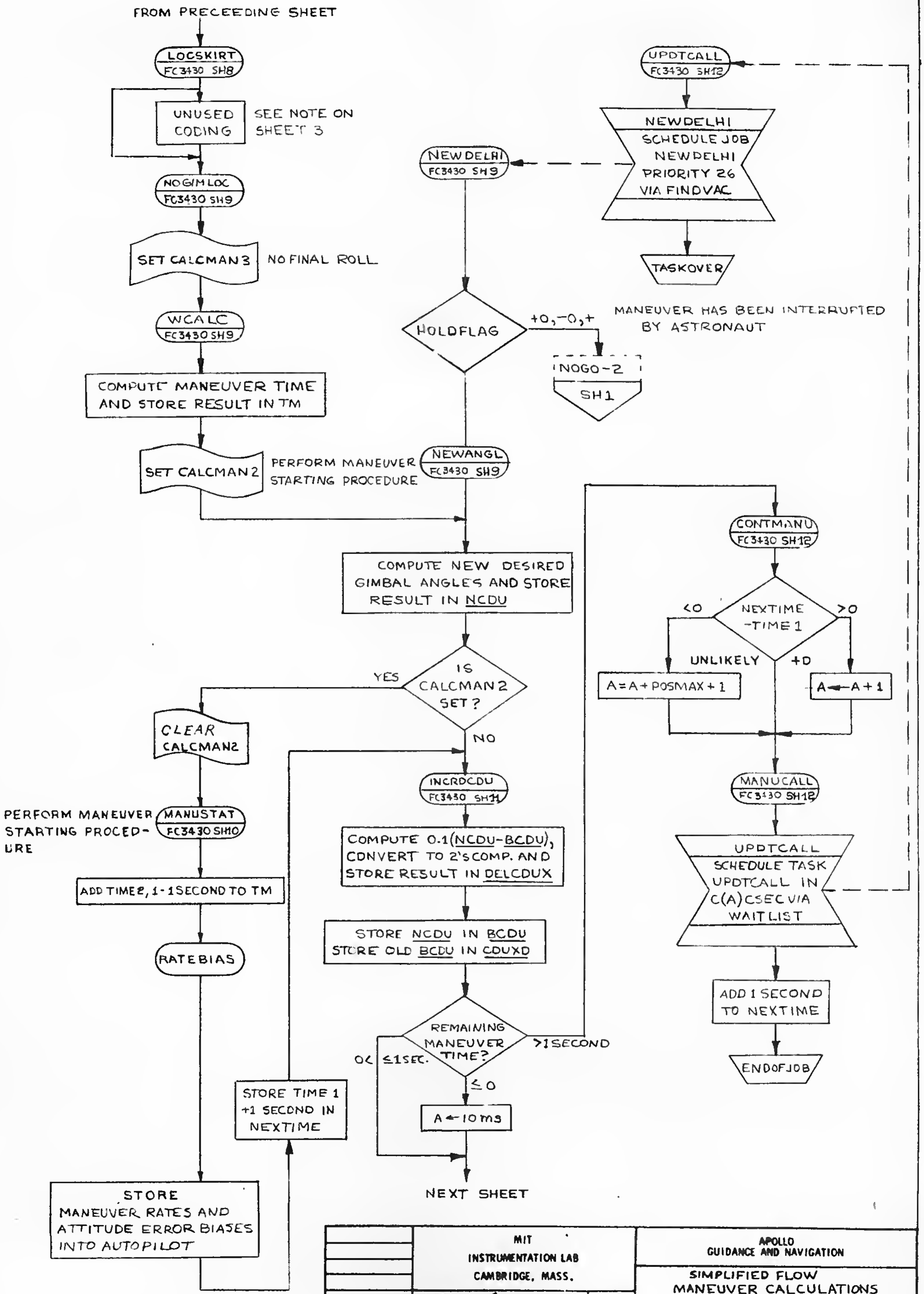

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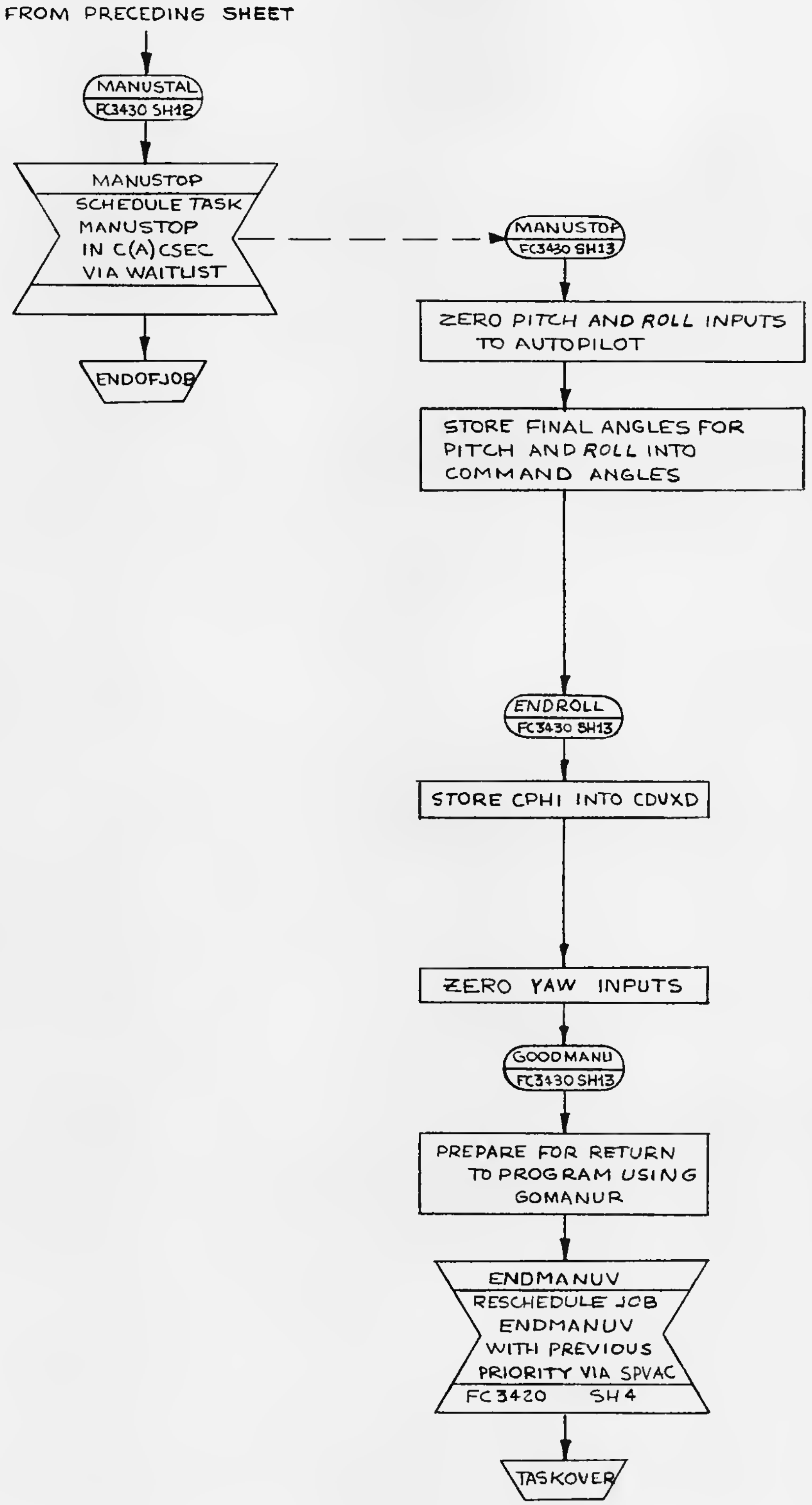

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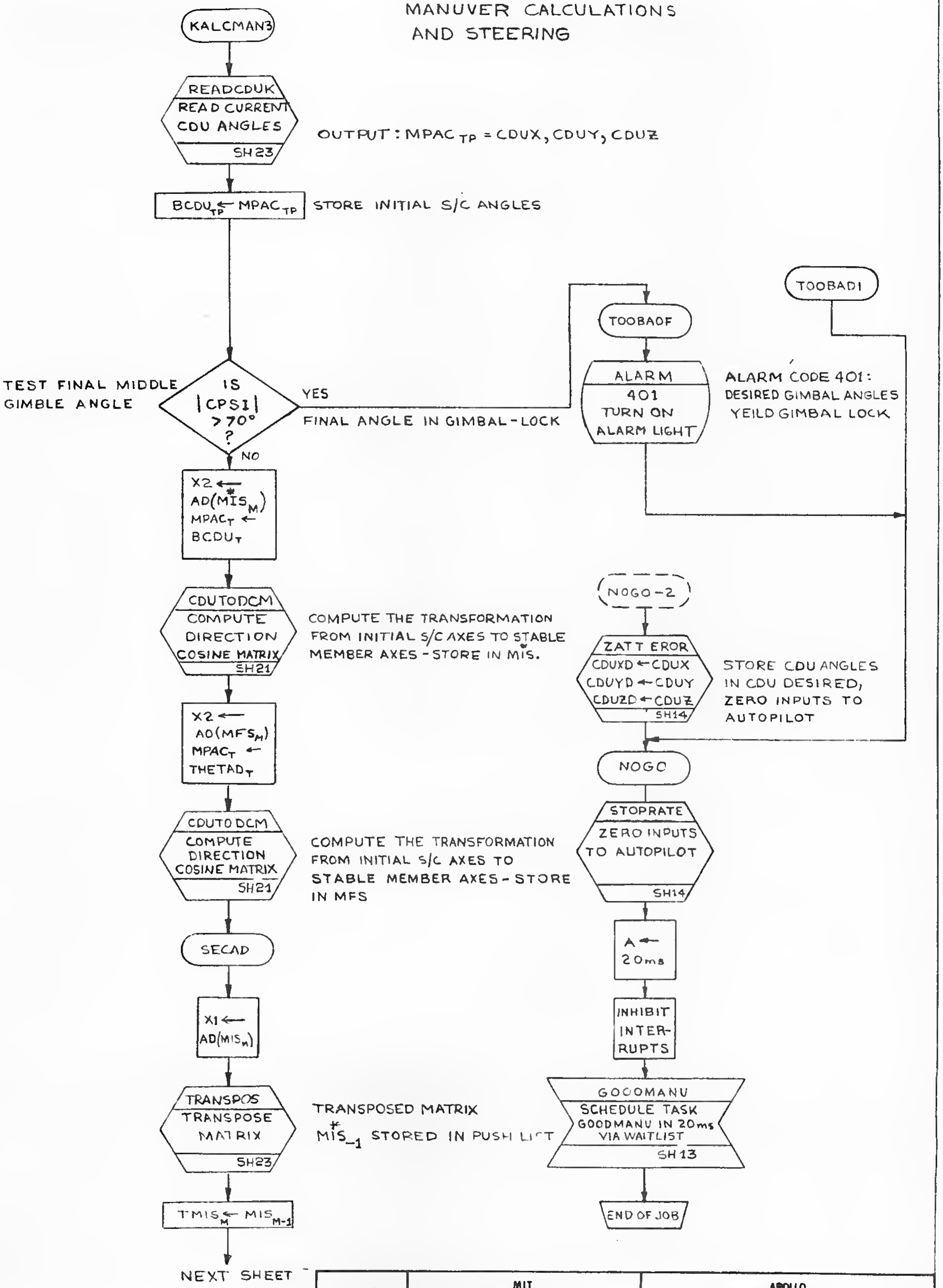
MANUVER CALCULATIONS AND STEERING



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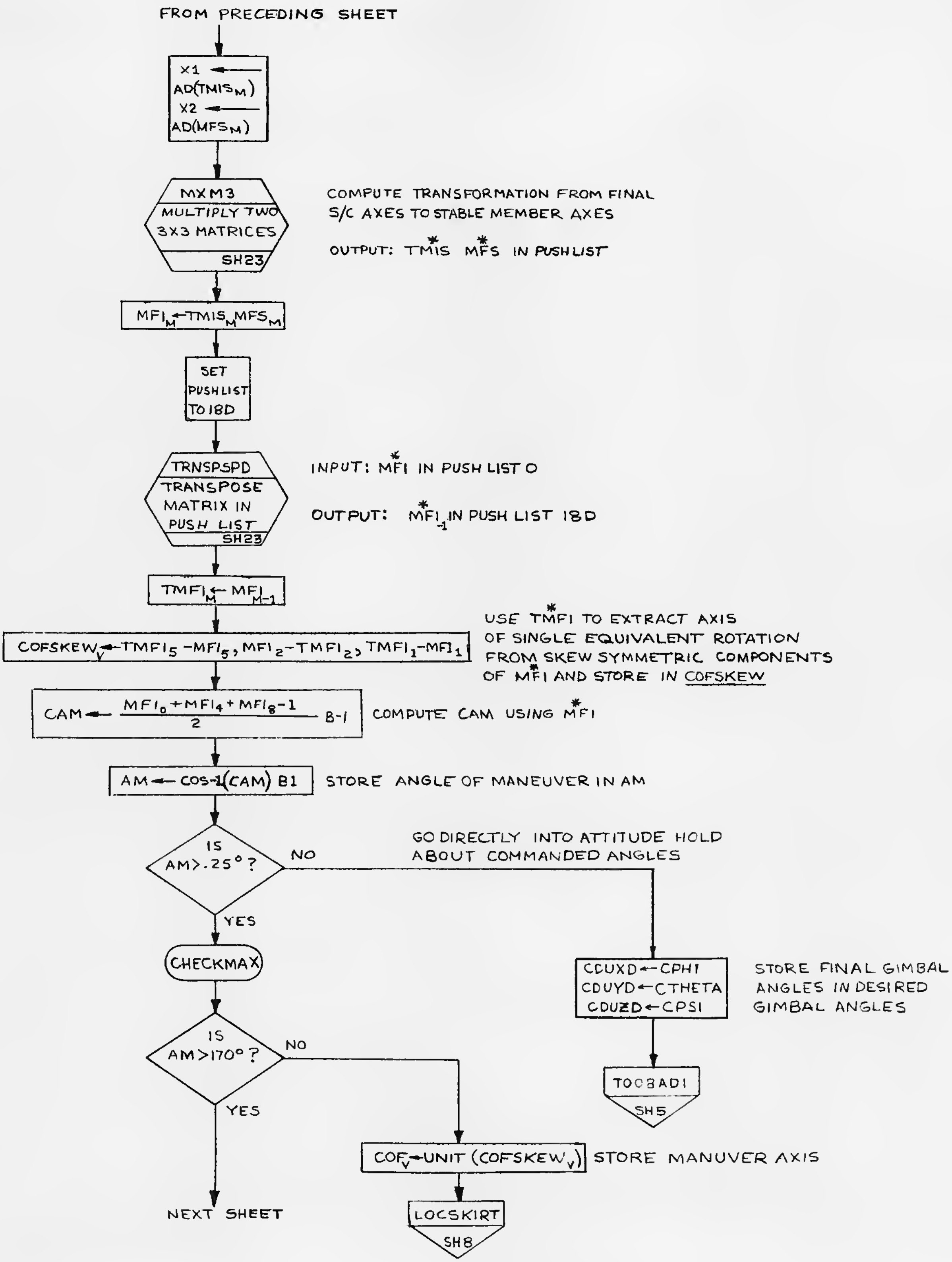

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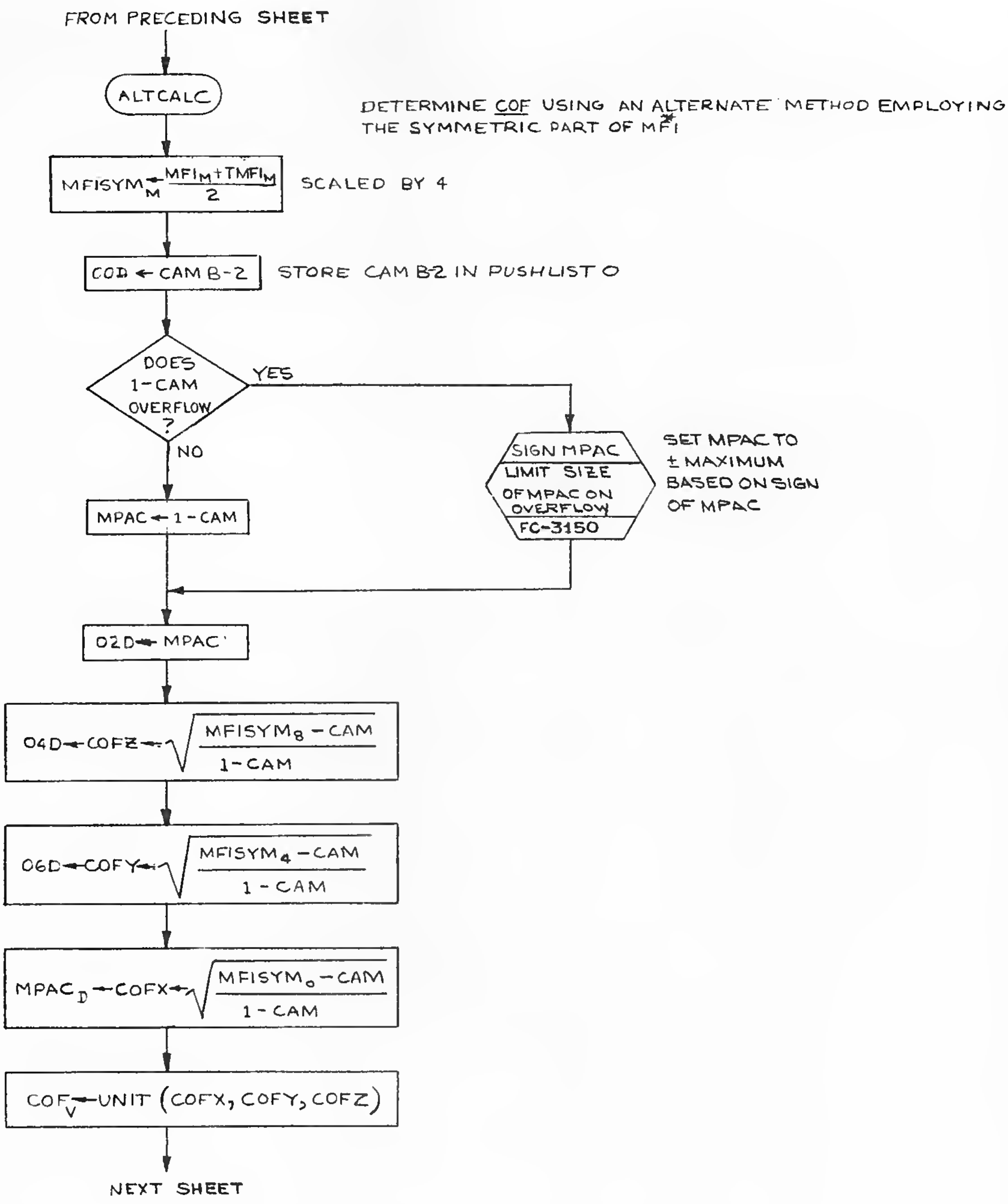

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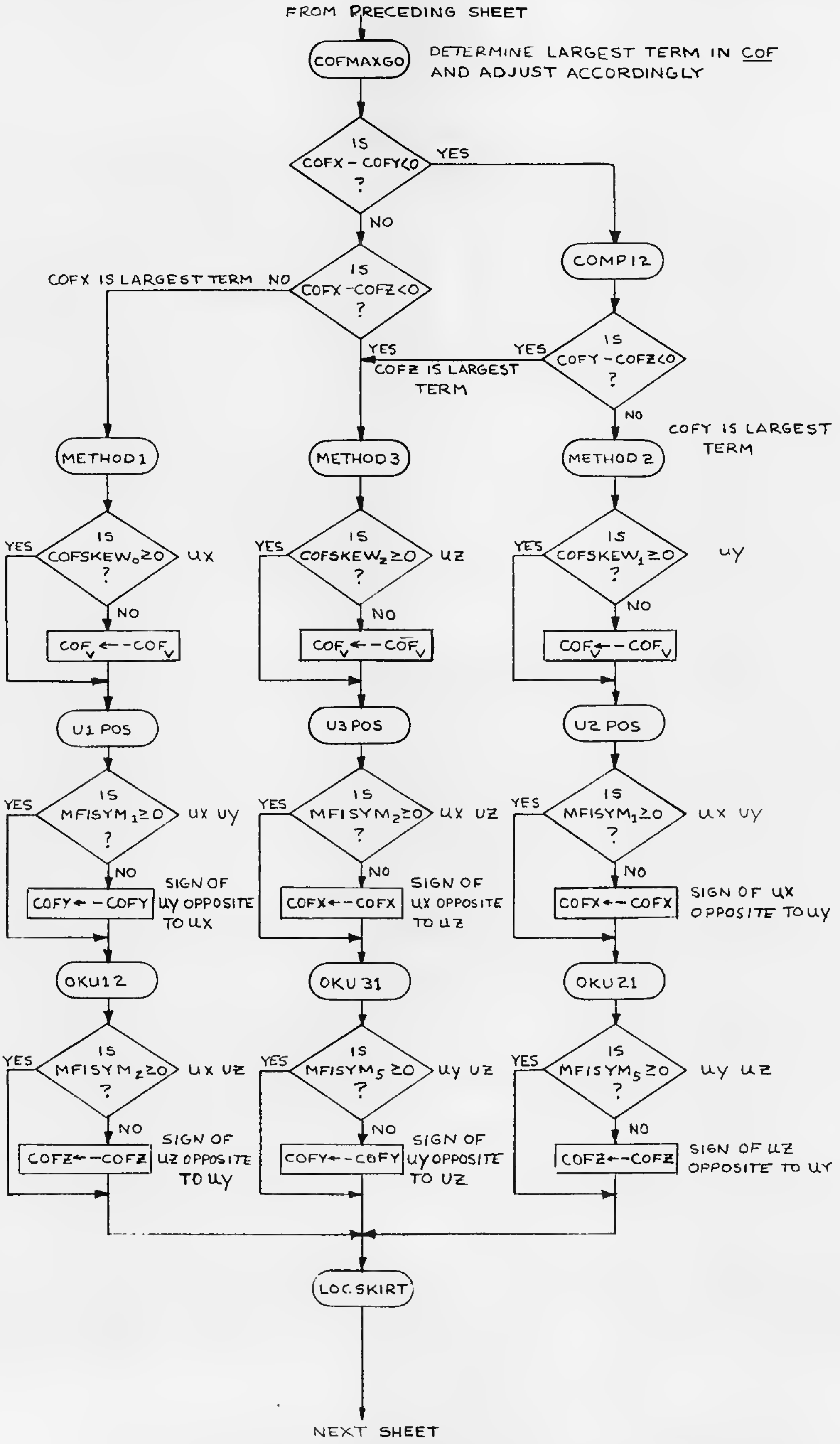

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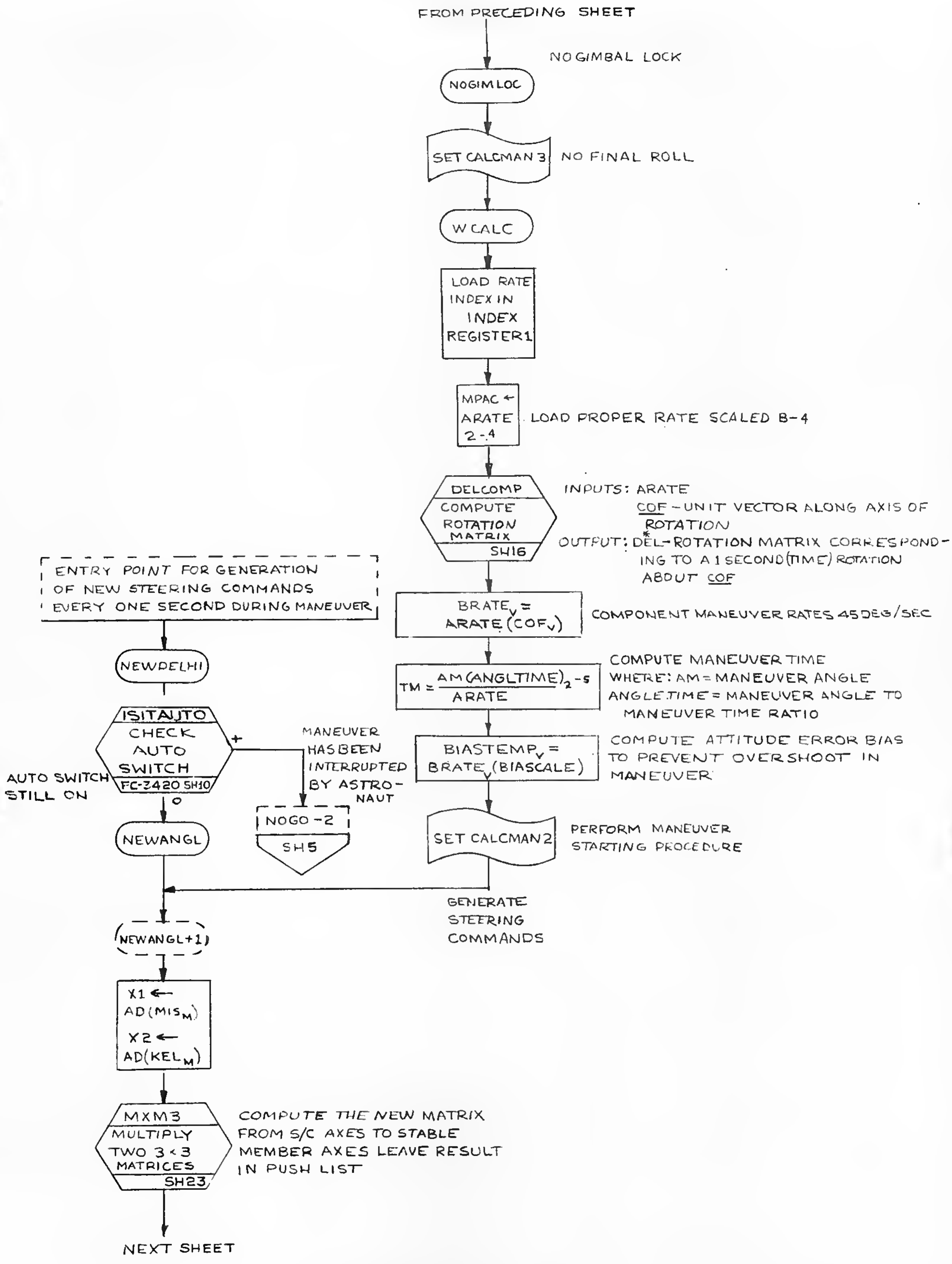
SHEET 8 OF 24



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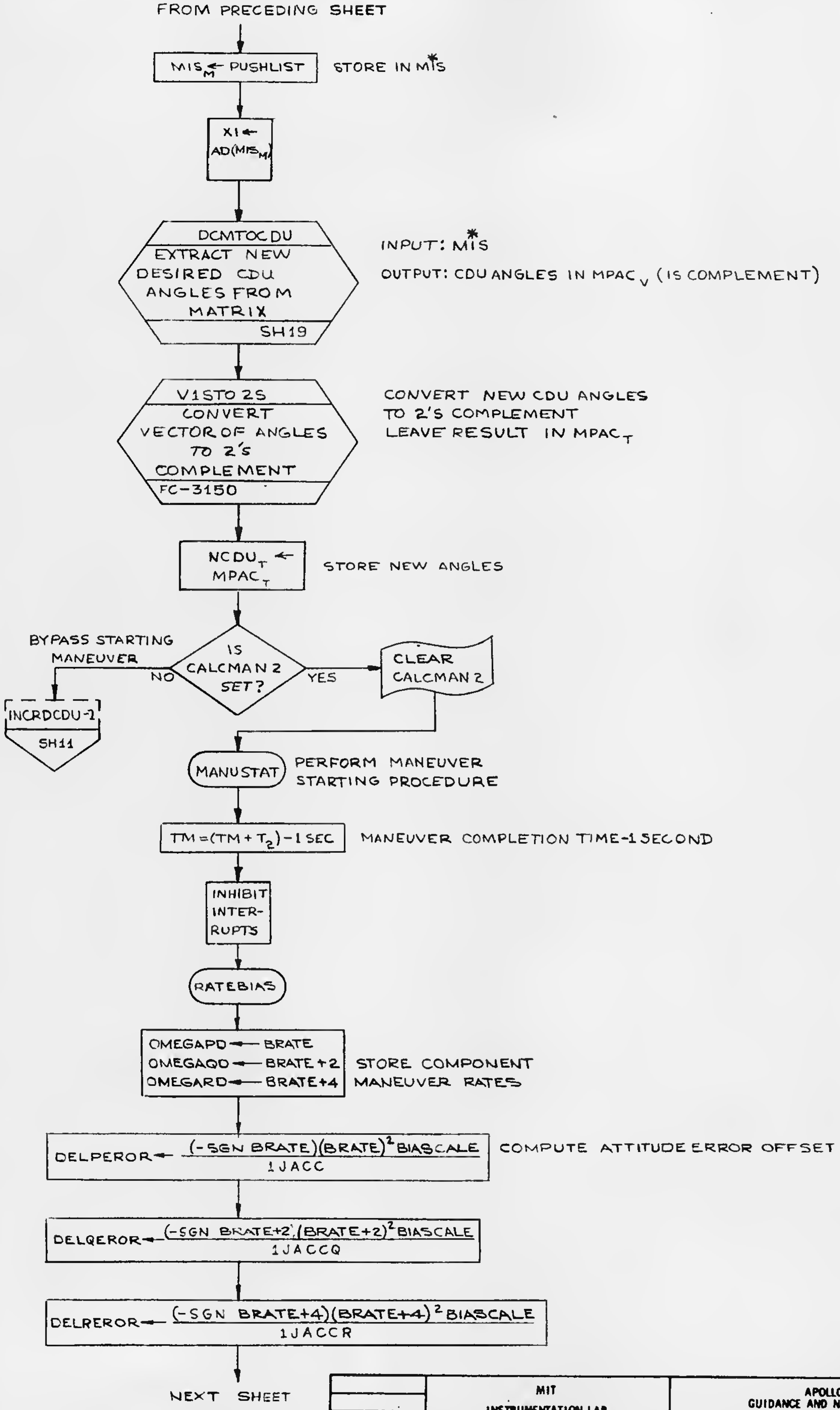

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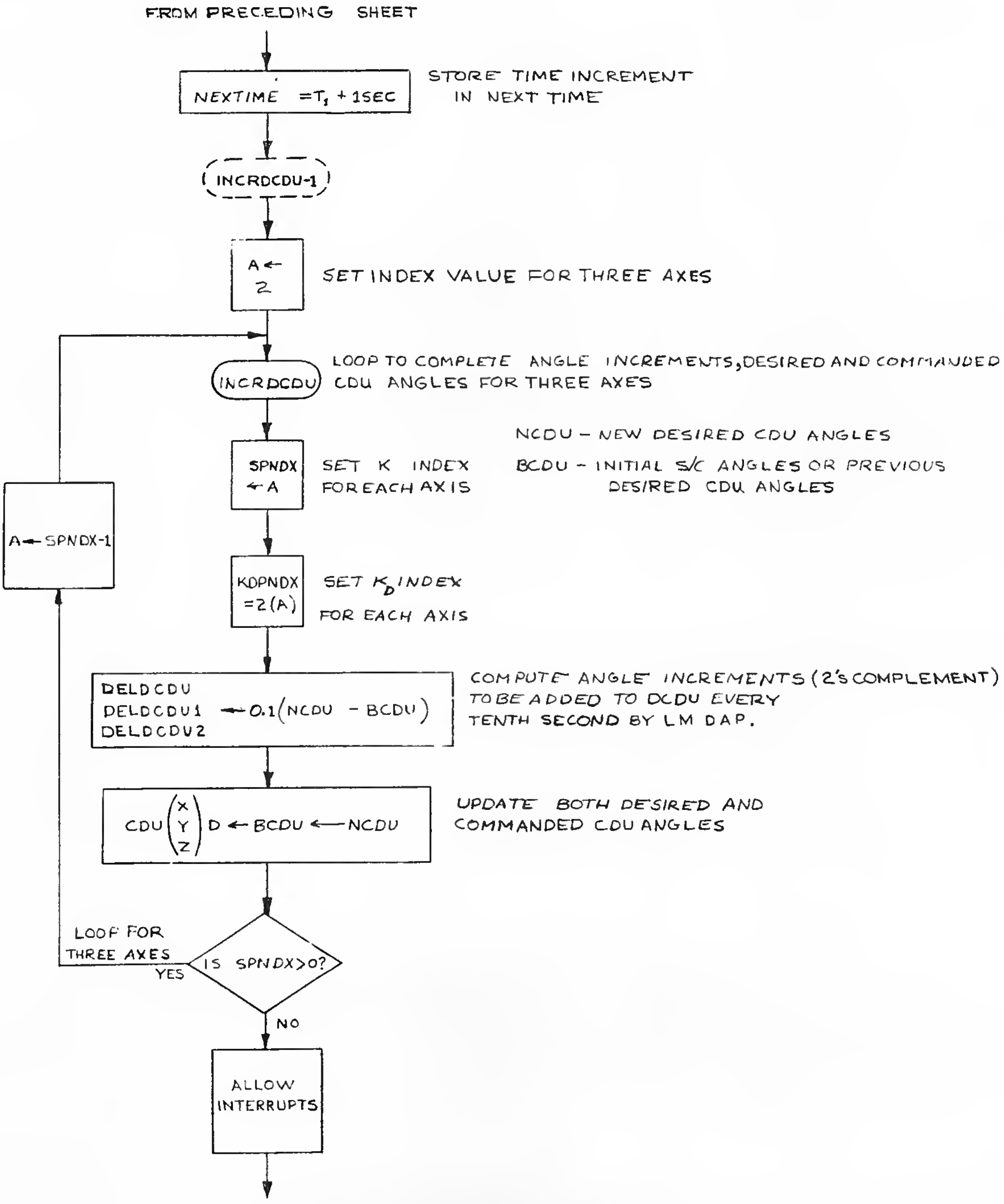
		LUMINARY 1D · DOCUMENT NO. FC-3430
USED ON	APPR'D John A. Moore 5 Sept 68	REV 2 · SHEET 10 OF 24



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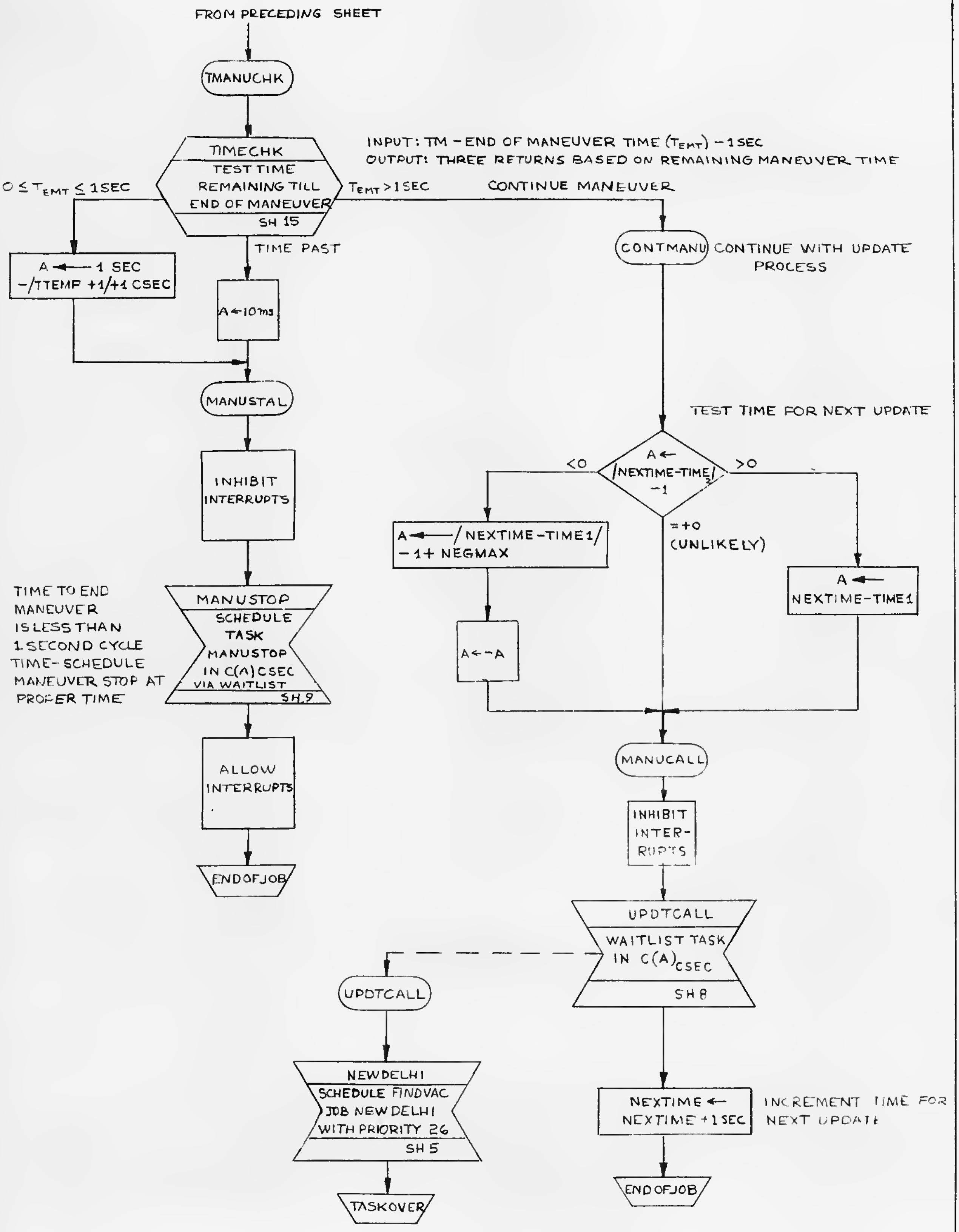

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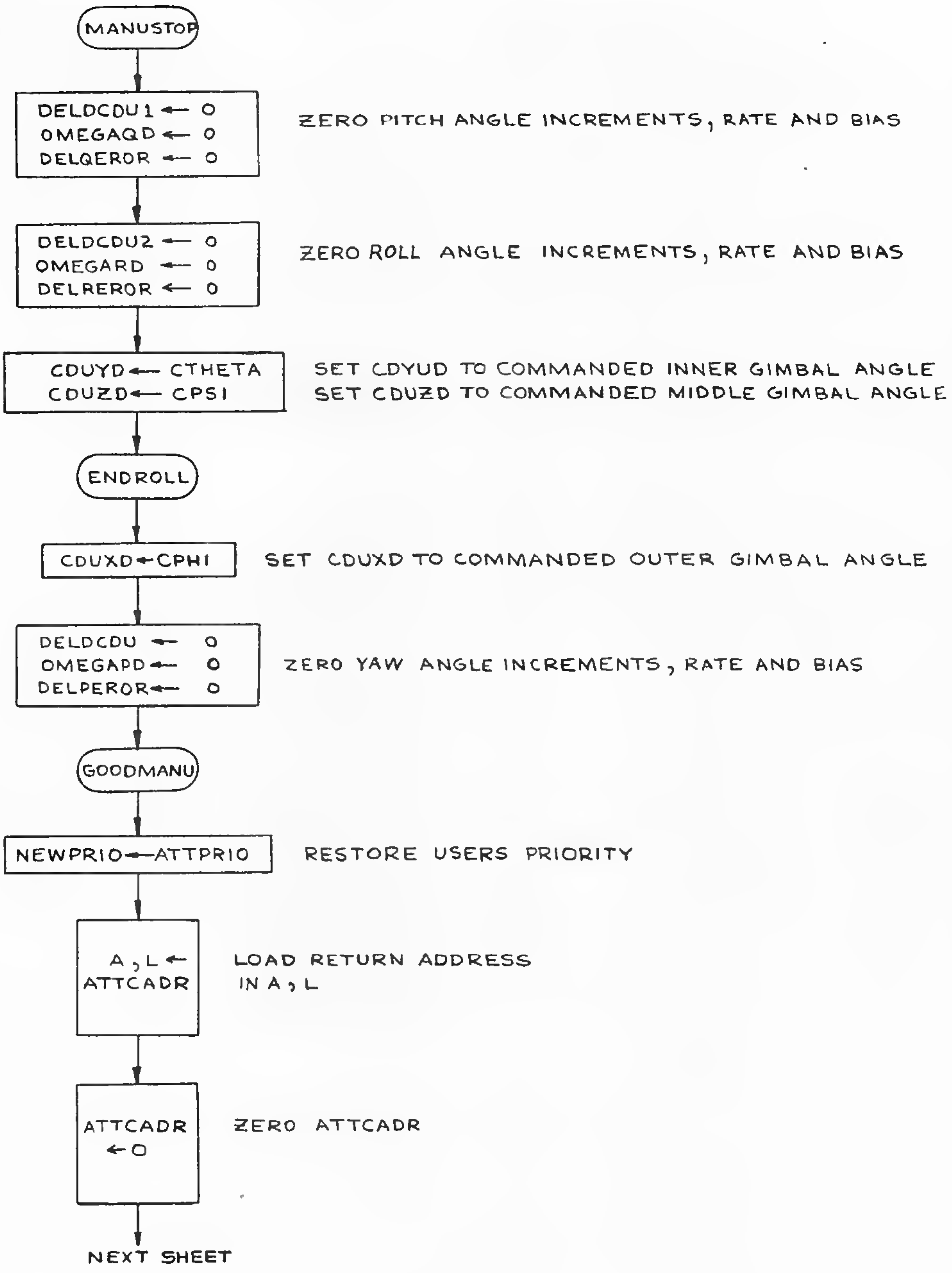

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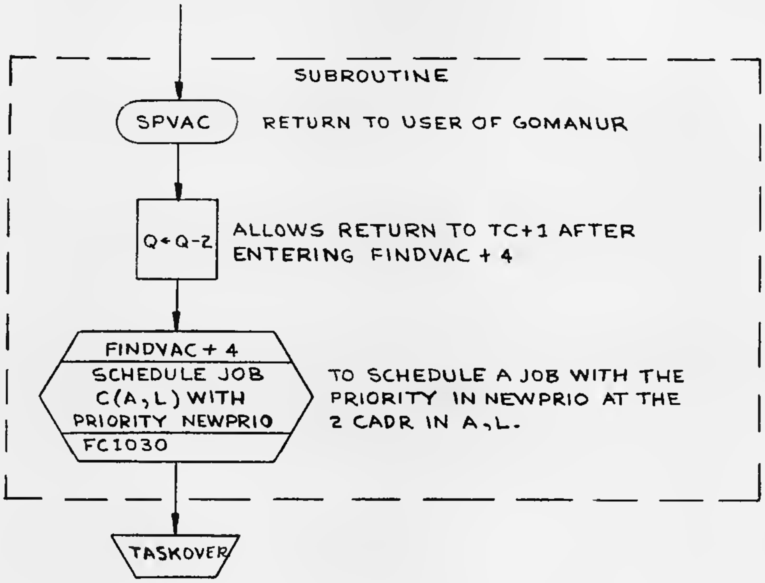
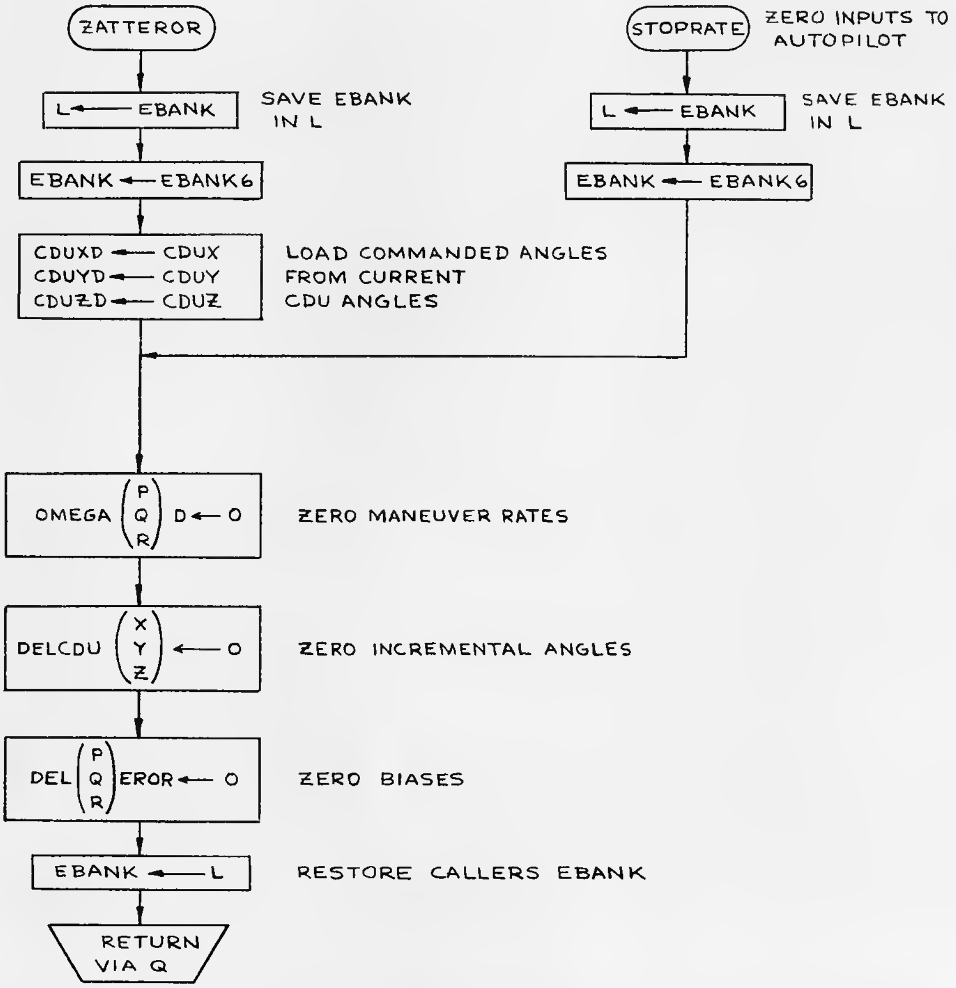
SHEET 13 OF 24

FROM PRECEDING SHEET





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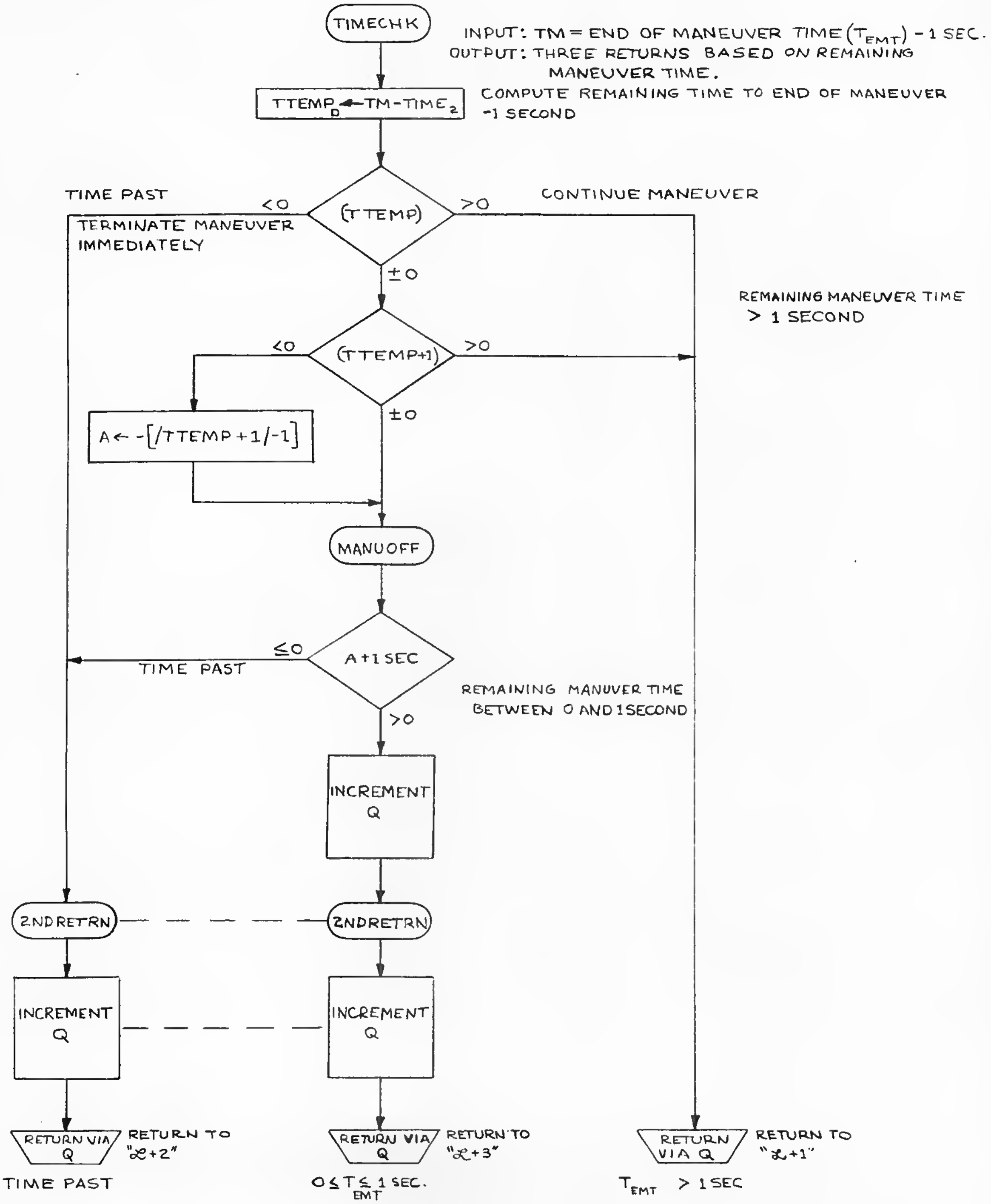
SHEET 14 OF 24



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REV 2
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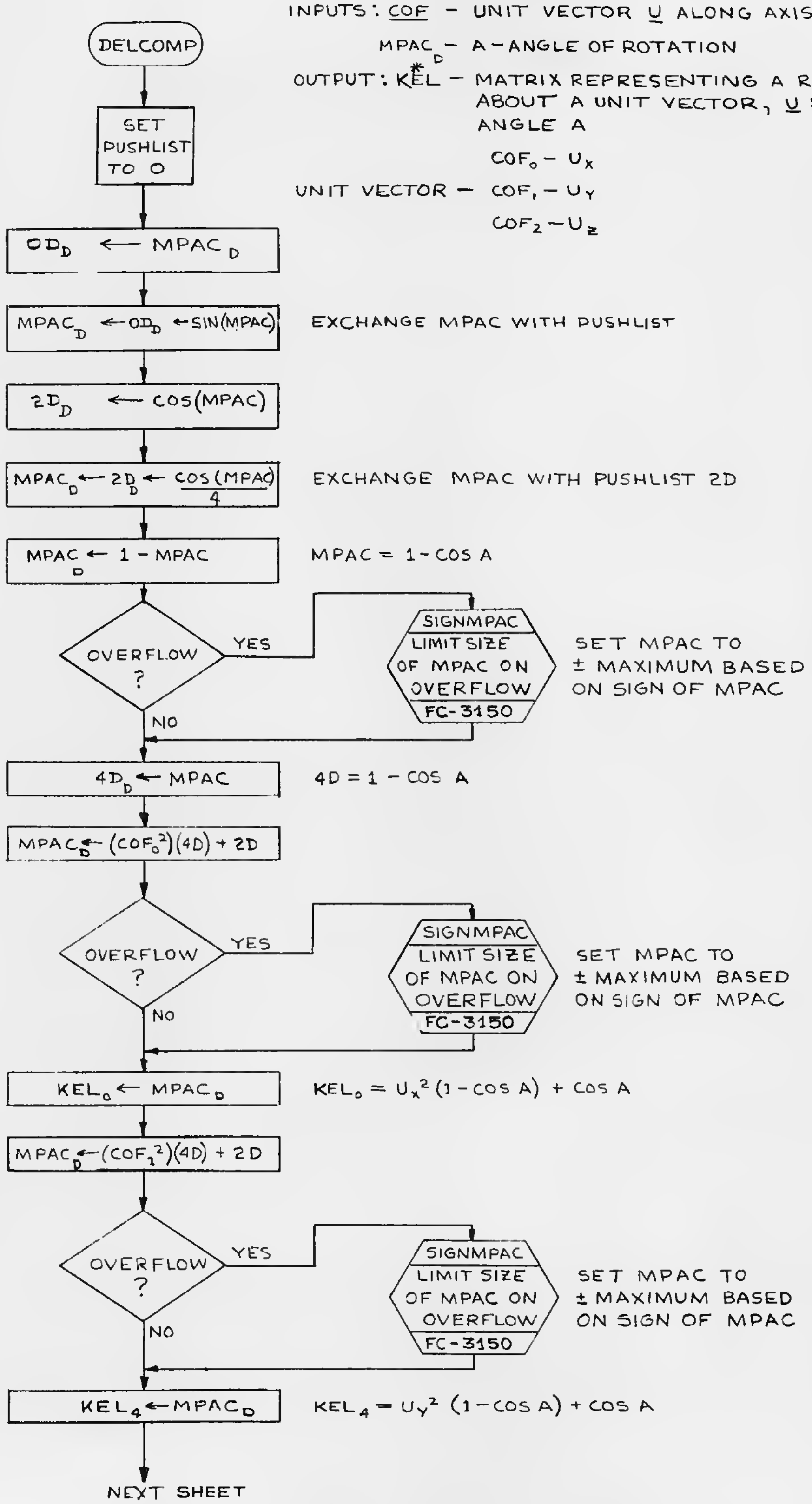
CALCULATION OF MATRIX $\overset{*}{KEL}$

INPUTS: COF – UNIT VECTOR U ALONG AXIS OF ROTATION

MPAC$_D$ – A – ANGLE OF ROTATION

OUTPUT: $\overset{*}{KEL}$ – MATRIX REPRESENTING A ROTATION ABOUT A UNIT VECTOR, U BY AN ANGLE A

UNIT VECTOR –
$COF_0 - U_X$
$COF_1 - U_Y$
$COF_2 - U_Z$



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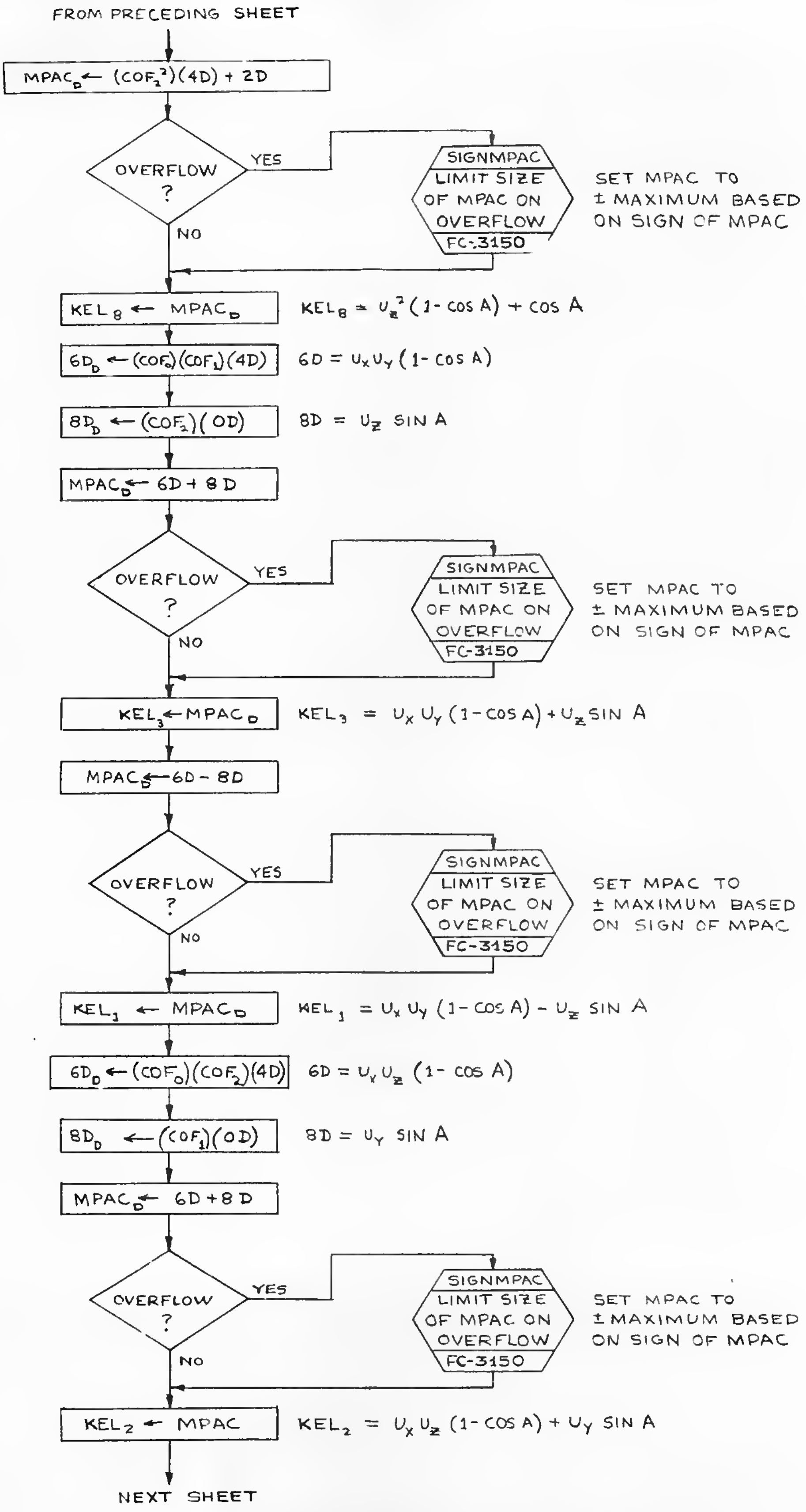
SHEET 16 OF 24



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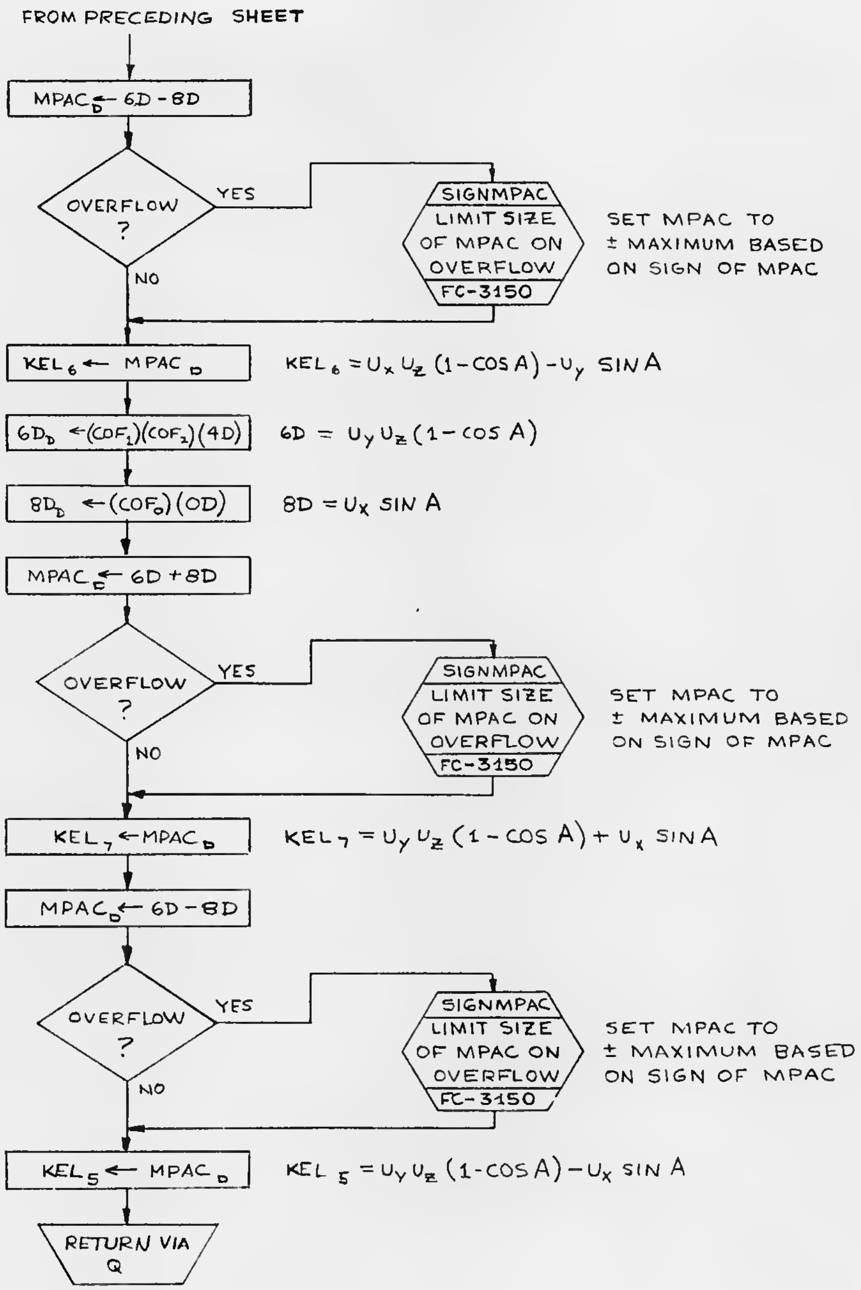
SHEET 17 OF 24



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PRGMR D. W. Keene	7 3 68	
DOCMR W. [illegible] Jr.	5-8-68	DOCUMENT NO. FC-3430
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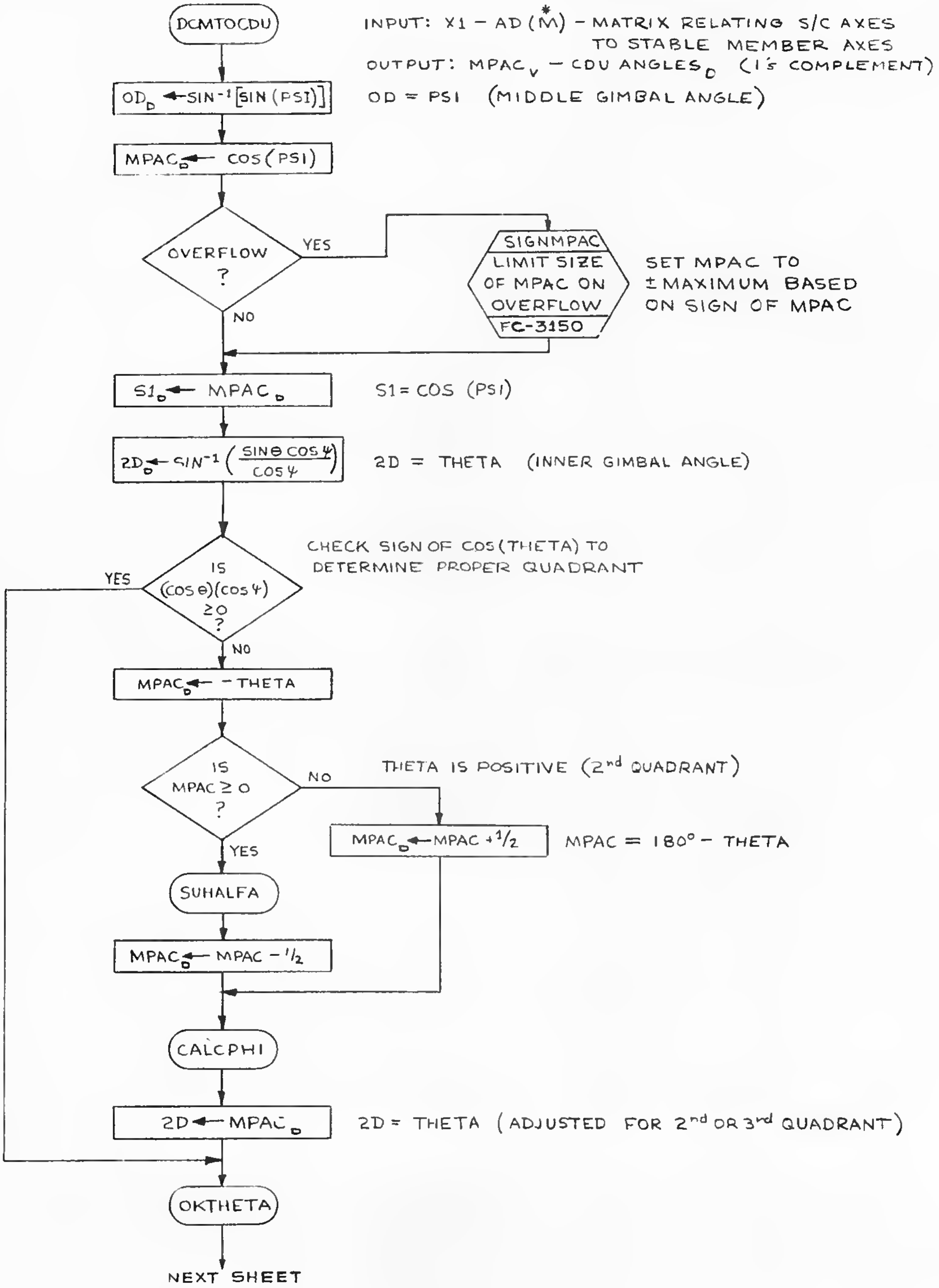
USED ON		SHEET 18 OF 24

COMPUTE CDU ANGLES FROM DIRECTION COSINE MATRIX



INPUT: X1 − AD ($\overset{*}{M}$) − MATRIX RELATING S/C AXES TO STABLE MEMBER AXES

OUTPUT: $MPAC_V$ − CDU ANGLES$_D$ (1's COMPLEMENT)

OD = PSI (MIDDLE GIMBAL ANGLE)

SET MPAC TO ± MAXIMUM BASED ON SIGN OF MPAC

S1 = COS (PSI)

2D = THETA (INNER GIMBAL ANGLE)

CHECK SIGN OF COS(THETA) TO DETERMINE PROPER QUADRANT

THETA IS POSITIVE (2nd QUADRANT)

MPAC = 180° − THETA

2D = THETA (ADJUSTED FOR 2nd OR 3rd QUADRANT)

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MANEUVER CALCULATIONS AND STEERING

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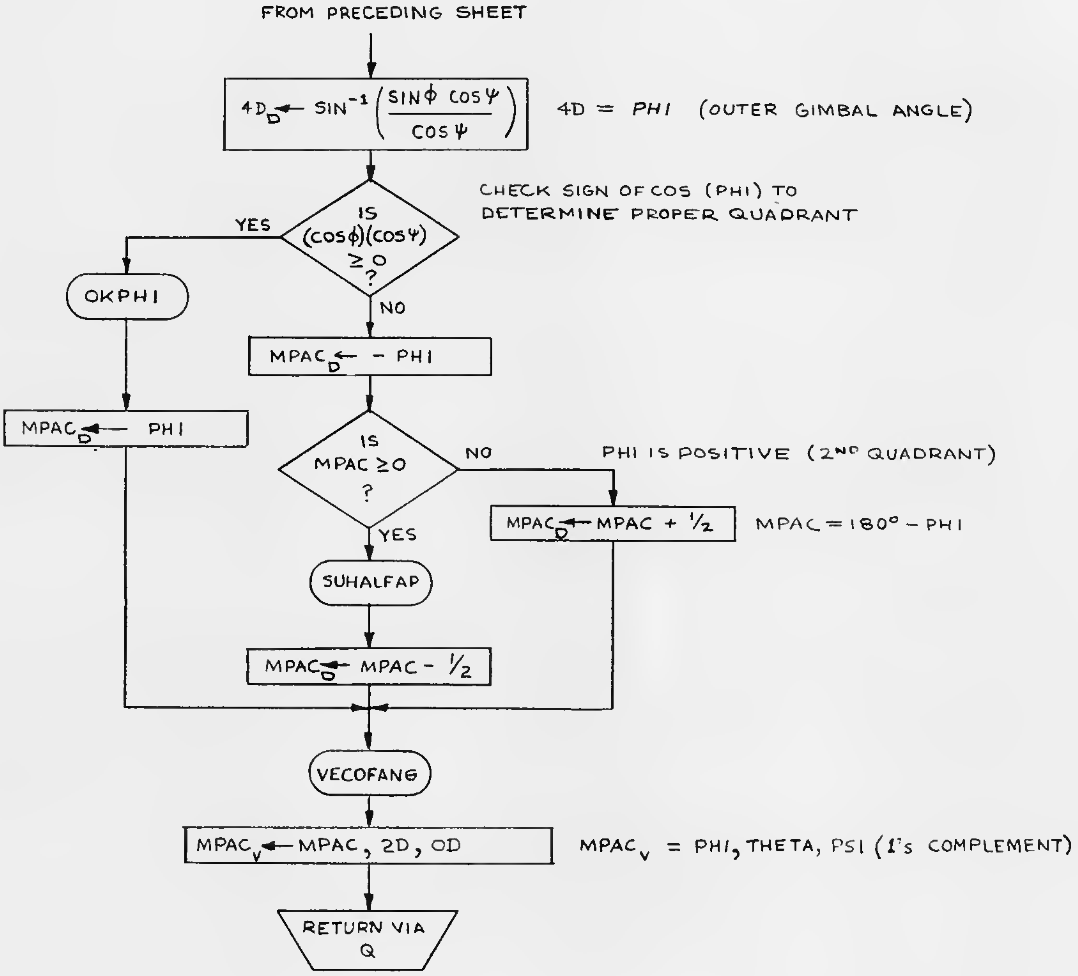
SHEET 19 OF 24



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	ANALIST	DOCUMENT NO. FC-3430
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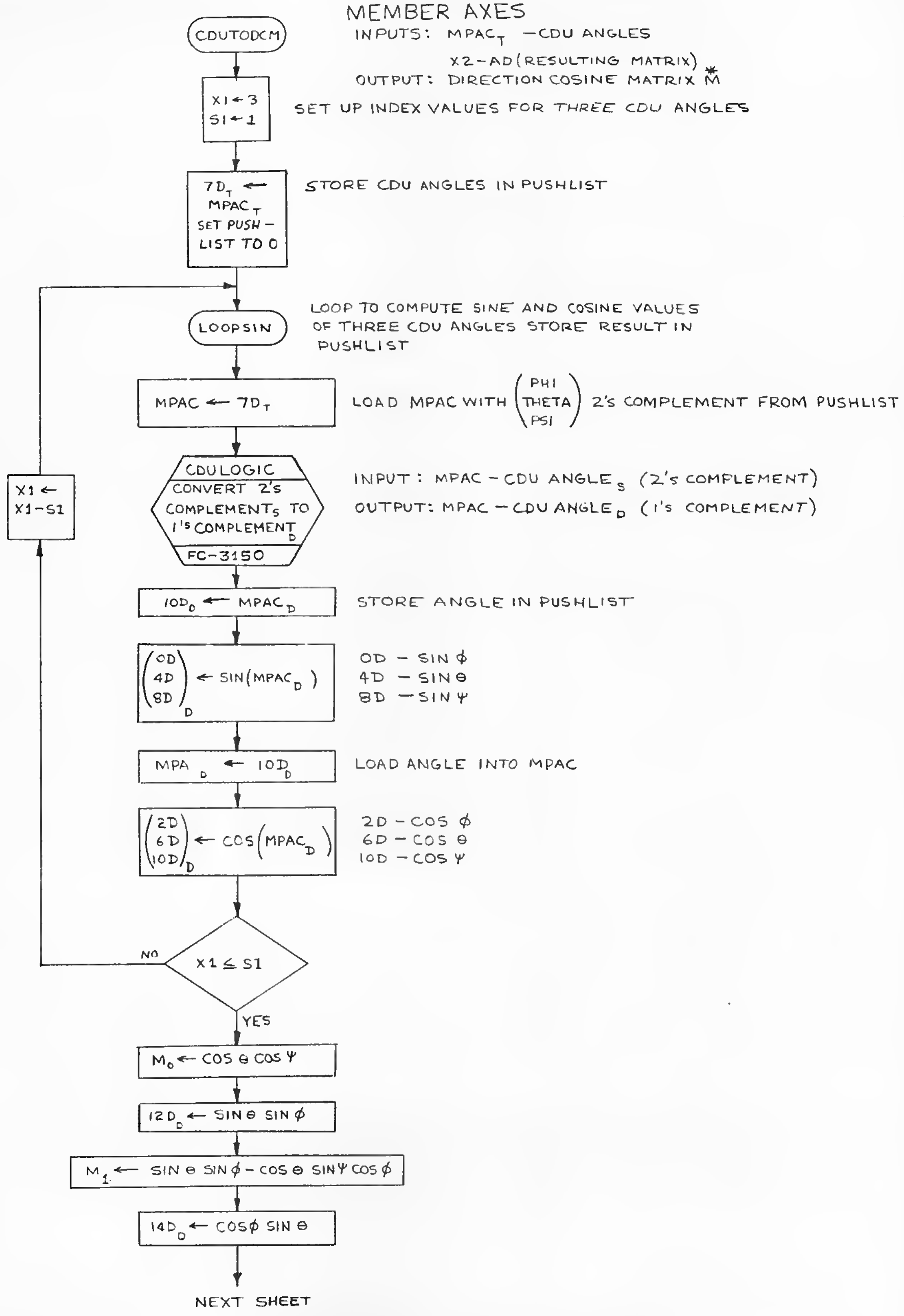
		SHEET 20 OF 24

COMPUTE DIRECTION COSINE MATRIX RELATING S/C AXES TO STABLE MEMBER AXES

INPUTS: $MPAC_T$ – CDU ANGLES

X2 – AD (RESULTING MATRIX)

OUTPUT: DIRECTION COSINE MATRIX $\overset{*}{M}$



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ANALYST			
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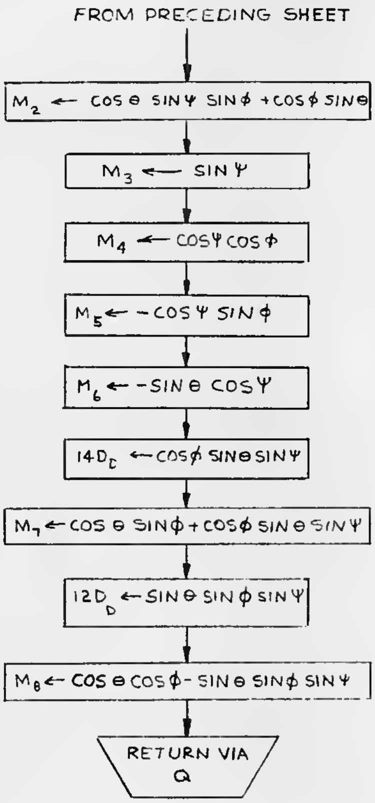

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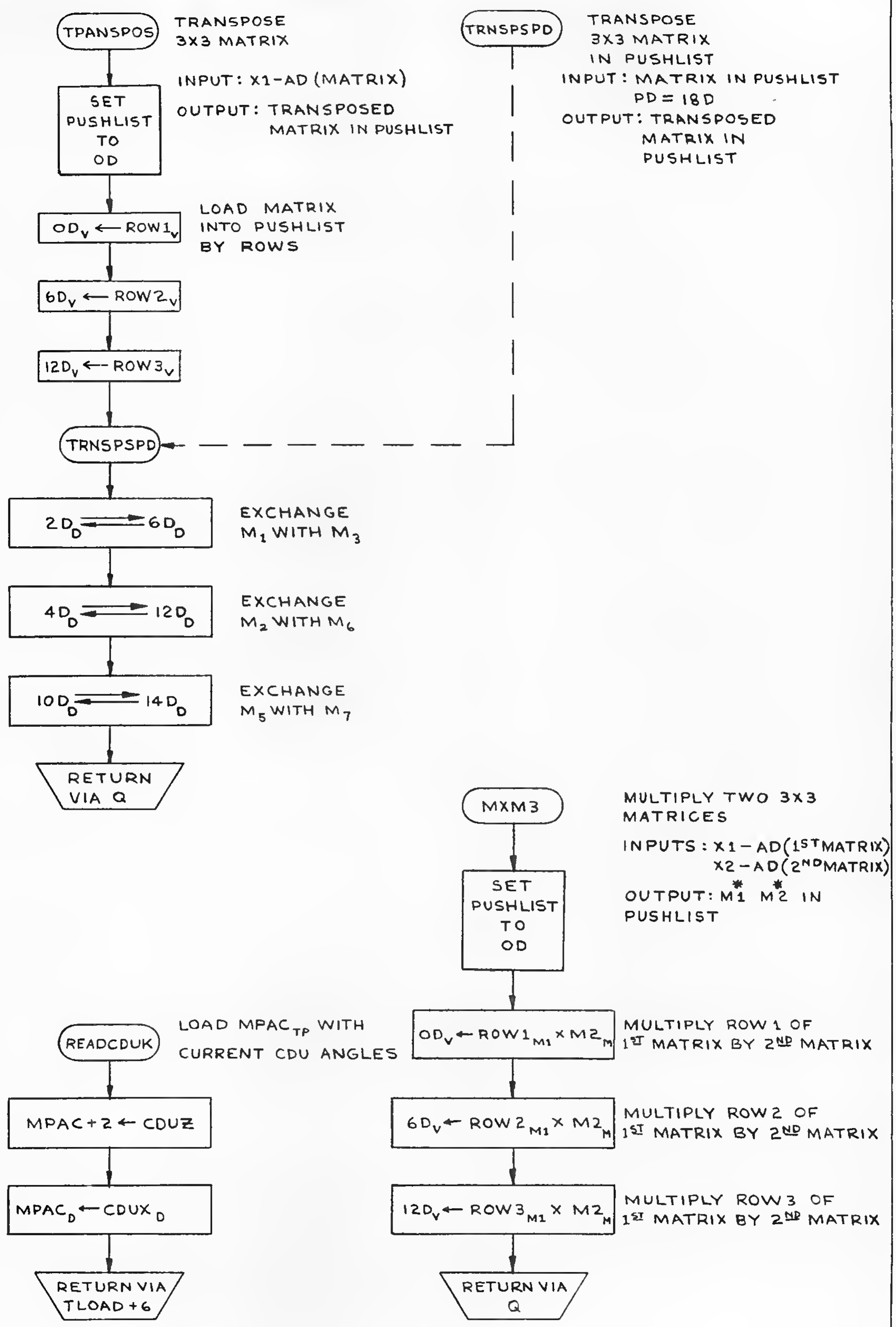

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SHEET 23 OF 24

KALCMANU – MANEUVER CALCULATIONS AND STEERING

SUBROUTINES

IN THIS CHART

READCDUK	READ PRESENT CDU ANGLES
CDUTODCM	COMPUTE DIRECTION COSINE MATRIX
TRANSPOS	TRANSPOSE MATRIX
ZATTEROR	LOAD COMMANDED ANGLES ; ZERO INPUTS TO AUTOPILOT
STOPRATE	ZERO INPUTS TO AUTOPILOT
MXM3	MULTIPLY TWO 3X3 MATRICES
TRNSPSPD	TRANSPOSE MATRIX IN PUSH LIST.
DELCOMP	COMPUTE TRANSFORMATION MATRIX
DCMTOCDU	EXTRACT DESIRED CDU ANGLES FROM MATRIX
TIMECHK	TEST TIME REMAINING TILL END OF MANEUVER

ON OTHER CHARTS

SIGNMPAC	SET $MPAC_D$ TO ± MAXIMUM BASED ON SIGN OF MPAC
ISITAUTO	TEST AUTO SWITCH
V1STO2S	CONVERT 1's COMPLEMENT ANGLES TO 2's COMPLEMENT ANGLES.
CDULOGIC	CONVERT 2's COMPLEMENT ANGLES TO 1's COMPLEMENT ANGLE

FLAGS	MEANING	SET	CLEARED	TESTED
CALCMAN 2	SET – PERFORM MANEUVER STARTING PROCEDURE CLEARED – BYPASS STARTING PROCEDURE	SH 9	SH10	SH10
CALCMAN 3	SET – NO FINAL ROLL CLEARED – FINAL ROLL IS NECESSARY	SH 9		

ALARMS	MEANING	USED
401	DESIRED GIMBAL ANGLES YIELD GIMBAL LOCK	SH5

ERASABLES	MEANING	UNITS	SCALING
CDUXD CDUYD CDUZD	CDU COMMANDED ANGLES	REV	2^{-1}
TM	MANEUVER COMPLETION TIME	CSEC	2^{28}
DELDCDU DELDCDU1 DELDCDU2	ROLL PITCH YAW } ANGLE INCREMENTS	REV	2^{-1}
OMEGAPD OMEGAQD OMEGARD	ROLL PITCH YAW } ANGLE RATES	REV/ DECI-SEC	2^{-3}
DELPEROR DELQEROR DELREROR	ROLL PITCH YAW } ANGLE BIASES	REV	2^{-1}

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SHEET 24 OF 24

S-BAND ANTENNA

MAJOR SUBROUTINES ON THIS CHART

VERB 64	Sh. 2
SBANDANT	Sh. 3

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S-Band Antenna

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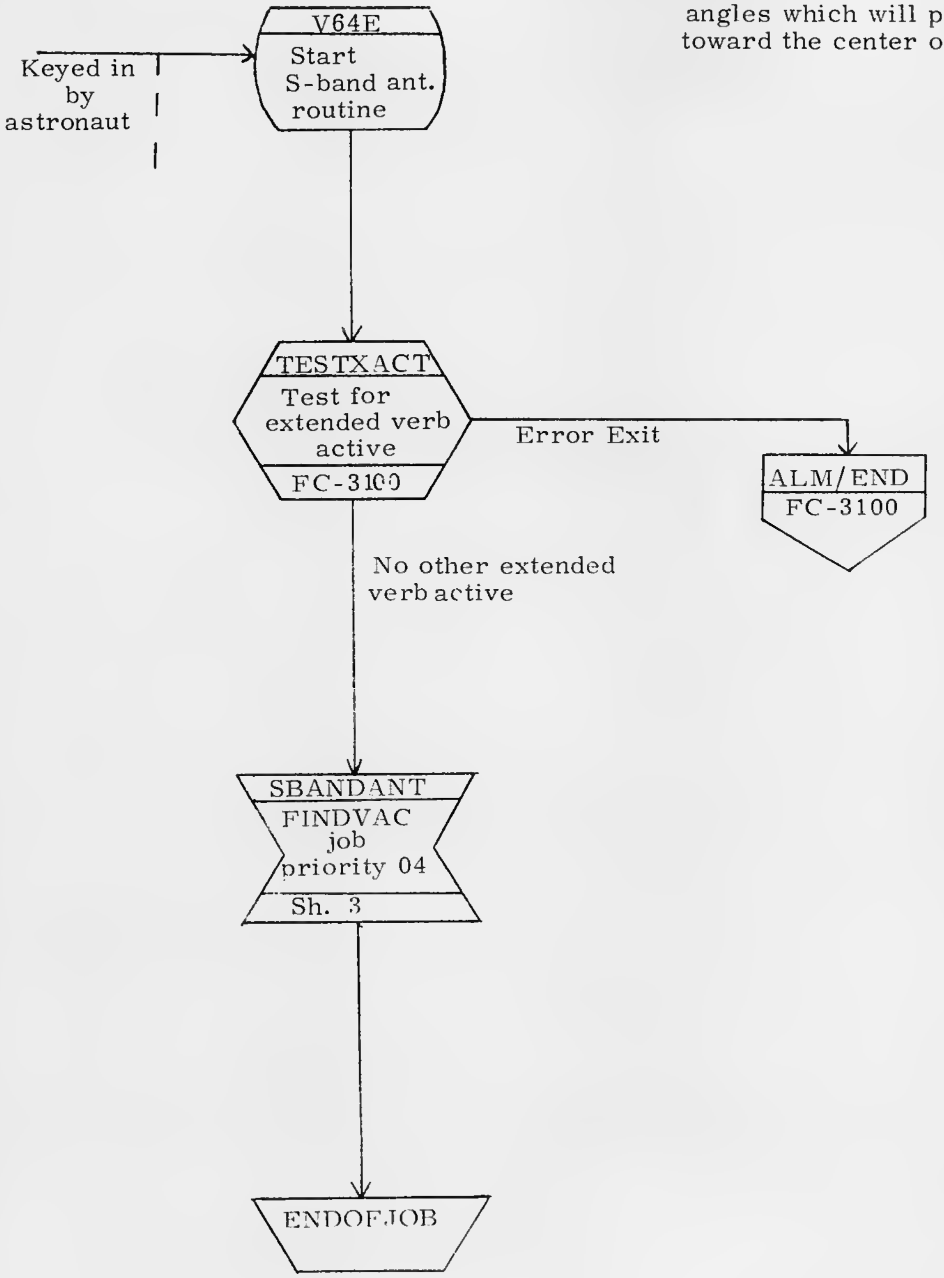
SHEET 1 OF 8

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



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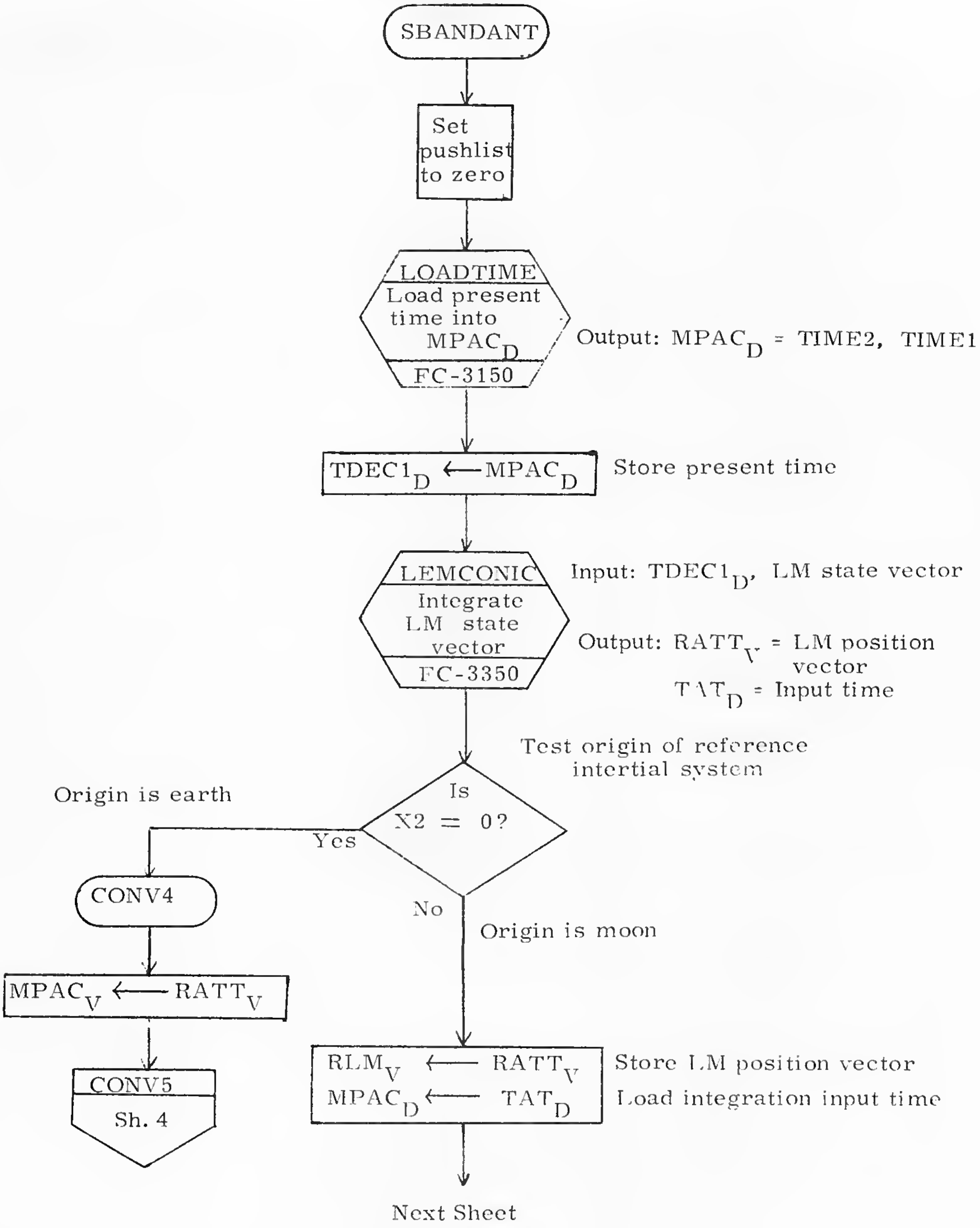
PRGMR Frances Kirven	11/26/69	LUMINARY 1D
ANALST		DOCUMENT NO. FC-3435
DOCMR W Danforth	10/20/69	
APPR'D Roberta M. Estes	11/26/69	REV 1
		SHEET 2 OF 8



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S-Band Antenna

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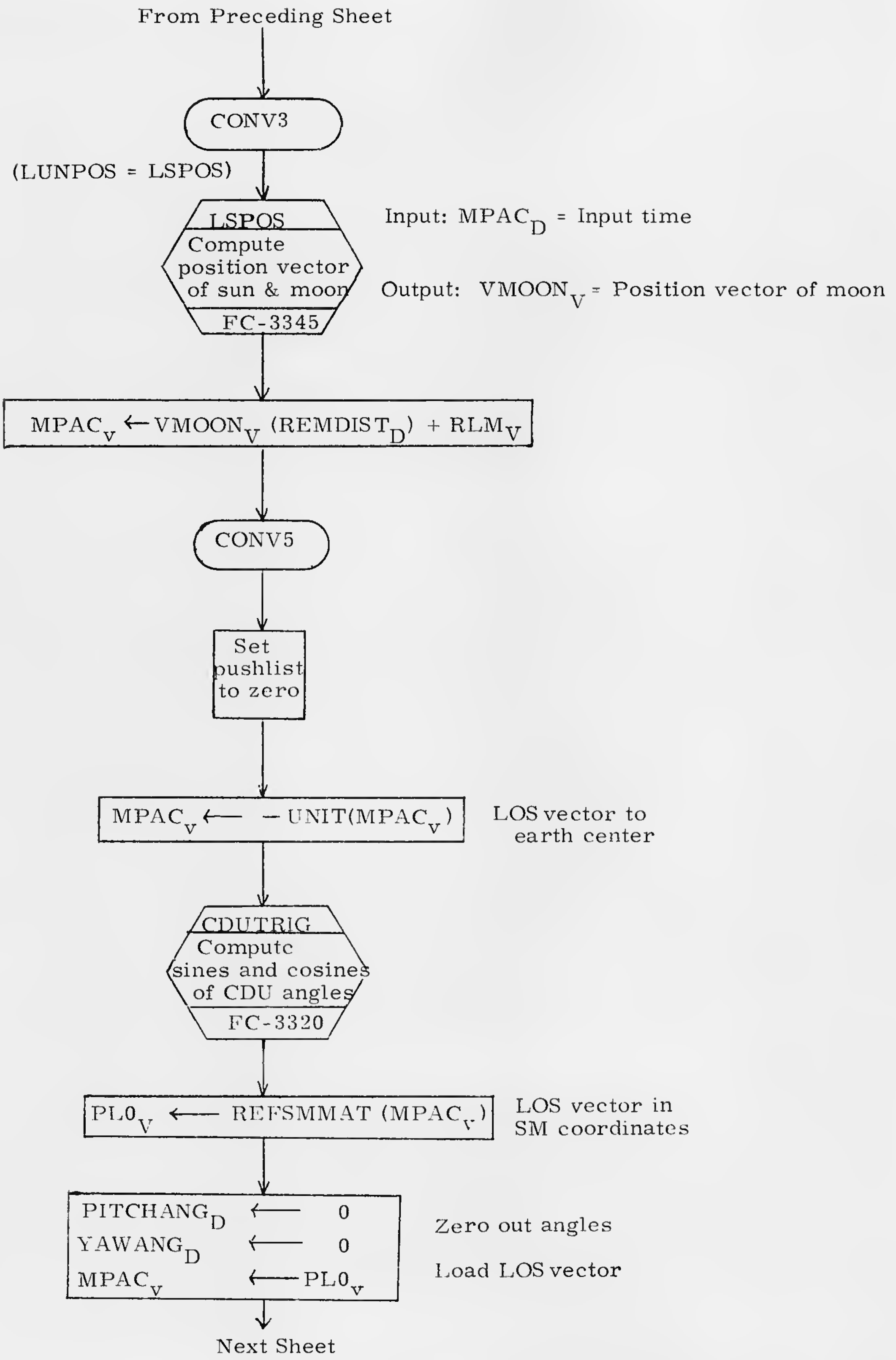

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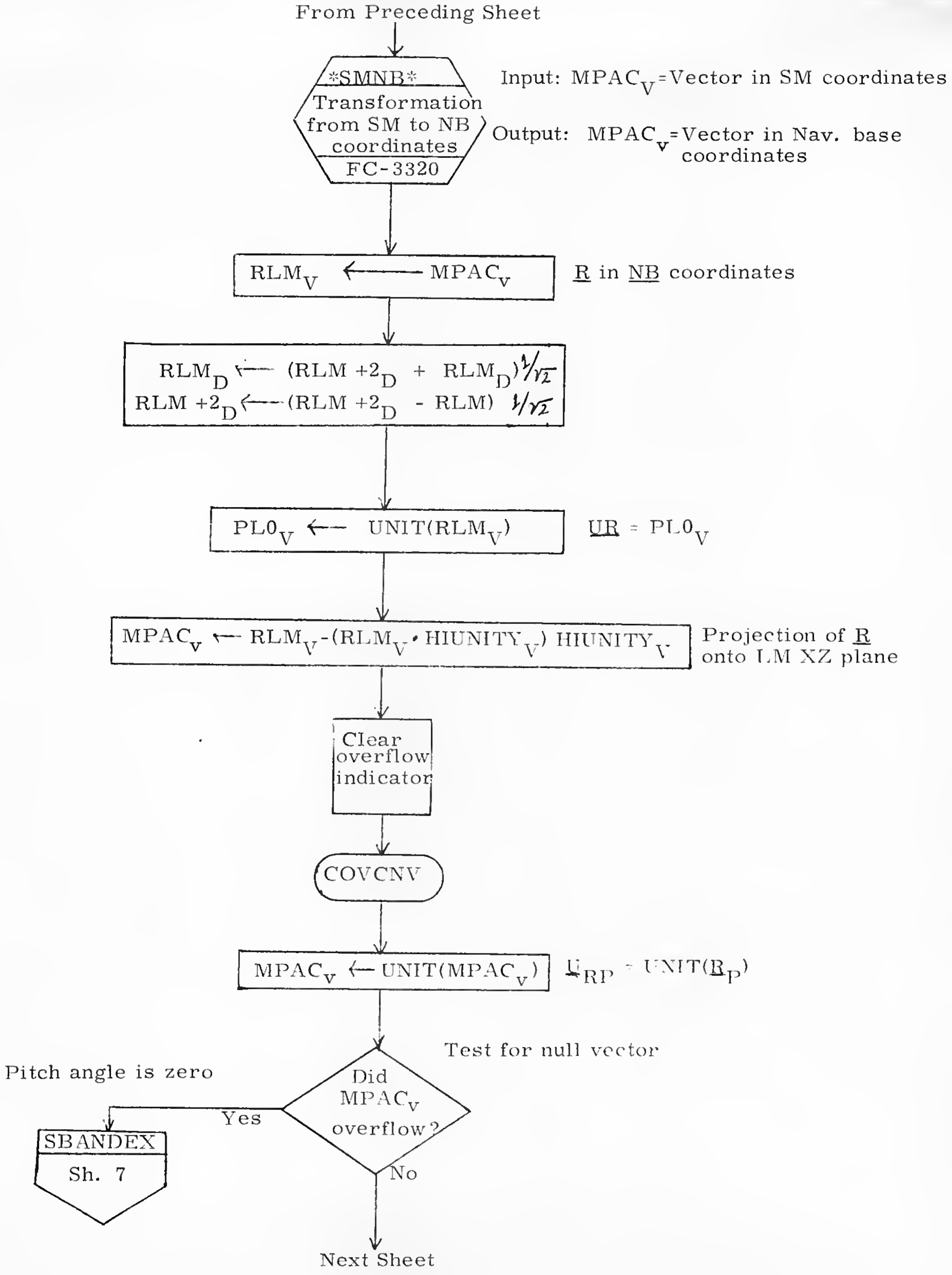

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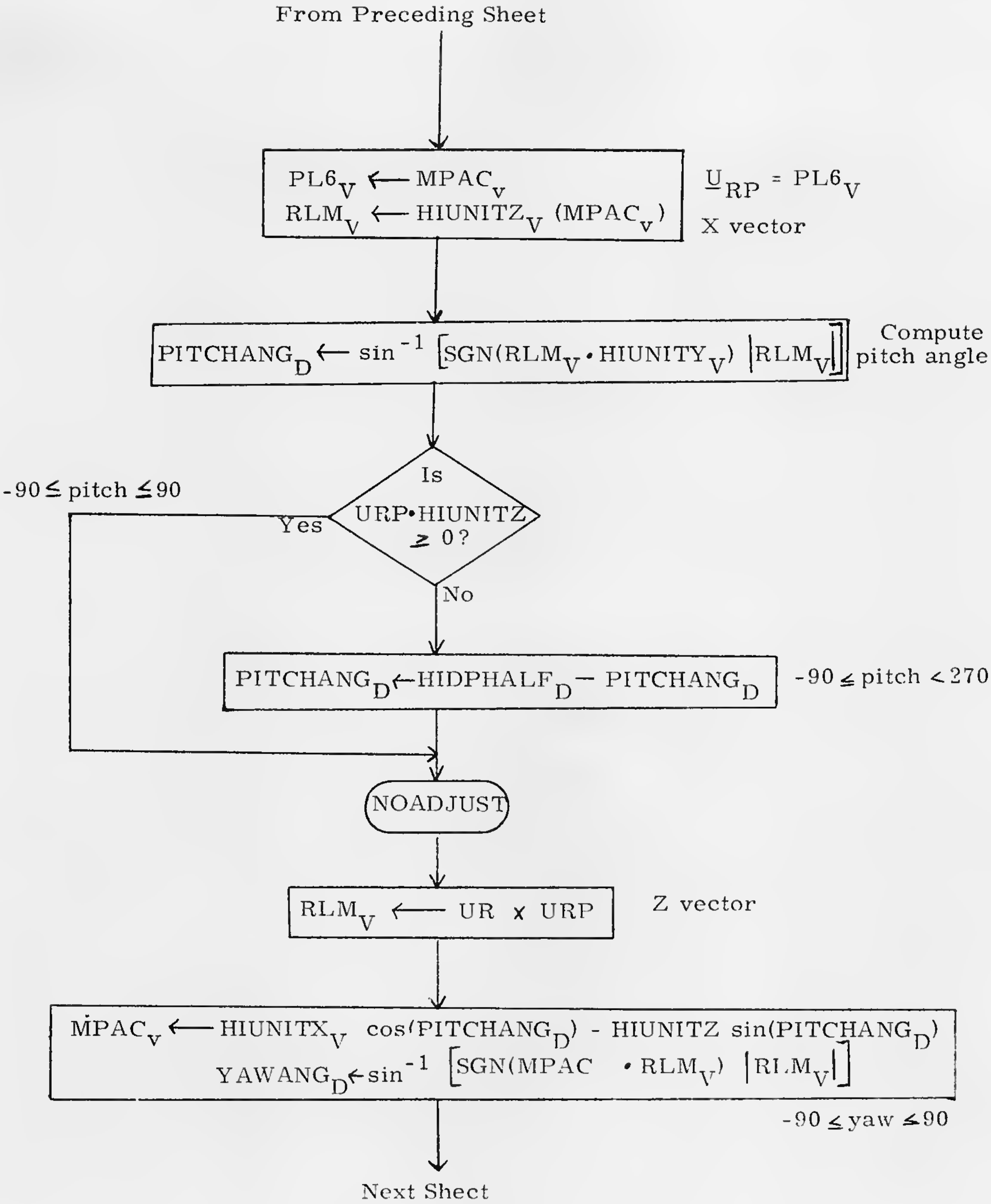

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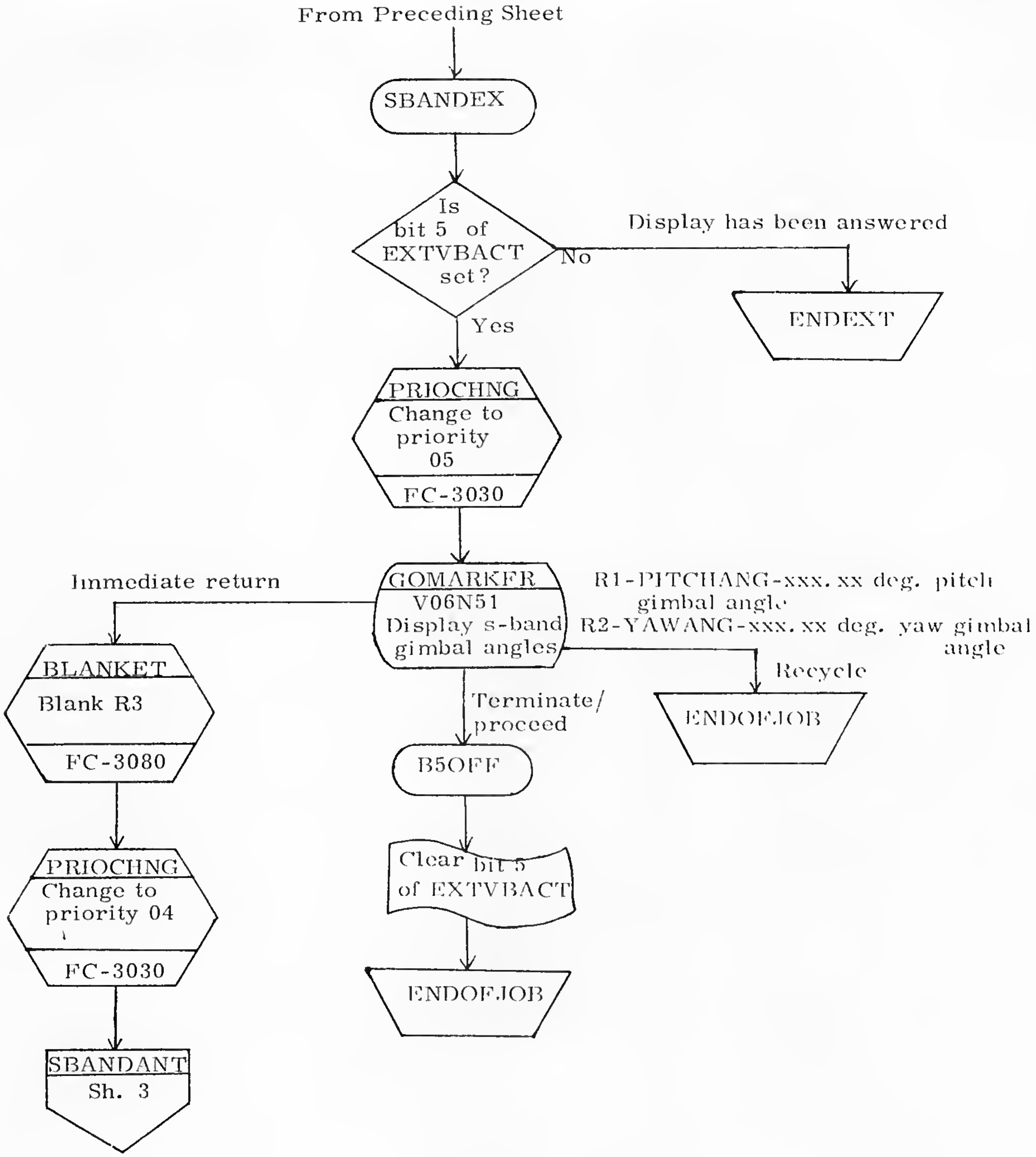
	LUMINARY 1D
	DOCUMENT NO. FC-3435
	REV 1
	SHEET 6 **OF** 8



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S-Band Antenna

LUMINARY 1D

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SHEET 7 OF 8

Subroutines Called on Other Flowcharts

Subroutine	Flowchart	Description	Where Called
TESTXACT	FC-3100	Test for extended verb active	Sh. 2
LOADTIME	FC-3150	Load present time into $MPAC_D$	Sh. 3
LEMCONIC	FC-3350	Integrate LM state vector	Sh. 3
LSPOS	FC-3345	Compute position vector of sun and moon	Sh. 4
CDUTRIG	FC-3320	Compute sines and cosines of CDU angles	Sh. 4
SMNB	FC-3320	Transform from SM to NB coordinates	Sh. 5
PRIOCHNG	FC-3030	Change priority of job	Sh. 7
BLANKET	FC-3080	Blank DSKY	Sh. 7

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8.0 LM DIGITAL AUTOPILOT

LEM DAP INTERFACE AND SERVICE ROUTINES

DAPDISP	Sh. 2
TRIMDONE	Sh. 12
DAPIDLER	Sh. 13
STARTDAP	Sh. 14
ALLCOAST	Sh. 17
RESTORDB	Sh. 18
PFLITEDB	Sh. 19
CHEKBITS	Sh. 20
NEEDLER	Sh. 25
DOT6RUPT	Sh. 28
T6JOBCHK	Sh. 29
JTLST	Sh. 32
1STOTWOS	Sh. 35
OVERSUB2	Sh. 35
SUBDVDE	Sh. 36
MINIMP	Sh. 37
GOPIN	Sh. 37
NOMINIMP	Sh. 37
TOTATTER	Sh. 38
DAPATTER	Sh. 38
SNUFFOUT	Sh. 39
OUTSNUFF	Sh. 39
C13STALL	Sh. 40

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LM DAP Interface and
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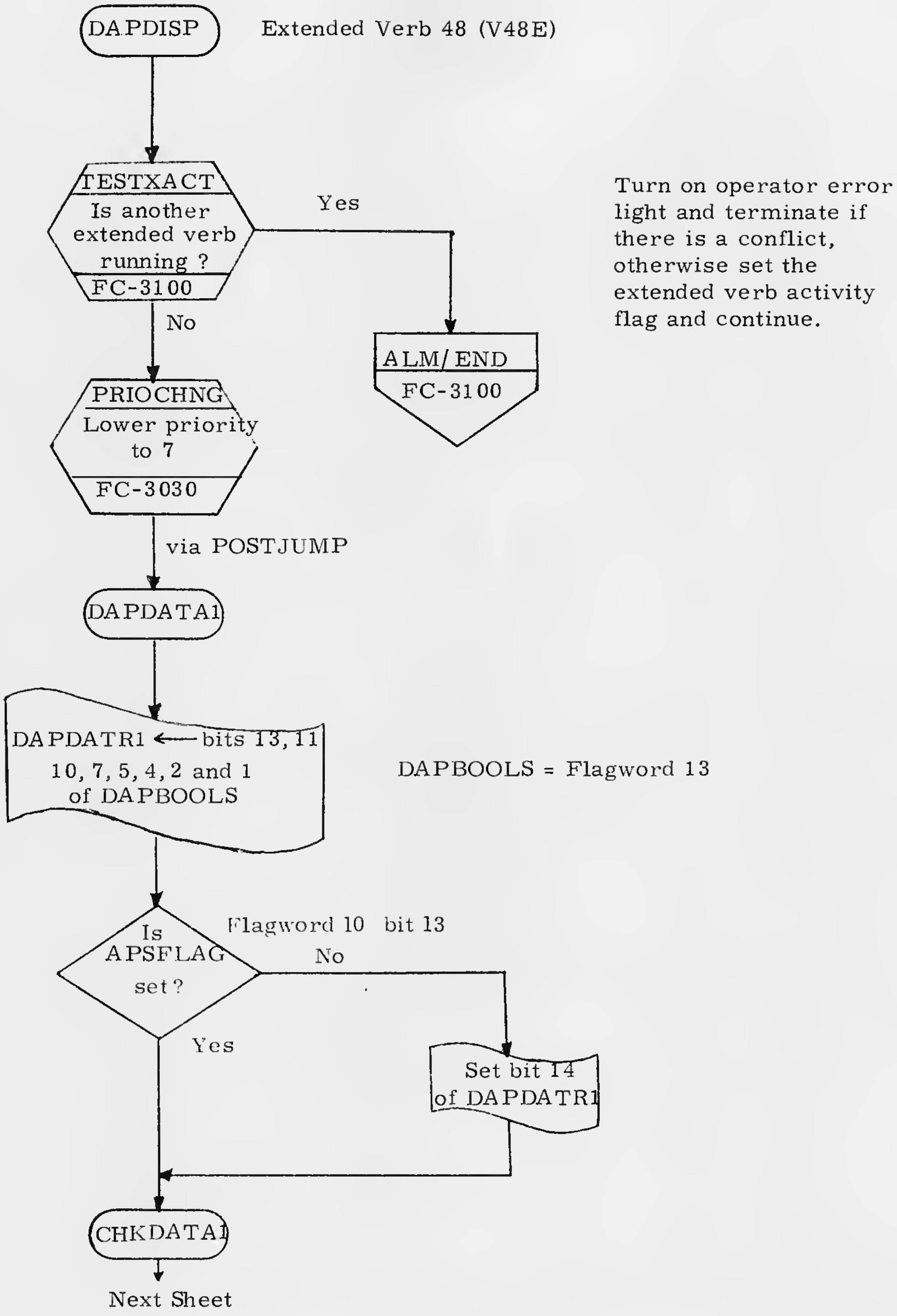

Extended Verb 48 (V48E)

Turn on operator error light and terminate if there is a conflict, otherwise set the extended verb activity flag and continue.

DAPBOOLS = Flagword 13

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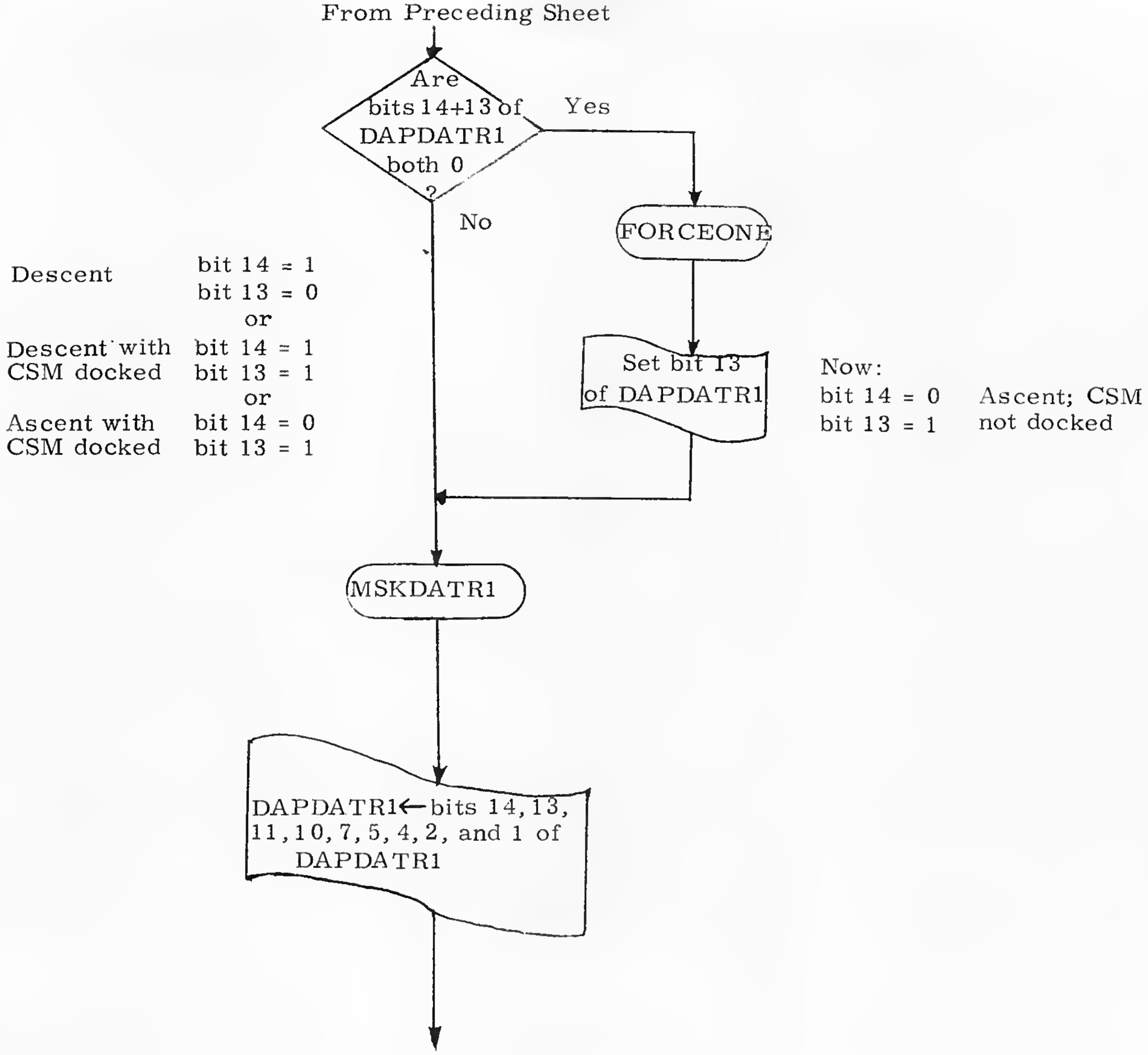

Next Sheet

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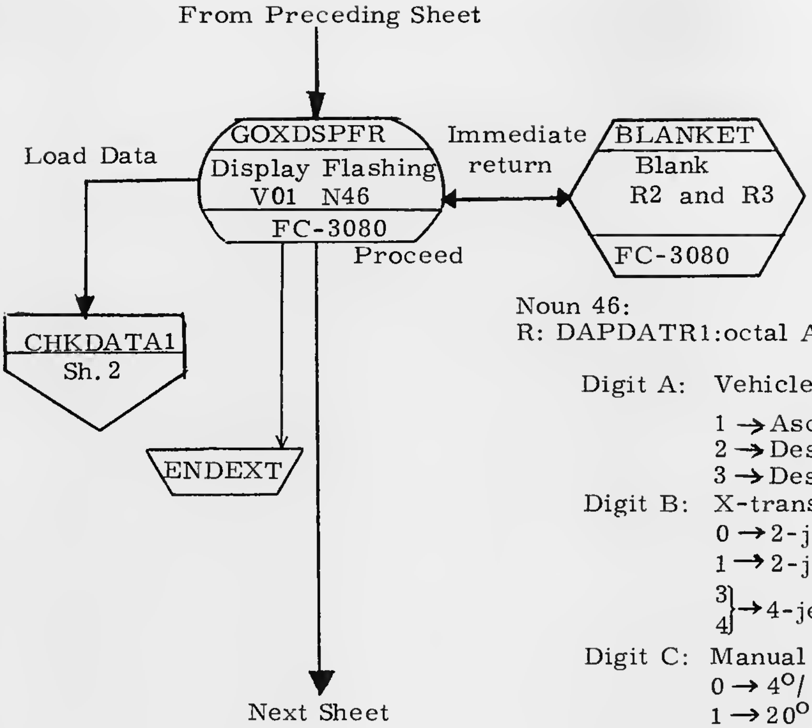

Noun 46:
R: DAPDATR1:octal ABCDE

Digit A: Vehicle configuration
- 1 → Ascent, CSM not docked
- 2 → Descent, CSM not docked
- 3 → Descent with CSM docked

Digit B: X-translation jet policy
- 0 → 2-jet, RCS system A
- 1 → 2-jet, RCS system B
- 3, 4 → 4-jet, both systems

Digit C: Manual rate command scaling
- 0 → 4°/ sec full stick deflection
- 1 → 20°/ sec full stick deflection

Digit D: Attitude dead band
- 0 → 0.3 deg
- 1 → 1.0 deg
- 2 → 5.0 deg

Digit E: Automatic maneuver rate
- 0 → 0.2 deg/ sec
- 1 → 0.5 deg/ sec
- 2 → 2.0 deg/ sec
- 3 → 10.0 deg/ sec

R2, R3 are blank

note:
GOXDSPFR = GOMARKER

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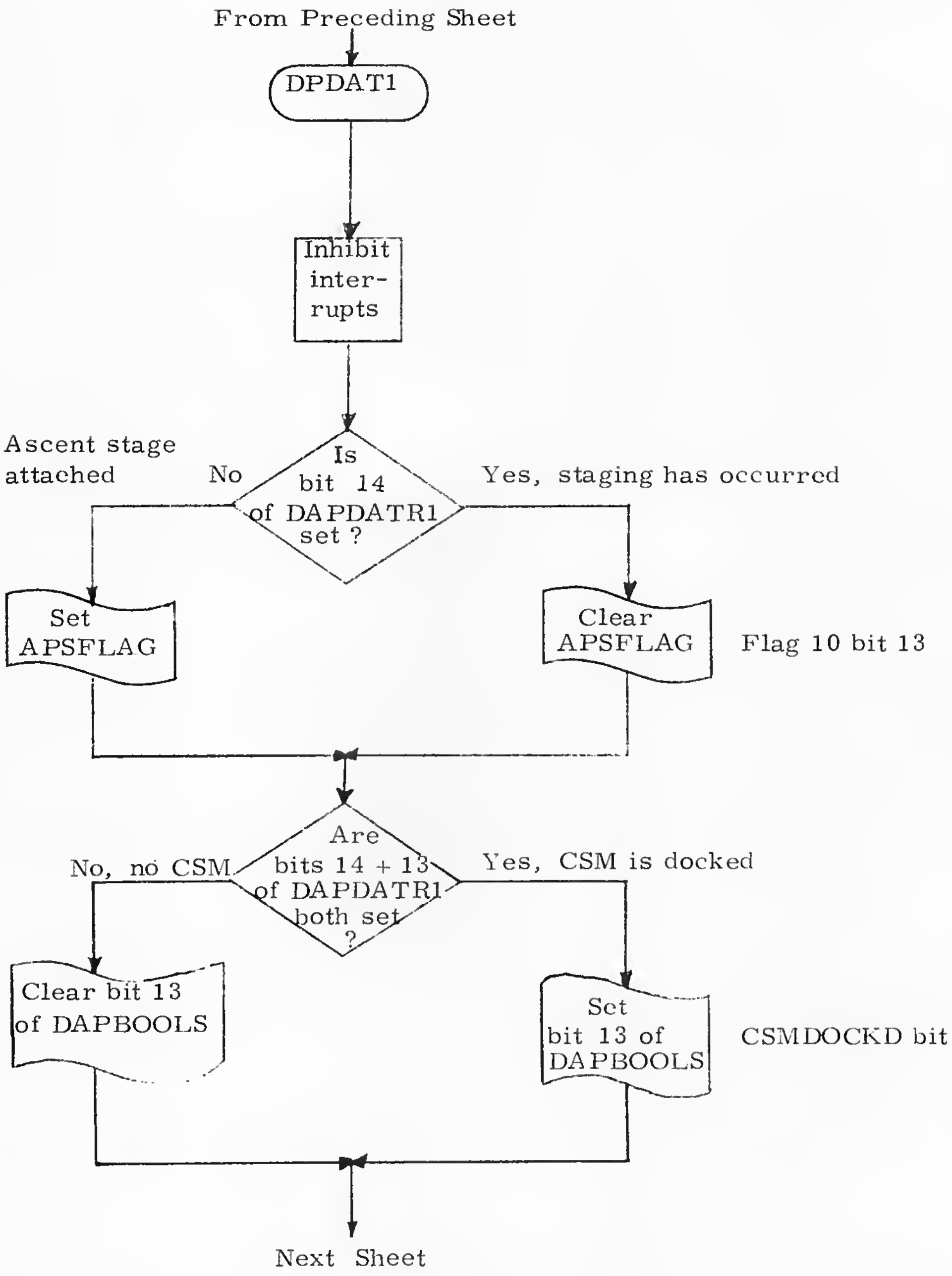

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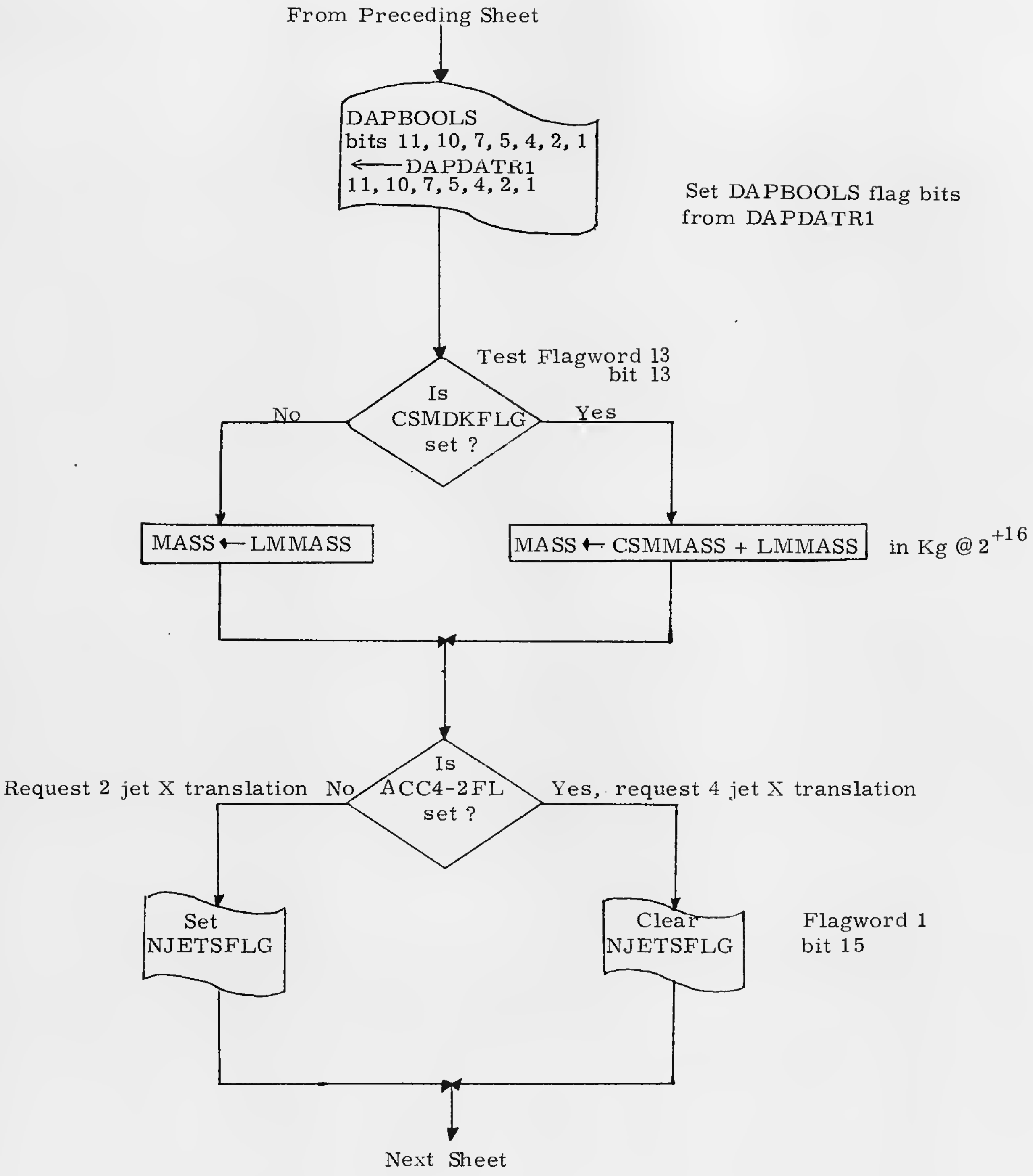

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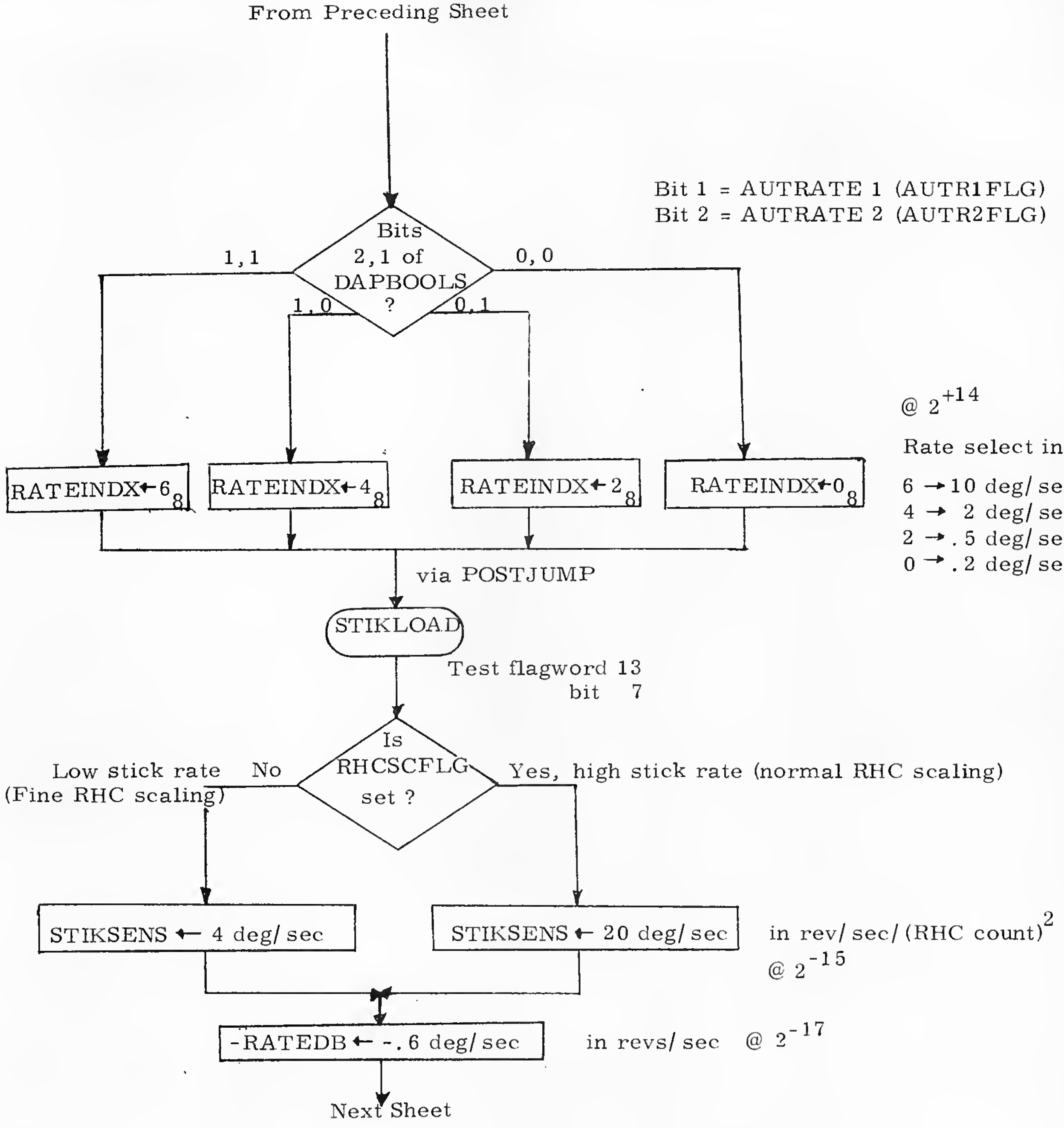

Bit 1 = AUTRATE 1 (AUTR1FLG)
Bit 2 = AUTRATE 2 (AUTR2FLG)

@ 2^{+14}

Rate select index

6 → 10 deg/sec
4 → 2 deg/sec
2 → .5 deg/sec
0 → .2 deg/sec

in rev/sec/(RHC count)^2 @ 2^{-15}

in revs/sec @ 2^{-17}

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LM DAP Interface and Service Routines

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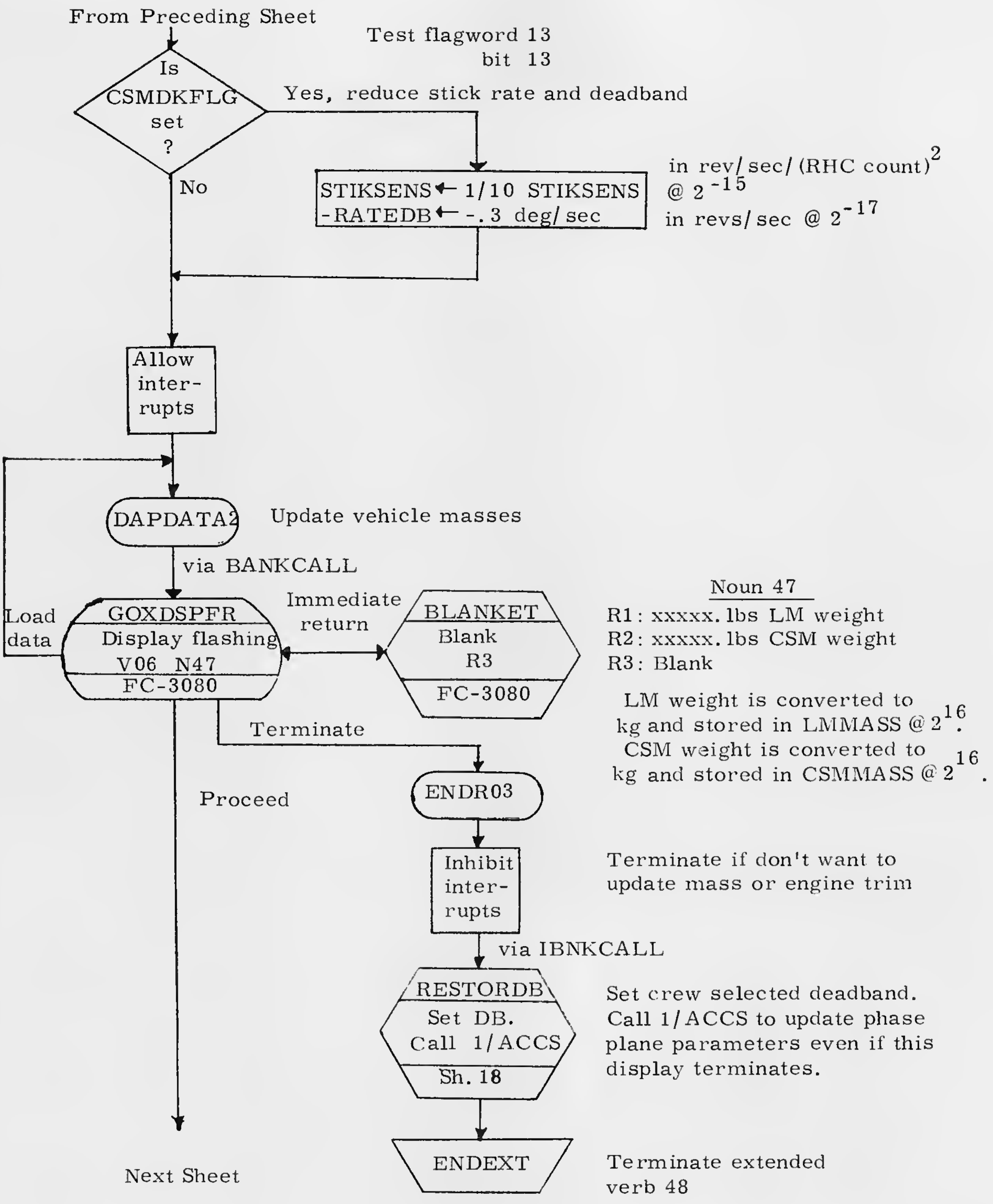

in rev/sec/(RHC count)^2 @ 2^{-15}

in revs/sec @ 2^{-17}

Update vehicle masses

Noun 47

R1: xxxxx. lbs LM weight
R2: xxxxx. lbs CSM weight
R3: Blank

LM weight is converted to kg and stored in LMMASS @ 2^{16}. CSM weight is converted to kg and stored in CSMMASS @ 2^{16}.

Terminate if don't want to update mass or engine trim

Set crew selected deadband. Call 1/ACCS to update phase plane parameters even if this display terminates.

Terminate extended verb 48

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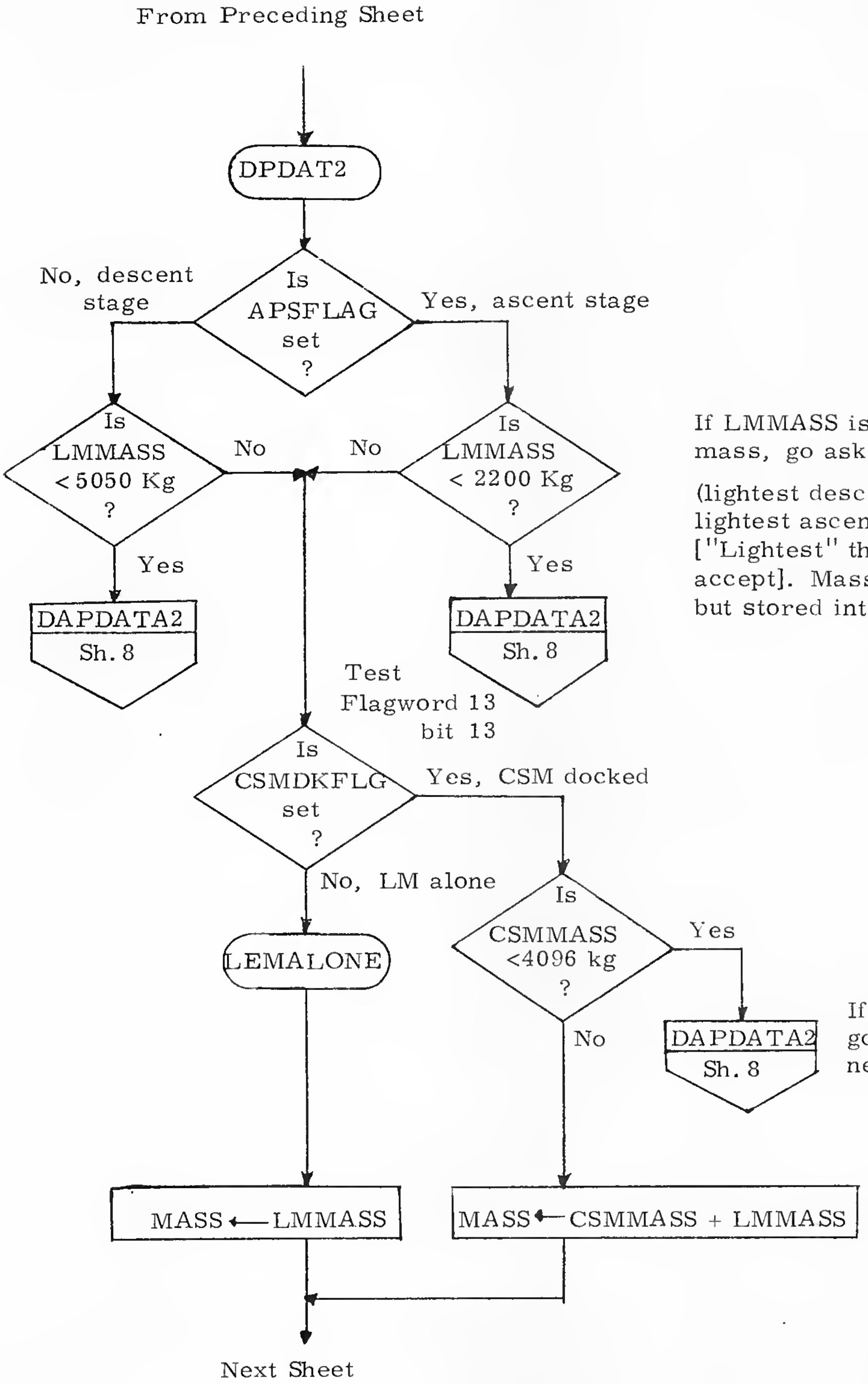

If LMMASS is less than empty mass, go ask for new masses

(lightest descent LM: 5050 Kg lightest ascent LM: 2200 Kg) ["Lightest" that the routine will accept]. Masses loaded in lbs, but stored internally in kilograms

If CSMMASS too light, go back to ask for new load

N. B. : LMMASS is merely used as a buffer here; CSMMASS will also be used by 1/ACCS

MASS in kg @ 2^{+16}

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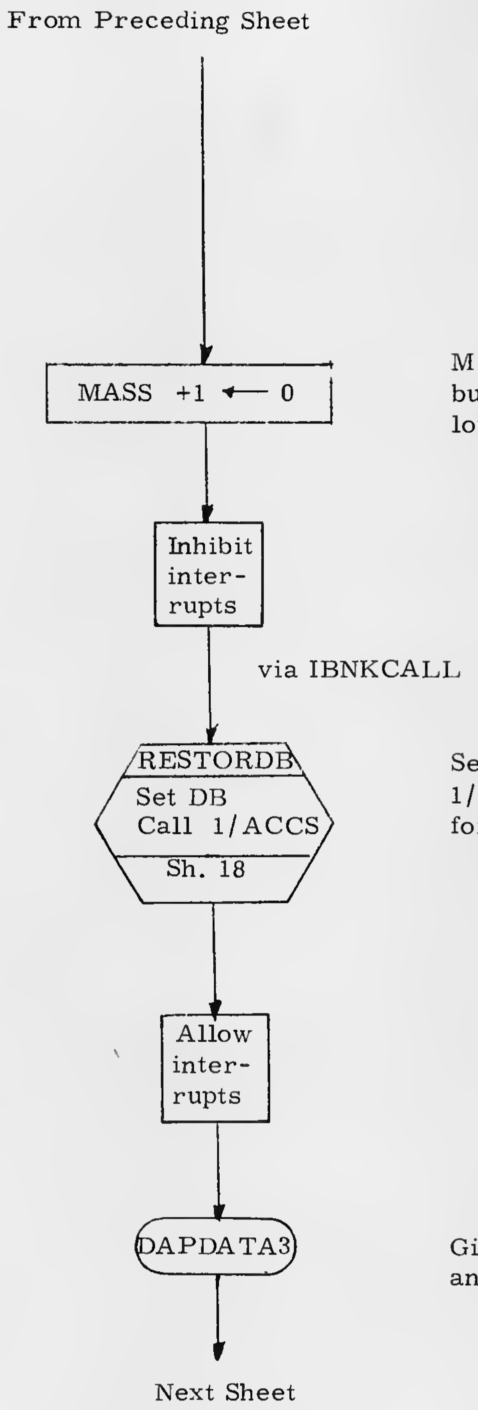

Mass monitor updates mass in d.p., but this initial load is s.p., so zero low order half.

Set crew selected deadband and call 1/ACCS to update phase plane parameters for new masses and deadband

Gimbal test/trim (if appropriate and requested)

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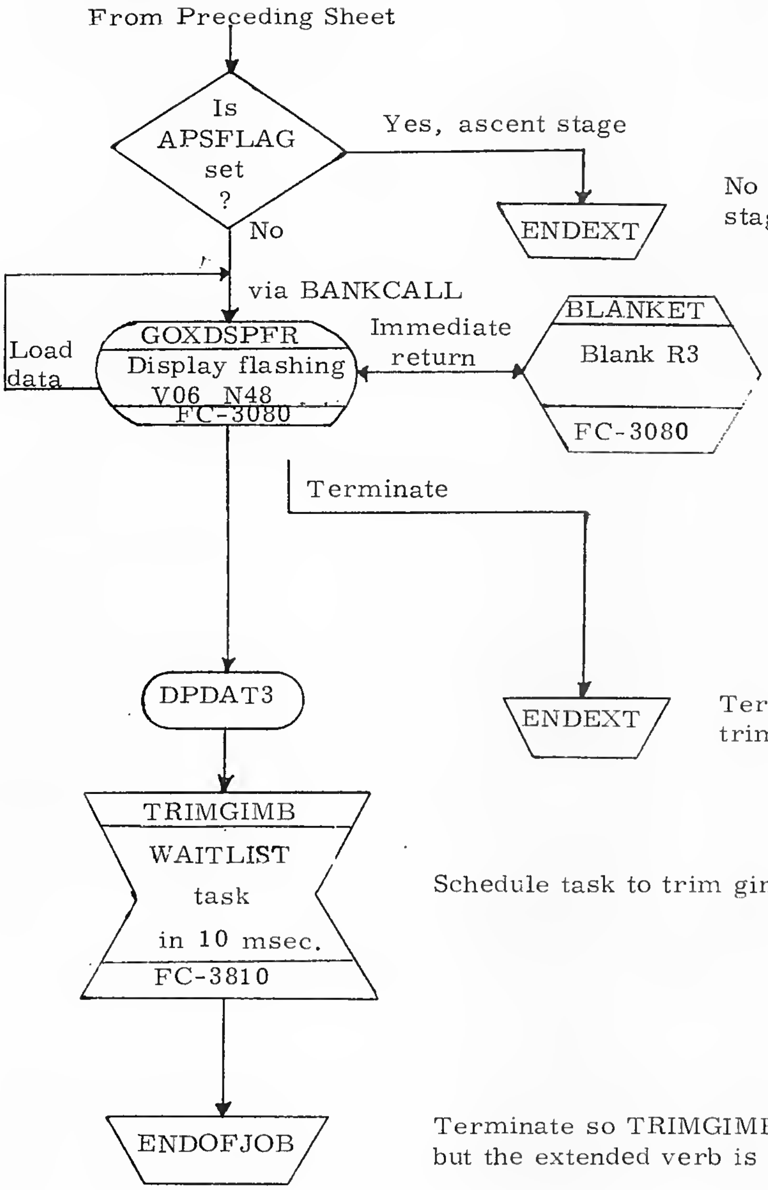

No gimbals if no descent stage, so terminate

Noun 48

R1 : xxx. xx deg. pitch trim angle
R2 : xxx. xx deg. roll trim angle
R3 : Blank
(angles measured from negative stops, i. e., position where greatest positive acceleration results)

Terminate without trimming gimbals

Schedule task to trim gimbals

Terminate so TRIMGIMB can execute, but the extended verb is still active

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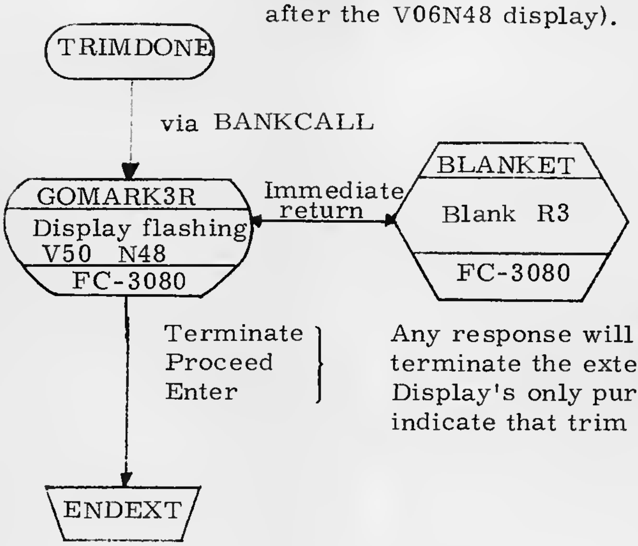
TRIMGIMB comes here when test/trim done.
(This may be as much as 2 min. after the V06N48 display).

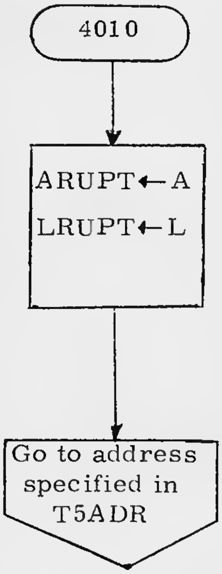


R1 : xxx.xx deg
gimbal pitch trim
R2: xxx.xx deg
gimbal roll trim
R3: blank

Noun as before
Verb50
(=VERB06)
for "Please
terminate"

Any response will serve to terminate the extended verb. Display's only purpose is to indicate that trim is done.

T5RUPT lead-in and DAP idling program



Come to here on T5 interrupt every 100 msec.

2 possibilities:
DAPIDLER (Sh. 13)
PAXIS (FC-3470)

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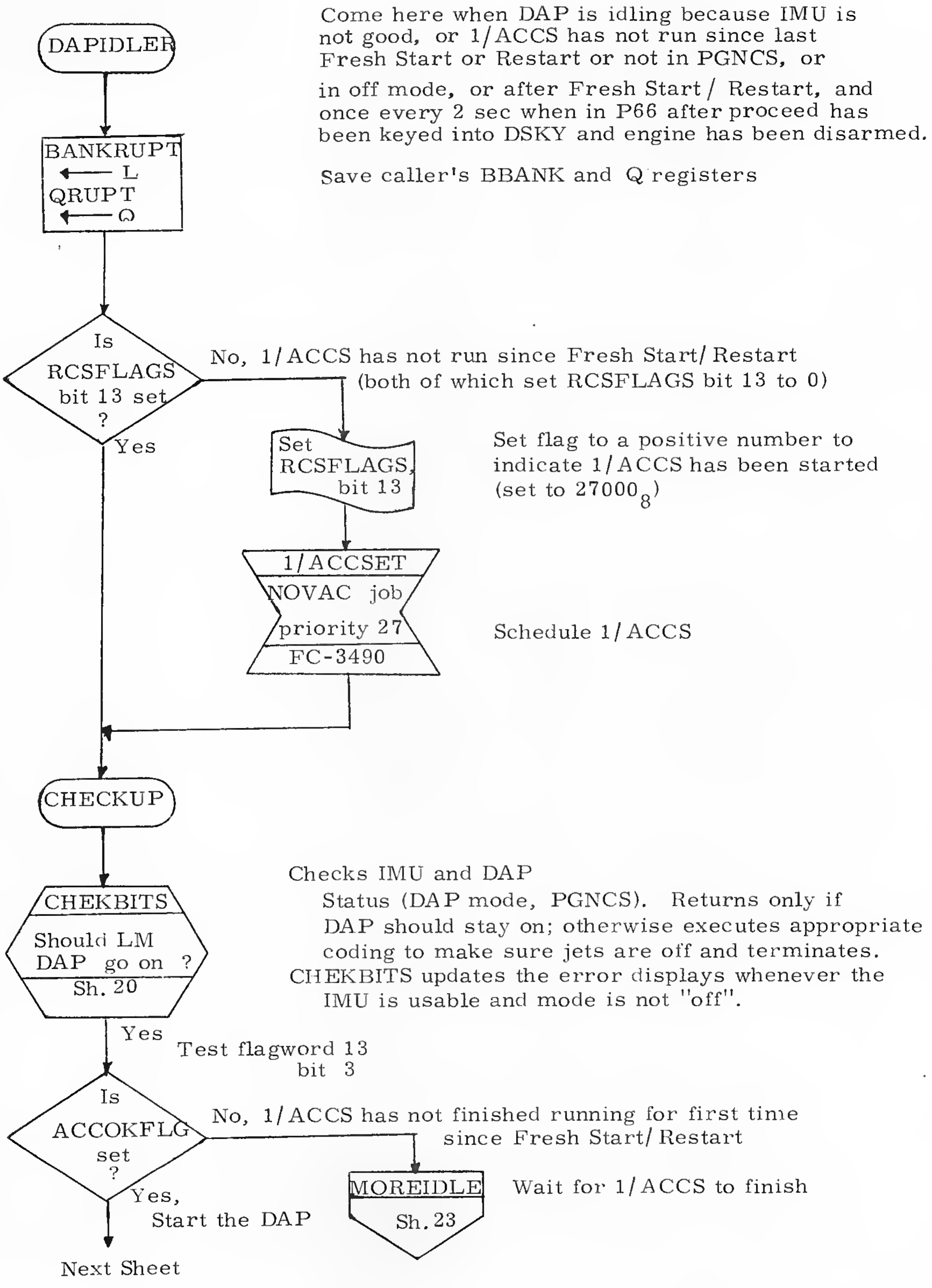

Come here when DAP is idling because IMU is not good, or 1/ACCS has not run since last Fresh Start or Restart or not in PGNCS, or in off mode, or after Fresh Start / Restart, and once every 2 sec when in P66 after proceed has been keyed into DSKY and engine has been disarmed.

Save caller's BBANK and Q registers

Set flag to a positive number to indicate 1/ACCS has been started (set to 27000_8)

Schedule 1/ACCS

Checks IMU and DAP
Status (DAP mode, PGNCS). Returns only if DAP should stay on; otherwise executes appropriate coding to make sure jets are off and terminates.
CHEKBITS updates the error displays whenever the IMU is usable and mode is not "off".

Wait for 1/ACCS to finish

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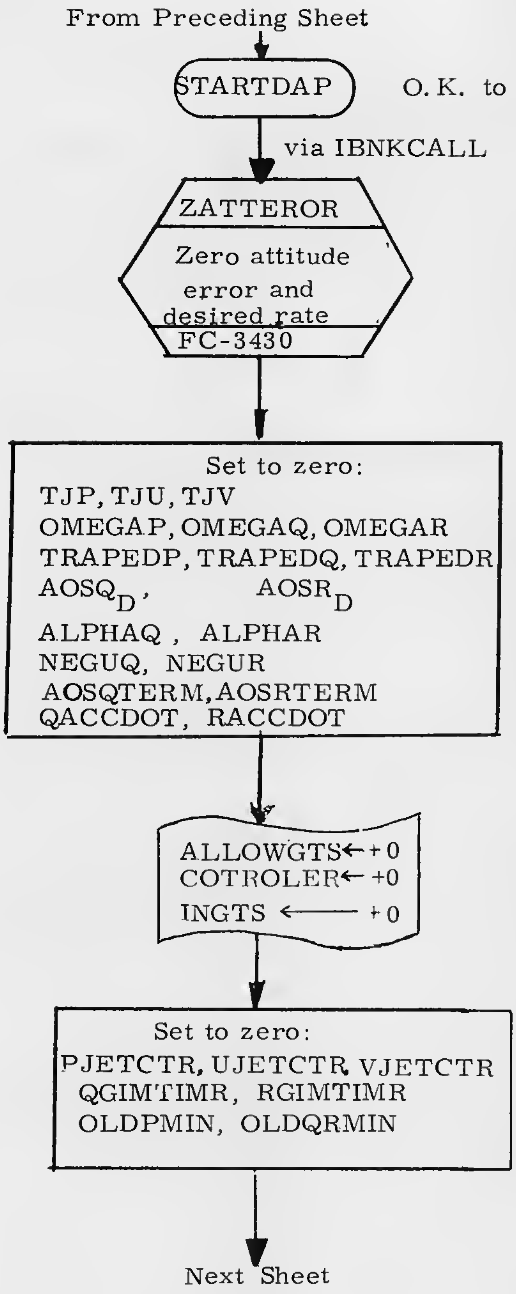

O.K. to start DAP if this point is reached

For the moment, establish present attitude as attitude reference, and zero commanded rates.

Erasable initialization for DAP

Jet firing, times for rate estimator rates, in body axes (pilot co-ords).
Noise Traps
Offset acceleration estimates
The same (s.p.) for Downlink
Gimbal drive switch words
Q, R - axis rate derivation terms
Jerk terms for rate estimation

Don't allow gimbal trim system control but try GTS control (it won't be allowed of course). Flag indicates GTS is not controlling

Initialize docked jet inhibition counters
Gimbal drive times (this will stop gimbal drives) Minimum impulse command registers

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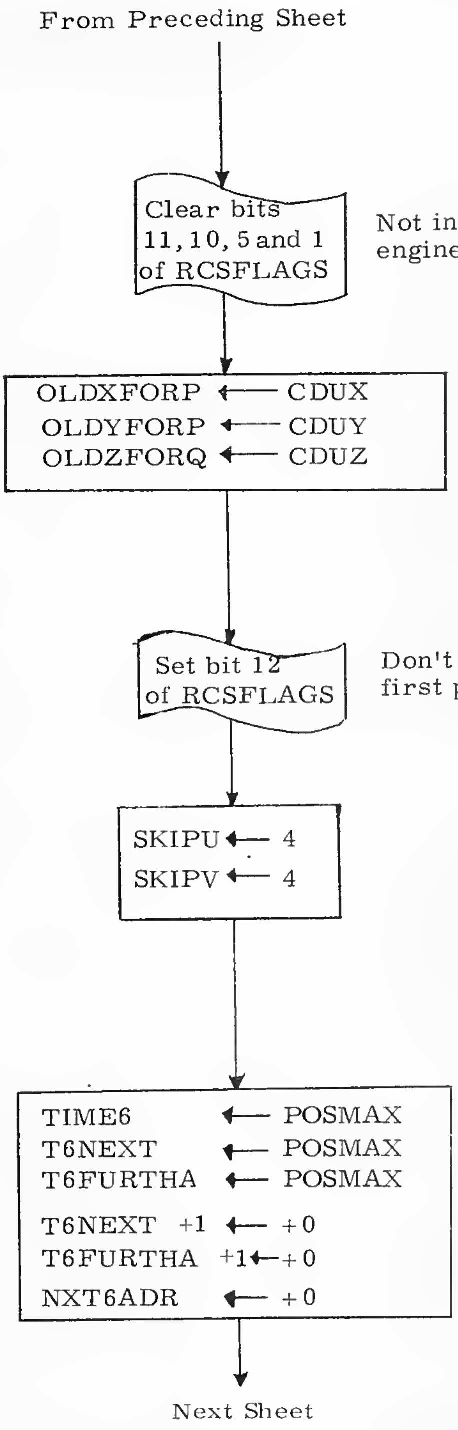


Not in direct rate manual mode; engine gimbal drive bits not being set

Initialize "old CDU" registers, so rate estimator (which runs for first time in 100 m sec) will have values to take differences with to estimate rates } in revs @ 2^{-1}

Don't skip P-axis RCS DAP on first pass

Don't skip U-axis RCS DAP on first pass
Don't skip V-axis RCS DAP on first pass
An axis is skipped if and only if:

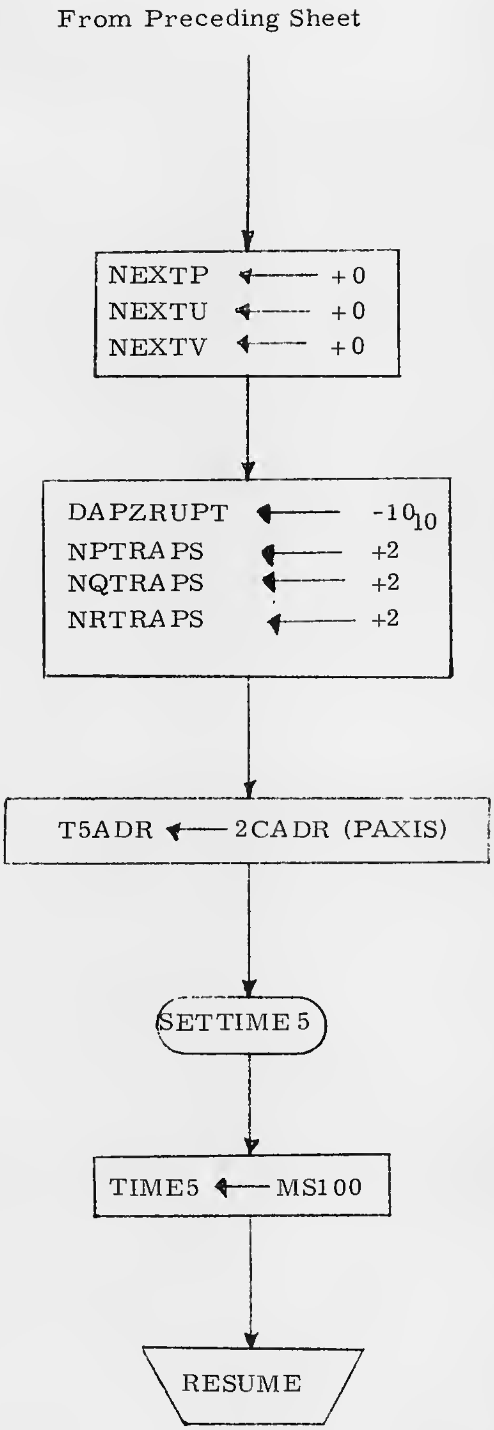
1. Jets were fired last time
and
2. The firing time was < 150 msec.

TIME 6 in csec @ 2^{-4}

No events awaiting execution by the T6 program (T6JOB)

POSMAX = 37777_8

Dummy event tags in the jet list since no events are waiting



No translations waiting to be executed

This will show JASK not running, since Z is never < 0

Initialize trap counters in all 3 axes for the noise traps. } @ 2^{+14}

T5RUPT goes to P-axis autopilot next time (i. e. DAP is now "TURNED ON")

in decisec @ 2^{+14}

End of T5RUPT

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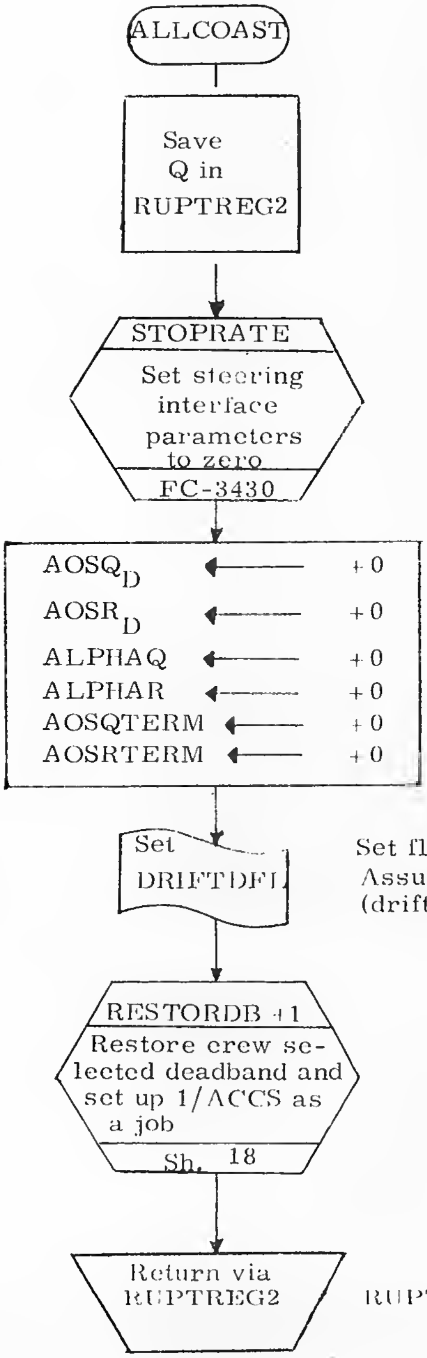

Set flagword 13 bit 8:
Assume no acceleration offset
(drifting flight)

RUPTREG2 contains Q

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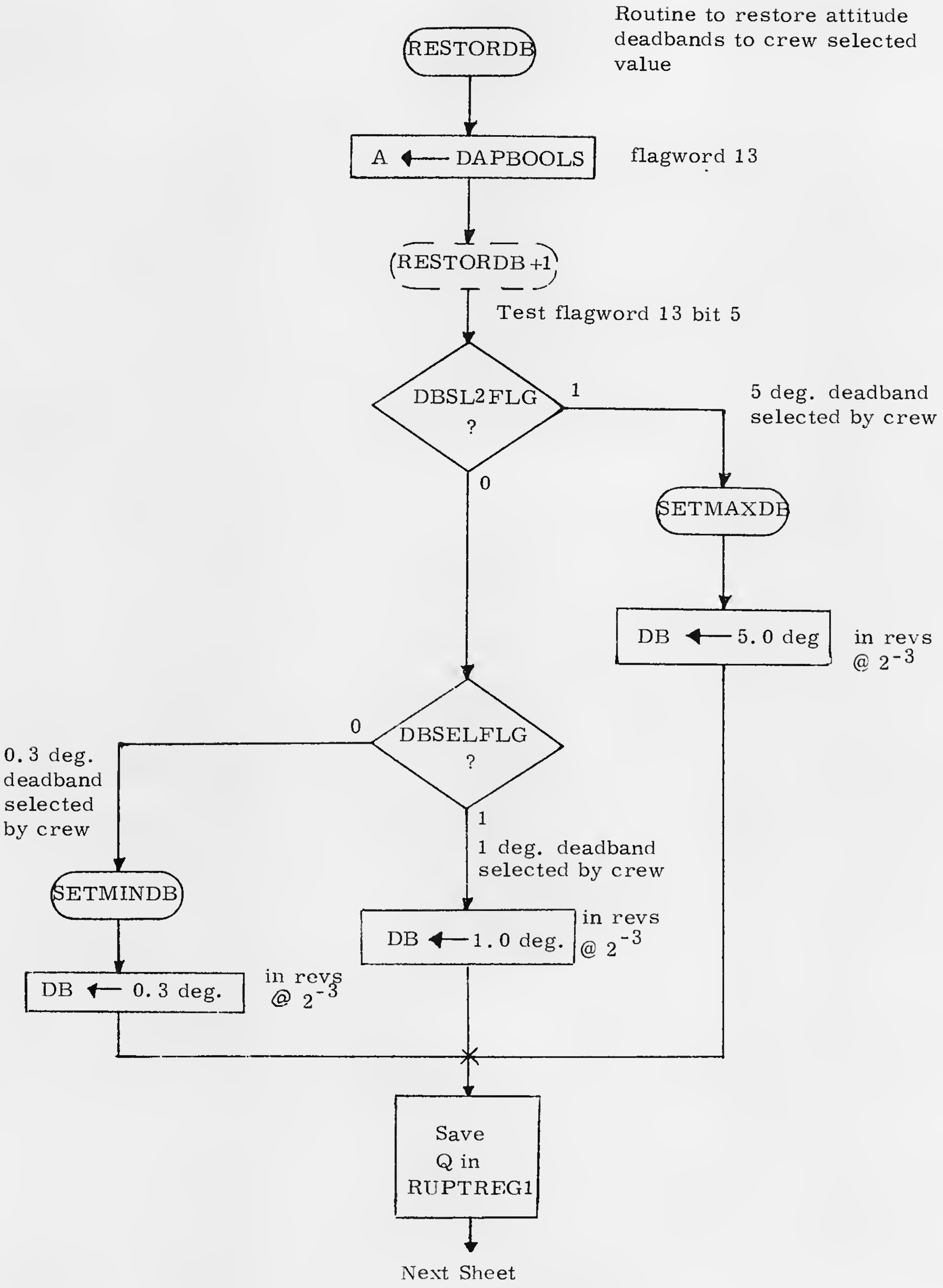

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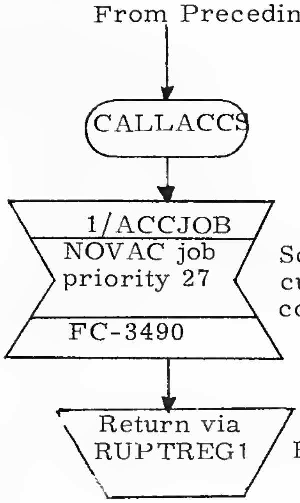
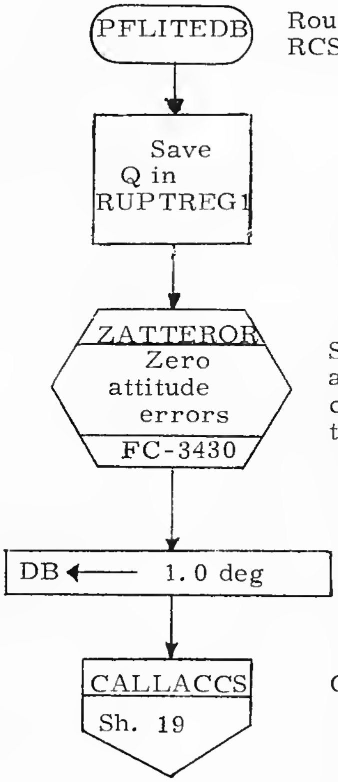


Schedule 1/ACCS to position switch curves for new deadbands and compute control authorities

RUPTREG1 contains Q



Routine to set attitude deadband for RCS to ± 1.0 deg for powered flight

Set reference attitude to present actual attitude so that if 5° DB were in effect, collapsing the DB to 1° will not cause jets to fire. Null commanded rates

in revs @ 2^{-3}

Continue above to schedule 1/ACCS

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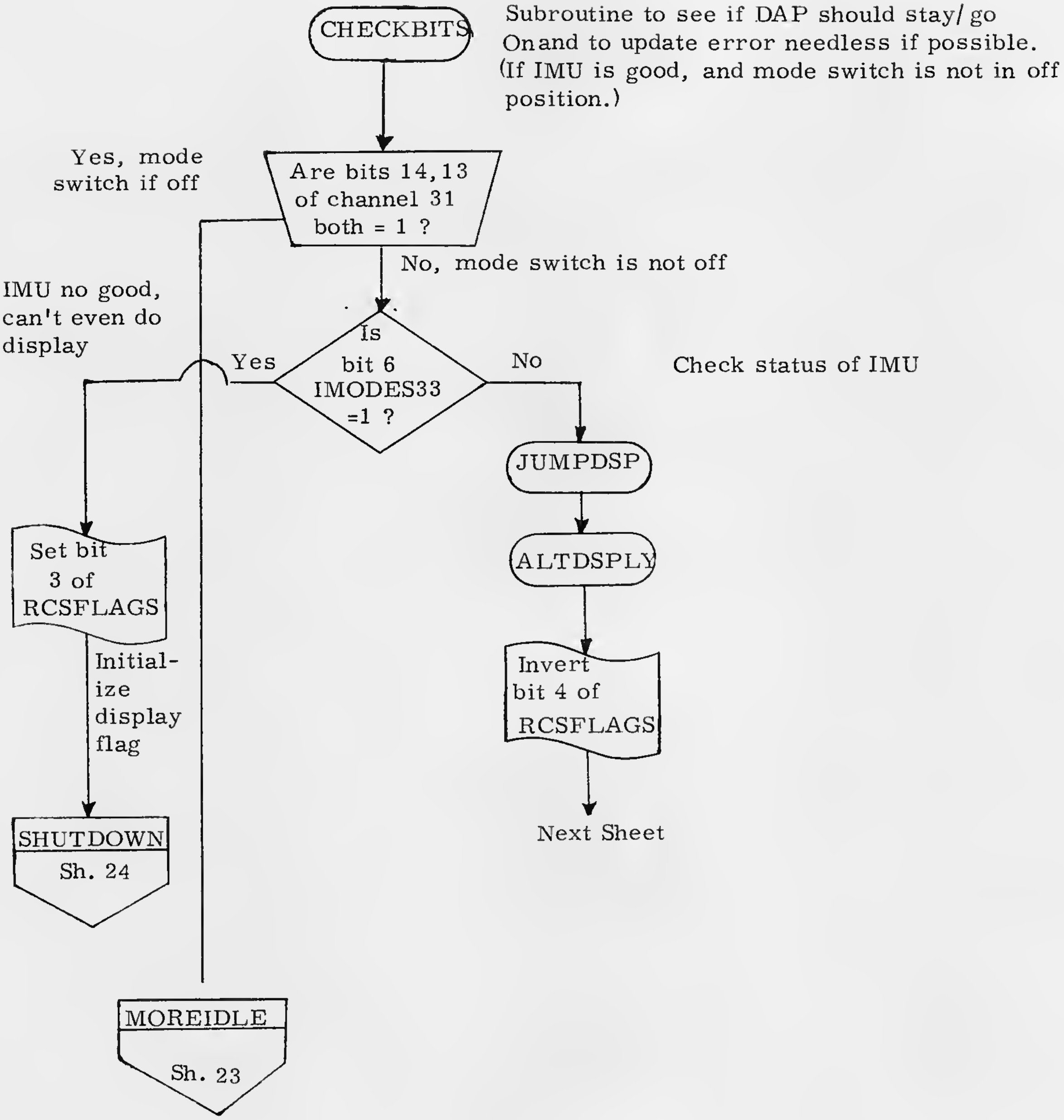

Subroutine to see if DAP should stay/go On and to update error needless if possible. (If IMU is good, and mode switch is not in off position.)

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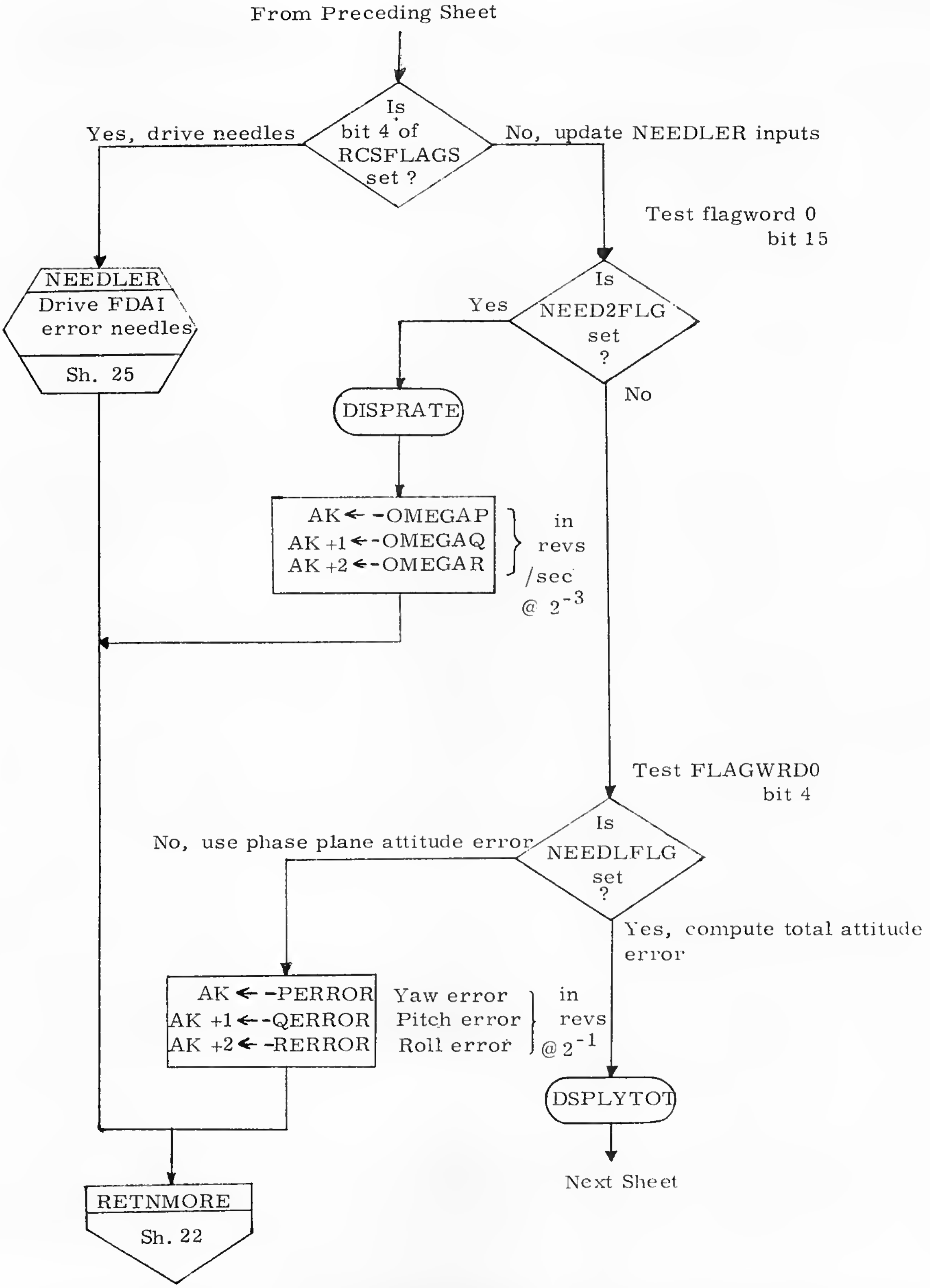

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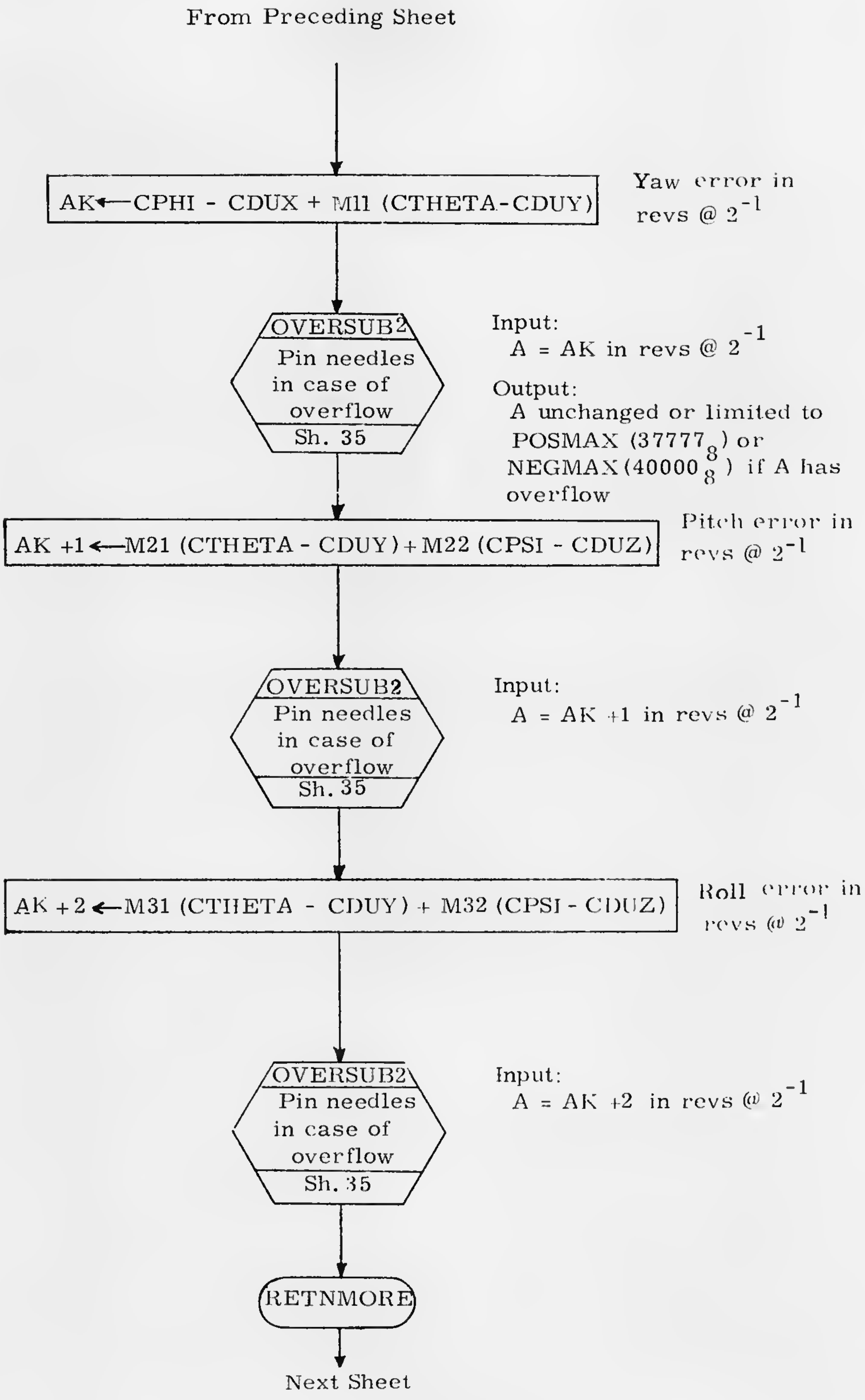

Yaw error in revs @ 2^{-1}

Input:
A = AK in revs @ 2^{-1}

Output:
A unchanged or limited to POSMAX (37777_8) or NEGMAX (40000_8) if A has overflow

Pitch error in revs @ 2^{-1}

Input:
A = AK +1 in revs @ 2^{-1}

Roll error in revs @ 2^{-1}

Input:
A = AK +2 in revs @ 2^{-1}

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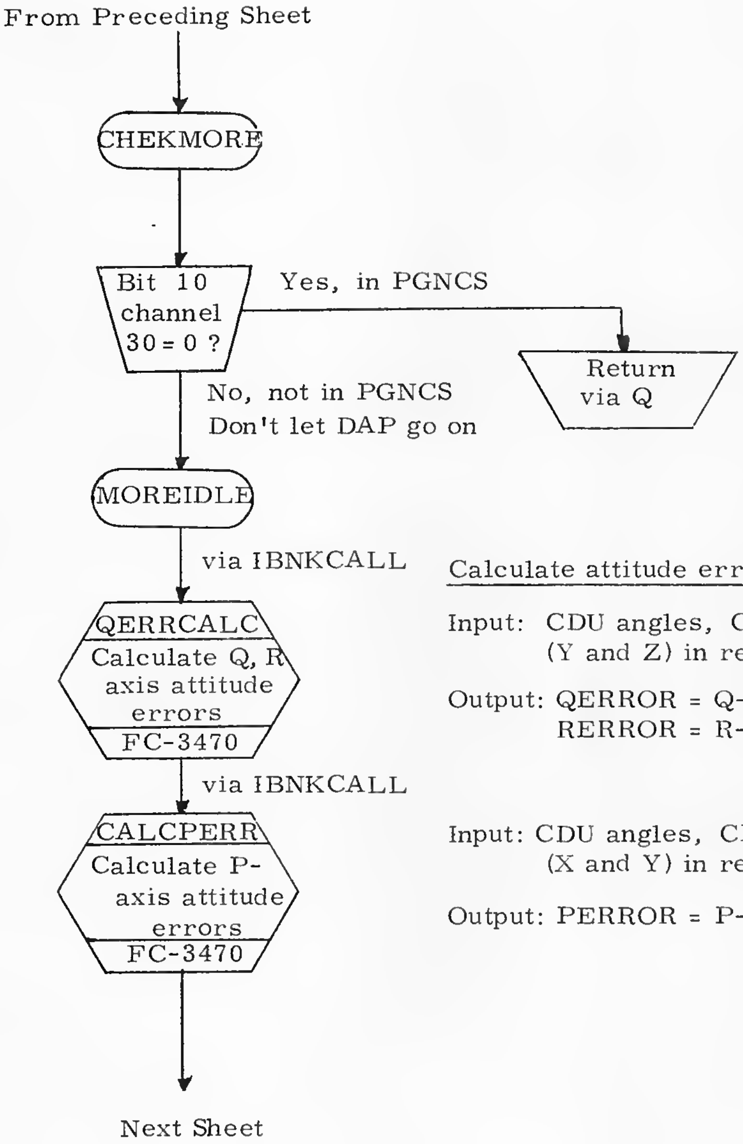

Return to caller,
DAP may go on

<u>Calculate attitude errors for display on next pass</u>

Input: CDU angles, CDU desired angles (Y and Z) in revs @ 2^{-1}

Output: QERROR = Q-axis attitude error
RERROR = R-axis attitude error

Input: CDU angles, CDU desired angles (X and Y) in revs @ 2^{-1}

Output: PERROR = P-axis attitude error

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LM DAP Interface and
Service Routines

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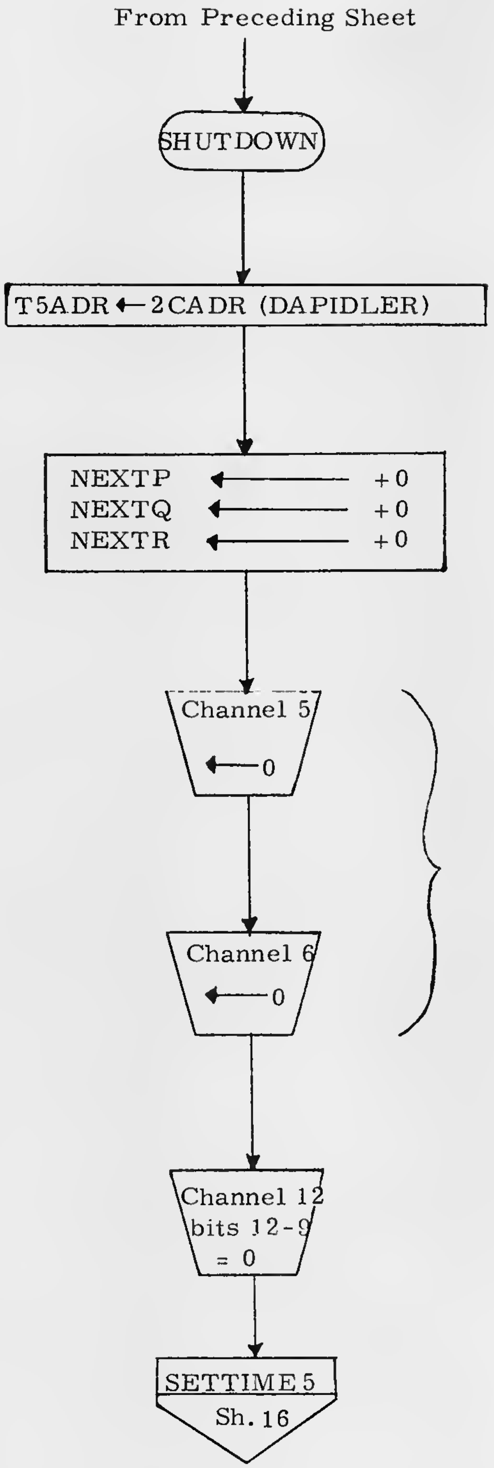

Shut off the DAP

Make sure no translation jets are waiting to go on

Turn off all jets

Turn off gimbal drive

Try again in 100 msec.

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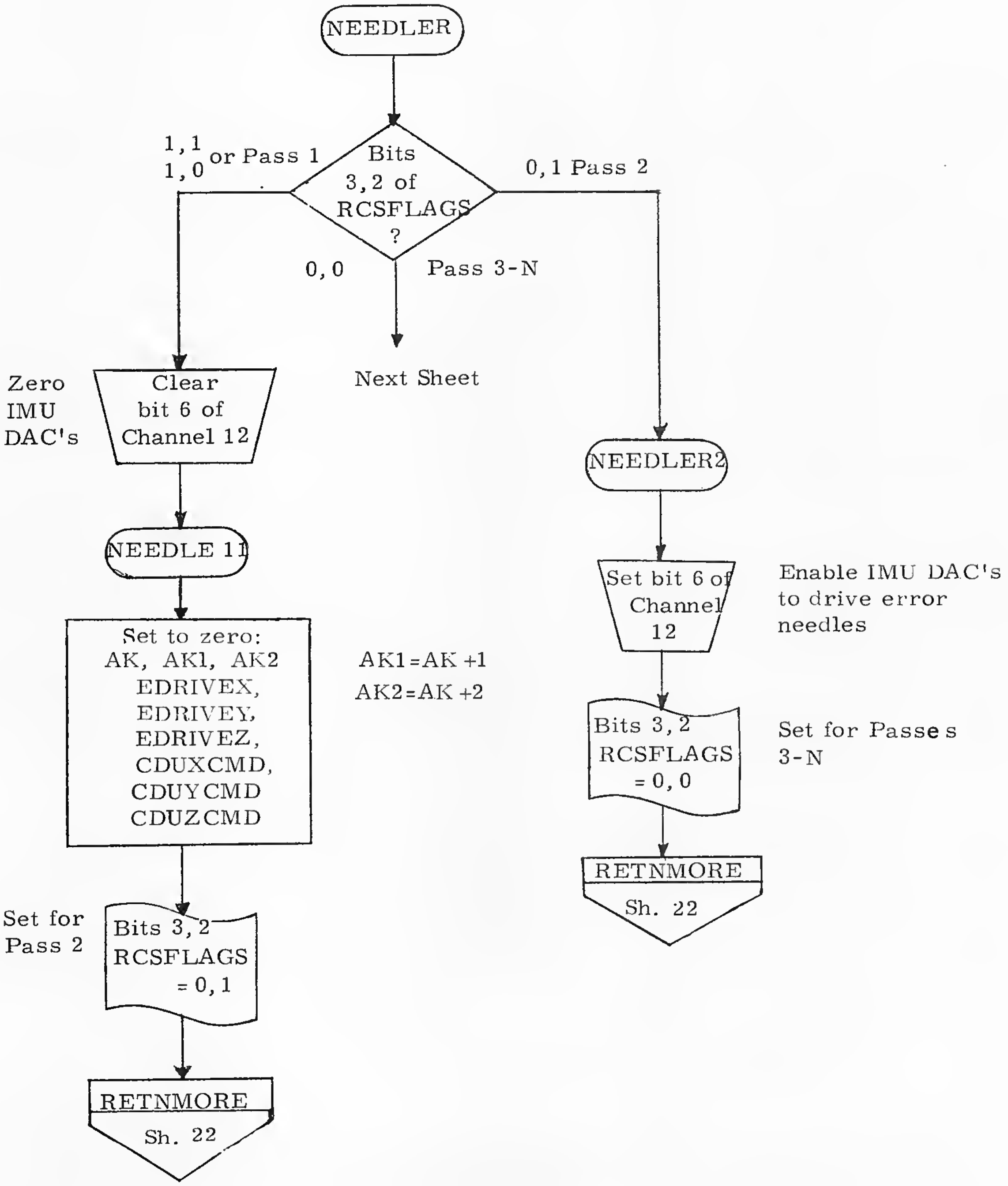

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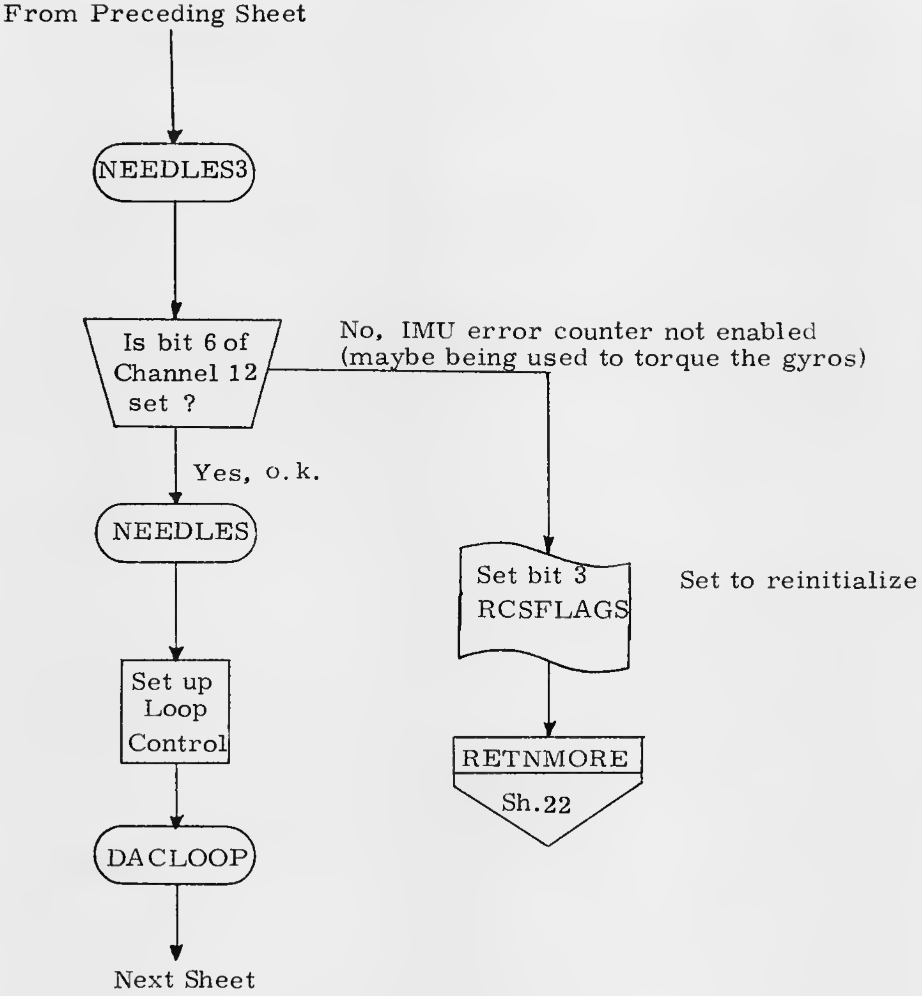

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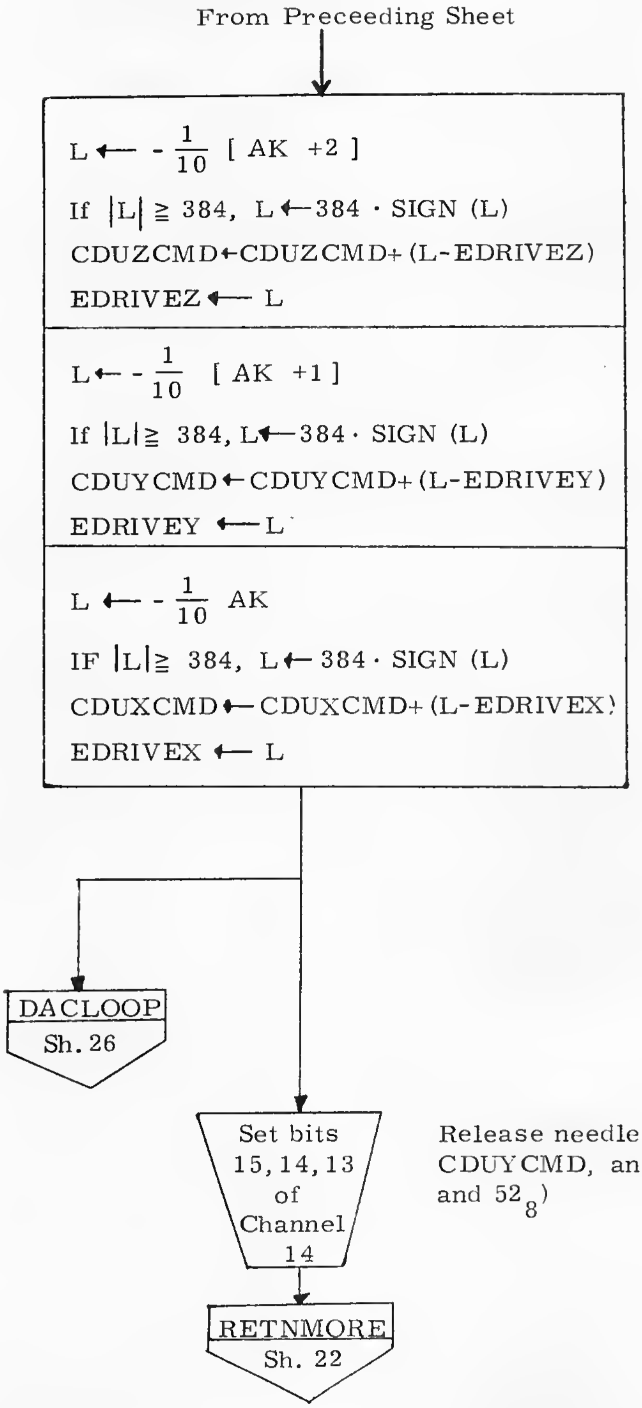

Loop Pass 1: Z-axis needle drive

Rescale to 10,000

Limit to ± 384 (maximum for counters) = ± 42 3/16 deg.

Add new Δ command to output registers

Save to form Δ command on next pass (in revs @ $2^{-1} \times 10$)

Loop Pass 2: Y-axis needle drive

Loop Pass 3: X-axis needle drive

Release needle drive bits from CDUXCMD, CDUYCMD, and CDUZCMD (= Registers 50_8, 51_8, and 52_8)

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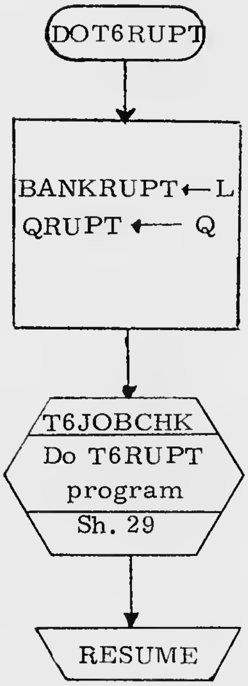

Continuation of T6 interrupt lead in

Store BBANK of interrupted program

Store contents of Q

This routine does all the work

End TIME6 interrupt processor

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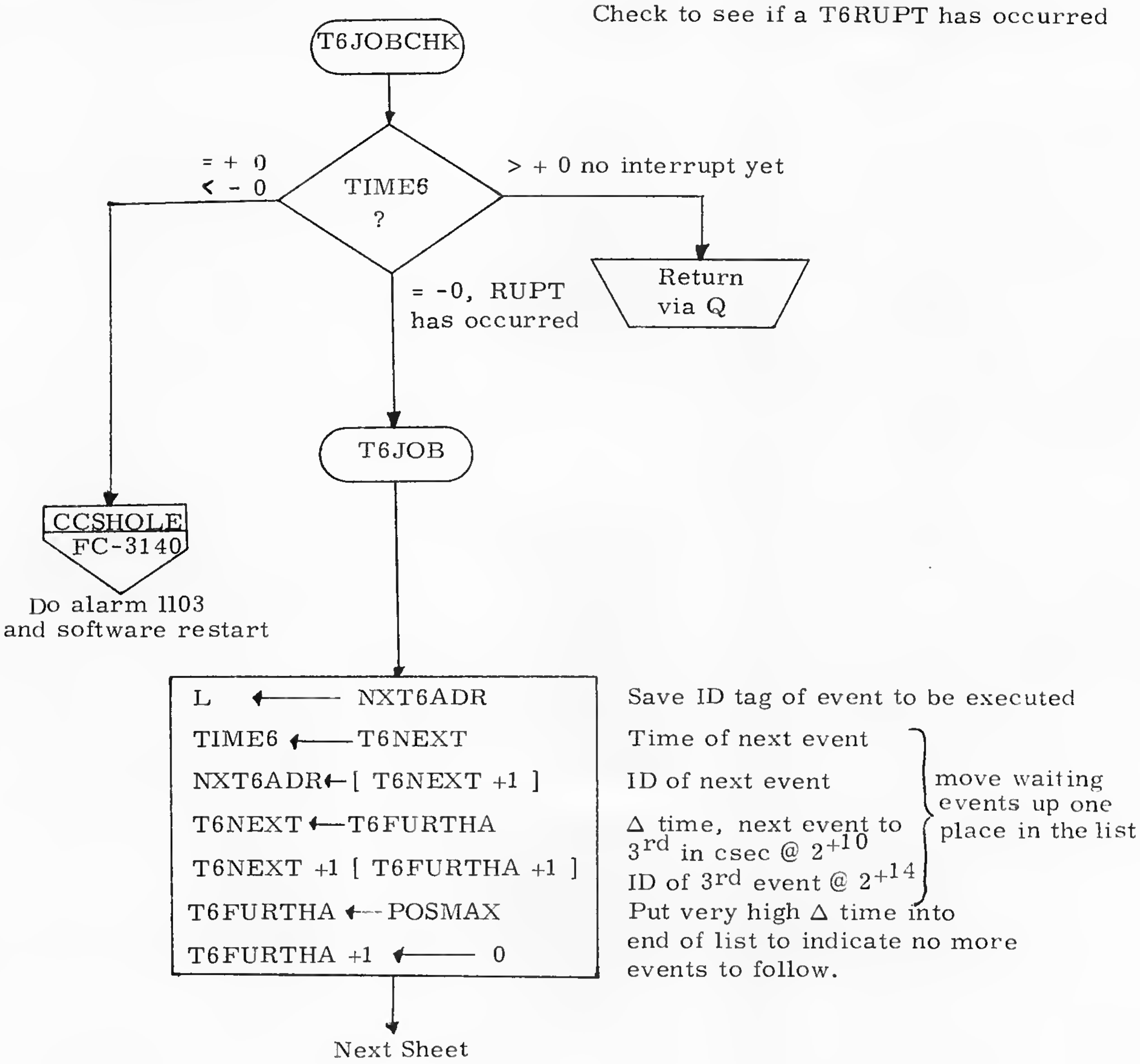

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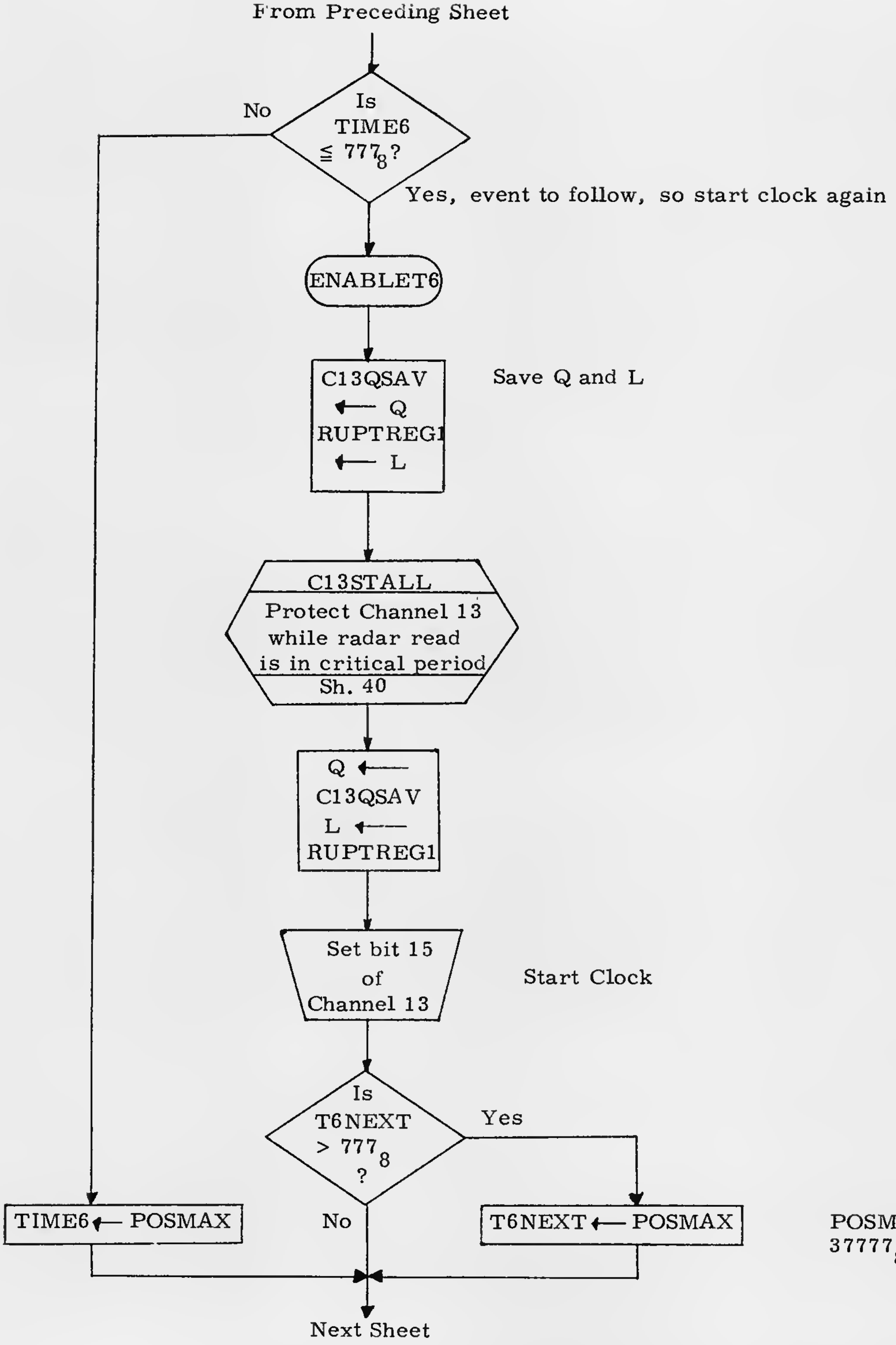

Save Q and L

Start Clock

POSMAX = 37777_8

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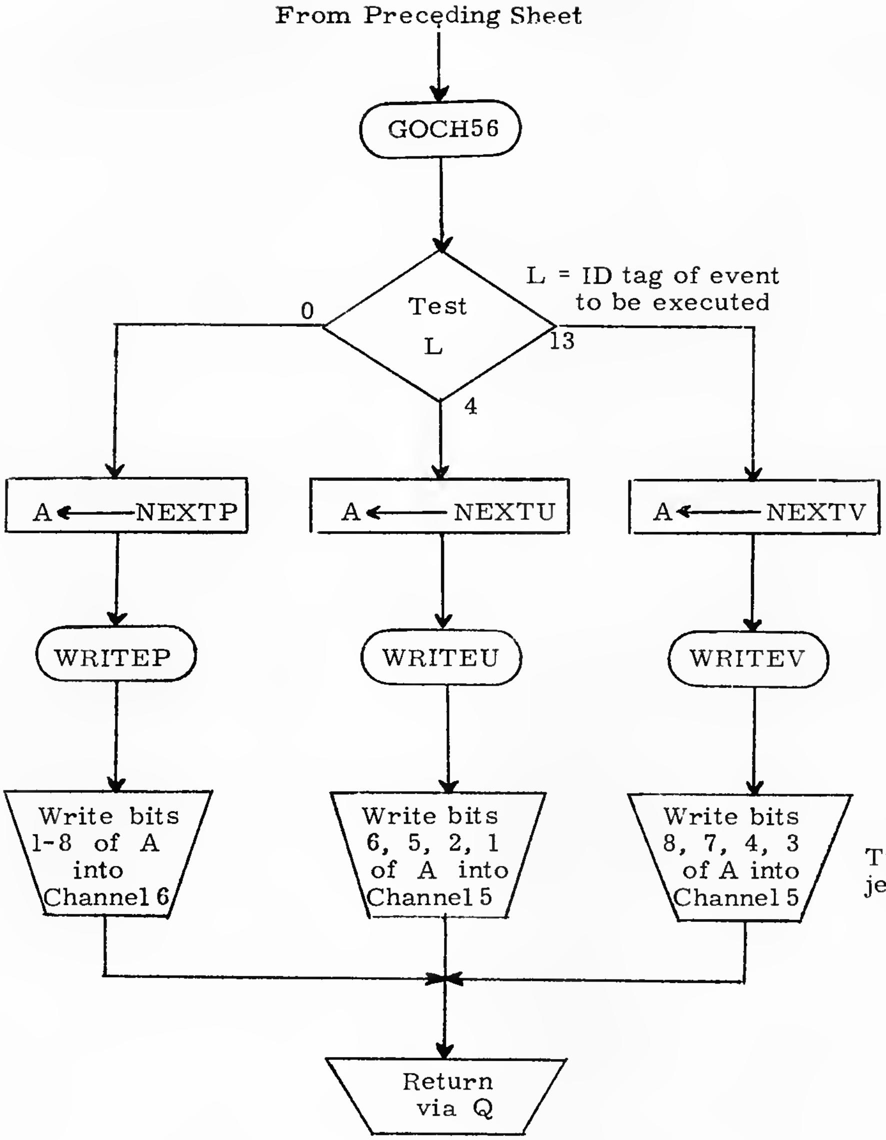

L = ID tag of event to be executed

NEXTP is Channel 6 jet code for Y and Z axis translation.
NEXTU is channel 5 jet code for X-axis translation using U-axis jets.
NEXTV is channel 5 jet code for X-axis translation using V-axis jets.

Turn on/off appropriate jets.

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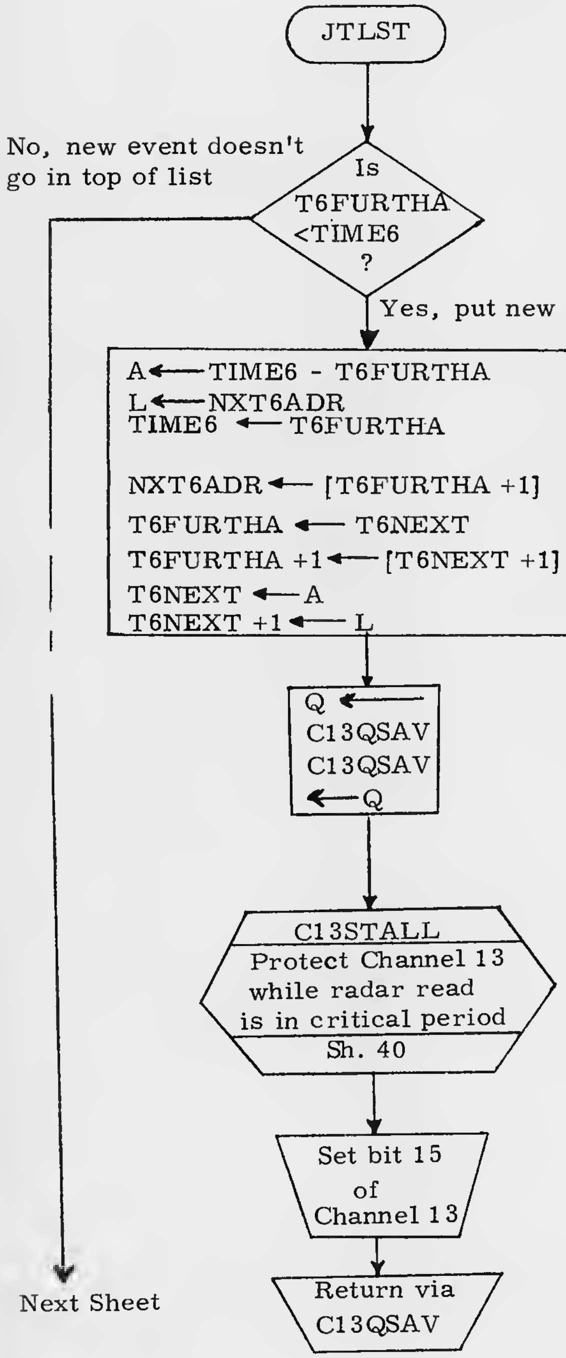
Maintain Jet list: Enter with event to be added in list position 3. Compare time of execution of new event with the events already scheduled, and place new event in proper place in list to keep list order equal to order of execution.



Is new event to occur before the event currently at the top of the list ?

Δ time in csec @ 2^{+10} new event to follow.
Save old top-of-list ID tag to go into position 2.
Set T6 timer to schedule new event (in csec @ 2^{+10}).
ID Tag for new event. (@ 2^{+14}).
Δ time (in csec @ 2^{+10})
ID Tag (@ 2^{+14})
} Move position 2 event to position 3.
Δ time (in csec @ 2^{+10})
ID Tag (@ 2^{+14})
} Place old top-of-list event into Posi Position 2.

Start TIME6 clock, in case this is the first event to be scheduled since the TIME6 clock shut down. If the clock is already running, this is redundant but harmless.

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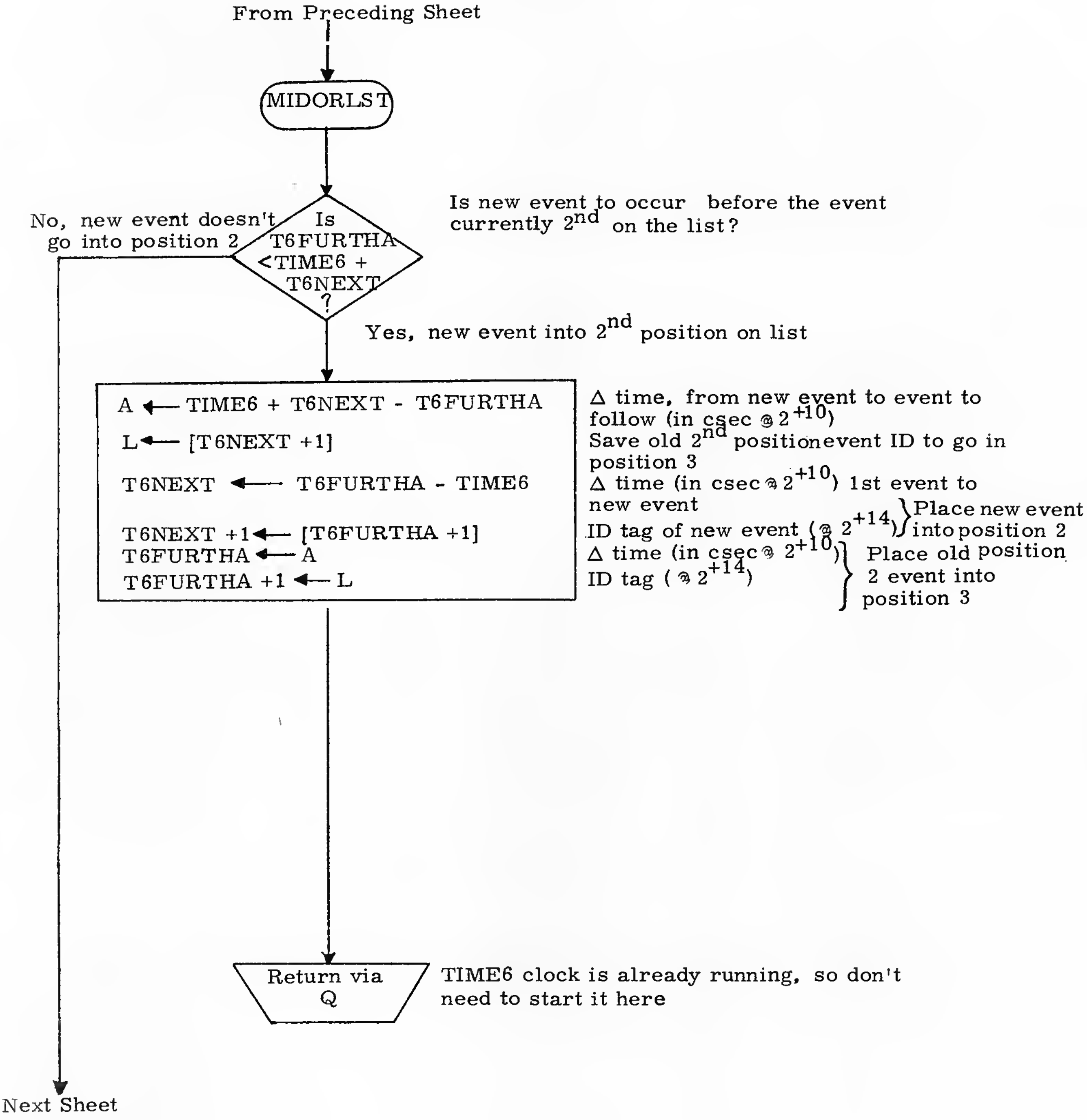

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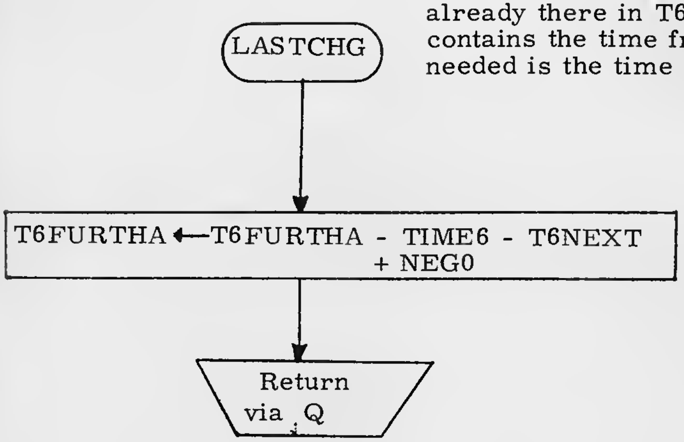
New event must go into postion 3. The ID tag is already there in T6FURTHA +1. T6FURTHA, however, contains the time from now to the new event, What is needed is the time from event 2 to the new event



Δ time (in csec @2^{+10}), event 2 to new event (-0 is added to insure that result will never be +0)

The jet list is composed of 6 words of memory- 3 times, and 3 event ID's as follows:

Position1	TIME6	Δ time, "now" to first event (This is the TIME6 register)
	NXT6ADR	ID of the first event
Position 2	T6NEXT	Δ time, first event to second event
	T6NEXT +1	ID of the second event
Position3	T6FURTHA	Δ time, secone event to third event
	T6FURTHA +1	ID of the third event

The events and their ID's are as follows:

ID=0: Stop P rotation jets, turn on Y, Z translation jets, if any
ID=4: Stop U rotation jets, turn on U-axis X trans. jets, if any
ID=3: Stop V rotation jets, turn on V-axis X trans. jets, if any

When the T6 clock counts to zero, T6JOB is entered. It executes event no. 1, and pushes the rest one position up the list. Δ time, event1 to event 2, becomes the new setting of the TIME6 clock. POSMAX (the largest positive number available) is entered for the Δ time at the bottom of the list. When all the scheduled events have been duly executed, T6JOB recognizes the execessively large Δ time it is about to put into TIME6, and leaves the timer turned off.

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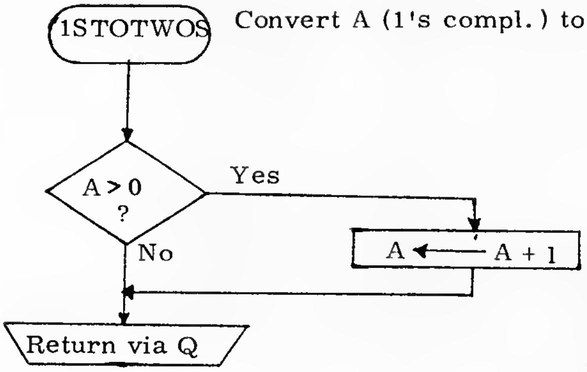
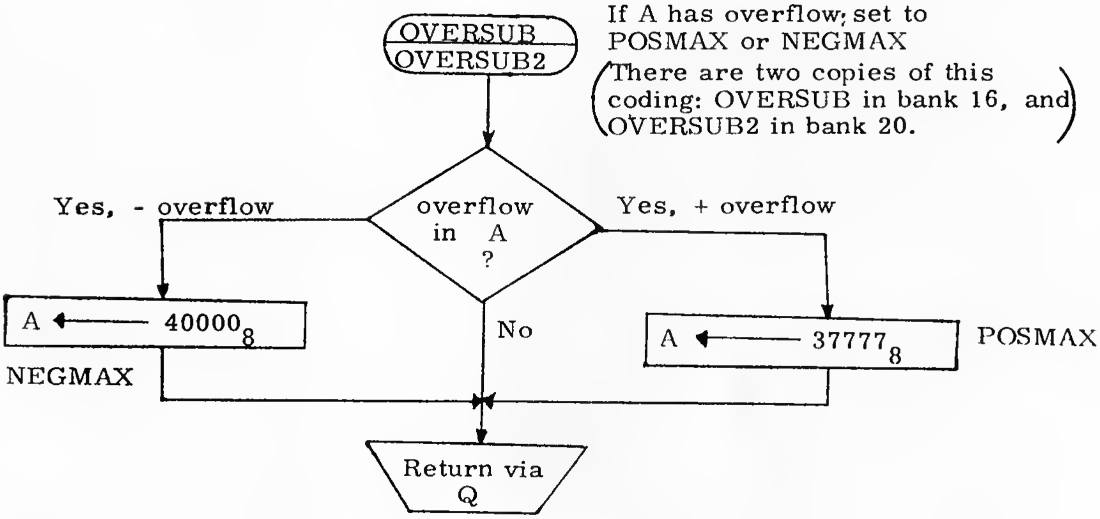


Convert A (1's compl.) to 2's compl.

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



If A has overflow; set to POSMAX or NEGMAX

(There are two copies of this coding: OVERSUB in bank 16, and OVERSUB2 in bank 20.)

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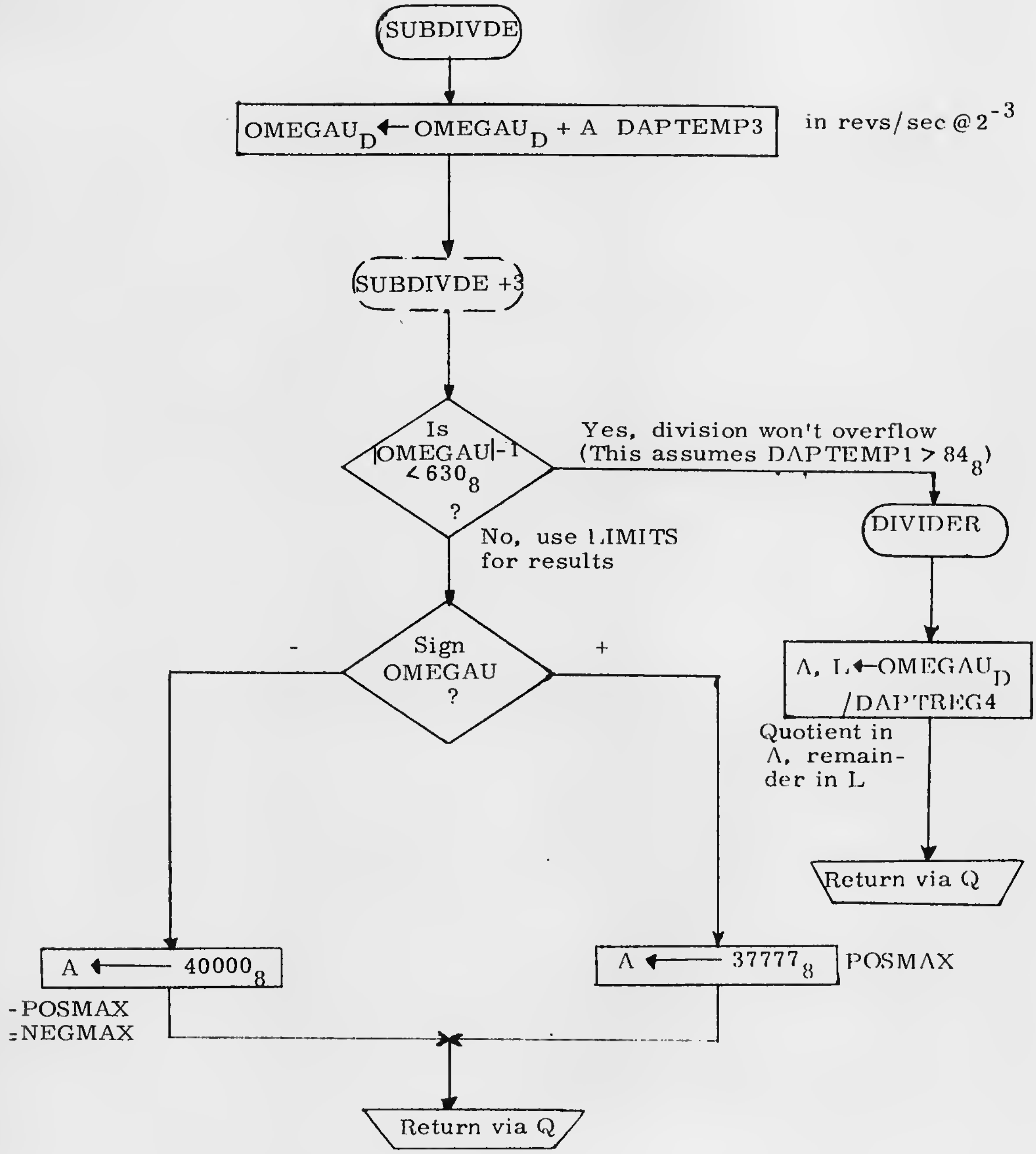

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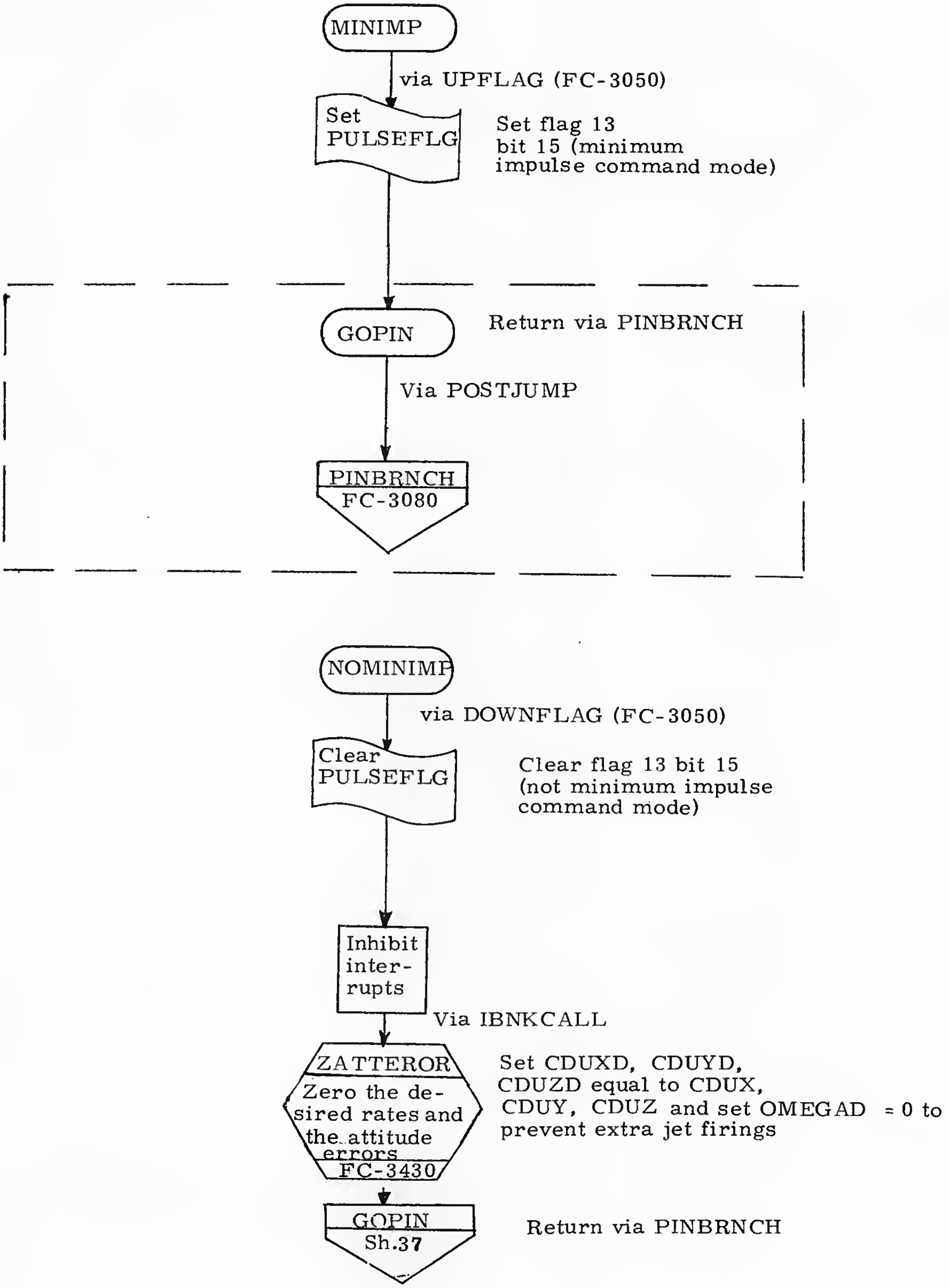

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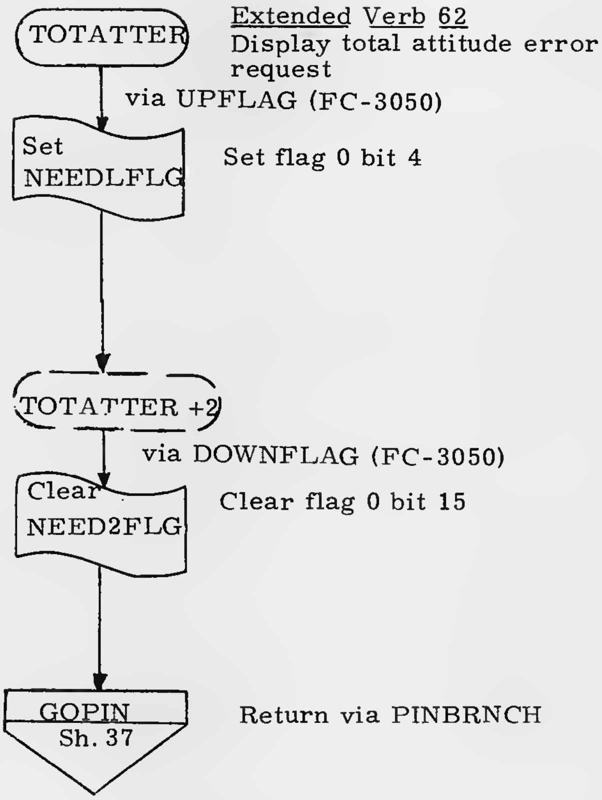
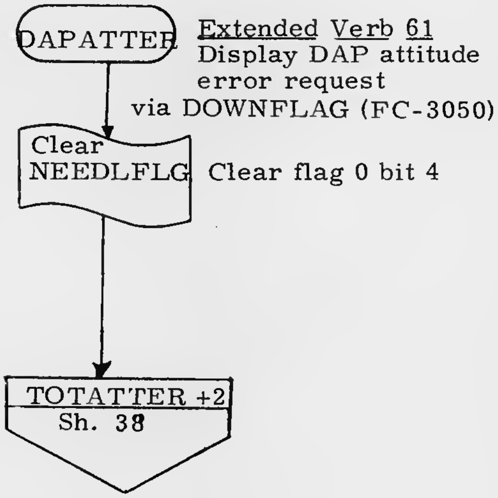
APPR'D Roberta M. Entas	3/25/70	REV 2	SHEET 37 OF 50





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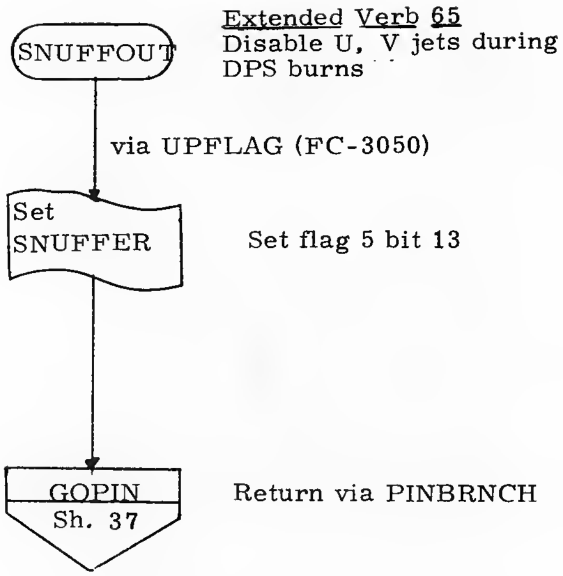

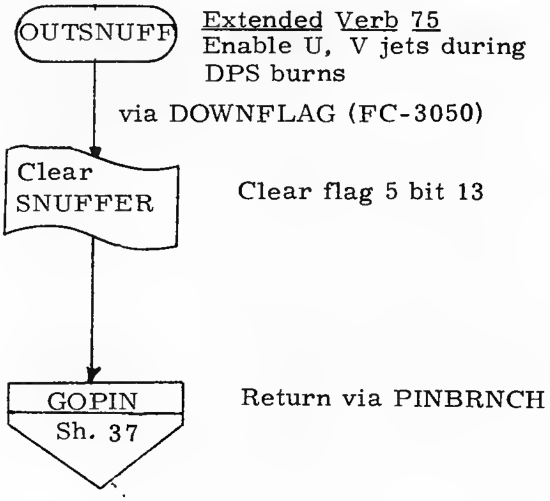

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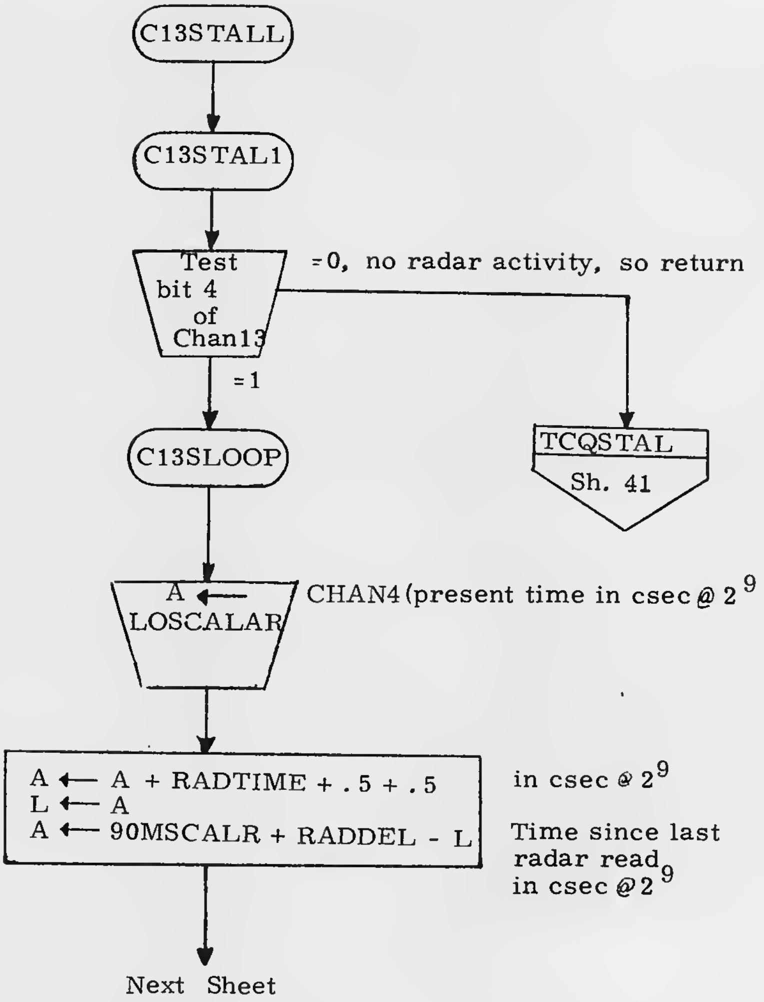

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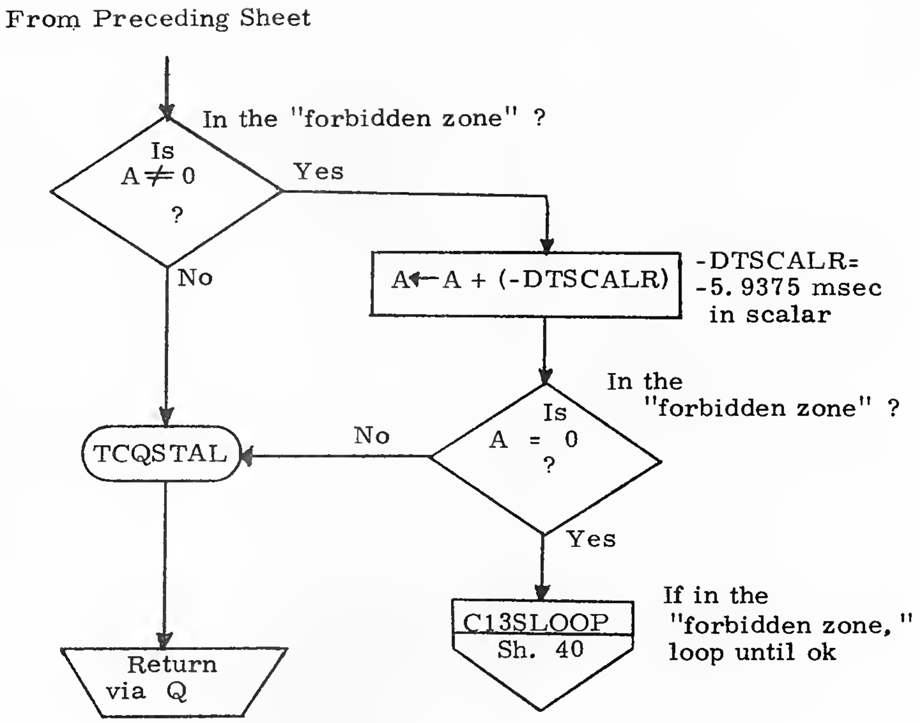

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SUBROUTINES CALLED WHICH ARE FLOWED
ON OTHER FLOW-CHARTS

Subroutine Name	Flow Chart	Description	Where Called
CCSHOLE	3140	Store abort code 1103 and cause restart	Sh. 29
BLANKET	3080	Blanks specified registers	Sh. 4, 8, 11, 12
CALCPERR	3470	Calculates P-axis attitude errors	Sh. 23
GOMARK3R	3080	Flashing display	Sh. 12
PAXIS	3470	State estimator and P axis DAP calculations	Sh. 12
PINBRNCH	3080	PINBALL entry to regenerate display after a key release	Sh. 37
PRIOCHNG	3030	Change priority	Sh. 2
QERRCALC	3470	Calculate Q-and R-axes attitude errors	Sh. 23
TESTXACT	3100	Tests extended verb activity	Sh 2
TRIMGIMB	3810	Trim gimbals	Sh. 11
GOXDSPFR	3080	Flash mark V/N and return	Sh. 4, 8, 11
1/ACCJOB	3490	Schedule 1/ACCS as a job	Sh. 19
1/ACCSET	3490	Null offset estimates and schedules 1/ACCS as a job	Sh. 13
STOPRATE	3430	Zero inputs to autopilot	Sh. 17
ZATTEROR	3430	Load commanded angles; zero inputs to autopilot	Sh. 14, 18, 36

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FLAGS

Name	Meaning When set	Meaning When Clear	Where Set	Where Cleared	Where Tested
CSMDKFLG (FLAGWRD13 BIT13)	CSM docked	CSM not docked to LM	Sh. 5	Sh. 5	Sh. 6, 8, 9
ACC4-2FL (FLAGWRD 13 BIT11)	4 Jet X-axis translation requested	2 jet X-axis translation requested			Sh. 6
DRIFTDFL (FLAGWRD 13 BIT8)	Null offset acceleration estimate	Use offset acceleration estimate	Sh. 17		
RHCSFLG (FLAGWRD 13 BIT7)	Normal RHC scaling requested	Fine RHC scaling requested			Sh. 7
DBSL2FLG (FLAGWRD 13 BIT5)	5 degree deadband selected by crew	1 or .3 degree deadband selected by crew (see BIT4 of FLAGWRD13)			Sh. 18
DBSELFLG (FLAGWRD 13 BIT4)	1 degree deadband selected by crew	.3 degree deadband selected by crew			Sh. 18
ACCOKFLG (FLAGWRD 13 BIT3)	Control authority values from 1/ACCS usable	Restart or fresh start since last 1/ACCS; outputs suspect			Sh. 13
AUTR2FLG (FLAGWRD 13 BIT2)	Used together to indicate astronaut-chosen KALCMANU maneuver rates (0, 0)=(BIT2, BIT1) = 0.2 deg/sec (0, 1)=0.5 deg/sec (1, 0)=2.0 deg/sec (1, 1)=10.0 deg/sec				Sh. 7
AUTR1FLG (FLAGWRD 13 BIT 1)					Sh. 7
NOTE: FLAGWRD 13 =	DAPBOOLS				

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FLAGS (CONTINUED)

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
APSFLAG (FLAGWRD 10 BIT13)	LM staged or on lunar surface	LM unstaged and not on lunar surface	Sh. 5	Sh. 5	Sh. 2, 9, 11
NJETSFLG (FLAGWRD 1 BIT15)	2 Jet RCS burn	4 Jet RCS burn	Sh. 6	Sh. 6	
NEED2FLG (FLAGWRD 0 BIT15)	Display DAP rates on FDAI needles	Check FLAGWRD 0 BIT4 for display modes		Sh. 38	Sh. 21
NEEDLFLG (FLAGWRD 0 BIT4)	Total attitude error displayed	Display DAP phase plane error	Sh. 38	Sh. 38	Sh. 21
PULSEFLG (FLAGWRD 13 BIT 15)	Minimum impulse command mode in "att hold" (V76)	Not in minimum impulse command mode (V77)	Sh. 37	Sh. 37	
SNUFFER (FLAGWORD 5 BIT 13)	U, V jets disabled during DPS burns (V65)	U, V jets enabled during DPS burns (V75)	Sh. 39	Sh. 39	
RCSFLAGS BIT13	1/ACCS has been scheduled since freshstart/restart	1/ACCS has not been scheduled since freshstart/restart	Sh. 13		Sh. 13
RCSFLAGS BIT12	Do not skip P-axis autopilot	Skip P-axis autopilot	Sh. 15		
RCSFLAGS BIT11	Doing Q-, R-axes direct rate control.	Not doing Q-, R-axes direct rate control.		Sh. 15	
RCSFLAGS BIT10	Doing P-axis direct rate control.	Not doing P-axis direct rate control.		Sh. 15	
RCSFLAGS BIT5	ACDT+C12 routine requested	ACDT+C12 routine not requested		Sh. 15	

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DOCMR Roberta M Enter	3/25/70	LUMINARY 1D	FC-3440
APPR'D Roberta M Enter	3/25/70	REV 2	SHEET 44 OF 50

FLAGS (CONTINUED)

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
RCSFLAGS BIT4	Display attitude errors on FDAI needles	Compute attitude errors for needle display			Sh. 21
RCSFLAGS BIT3	(BIT3, BIT2)= (1, 1) or (1, 0) → needler pass 1		Sh. 26	Sh. 25	Sh. 25
RCSFLAGS BIT2)	(0, 1) → needler pass 2 (0, 0) → needler pass 3	N	Sh. 25	Sh. 25	Sh. 25
RCSFLAGS BIT1	Used to alternate " tacks" for failed jet translation policies			Sh. 15	

DISPLAYS

Verb-Noun	Type of Display	Description of Each Register	Where Executed
V01N46	Flashing	R1: Octal only R2: blank R3: blank	Sh. 3
V06N47	Flashing	R1: xxxxx. lbs LM weight R2: xxxxx. lbs CSM weight R3: blank	Sh. 8
V06N48	Flashing	R1: xxx. xx deg gimbal pitch trim R2: xxx. xx deg gimbal roll trim R3: blank	Sh. 11
V50N48	Flashing	See V06N48	Sh. 12

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ERASABLE LOCATIONS USED

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scaling
-RATEDB	Rate deadband	deg/sec	rev/sec	2^{-17}
AK	Desired setting of FDAI error needles-yaw	deg/sec (or deg)	rev/sec (or revs)	2^{-3} (or 2^{-1})
AK +1 (=AK1)	Desired setting of FDAI error needles-pitch	deg/sec (or deg)	rev/sec (or revs)	2^{-3} (or 2^{-1})
AK +2 (=AK2)	Desired setting of FDAI error needles-roll	deg/sec (or deg)	rev/sec (or revs)	2^{-3} (or 2^{-1})
ALLOWGTS	Binary switch to allow entry into gimbal trim system attitude control law if other conditions are satisfied			2^{+14}
ALPHAQ ALPHAR }	Storage for most significant halves of AOSQ and AOSR for down telemetry	deg/sec^2	rev/sec^2	2^{-2}
$AOSQ_D$ $AOSR_D$ }	Disturbing acceleration due to thrust vector, c. g. offset, or other external torques	deg/sec^2	rev/sec^2	2^{-2}

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LM DAP Interface and Service Routines

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ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scaling
AOSQTERM AOSRTERM	Addition to vehicle rate that would be added during one 100 msec period as a result of disturbing accelerations	deg/sec	rev/sec	2^{-3}
CDUXD CDUYD CDUZD	Autopilot reference attitude	deg	rev	2^{-1}
COTROLER	Controls access to Q, R-axis gimbal trim system			2^{+14}
CSMMASS	CSM mass	kg	kg	2^{+16}
DB	Deadband	deg	rev	2^{-3}
DELCDUX DELCDUY DELCDUZ	Δ attitude commands	deg	rev	2^{-1}
DELPEROR DELQEROR DELREROR	Attitude error lag angles	deg	rev	2^{-1}

ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scaling
EDRIVEX EDRIVEY EDRIVEZ	Present setting of FDAI error needles	deg	rev	$2^{-1} \times 10$
LEMMASS	LM mass	kg	kg	2^{+16}
MASS	Vehicle mass	kg	kg	2^{+16}
NEGUQ NEGUR	Switches to indicate whether DPS gimbal drives should be driven			2^{+14} 2^{+14}
NEXTP NEXTQ NEXTR	Translation jets waiting to go on			2^{+14} 2^{+14} 2^{+14}
NPTRAPS NQTRAPS NRTRAPS	Threshold counter variables in LM DAP state estimator X-axis Y-axis Z-axis			2^{+14} 2^{+14} 2^{+14}
NXT6ADR	Indicates which set of jets is to be turned off at next TIME6 interrupt			2^{+14}

ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scaling
OLDXFORP	"old" CDUX register	deg	rev	2^{-1}
OLDYFORP	"old" CDUY register	deg	rev	2^{-1}
OLDZFORQ	"old" CDUZ register	deg	rev	2^{-1}
OMEGAPD OMEGAQD OMEGARD	Commanded rates	deg/sec deg/sec deg/sec	rev/sec rev/sec rev/sec	2^{-3} 2^{-3} 2^{-3}
OMEGAU_D	Temporary storage			
PJETCTR	Docked jet inhibition counter	decisec	decisec	2^{+14}
QGIMTIMR	Gimbal drive time	decisec	decisec	2^{+14}
RADDEL	Δ time to the next TS tick	csec	csec	2^{9}
RADTIME	Negative of time of radar reading	csec	csec	2^{9}
RGIMTIMR	Gimbal drive time	decisec	decisec	2^{+14}
STIKSENS	Stick rate	deg/sec	rev/sec/(RHC count)^2	2^{-15}
TIME6	Δ time, "now" to 1st event	csec	csec	2^{+10}

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ERASABLE LOCATIONS USED (CONTINUED)

AGC Tag	Meaning	Engineering Units	AGC Units	AGC Scaling
TJP	Jet fire times	csec	csec	2^{+10}
TJU		csec	csec	2^{+10}
TJV		csec	csec	2^{+10}
TRAPEDP	Transient rate error	deg/sec	rev/sec	2^{-3}
TRAPEDQ		deg/sec	rev/sec	2^{-3}
TRAPEDR		deg/sec	rev/sec	2^{-3}
T6FURTHA	Time interval after the next TIME6 interval when jets indicated in T6NEXT +1 and T6FURTHA +1 are to be cut off	csec	csec	2^{+10}
T6NEXT		csec	csec	2^{+10}
T6FURTHA +1	Which jets are to be cut off at various intervals after the next TIME6 interrupt			2^{+14}
T6NEXT +1				2^{+14}
UJETCTR VJETCTR }	Docked jet inhibition counters	decisec	decisec	2^{+14}

PROGRAM CONSTANTS

AGC Tag	Meaning	Valve	AGC Scaling
-DTSCALR	-5.9375 msec in scalar	77754_8	csec @ 2^9
90MSCALR	90 msec in scalar	440_8	csec @ 2^9

LM RCS DAP

PAXIS	Sh. 2
CHKVISFZ	Sh. 21
PJETSLEC	Sh. 40
QRAXIS	Sh. 43
SPSRCS	Sh. 80
TJETLAW	Sh. 86

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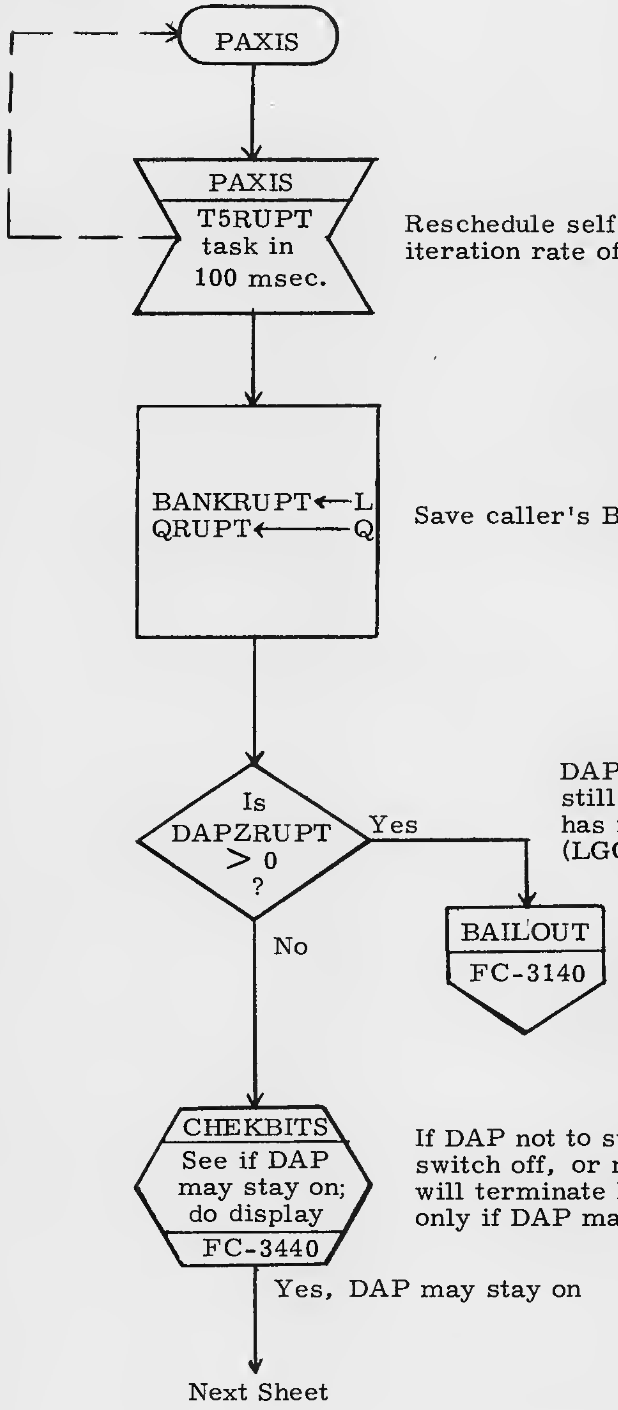
Entry to LM DAP



Reschedule self in 100 msec. to maintain DAP iteration rate of 10 per second

Save caller's BBANK and Q registers

DAPZRUPT is>0 only if jask is still running, which means the DAP has interrupted itself--disaster! (LGC itself is probably in trouble)

Alarm code 32000: "DAP still in progress at next TIME5 rupt" and then do restart.

If DAP not to stay on (IMU no good, mode switch off, or not in PGNCS), this routine will terminate DAP. It returns to caller only if DAP may stay on.

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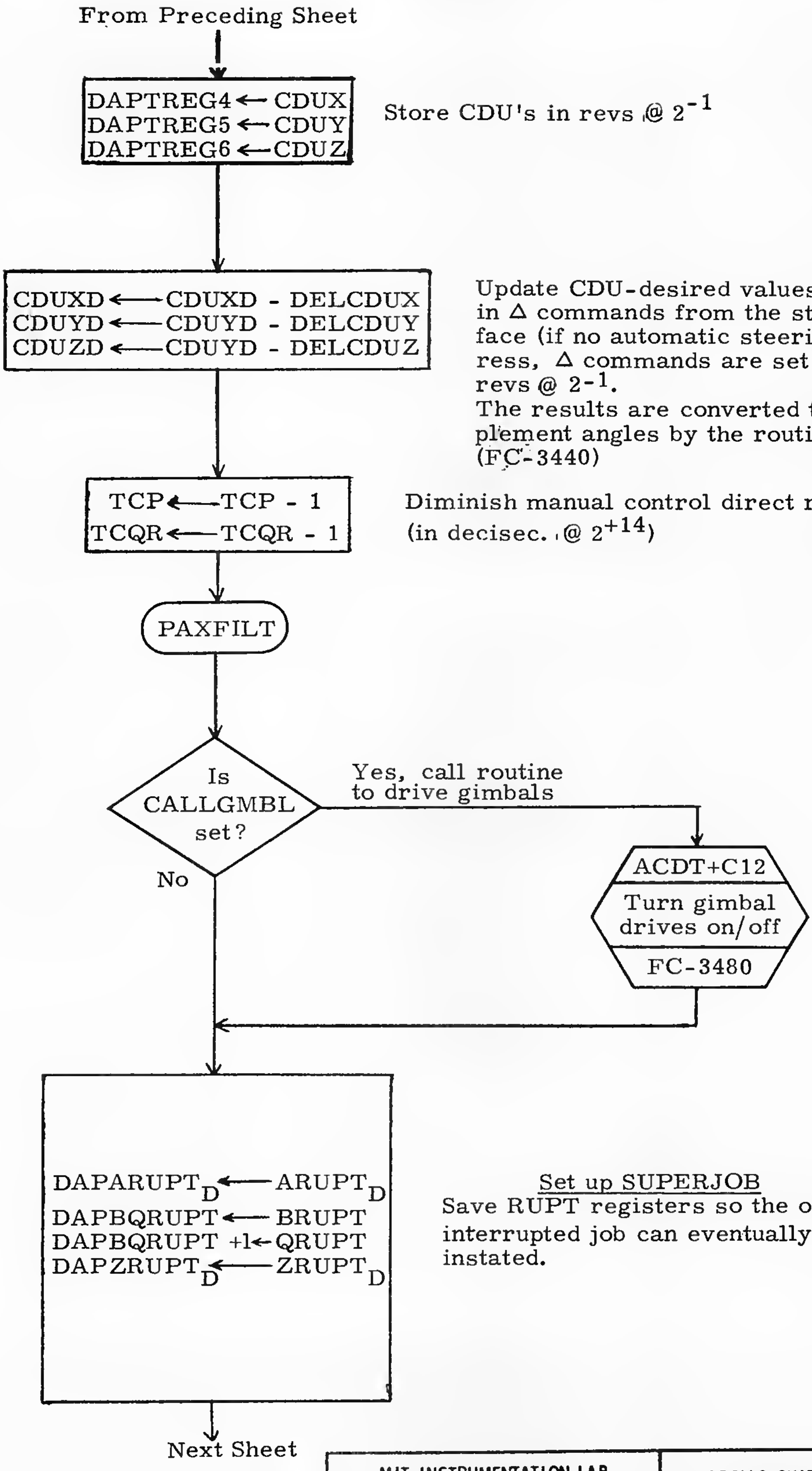

Store CDU's in revs @ 2^{-1}

Update CDU-desired values by adding in Δ commands from the steering interface (if no automatic steering in progress, Δ commands are set to zero) in revs @ 2^{-1}.
The results are converted to 2's complement angles by the routine 1STOTWOS (FC-3440)

Diminish manual control direct rate timers (in decisec. @ 2^{+14})

Set up SUPERJOB
Save RUPT registers so the original interrupted job can eventually be reinstated.

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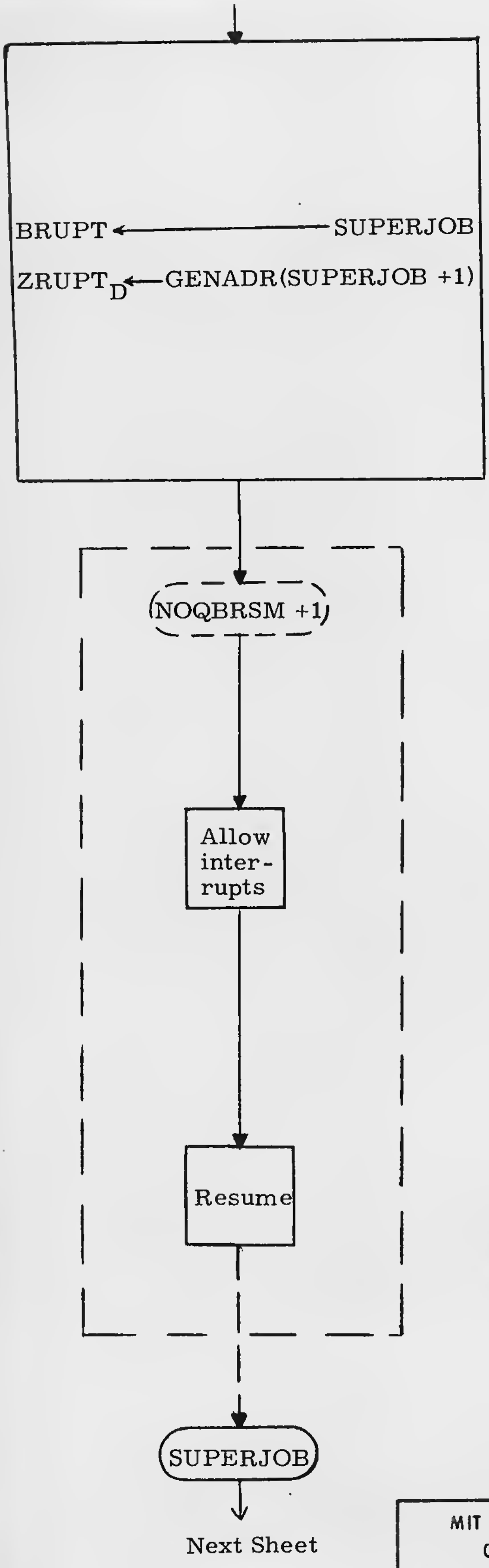

Now set up RUPT registers so that control will go to SUPERJOB when RESUME is executed.
C(SUPERJOB) = "TCF RATELOOP", the first instruction to be executed following the RESUME.

Location of instruction to follow

Leaving interrupt mode

Causes BRUPT to go to the hardware B register for execution and ZRUPT to go to Z. Result is as if interrupt had "resumed" at location SUPERJOB

Beginning of the "jask"

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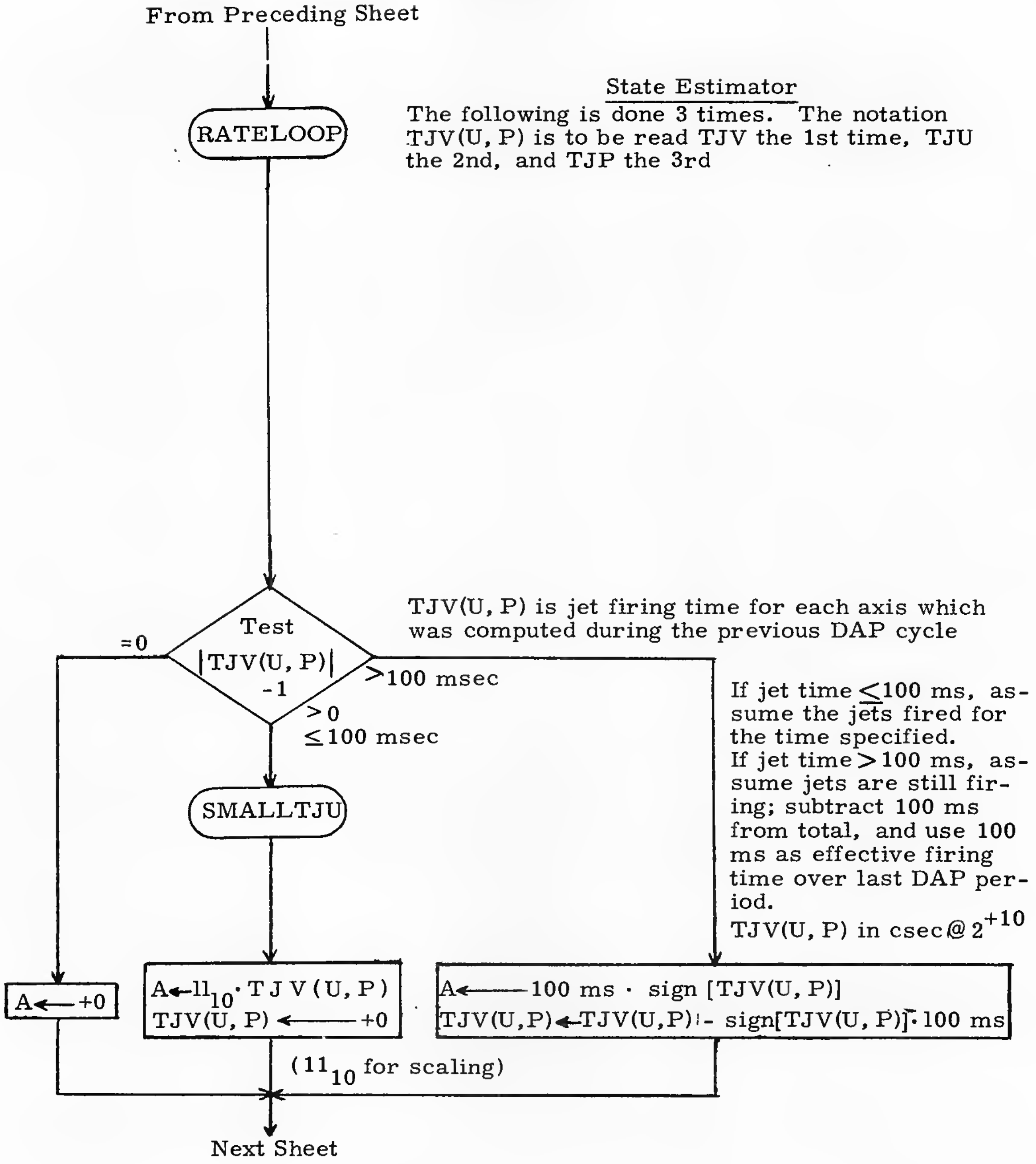

State Estimator

The following is done 3 times. The notation TJV(U, P) is to be read TJV the 1st time, TJU the 2nd, and TJP the 3rd

TJV(U, P) is jet firing time for each axis which was computed during the previous DAP cycle

If jet time ≤100 ms, assume the jets fired for the time specified.
If jet time >100 ms, assume jets are still firing; subtract 100 ms from total, and use 100 ms as effective firing time over last DAP period.
TJV(U, P) in csec @ 2^{+10}

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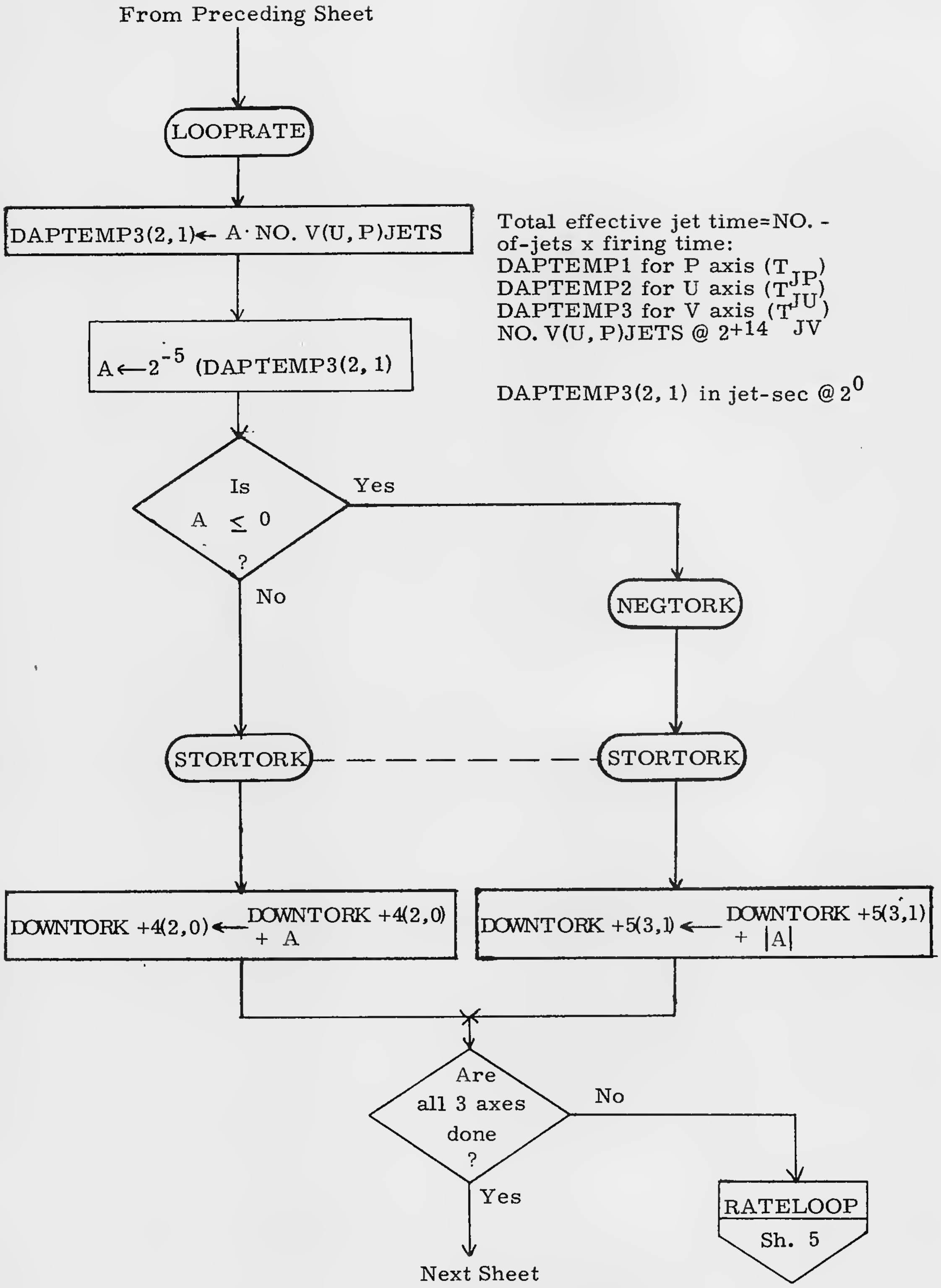

Total effective jet time=NO. -of-jets x firing time:
DAPTEMP1 for P axis (T_{JP})
DAPTEMP2 for U axis (T_{JU})
DAPTEMP3 for V axis (T_{JV})
NO. V(U, P)JETS @ 2^{+14}

DAPTEMP3(2, 1) in jet-sec @ 2^0

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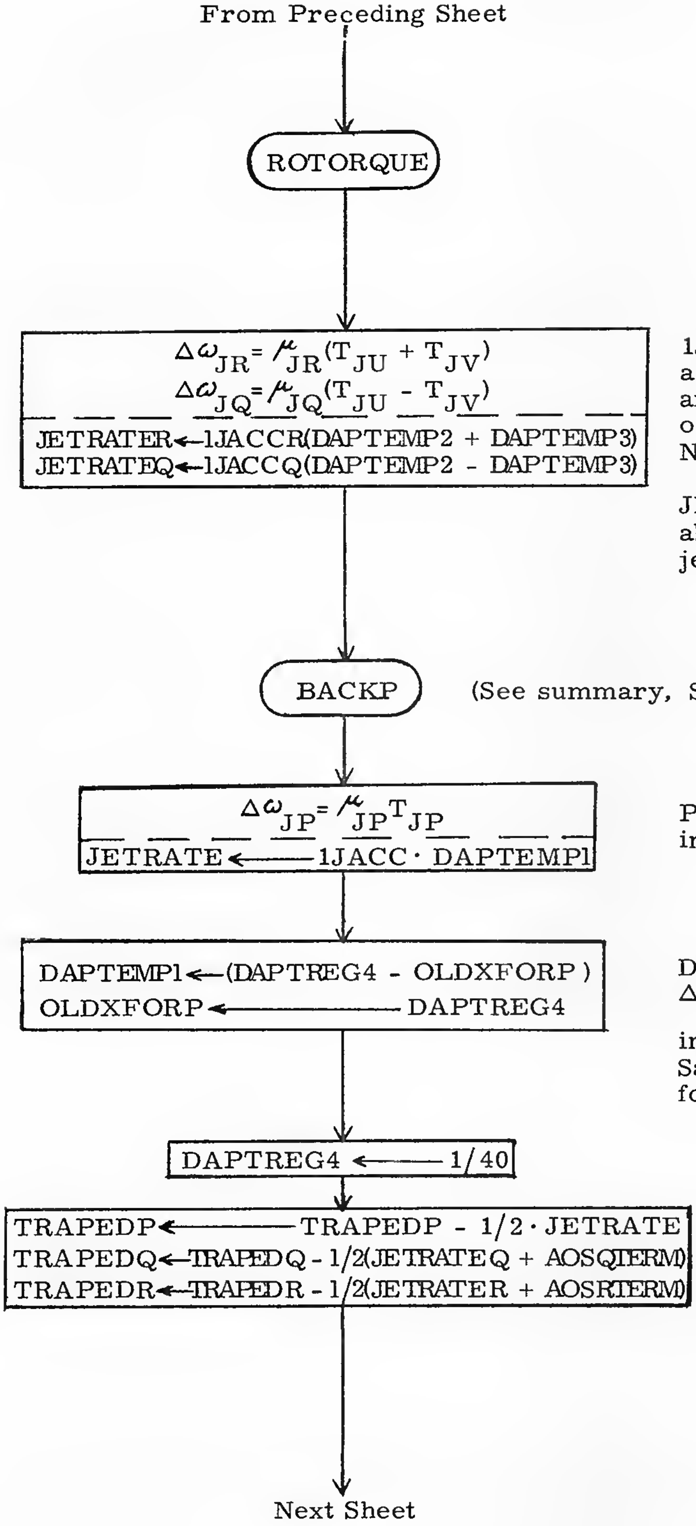

1JACCR(Q) is the effective acceleration about the R(Q) axis caused by a single jet on the U or V axis.
Note that a +U jet → +Q and +R
but a +V jet → -Q and +R
JETRATER(Q)=predicted Δ rate about the R(Q) axis caused by jet firings in rev/sec @2^{-3}

(See summary, Sh. 9)

Predicted Δ rate in the P axis in rev/sec @ 2^{-3}

DAPTREG4 contains CDUX
$\Delta CDUX = CDUX_n - CDUX_{n-1}$
in rev @ 2^{-1}
Save CDUX (outer gimbal angle) for next time

Add in average rate change due to jet firing and (for Q and R axes) due to AOS (in rev/sec @ 2^{-3}).
Average rate change = 1/2 Δrate (in rev/sec @ 2^{-3})

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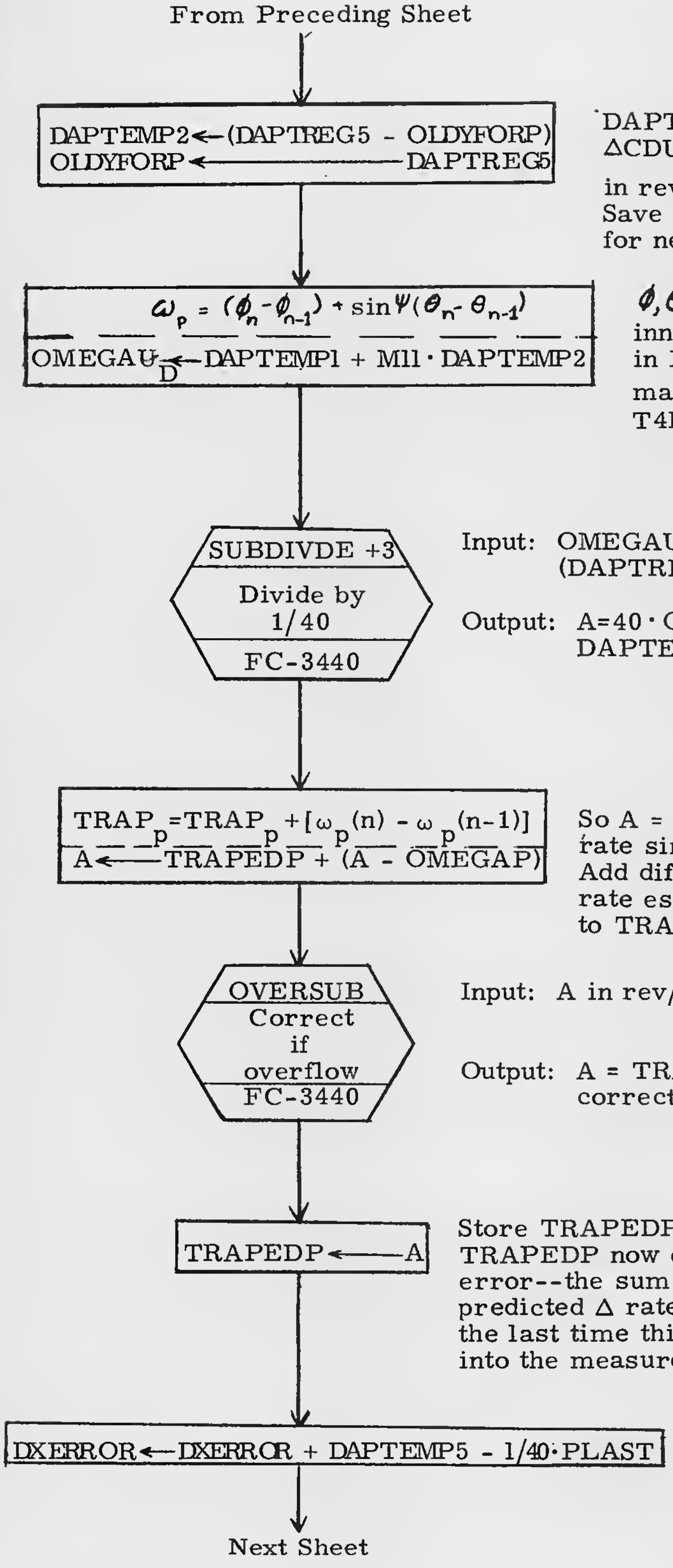

DAPTREG5 contains CDUY
$\Delta CDUY = CDUY_n - CDUY_{n-1}$
in revs @ 2^{-1}
Save CDUY (inner gimbal angle) for next time

$\phi, \theta, \psi \equiv$ CDUX, CDUY, CDUZ $\equiv$ outer, inner, middle measured Δ attitude in P axis (M_{11} is element of GP matrix which is maintained by a T4RUPT routine.)

Input: OMEGAU = Δ attitude in revs @ 2^{-1}
(DAPTREG4 = 1/40)

Output: A = 40 · OMEGAU
DAPTEMP5 = OMEGAU

So A = Measured average P-axis rate since last DAP pass in rev/sec @ 2^{-3}. Add difference between "A" and P-axis rate estimated on last pass (OMEGAP) to TRAPEDP

Input: A in rev/sec @ 2^{-3}

Output: A = TRAPEDP in rev/sec @ 2^{-3} corrected for overflow

Store TRAPEDP in rev/sec @ 2^{3}
TRAPEDP now contains accumulated rate error--the sum of measured Δ rate vs. predicted Δ rate for each DAP pass since the last time this error was incorporated into the measurement.

Manual mode X attitude error in revs @ 2^{-1}

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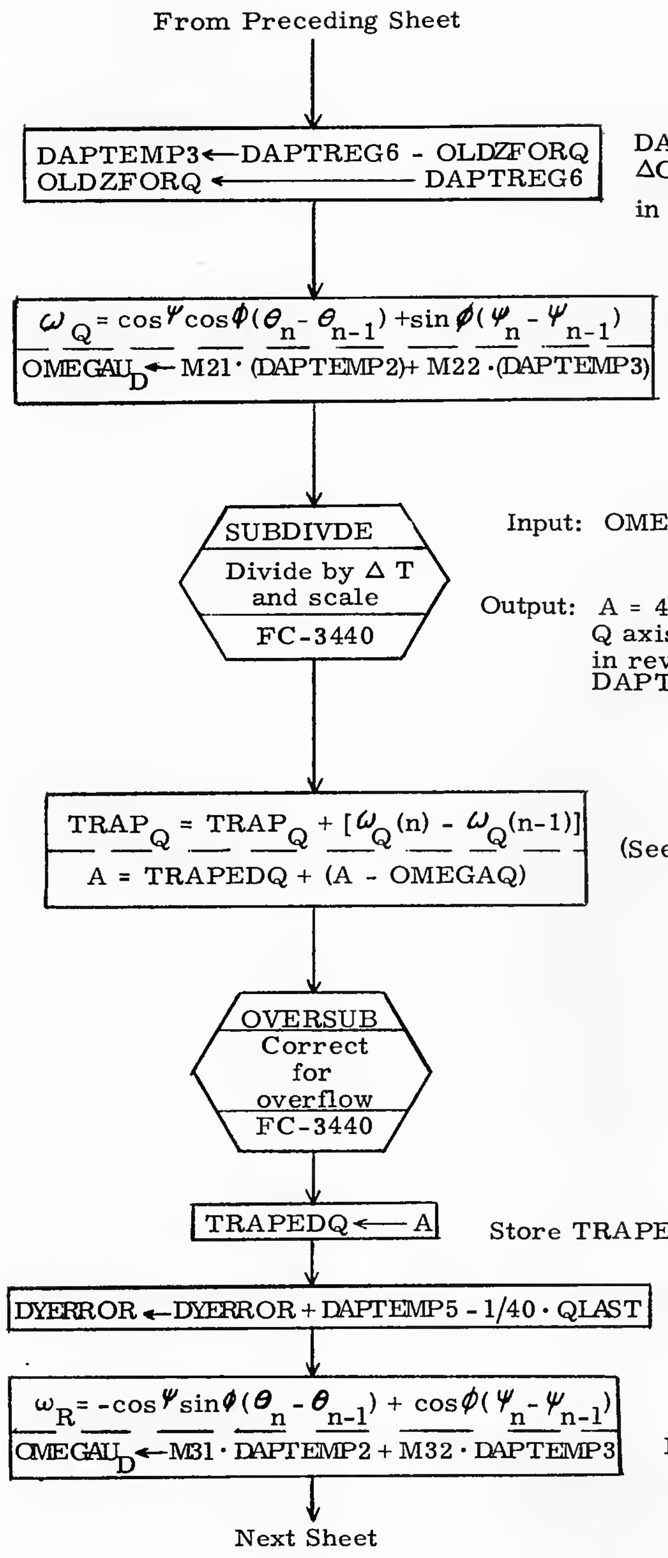

DAPTREG6 contains CDUZ
$\Delta CDUZ = (CDUZ_n - CDUZ_{n-1})$ angle in revs @ 2^{-1}

Measured Δ attitude, Q axis in revs @ 2^{-1}

Input: OMEGAU in revs @ 2^{-1}

Output: A = 40 · OMEGAU = Measured average Q axis rate since last DAP pass in rev/sec @ 2^{-3}
DAPTEMP5 = OMEGAU

(See comments for TRAPEDP)

Store TRAPEDQ in rev/sec @ 2^{-3}

Manual mode Y attitude error in revs @ 2^{-1}

Measured Δ attitude, R axis, in revs @ 2^{-1}

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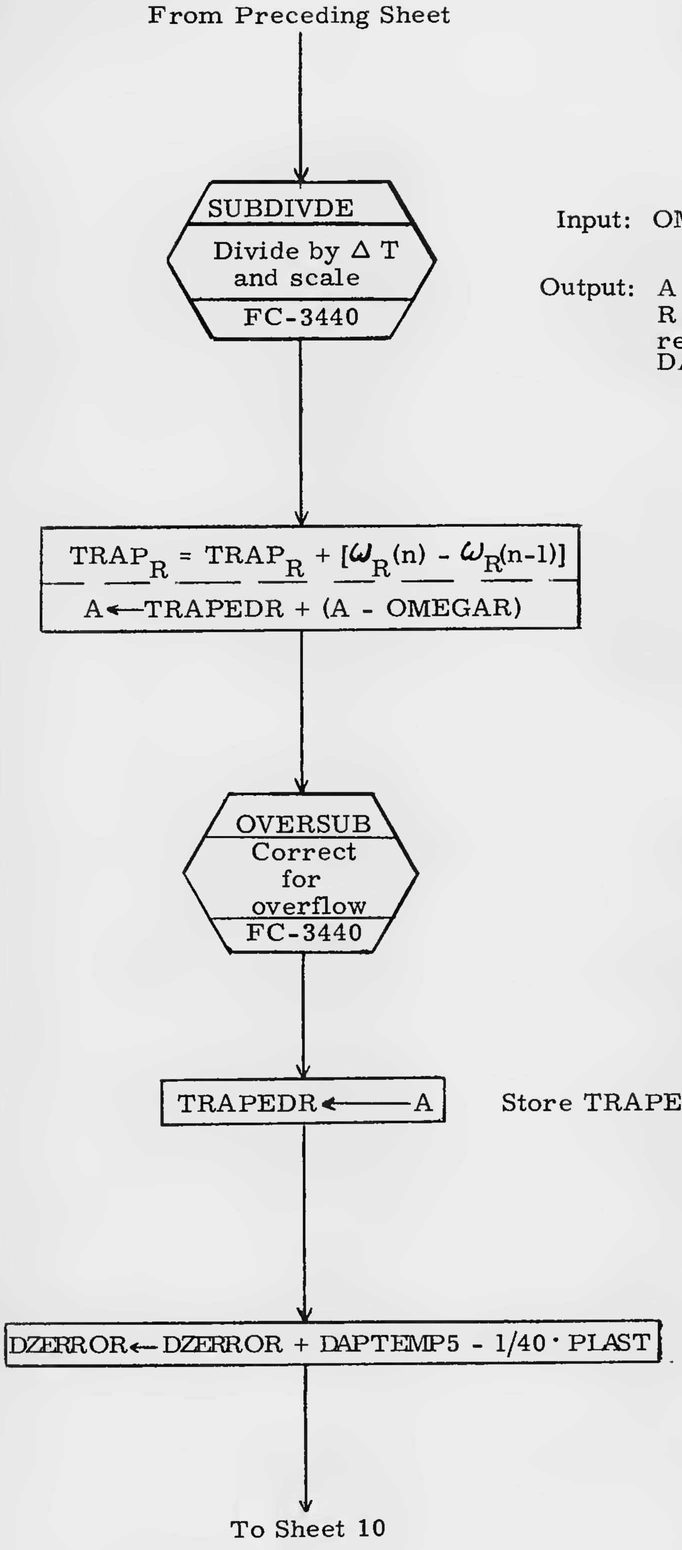

Input: OMEGAU in revs@ 2^{-1}

Output: A = 40· OMEGAU = Measured average R axis rate since last DAP pass in rev/sec@ 2^{-3}
DAPTEMP5 = OMEGAU

Store TRAPEDR in rev/sec @ 2^{-3}

Manual mode Z attitude error in rev @ 2^{-1}

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In summary:

$$\begin{bmatrix} TRAP_P \\ TRAP_Q \\ TRAP_R \end{bmatrix} = \begin{bmatrix} TRAP_P \\ TRAP_Q \\ TRAP_R \end{bmatrix} + \left[\frac{\overset{*}{GP}}{\Delta T} \begin{bmatrix} \Delta\phi \\ \Delta\theta \\ \Delta\Psi \end{bmatrix} - \begin{bmatrix} \omega_P \\ \omega_Q \\ \omega_R \end{bmatrix} \right] - \left[\frac{1}{2} \begin{bmatrix} \Delta\omega_{JP} \\ \Delta\omega_{JQ} \\ \Delta\omega_{JR} \end{bmatrix} + \frac{1}{2} \begin{bmatrix} 0 \\ \mu_{GQ} \\ \mu_{GR} \end{bmatrix} \right]$$

Where $\overset{*}{GP}$ = gimbal rates to pilot rates transformation matrix

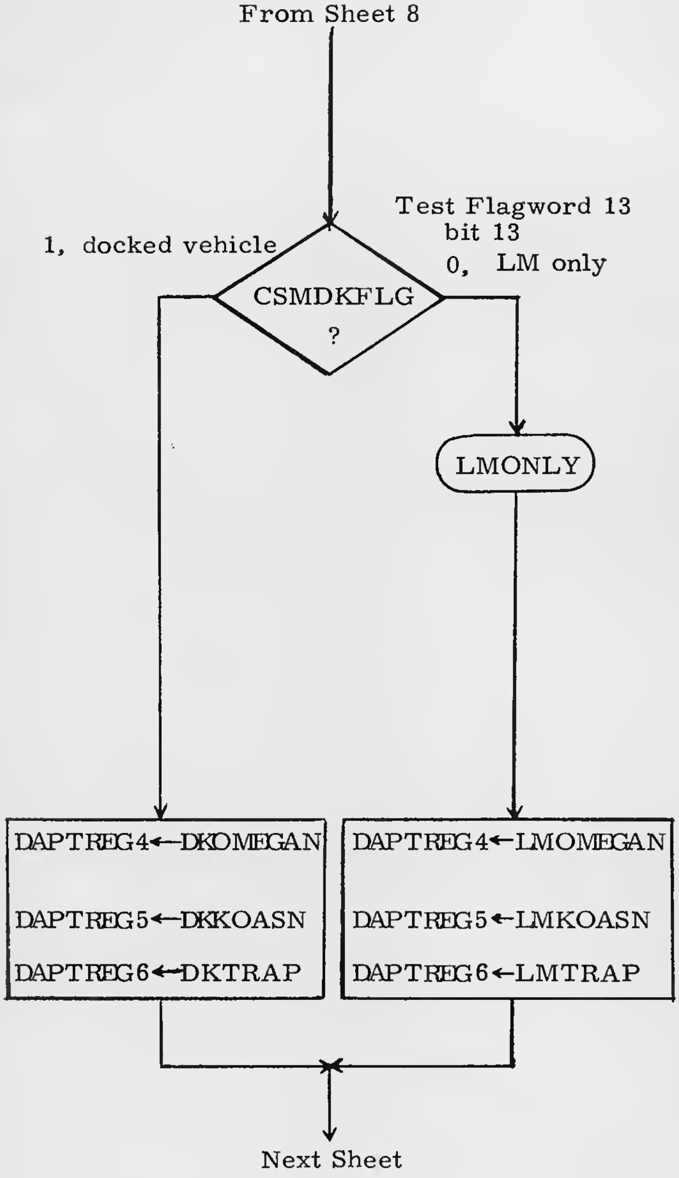
$\overline{\omega}$ = old rate estimate

$\overline{\Delta\omega_J}$ = Δ rate due to jets

$\overline{\mu_G}$ = Δ rate due to thrust offset

So that trap is the accumulated error between observed and predicted attitude rates.

$\Delta T = .1$ sec = 1 DAP pass



<u>Get pad loaded state estimator gains</u>

All pad loads are set to a nominal valve in Fresh Start as indicated

Gain for omega: nominal value - dec 10 if docked, 0 otherwise
Gain for alpha: nominally dec 60
} $@2^{+14}$

Limit for trap overflow- nominally - 1.4 (in rev/sec $@2^{-3}$)

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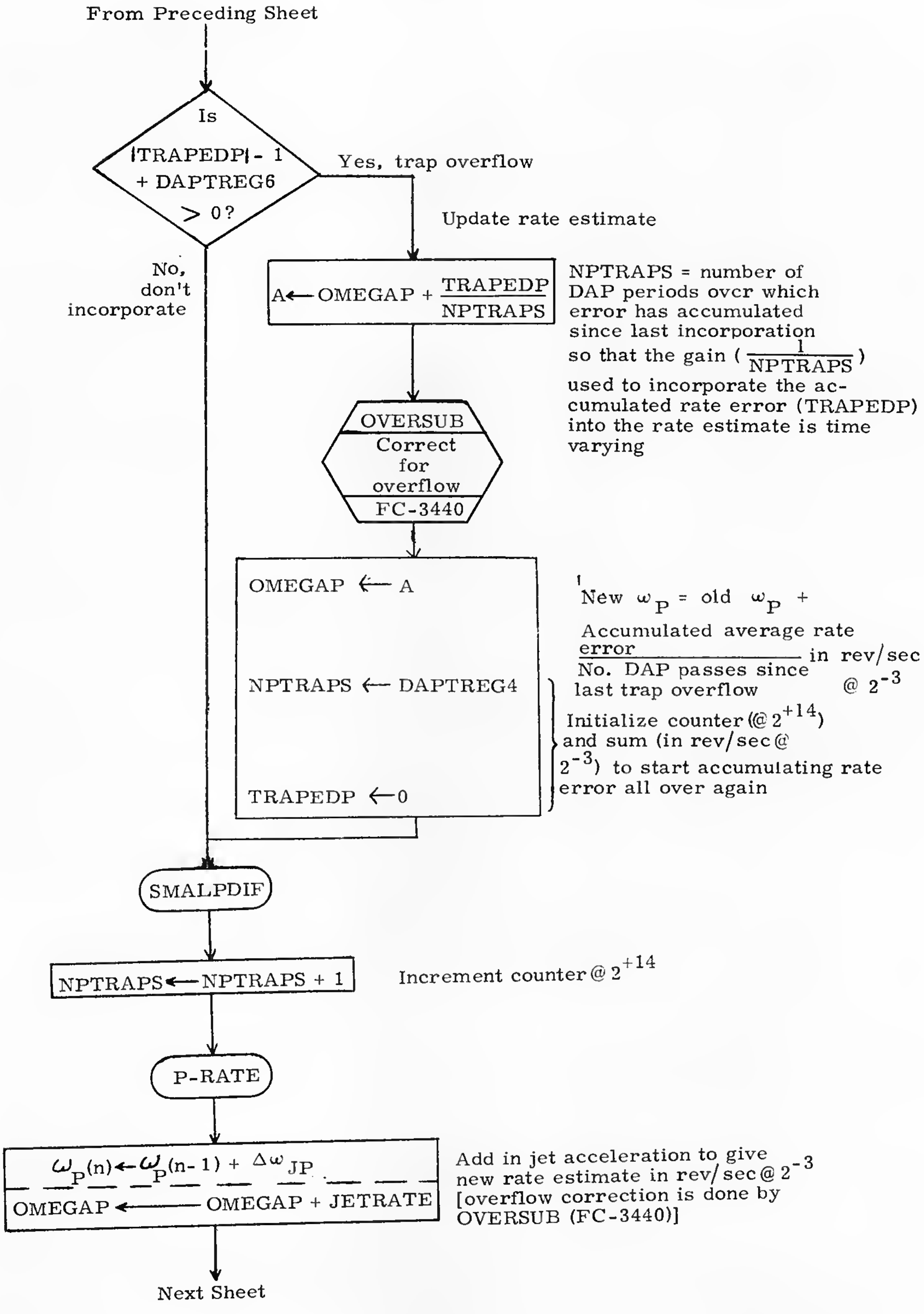

NPTRAPS = number of DAP periods ovcr which error has accumulated since last incorporation so that the gain ($\frac{1}{NPTRAPS}$) used to incorporate the accumulated rate error (TRAPEDP) into the rate estimate is time varying

New ω_P = old ω_P + $\frac{\text{Accumulated average rate error}}{\text{No. DAP passes since last trap overflow}}$ in rev/sec @ 2^{-3}

Initialize counter (@ 2^{+14}) and sum (in rev/sec @ 2^{-3}) to start accumulating rate error all over again

Increment counter @ 2^{+14}

Add in jet acceleration to give new rate estimate in rev/sec @ 2^{-3} [overflow correction is done by OVERSUB (FC-3440)]

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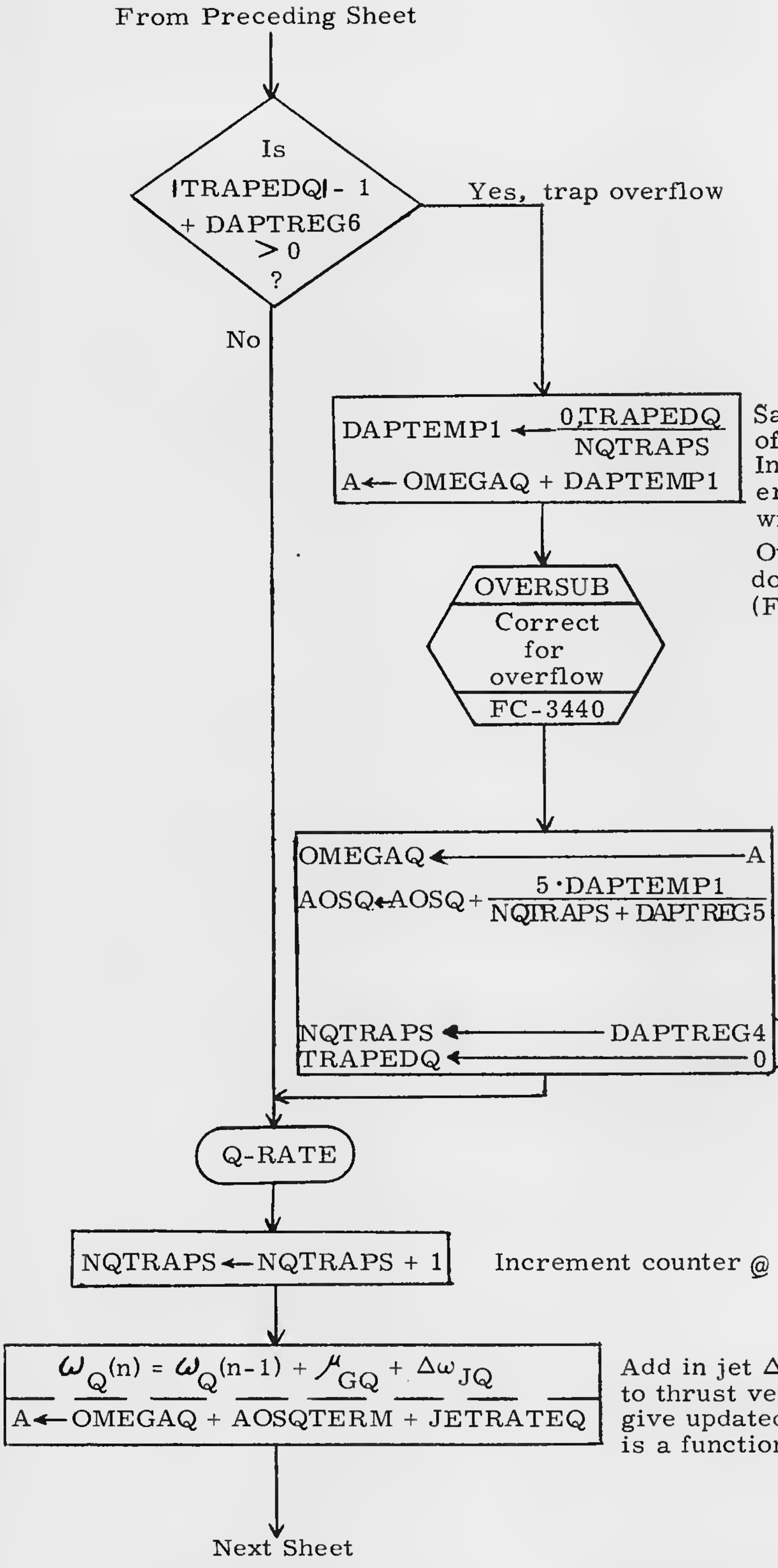

Save rate correction for offset estimator. Incorporate average rate error into rate estimate with time varying gain.

Overflow correction is done by OVERSUB (FC-3440)

Incorporate average rate error into angular offset estimate with a time-dependent gain (in rev/sec^2 @ 2^{-2})

Initialize error accumulation again

Increment counter @ 2^{+14}

Add in jet Δ rate and Δ rate due to thrust vector - c.g. offset to give updated Q-axis. AOSQTERM is a function of AOS

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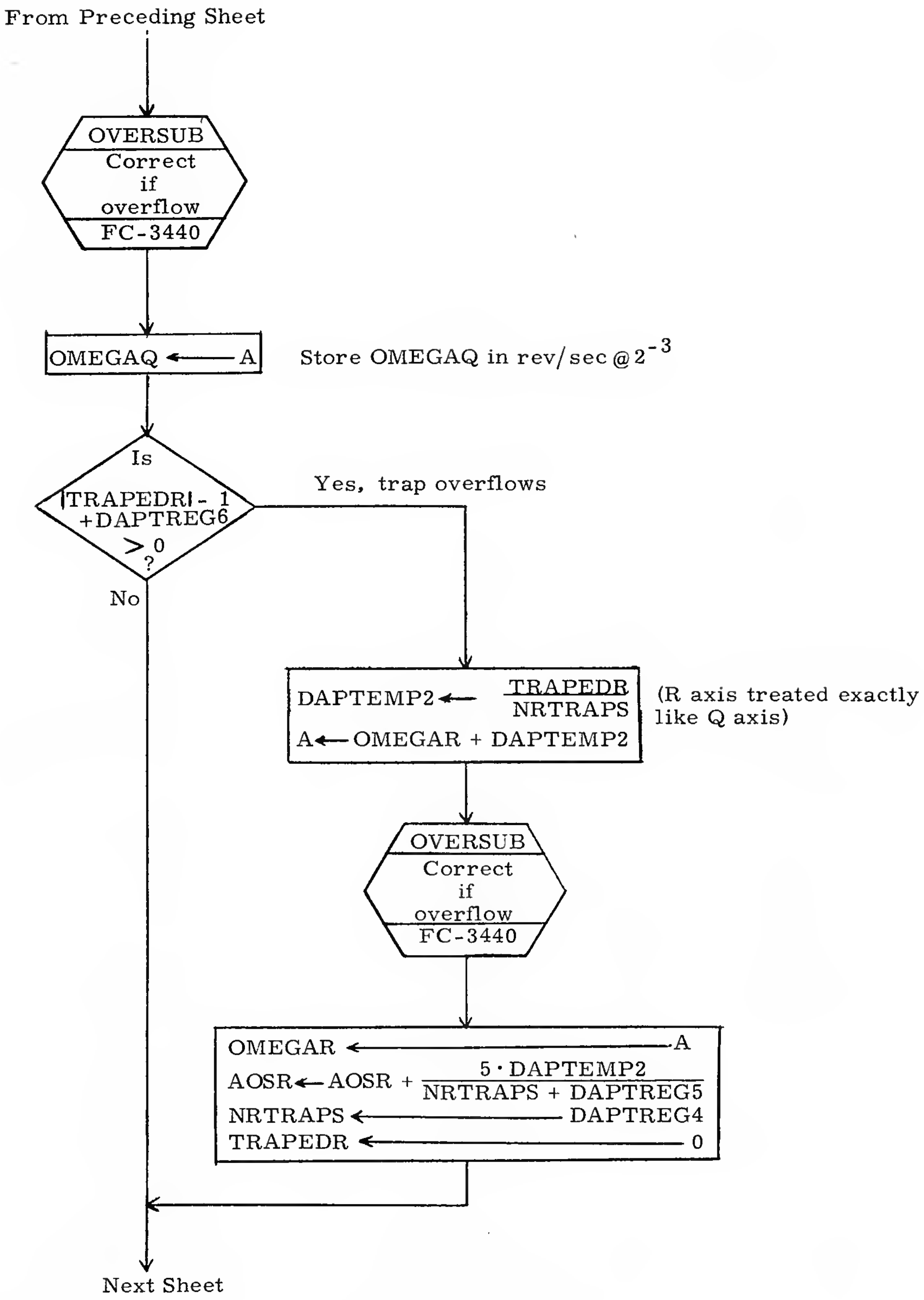

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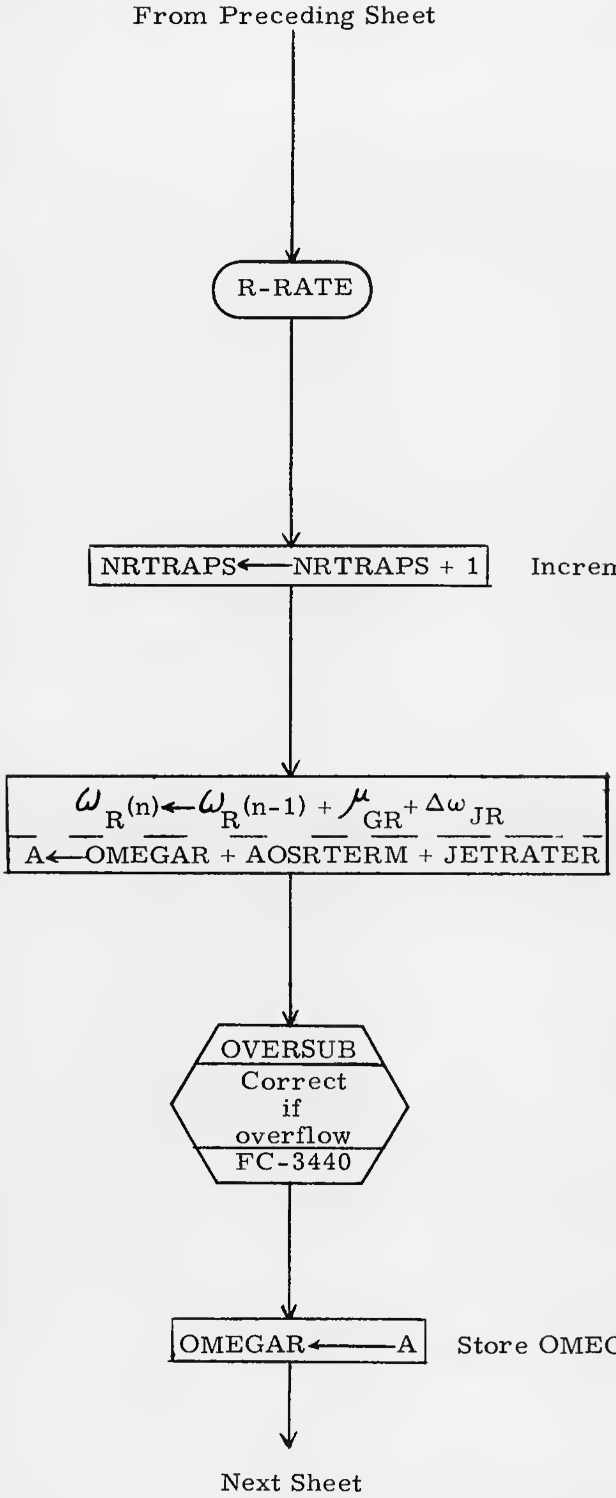

Increment counter @ 2^{+14}

in rev/sec @ 2^{-3}

Store OMEGAR in rev/sec @ 2^{-3}

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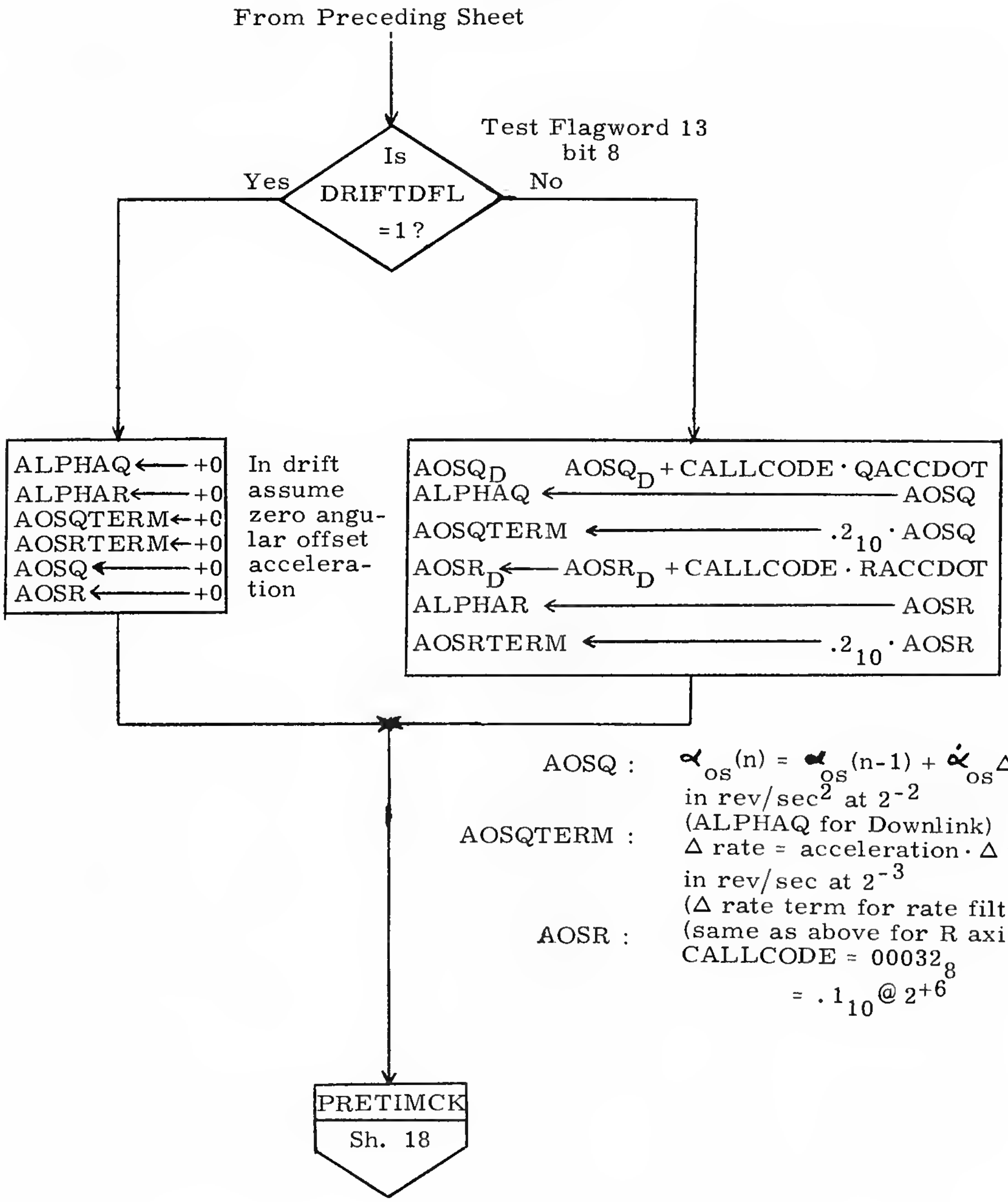

AOSQ : $\alpha_{os}(n) = \alpha_{os}(n-1) + \dot{\alpha}_{os}\Delta T$
in rev/sec^2 at 2^{-2}
(ALPHAQ for Downlink)

AOSQTERM : Δ rate = acceleration $\cdot$ Δ time
in rev/sec at 2^{-3}
(Δ rate term for rate filter)

AOSR : (same as above for R axis)

CALLCODE = 00032_8
$= .1_{10} @ 2^{+6}$

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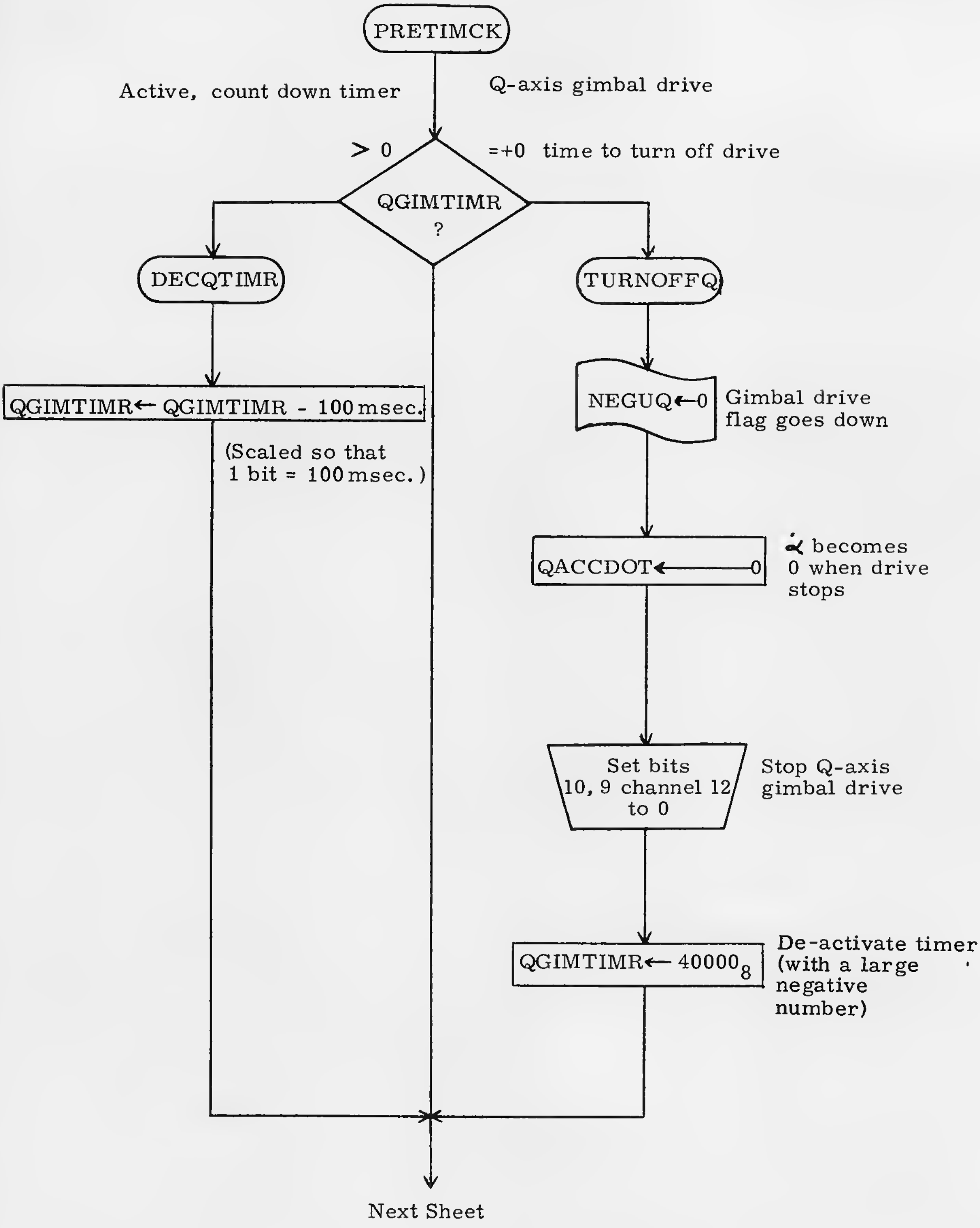

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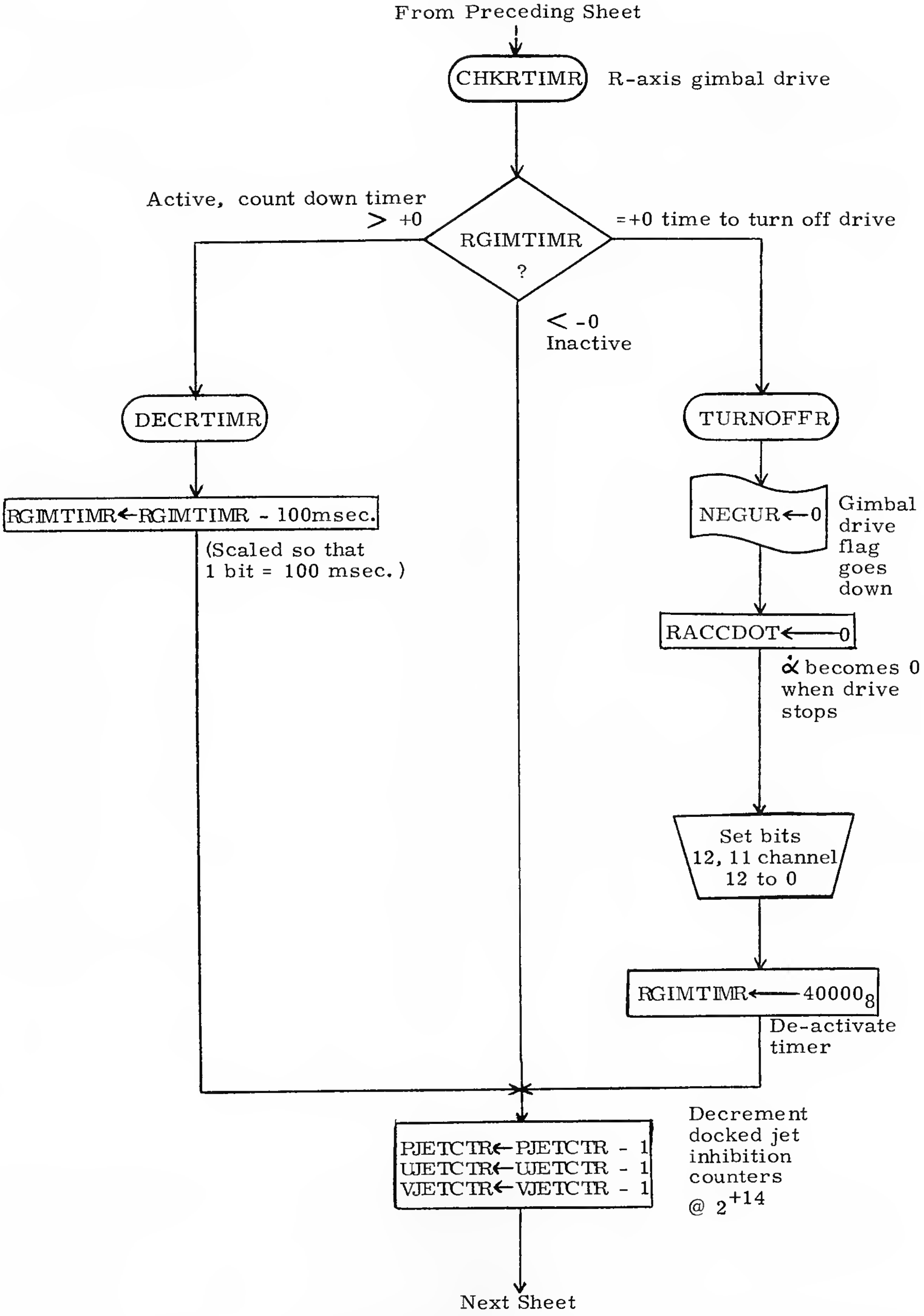

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LM RCS DAP

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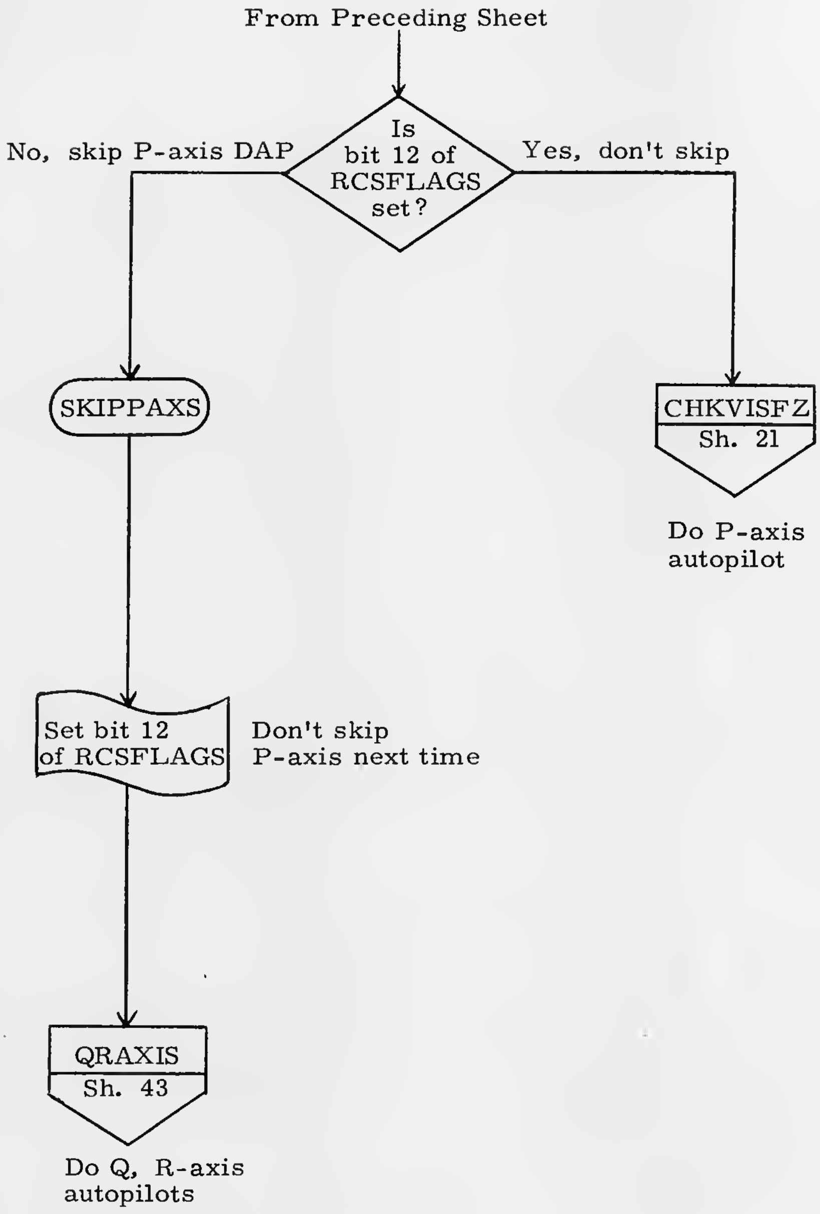

Skip logic: bit 12 RCSFLAGS clear if and only if:

1. the autopilot fired P-axis jets the last time

and

2. the firing time was ≤ 150 msec.

Otherwise, bit 12 is set and the P-axis DAP is done.

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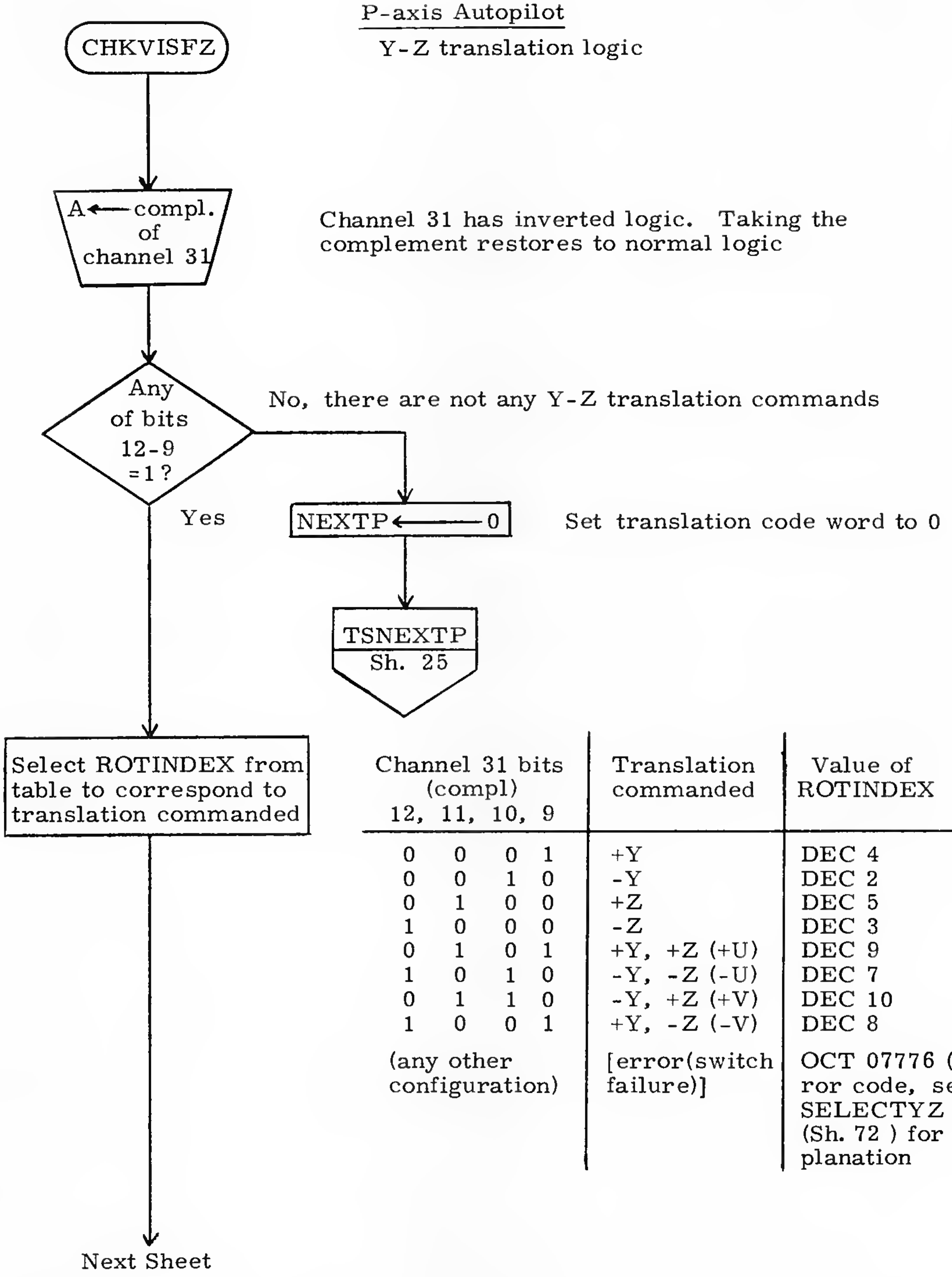
P-axis Autopilot

Y-Z translation logic



Channel 31 has inverted logic. Taking the complement restores to normal logic

Set translation code word to 0

Channel 31 bits (compl) 12, 11, 10, 9	Translation commanded	Value of ROTINDEX
0 0 0 1	+Y	DEC 4
0 0 1 0	-Y	DEC 2
0 1 0 0	+Z	DEC 5
1 0 0 0	-Z	DEC 3
0 1 0 1	+Y, +Z (+U)	DEC 9
1 0 1 0	-Y, -Z (-U)	DEC 7
0 1 1 0	-Y, +Z (+V)	DEC 10
1 0 0 1	+Y, -Z (-V)	DEC 8
(any other configuration)	[error(switch failure)]	OCT 07776 (error code, see SELECTYZ (Sh. 72) for explanation

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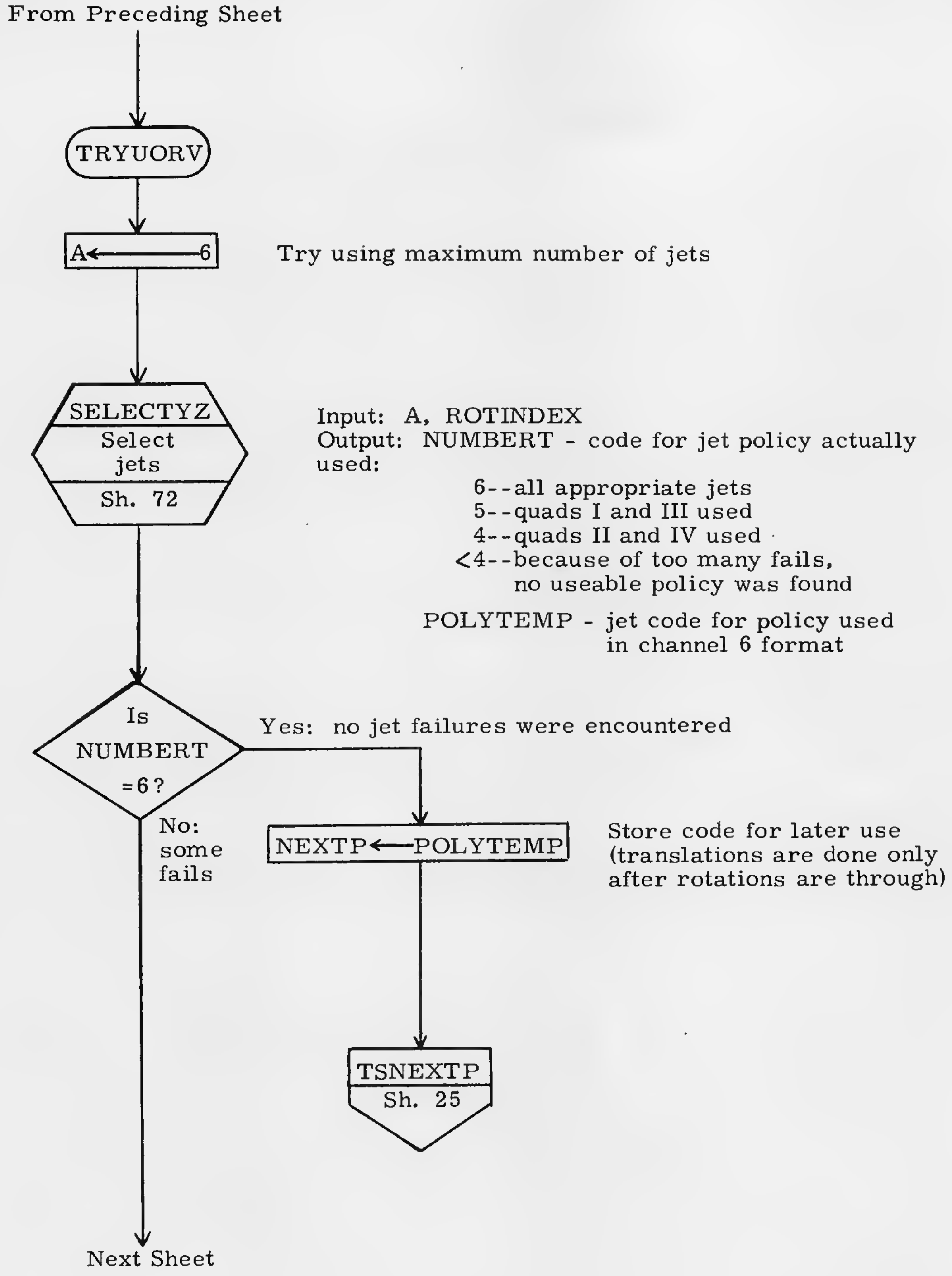

Try using maximum number of jets

Input: A, ROTINDEX
Output: NUMBERT - code for jet policy actually used:

6--all appropriate jets
5--quads I and III used
4--quads II and IV used
<4--because of too many fails, no useable policy was found

POLYTEMP - jet code for policy used in channel 6 format

Store code for later use (translations are done only after rotations are through)

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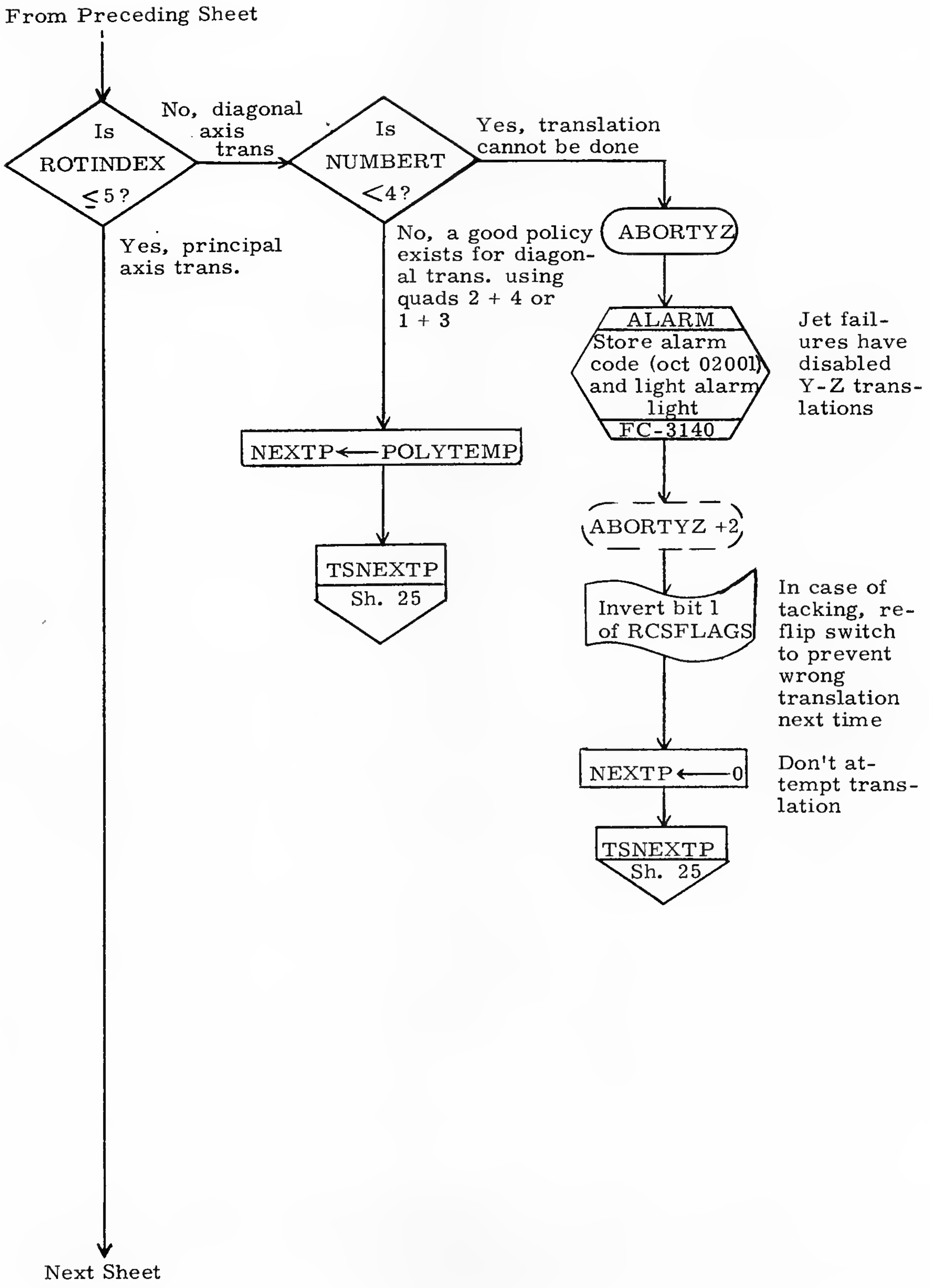

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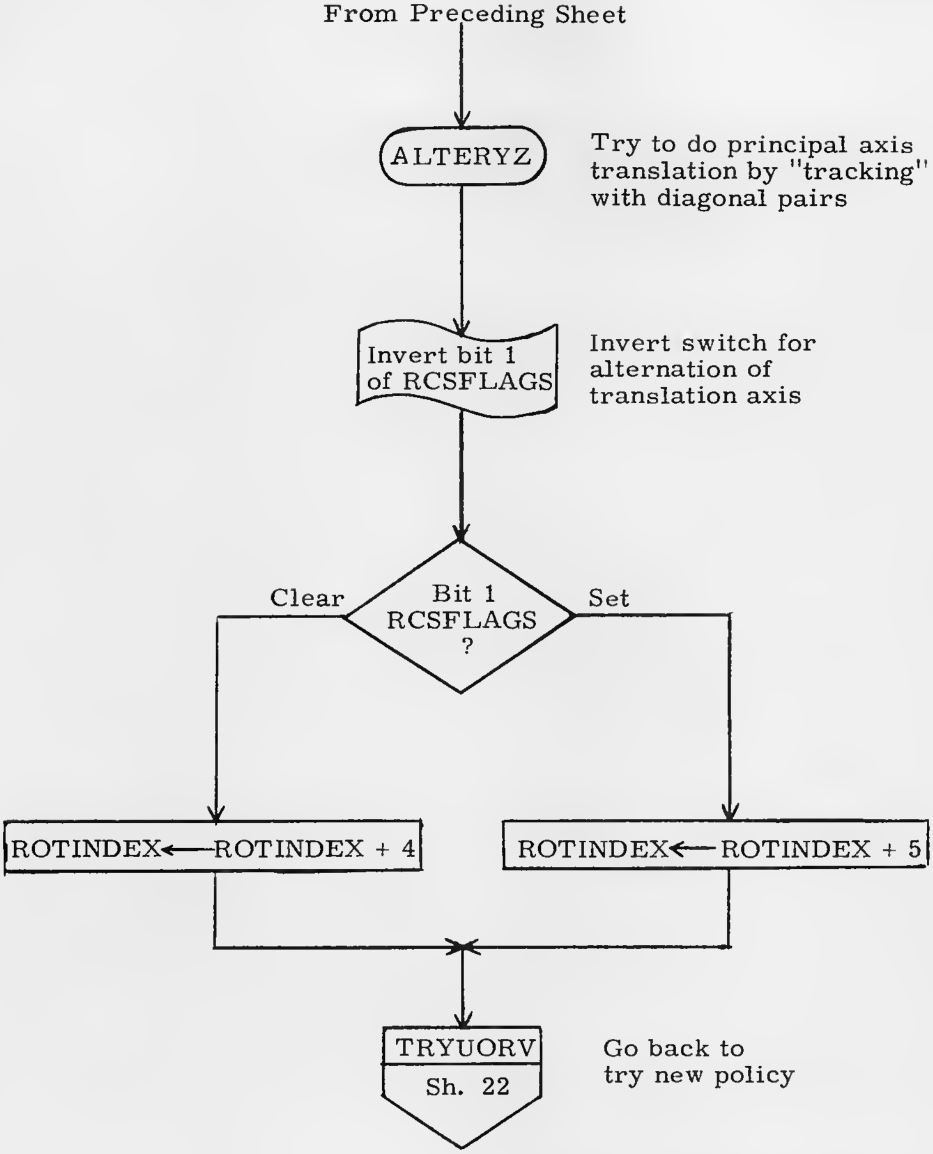

Try to do principal axis translation by "tracking" with diagonal pairs

Invert switch for alternation of translation axis

Go back to try new policy

If +Y request	(ROTINDEX = 4)
do -V	(ROTINDEX = 8)
then +U	(ROTINDEX = 9)
If -Y request	(ROTINDEX = 2)
do +V	(ROTINDEX = 6)
then -U	(ROTINDEX = 7)
If +Z request	(ROTINDEX = 5)
do +U	(ROTINDEX = 9)
then +V	(ROTINDEX = 10)
If -Z request	(ROTINDEX = 3)
do -U	(ROTINDEX = 7)
then -V	(ROTINDEX = 8)

(The coding for select YZ accepts a value of 6 for ROTINDEX to mean +V to implement this)

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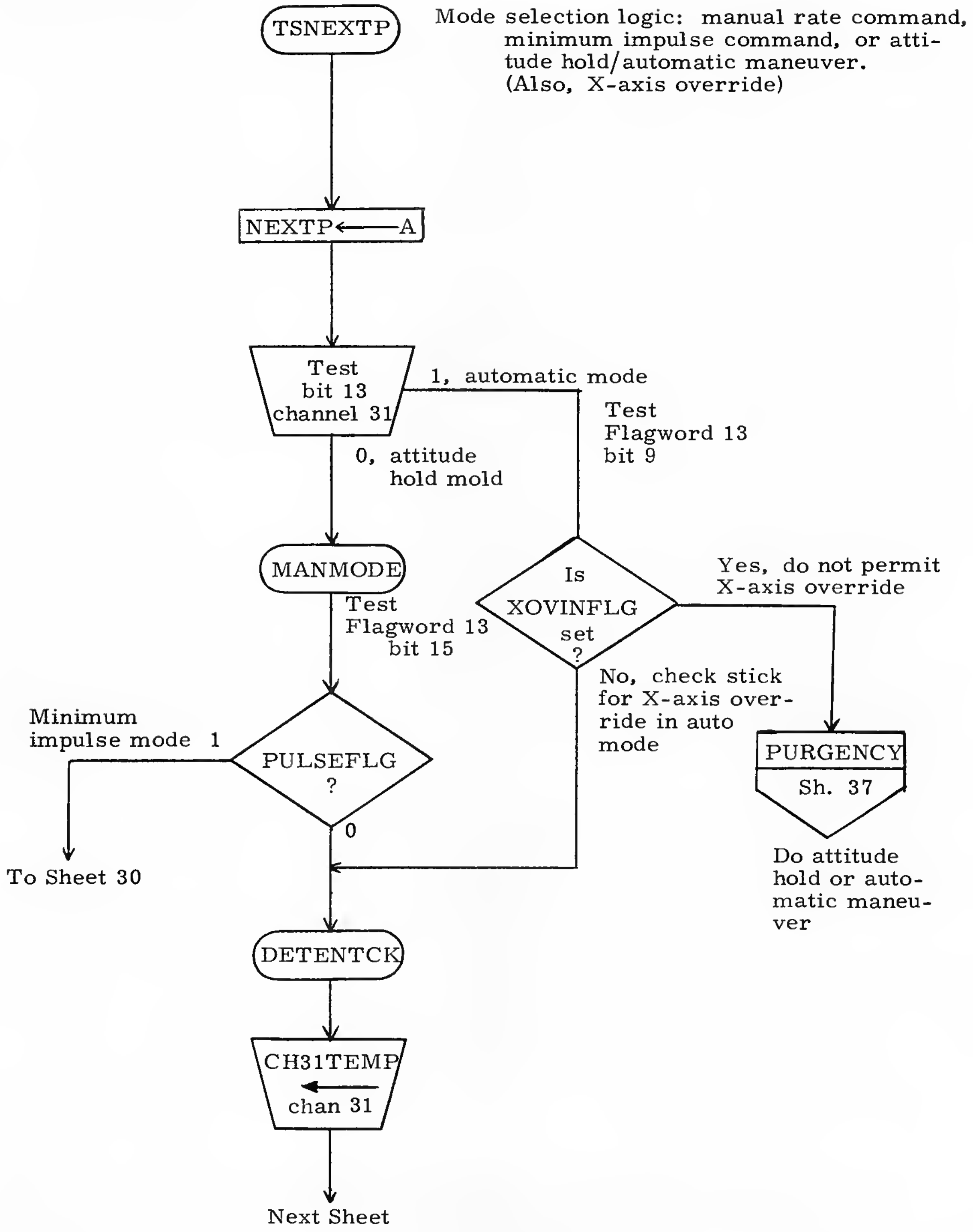

Mode selection logic: manual rate command, minimum impulse command, or attitude hold/automatic maneuver. (Also, X-axis override)

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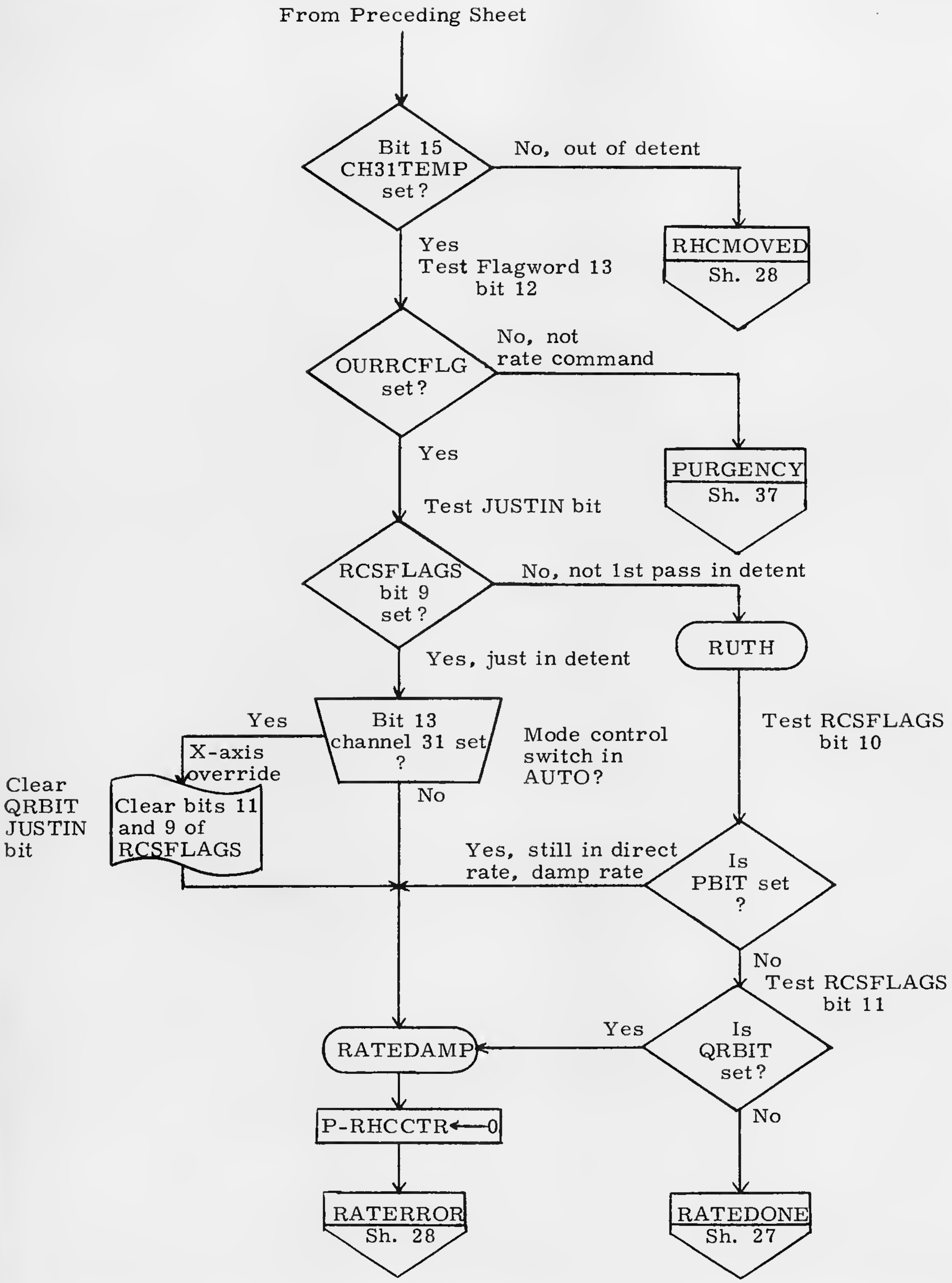

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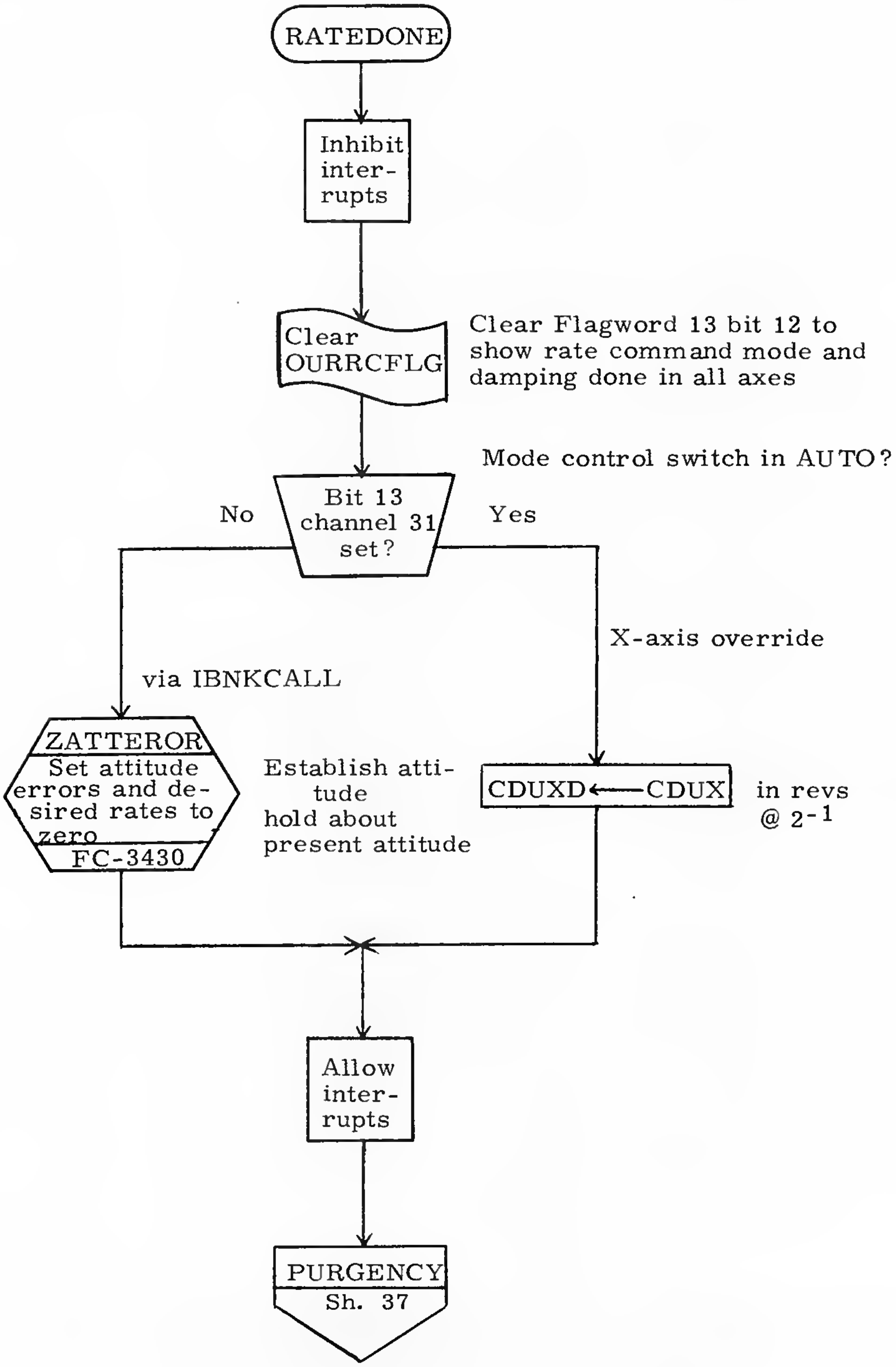

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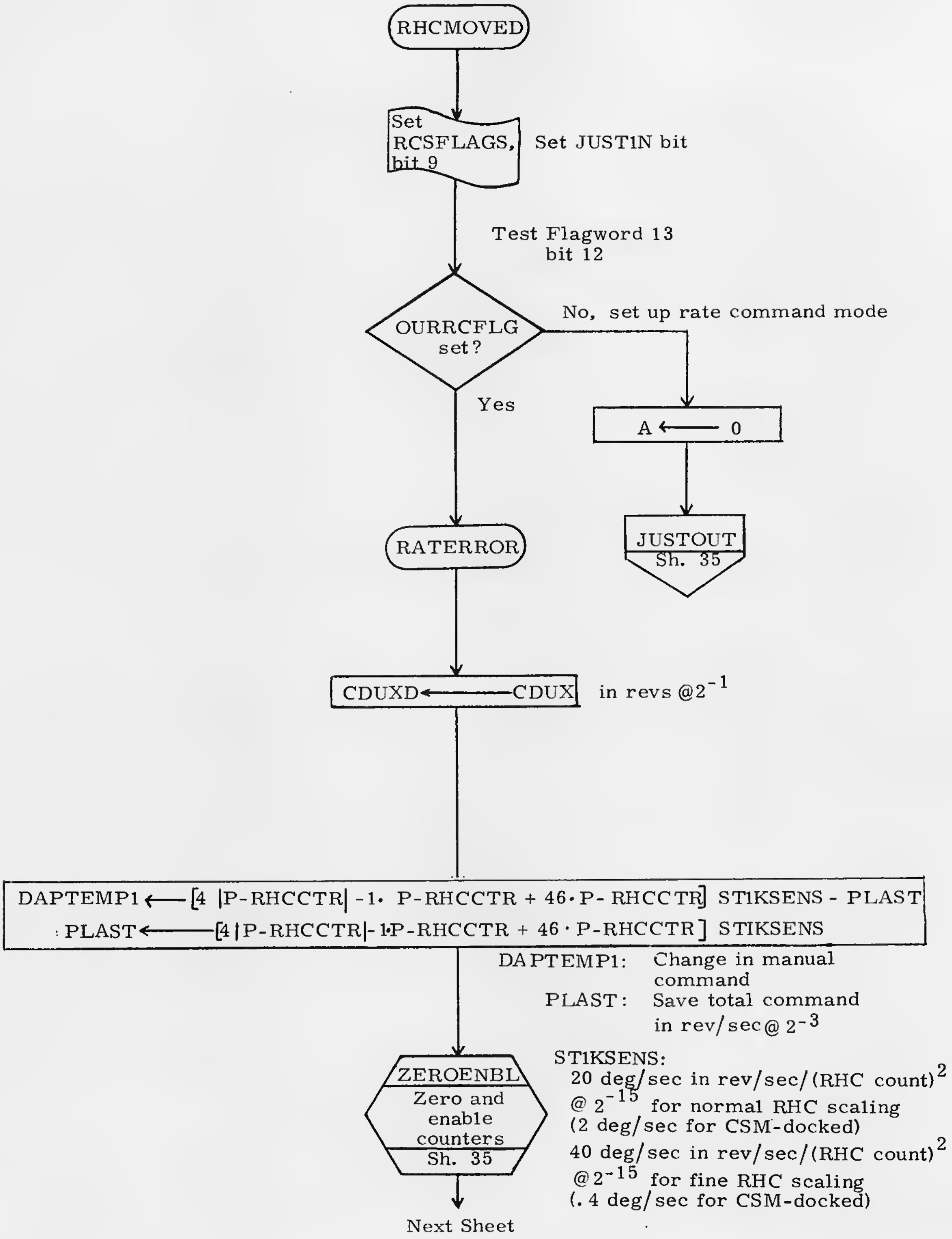

DAPTEMP1: Change in manual command
PLAST: Save total command in rev/sec@ 2^{-3}

STIKSENS:
20 deg/sec in rev/sec/(RHC count)^2 @ 2^{-15} for normal RHC scaling
(2 deg/sec for CSM-docked)
40 deg/sec in rev/sec/(RHC count)^2 @2^{-15} for fine RHC scaling
(.4 deg/sec for CSM-docked)

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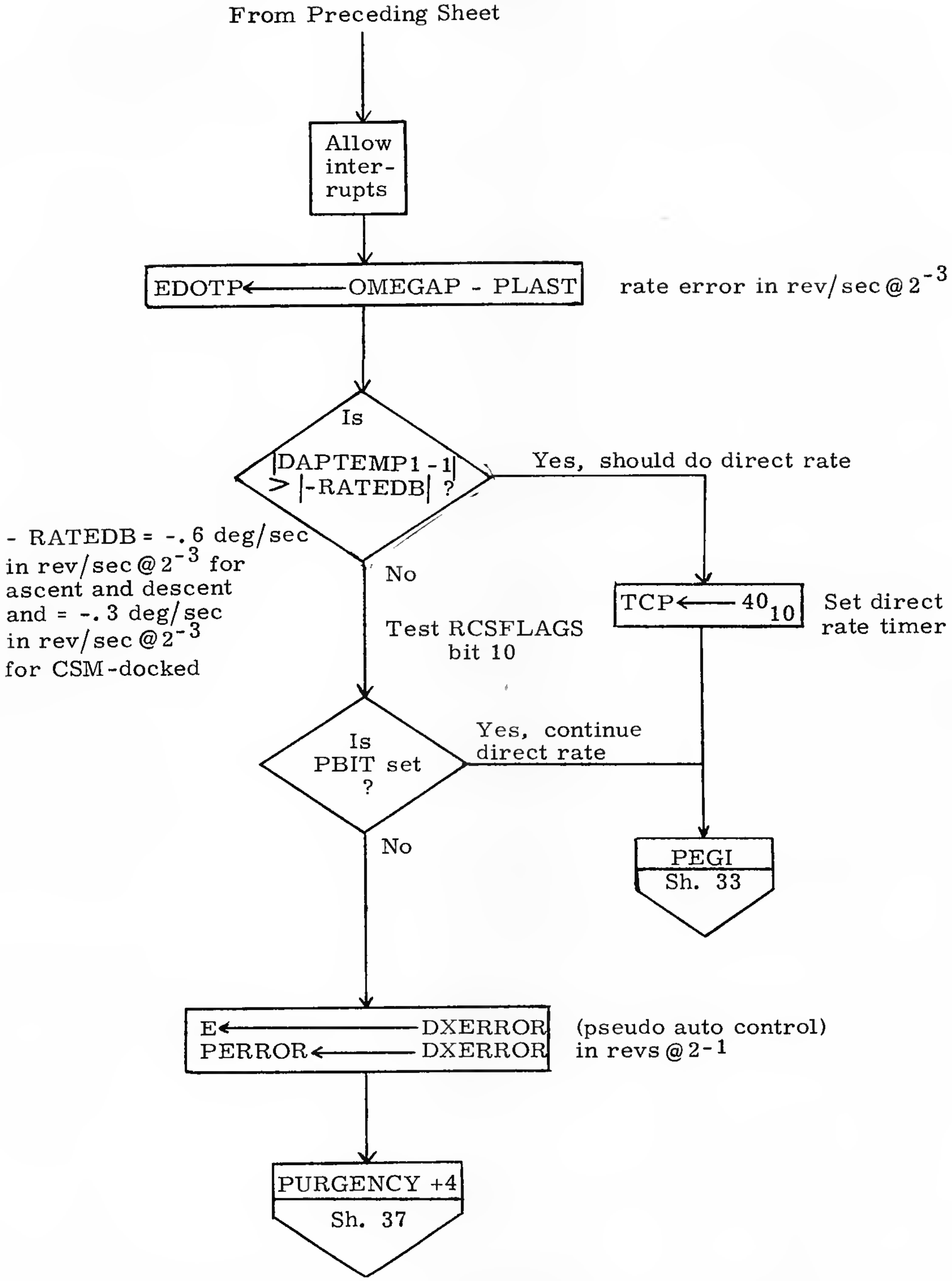

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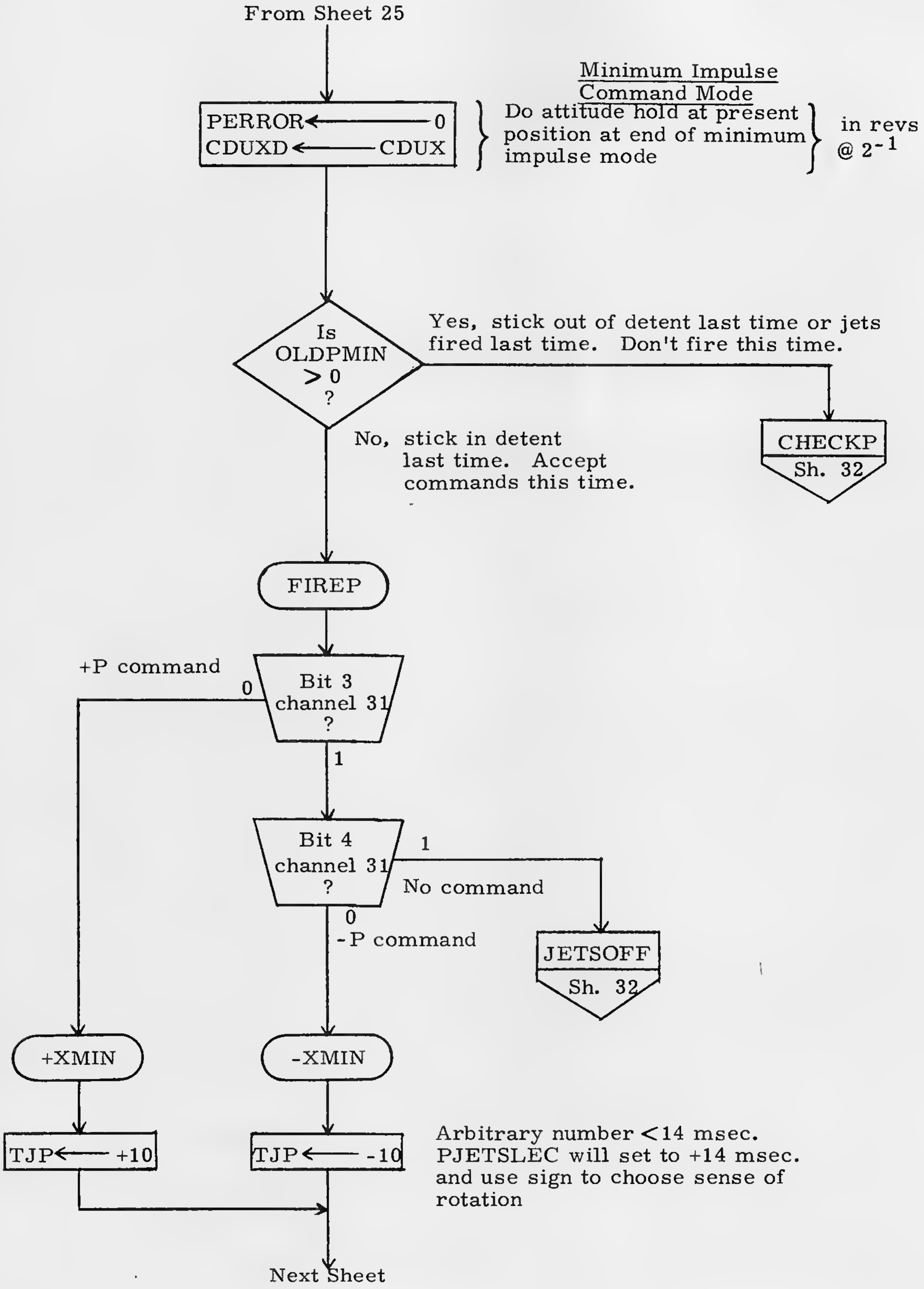

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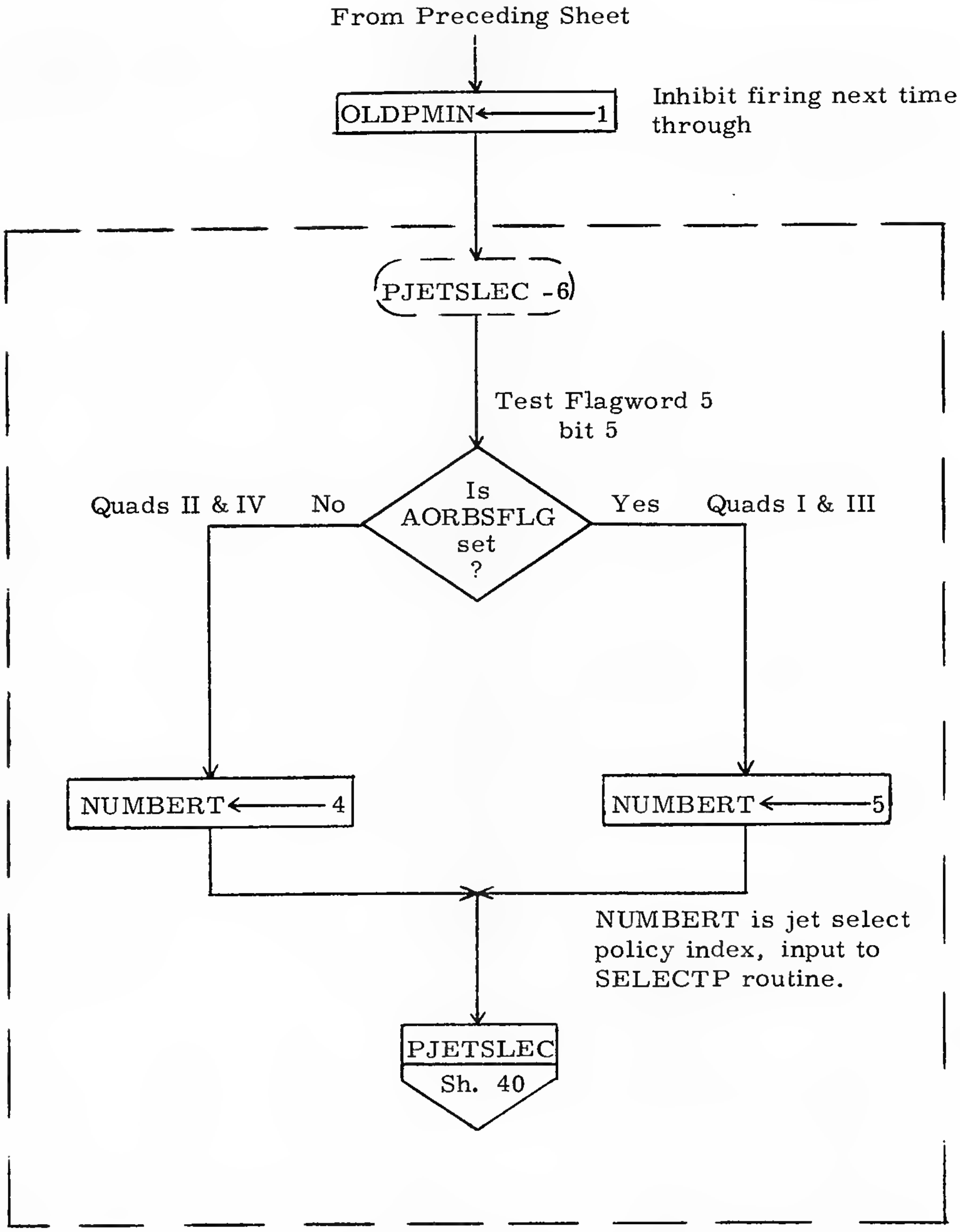

Inhibit firing next time through

NUMBERT is jet select policy index, input to SELECTP routine.

Minimum impulse command always 2-jet burns

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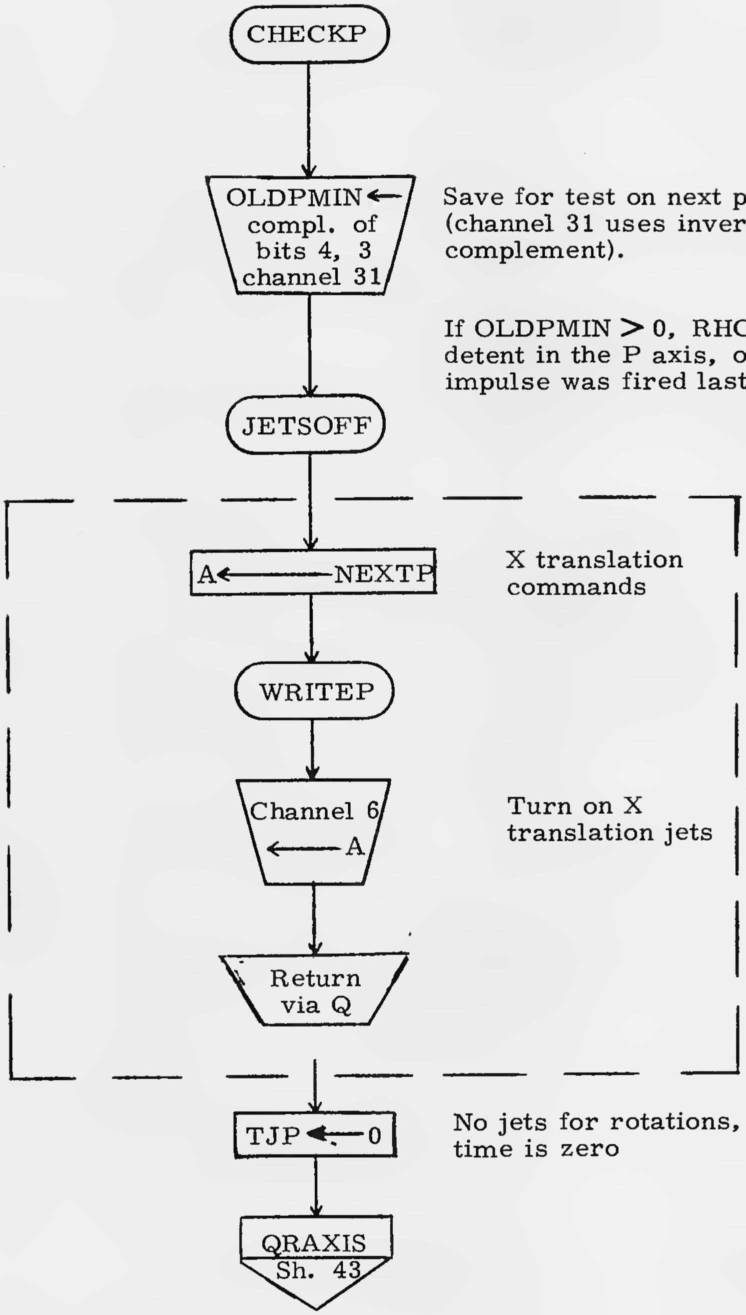

Save for test on next pass (channel 31 uses inverted logic, so complement).

If OLDPMIN > 0, RHC is out of detent in the P axis, or a min. impulse was fired last time.

X translation commands

Turn on X translation jets

No jets for rotations, so time is zero

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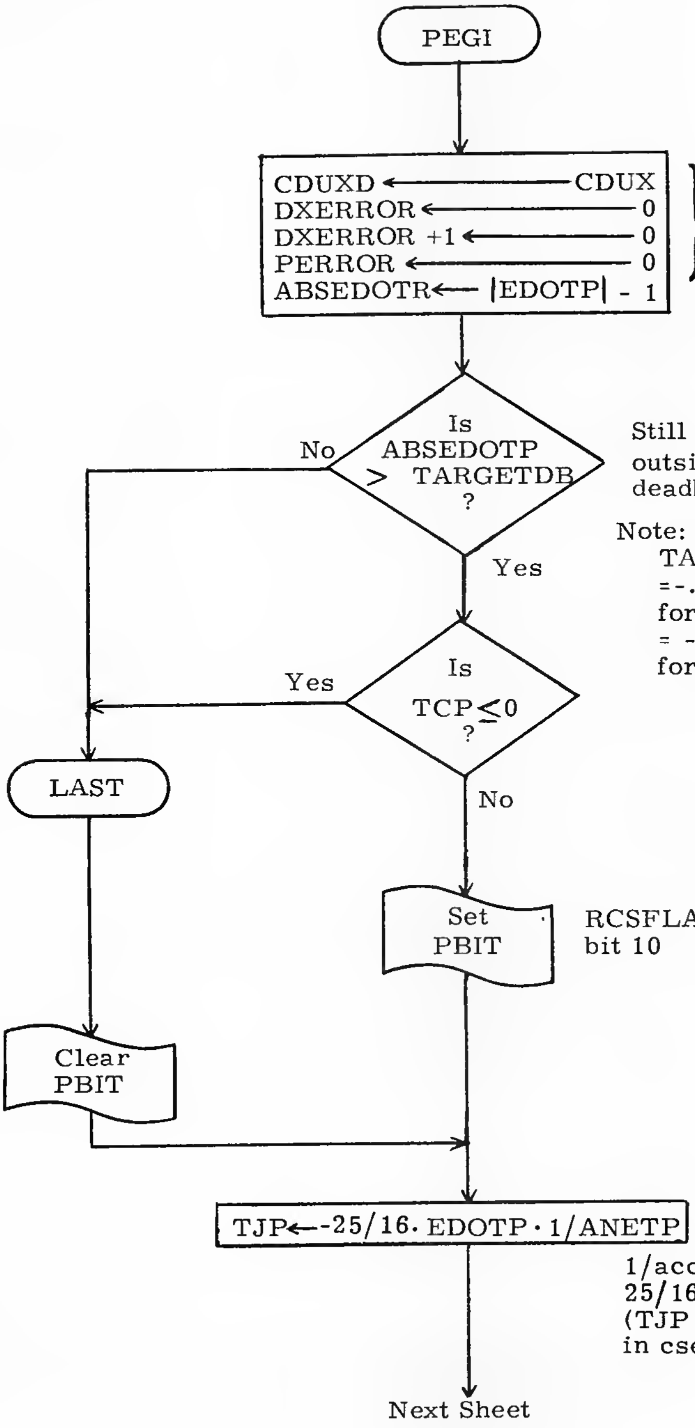

in revs $@2^{-1}$

in rev/sec $@2^{-3}$

Still outside deadband?

Note:
TARGETDB = -RATEDB
=-.6 deg/sec in rev/sec$@2^{-3}$
for ascent and descent and
= -.3 deg/sec in rev/sec$@2^{-3}$
for CSM-docked

RCSFLAGS bit 10

Jet time = Δ rate × 1/acceleration.
25/16 re-scales to T6 scaling
(TJP is now for 4 jets)
in csec $@ 2^{+10}$

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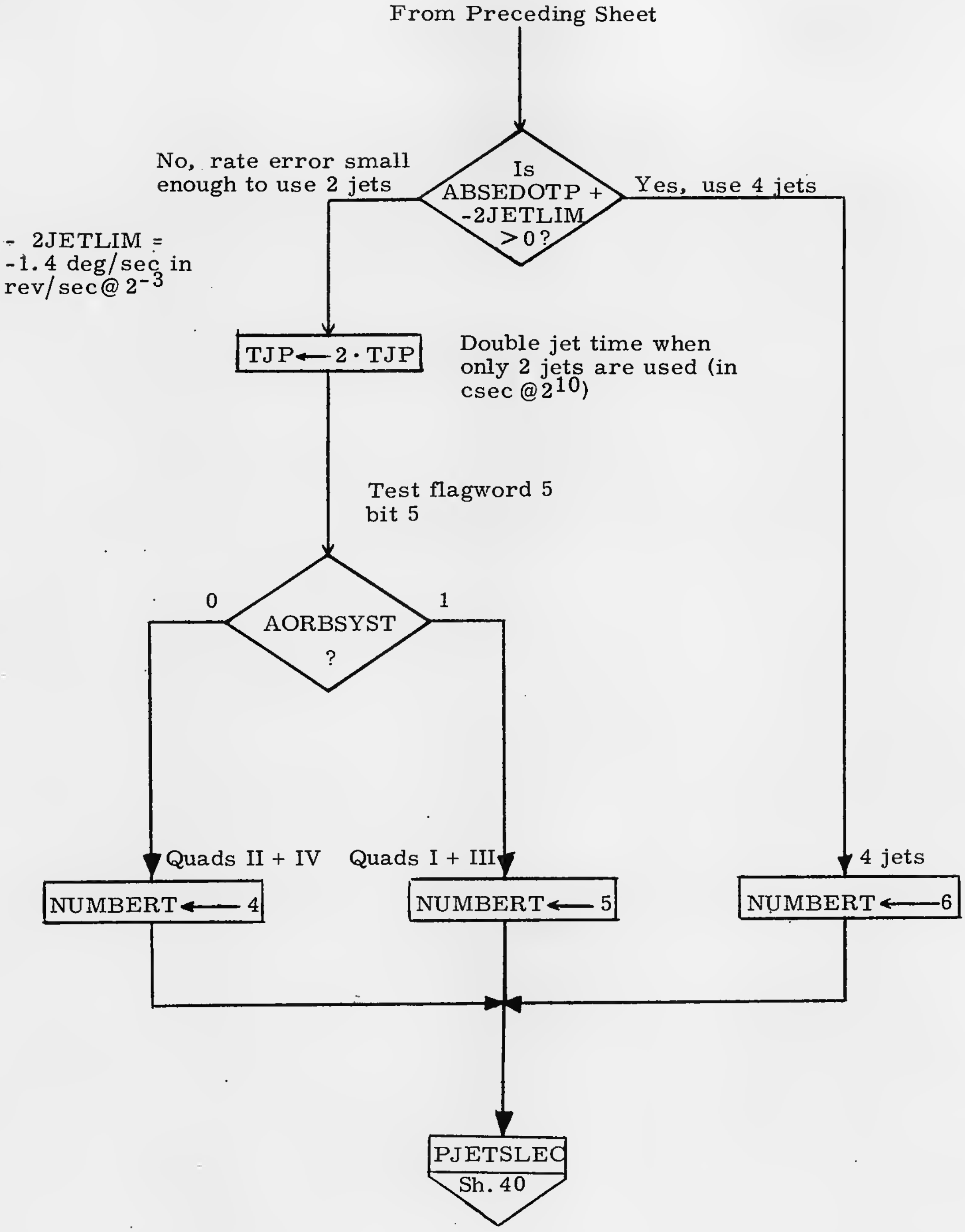

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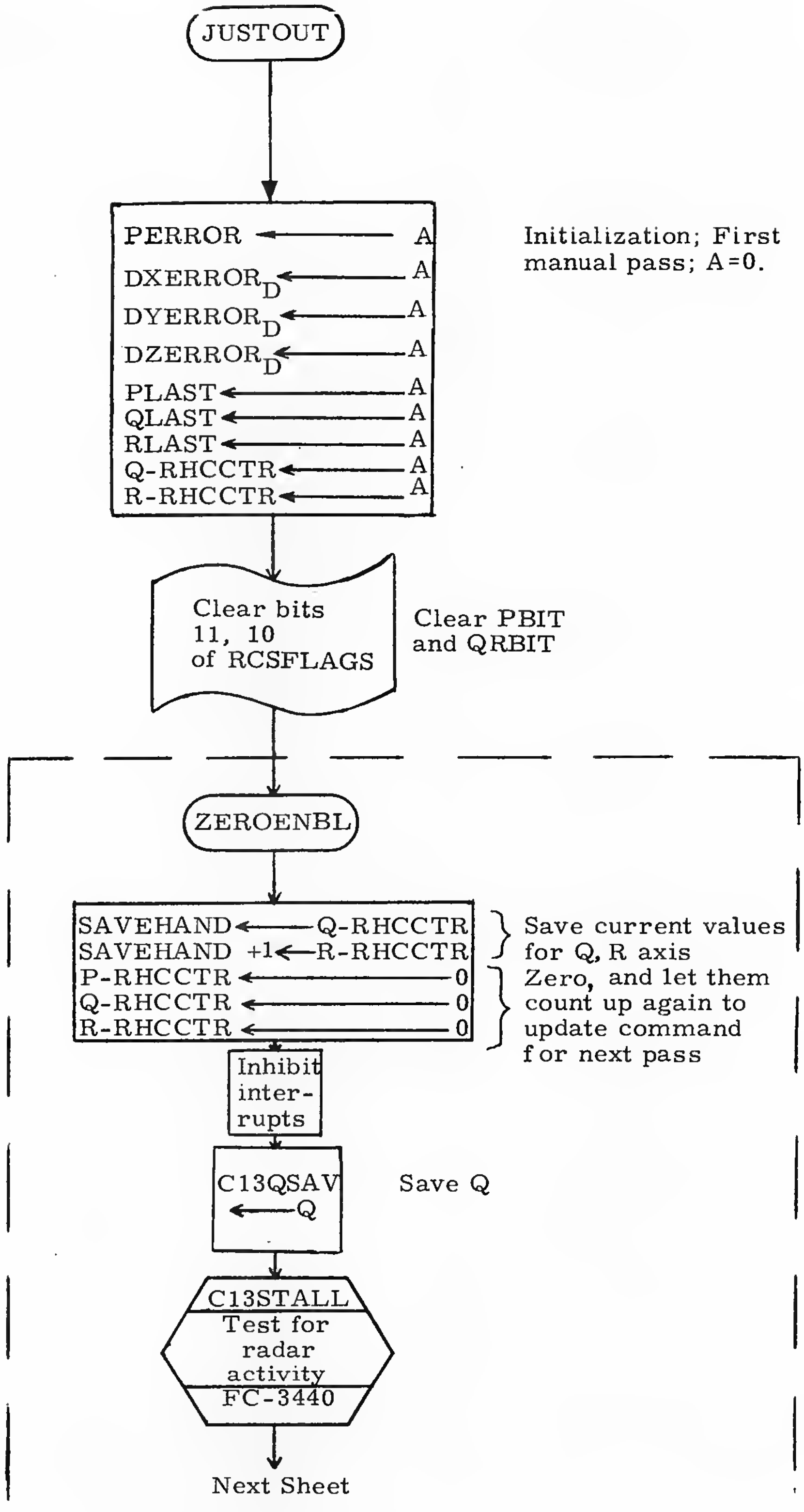

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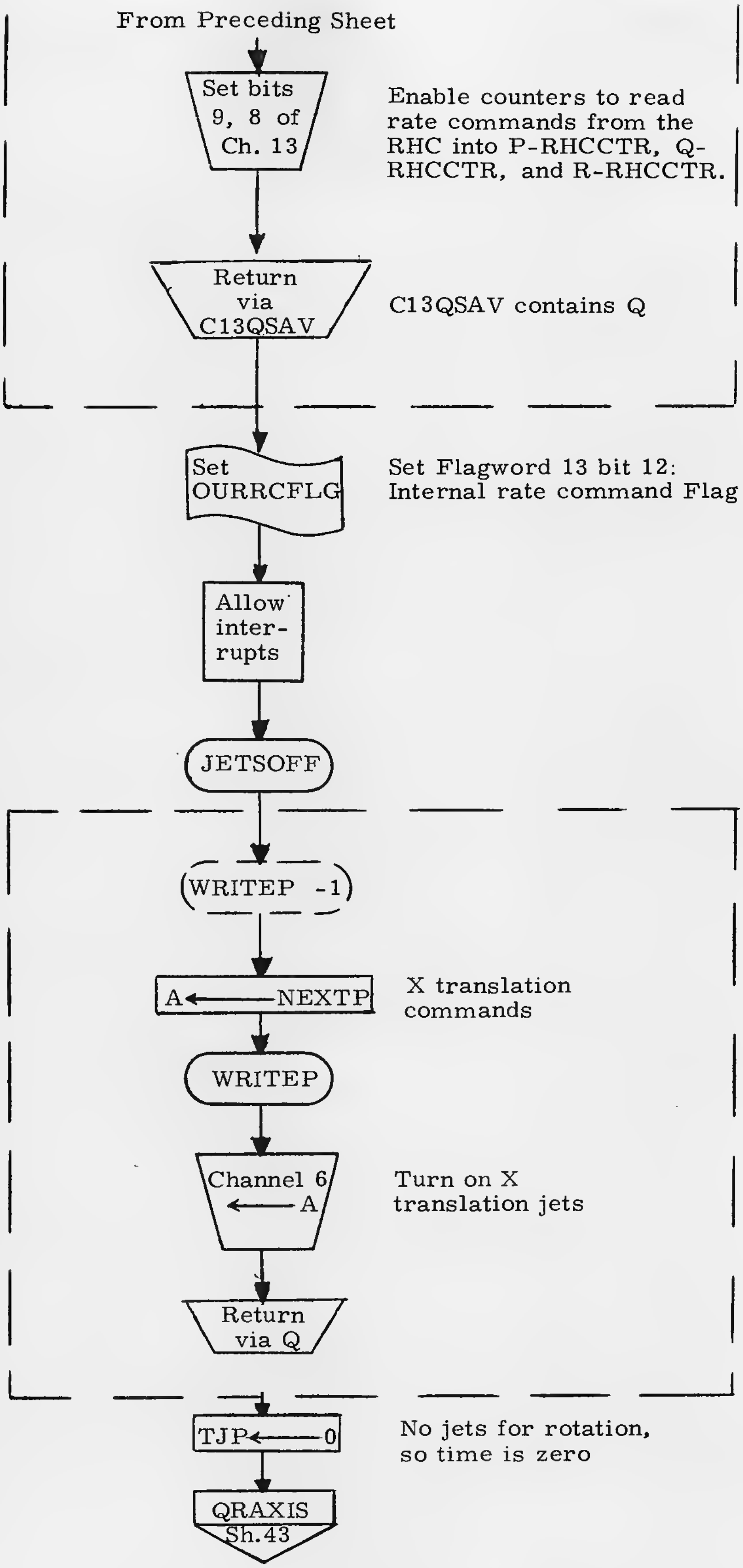

Enable counters to read rate commands from the RHC into P-RHCCTR, Q-RHCCTR, and R-RHCCTR.

C13QSAV contains Q

Set Flagword 13 bit 12: Internal rate command Flag

X translation commands

Turn on X translation jets

No jets for rotation, so time is zero

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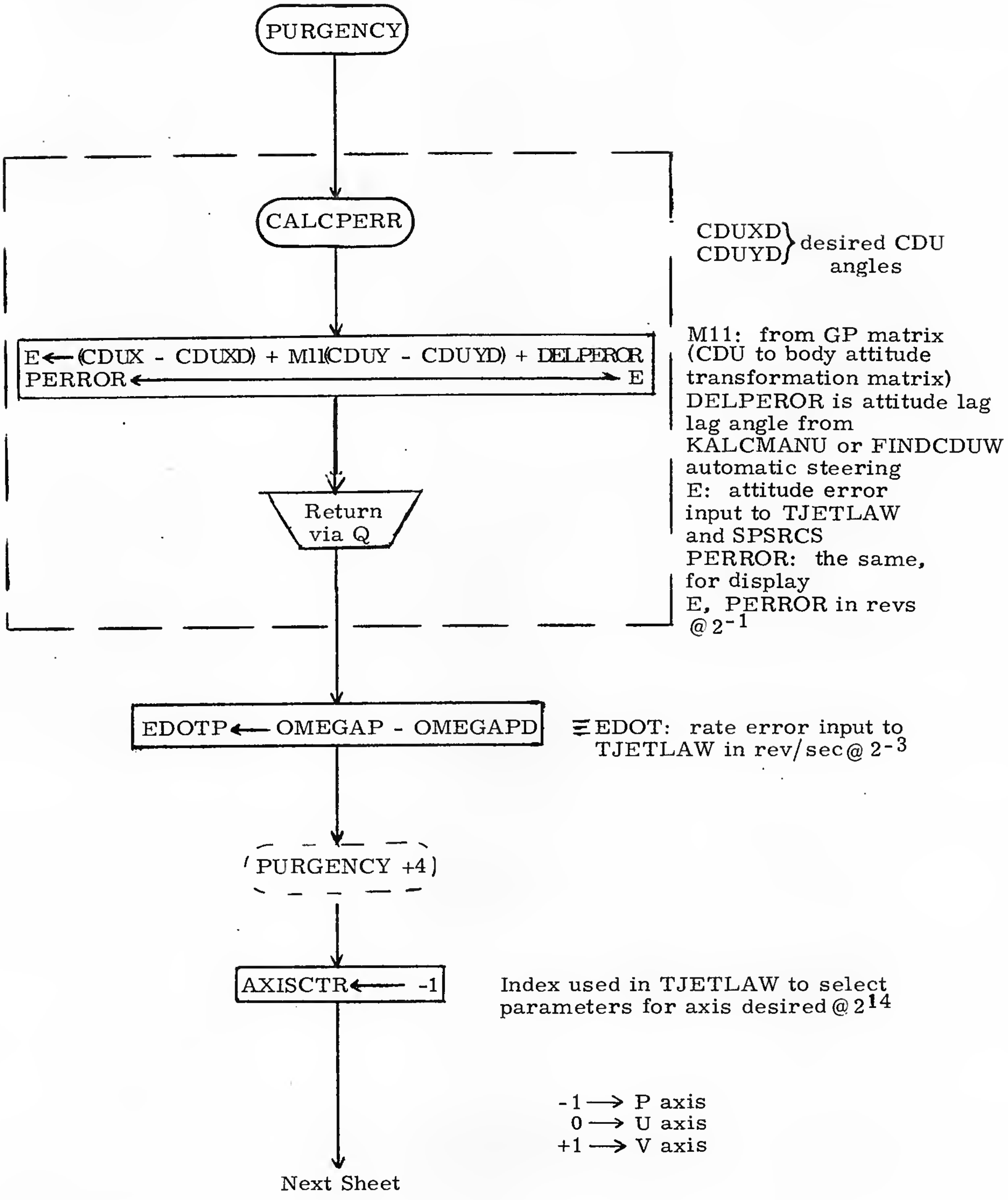

CDUXD, CDUYD } desired CDU angles

M11: from GP matrix (CDU to body attitude transformation matrix)
DELPEROR is attitude lag lag angle from KALCMANU or FINDCDUW automatic steering
E: attitude error input to TJETLAW and SPSRCS
PERROR: the same, for display
E, PERROR in revs @ 2^{-1}

≡ EDOT: rate error input to TJETLAW in rev/sec @ 2^{-3}

Index used in TJETLAW to select parameters for axis desired @ 2^{14}

-1 → P axis
0 → U axis
+1 → V axis

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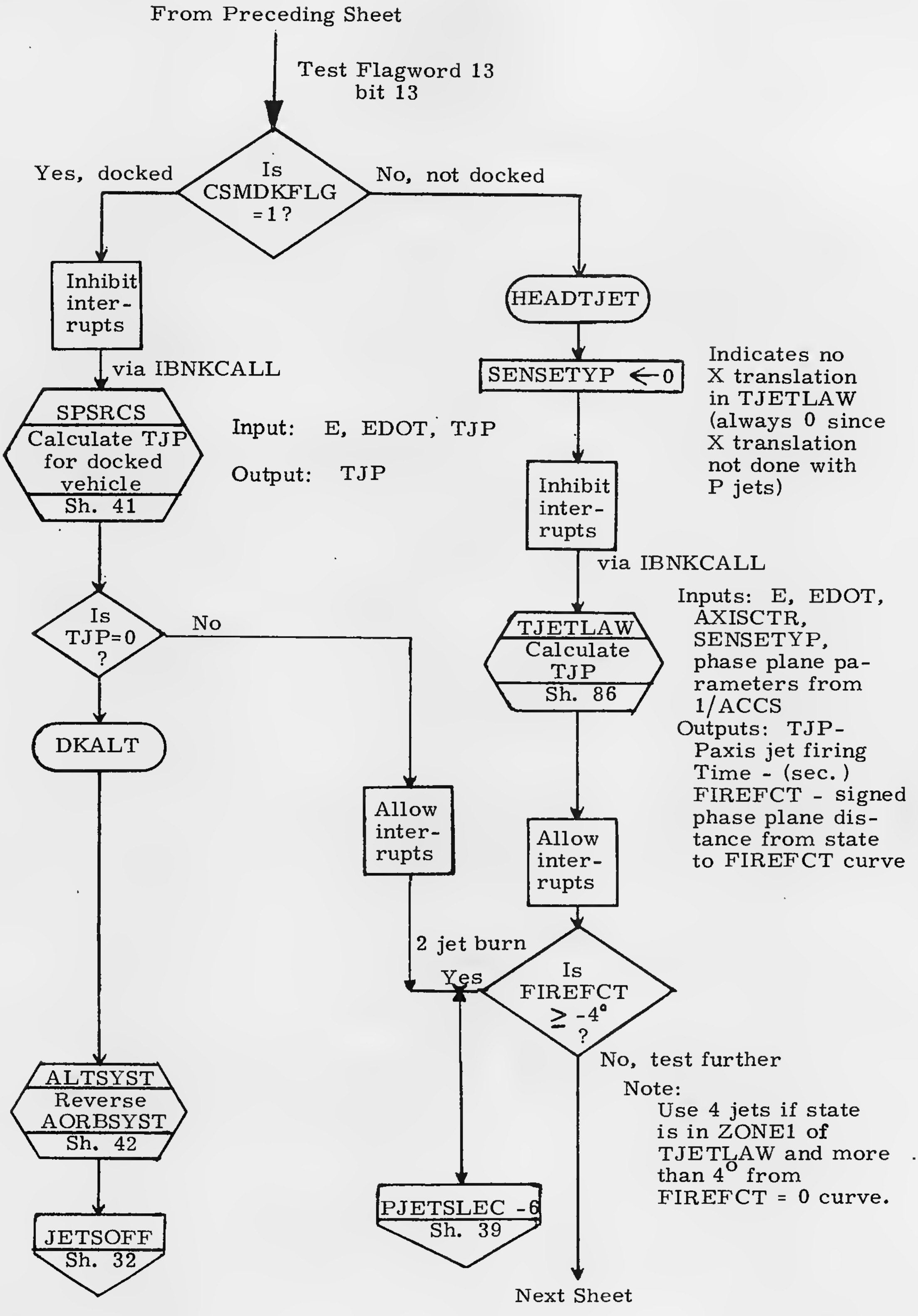

Input: E, EDOT, TJP

Output: TJP

Indicates no X translation in TJETLAW (always 0 since X translation not done with P jets)

Inputs: E, EDOT, AXISCTR, SENSETYP, phase plane parameters from 1/ACCS

Outputs: TJP-Paxis jet firing Time - (sec.)

FIREFCT - signed phase plane distance from state to FIREFCT curve

Note:
Use 4 jets if state is in ZONE1 of TJETLAW and more than 4° from FIREFCT = 0 curve.

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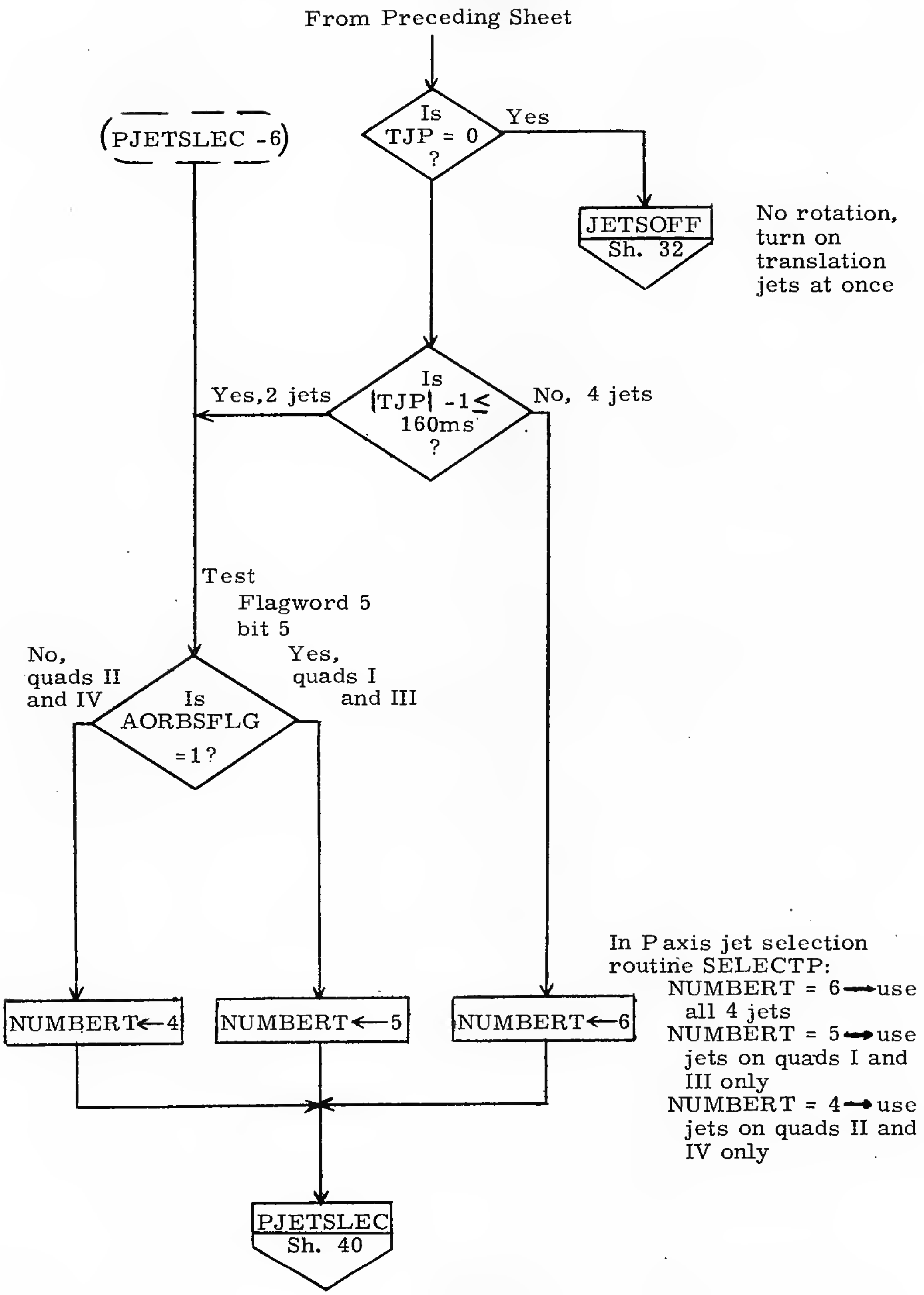

No rotation,
turn on
translation
jets at once

In P axis jet selection
routine SELECTP:
NUMBERT = 6 → use all 4 jets
NUMBERT = 5 → use jets on quads I and III only
NUMBERT = 4 → use jets on quads II and IV only

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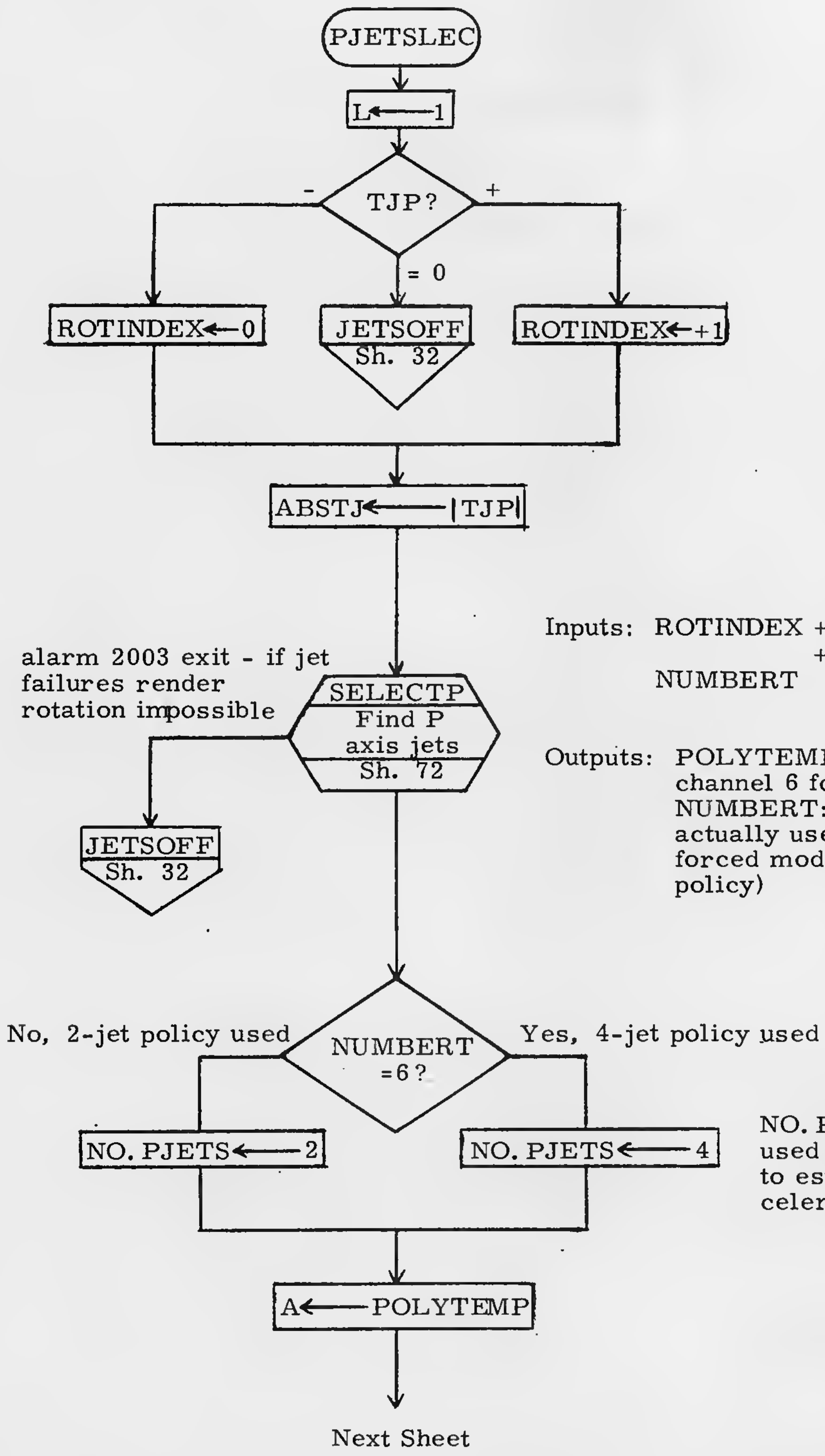

Inputs: ROTINDEX +1 for +P;
+0 for -P
NUMBERT

Outputs: POLYTEMP jet command in channel 6 format
NUMBERT: code for jet policy actually used (failures may have forced modification of requested policy)

NO. PJETS and TJP are used by state estimator to estimate net jet acceleration.

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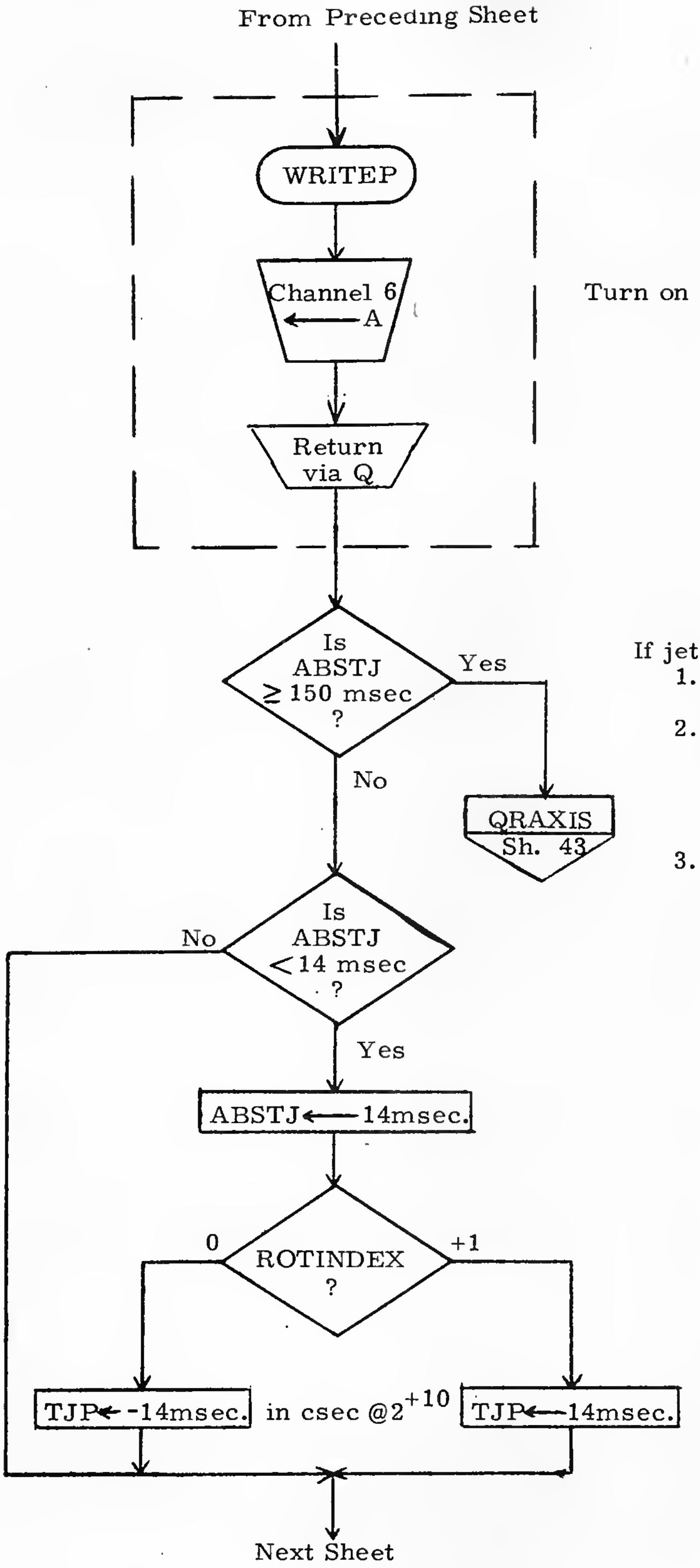

Turn on P jets for rotation

If jet time ≥ 150 msec.:
1. Don't skip P axis next cycle
2. Since time will be recomputed before it expires, don't set up T6JOB to turn jets off
3. Go directly to Q, R axis computations.

14msec. is the shortest jet time allowed: any (non-zero) jet time less than 14msec. is set equal to 14msec. and given the sign of the sense of the rotation

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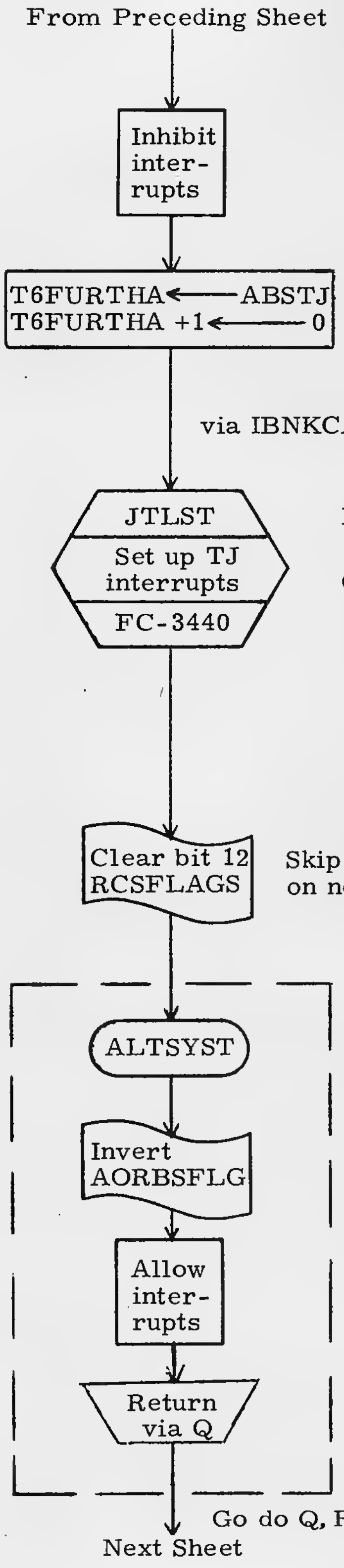

Set up for Jetlist T6 program

Δ time to turn off P jets
Index to indicate that this is a P axis setup
(4 → Q axis; 13 → R axis)

via IBNKCALL

Inputs: T6FURTHA, T6FURTHA +1

Outputs: jetlist places this request in a list of requests to be honored, and computes Δ times for execution, setting TIME6 to cause a T6RUPT at the proper time to execute the first item on the list. The T6RUPT program (T6JOB, FC-3440) will reset TIME6 for the next item, and so on through the list.

Skip P-axis control on next DAP pass

Alternate systems used for 2-jet burns to even out fuel consumption. (Flagword 5, bit 5)

Go do Q, R - axis autopilot.

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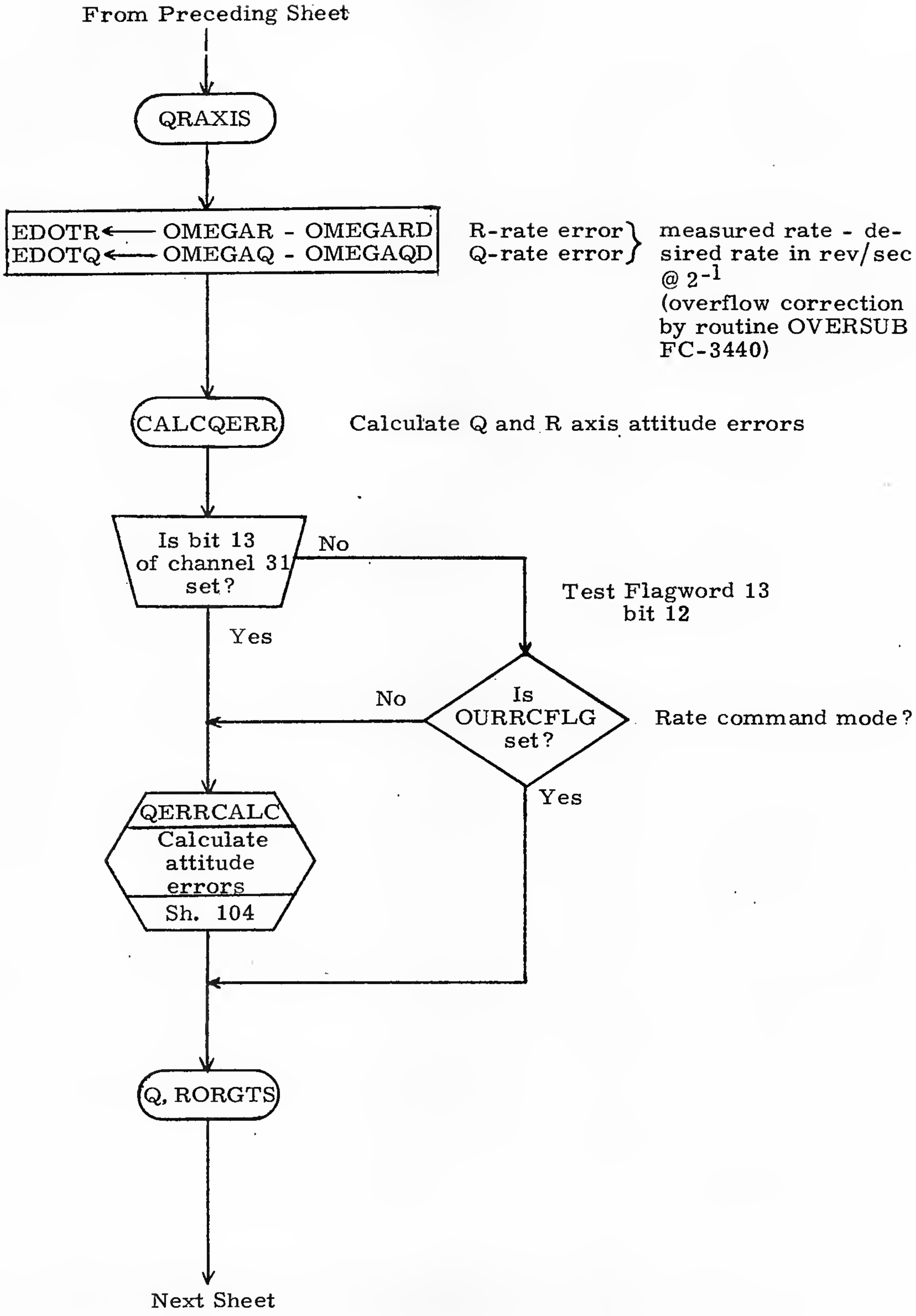

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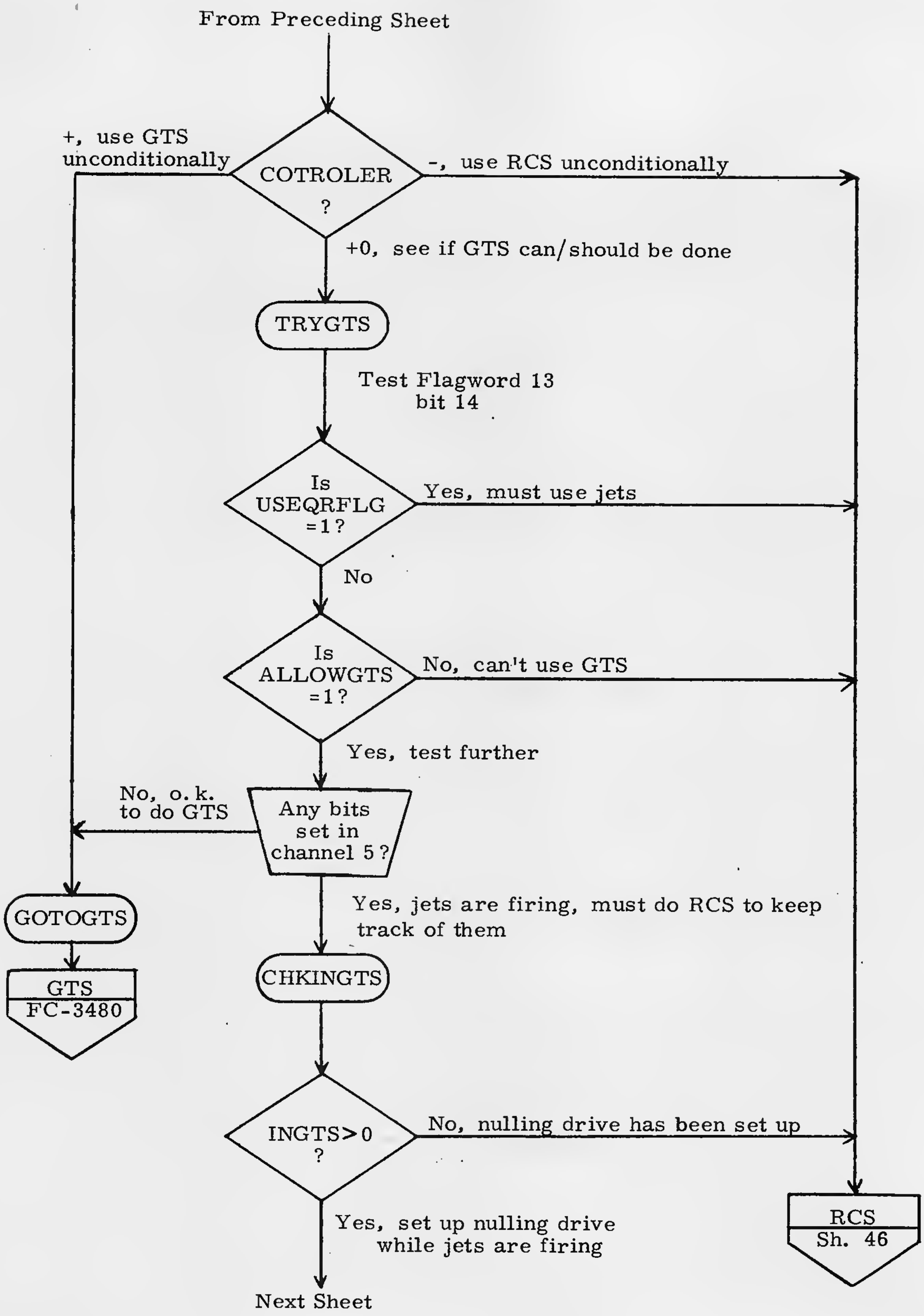

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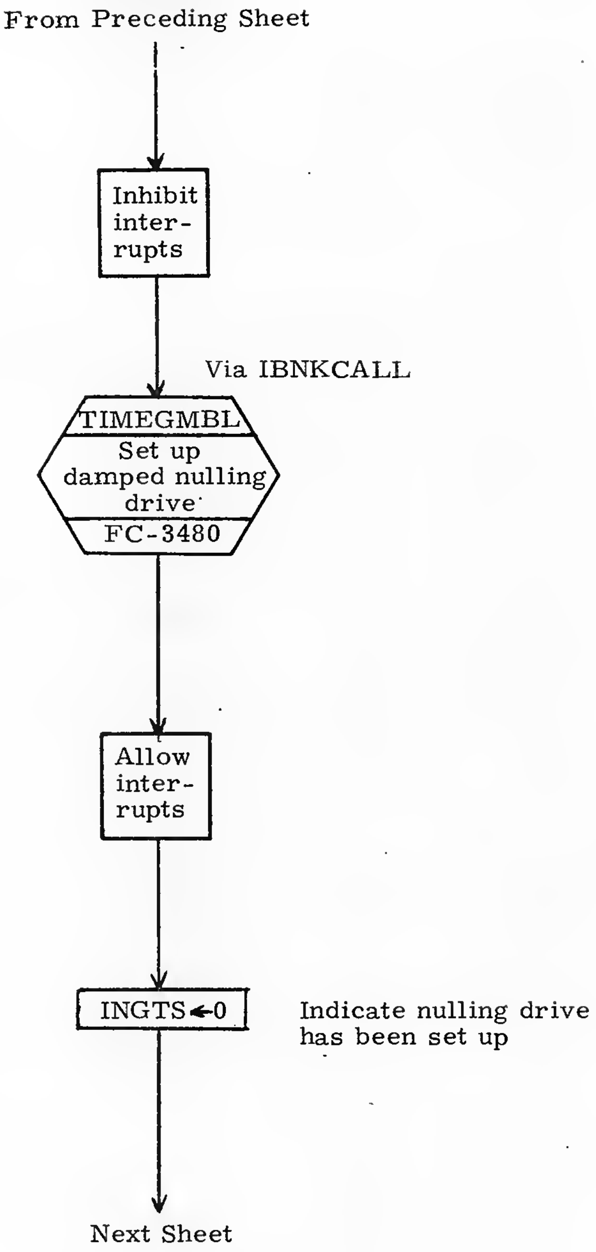

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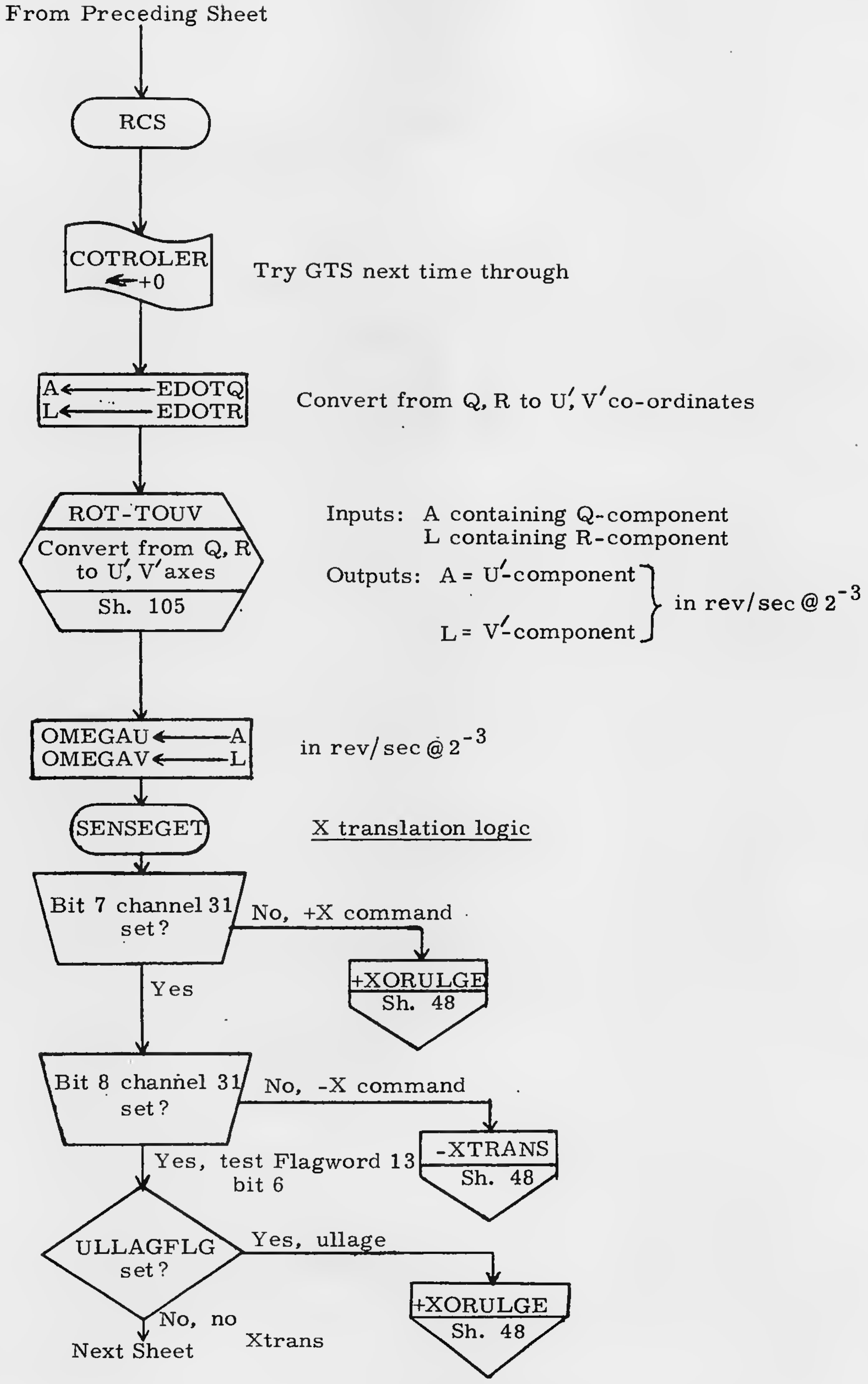

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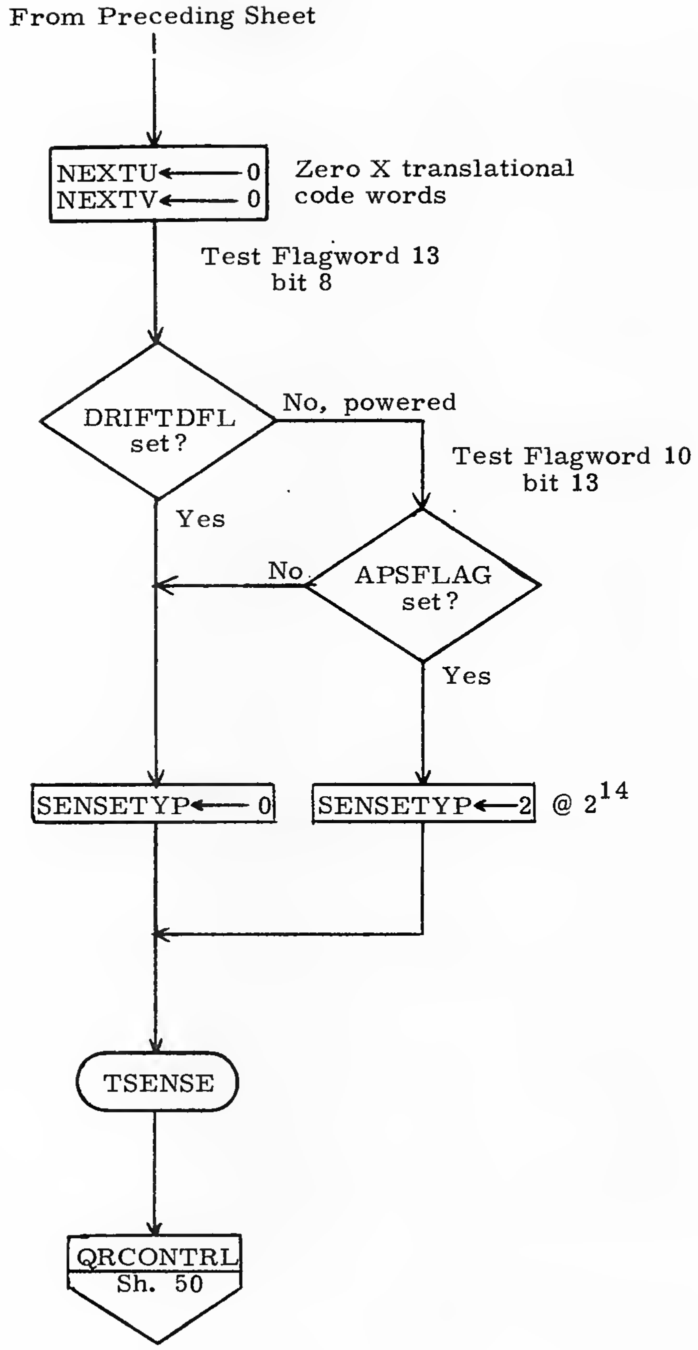

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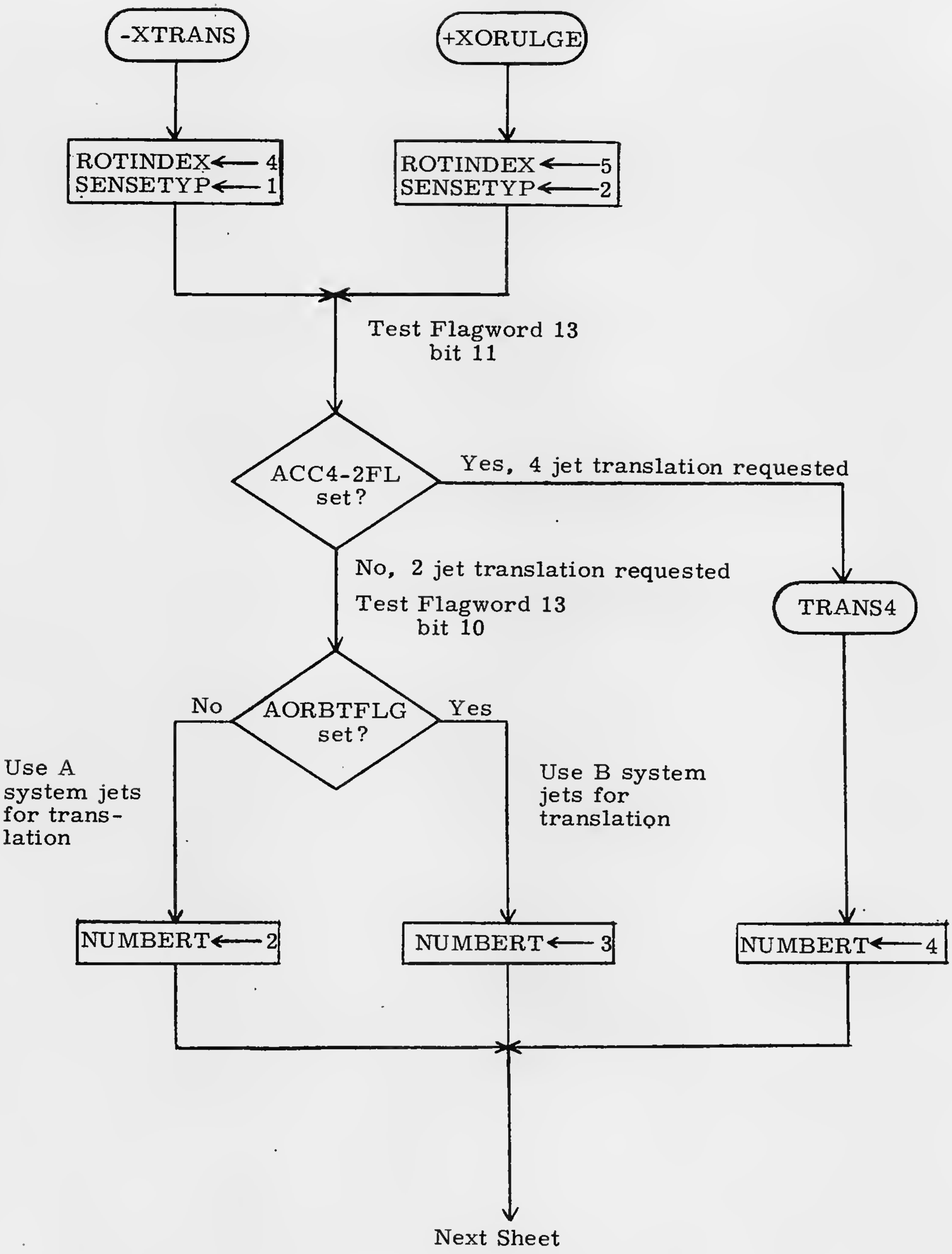

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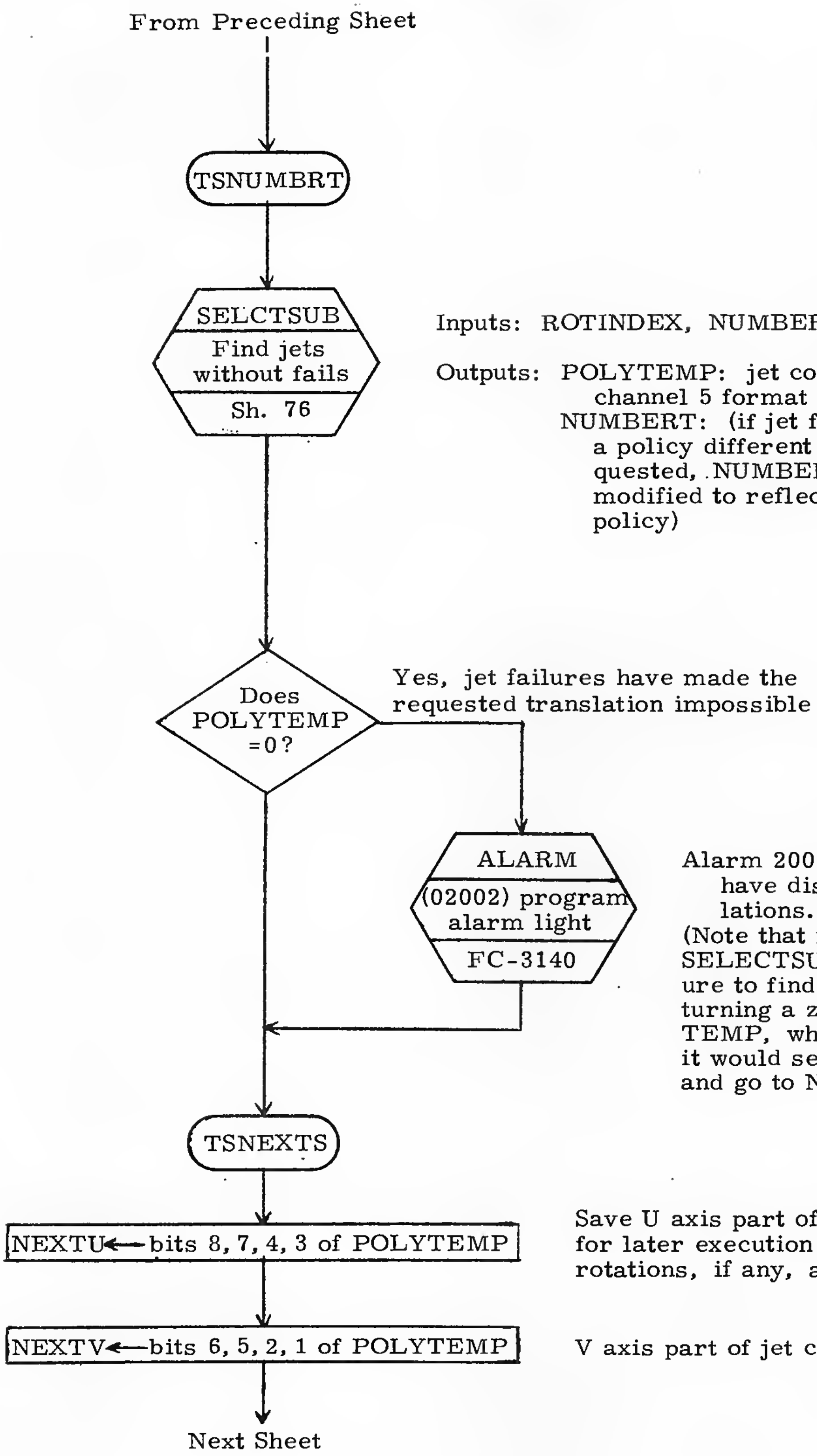

Inputs: ROTINDEX, NUMBERT

Outputs: POLYTEMP: jet commands in channel 5 format
NUMBERT: (if jet failures force a policy different from that requested, NUMBERT will be modified to reflect the new policy)

Alarm 2002: "jet failures have disabled X translations."
(Note that for translations, SELECTSUB indicates failure to find good jets by returning a zero in POLYTEMP, while for rotations, it would set its own alarm and go to NOROTAT.)

Save U axis part of jet code for later execution (when U rotations, if any, are done)

V axis part of jet code (as above)

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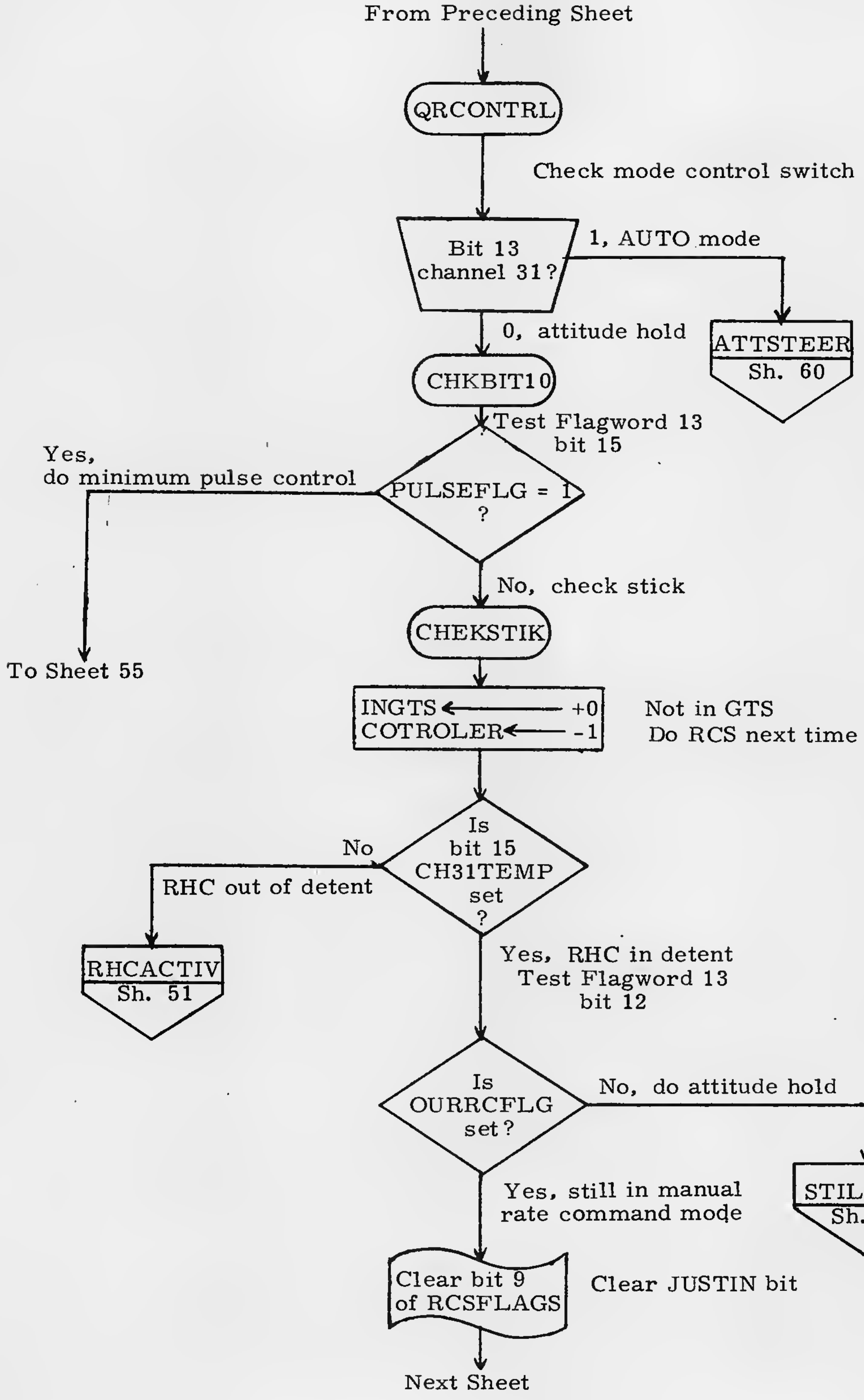

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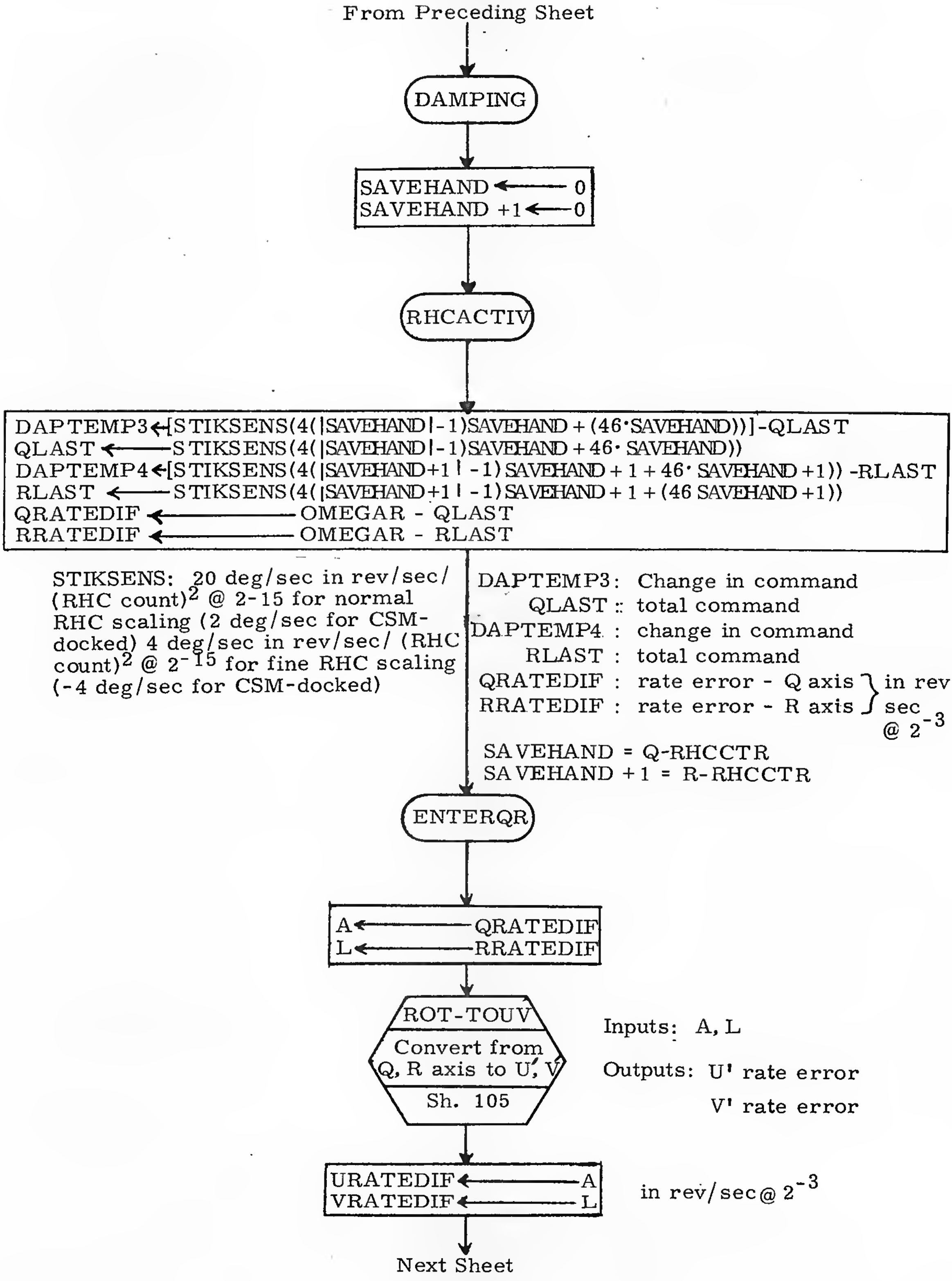

STIKSENS: 20 deg/sec in rev/sec/(RHC count)^2 @ 2-15 for normal RHC scaling (2 deg/sec for CSM-docked) 4 deg/sec in rev/sec/ (RHC count)^2 @ 2^{-15} for fine RHC scaling (-4 deg/sec for CSM-docked)

DAPTEMP3: Change in command
QLAST :: total command
DAPTEMP4 : change in command
RLAST : total command
QRATEDIF : rate error - Q axis } in rev/sec @ 2^{-3}
RRATEDIF : rate error - R axis } in rev/sec @ 2^{-3}

SAVEHAND = Q-RHCCTR
SAVEHAND +1 = R-RHCCTR

Inputs: A, L

Outputs: U' rate error
V' rate error

in rev/sec @ 2^{-3}

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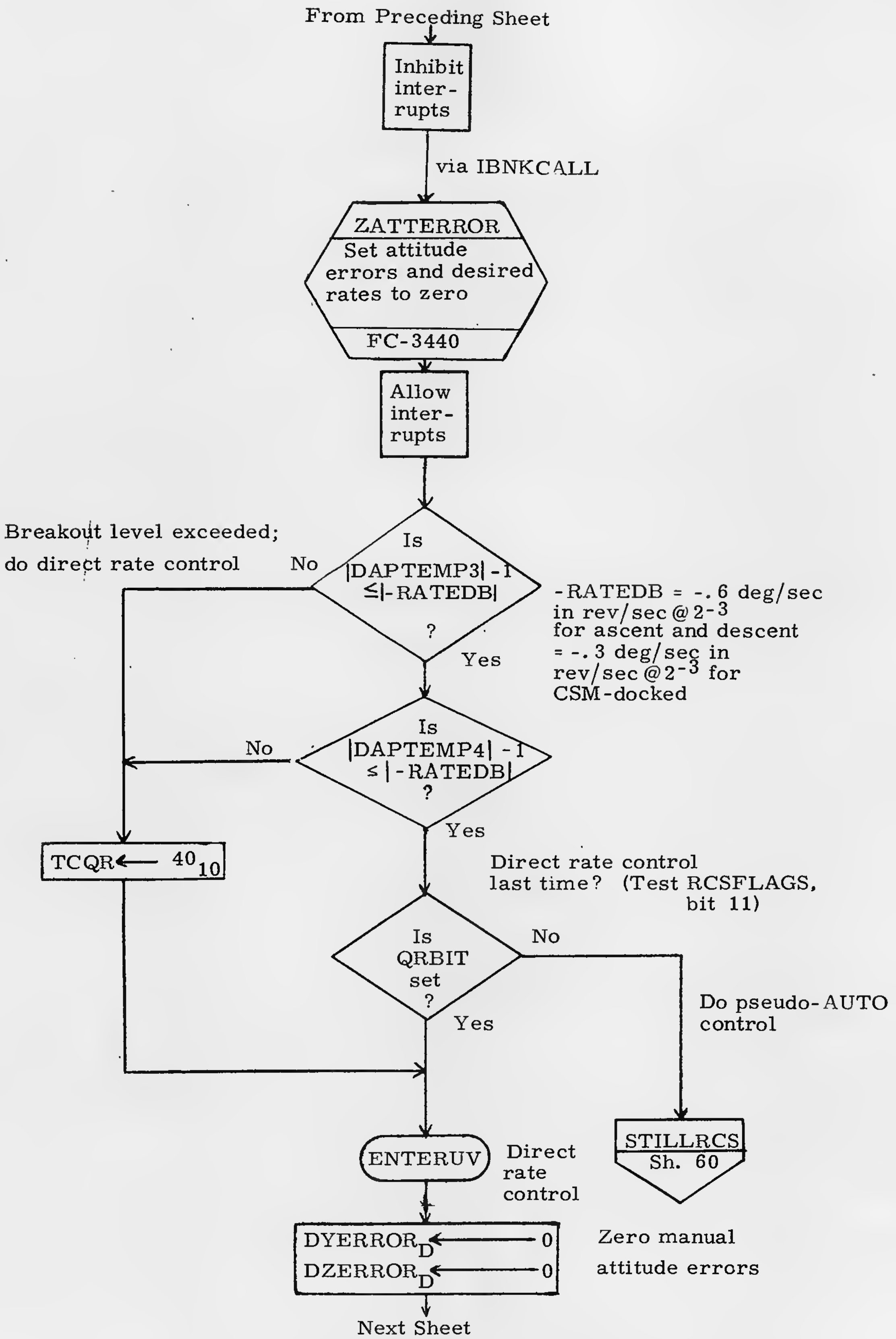

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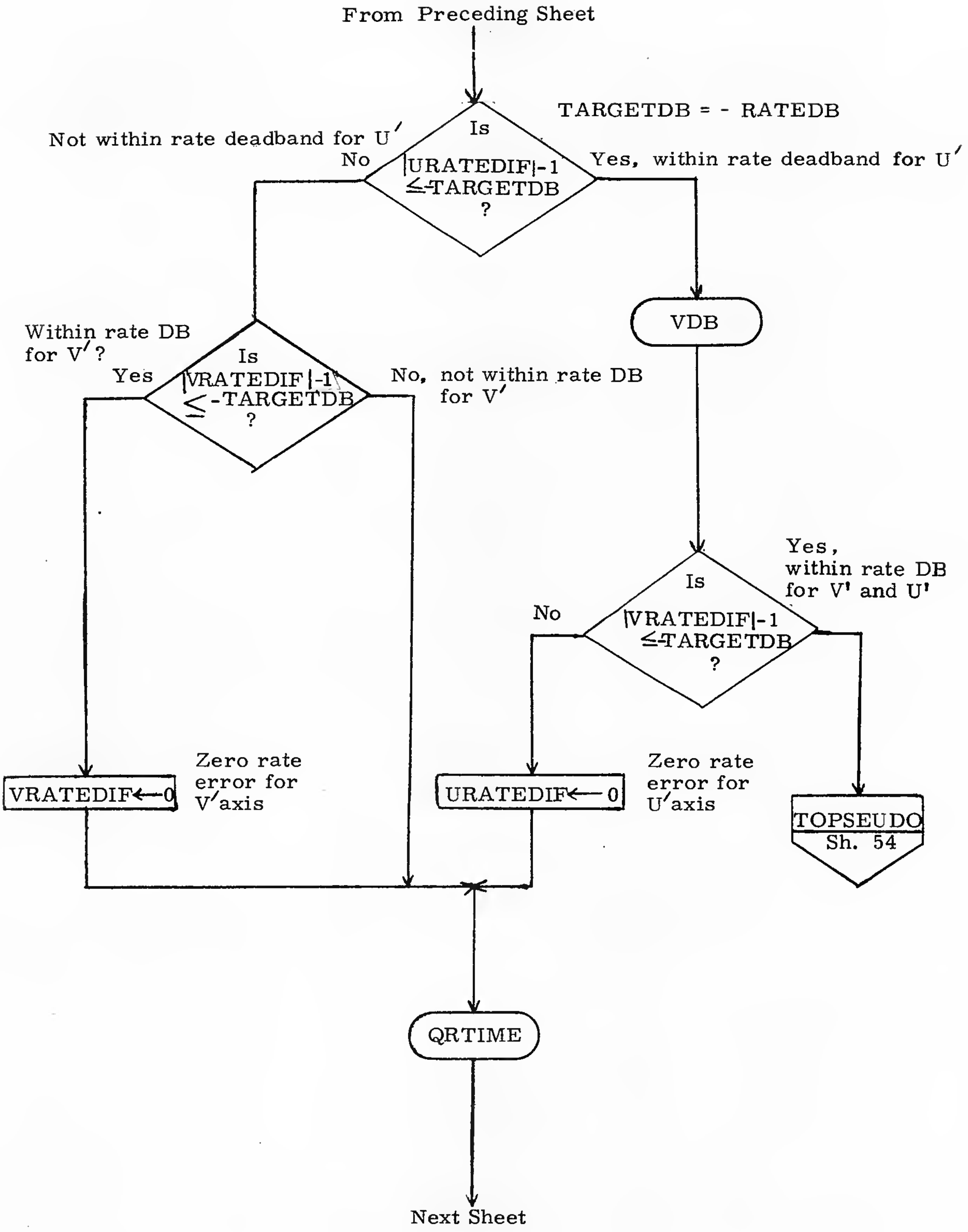

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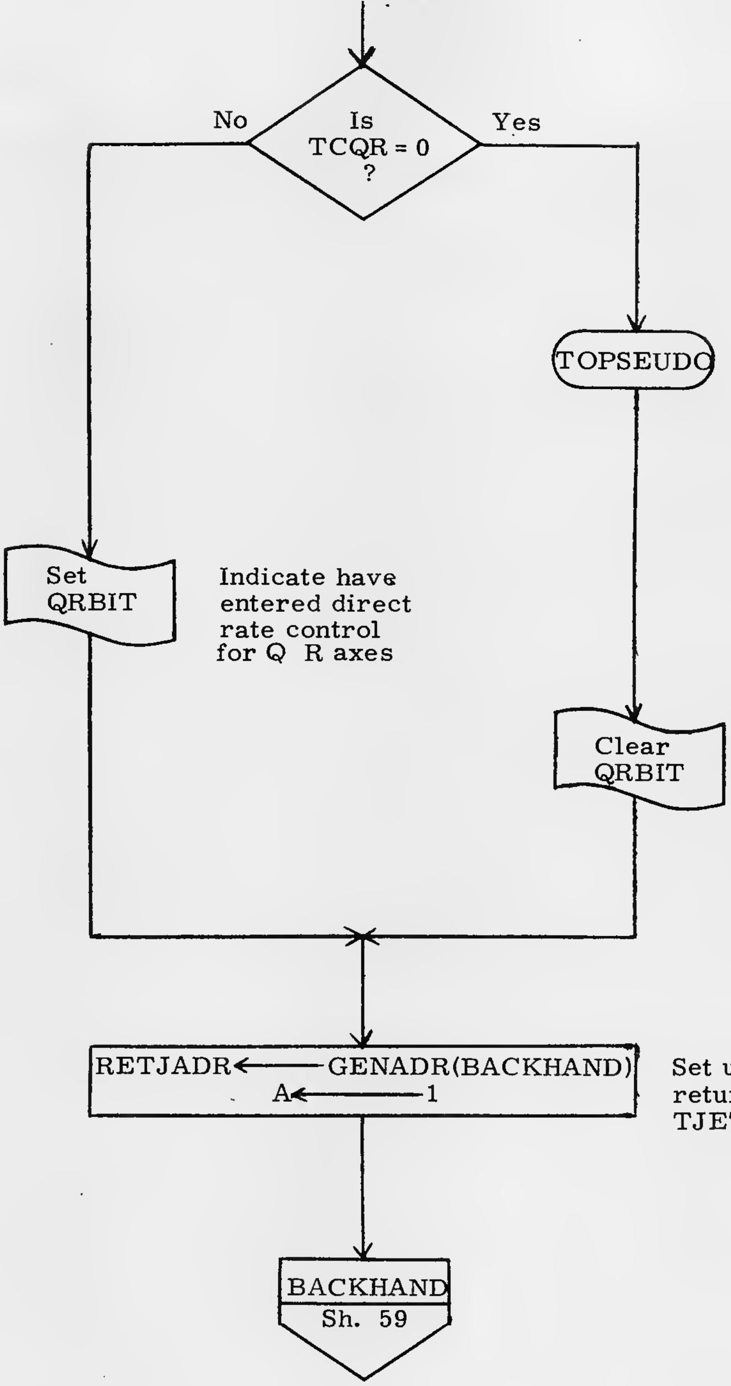
From Preceding Sheet



RCSFLAGS
bit 11

Indicate have entered direct rate control for Q R axes

In direct rate over 4 sec. so clear RCSFLAGS bit 11 to indicate next pass should be pseudo-AUTO

Set up for return from TJETLAW

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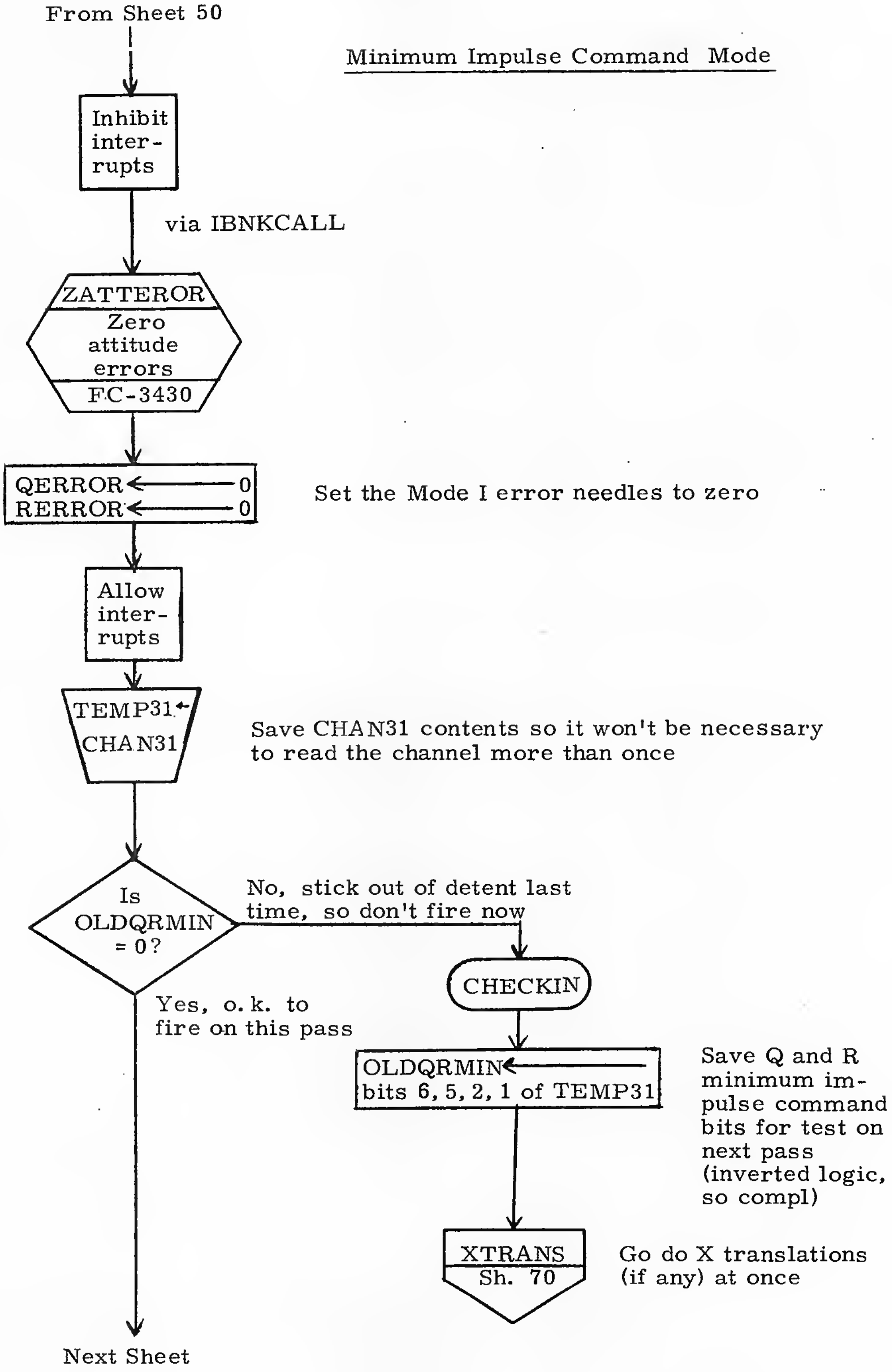
Minimum Impulse Command Mode



Set the Mode I error needles to zero

Save CHAN31 contents so it won't be necessary to read the channel more than once

Save Q and R minimum impulse command bits for test on next pass (inverted logic, so compl)

Go do X translations (if any) at once

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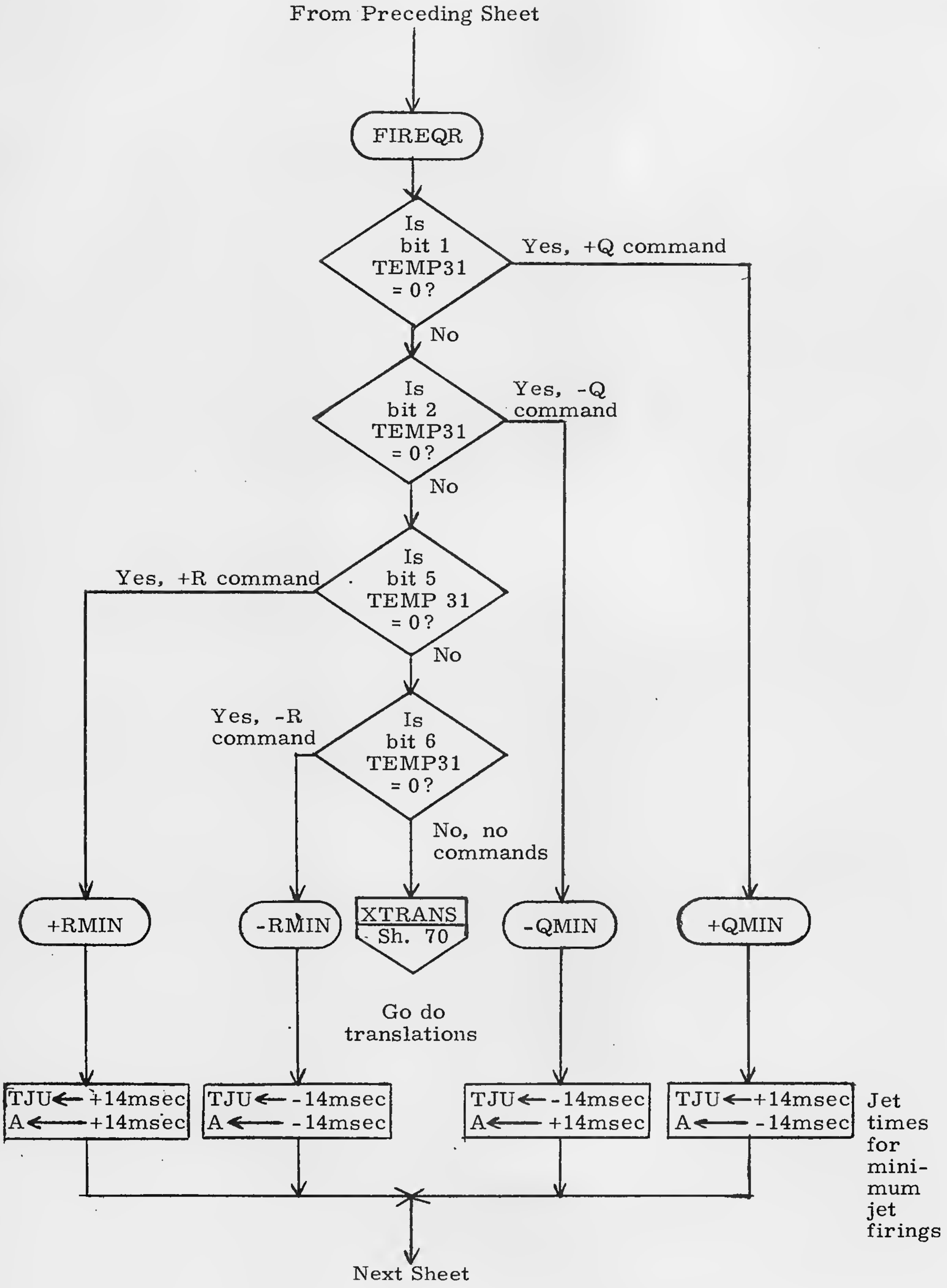

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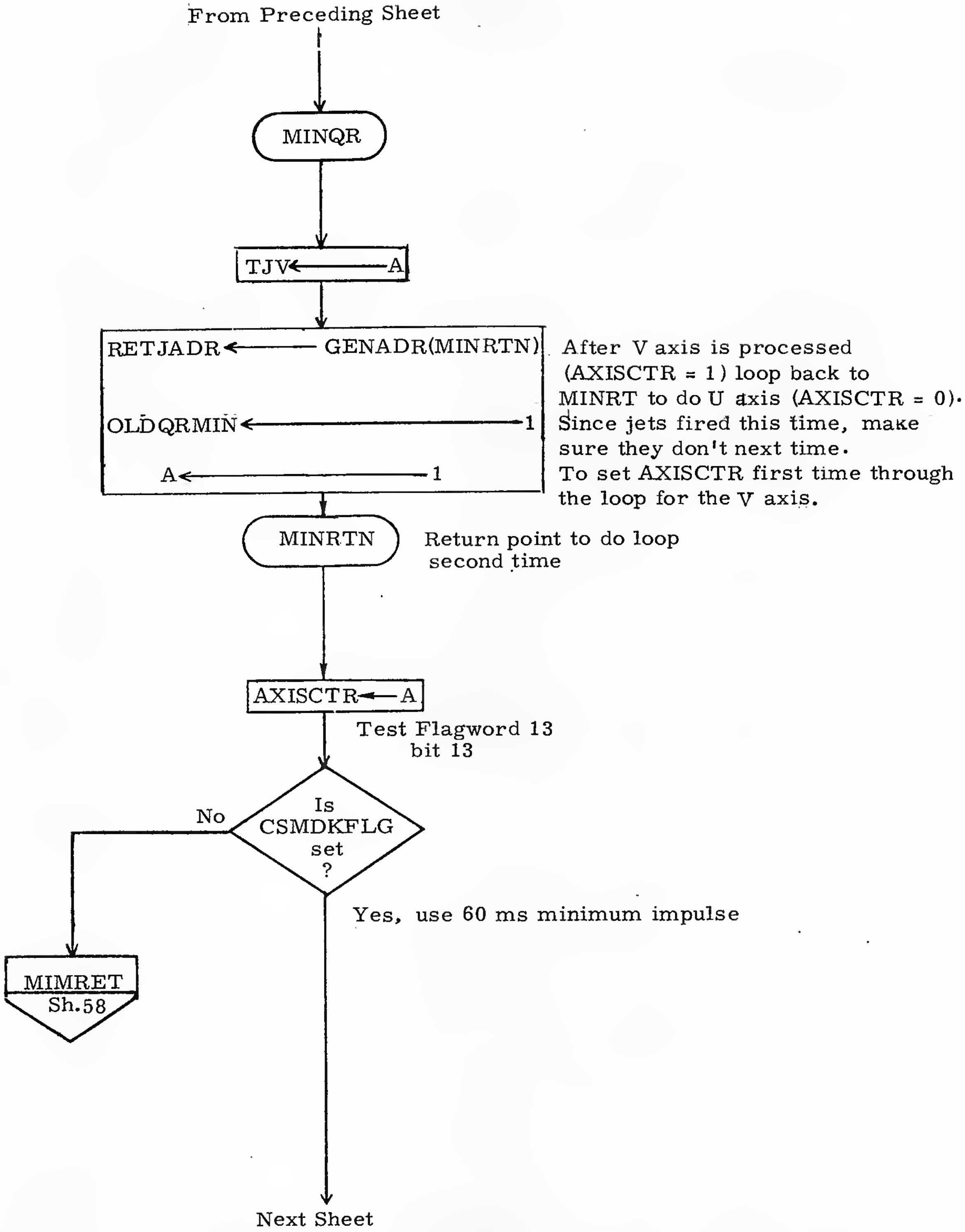

After V axis is processed (AXISCTR = 1) loop back to MINRT to do U axis (AXISCTR = 0).
Since jets fired this time, make sure they don't next time.
To set AXISCTR first time through the loop for the V axis.

Return point to do loop second time

Test Flagword 13 bit 13

Yes, use 60 ms minimum impulse

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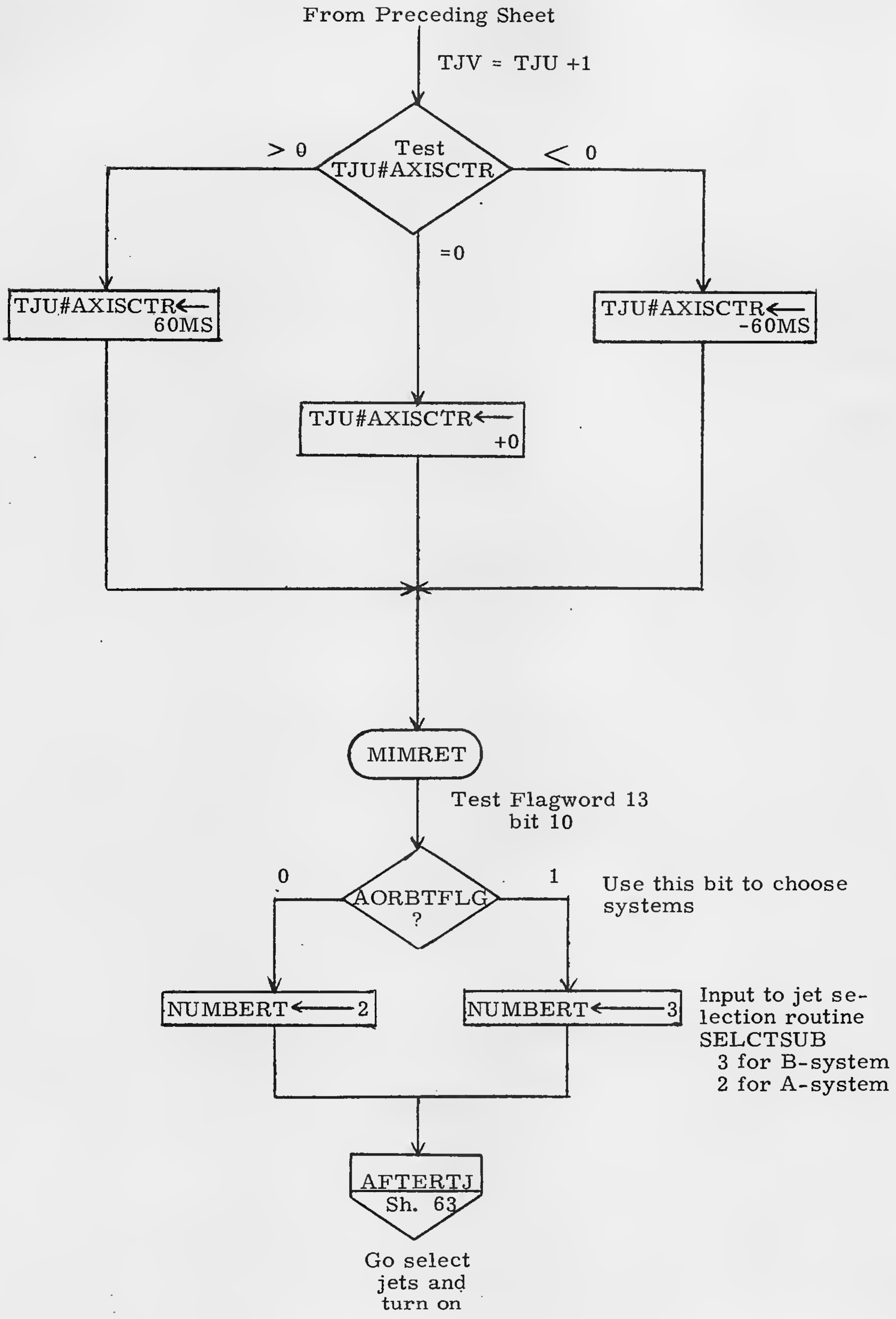

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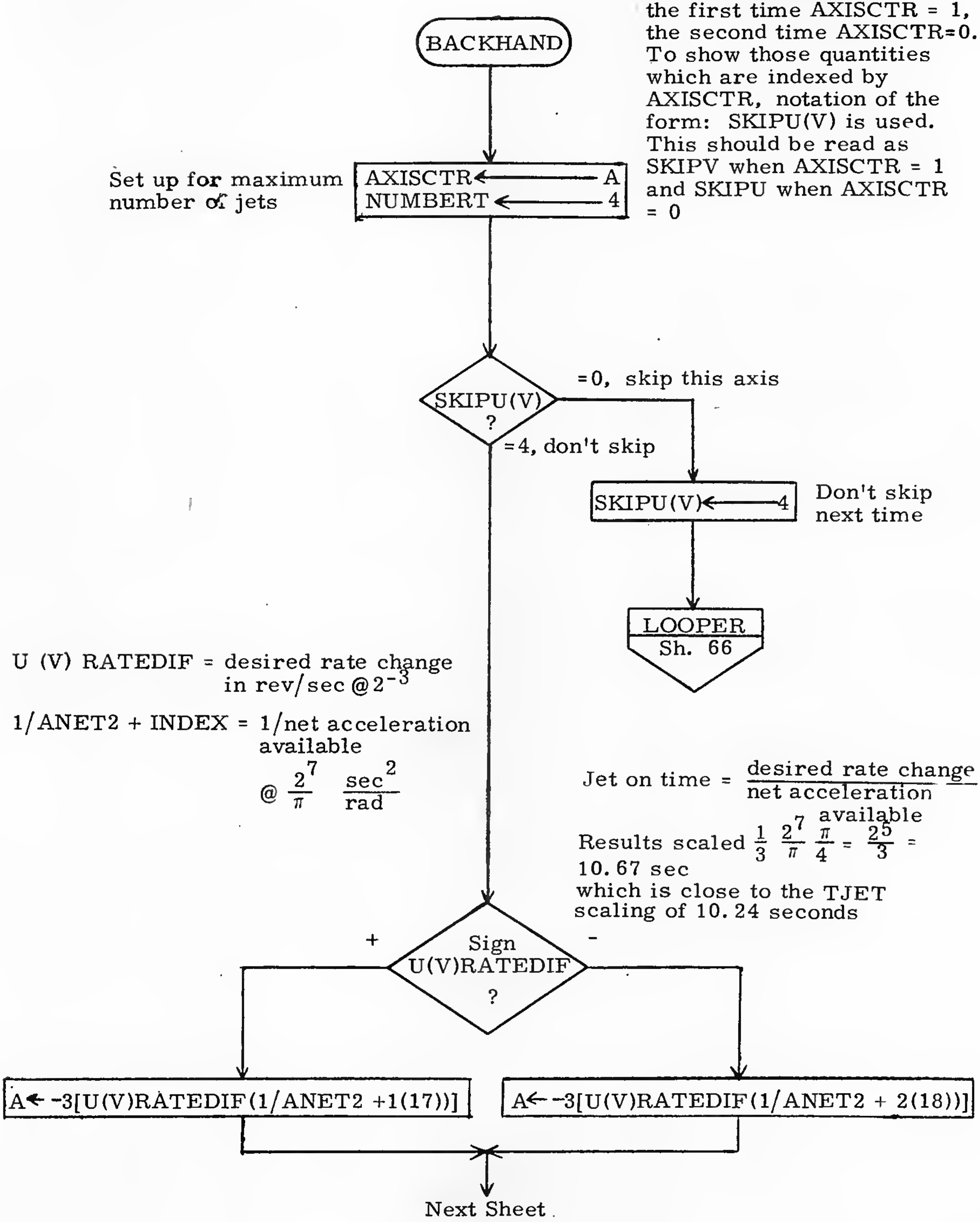
Note: The following section of coding is executed twice; the first time AXISCTR = 1, the second time AXISCTR=0. To show those quantities which are indexed by AXISCTR, notation of the form: SKIPU(V) is used. This should be read as SKIPV when AXISCTR = 1 and SKIPU when AXISCTR = 0



Set up for maximum number of jets

Don't skip next time

U (V) RATEDIF = desired rate change in rev/sec @2^{-3}

1/ANET2 + INDEX = 1/net acceleration available @ $\frac{2^7}{\pi}$ $\frac{\text{sec}^2}{\text{rad}}$

Jet on time = $\frac{\text{desired rate change}}{\text{net acceleration available}}$

Results scaled $\frac{1}{3}\ \frac{2^7}{\pi}\ \frac{\pi}{4} = \frac{2^5}{3} =$ 10.67 sec which is close to the TJET scaling of 10.24 seconds

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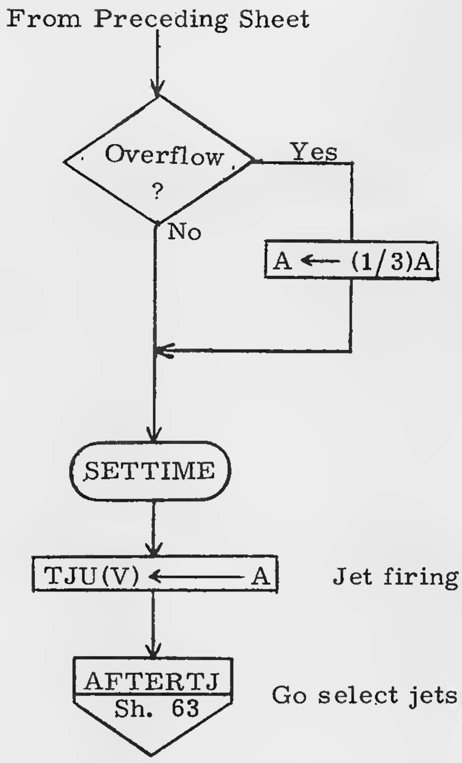
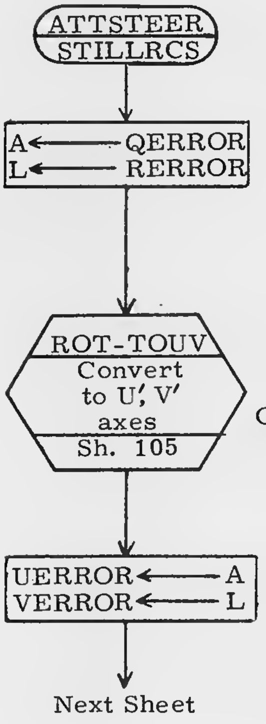


If there is overflow, even 1/3 the correct value will be >150 msec., which is enough to force a full period jet firing

Jet firing time in csec. @ 2^{10}

Go select jets



RCS Attitude Steering

Q axis attitude error
R axis attitude error

Inputs: A containing Q-component
L containing R-component

Outputs: A = U'-component, L = V'-component } in revs @ 2^{-1}

} in revs @ 2^{-1}

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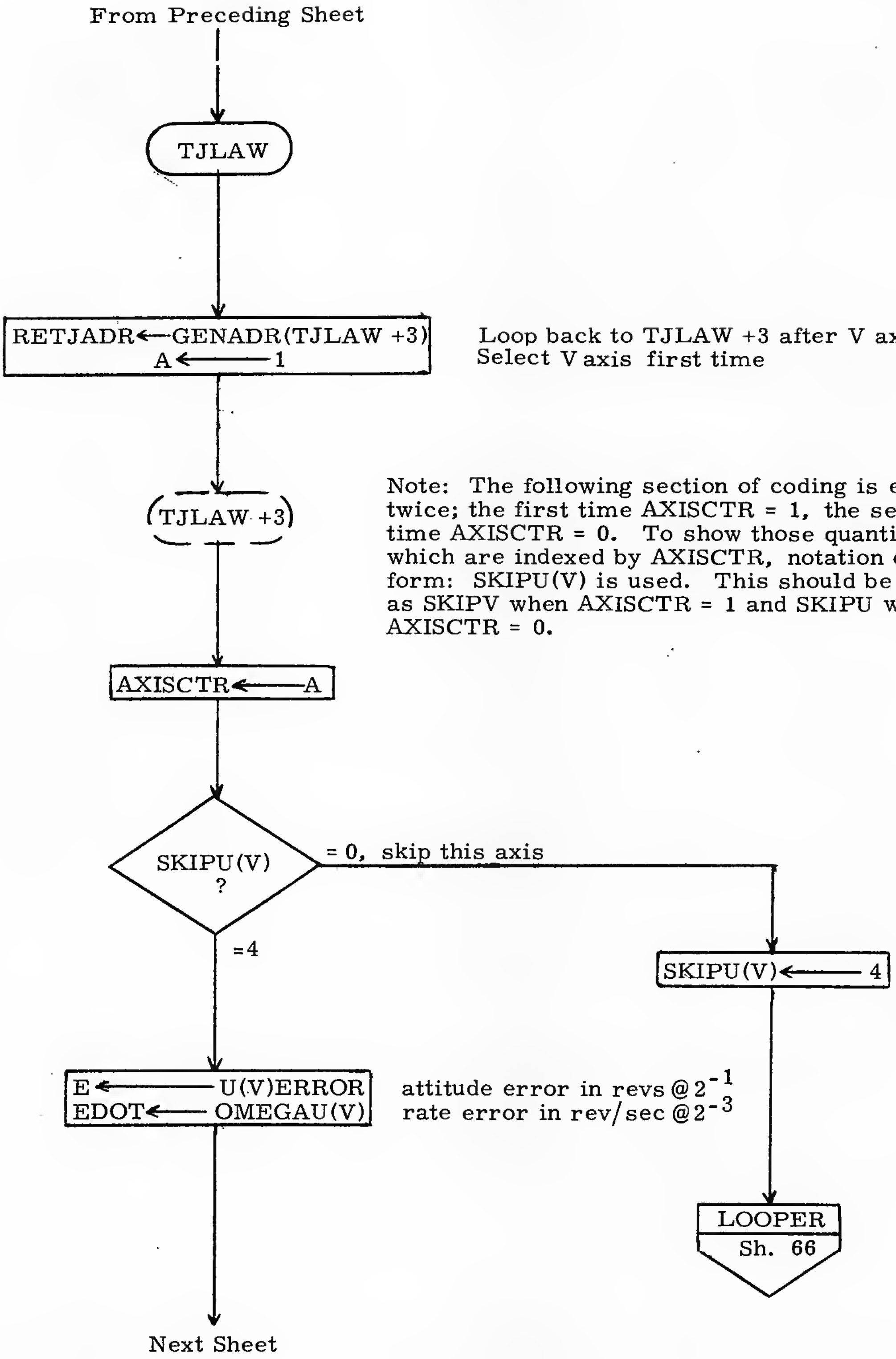

Loop back to TJLAW +3 after V axis done
Select V axis first time

Note: The following section of coding is executed twice; the first time AXISCTR = 1, the second time AXISCTR = 0. To show those quantities which are indexed by AXISCTR, notation of the form: SKIPU(V) is used. This should be read as SKIPV when AXISCTR = 1 and SKIPU when AXISCTR = 0.

Don't skip next time

attitude error in revs @ 2^{-1}
rate error in rev/sec @ 2^{-3}

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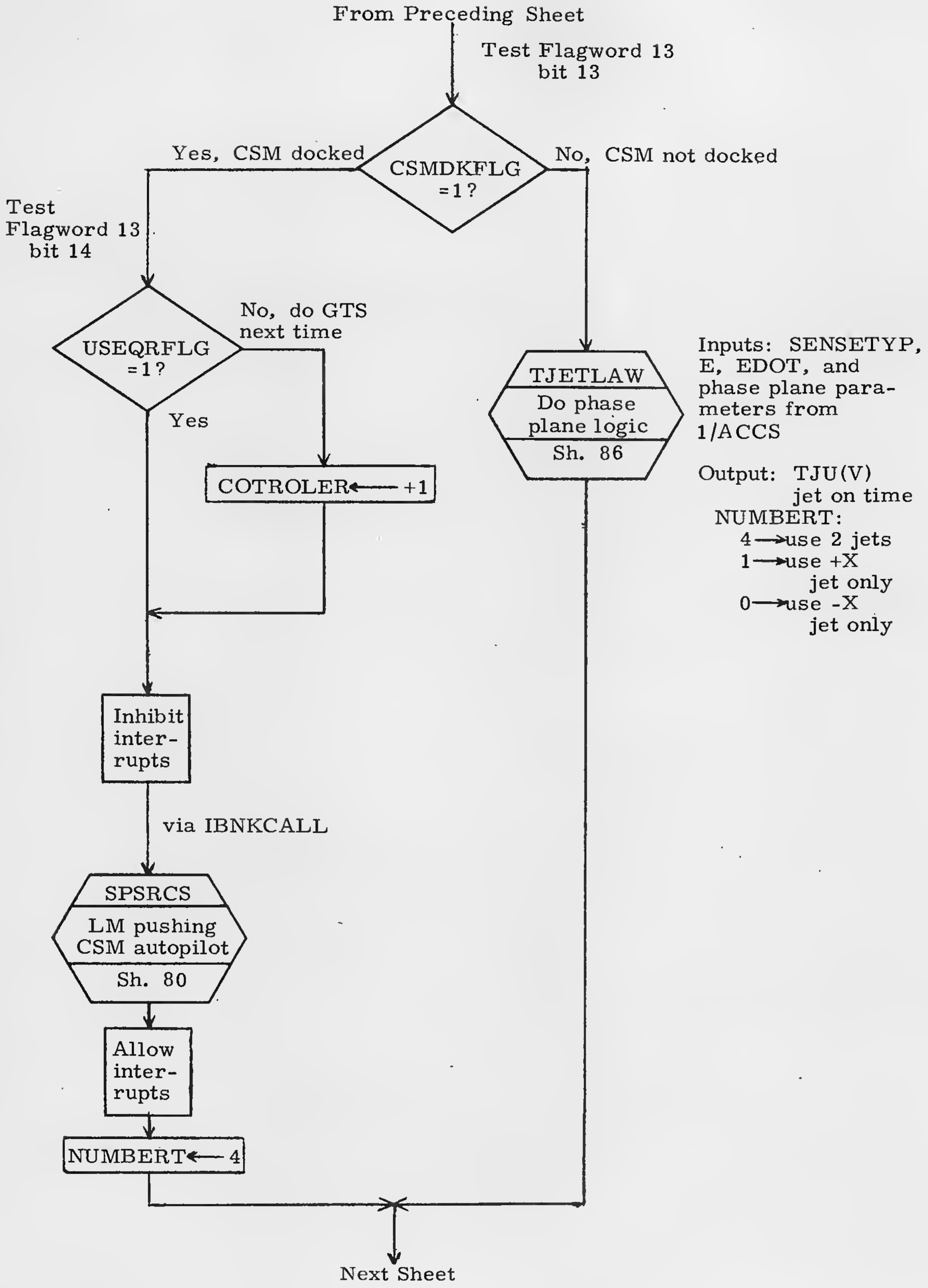

Inputs: SENSETYP, E, EDOT, and phase plane parameters from 1/ACCS

Output: TJU(V) jet on time

NUMBERT:
4 → use 2 jets
1 → use +X jet only
0 → use -X jet only

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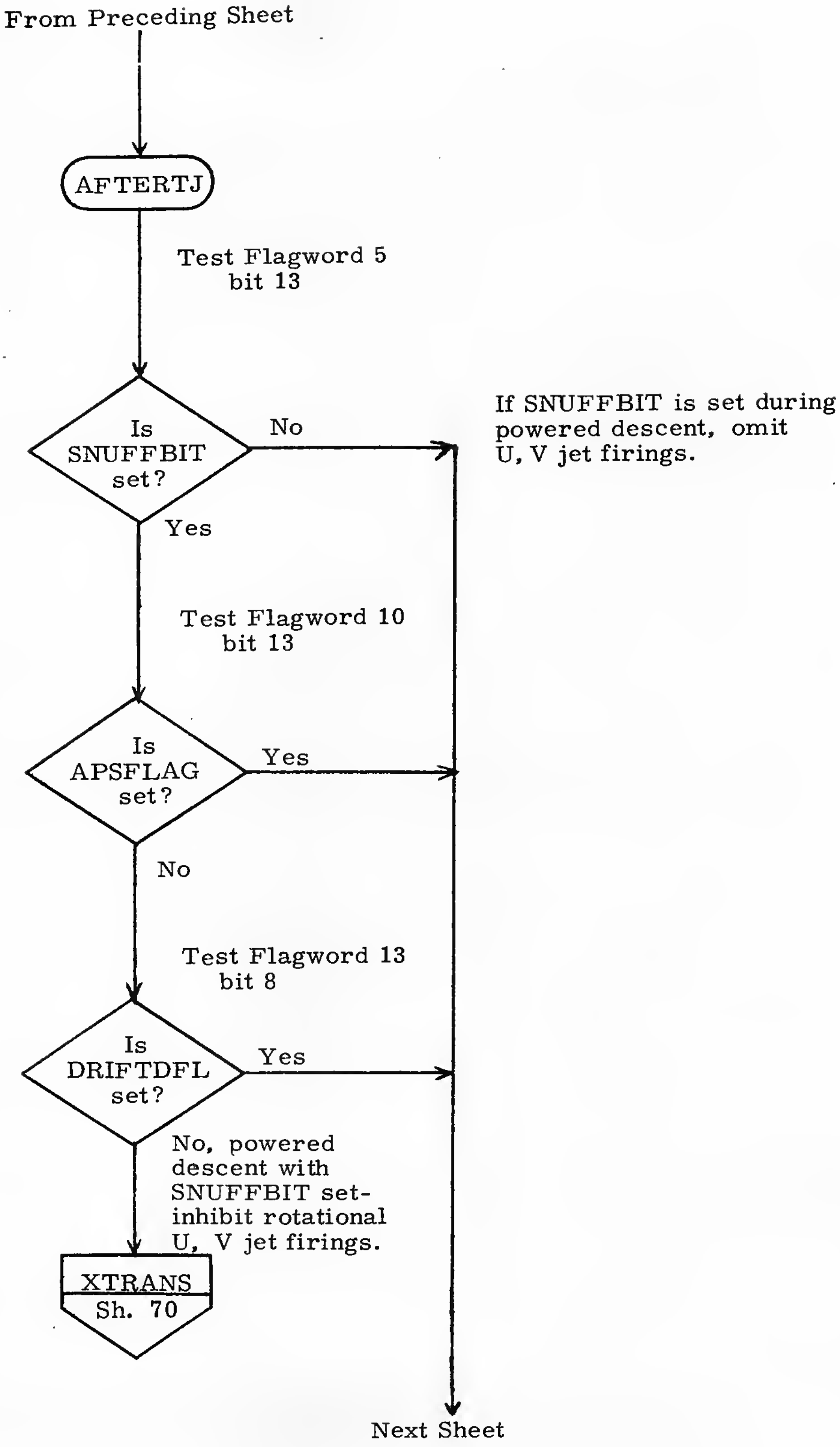

If SNUFFBIT is set during powered descent, omit U, V jet firings.

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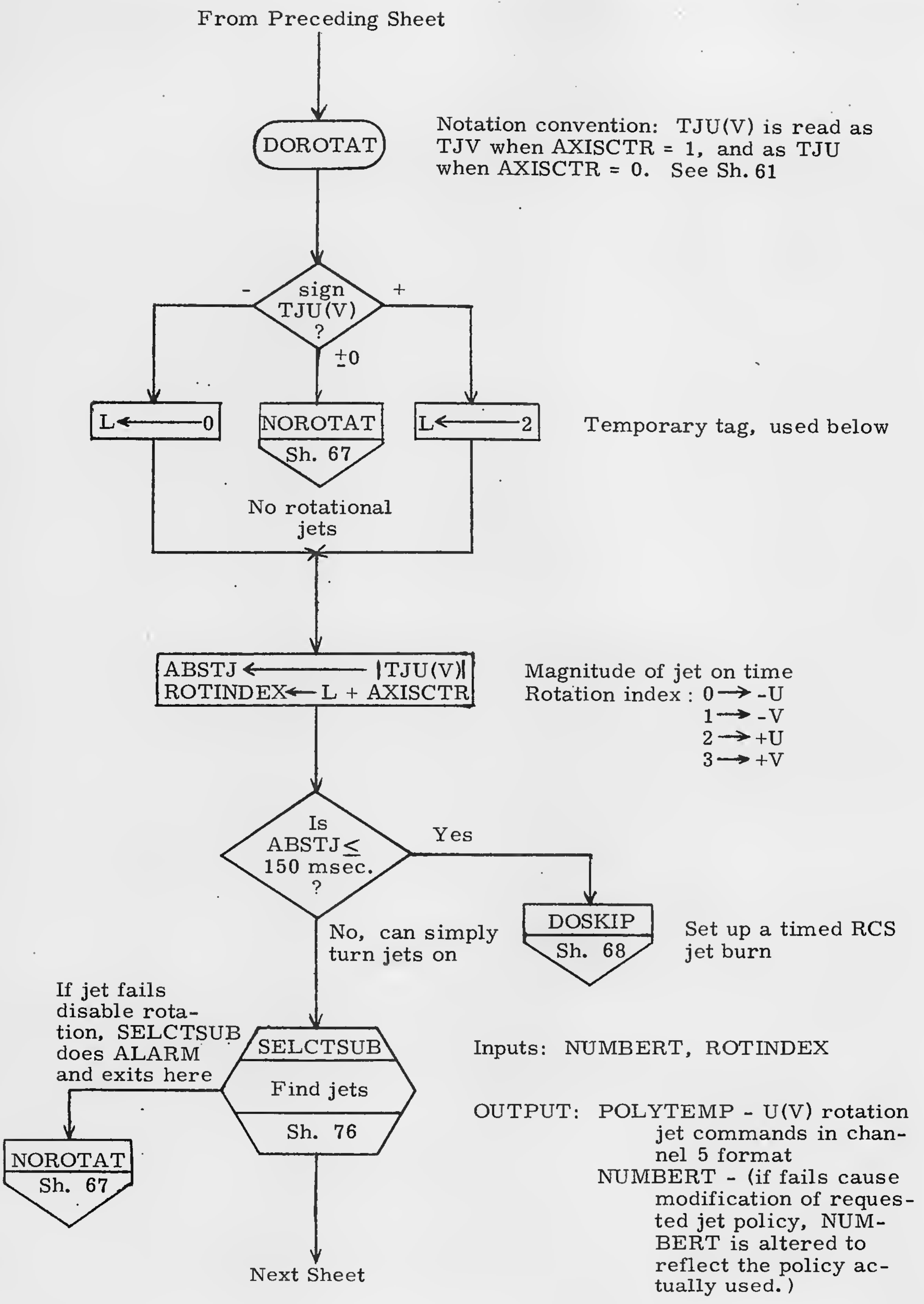

Notation convention: TJU(V) is read as TJV when AXISCTR = 1, and as TJU when AXISCTR = 0. See Sh. 61

Temporary tag, used below

Magnitude of jet on time

Rotation index : 0 → -U
1 → -V
2 → +U
3 → +V

Set up a timed RCS jet burn

If jet fails disable rotation, SELCTSUB does ALARM and exits here

Inputs: NUMBERT, ROTINDEX

OUTPUT: POLYTEMP - U(V) rotation jet commands in channel 5 format
NUMBERT - (if fails cause modification of requested jet policy, NUMBERT is altered to reflect the policy actually used.)

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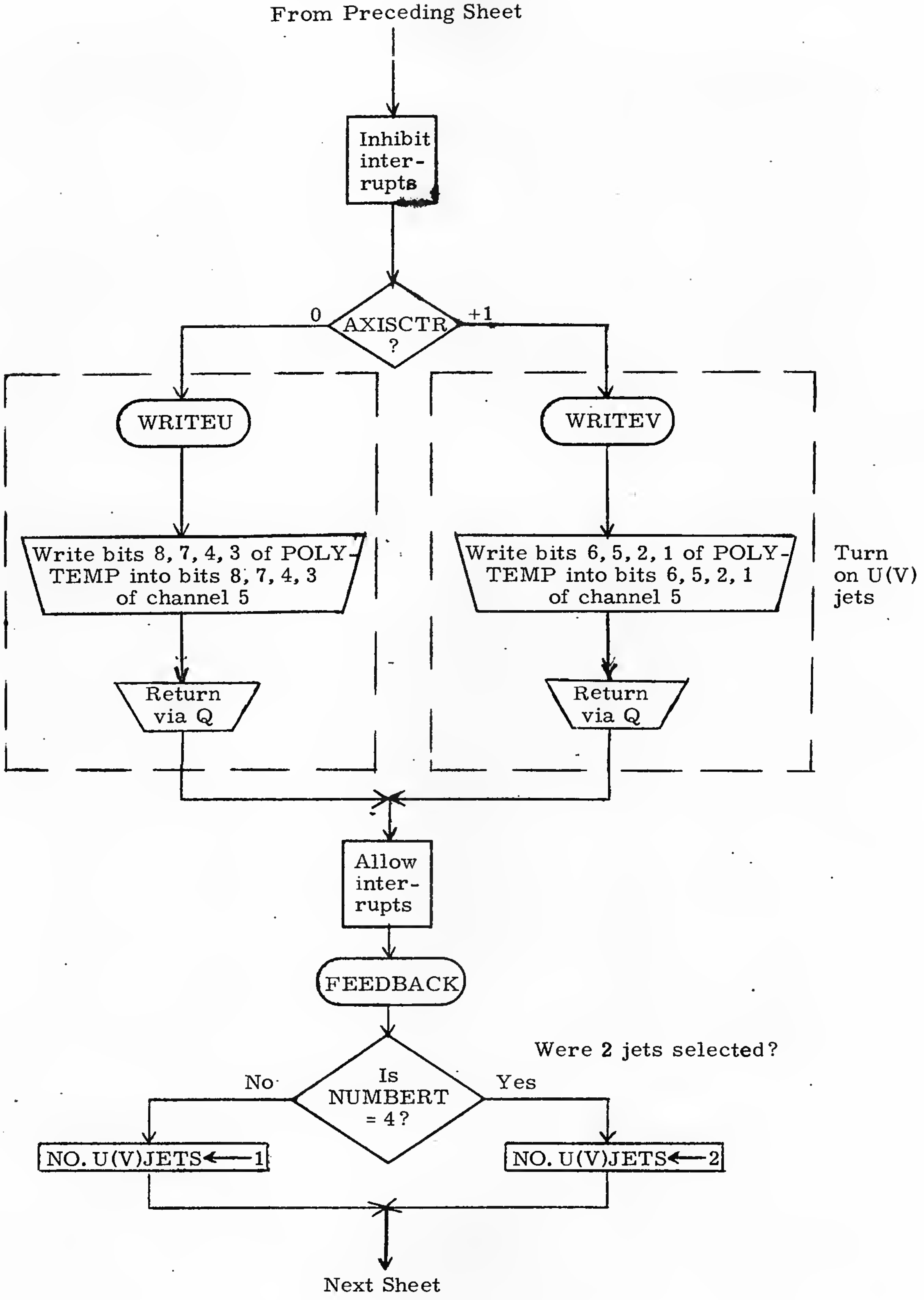

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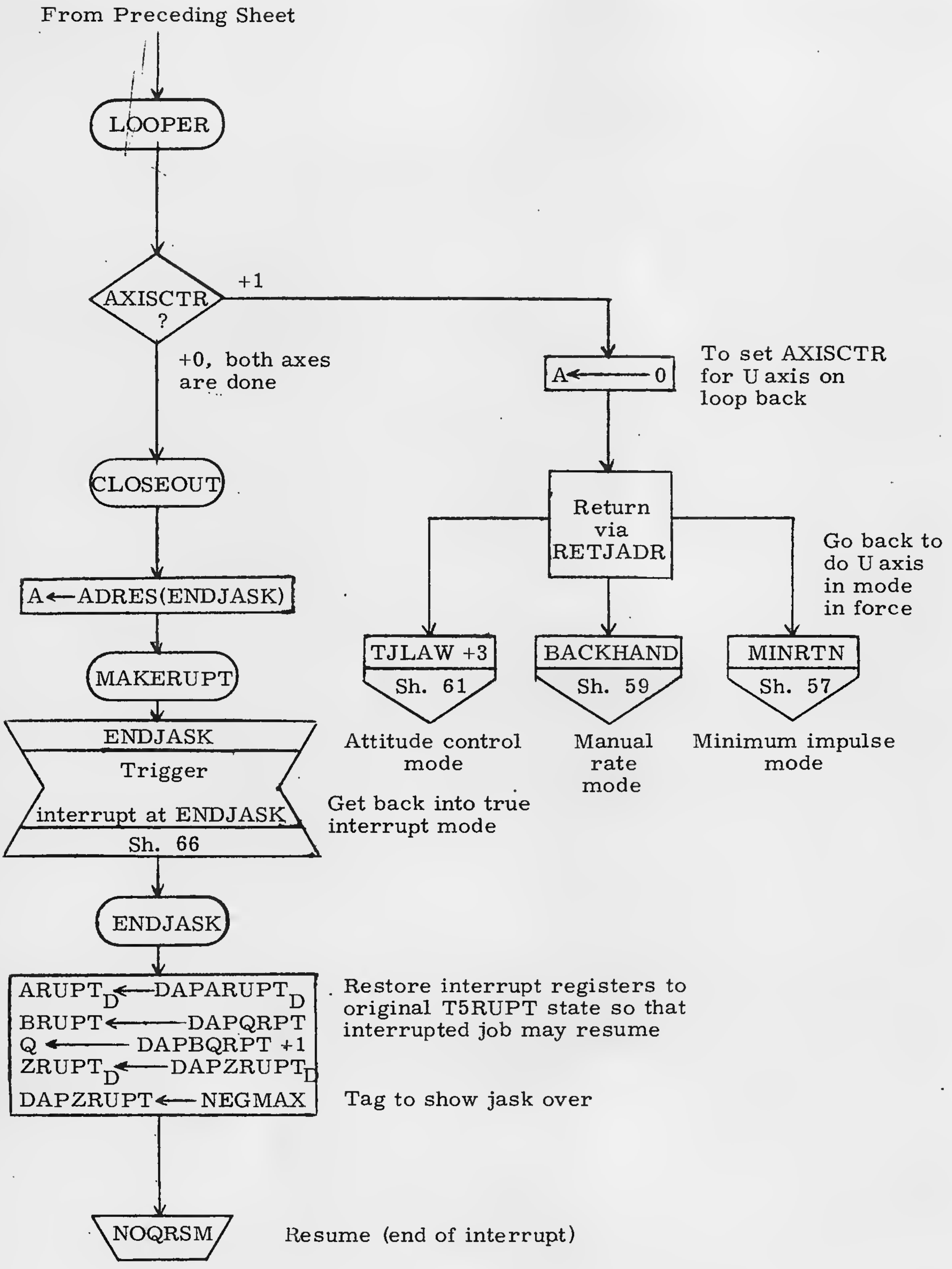

To set AXISCTR for U axis on loop back

Go back to do U axis in mode in force

Attitude control mode

Manual rate mode

Minimum impulse mode

Get back into true interrupt mode

Restore interrupt registers to original T5RUPT state so that interrupted job may resume

Tag to show jask over

Resume (end of interrupt)

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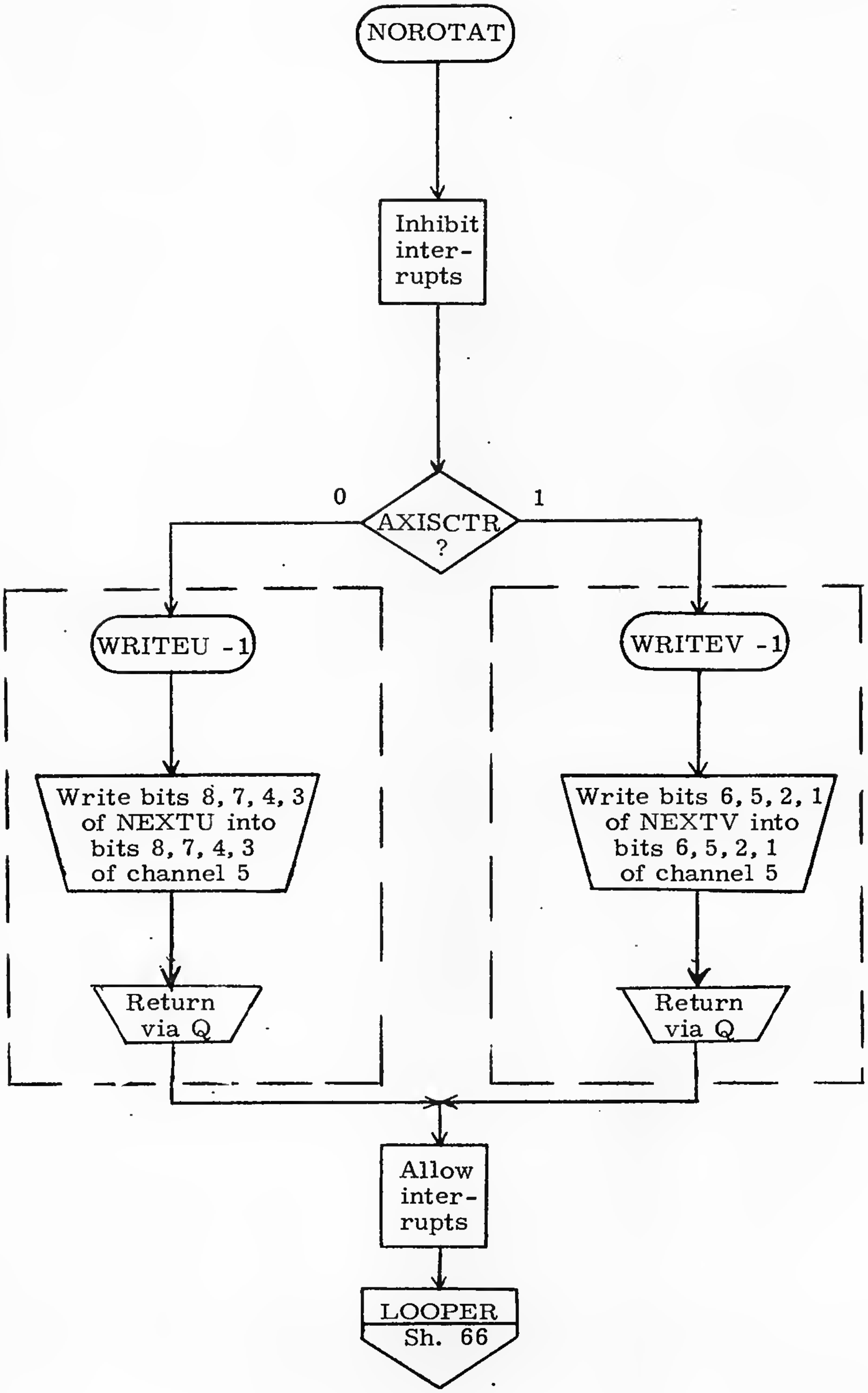

Since there are no rotation commands, turn on translation jets at once

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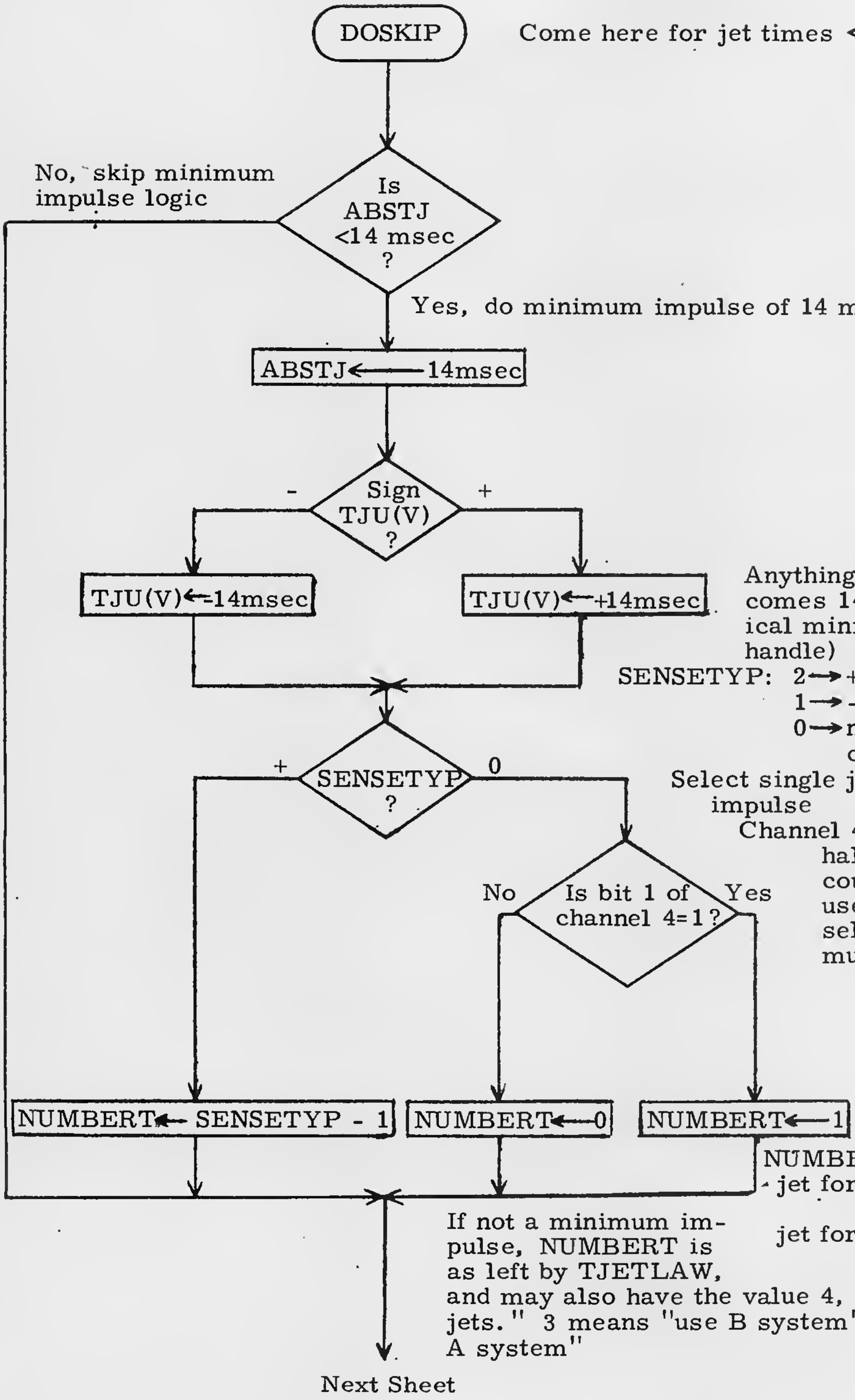

Come here for jet times <150 msec.

Anything <14 msec. becomes 14 msec. (theoretical minimum the jets can handle)

SENSETYP: 2 → +X or ascent burn
1 → -X
0 → no ±X trans or ascent burn

Select single jet for minimum impulse

Channel 4 is the low order half of a 33 stage counter. Bit 1 is used for "random" selection of minimum impulse jets.

NUMBERT: 1 → use +X jet for U(V) rotation
0 → use -X jet for U(V) rotation

If not a minimum impulse, NUMBERT is as left by TJETLAW, and may also have the value 4, meaning "use 2 jets." 3 means "use B system"; 2 means "use A system"

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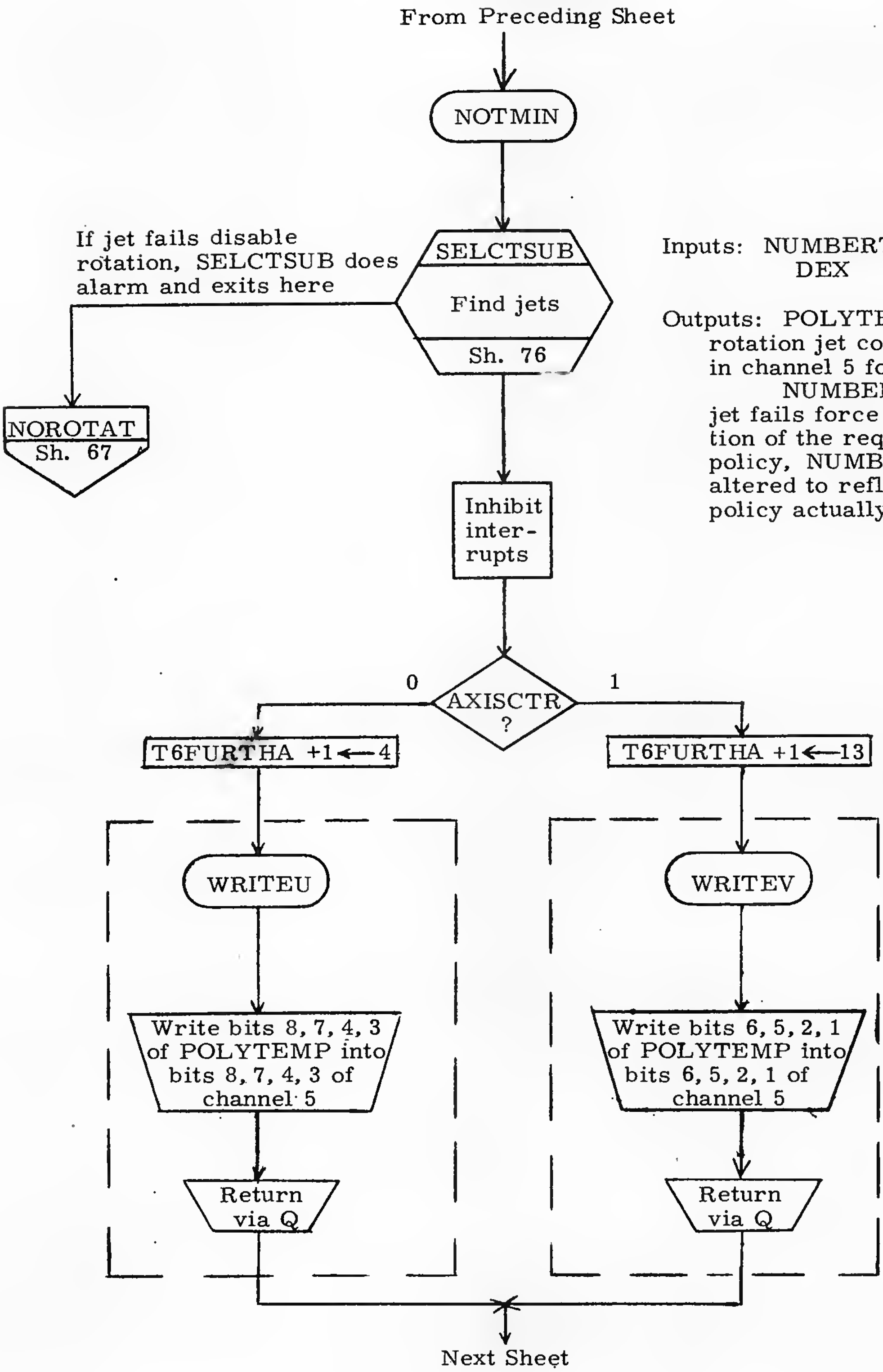

If jet fails disable rotation, SELCTSUB does alarm and exits here

Inputs: NUMBERT, ROTINDEX

Outputs: POLYTEMP : U(V) rotation jet commands in channel 5 format
NUMBERT : if jet fails force modification of the requested jet policy, NUMBERT is altered to reflect the policy actually used.

Axis tag for T6jet turnoff routine (T6JOB) to use to select the axis for which jets are to be turned off.

Turn on U(V) jets

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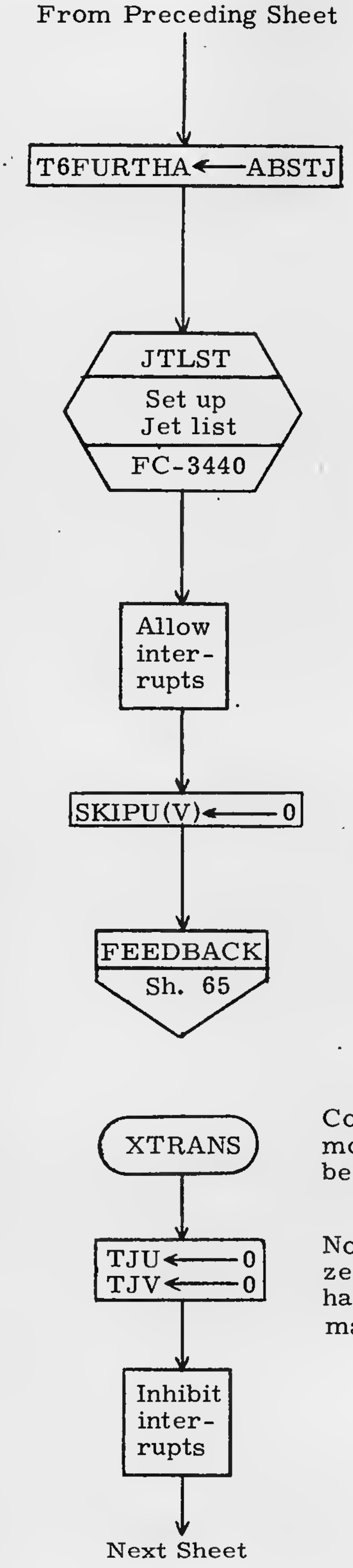

Δ time at which T6JOB should turn off jets for this axis

Put this turn-off request in proper chronological order with respect to other requests.

Skip this axis the next time (note that this is the only place that SKIPU(V) is set to zero)

Come here in manual modes if no rotations are to be done to do translations

No rotations in U or V axes - zero times so rate estimator has accurate jet firing information.

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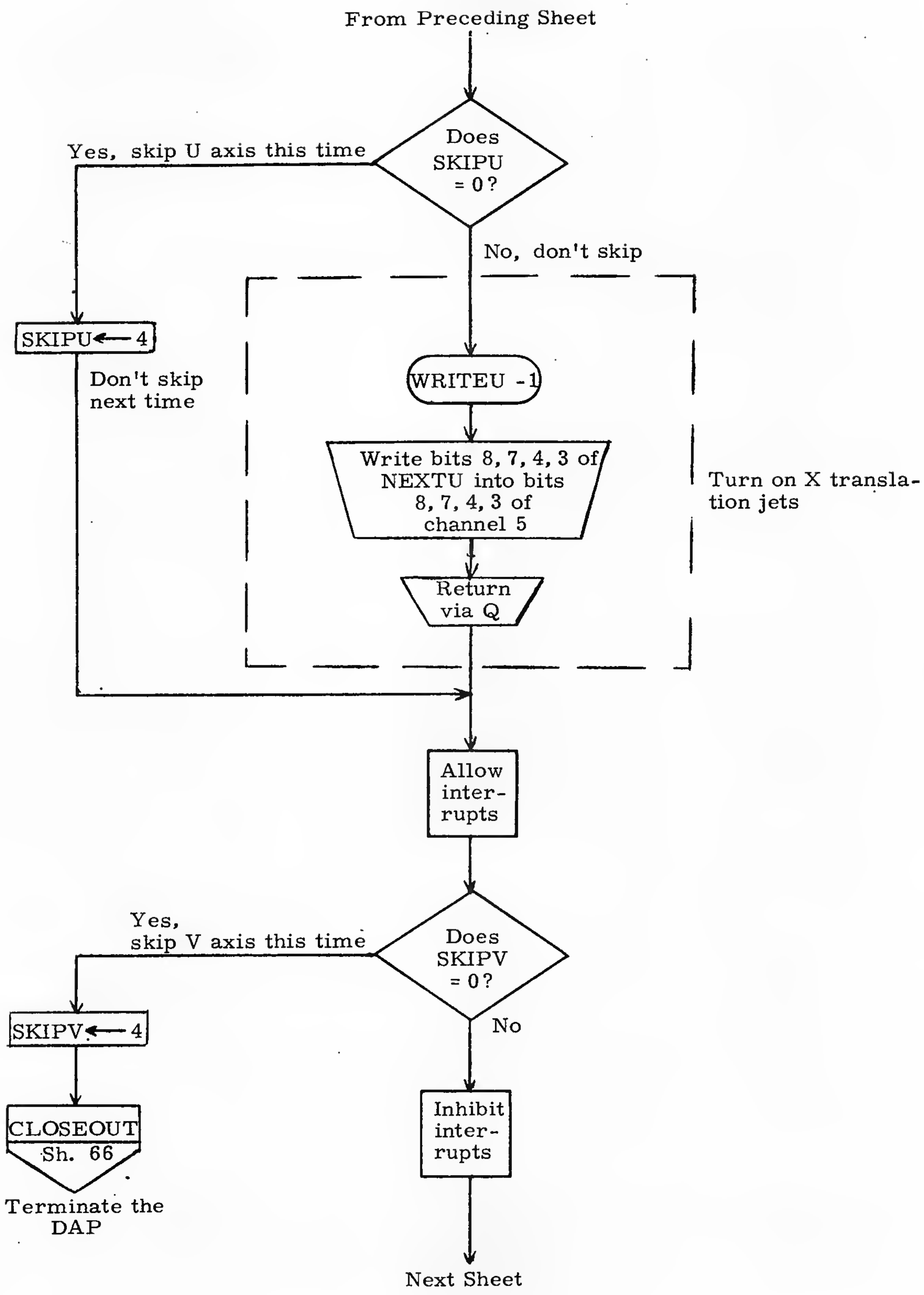

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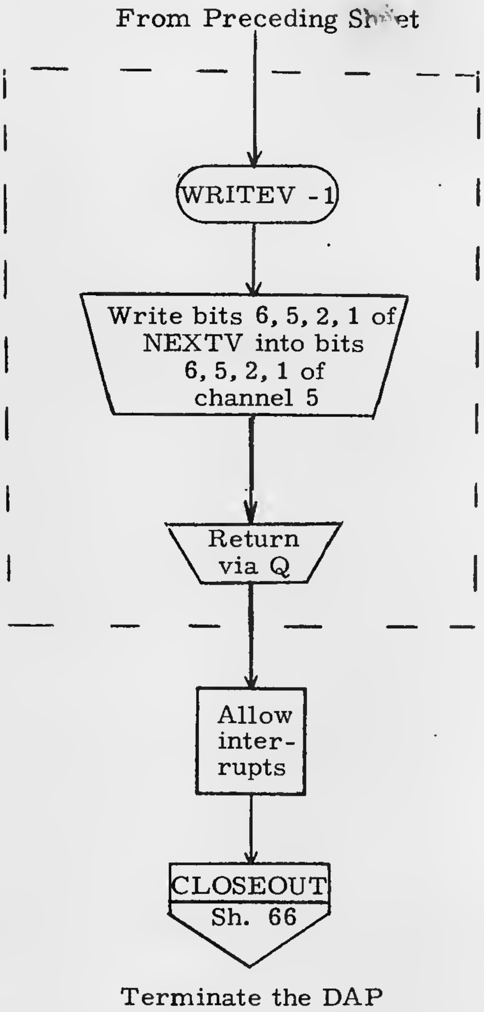
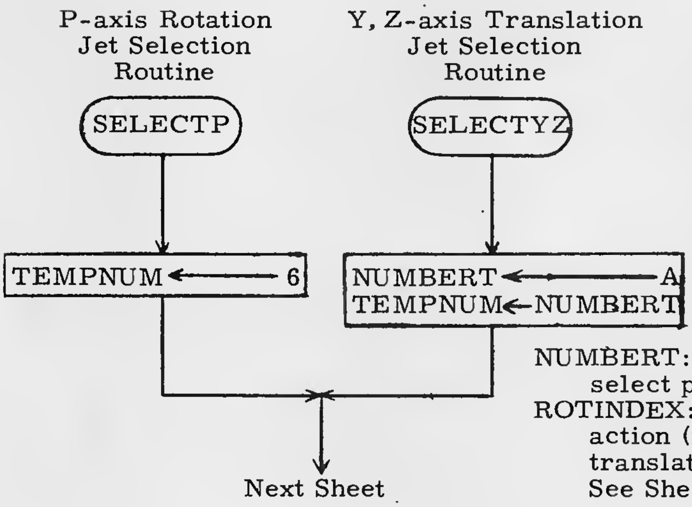


Turn on X translation jets



For SELECTYZ enter with desired value for NUMBERT in A. Otherwise, inputs are the following:

NUMBERT: index for jet select policy
ROTINDEX: index for reaction (rotation or translation) desired See Sheet 75

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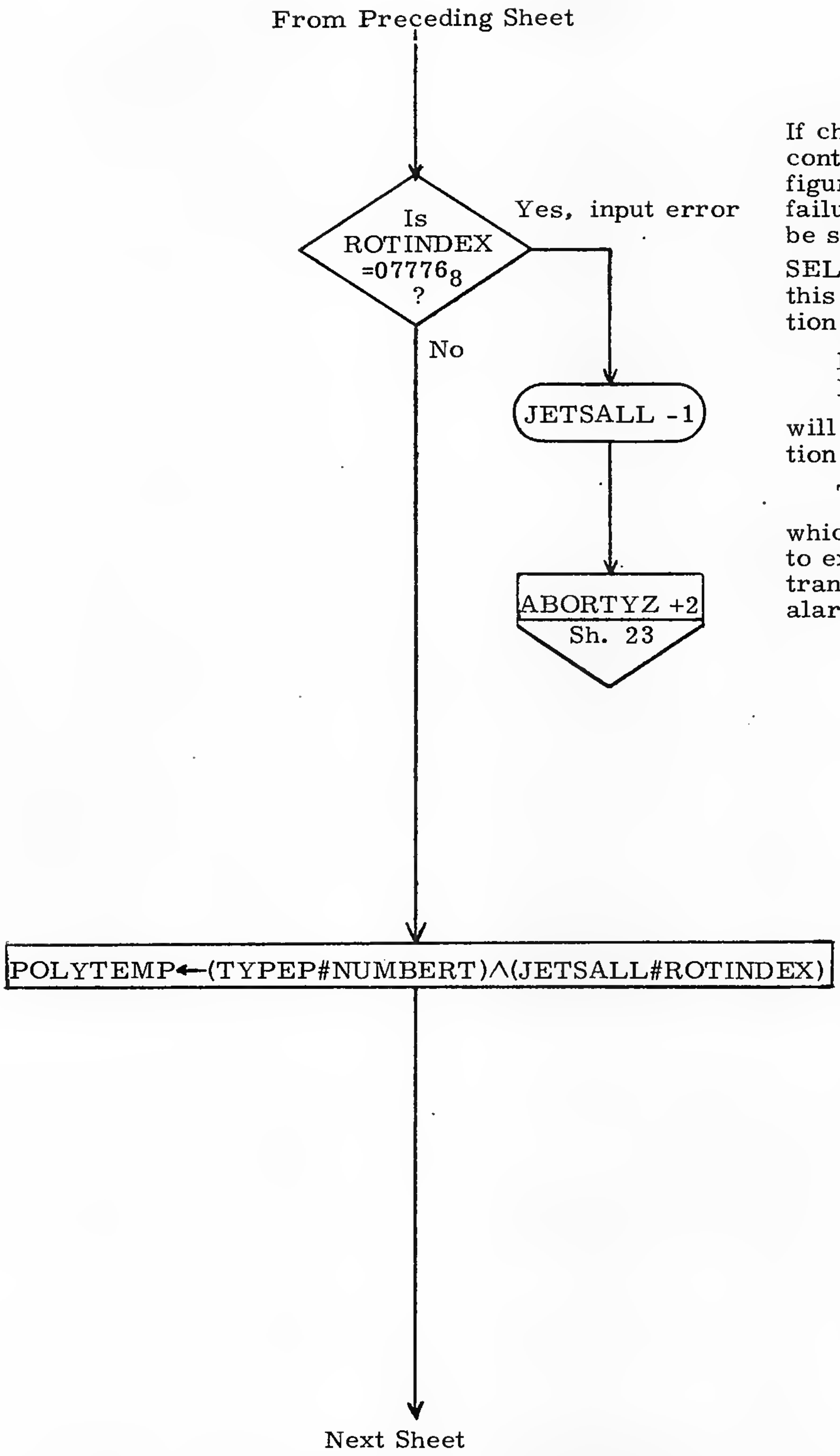


If channel 31 bits 12-9 contains an invalid configuration (due to switch failure), ROTINDEX will be set to 07776_8 before SELECTYZ is called. If this occurs, the instruction sequence:

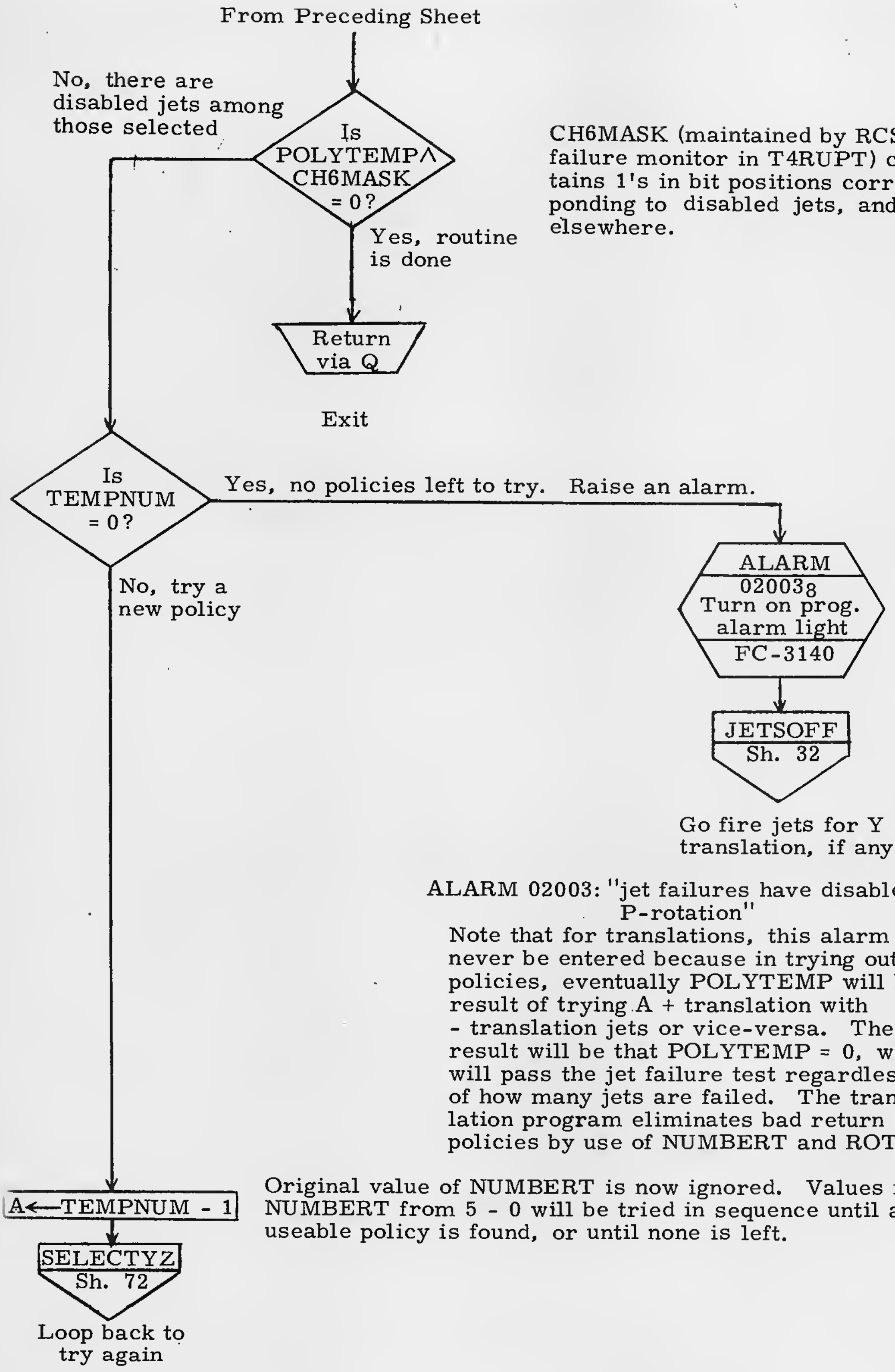
```
INDEX    ROTINDEX
MASK     JETSALL
```

will become the instruction

```
TC       JETSALL -1
```

which causes the routine to exit, skipping the translation, but with no alarm

# denotes indexing. ∧ denotes logical "and", implemented by the mask instruction. POLYTEMP now has only those bits set appropriate to both the reaction desired and the jet policy desired, formatted for writing into channel 6.



CH6MASK (maintained by RCS failure monitor in T4RUPT) contains 1's in bit positions corresponding to disabled jets, and zeros elsewhere.

ALARM 02003: "jet failures have disabled P-rotation"
Note that for translations, this alarm will never be entered because in trying out policies, eventually POLYTEMP will be the result of trying A + translation with - translation jets or vice-versa. The result will be that POLYTEMP = 0, which will pass the jet failure test regardless of how many jets are failed. The translation program eliminates bad return policies by use of NUMBERT and ROTINDEX.

Original value of NUMBERT is now ignored. Values for NUMBERT from 5 - 0 will be tried in sequence until a useable policy is found, or until none is left.

Values for JETSALL (indexed by ROTINDEX)

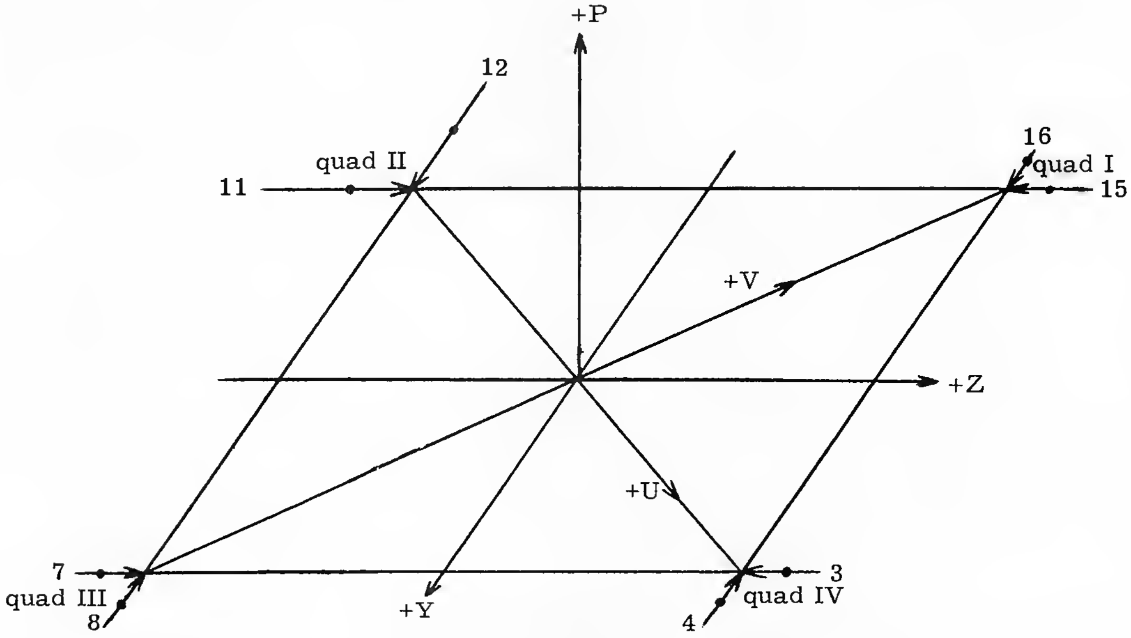
	Octal value	Jets	Reaction
JETSALL	00252	16, 8, 11, 3	-P rot.
+1	00125	4, 12, 15, 7	+P rot.
+2	00140	4, 8	-Y trans.
+3	00006	15, 3	-Z trans.
+4	00220	16, 12	+Y trans.
+5	00011	11, 7	+Z trans.
+6	00151	4, 8, 11, 7	+V trans.
+7	00146	4, 8, 15, 3	-U trans.
+8	00226	16, 12, 15, 3	-V trans.
+9	00231	16, 12, 11, 7	+U trans.
+10D	00151	4, 8, 11, 7	+V trans.

Channel 6 bit assignments

Bit no.	8	7	6	5	4	3	2	1
Jet no.	16	4	8	12	11	15	3	7

Values for TYPEP (indexed by NUMBERT)

	Octal value	Jets	Reaction
TYPEP	00146	4, 8, 15, 3	-U jets
+1	00226	16, 12, 15, 3	-V jets
+2	00231	16, 12, 11, 7	+U jets
+3	00151	4, 8, 11, 7	+V jets
+4	00132	4, 12, 11, 3	quads II & IV
+5	00245	16, 8, 15, 7	quads I & III
+6	00377	16, 4, 8, 12 11, 15, 3, 7	all



P-jet configuration for LM with P rotational axis, and U, V, Y, Z translational axes

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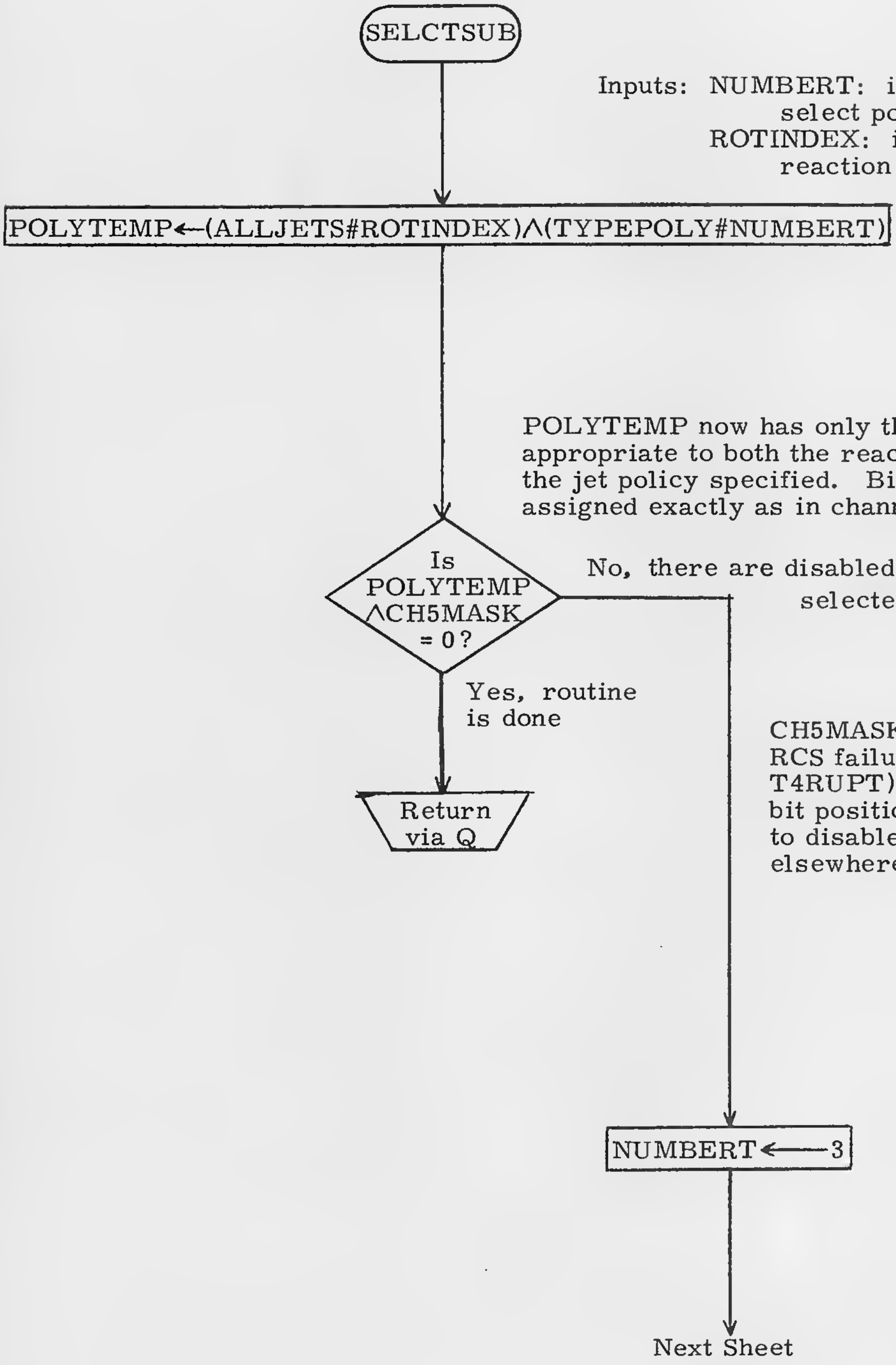
Q, R Rotation
and X Translation
Jet Selection Routine



Inputs: NUMBERT: index for jet select policy
ROTINDEX: index for desired reaction

\# denotes indexing
∧ denotes logical "and", implemented by the mask instruction.

POLYTEMP now has only those bits set appropriate to both the reaction desired and the jet policy specified. Bit positions are assigned exactly as in channel 5.

CH5MASK (maintained by RCS failure monitor in T4RUPT) contains 1's in bit positions corresponding to disabled jets, and 0's elsewhere.

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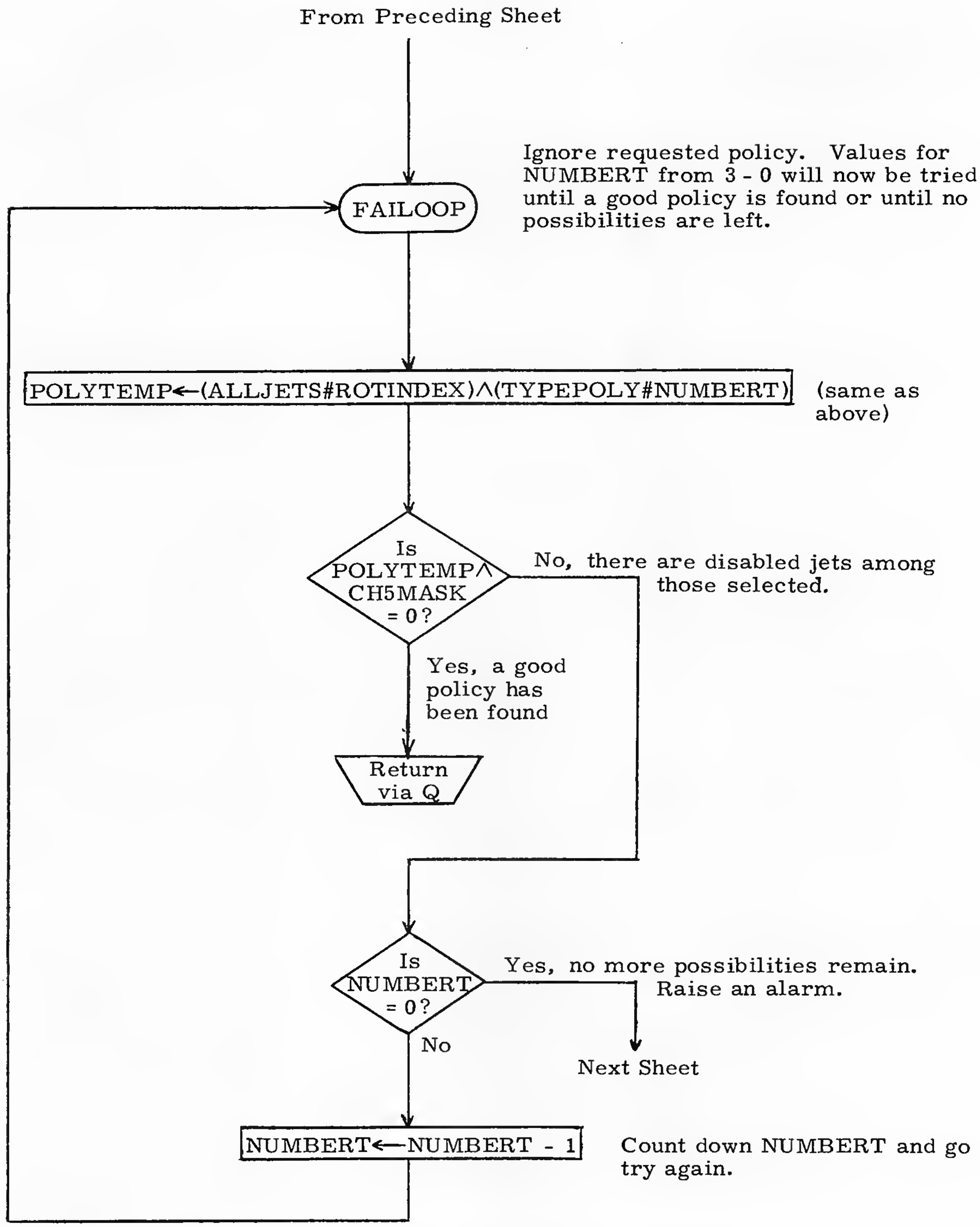

Ignore requested policy. Values for NUMBERT from 3 - 0 will now be tried until a good policy is found or until no possibilities are left.

(same as above)

Count down NUMBERT and go try again.

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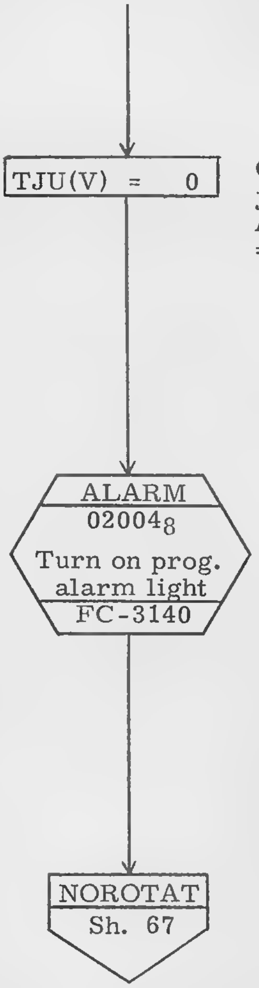

Cannot fire jets, so effective jet-on time is 0. TJU if AXISCTR = 0; TJV if AXISCTR = 1.

ALARM 02004: "jet failures have disabled U-V rotations."
Note that for translations, this alarm will never be entered, because before NUMBERT becomes 0, a policy will have been tried which involves doing +X translations with -X jets or vice-versa. The result will be that POLYTEMP = 0, which will pass the jet failure test regardless of how many jets are failed. The routine then returns. POLYTEMP = 0 will indicate to the calling program that a good jet policy for translation could not be found.

Continue as if no rotations had been commanded for this axis.

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Values for ALLJETS (indexed by ROTINDEX)

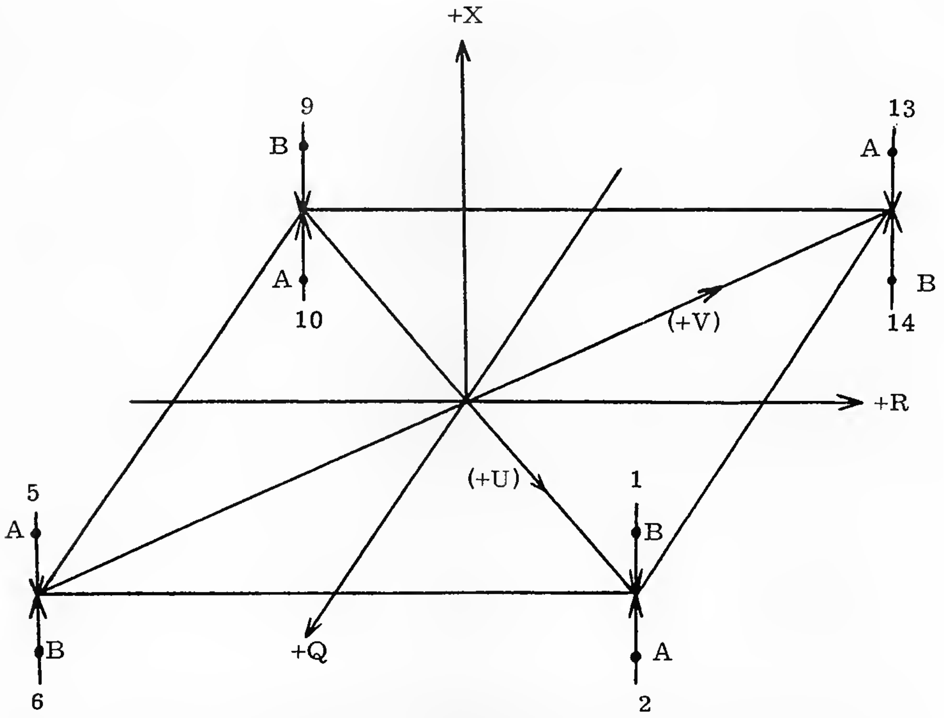
	Octal value	Jets	Reaction
ALLJETS	00110	13, 6	-U rot.
+1	00022	9, 2	-V rot.
+2	00204	14, 5	+U rot.
+3	00041	10, 1	+V rot.
+4	00125	13, 9, 5, 1	-X trans.
+5	00252	14, 10, 6, 2	+X trans.

Channel 5 bit assignments

Bit no.	8	7	6	5	4	3	2	1
Jet no.	14	13	10	9	6	5	2	1

Values for TYPEPOLY (indexed by NUMBERT)

	Octal value	Jets	Policy
TYPEPOLY	00125	13, 9, 5, 1	-X jets
+1	00252	14, 10, 6, 2	+X jets
+2	00146	13, 10, 5, 2	system A jets
+3	00231	14, 9, 6, 1	system B jets
+4	00377	14, 13, 10, 9 6, 5, 2, 1	all jets



U-V Jet Configuration

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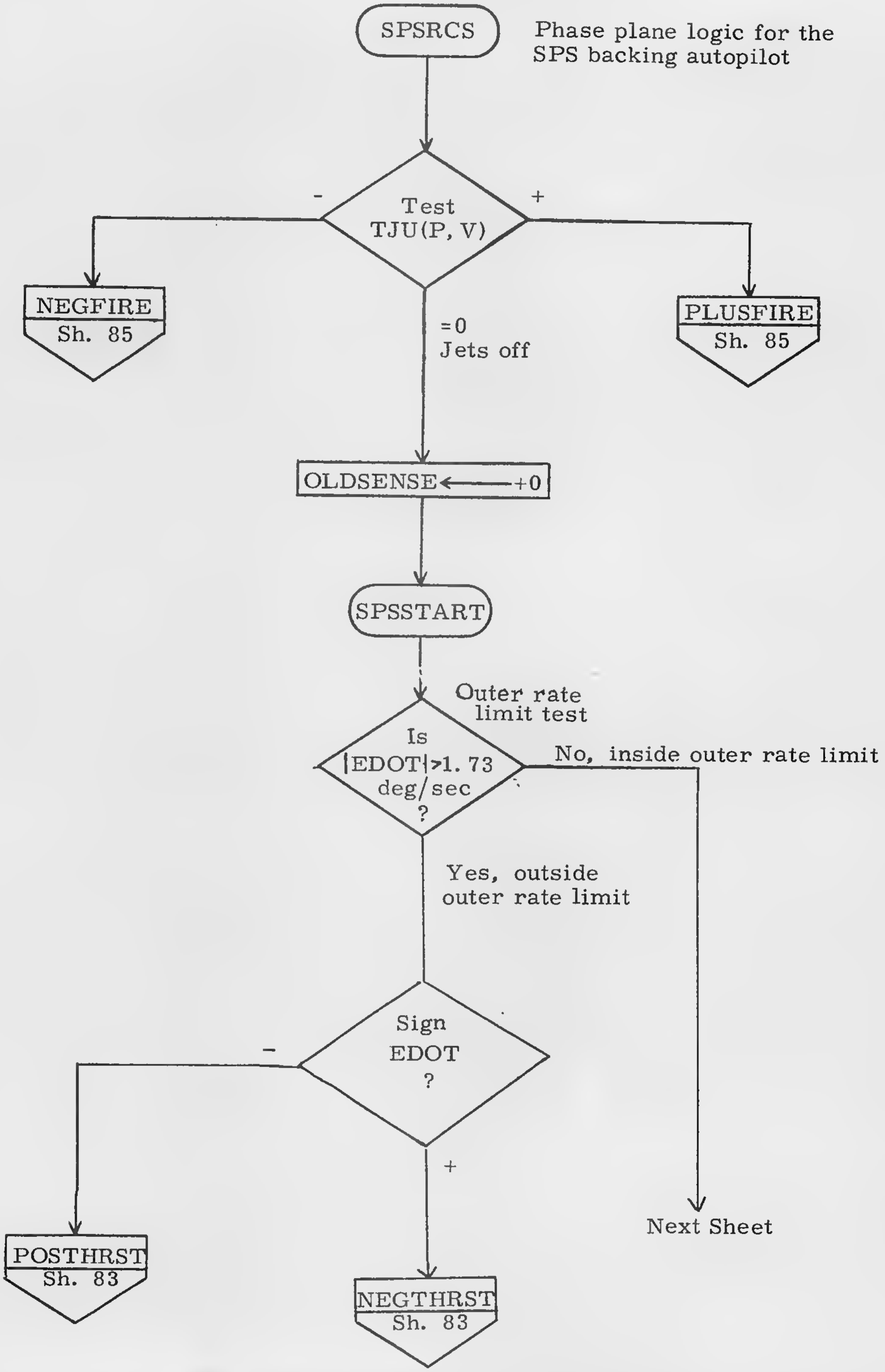

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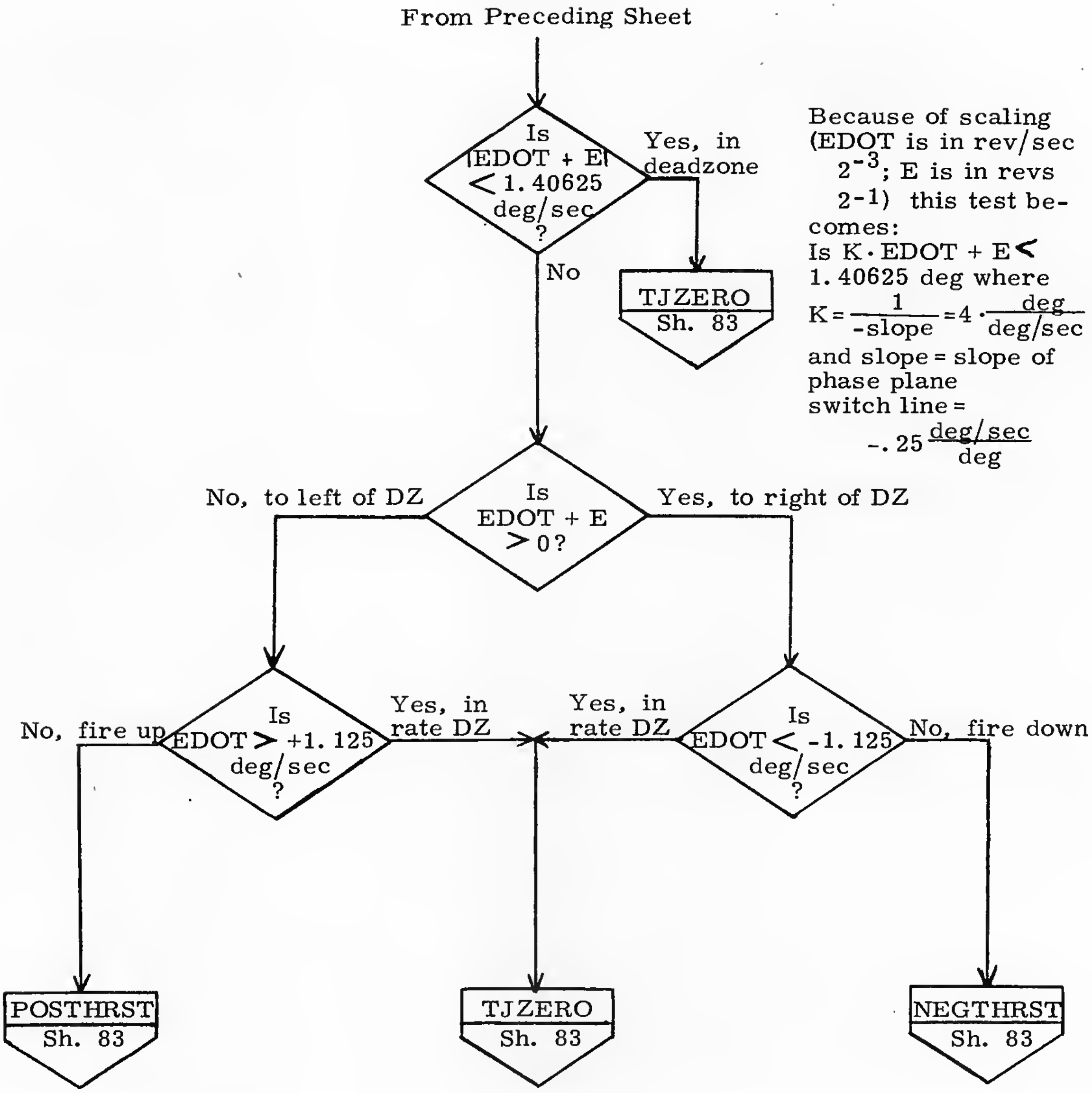

Because of scaling (EDOT is in rev/sec 2^{-3}; E is in revs 2^{-1}) this test becomes: Is $K \cdot EDOT + E <$ 1.40625 deg where $K = \frac{1}{-slope} = 4 \cdot \frac{deg}{deg/sec}$ and slope = slope of phase plane switch line = $-.25 \frac{deg/sec}{deg}$

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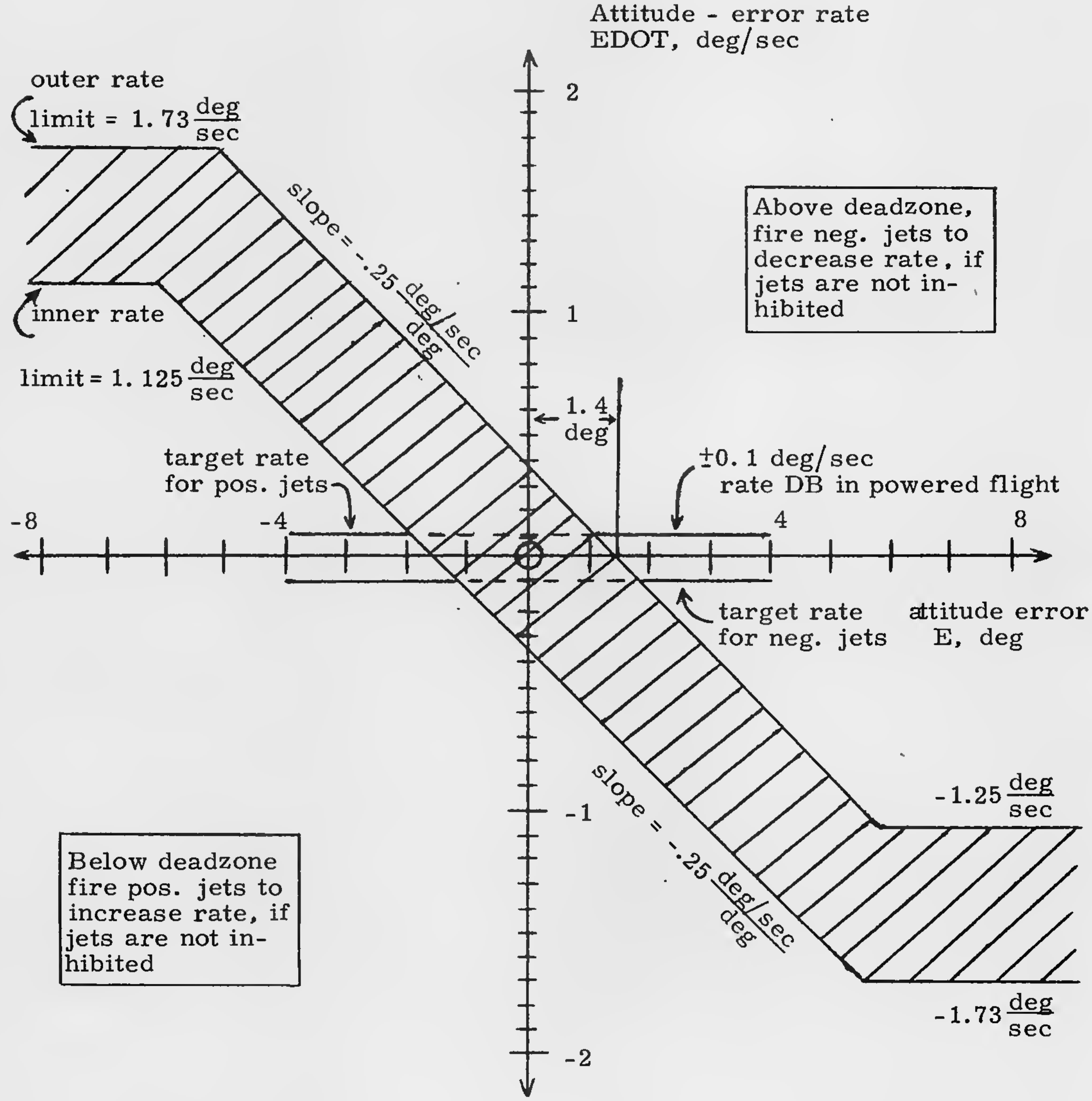

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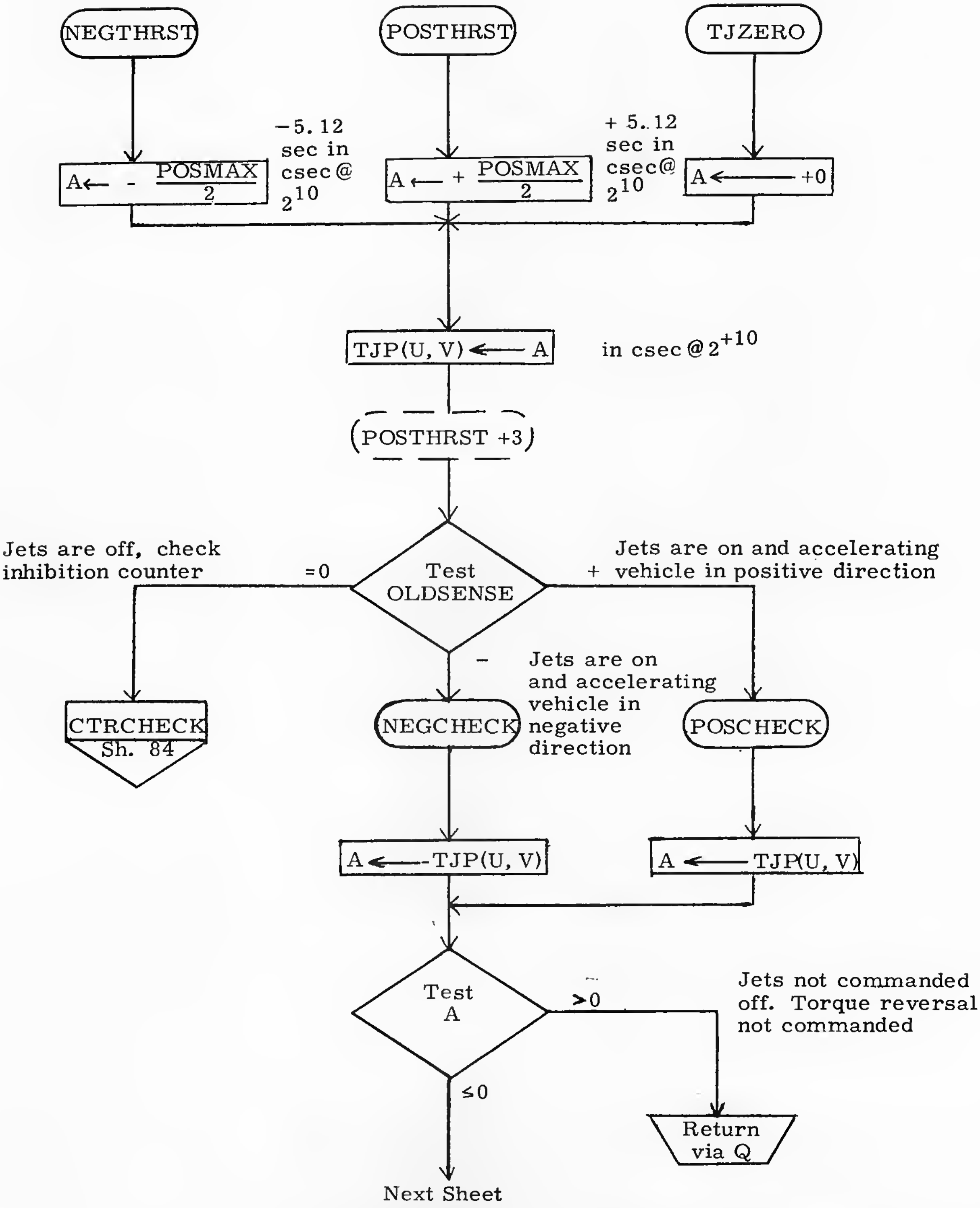

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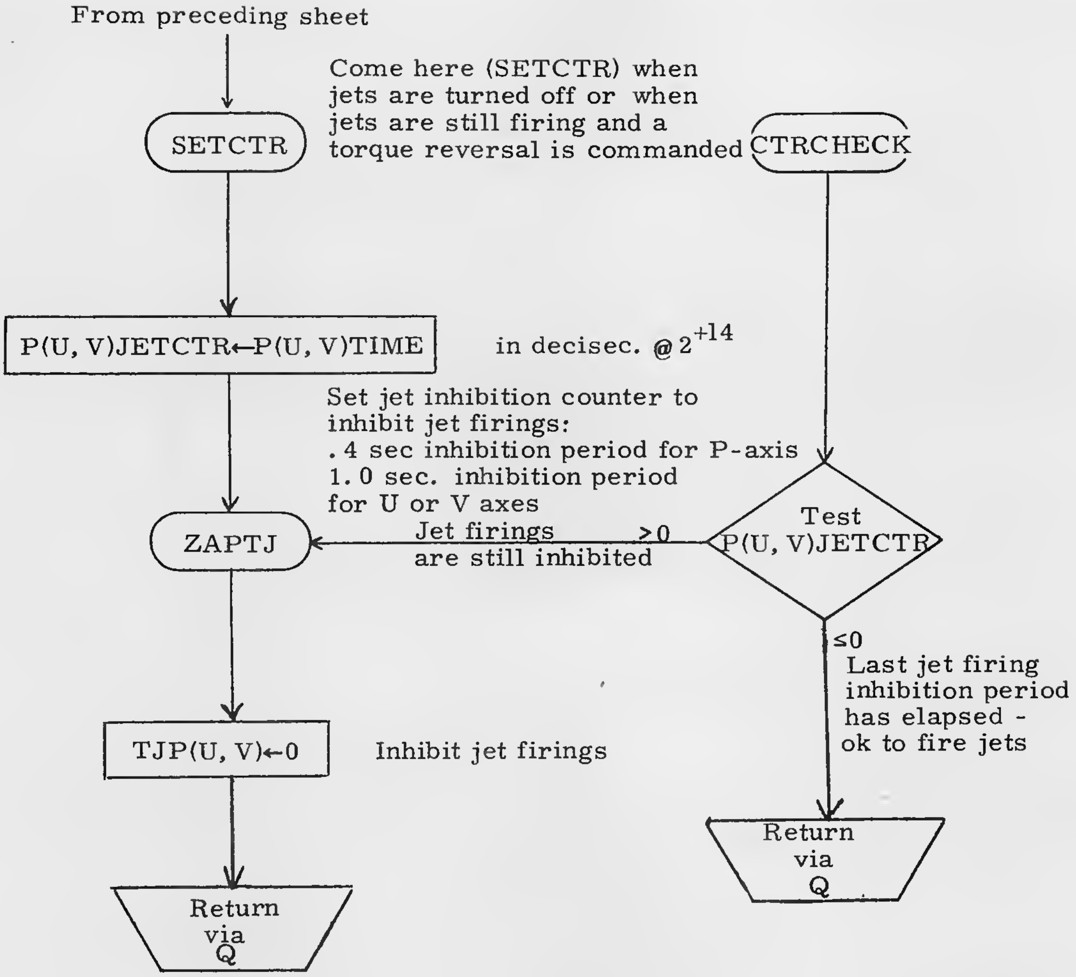

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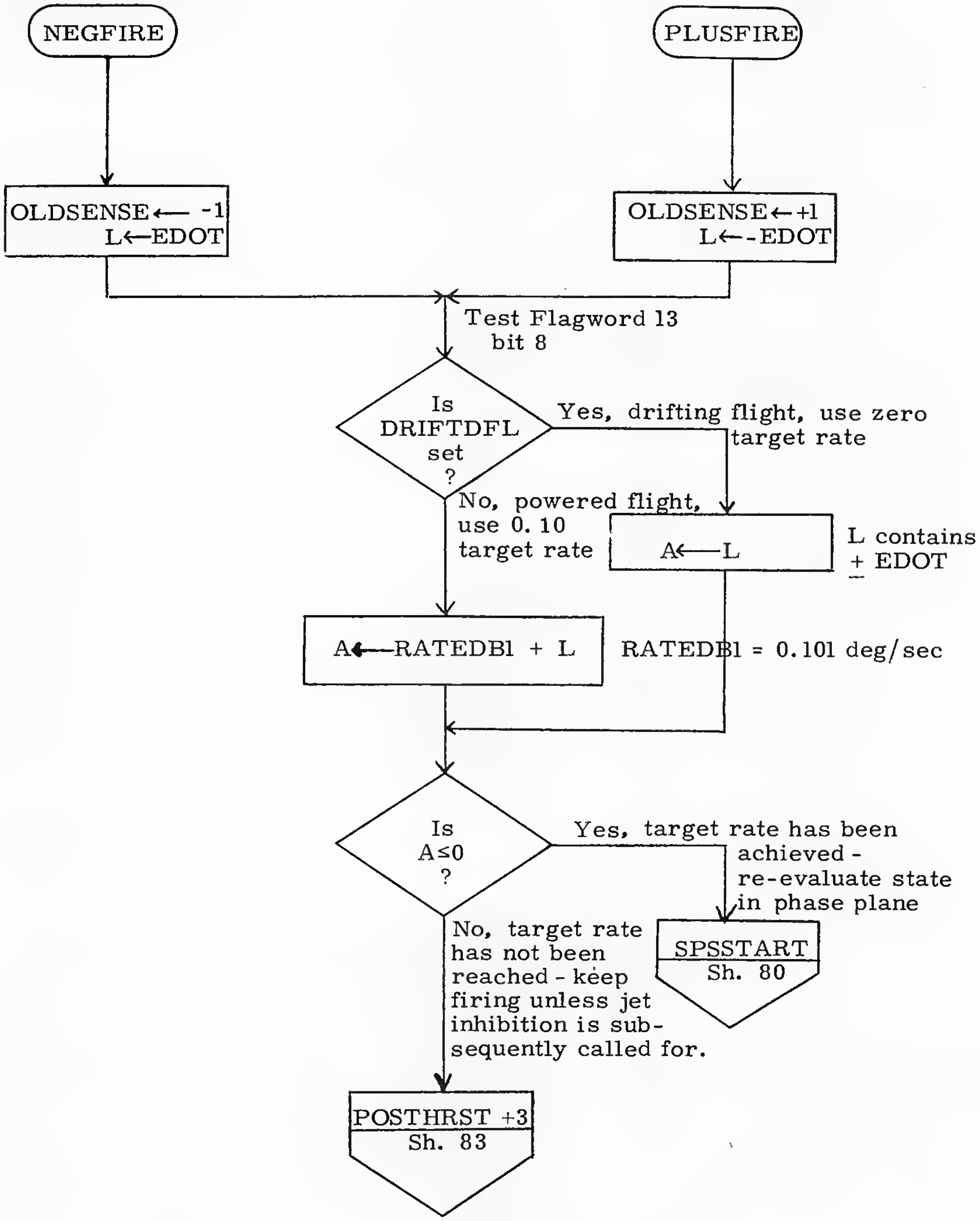

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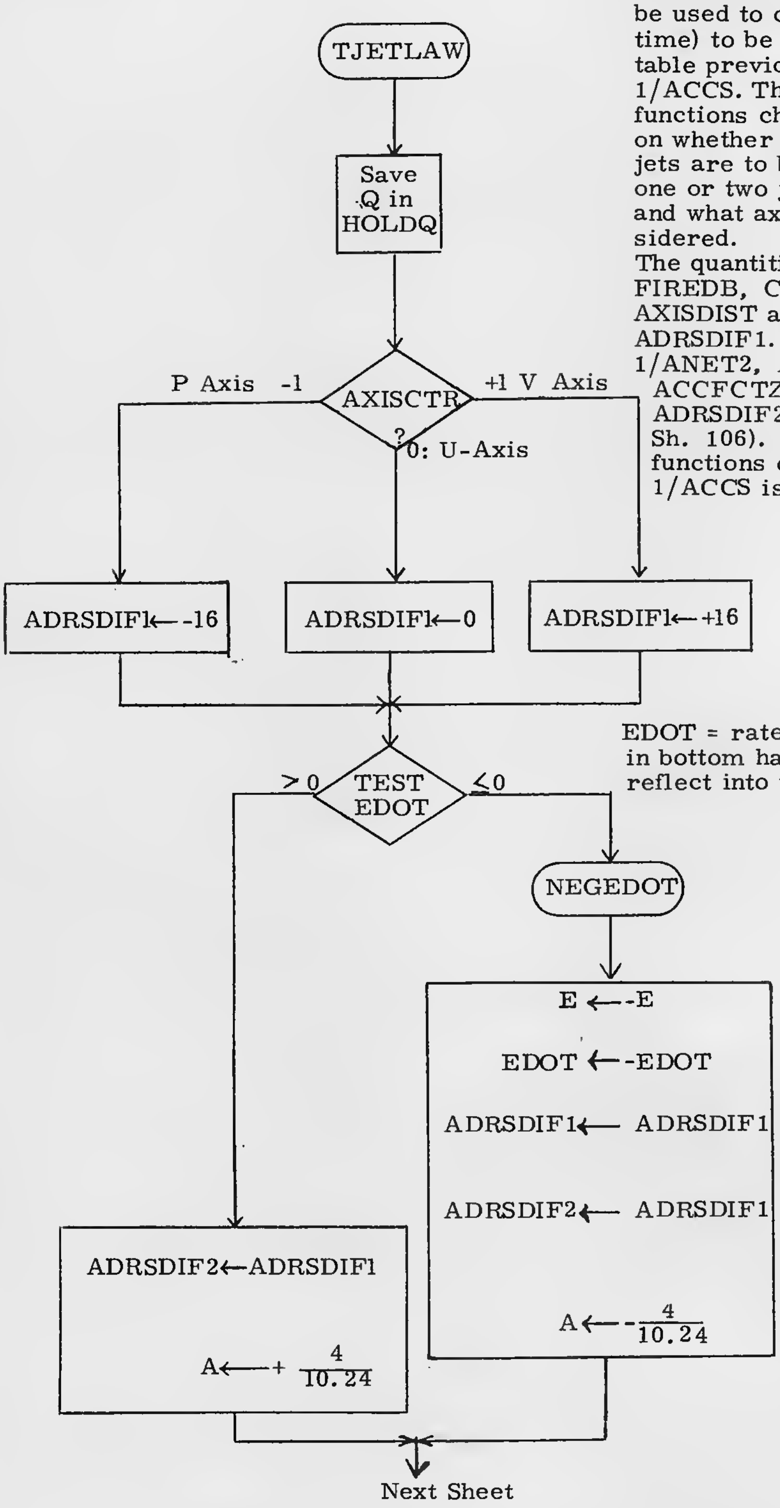
Note: The quantities ADRSDIF1 and ADRSDIF2 are used as indices to allow the appropriate functions (which are to be used to compute jet-on time) to be selected from the table previously set up in 1/ACCS. The particular functions chosen will depend on whether positive or negative jets are to be fired, whether one or two jets are to be used, and what axis is being considered.
The quantities 1/ACOAST, FIREDB, COASTDB, and AXISDIST are indexed by ADRSDIF1. 1/ANET1, 1/ANET2, ACCFCTZ1, and ACCFCTZ5 are indexed by ADRSDIF2. (See table on Sh. 106). The table of functions computed in 1/ACCS is on Sh. 107.



EDOT = rate error in bottom half of plane; reflect into top half

Attitude error in rad @ π.

Attitude error rate in rad/sec @ π/4.

Shift to parameters for bottom half of plane.

Index for jet parameters--may be changed later for 4-jet burns

The value in A is to be stored in ROTSENSE and is used both to determine the direction of rotation and to rescale from the TJETLAW scaling of 4 sec. to the T6 scaling of 10.24 sec.

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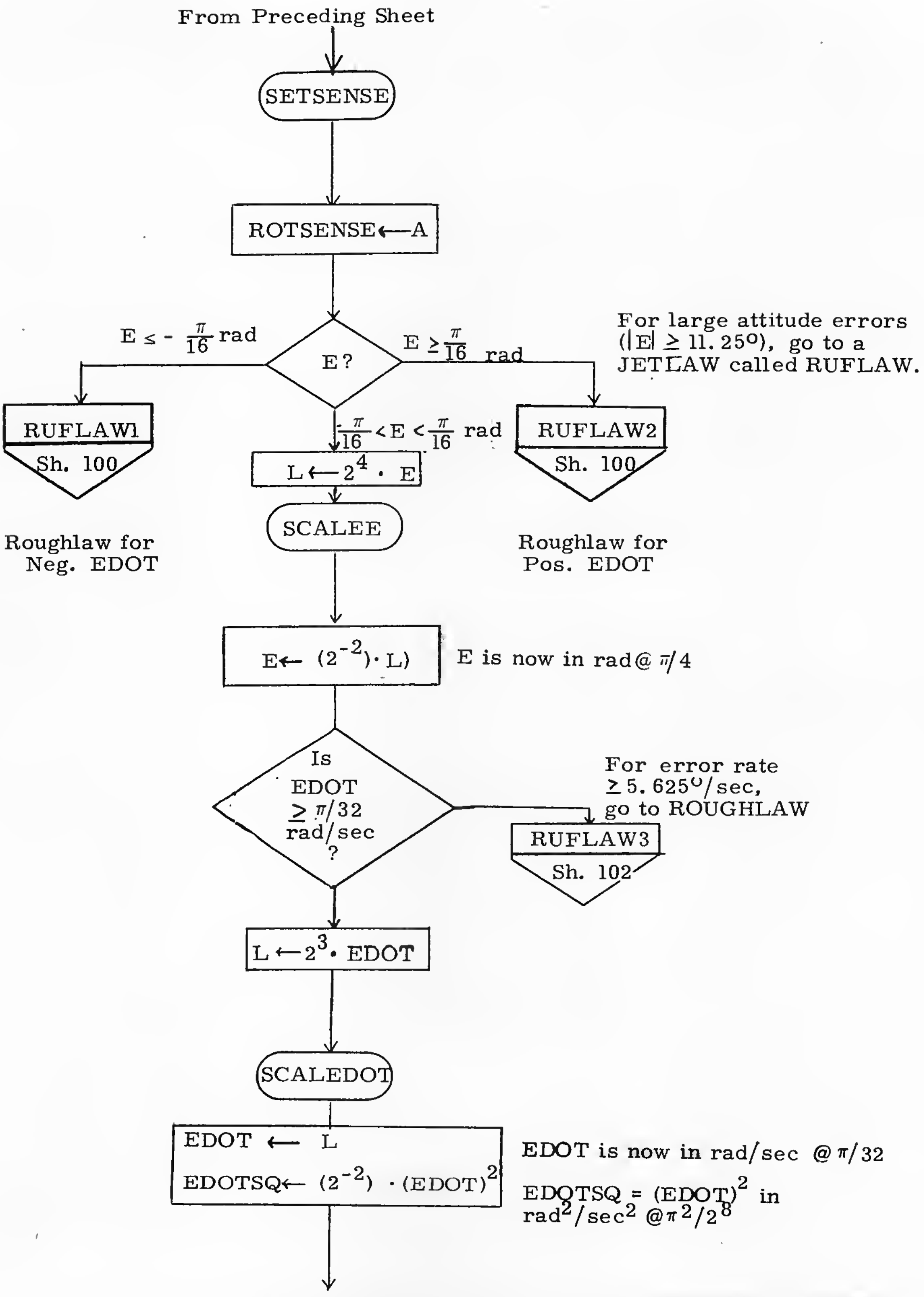

For large attitude errors ($|E| \geq 11.25^{\circ}$), go to a JETLAW called RUFLAW.

Roughlaw for Neg. EDOT

Roughlaw for Pos. EDOT

E is now in rad@ $\pi/4$

For error rate $\geq 5.625^{\circ}$/sec, go to ROUGHLAW

EDOT is now in rad/sec @ $\pi/32$

$EDOTSQ = (EDOT)^2$ in rad^2/sec^2 @ $\pi^2/2^8$

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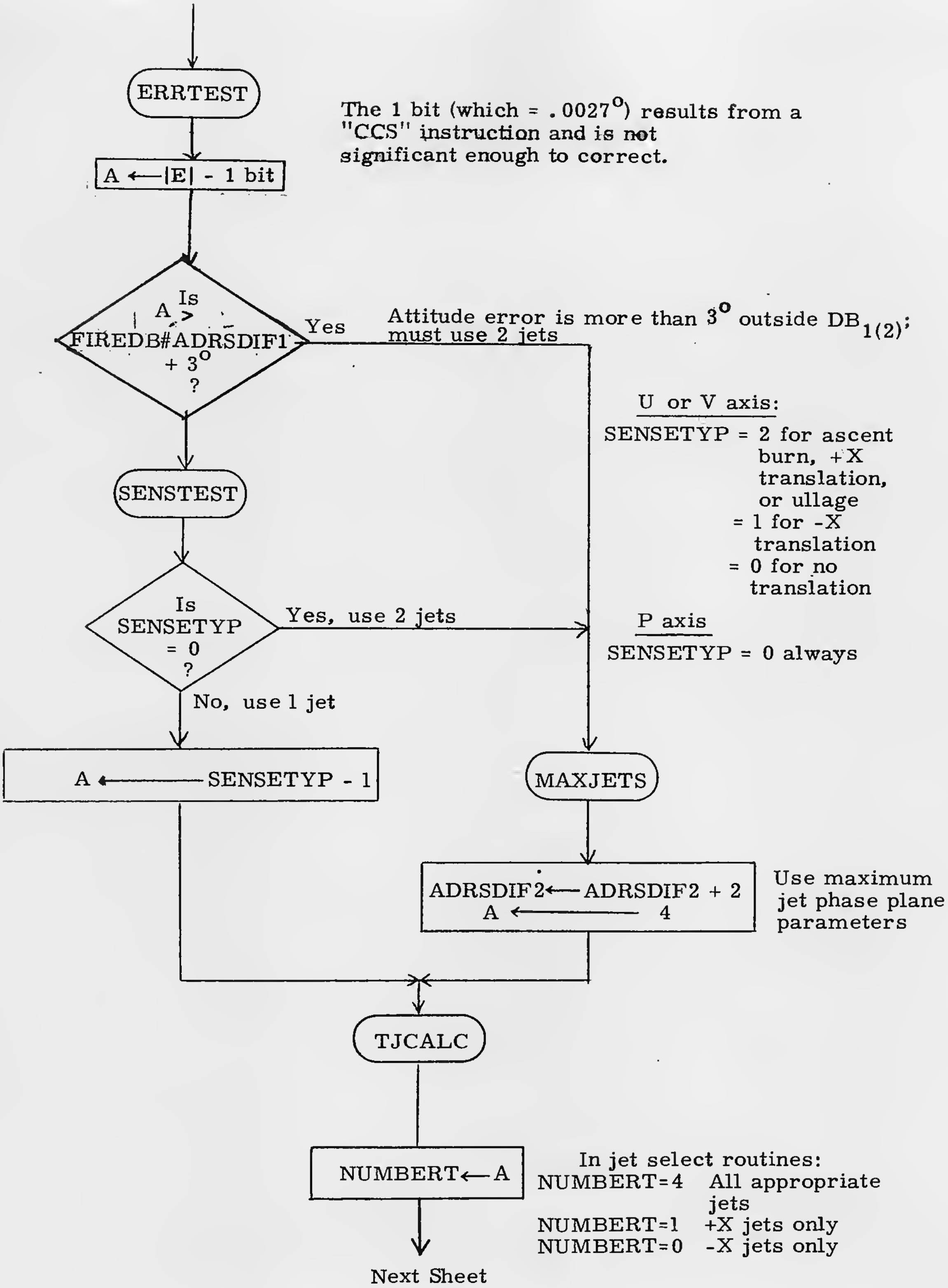

The 1 bit (which = .0027°) results from a "CCS" instruction and is not significant enough to correct.

Attitude error is more than 3° outside $DB_{1(2)}$; must use 2 jets

U or V axis:

SENSETYP = 2 for ascent burn, +X translation, or ullage
= 1 for -X translation
= 0 for no translation

P axis

SENSETYP = 0 always

Use maximum jet phase plane parameters

In jet select routines:

NUMBERT=4	All appropriate jets
NUMBERT=1	+X jets only
NUMBERT=0	-X jets only

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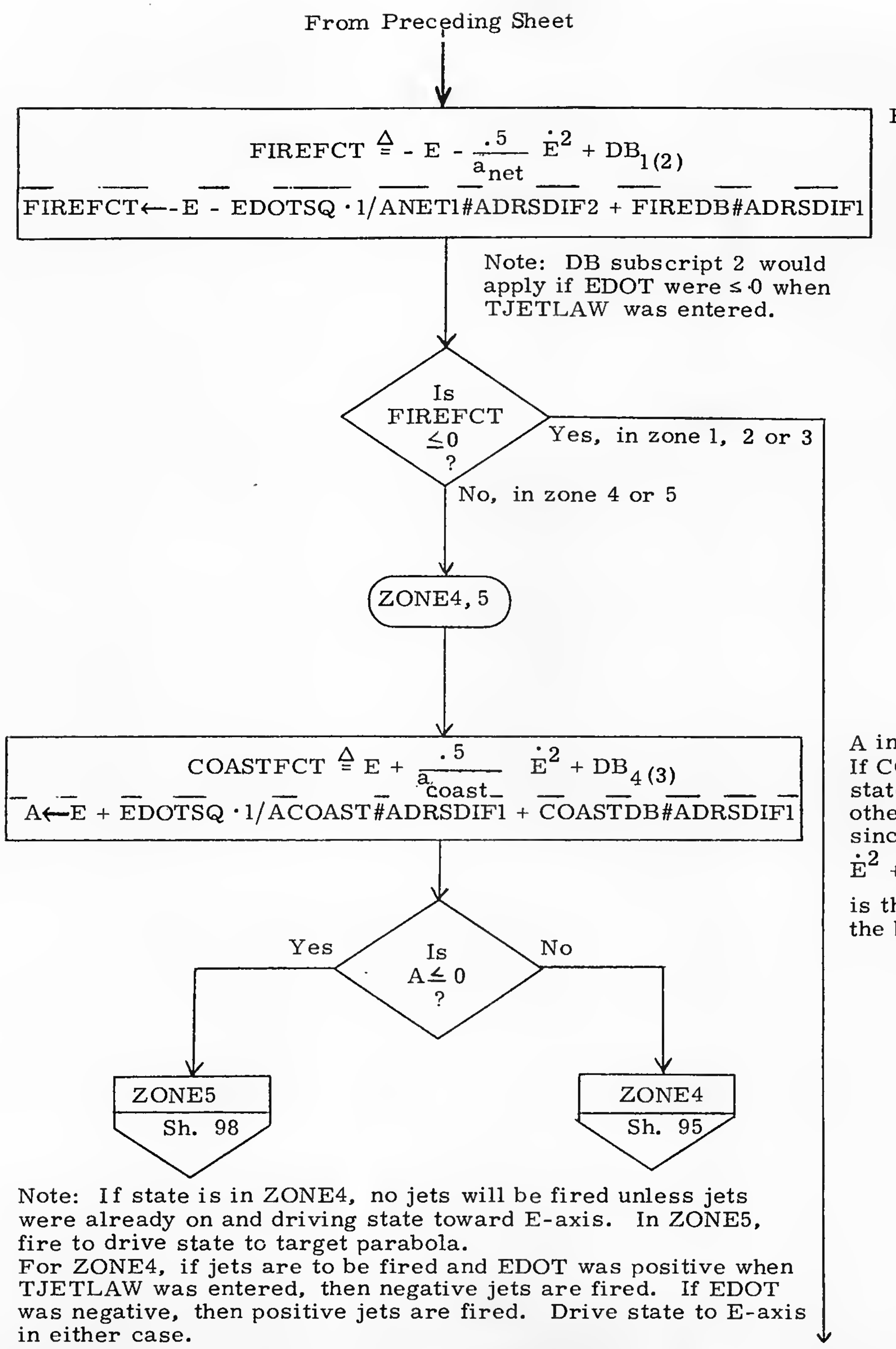

Note: DB subscript 2 would apply if EDOT were ≤ 0 when TJETLAW was entered.

FIREFCT (in rad @ π/4) is the signed distance from the point where the state would cross the E axis if jets were fired now to the point $DB_{1(2)}$ (see phase plane).

$-E - \frac{.5}{a_{net}}\dot{E}^2 + DB_1 = 0$

is equation of boundary between zone 4 and zones 1, 2, 3

A in rad @ π/4
If COASTFCT ≤ 0, state is in zone 5; otherwise in zone 4, since $E + \frac{0.5}{a_{coast}} \times \dot{E}^2 + DB_{4(3)} = 0$ is the equation of the boundary.

Note: If state is in ZONE4, no jets will be fired unless jets were already on and driving state toward E-axis. In ZONE5, fire to drive state to target parabola.
For ZONE4, if jets are to be fired and EDOT was positive when TJETLAW was entered, then negative jets are fired. If EDOT was negative, then positive jets are fired. Drive state to E-axis in either case.
For ZONE5, if EDOT was positive when TJETLAW was entered, then positive jets are to be fired. If EDOT was negative, then negative jets are to be fired.

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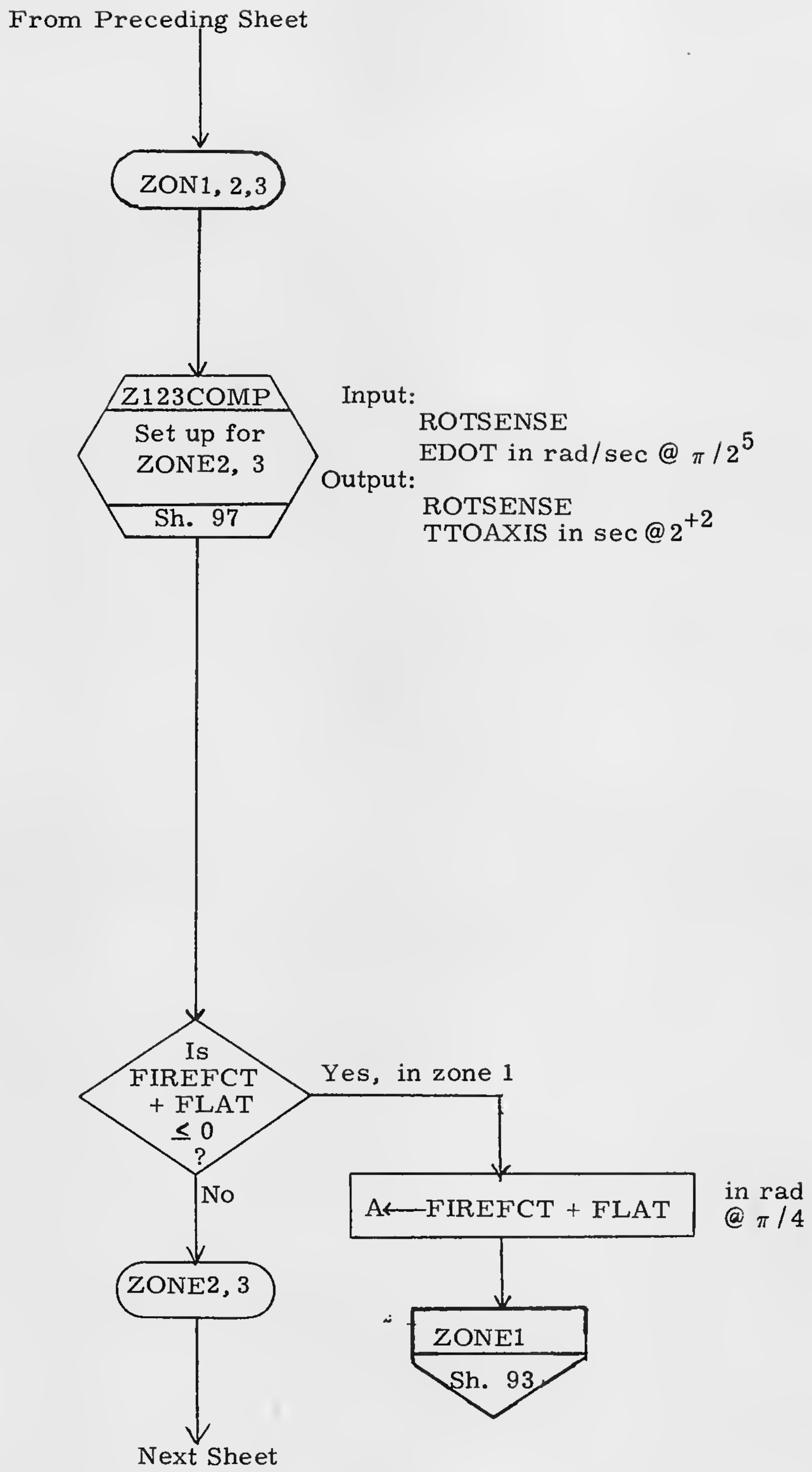

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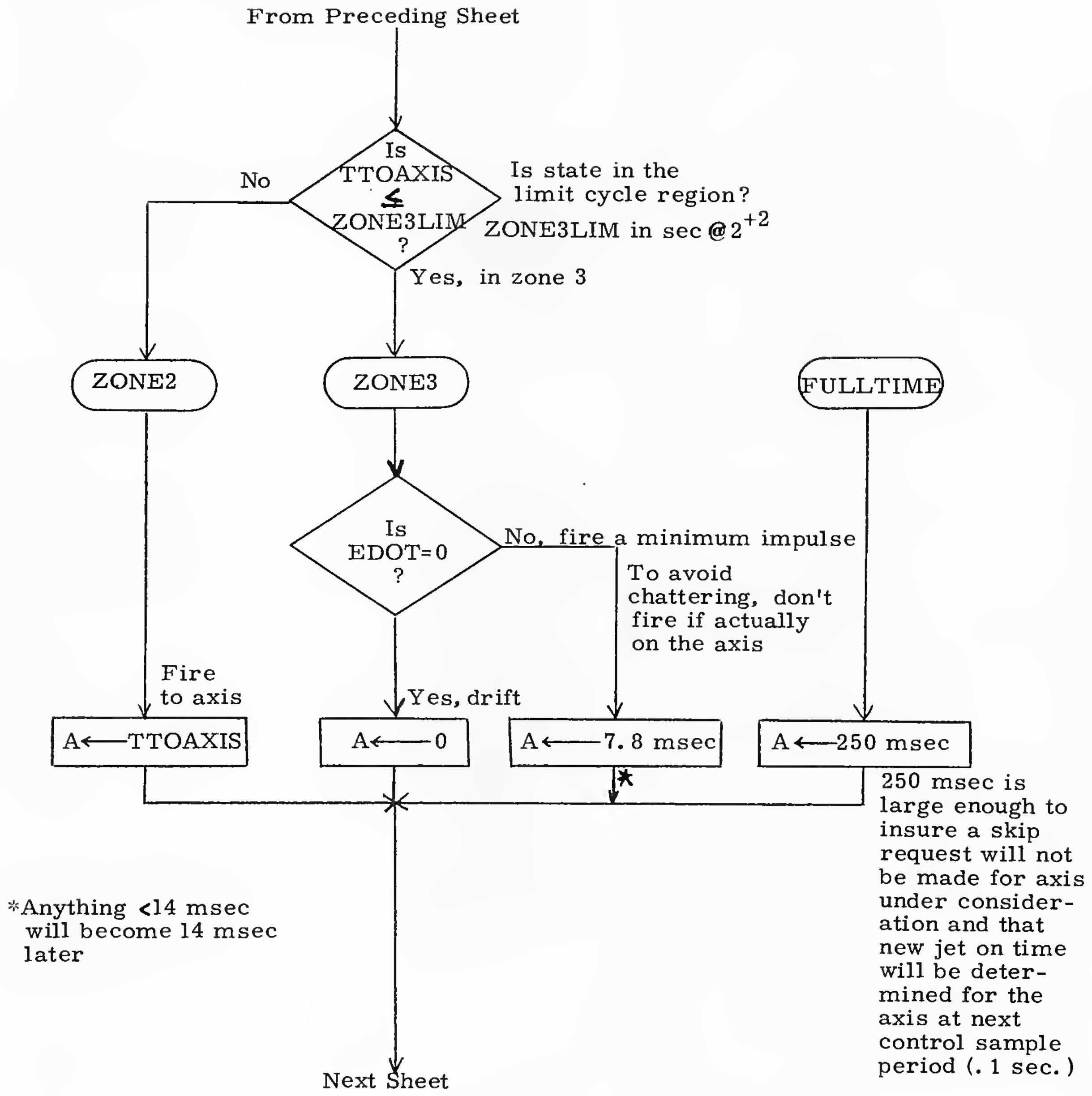

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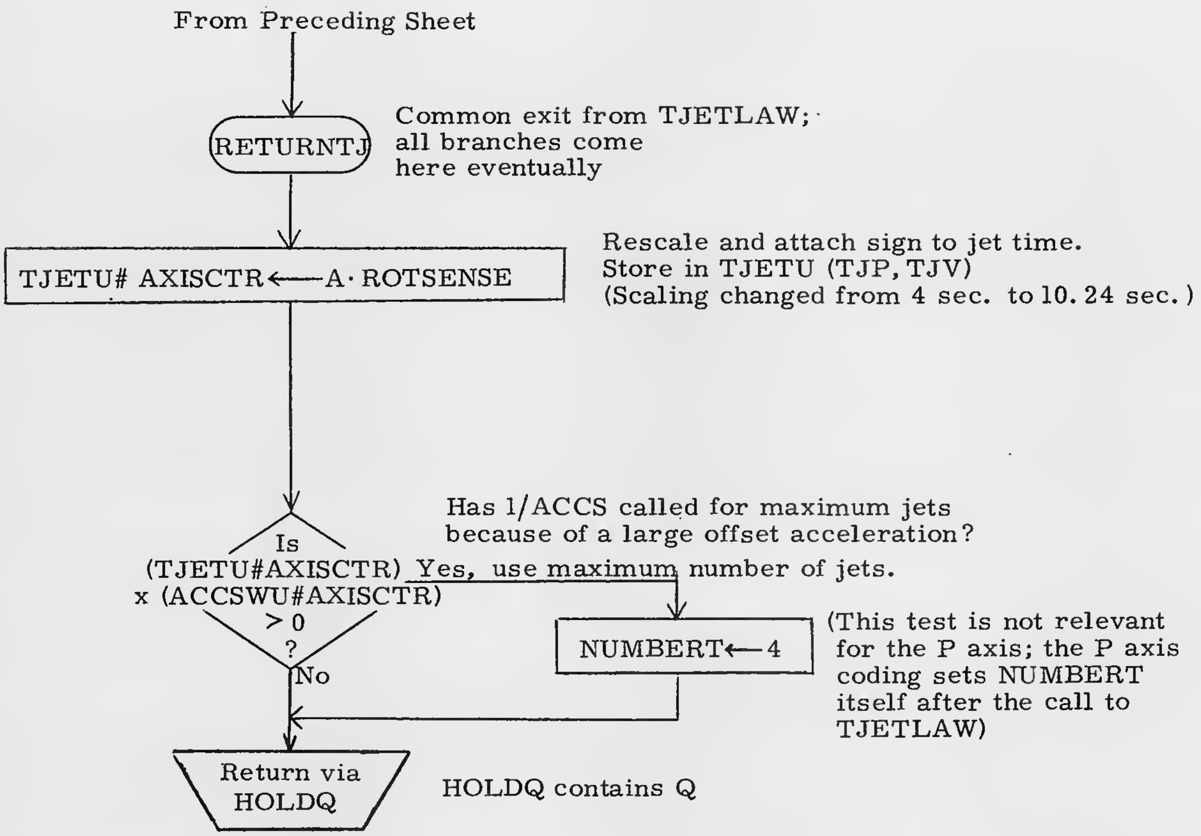

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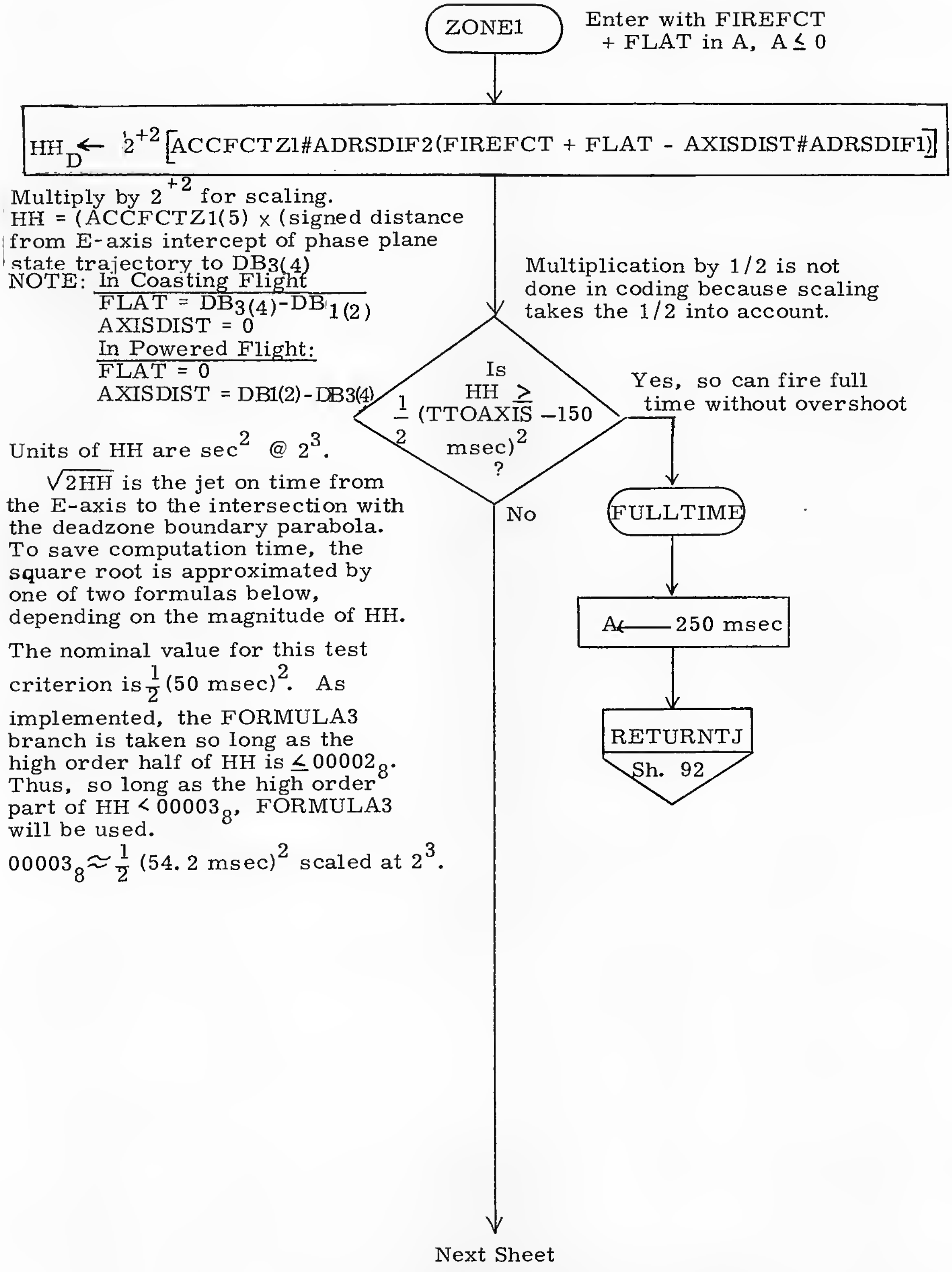

Multiply by 2^{+2} for scaling. HH = (ACCFCTZ1(5) x (signed distance from E-axis intercept of phase plane state trajectory to DB3(4)

NOTE: In Coasting Flight
FLAT = DB3(4)-DB1(2)
AXISDIST = 0
In Powered Flight:
FLAT = 0
AXISDIST = DB1(2)-DB3(4)

Multiplication by 1/2 is not done in coding because scaling takes the 1/2 into account.

Units of HH are sec^2 @ 2^3.

$\sqrt{2HH}$ is the jet on time from the E-axis to the intersection with the deadzone boundary parabola. To save computation time, the square root is approximated by one of two formulas below, depending on the magnitude of HH.

The nominal value for this test criterion is $\frac{1}{2}$(50 msec)^2. As implemented, the FORMULA3 branch is taken so long as the high order half of HH is ≤ 00002_8. Thus, so long as the high order part of HH < 00003_8, FORMULA3 will be used.

$00003_8 \approx \frac{1}{2}$ (54. 2 msec)^2 scaled at 2^3.

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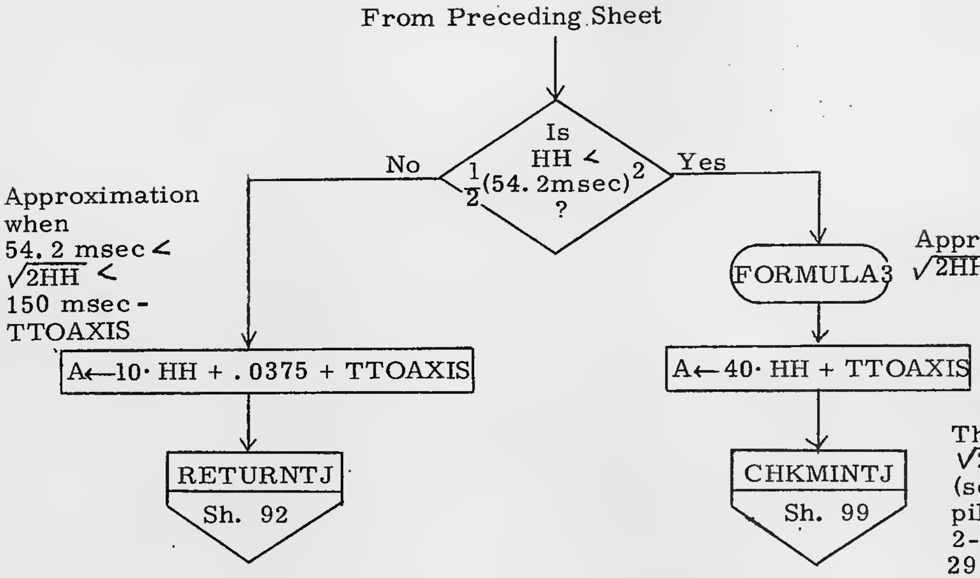


Approximation when $54.2 \text{ msec} < \sqrt{2HH} < 150 \text{ msec} - \text{TTOAXIS}$

Approximation when $\sqrt{2HH} < 54.2$ msec.

Firing time = (time-to-axis + time-beyond axis) in sec @2^{+2}

The approximations for $\sqrt{2HH}$ are as follows (see spacecraft autopilot development memo 2-68 by R. D. Goss, Eq. 29 and Eq. 30) [MIT/IL, 2/1/68]

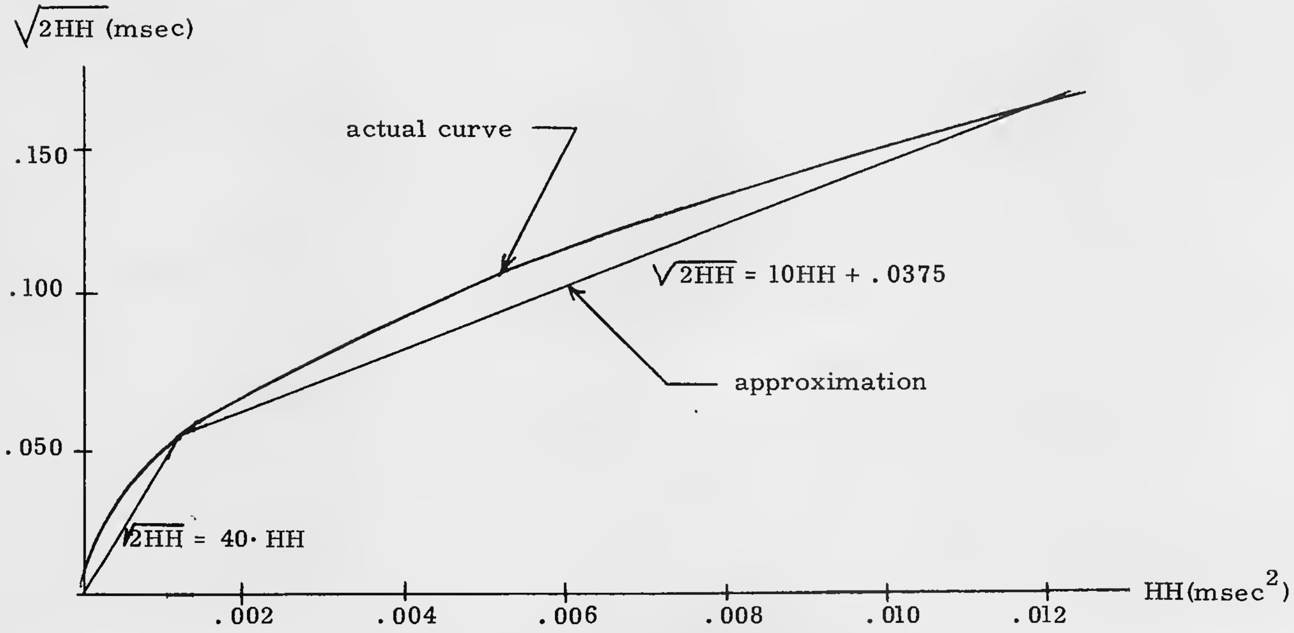
$$\sqrt{2HH} \approx 40 \cdot HH \text{ for } \sqrt{2HH} < 54.2 \text{ msec}$$

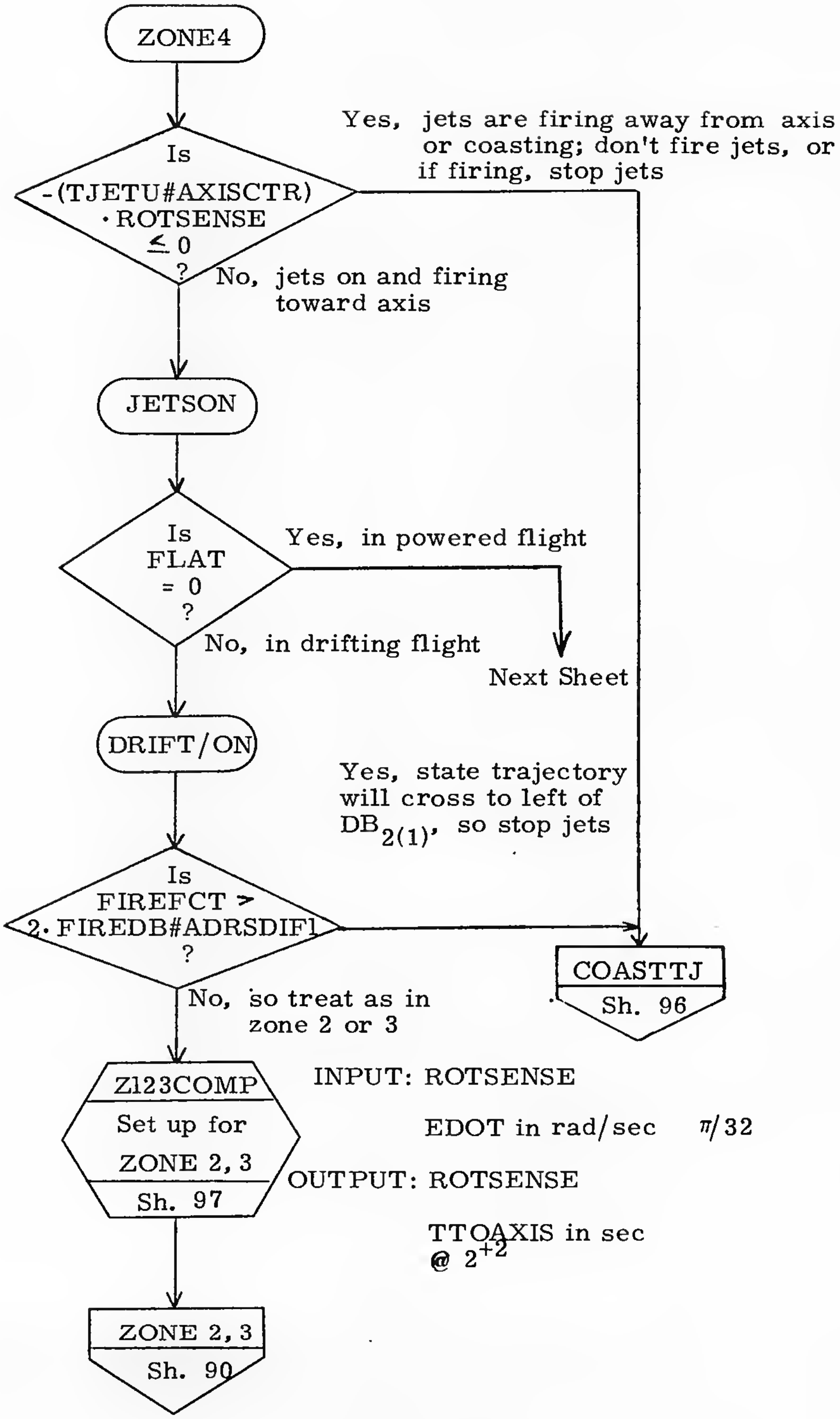
$$\text{i.e. for } HH < \frac{1}{2}(54.2 \text{ msec})^2$$

$$\sqrt{2HH} \approx 10 \cdot HH + .0375 \text{ for}$$

$$54.2 \text{ msec} < \sqrt{2HH} < 150 \text{ msec} - \text{TTOAXIS}$$

$$\text{i.e. for } \frac{1}{2}(54.2 \text{ msec})^2 < HH < \frac{1}{2}(150 \text{ msec} - \text{TTOAXIS})^2$$





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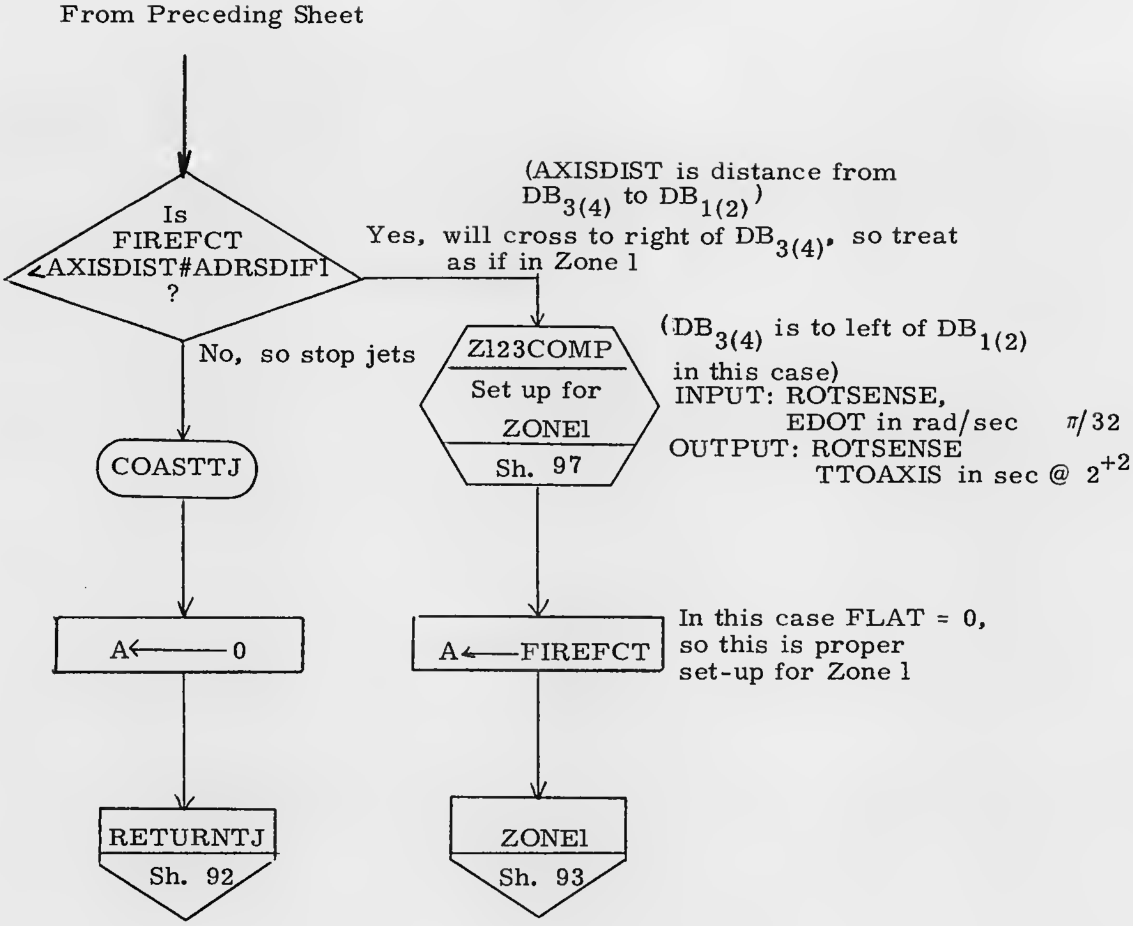

(AXISDIST is distance from $DB_{3(4)}$ to $DB_{1(2)}$)

($DB_{3(4)}$ is to left of $DB_{1(2)}$ in this case)
INPUT: ROTSENSE,
EDOT in rad/sec $\pi/32$
OUTPUT: ROTSENSE
TTOAXIS in sec @ 2^{+2}

In this case FLAT = 0, so this is proper set-up for Zone 1

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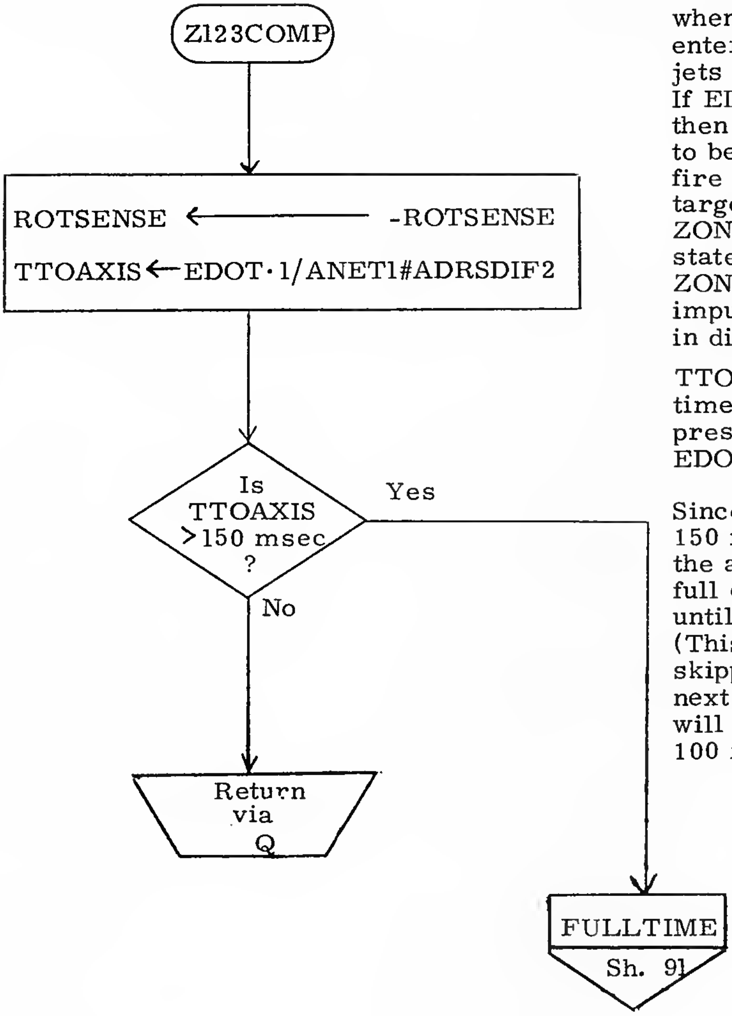

In ZONE 1, 2, or 3:
If EDOT was positive when TJETLAW was entered, then negative jets are to be fired.
If EDOT was negative, then positive jets are to be fired. In ZONE1, fire to drive state to target parabola. In ZONE2, fire to drive state to E-axis; and in ZONE3, fire minimum impulse (driving state in direction of E-axis)

TTOAXIS is jet firing time to reach axis from present state in secs@2^{+2}
EDOT in rad/sec @ $\pi/2^5$

Since it will take 150 msec just to get to the axis, turn jets on for full control sample period until next time through. (This will inhibit skipping of the axis next cycle so TJET will be recomputed in 100 msec)

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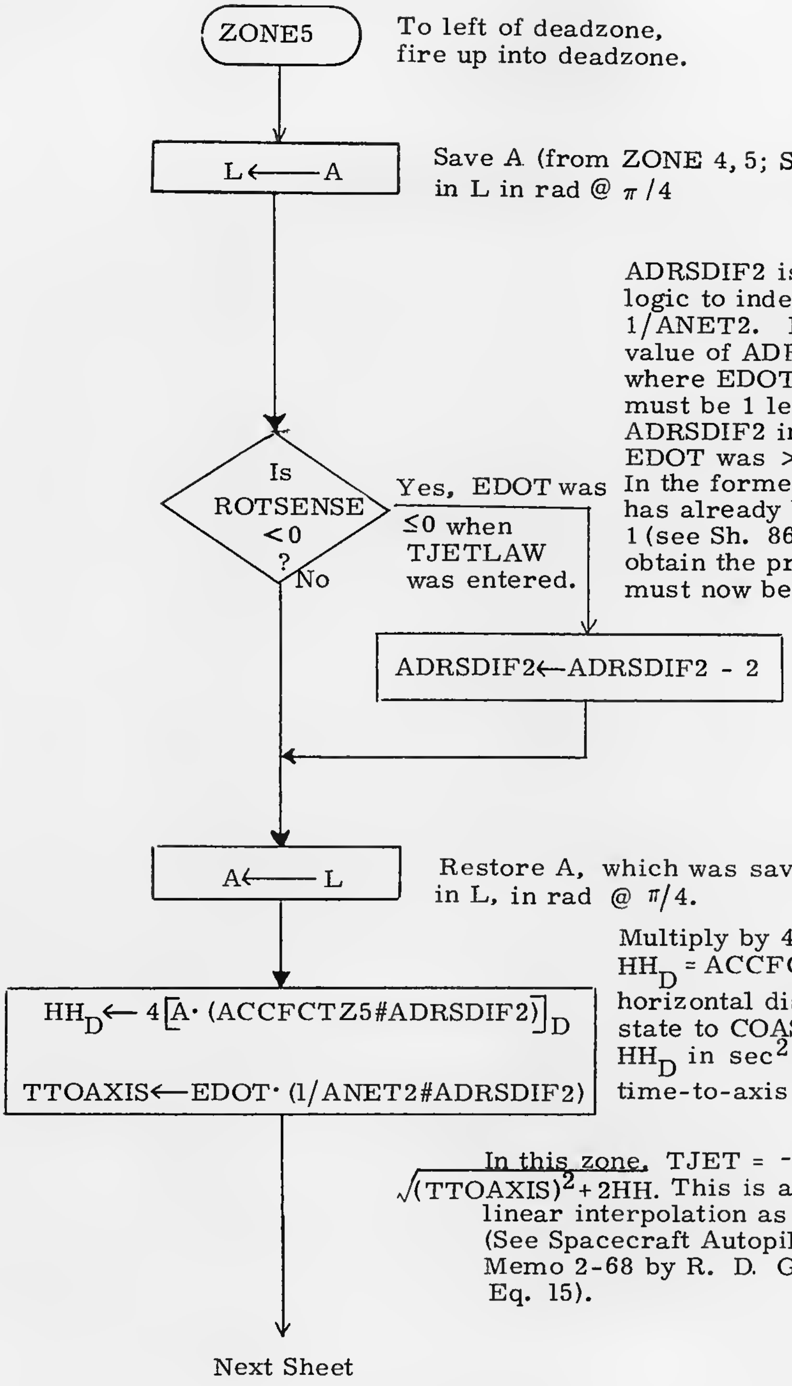

To left of deadzone, fire up into deadzone.

Save A (from ZONE 4, 5; Sh. 89) in L in rad @ $\pi/4$

ADRSDIF2 is used in the following logic to index ACCFCTZ5 and 1/ANET2. For this purpose, the value of ADRSDIF2 in the case where EDOT was originally ≤ 0 must be 1 less than the value of ADRSDIF2 in the case where EDOT was > 0 (see Sh. 106). In the former case, ADRSDIF2 has already been incremented by 1 (see Sh. 86). Therefore, to obtain the proper value, ADRSDIF2 must now be decremented by 2.

Restore A, which was saved in L, in rad @ $\pi/4$.

Multiply by 4 for scaling.
HH_D = ACCFCTZ5 (1) x (signed horizontal distance from vehicle state to COASTFCT = 0 target parabola).
HH_D in sec^2 @ 2^3
time-to-axis = $\dot{E} \times \frac{1}{a_{net}}$ in sec @ 2^{+2}

In this zone, TJET = - TTOAXIS + $\sqrt{(TTOAXIS)^2 + 2HH}$. This is approximated by linear interpolation as shown on next sheet. (See Spacecraft Autopilot Development Memo 2-68 by R. D. Goss, Eq. 14 and Eq. 15).

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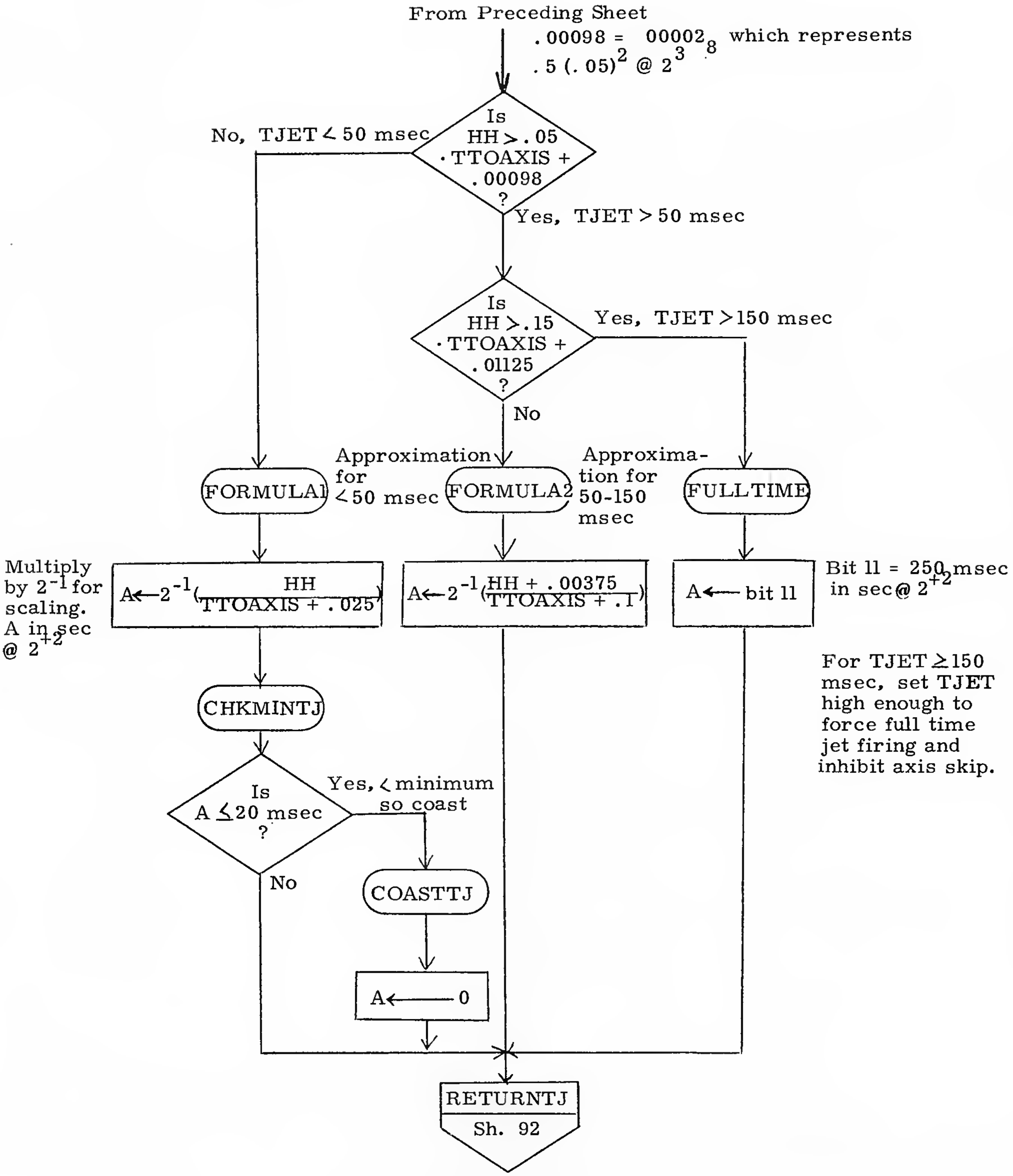

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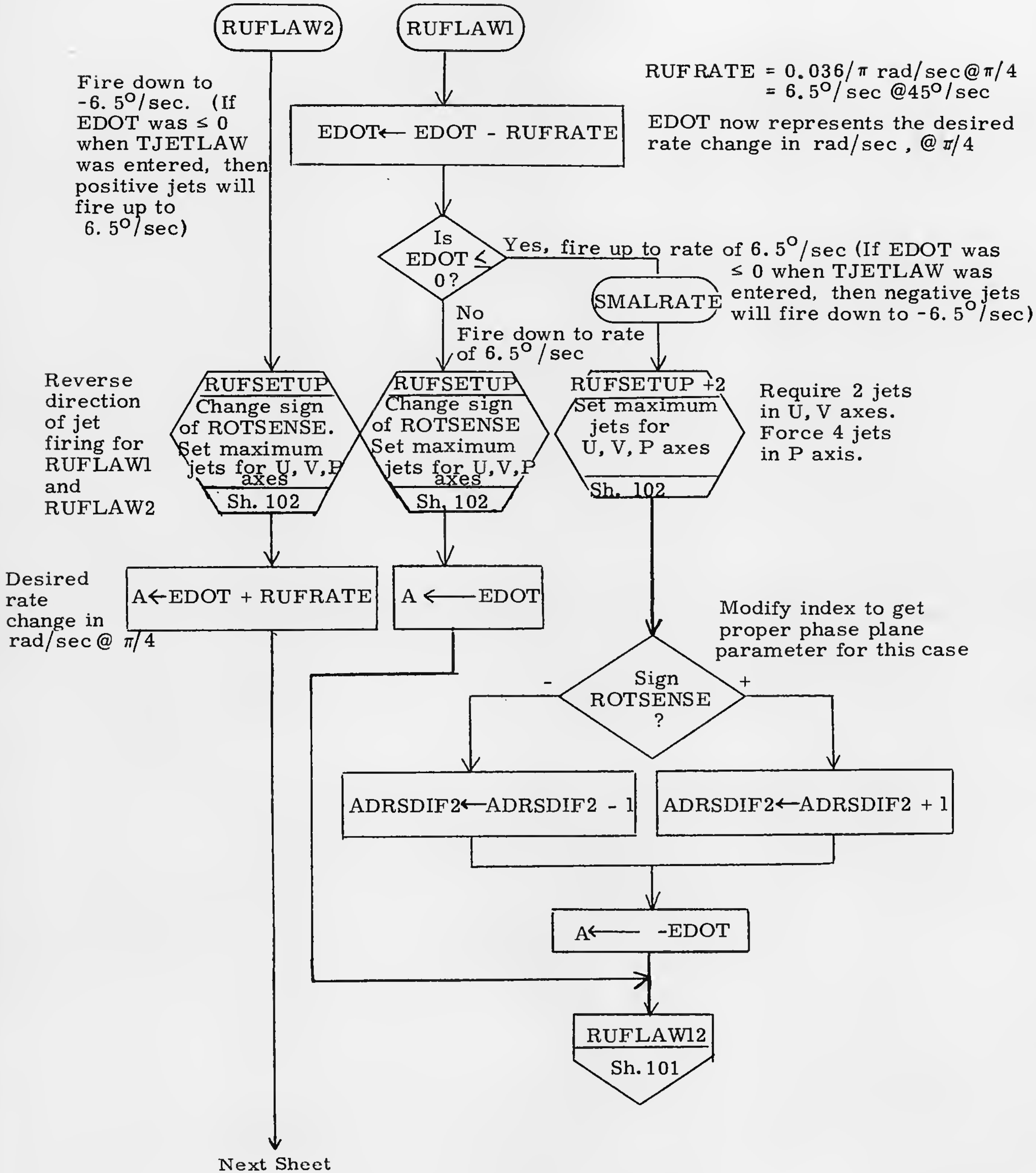

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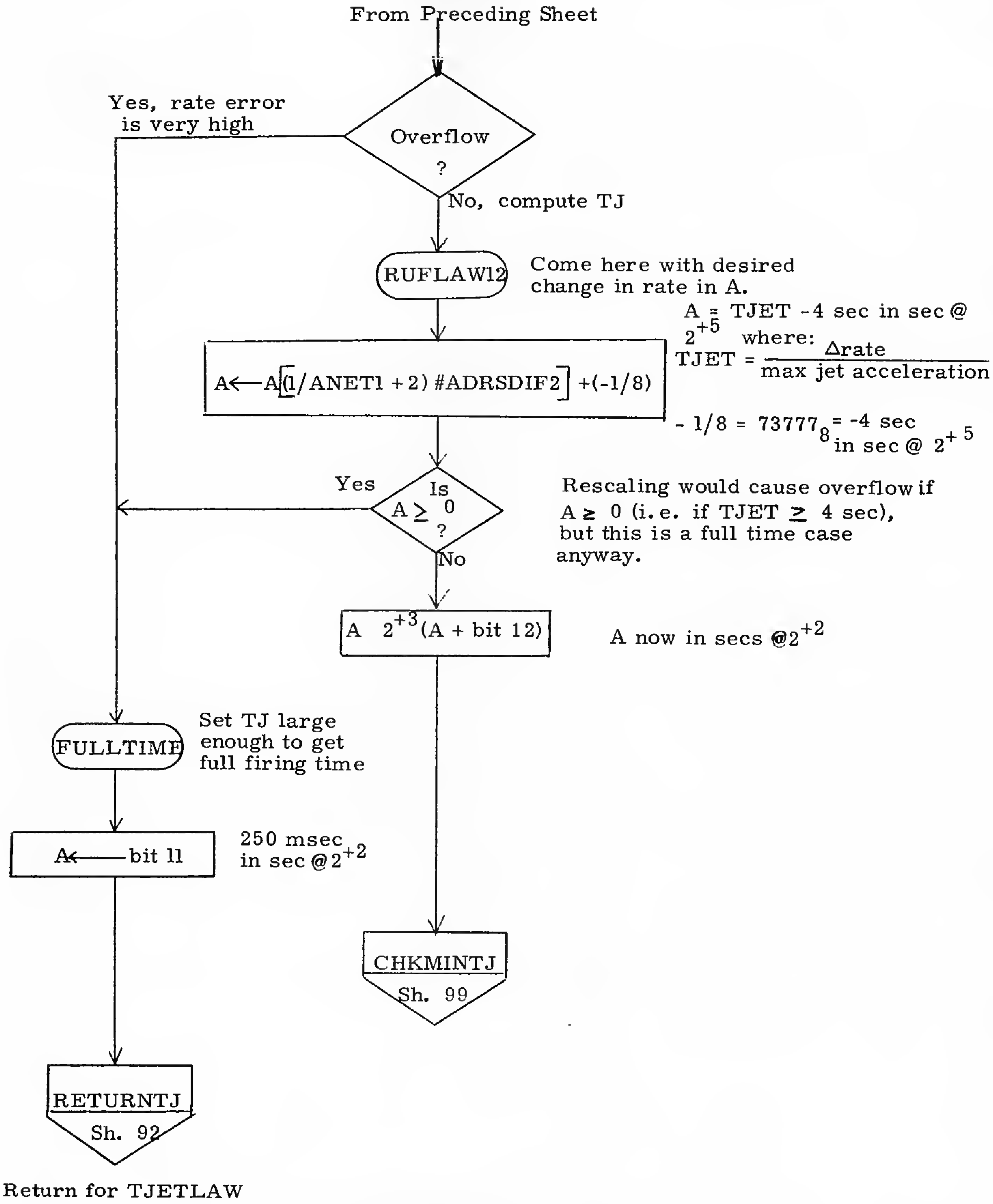

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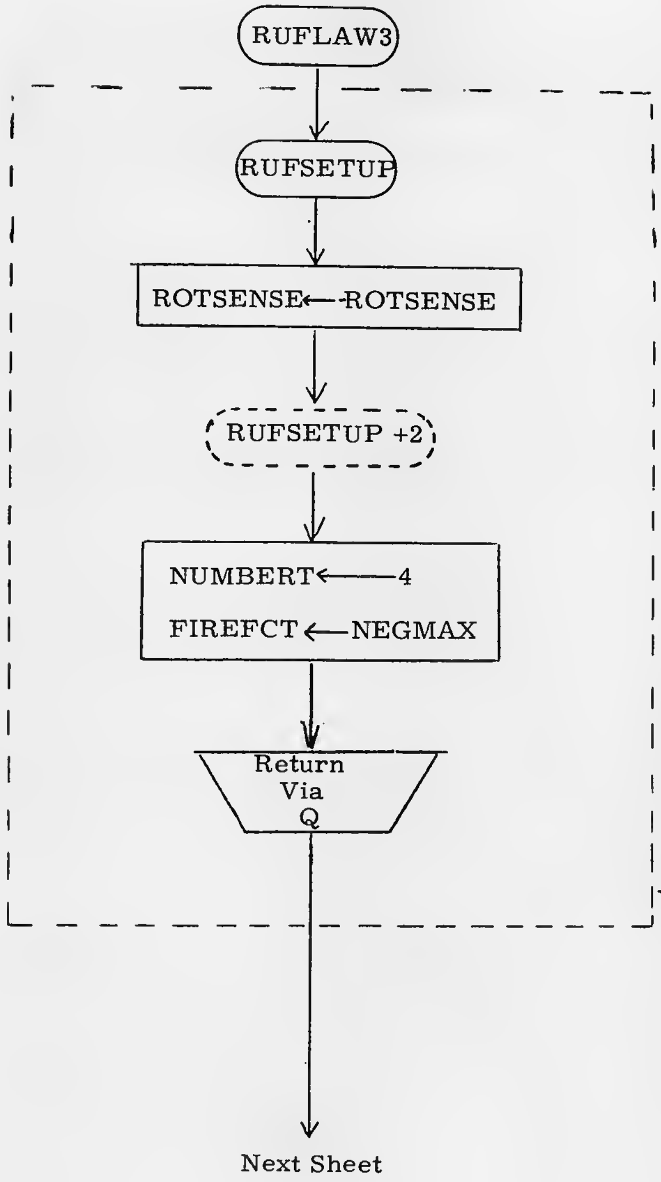

Maximum jets for U, V axes @ 2^{14}

In jet selection routine for P-axis, a test is made on -FIREFCT. If -FIREFCT > 4° and TJP (jet on time) >160 msec, then 4 P-axis jets are required. Setting of FIREFCT to NEGMAX (=40000_8 = -45° @ 45°) guarantees that 4 P-axis jets will be used if TJP > 160 msec. FIREFCT is not used again in RUFLAW and is not destroyed.

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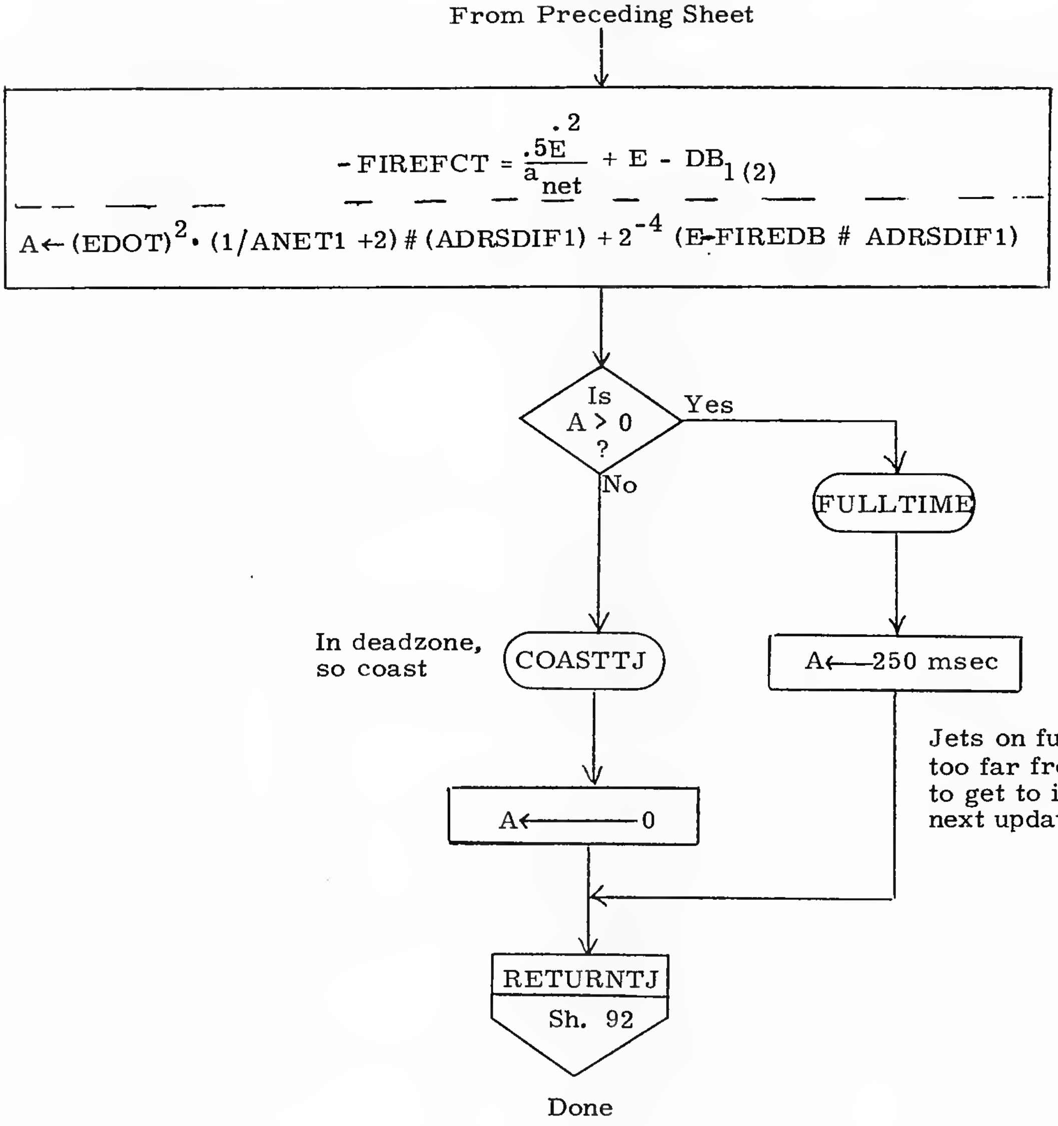

Multiply by 2^{-4} for scaling. -FIREFCT (in rad @4π) is the signed distance from the point where the state trajectory would cross the E-axis if jets were fired now to the point $DB_{1(2)}$ on the E-axis. If -FIREFCT > 0, state is out of the deadzone and jets are to be fired. If -FIREFCT ≤ 0, state is in the deadzone and no jets are to be fired.

In deadzone, so coast

Jets on full time; too far from axis to get to it before next update.

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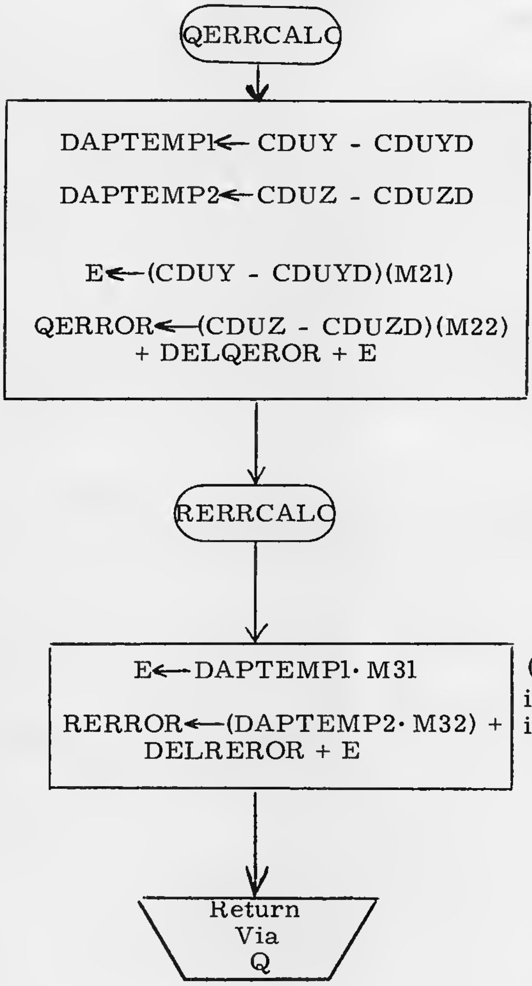

2's complement difference between CDU angle and angle desired in rad @ π.

In rad @ π
M21, M22, M31, M32 are components of the axis transformation matrix: gimbal to pilot axes.

(CDUY - CDUYD)(M31)
in rad @ π
in rad @ π

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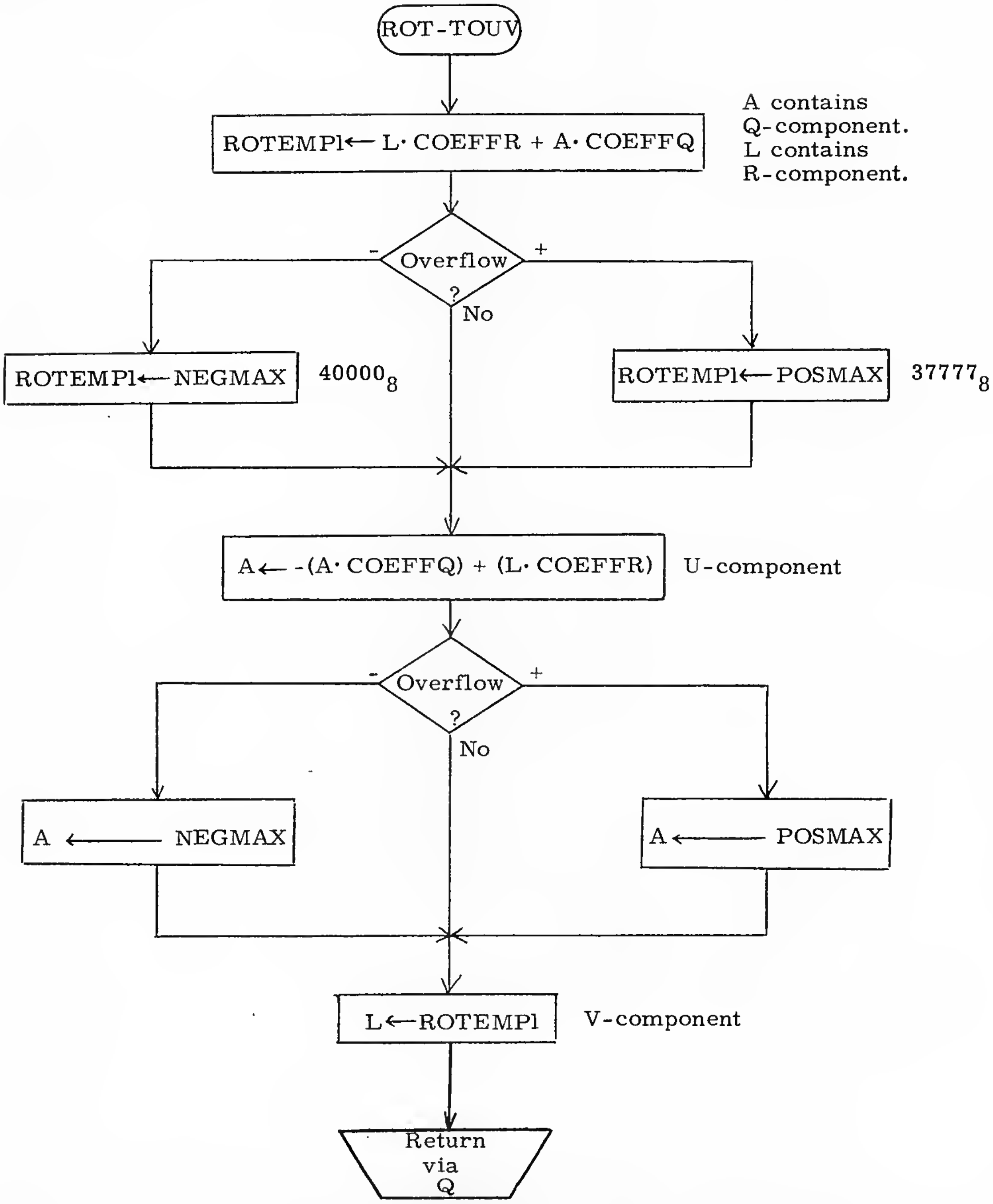

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Table of Values Assigned to the Indexes ADRSD1F1 and ADRSD1F2

	P-AXIS		U-AXIS				V-AXIS			
	$\dot{E}>0$	$\dot{E}<0$	$\dot{E}>0$		$\dot{E}<0$		$\dot{E}>0$		$\dot{E}<0$	
			1-JET	2-JET	1-JET	2-JET	1-JET	2-JET	1-JET	2-JET
ADRSDIF2	-14	-13 when indexing 1/ANET1 or ACCFCTZ1 - - - - - - -15 when indexing 1/ANET2 or ACCFCTZ5	0	2	1 when indexing 1/ANET1 or ACCFCTZ1 - - - - - - -1 when indexing 1/ANET2 or ACCFCTZ5	3 when indexing 1/ANET1 or ACCFCTZ1 - - - - - - 1 when indexing 1/ANET2 or ACCFCTZ5	16	18	17 when indexing 1/ANET1,or ACCFCTZ1 - - - - - - 15 when indexing 1/ANET2 or ACCFCTZ5	19 when indexing 1/ANET1 or ACCFCTZ1 - - - - - - 17 when indexing 1/ANET2 or ACCFCTZ5
ADRSD1F1	-16	-15	0	0	1	1	16	16	17	17

The quantities 1/ANET1, 1/ANET2, ACCFCTZ1 and ACCFCTZ5 are indexed by ADRSDIF2:
1/ANET1 + ADRSDIF2, 1/ANET2 + ADRSDIF2 etc.

The quantities 1/ACOAST, FIREDB, COASTDB and AXISDIST are indexed by ADRSDIF1:
1/ACOAST + ADRSDIF1, FIREDB + ADRSDIF1 etc.

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1/ACCS Table for Functions Required by TJETLAW

	P-AXIS	U-AXIS	V-AXIS
BLOCK TOP →	ACCSWU	1/ANET1 = $1/a_{netneg}$ (1-Jet)	$1/a_{netneg}$ (1-Jet)
+1	ACCSWU +1 = ACCSWV	1/ANET2 = $1/a_{netpos}$ (1-Jet)	$1/a_{netpos}$ (1-Jet)
+2	$1/a_{netneg}$ (2-Jets)	$1/a_{netneg}$ (2-Jets)	$1/a_{netneg}$ (2-Jets)
+3	$1/a_{netpos}$ (2-Jets)	$1/a_{netpos}$ (2-Jets)	$1/a_{netpos}$ (2-Jets)
+4	$1/a_{coastneg}$	1/ACOAST = $1/a_{coastneg}$	$1/a_{coastneg}$
+5	$1/a_{coastpos}$	$1/a_{coastpos}$	$1/a_{coastpos}$
+6	FLAT	ACCFCTZ1 = $-1/\left(a_{netneg} + \frac{a^2_{netneg}}{a_{coastpos}}\right)$ (1-Jet)	$-1/\left(a_{netneg} + \frac{a^2_{netneg}}{a_{coastpos}}\right)$ (1-Jet)
+7	ZONE3LIM	ACCFCTZ5 $-1/\left(a_{netpos} + \frac{a^2_{netpos}}{a_{coastneg}}\right)$	$-1/\left(a_{netpos} + \frac{a^2_{netpos}}{a_{coastneg}}\right)$ (1-Jet)
+8	$-1/\left(a_{netneg} + \frac{a^2_{netneg}}{a_{coastpos}}\right)$ (2-Jets)	$-1/\left(a_{netneg} + \frac{a^2_{negneg}}{a_{coastpos}}\right)$ (2-Jets)	$-1/\left(a_{negneg} + \frac{a^2_{netneg}}{a_{coastpos}}\right)$ (2-Jets)
+9	$-1/\left(a_{netpos} + \frac{a^2_{netpos}}{a_{coastneg}}\right)$ (2-Jets)	$-1/\left(a_{netpos} + \frac{a^2_{netpos}}{a_{coastneg}}\right)$ (2-Jets)	$-1/\left(a_{netpos} + \frac{a^2_{netpos}}{a_{coastneg}}\right)$ (2-Jets)
+10	DB_1	FIREDB = DB_1	DB_1
11	DB_2	DB_2	DB_2
12	DB_4	COASTDB = DB_4	DB_4
13	DB_3	DB_3	DB_3
14	$DB_1 - DB_3 + FLAT$	AXISDIST = $DB_1 - DB_3 + FLAT$	$DB_1 - DB_3 + FLAT$
15	$DB_2 - DB_4 + FLAT$	$DB_2 - DB_4 + FLAT$	$DB_2 - DB_4 + FLAT$

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LM RCS DAP

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ROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Routine Name	Where Flowed	Description	Where Called
ACDT+C12	FC-3480	Turn gimbal drives on/off	3
ALARM	FC-3140	Store alarm code and light alarm light	23, 49, 74, 78
BAILOUT	FC-3140	Store abort code and cause restart	2
CHEKBITS	FC-3440	See if DAP may stay on	2
C13STALL	FC-3440	Test for radar activity	35
GTS	FC-3480	Gimbal trim control system entry	44
JTLST	FC-3440	Set up jet list	70
OVERSUB	FC-3440	Correct if overflow	8, 9, 10, 13, 14, 15, 16
SUBDIVDE	FC-3440	Division subroutine	8, 9, 10
TIMEGMBL	FC-3480	Set up damped nulling drive	45
ZATTEROR	FC-3430	Zero attitude errors	27, 52, 55

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FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
PULSEFLG (Flagword 13 bit 15)	Minimum impulse command mode in "att hold" (V76)	Not in minimum impulse command mode (V77)			22, 50
USEQRFLG (Flagword 13 bit 14)	Gimbal unusable. Use jets only.	Trim gimbal may be used			44, 62
CSMDKFLG (Flagword 13 bit 13)	CSM docked to LM.	CSM not docked to LM.			12, 38, 57, 62
OURRCFLG (Flagword 13 bit 12)	Current DAP pass is rate command	Current DAP pass is not rate command	36	27	26, 28, 43, 50
ACC4-2FL (Flagword 13 bit 11)	4 jet X-axis translation requested	2 jet X-axis translation requested			48
AORBTFLG (Flagword 13 bit 10)	B system for X-translation	A system for X-translation preferred			48, 58
XOVINFLG (Flagword 13 bit 9)	X-axis override locked out	X-axis override okay			25
DRIFTDFL (Flagword 13 bit 8)	Assume 0 offset drifting flight	Use offset acceleration estimate			17, 47, 63, 85
ULLAGFLG (Flagword 13 bit 6)	Ullage request by mission program	No internal ullage requested			46
APSFLAG (Flagword 10 bit 13)	Ascent stage	Descent stagc			47, 63
SNUFFBIT (Flagword 5) bit 13)	U, V jets disabled during DPS burns (V65)	U, V jets enabled during DPS burns (V75)			63
AORBSFLG (Flagword 5 bit 5)	Prefer P-axis jet pairs 7, 15 and 8, 16	Prefer P-axis jet pairs 4, 12 and 3, 11	42	42	31, 39
RCSFLAGS (bit 12)	Perform P-axis calculations	Skip P-axis calculations	20	42	20

FLAGS (cont)

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
QRBIT (RCSFLAGS bit 11)	In "direct" rate command for Q, R axes	Not in "direct" rate command	54	26, 35 54	26, 52
PBIT (RCSFLAGS bit 10)	In "direct" rate command for P-axis	Not in "direct" rate command	33	33, 35	26, 29
RCSFLAGS (bit 9)	Hand-controller just sensed as out of detent	Hand-controller just sensed as in detent	28	26, 50	26
CALLGMBL (RCSFLAG5 bit 5)	Perform ACDT+C12 routine to set engine gimbal bits	ACDT+C12 not being called			3
RCSFLAGS (bit 1)	Used to alternate in "tacking" translation policies	Used to alternate in "tacking" translation policies	23, 24	23, 24	24

ERASABLE LOCATIONS USED

AGC Tag	Meaning	AGC Units	AGC Scaling
ABSEDOTP	Temporary storage for magnitude of EDOT(=/EDOTP - 1)	rev/sec	2^{-3}
ABSTJ	Temporary storage for magnitude of TJP(U, V)	csec	2^{+10}
ADRSDIF1	Index to select phase plane parameters for the axis being computed		2^{+14}
ADRSDIF2	Index for jet parameters		2^{+14}
ALPHAQ(R)	Most significant half of AOSQ and AOSR	rev/sec^2	2^{-2}
AOSQ(R)$_D$	Disturbing acceleration due to thrust vector /c.g. offset or other external torques (=GSOP ∂)	rev/sec^2	2^{-2}
AOSQ(R)TERM	Addition to vehicle rate resulting from AOSQ(R) during one 100 msec. period	rev/sec	2^{-3}
AXISCTR	Index to select parameters for axis desired: -1⟵P-axis; 0⟵U-axis; +1⟵V-axis		2^{+14}
CDUX(Y, Z)D	CDU - desired values	rev	2^{-1}
COEFFQ	Used for first column of matrix to convert vector from Q, R coordinates to U′, V′ coordinates		2^{0}
COEFFR	Used for second column of matrix to convert vector from Q, R coordinates to U′, V′ coordinates		2^{0}
COTROLER	Controls access to Q, R axis gimbal trim system		2^{+14}
DELCDUX(Y, Z)	Δ commands from steering interface; used to update CDUX(Y, Z)D (above)	rev	2^{-1}
DELP(Q, R) EROR	Attitude error lag angles from automatic steering routines	rev	2^{-1}
DKKOASN	Kalman filter gain parameter (α) for CSM/LM		2^{+14}
DKOMEGAN	Kalman filter gain parameter (ω) for CSM/LM		2^{+14}
DKTRAP	Trapsize for state estimator: CSM/LM	rev/sec	2^{-3}

ERASABLE LOCATIONS USED (cont)

AGC Tag	Meaning	AGC Units	AGC Scaling
DOWNTORK	Downlink; cumulative jet on times for axes: 0 ⟶ +P; 1 ⟶ -P; 2 ⟶ +U; 3 ⟶ -U; 4 ⟶ +V; 5 ⟶ -V	sec	2^{+5}
DX(YZ)ERROR	Manual mode X(Y, Z) attitude error - cumulative	rev	2^{-1}
E	Attitude error	rev	2^{-1}
EDOT	Attitude rate error	rev/sec	2^{-3}
EDOTP(Q, R)	Biased rate estimates	rev/sec	2^{-3}
FIREFCT	Signed distance from point where state would cross E-axis if jets were fired now to point $DB_{1\ (2)}$ in TJETLAW phase plane	rev	2^{-3}
FLAT	Limits for ZONE1 and ZONE2-3 in TJETLAW	rev	2^{-3}
HH	Square of time to get from E-axis to switch curve in TJETLAW	sec^2	2^{+3}
INGTS	2-valued switch. Set GTS attitude control law was operating during the previous cycle		2^{+14}
JETRATE	Predicted Δ rate in P-axis caused by jet firings	rev/sec	2^{-3}
JETRATEQ(R)	Predicted Δ rate about the Q(R)-axis caused by jet firings	rev/sec	2^{-3}
LMKOASN	Kalman filter gain parameter (α) for LM alone		2^{+14}
LMOMEGAN	Kalman filter gain parameter (ω) for LM alone		2^{+14}
LMTRAP	Trapsize for state estimator: LM alone	rev/sec	2^{-3}
NEXTP(U, V)	Translation command codes (octal) for Y, Z, X translation		2^{+14}
NO. V(U, P)JETS	Number of jets for V(U, P)-axis rotation		2^{+14}
NP(Q, R)TRAPS	Number of DAP periods over which error has accumulated since last incorporation; time varying portion of Kalman filter gain		2^{+14}
NUMBERT	Code word for jet select logic		2^{+14}
OLDP(QR)MIN	Flagwords set > 0 when a minimum impulse command is sensed and cleared when no commands are present		

ERASABLE LOCATIONS USED (cont)

AGC Tag	Meaning	AGC Units	AGC Scaling
OLDSENSE	Sign of jet firing time computed on last DAP pass for axis under consideration in CSM-docked control law	dsec	2^{+14}
OLDX(Y, Z)FORP	Previous CDUX(Y, Z) value	rev	2^{-1}
OMEGAP(Q, R)	Rate estimate	rev/sec	2^{-3}
P(Q, R)ERROR	P(Q, R)-axis error	rev	2^{-1}
P(U, V)JETCTR	Docked jet inhibition counters	dsec	2^{+14}
P(Q, R)LAST	Rate requested by astronaut via hand controller on last DAP pass	rev/sec	2^{-3}
POLYTEMP	Jet code policy used in channel 6 or channel 5 format (octal)		
Q(R)ACCDOT	Rate of change of the accelerations induced by the thrust vector motion	rev/sec^3	2^{-8}
Q(R)GIMTIMR	Gimbal drive counters - 100 msec. intervals	dsec	2^{+14}
Q(R)RATEDIF	Rate error for manual rate command mode	rev/sec	2^{-3}
Q(R)-RHCCTR	Counters - in units of counts from Rotational Hand Controller (variable)		2^{+14}
ROTINDEX	Index to indicate type of maneuver for which jets are to be selected		2^{+14}
ROTSENSE	2-valued switch to determine direction of rotation and to rescale time in TJETLAW	csec/sec	2^{+8}
SAVEHAND$_D$	Temporary storage for RHC inputs from the Q and R axes		
SENSETYP Set to	2→ascent burn, +X translation, or ullage - to fire only +X jets for U(V) axis attitude control if possible . 1→ -X translation- to fire only -X jets for U(V) axis attitude control if possible 0→No preference for use of +X or -X jets		
SKIPU(V)	Flags, cleared when U(V) axis computations are to be skipped because a short jet firing was calculated on the last DAP pass		2^{+14}
TCP(Q, R)	Manual control direct rate timers	dsec	2^{+14}
TJP(U, V)	Jet firing time for P(U, V)-axis	csec	2^{+10}
TRAPEDP (Q, R)	Accumulated unexplained rate error	rev/sec	2^{-3}

ERASABLE LOCATIONS USED (cont)

AGC Tag	Meaning	AGC Units	AGC Scaling
TTOAXIS	Jet firing time to reach E-axis from present state in TJETLAW phase plane	sec	2^{+2}
U(V)RATEDIF	Attitude rate error in manual rate command mode	rev/sec	2^{-3}
ZONE3L1M	Border between ZONE2 and ZONE3 in TJETLAW	sec	2^{+2}
1/ANET(2)	Inverse of 1(2) jet net acceleration expected around an axis	sec^2/rev	2^{+8}
1JACCQ(R)	Effective acceleration about the Q(R)-axis caused by a single jet on the U- or V-axis	rev/sec^2	2^{-3}

LM DAP TRIM
GIMBAL CONTROL SYSTEM

GTS	Sh. 2
TIMEGMBL	Sh. 13
ACDT+C12	Sh. 17

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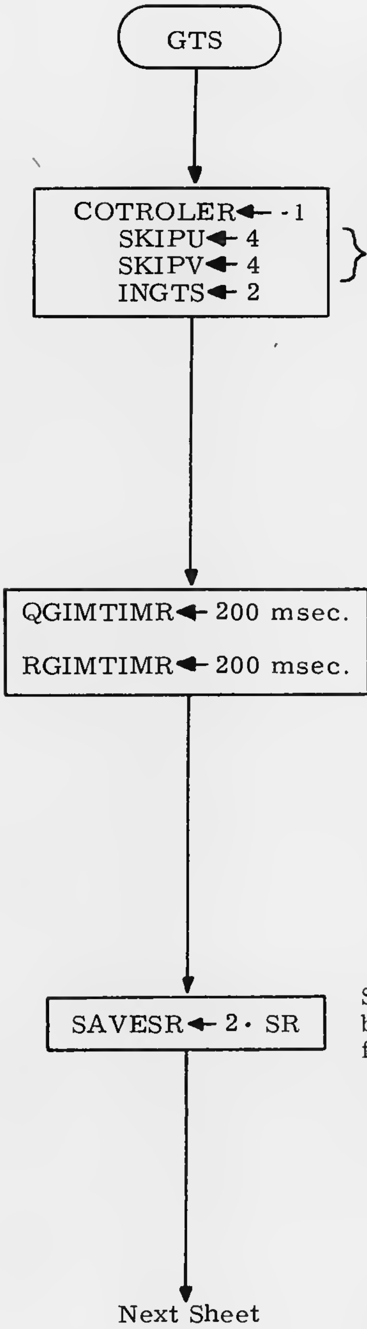
DRAWN L. BEDDOE	21 OCT	LM DAP Trim Gimbal Control System	
PRGMR Craig C. Work	10 [illegible]	LUMINARY 1D	**DOCUMENT NO.** FC-3480
ANALST Craig C. Work	10 Nov 69		
DOCMR Roberta M. Estes	11/10/69		
APPR'D Roberta M Estes	11/10/69	**REV** 1	**SHEET** 1 **OF** 19



Do Q-R RCS control next time

Do not skip either axis

Doing GTS control

Scaled 1 bit = 100 msec. GTS has taken over control of the gimbals. Setting the timers to 200 msec. insures against interference with this control. GTS does not time the gimbals, but updates the drive commands every time it runs (every 200 msec.).

Save shift register contents so it can be used later. Double to compensate for right shift on readout.

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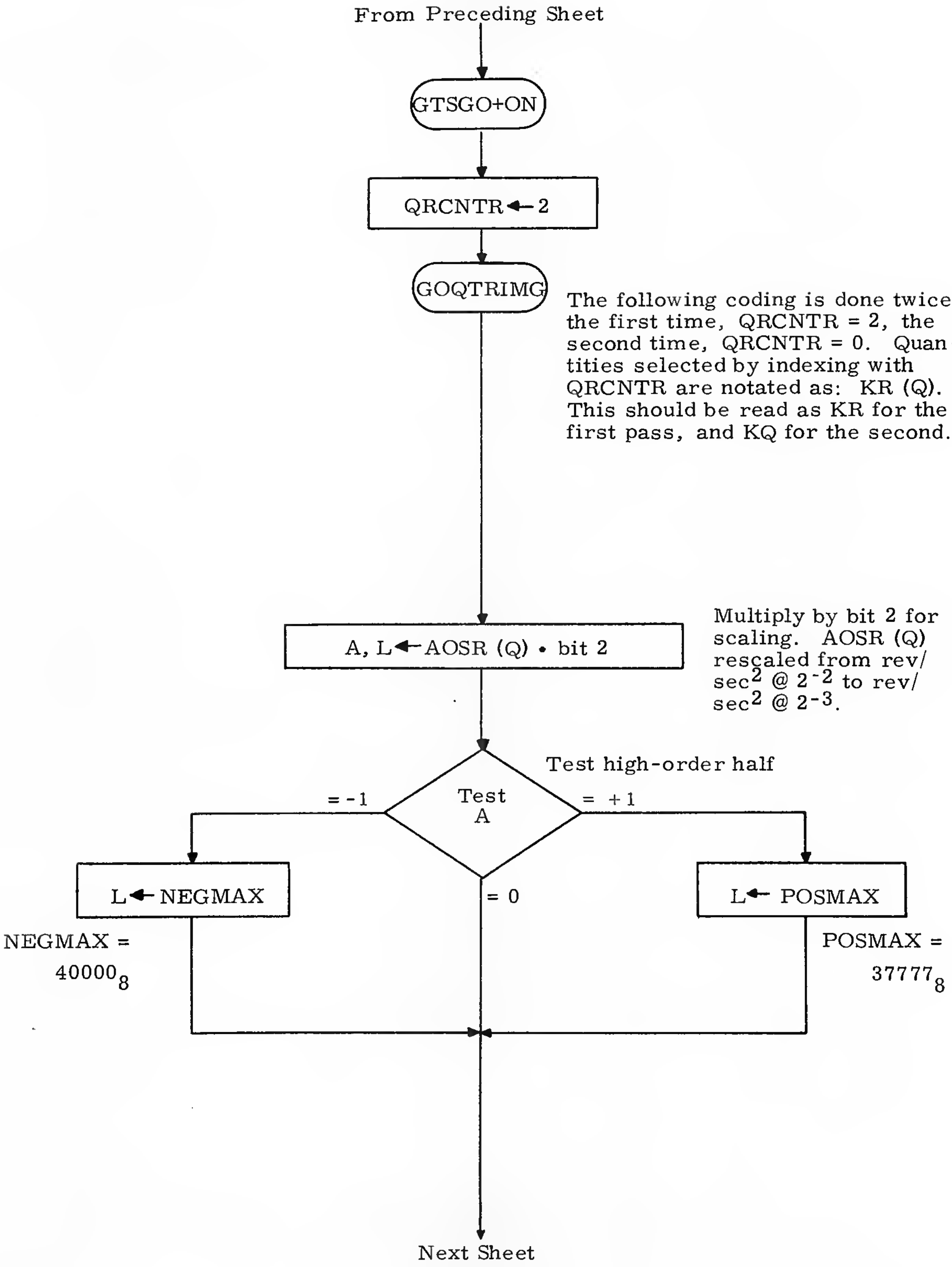
DRAWN M. Guerin	10/21/69	LM DAP Trim Gimbal Control System	
PRGMR Craig C. Work	10Nov69		DOCUMENT NO.
ANALST			
DOCMR Roberta M. Estes	11/10/69	LUMINARY 1D	FC-3480
APPR'D Roberta M. Estes	11/10/69	REV 1	SHEET 2 OF 19



The following coding is done twice; the first time, QRCNTR = 2, the second time, QRCNTR = 0. Quantities selected by indexing with QRCNTR are notated as: KR (Q). This should be read as KR for the first pass, and KQ for the second.

Multiply by bit 2 for scaling. AOSR (Q) rescaled from rev/sec^2 @ 2^{-2} to rev/sec^2 @ 2^{-3}.

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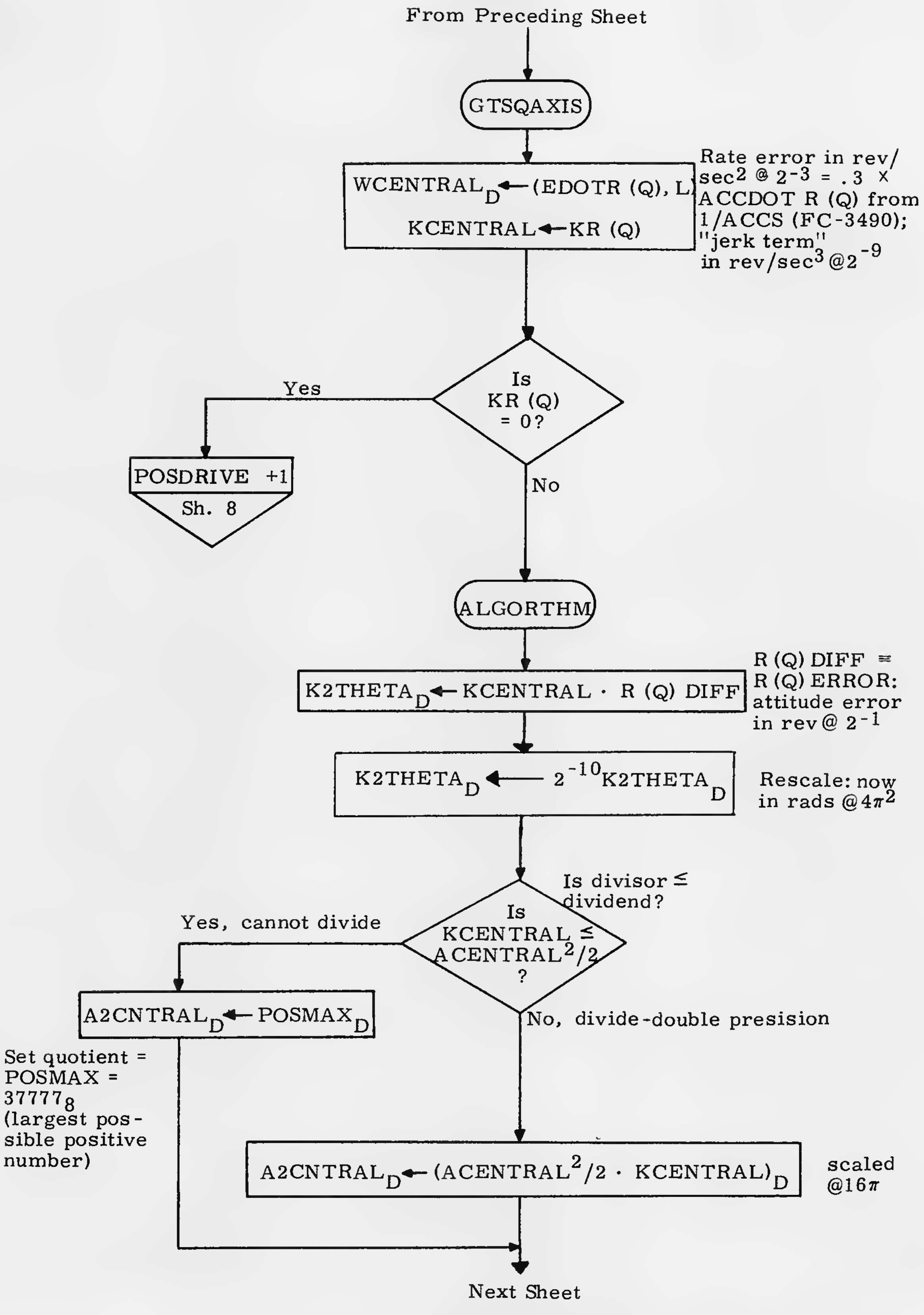
APOLLO GUIDANCE AND NAVIGATION

LM DAP Trim
Gimbal Control System

LUMINARY 1D
DOCUMENT NO. FC-3480

REV . 1
SHEET 3 OF 19



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APOLLO GUIDANCE AND NAVIGATION

LM DAP Trim
Gimbal Control System

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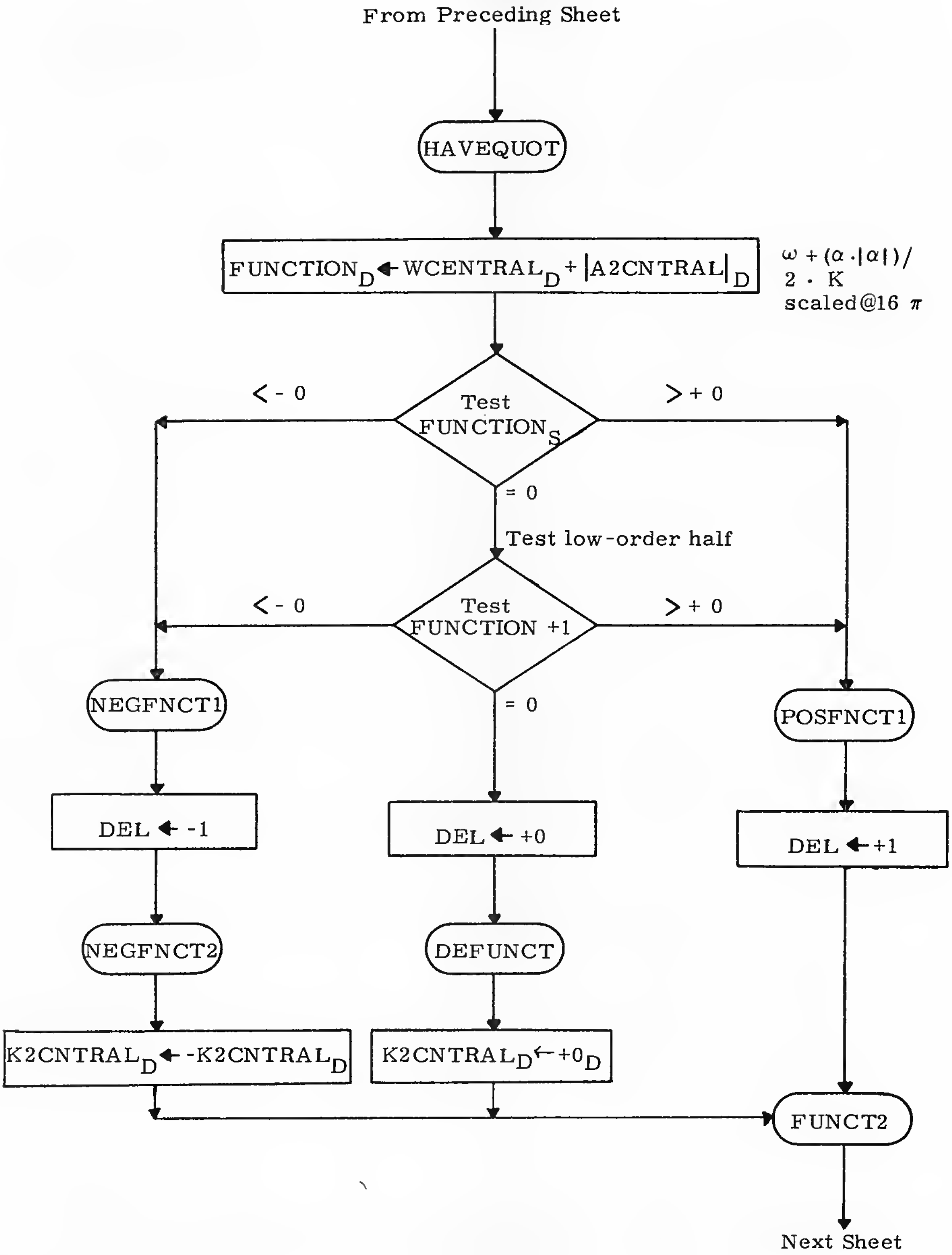
DOCUMENT NO.
FC-3480

REV 1

SHEET 4 OF 19



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APOLLO GUIDANCE AND NAVIGATION

LM DAP Trim
Gimbal Control System

LUMINARY 1D

DOCUMENT NO.
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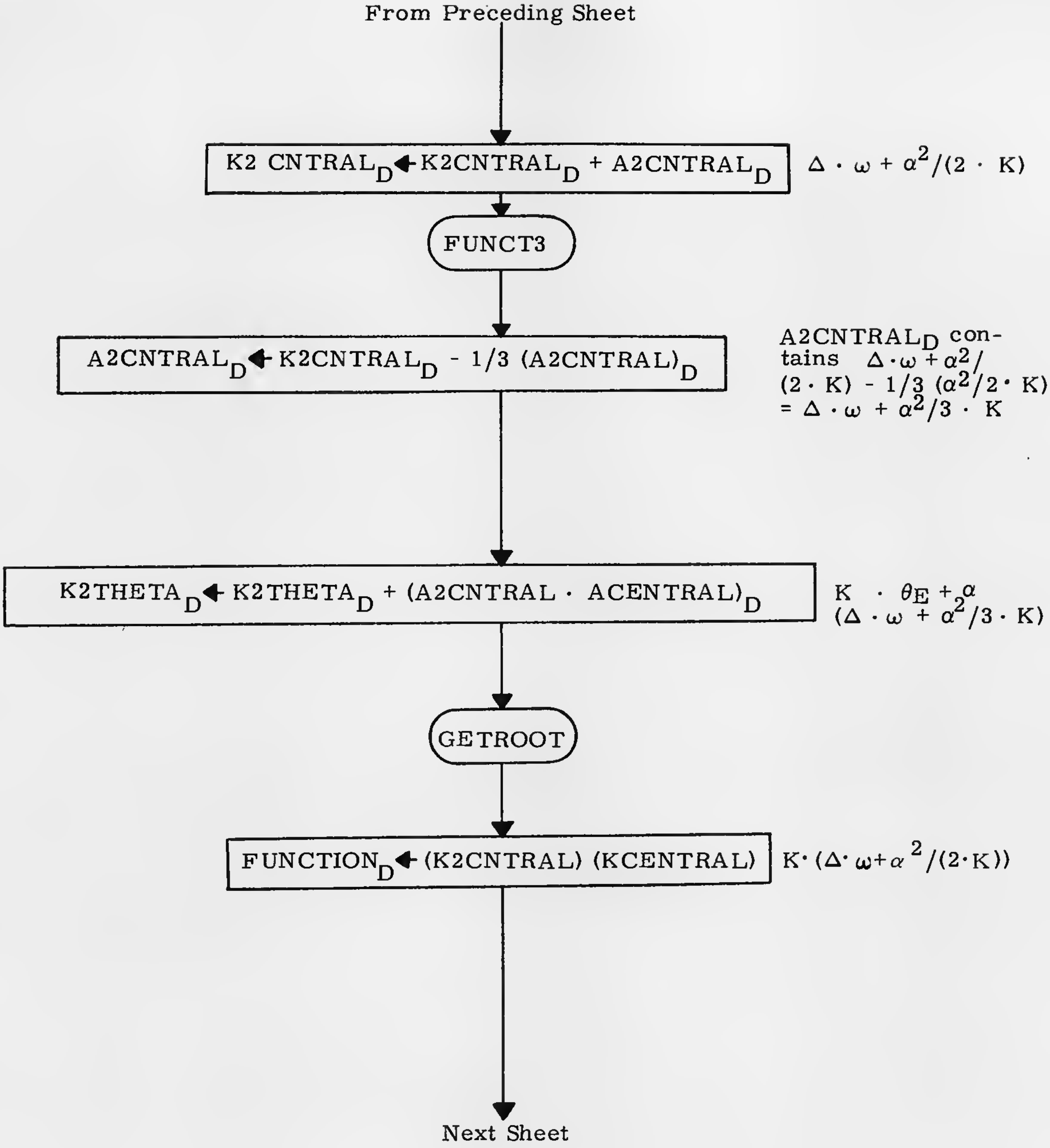
SHEET 5 OF 19



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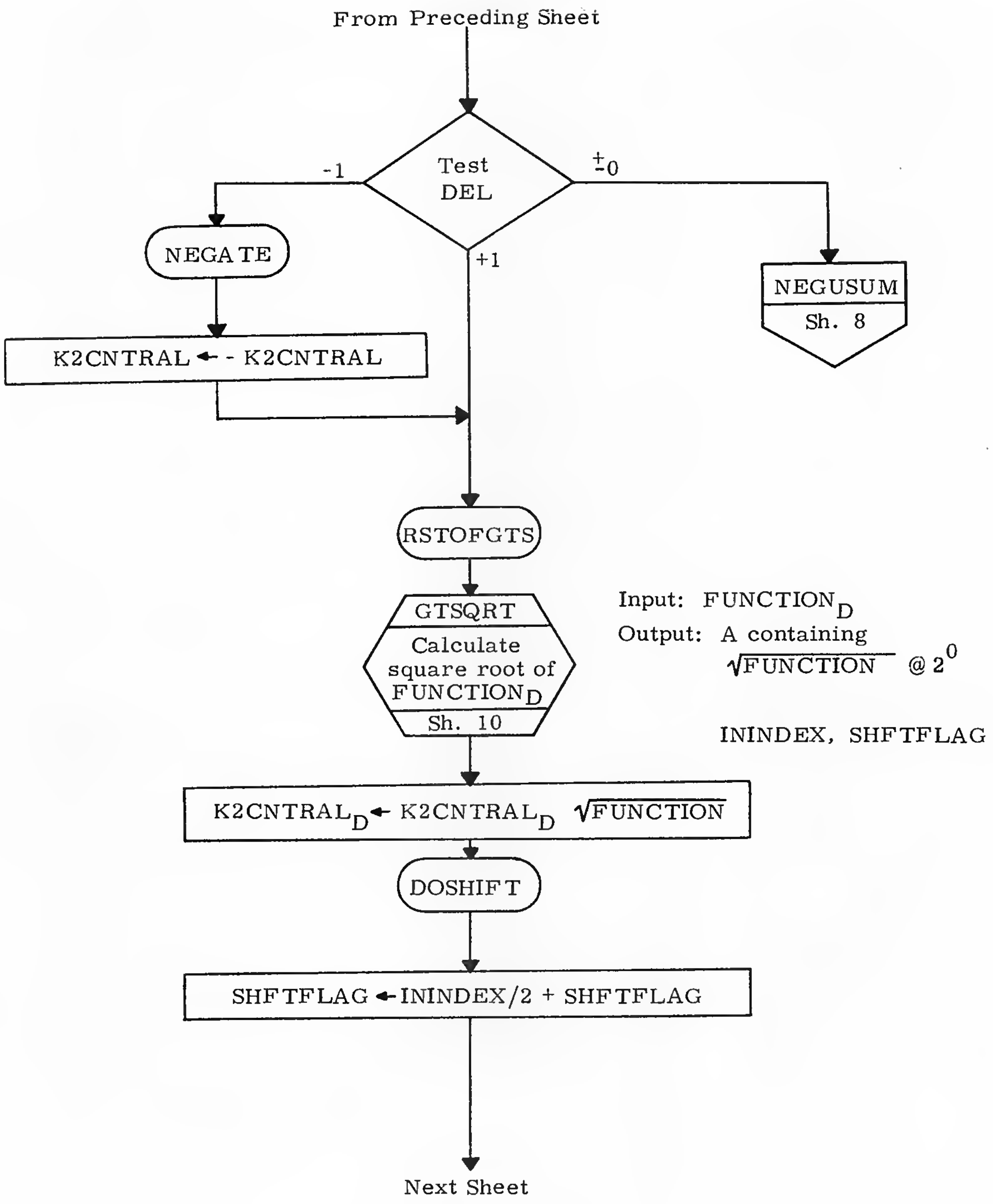
DRAWN M. Guerin	10/21/69	LM DAP Trim Gimbal Control System	
PRGMR Craig C. Kosk	10Nov69		
ANALST		LUMINARY 1_D	DOCUMENT NO. FC-3480
DOCMR Robert M. Estes	11/10/69		
APPR'D Robert M. Estes	11/10/69	REV 1	SHEET 6 OF 19



Input: FUNCTION$_D$

Output: A containing $\sqrt{\text{FUNCTION}}$ @ 2^0

ININDEX, SHFTFLAG

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APOLLO GUIDANCE AND NAVIGATION

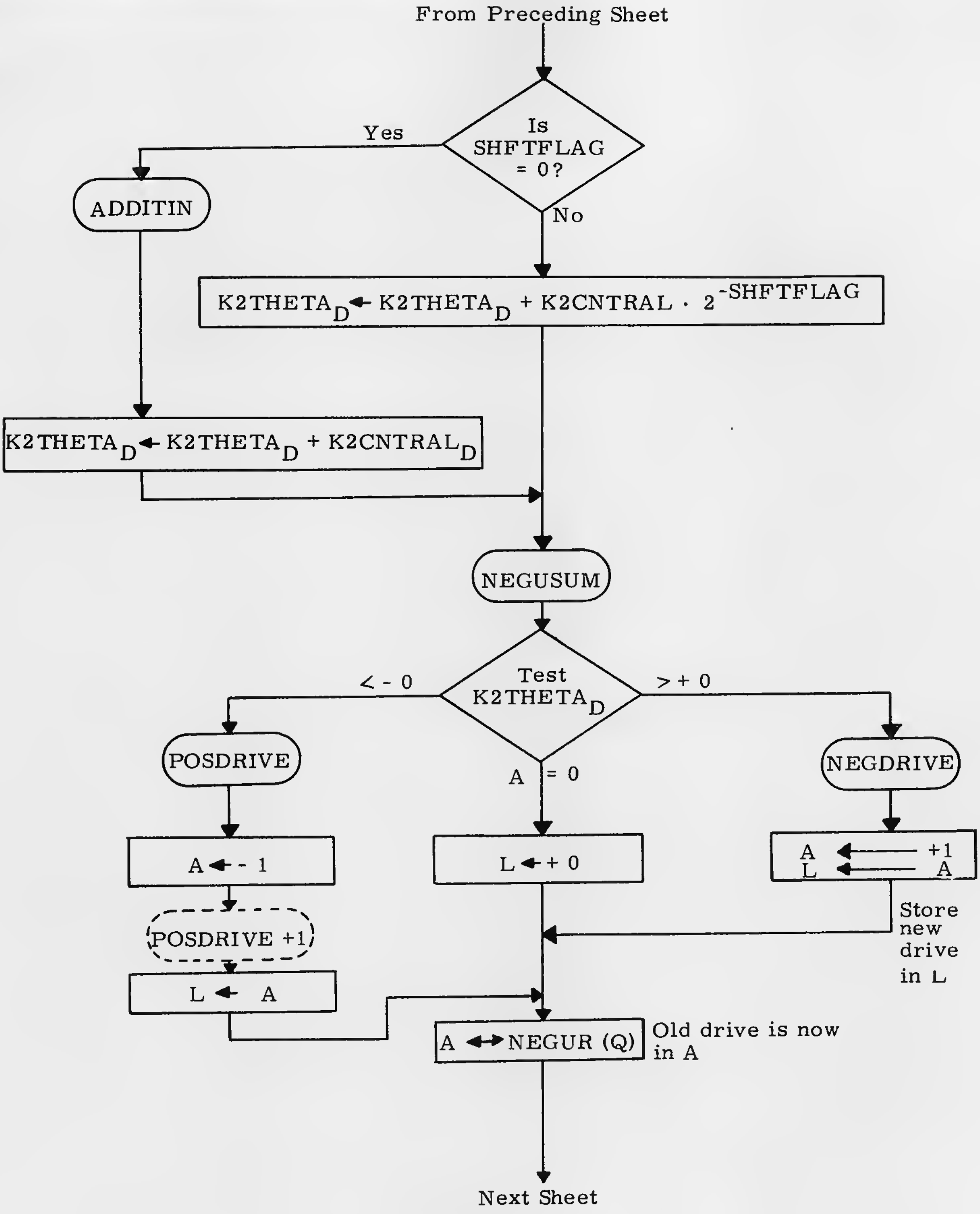
LM DAP Trim
Gimbal Control System

LUMINARY 1D

DOCUMENT NO. FC-3480

REV 1

SHEET 7 OF 19



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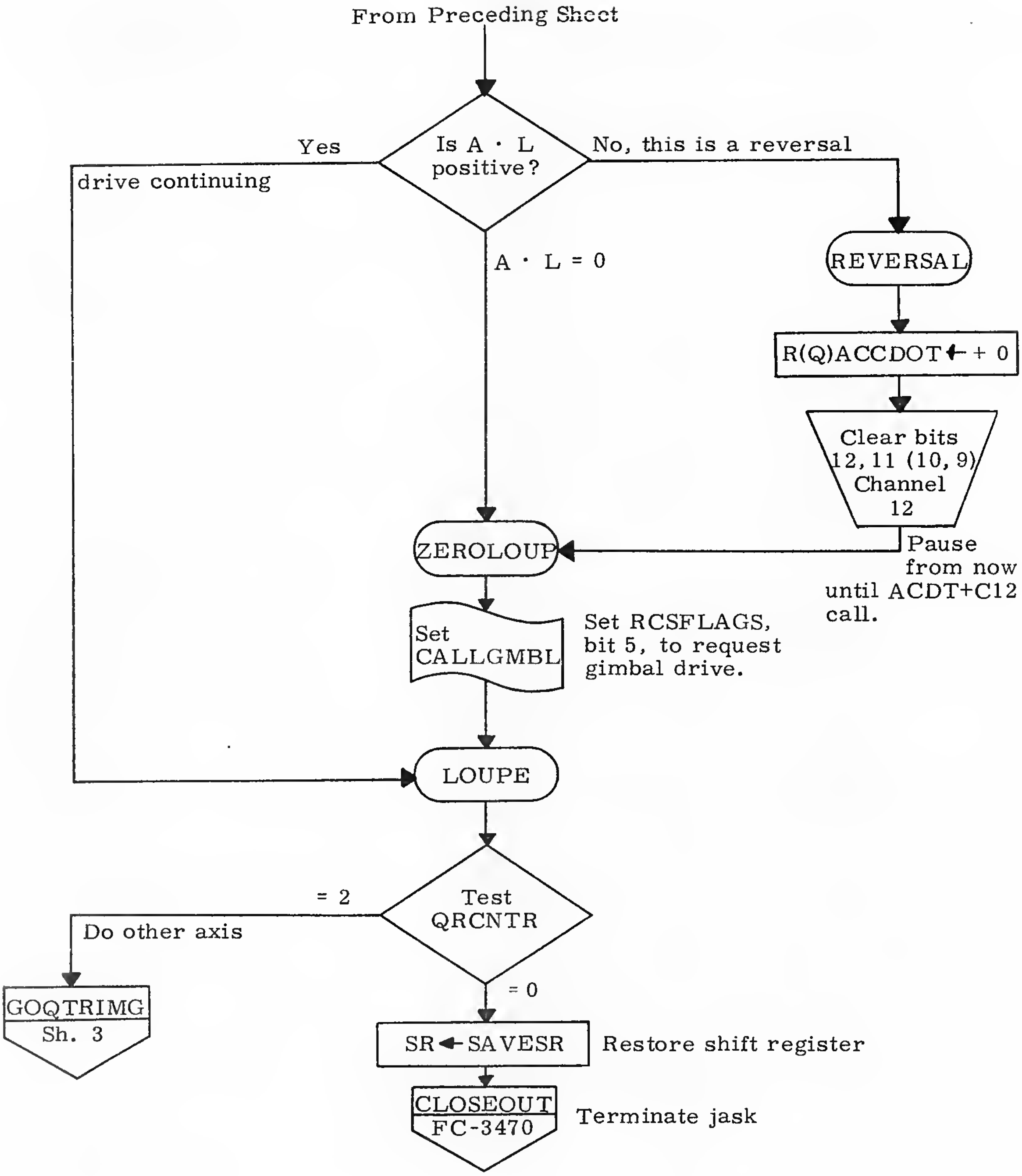
LM DAP Trim
Gimbal Control System

LUMINARY 1D

DOCUMENT NO. FC-3480

REV 1

SHEET 8 OF 19



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APOLLO GUIDANCE AND NAVIGATION

LM DAP Trim
Gimbal Control System

LUMINARY 1D

DOCUMENT NO.
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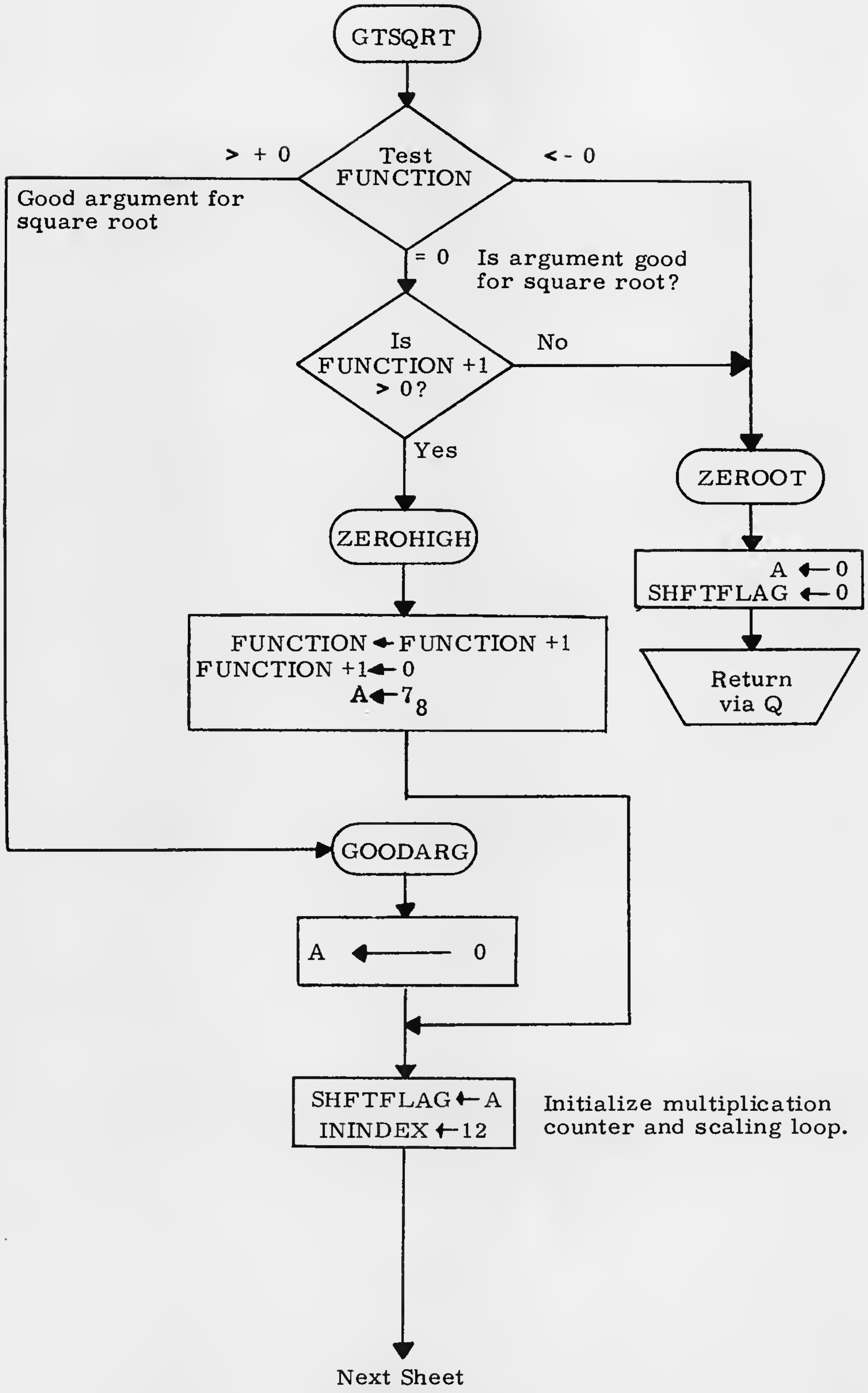
REV 1

SHEET 9 OF 19



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LM DAP Trim
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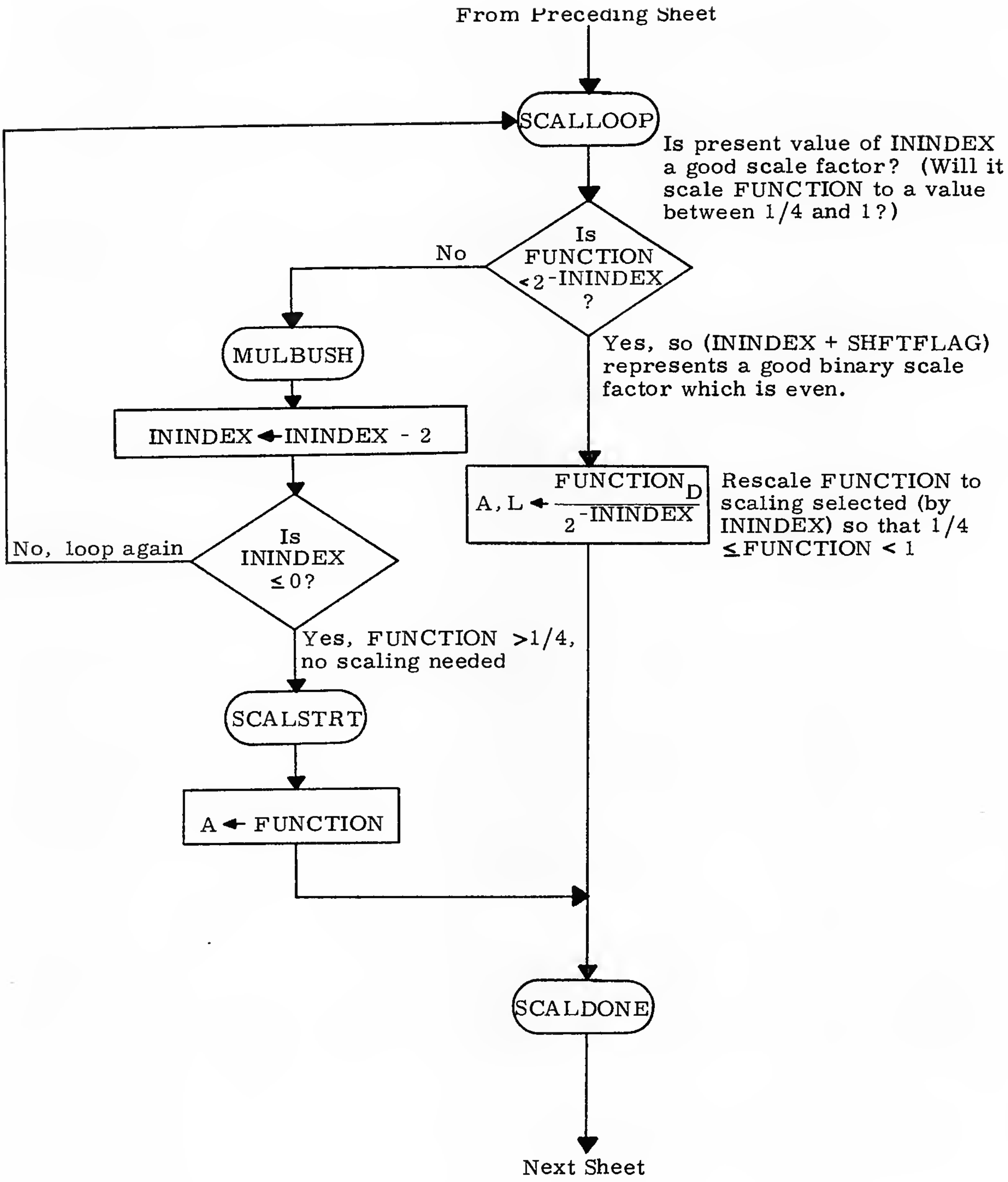
LUMINARY 1D

DOCUMENT NO.
FC-3480

REV 1

SHEET 10 OF 19



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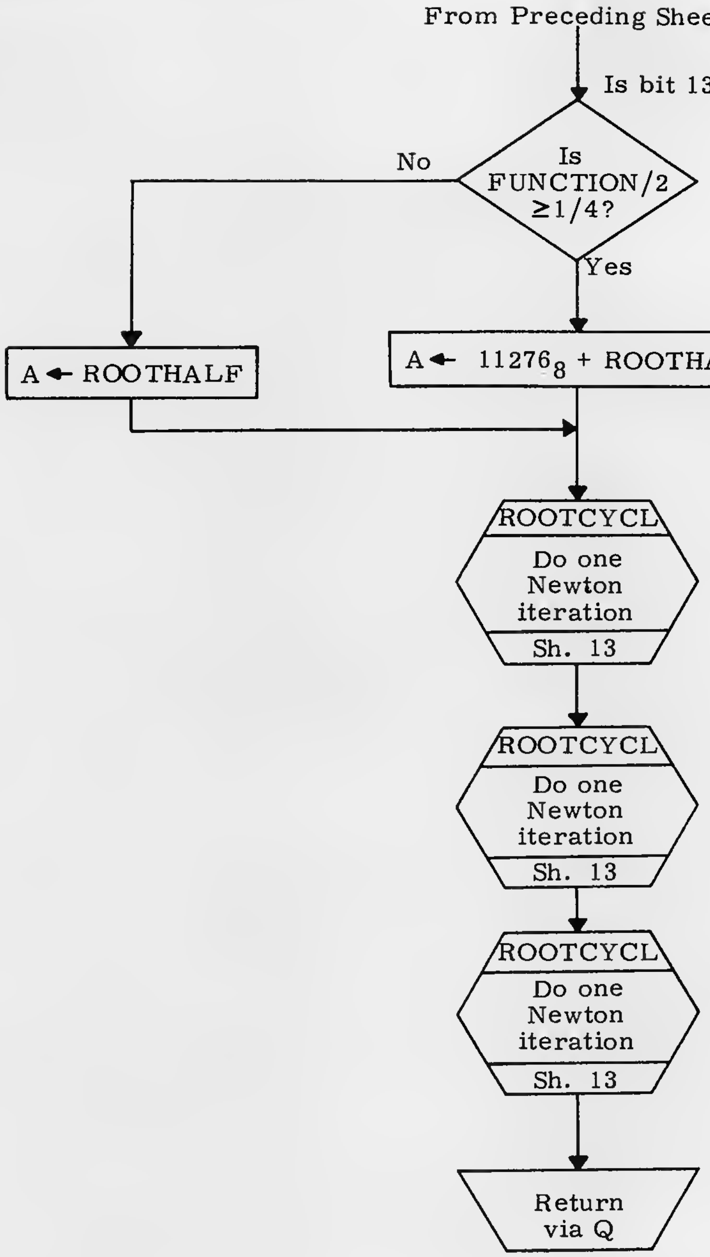
DRAWN M. Guzesin	10/21/69	LM DAP Trim Gimbal Control System	
PRGMR Craig C. Work	10 Nov 69	LUMINARY 1D	DOCUMENT NO. FC-3480
ANALST			
DOCMR Roberta M. Eaton	11/10/69		
APPR'D Roberta M. Eaton	11/10/69	REV 1	SHEET 11 OF 19



ROOTHALF = $\sqrt{1/2}$ = 26501_8 (equation value = 0.70710). $11276_8 + 26501_8 = 37777_8$ = POSMAX.

Do 3 iterations of a Newton square root algorithm of the form:

$$A \leftarrow \frac{A + \frac{\text{argument}}{A}}{2}$$

Final Output: A, containing ≈ $\sqrt{\text{FUNCTION}}$ scaled @ 2^0

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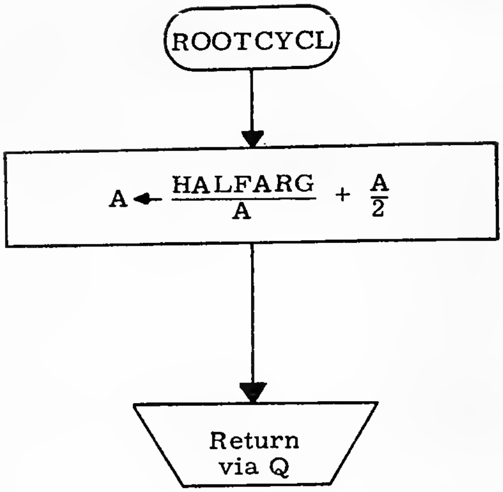
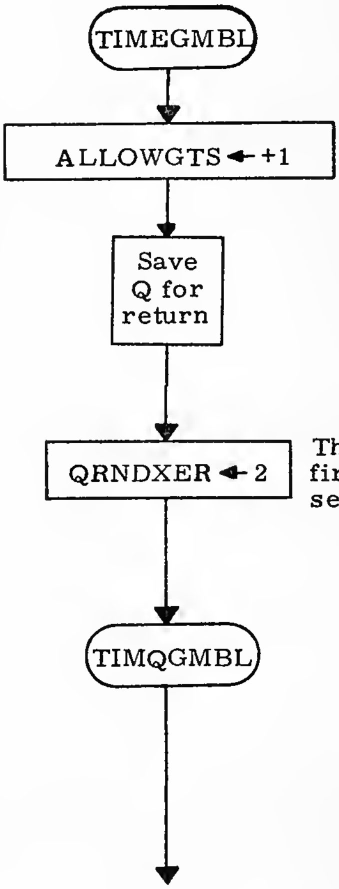
ANALST			LUMINARY 1D — DOCUMENT NO. FC-3480
DOCMR	Roberta M. Estes	11/10/69	
APPR'D	Roberta M. Estes	11/10/69	REV 1 — SHEET 12 OF 19



A now contains

$$\frac{A + \frac{\text{argument}}{A}}{2}$$



Initialize ALLOWGTS

The following section is done twice; the first time, QRNDXER = 2 (R-axis); the second time, QRNDXER = 0 (Q-axis).

Next Sheet

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APOLLO GUIDANCE AND NAVIGATION

LM DAP Trim
Gimbal Control System

LUMINARY 1D

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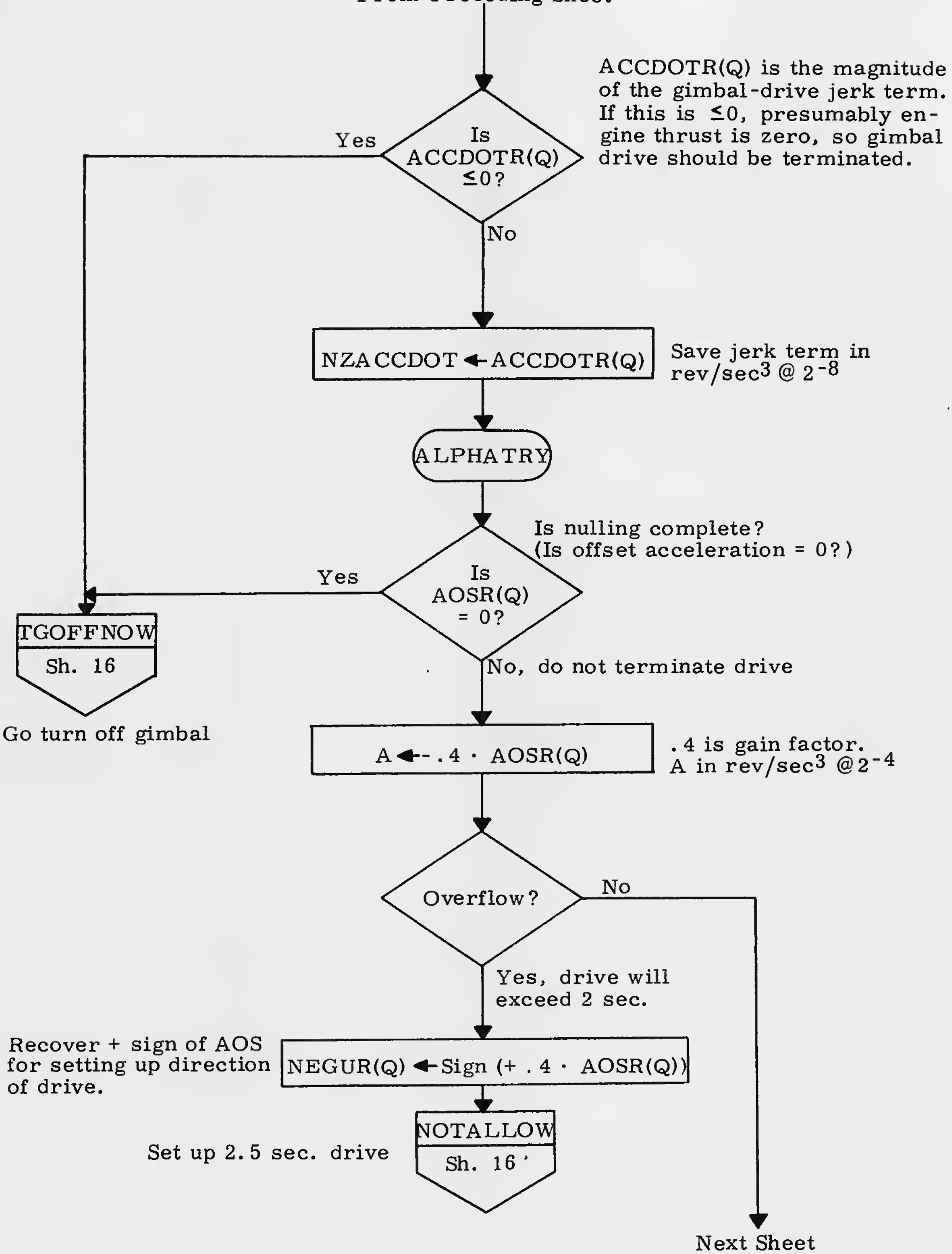
REV 1

SHEET 13 OF 19

From Preceding Sheet



ACCDOTR(Q) is the magnitude of the gimbal-drive jerk term. If this is ≤0, presumably engine thrust is zero, so gimbal drive should be terminated.

Save jerk term in rev/sec^3 @ 2^{-8}

Is nulling complete? (Is offset acceleration = 0?)

Go turn off gimbal

.4 is gain factor. A in rev/sec^3 @2^{-4}

Recover + sign of AOS for setting up direction of drive.

Set up 2.5 sec. drive

Next Sheet

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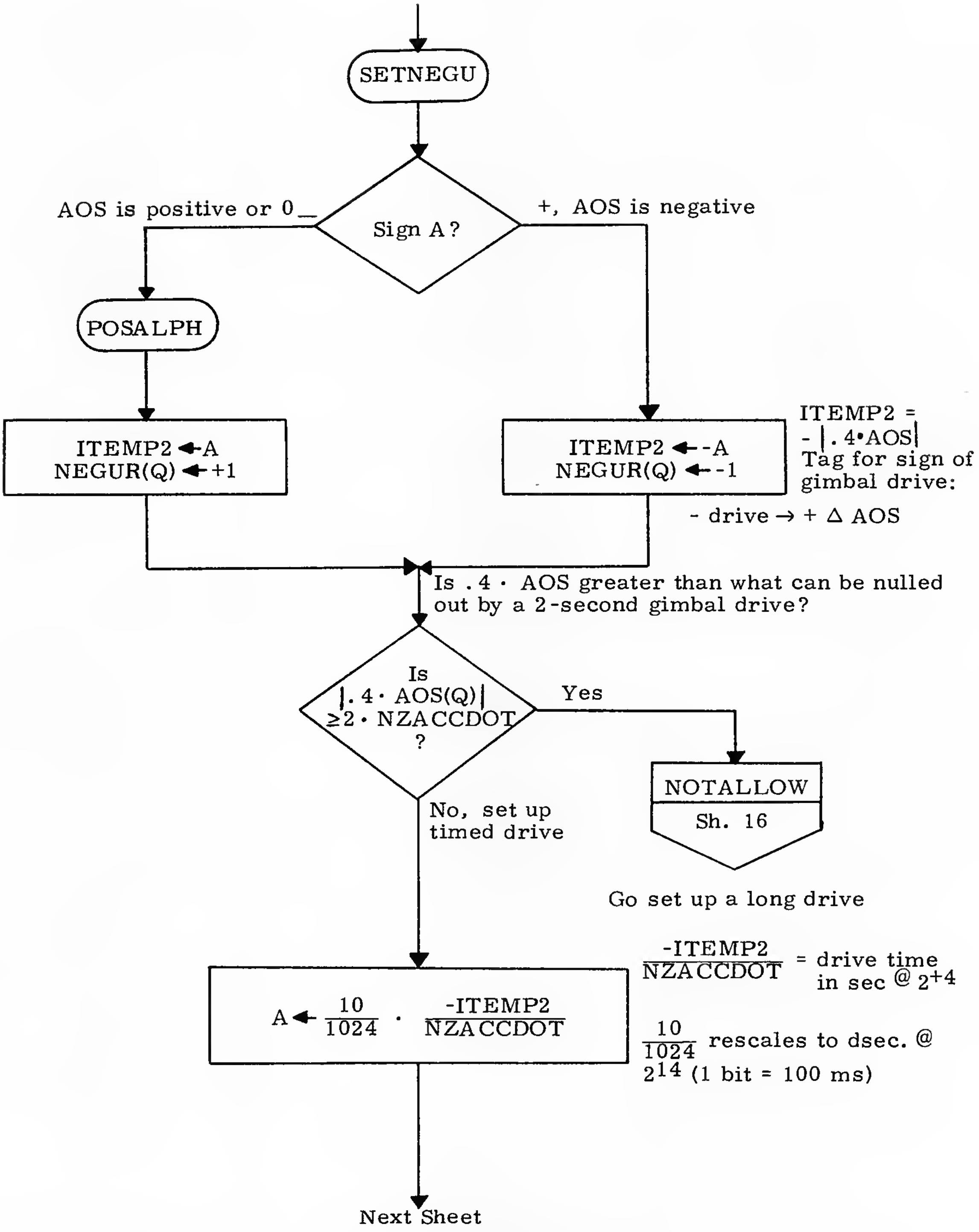
ANALST			
DOCMR Robert M. Estes	11/10/69		
APPR'D Robert M. Estes	11/10/69	REV 1	SHEET 14 OF 19



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ANALST
DOCMR Roberta M. Eutes 11/10/69
APPR'D Roberta M. Eutes 11/10/69

APOLLO GUIDANCE AND NAVIGATION

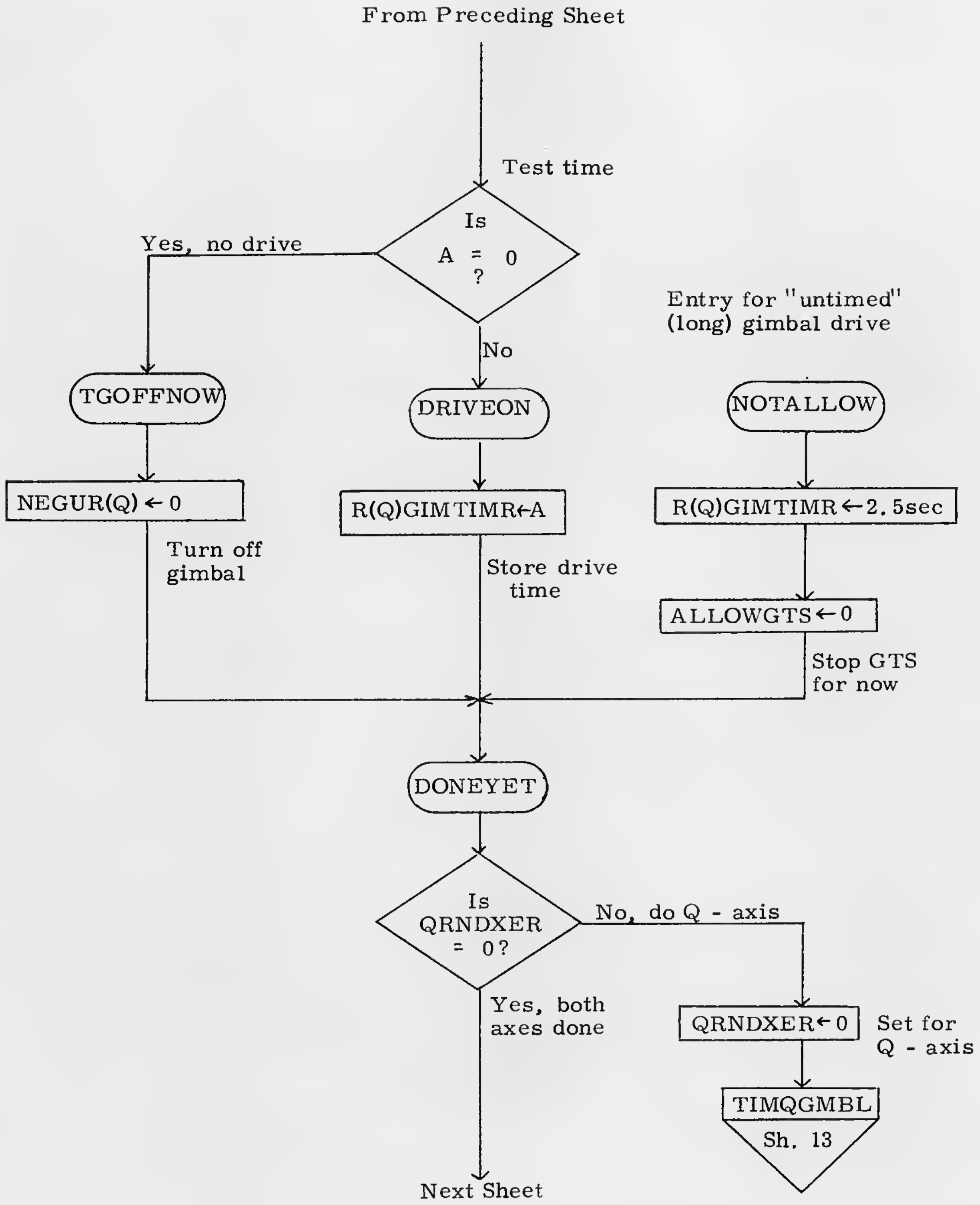
LM DAP Trim
Gimbal Control System

LUMINARY 1D

DOCUMENT NO.
FC-3480

REV 1

SHEET 15 OF 19



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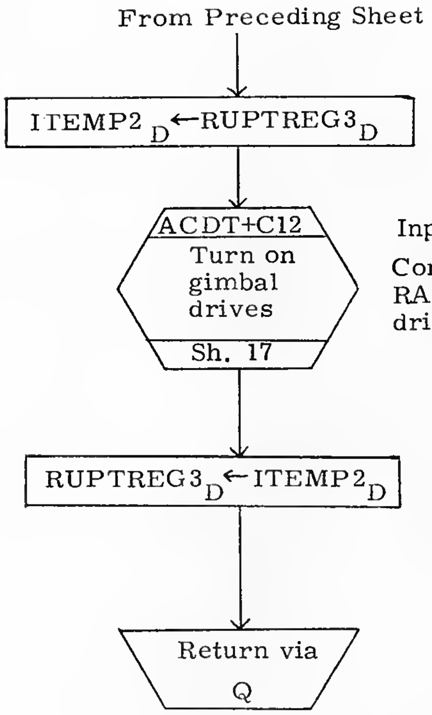
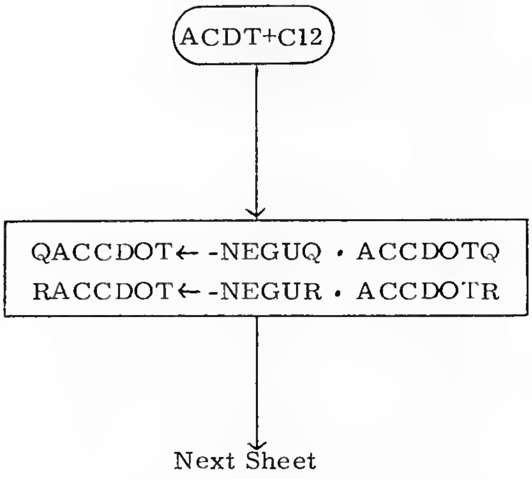
DRAWN L. BEDDOE 21 OCT 69	LM DAP Trim Gimbal Control System	
PRGMR Craig G. Work 10/16/69		
ANALST	LUMINARY 1D	DOCUMENT NO. FC-3480
DOCMR 11/10/69		
APPR'D 11/10/69	REV 1	SHEET 16 OF 19



Input: NEGUQ, NEGUR

Computes QACCDOT and RACCDOT for new gimbal drives also.

RUPTREG3 must be saved and restored so that IBNKCALL may be used by the jask.



Update jerk terms:
magnitude of jerk term
signed jerk term

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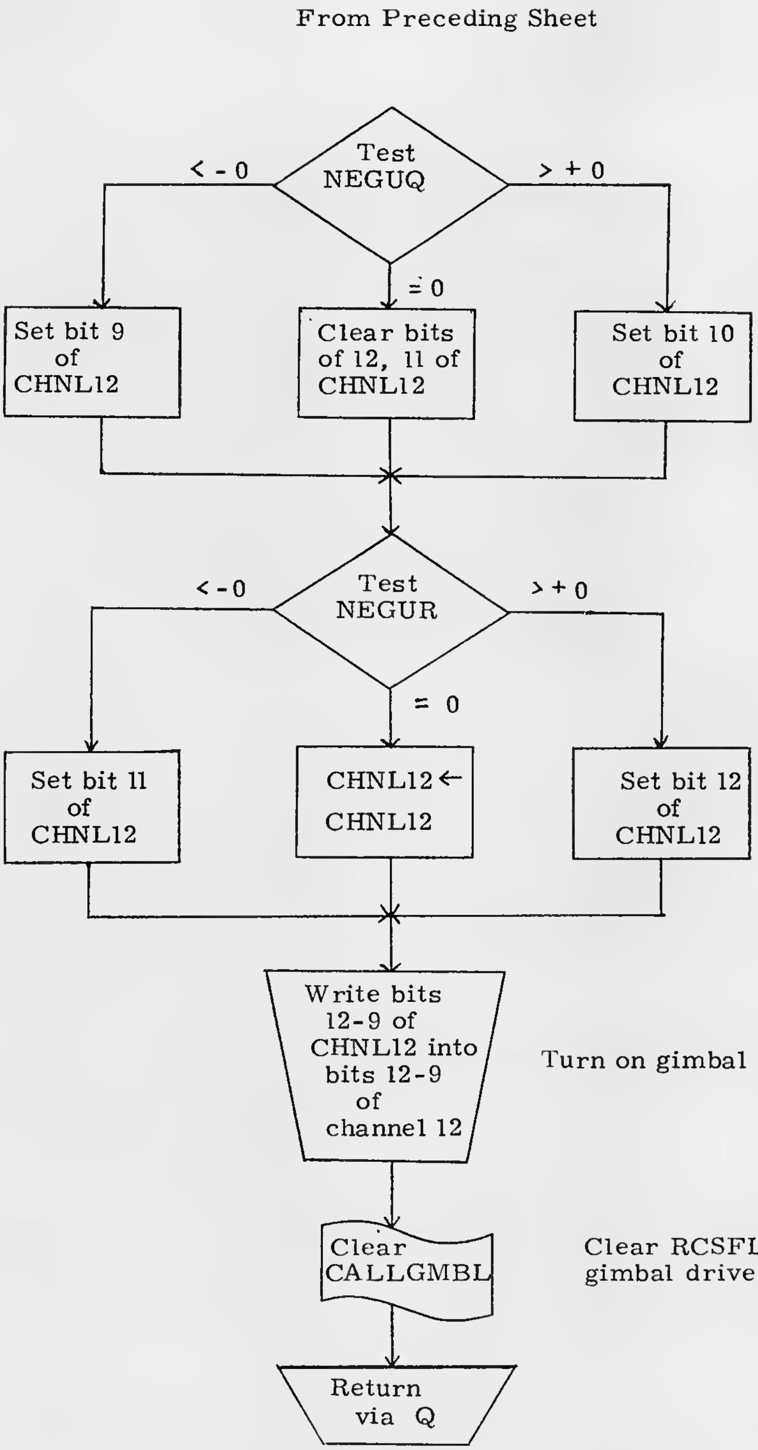
PRGMR Craig C. Work	10 Nov 69	LUMINARY 1D	DOCUMENT NO. FC-3480
ANALST			
DOCMR	11/10/69		
APPR'D	11/10/69	REV 1	SHEET 17 OF 19



CHNL 12 is temporary storage. Bits not set are 0 at this point.

In channel 12:
bit 10→+Q gimbal drive
bit 9 →-Q gimbal drive

Note: + gimbal drive causes a - change in angular acceleration, and vice-versa.

In channel 12:
bit 12→ +R gimbal drive
bit 11→ -R gimbal drive

Turn on gimbal drives

Clear RCSFLAGS, bit 5, to show that gimbal drive has been done.

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APOLLO GUIDANCE AND NAVIGATION

LM DAP Trim
Gimbal Control System

LUMINARY 1D

DOCUMENT NO.
FC-3480

REV 1

SHEET 18 OF 19

SUBROUTINE CALLED WHICH IS
FLOWED ON OTHER FLOWCHART

Subroutine Name	Where Flowed	Description	Where Called
CLOSEOUT	FC-3470	Terminates jask	Sh. 9

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PRGMR Craig C. Work	10Nov69		
ANALST		LUMINARY 1D	**DOCUMENT NO.** FC-3480
DOCMR Roberta M. Estes	11/10/69		
APPR'D Roberta M. Estes	11/10/69	**REV** 1	**SHEET** 19 **OF** 19

AOSJOB and AOSTASK

1/ACCSET	Sh. 2
1/ACCJOB	Sh. 2
1/ACCS	Sh. 2
1/ANET	Sh. 31
DO1/NET+	Sh. 32
DOACCFUN	Sh. 32

Special Conventions:

Notation for magnitude of net acceleration produced by firing U(V) jets (See Sh. 19 and on)	Sign of AOSU(V) (angular acceleration produced by thrust of main engine)	Sign of acceleration produced by U(V) jets	Number of U(V) jets
$a_{\text{netpos(neg)max}}$	+ or - (but whether + or - not yet specified)	same as sign of AOSU(V)	2
$a_{\text{netpos(neg)min}}$			1
$a_{\text{netneg(pos)max}}$	+ or - (but whether + or - not yet specified)	opposite from sign of AOSU(V)	2
$a_{\text{netneg(pos)min}}$			1
$a_{\text{netposmax}}$	+ or - (specified)	+	2
$a_{\text{netposmin}}$			1
$a_{\text{netnegmax}}$	+ or - (specified)	—	2
$a_{\text{netnegmin}}$			1
Notation for magnitude of "coast" acceleration	**Sign of AOSU(V)**	**Sign of acceleration produced by U(V) jets**	
$a_{\text{coastneg(pos)}}$	+ or - (but whether + or - not yet specified)	same as sign of AOSU(V)	
$a_{\text{coastpos(neg)}}$	+ or - (but whether + or - not yet specified)	opposite from sign of AOSU(V)	
a_{coastneg}	+ or - (specified)	+	
a_{coastpos}	+ or -	—	

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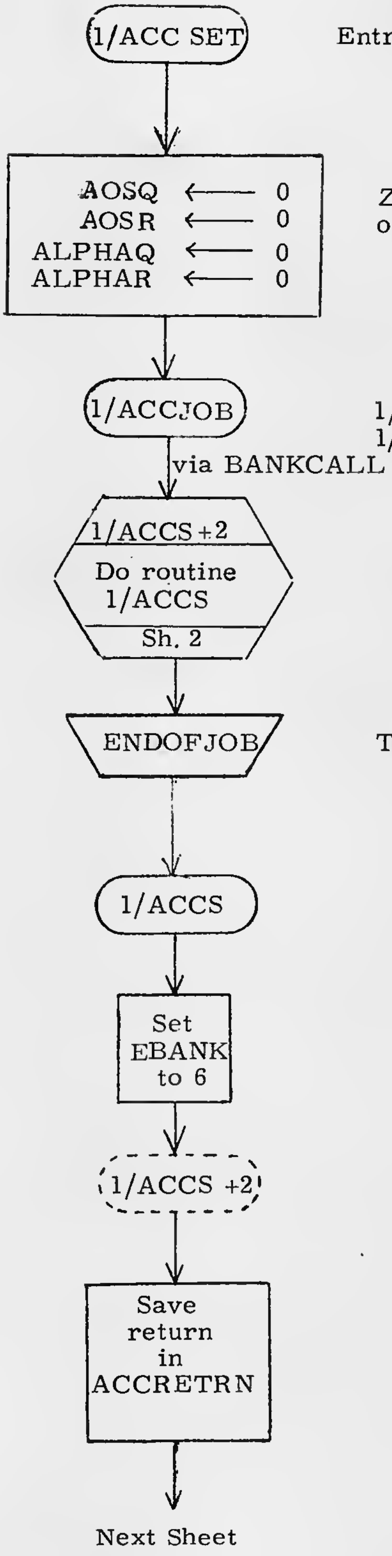
DRAWN E. Felix	10/20/69	AOSJOB and AOSTASK	
PRGMR R. Goss	3/19/70		DOCUMENT NO.
ANALST			
DOCMR Roberta M Estes	3/19/70	LUMINARY 1D	FC-3490
APPR'D Roberta M Estes	3/19/70	REV 1	SHEET 1 OF 36



Entry from DAPIDLER after Fresh Start or Restart

Zero the Q and R axis angular offset estimates

1/ACCS is a subroutine. This entry allows 1/ACCS to be done as a job.

Terminate job

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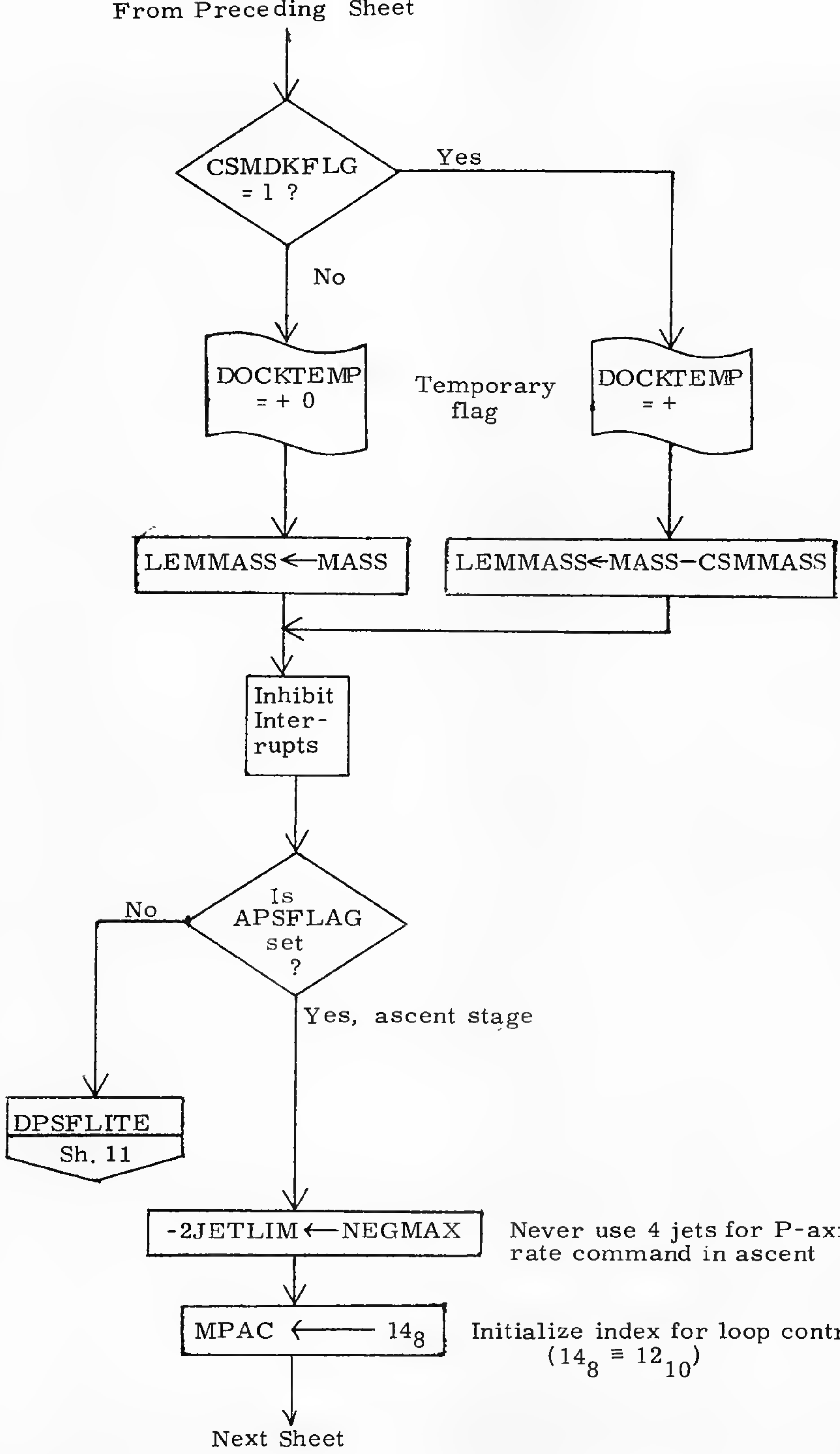
DRAWN E. Reiser	10/20/69	AOSJOB and AOSTASK	
PRGMR			
ANALST			DOCUMENT NO.
DOCMR R M Exton	3/19/70	LUMINARY 1D	FC-3490
APPR'D R M Exton	3/19/70	REV 1	SHEET 2 OF 36



Temporary flag

If docked configuration, must subtract CSM mass from total mass to get LM mass (in kg @ 2^{+16})

Never use 4 jets for P-axis rate command in ascent

Initialize index for loop control ($14_8 \equiv 12_{10}$)

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APOLLO GUIDANCE AND NAVIGATION

DRAWN G. Reiser 10/20/69
PRGMR
ANALST
DOCMR 3/19/70
APPR'D 3/19/70

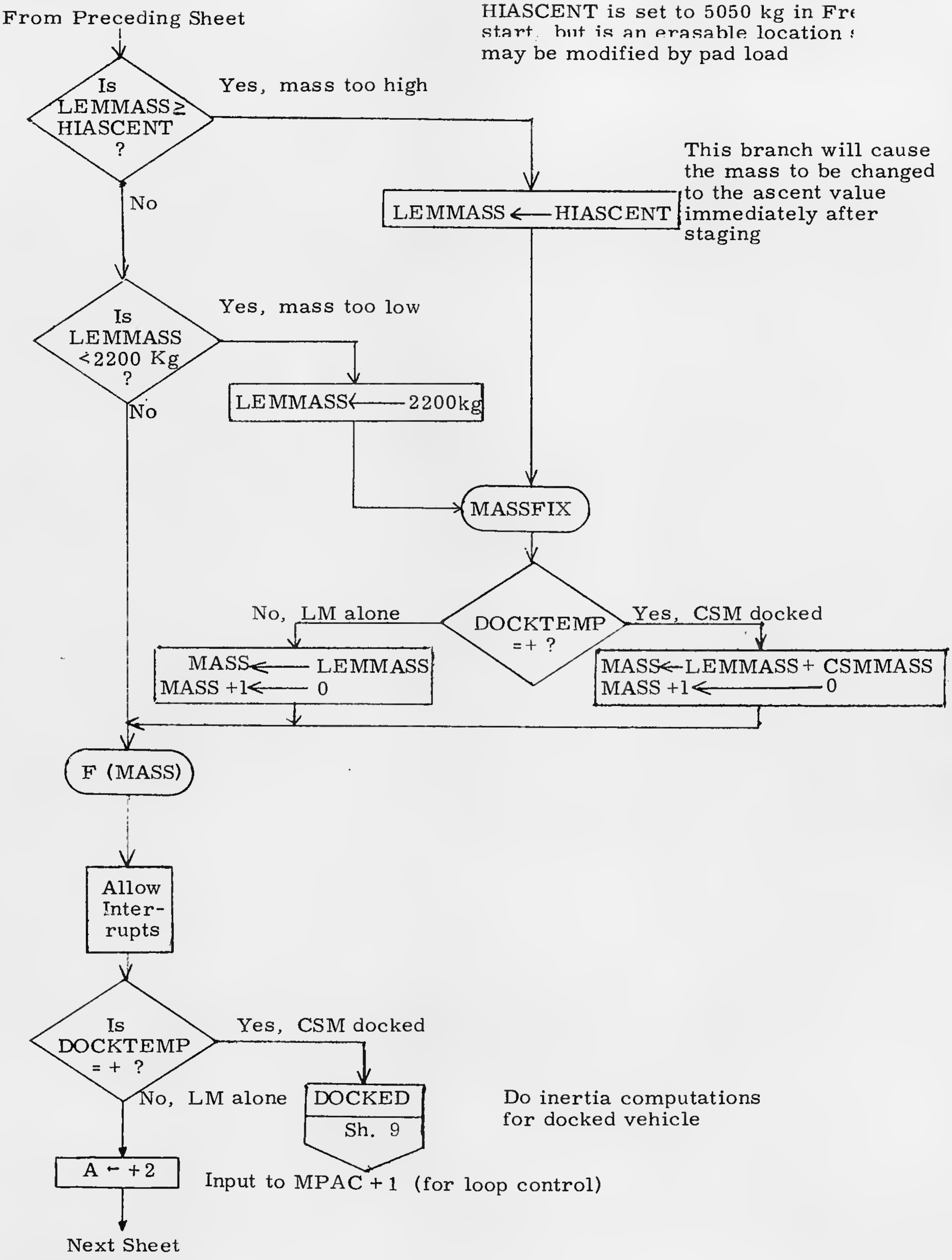
AOSJOB and AOSTASK

LUMINARY 1D

DOCUMENT NO. FC-3490

REV 1

SHEET 3 OF 36



HIASCENT is set to 5050 kg in Fre
start, but is an erasable location
may be modified by pad load

This branch will cause the mass to be changed to the ascent value immediately after staging

Do inertia computations for docked vehicle

Input to MPAC + 1 (for loop control)

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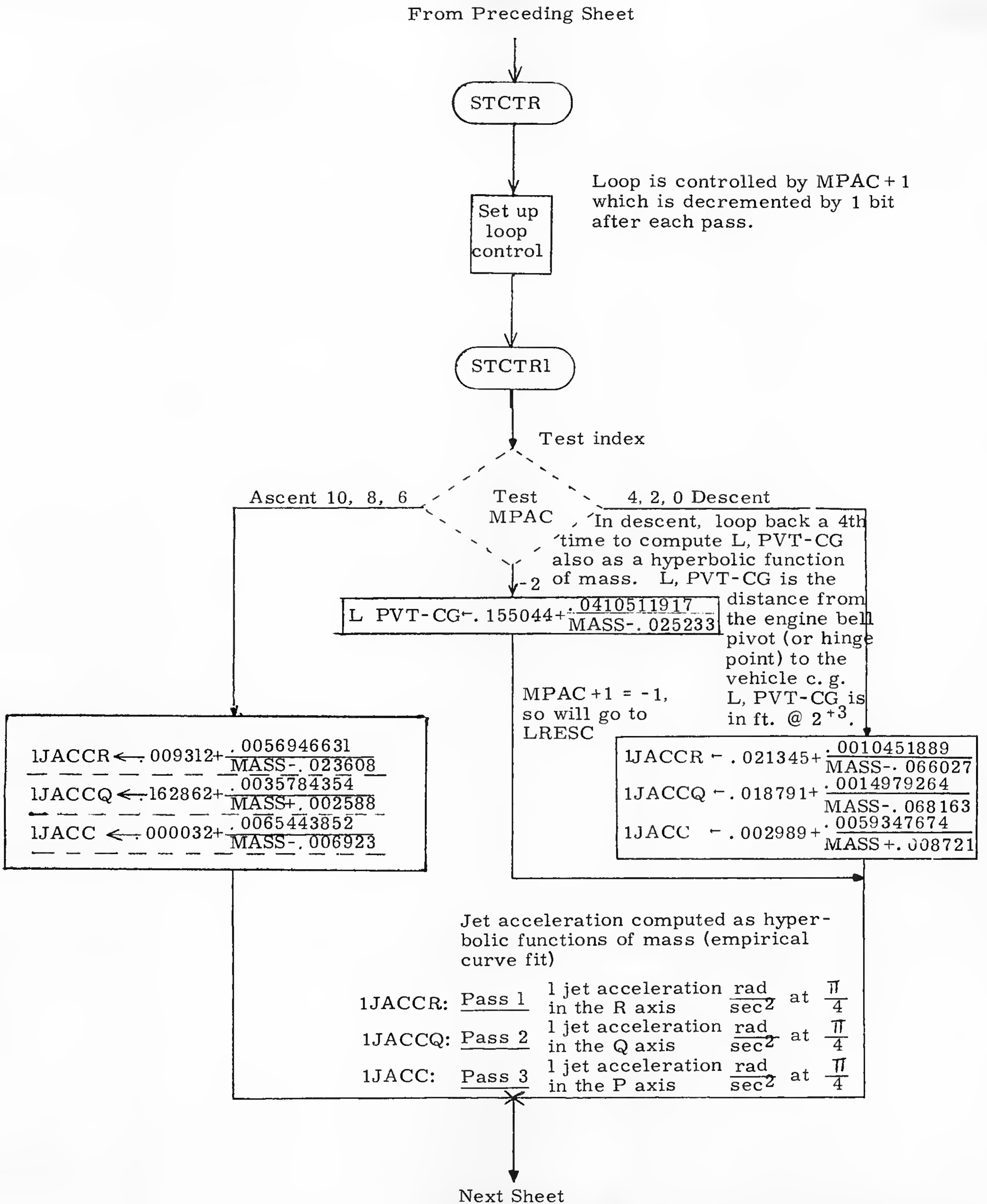
PRGMR			
ANALST		LUMINARY 1D	DOCUMENT NO. FC-3490
DOCMR R M Estes	3/19/70		
APPR'D R M Estes	3/19/70	REV 1	SHEET 4 OF 36



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DRAWN P. Keisen 10/20/69
PRGMR
ANALST
DOCMR RM Estes 3/19/70
APPR'D RM Estes 3/19/70

APOLLO GUIDANCE AND NAVIGATION

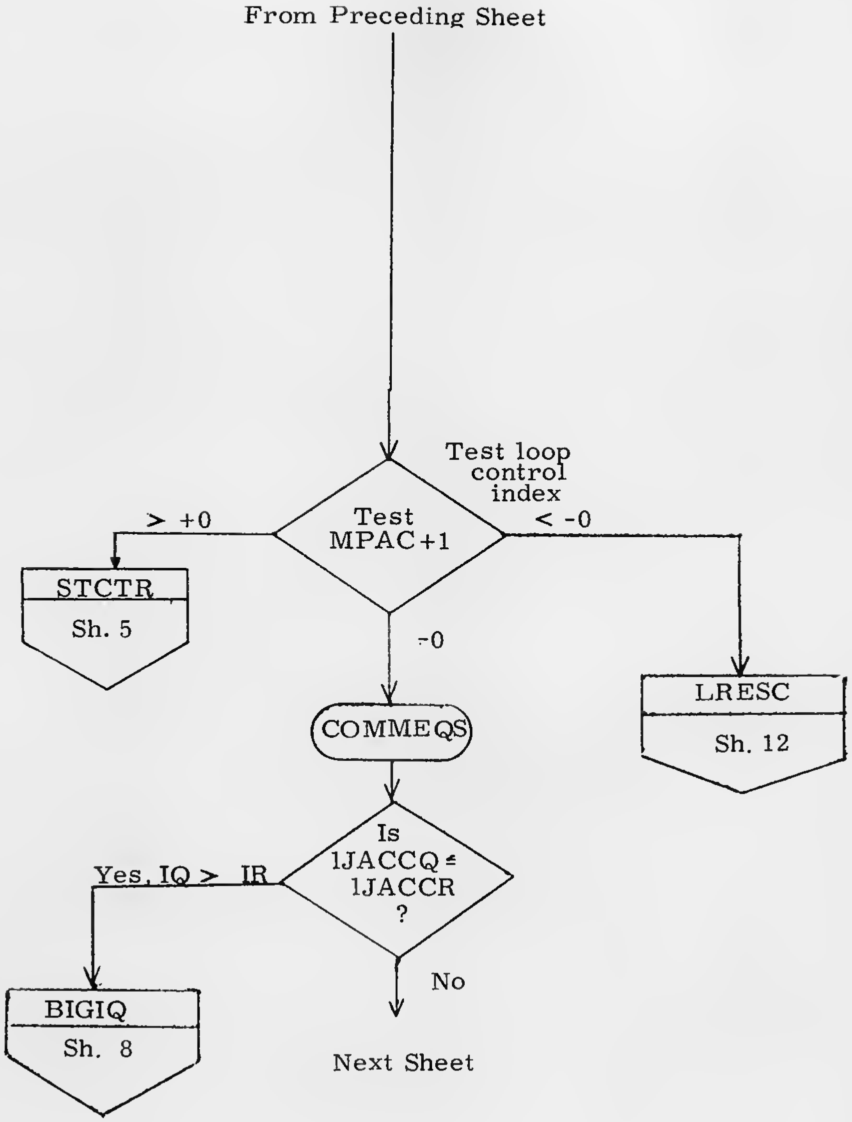
AOSJOB and AOSTASK

LUMINARY 1D

DOCUMENT NO. FC-3490

REV 1

SHEET 5 OF 36



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PRGMR
ANALST
DOCMR RM Estes 3/19/70
APPR'D RM Estes 3/19/70

APOLLO GUIDANCE AND NAVIGATION

AOSJOB and AOSTASK

LUMINARY 1D

DOCUMENT NO. FC-3490

REV 1

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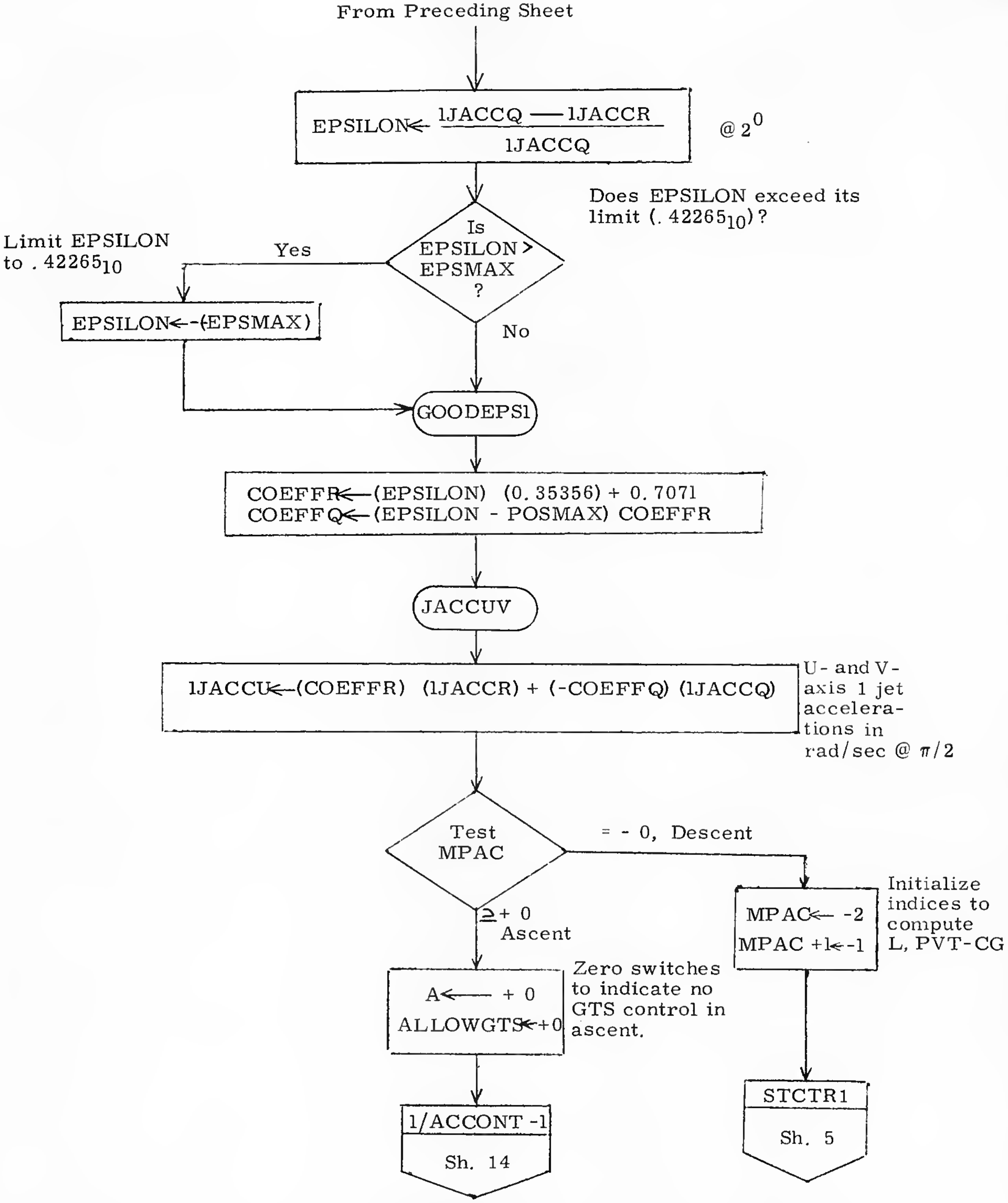

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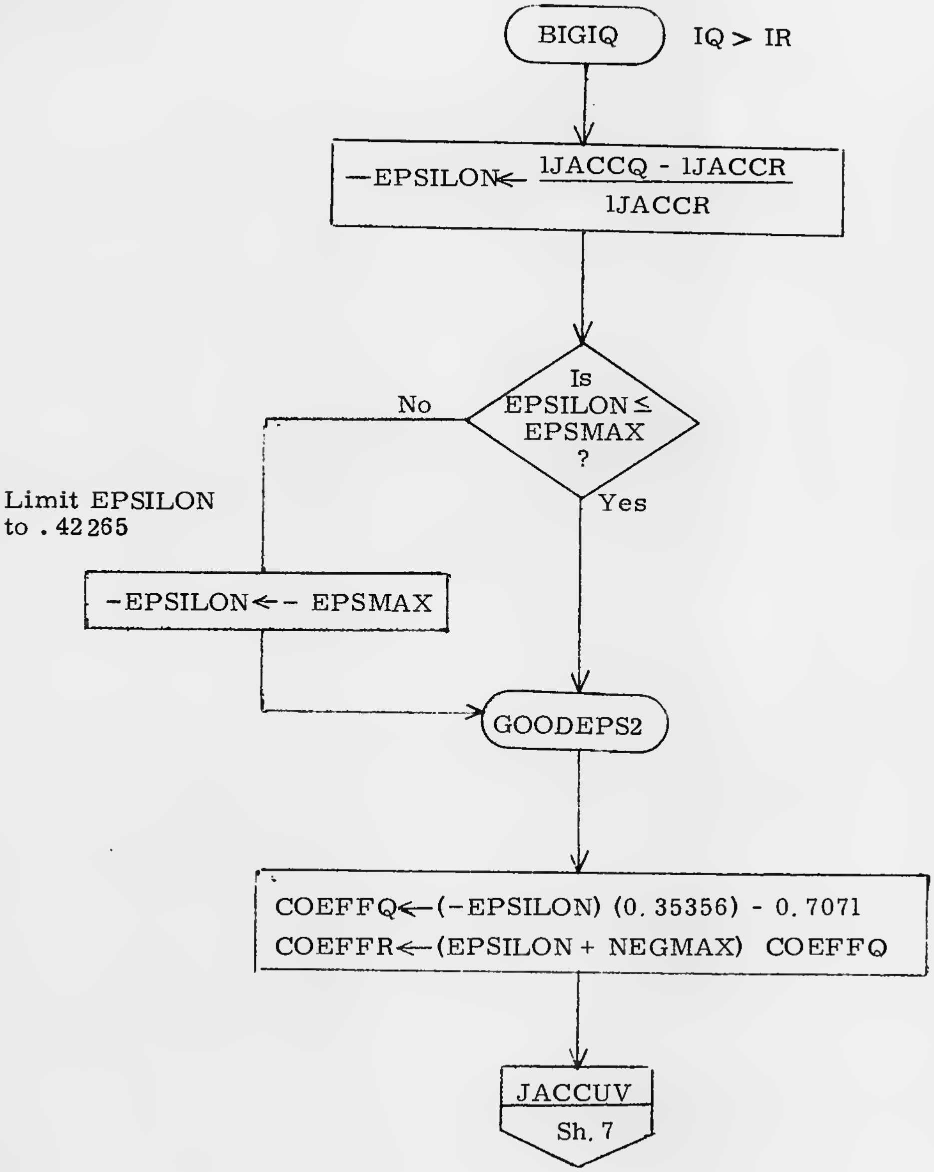

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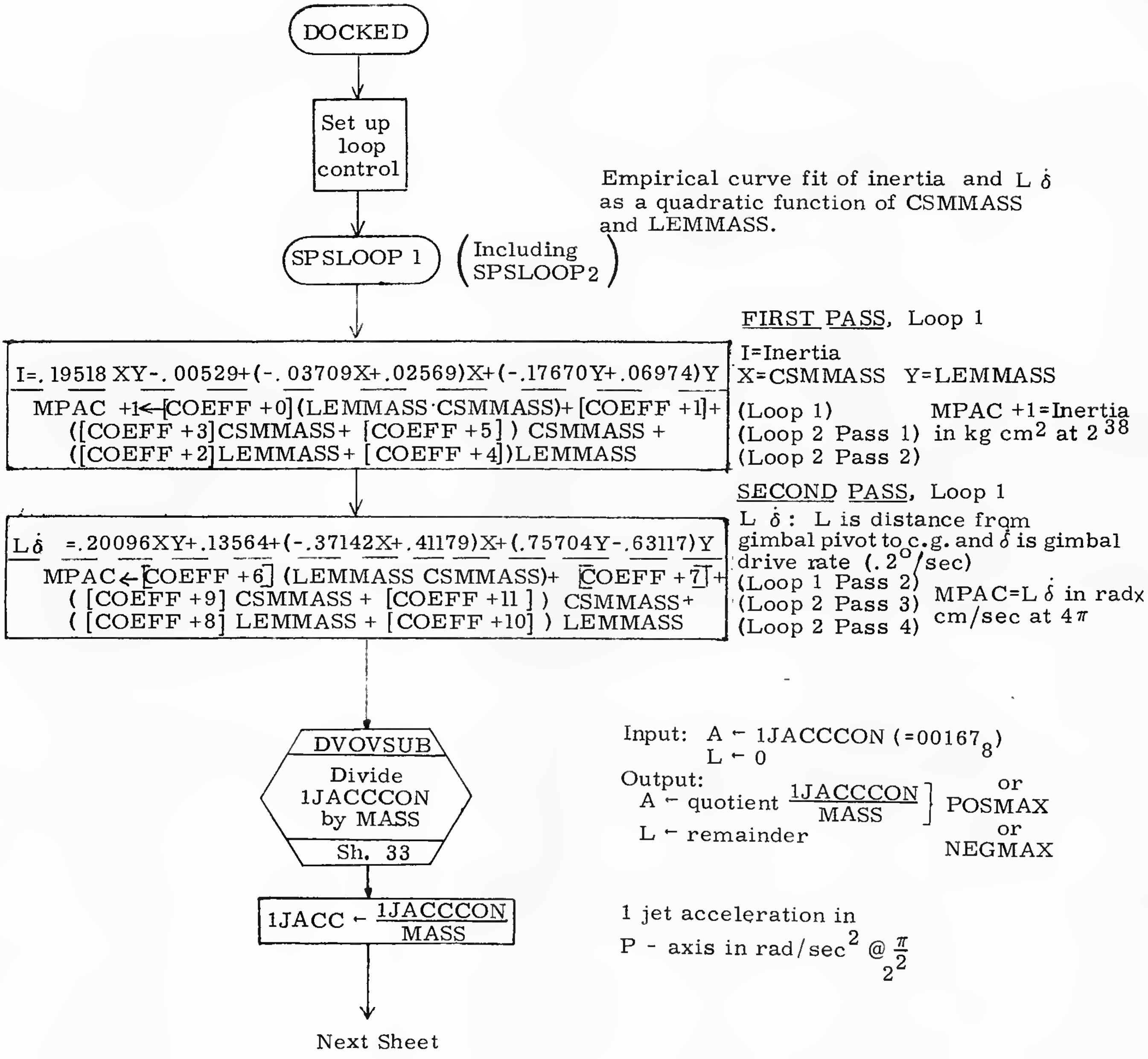

I=.19518 XY-.00529+(-.03709X+.02569)X+(-.17670Y+.06974)Y

MPAC +1←[COEFF +0](LEMMASS·CSMMASS)+[COEFF +1]+([COEFF +3]CSMMASS+ [COEFF +5]) CSMMASS + ([COEFF +2]LEMMASS+ [COEFF +4])LEMMASS

Lδ̇ =.20096XY+.13564+(-.37142X+.41179)X+(.75704Y-.63117)Y

MPAC←[COEFF +6] (LEMMASS CSMMASS)+ [COEFF +7]+ ([COEFF +9] CSMMASS + [COEFF +11]) CSMMASS+ ([COEFF +8] LEMMASS + [COEFF +10]) LEMMASS

$1JACC \leftarrow \frac{1JACCCON}{MASS}$

Empirical curve fit of inertia and L δ̇ as a quadratic function of CSMMASS and LEMMASS.

FIRST PASS, Loop 1

I=Inertia

X=CSMMASS Y=LEMMASS

(Loop 1)
(Loop 2 Pass 1)
(Loop 2 Pass 2)

MPAC +1=Inertia in kg cm^2 at 2^{38}

SECOND PASS, Loop 1

L δ̇ : L is distance from gimbal pivot to c.g. and δ̇ is gimbal drive rate (.2°/sec)

(Loop 1 Pass 2)
(Loop 2 Pass 3)
(Loop 2 Pass 4)

MPAC=L δ̇ in radx cm/sec at 4π

Input: A ← 1JACCCON (=00167_8)
L ← 0

Output:
A ← quotient $\left.\frac{1JACCCON}{MASS}\right]$ or POSMAX or NEGMAX
L ← remainder

1 jet acceleration in P - axis in rad/sec^2 @ $\frac{\pi}{2^2}$

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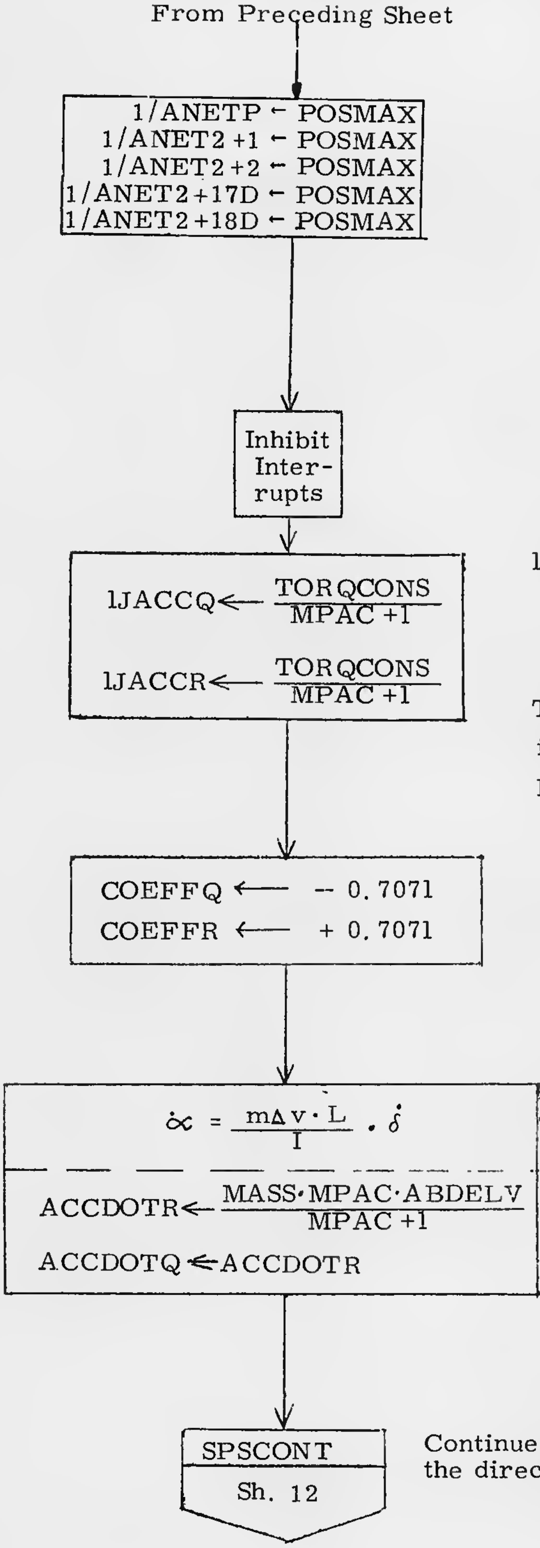

1 jet acceleration $= \frac{\text{torque}}{\text{inertia}} = \frac{\text{cm}\ \frac{\text{kgcm}}{\text{sec}^2} @\pi\ 2^{36}}{\text{kg-cm}^2\ @ 2^{38}}$

in $\frac{\text{rad}}{\text{sec}^2}$ @ $\frac{\pi}{2^2}$

TORQCONS is the equivalent of 500 ft - lbs in metric units ($\frac{\text{kgcm}^2}{\text{sec}^2}$) scaled at $\pi \cdot 2^{36}$
It is approximately 6.78 x 10^4 Newton-cm
or 6.78 x 10^6 Kg-cm^2/sec^2

Chosen to make U- and V- axes orthogonal (CSM/LM case)

Jerk calculation : via DVOVSUB (Sh.33)

MPAC$\equiv L\dot{\delta}$ (from above) in $\frac{\text{rad cm}}{\text{sec}}$ at 4 π
MPAC +1$\equiv$I (from above) in kgcm^2 at 2^{38}
ABDELV$\equiv\Delta$V (from SERVICER) in cm/sec^2 at 2^{13}
MASS$\equiv$ m in kg at 2^{16}
(mΔv= engine thrust)
Results in rad/sec^3 @ $\pi \cdot 2^{-7}$
ACCDOTQ for Q axis
ACCDOTR for R axis

Continue to find sign of jerk terms from the direction of gimbal drive

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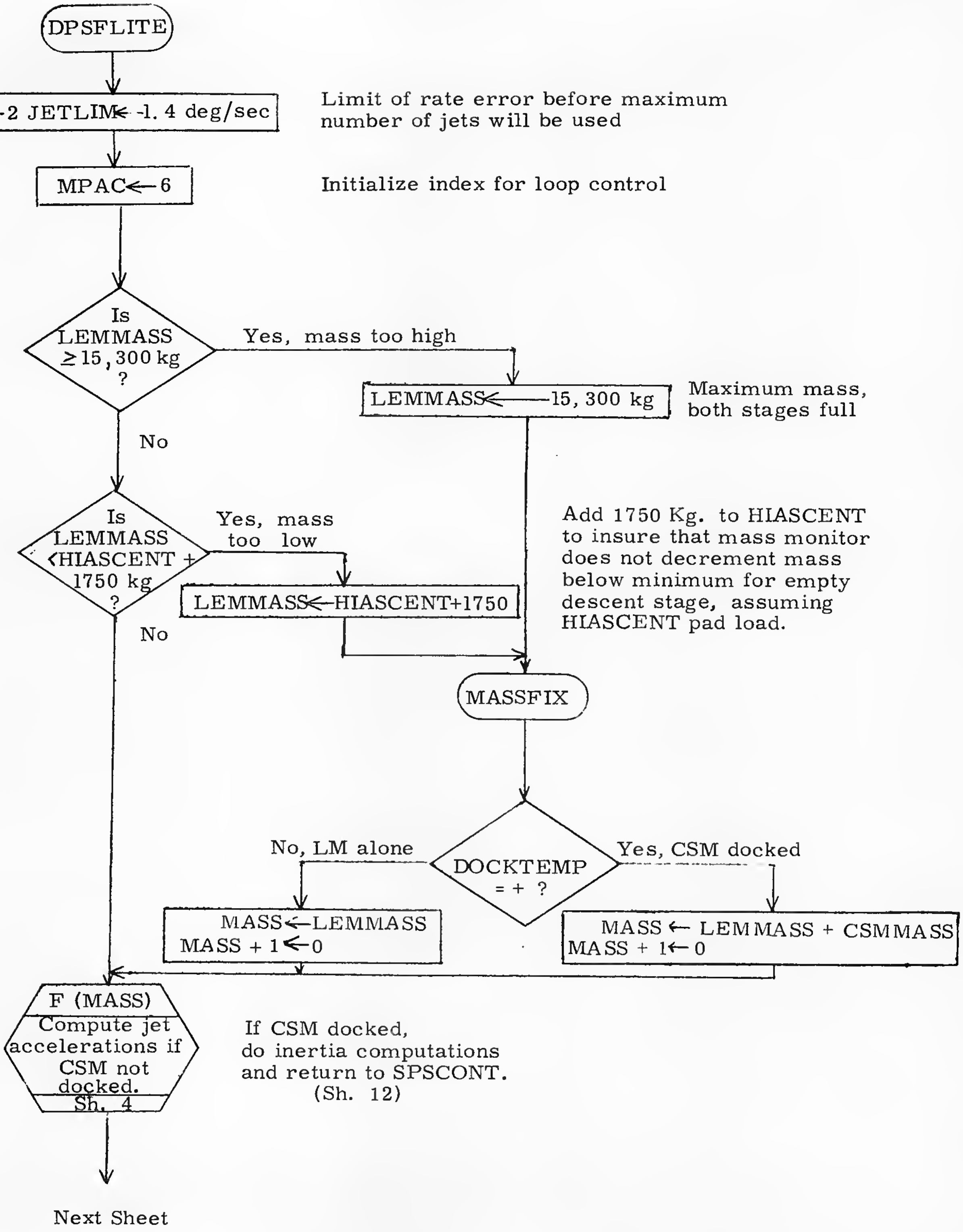

Limit of rate error before maximum number of jets will be used

Initialize index for loop control

Maximum mass, both stages full

Add 1750 Kg. to HIASCENT to insure that mass monitor does not decrement mass below minimum for empty descent stage, assuming HIASCENT pad load.

If CSM docked, do inertia computations and return to SPSCONT. (Sh. 12)

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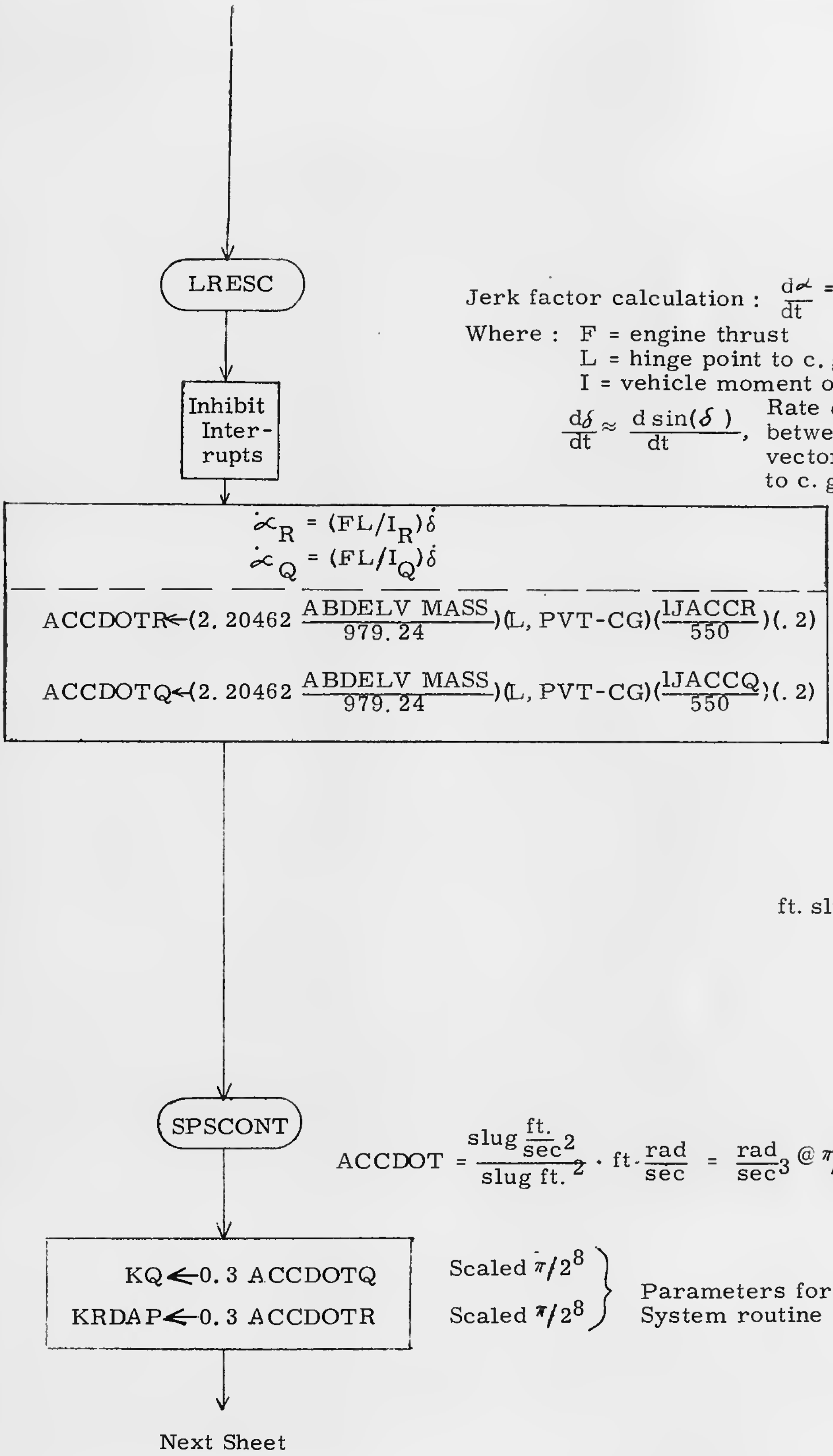

Jerk factor calculation : $\frac{d\alpha}{dt} = \frac{FL}{I}\frac{d\delta}{dt}$ (Division via DVOVSUB Sh. 33)

Where : F = engine thrust
L = hinge point to c. g distance
I = vehicle moment of inertia

$\frac{d\delta}{dt} \approx \frac{d \sin(\delta)}{dt}$, Rate of change of angle between thrust vector and vector from hinge point to c. g.

$$\dot{\alpha}_R = (FL/I_R)\dot{\delta}$$
$$\dot{\alpha}_Q = (FL/I_Q)\dot{\delta}$$

$$\text{ACCDOTR} \leftarrow (2.20462\ \frac{\text{ABDELV MASS}}{979.24})(\text{L, PVT-CG})(\frac{\text{1JACCR}}{550})(.2)$$

$$\text{ACCDOTQ} \leftarrow (2.20462\ \frac{\text{ABDELV MASS}}{979.24})(\text{L, PVT-CG})(\frac{\text{1JACCQ}}{550})(.2)$$

ABDELV=magnitude of Δ velocity vector (from SERVICER)/ΔT in cm/sec^2 @ 2^{13}

ABDELV·MASS=engine thrust in $\frac{newtons}{100}$

$\frac{2.20462}{979.24}$ converts to lbs. of force

$$\frac{1JACCR}{550} = \frac{\text{1-jet accel.}}{\text{1-jet torque}} = \frac{rad/sec^2}{ft.\ slug.\ ft/sec^2 \cdot ft} = \frac{rad}{slug\ ft.^2} = \frac{1}{\text{vehicle moment of inertia}}$$

$.2^{o}/sec$ = gimbal drive rate $=\dot{\delta}$

$$\text{ACCDOT} = \frac{slug\ \frac{ft.}{sec^2}}{slug\ ft.^2}\cdot ft\cdot\frac{rad}{sec} = \frac{rad}{sec^3} @ \pi/2^7$$

KQ ← 0.3 ACCDOTQ Scaled $\pi/2^8$
KRDAP ← 0.3 ACCDOTR Scaled $\pi/2^8$
Parameters for Trim Gimbal System routine

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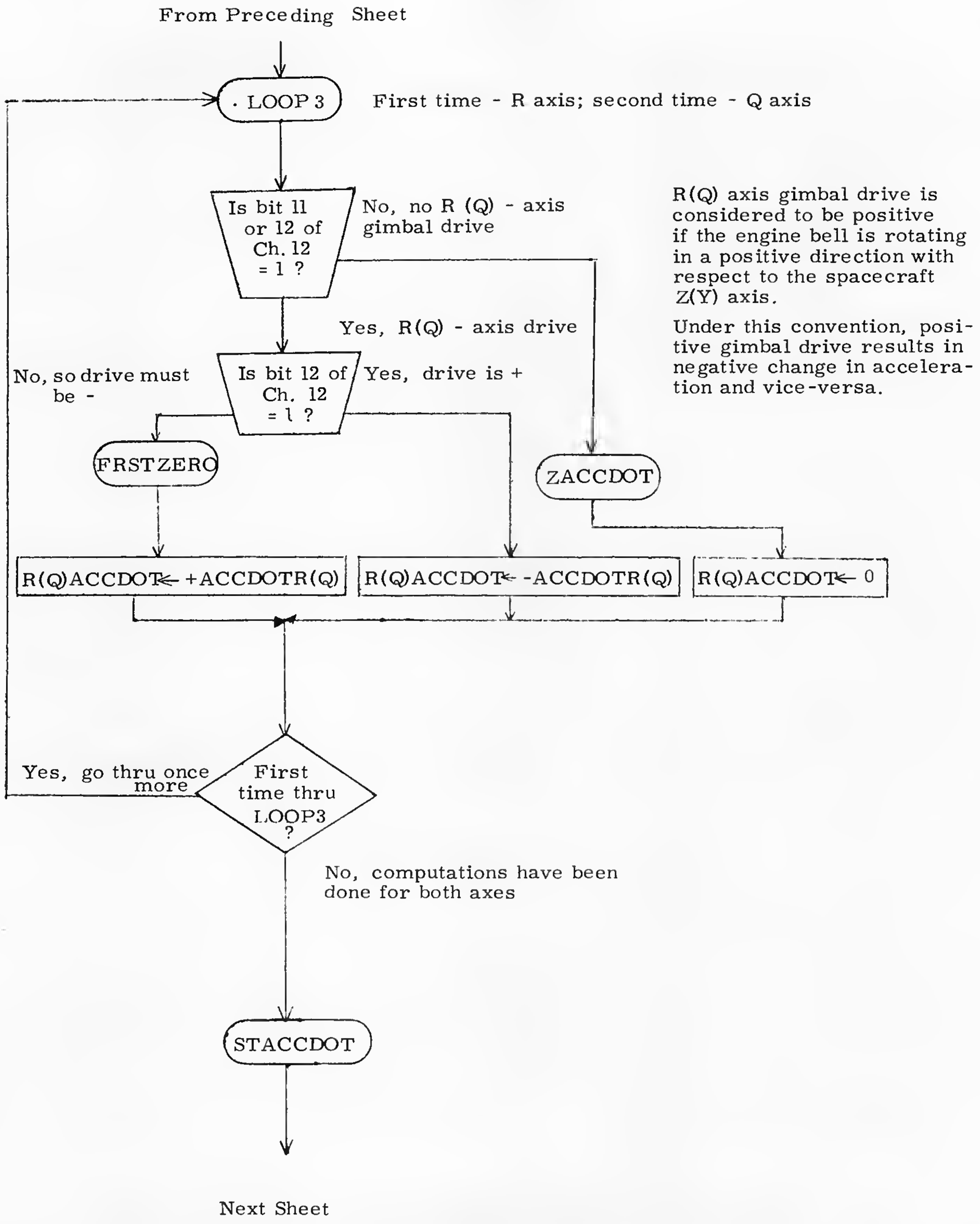

R(Q) axis gimbal drive is considered to be positive if the engine bell is rotating in a positive direction with respect to the spacecraft Z(Y) axis.

Under this convention, positive gimbal drive results in negative change in acceleration and vice-versa.

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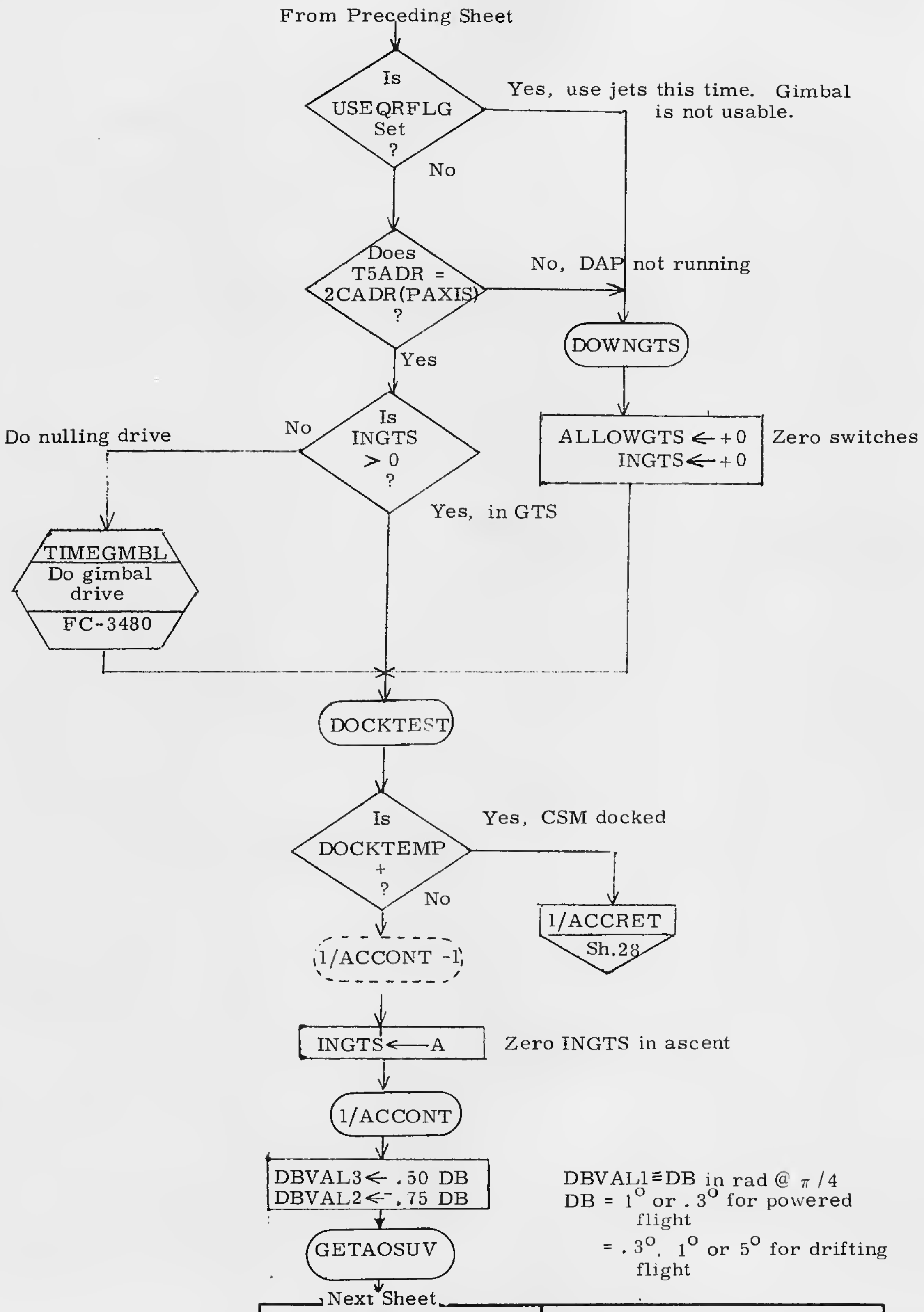

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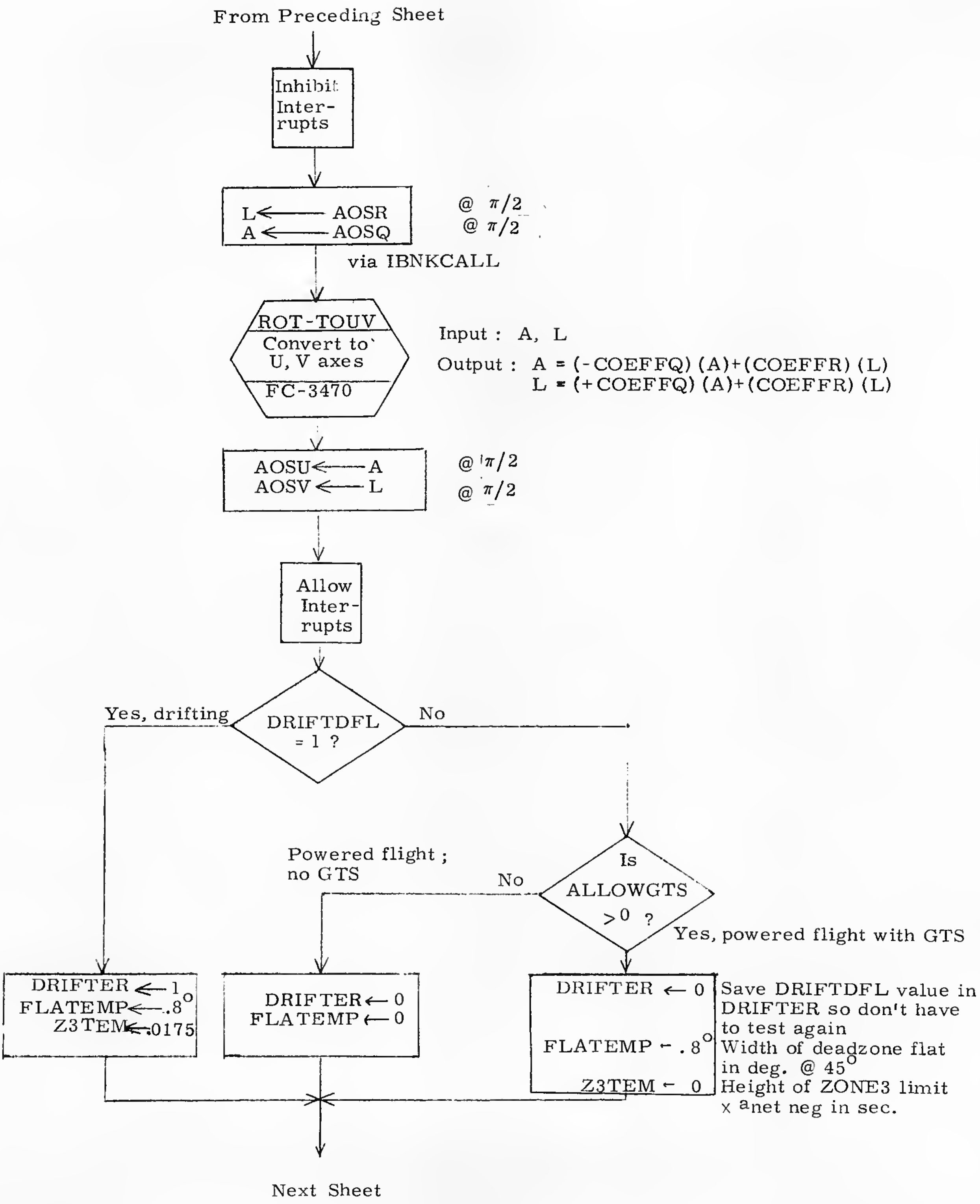

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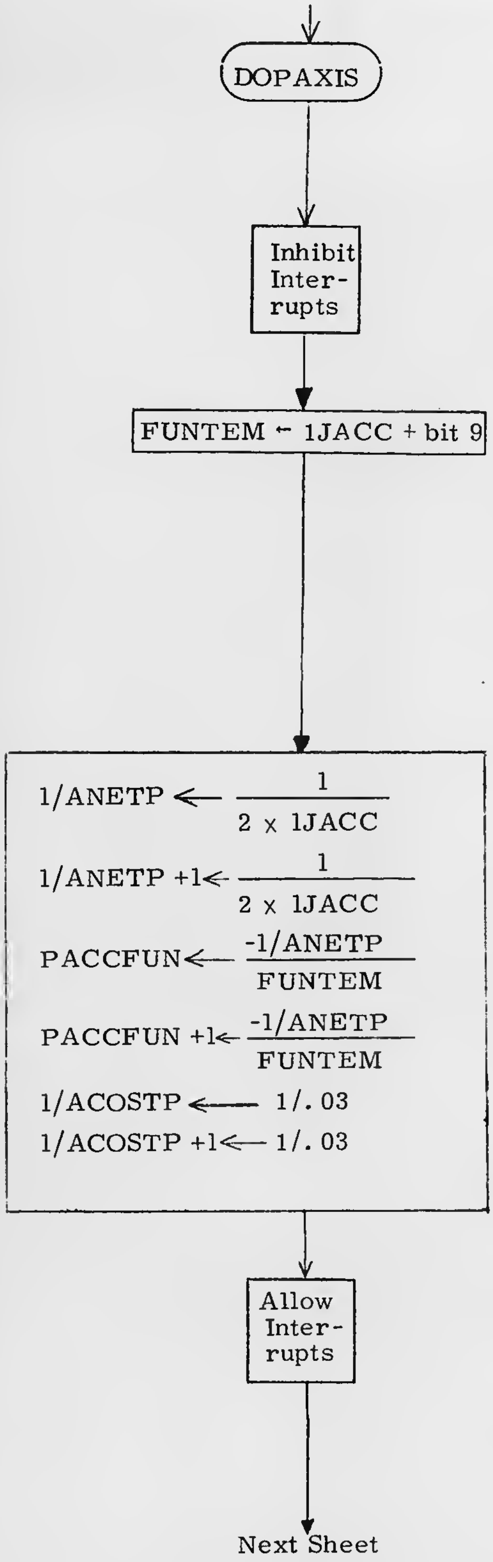

Temporary storage. 1JACC scaled @ $\pi/4$.
1JACC @ $\pi/4$ = 2 x 1JACC @ $\pi/2$.
2 x 1JACC ≡ angular acceleration produced by two P-axis jets = ANETP. Therefore 1JACC @ $\pi/4$ ≡ ANETP @ $\pi/2$.

1/ACOSTP @ $2^7/\pi$ = POSMAX

$$\left(1JACC @ \pi/4 = ANETP @ \pi/2 = \frac{ANETP}{ACOSTP} @ 2^6\right)$$

Bit 9 = 1 @ 2^6

Therefore: $FUNTEM = \left(\frac{ANETP}{ACOSTP} + 1\right) @ 2^6$

Reciprocal of net acceleration in the P-axis (Subroutine INVERT (Sh. 34) used to scale to $2^7/\pi$). Functions computed here apply to either positive or negative P-axis rotation, since offset acceleration is assumed 0 for P-axis.

$$PACCFUN = \frac{-1}{\left(ANETP + \frac{ANETP^2}{ACOASTP}\right)} @ \frac{2^7}{\pi}$$

ACOSTP represents a "coasting" acceleration: the P-axis angular acceleration which exists when no P-axis jets are firing. This acceleration is assumed to be 0.
1/. 03 is the tag name for 1/. 02454, the smallest value which can be assigned to ACOSTP so that its reciprocal @ $2^7/\pi$ will not overflow. (Hence, 1/ACOSTP = POSMAX).

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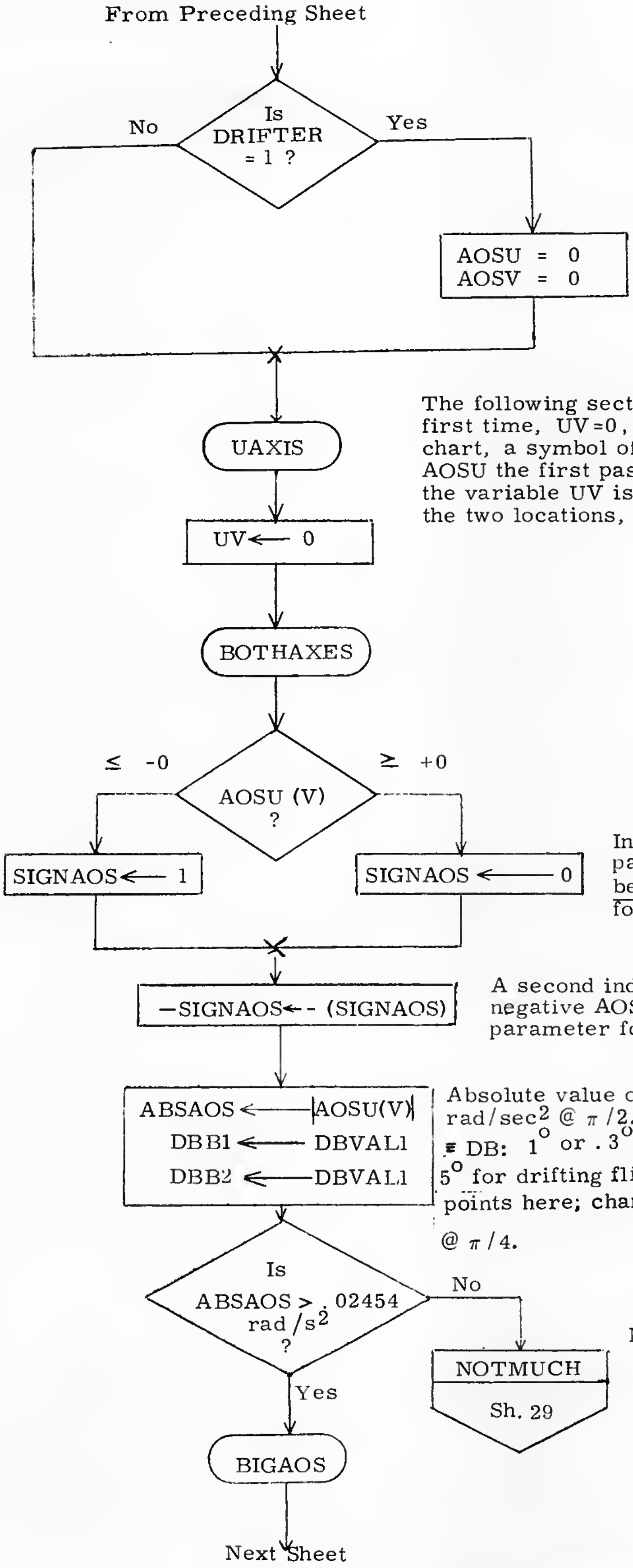

Make sure angular offset is set to zero in U and V axes in drifting flight.

The following section of coding is executed twice. The first time, UV=0, the second time, UV=1. In this flow chart, a symbol of the form AOSU(V) is to be read as AOSU the first pass, and AOSV the second. In practice, the variable UV is used as an index to select between the two locations, which are adjacent in memory.

Index to select jet parameters - when parameter for negative AOS is located below the corresponding parameter for positive AOS.

A second index for cases where parameter for negative AOS is located above the corresponding parameter for positive AOS.

Absolute value of angular offset acceleration in rad/sec^2 @ $\pi/2$.

DB: 1° or .3° for powered flight; .3°, 1°, or 5° for drifting flight. Set nominal DB$_1$ and DB$_2$ points here; change later if needed. DB in rad. @ $\pi/4$.

Note:

The location -.03R/S2 contains $-\pi/2^7$ @ $\pi/2$ (-.02454 rad/sec^2).
The location 1/.03 (used on Sh. 16) contains $2^7/\pi$ Sec^2/rad @ $2^7/\pi$ or 1/.02454 sec^2/rad.

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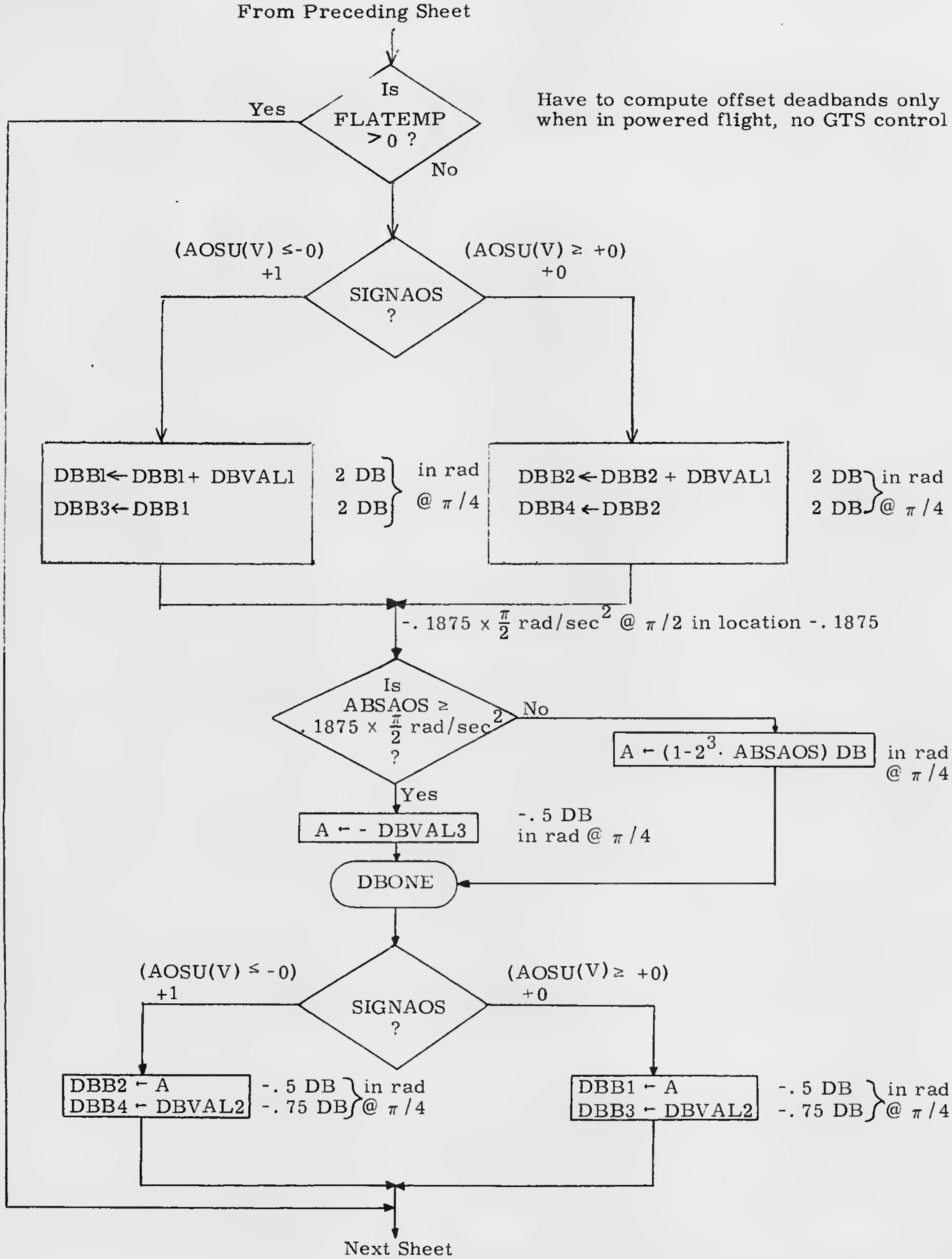

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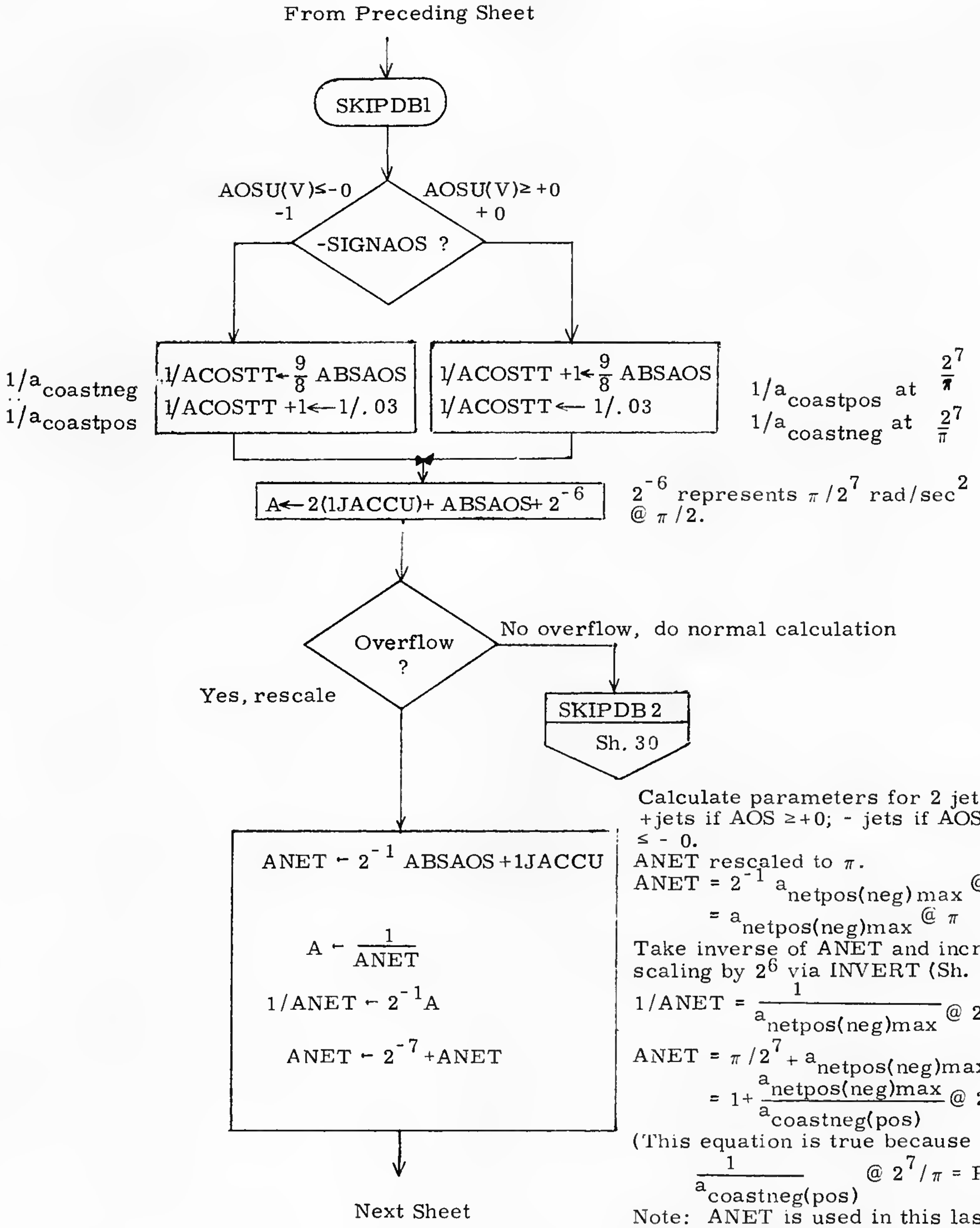

Calculate parameters for 2 jets: +jets if AOS ≥+0; - jets if AOS ≤ - 0.

ANET rescaled to π.

ANET = $2^{-1} a_{netpos(neg)\,max}$ @ $\pi/2$

= $a_{netpos(neg)max}$ @ π

Take inverse of ANET and increase scaling by 2^6 via INVERT (Sh. 34).

1/ANET = $\frac{1}{a_{netpos(neg)max}}$ @ $2^7/\pi$

ANET = $\pi/2^7 + a_{netpos(neg)max}$ @ π

= $1+\frac{a_{netpos(neg)max}}{a_{coastneg(pos)}}$ @ 2^7

(This equation is true because $\frac{1}{a_{coastneg(pos)}}$ @ $2^7/\pi$ = POSMAX.)

Note: ANET is used in this last equation for temporary storage (for input to subroutine DOACCFUN) and does not = $a_{netpos(neg)max}$ (see above).

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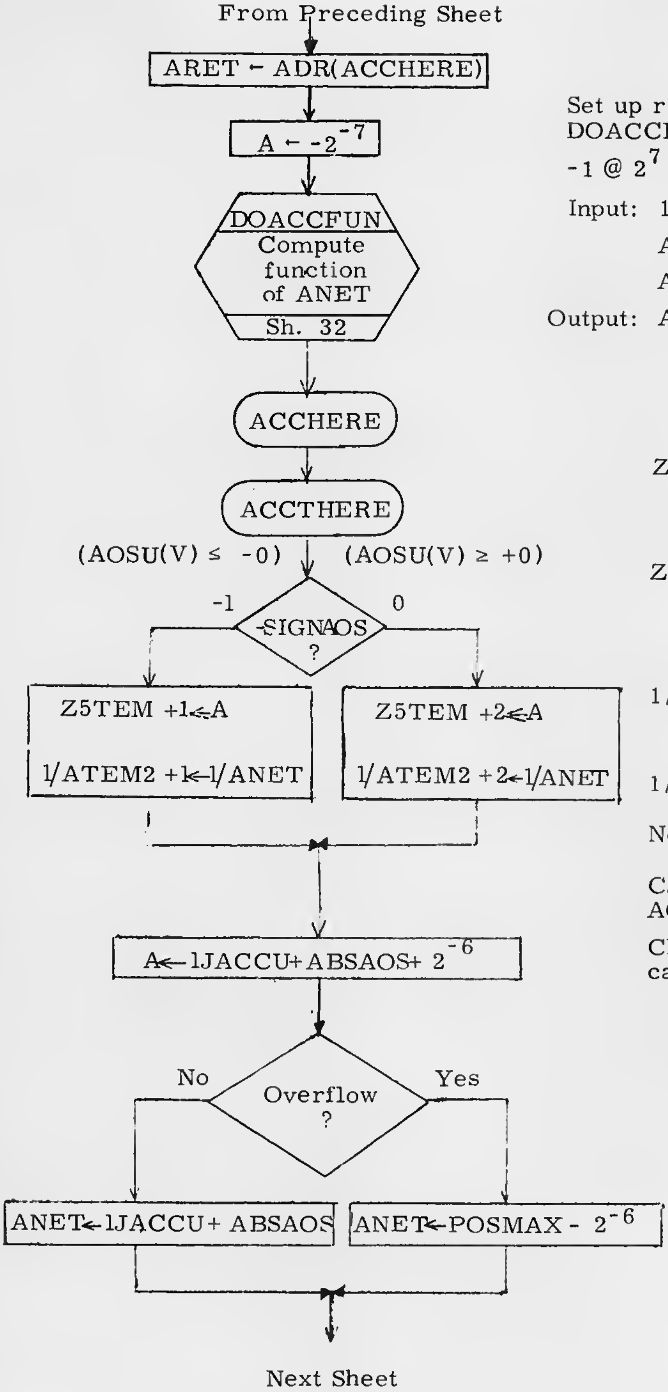

Set up return for ACCHERE at completion of DOACCFUN

$-1 @ 2^7 = -2^{-7}$

Input: $1/\text{ANET} @ 2^7/\pi$

A containing $-1 @ 2^7$

ANET @ 2^7

Output: A containing $\frac{-1/\text{ANET}}{\text{ANET}} @ 2^7/\pi$

$$\text{Z5TEM+1} = \frac{-1}{a_{netnegmax} + \frac{a^2_{netnegmax}}{a_{coastpos}}} @ \frac{2^7}{\pi}$$

$$\text{Z5TEM+2} = \frac{-1}{a_{netposmax} + \frac{a^2_{netposmax}}{a_{coastneg}}} @ \frac{2^7}{\pi}$$

$$1/\text{ATEM2+1} = \frac{1}{a_{netnegmax}} @ \frac{2^7}{\pi}$$

$$1/\text{ATEM2+2} = \frac{1}{a_{netposmax}} @ \frac{2^7}{\pi}$$

Note: Z5TEM+1 = Z1TEM+2
1/ATEM+1 = 1/ATEM1+2

Calculate parameters for 1 jet:+jets if AOS ≥+0; - jets if AOS ≤ -0.

Check for overflow in minimum (1-jet) case also. $2^{-6} = \pi/2^7$ rad/sec^2 @ $\pi/2$.

If overflow, set ANET to maximum value which will not overflow.

@ $\pi/2$

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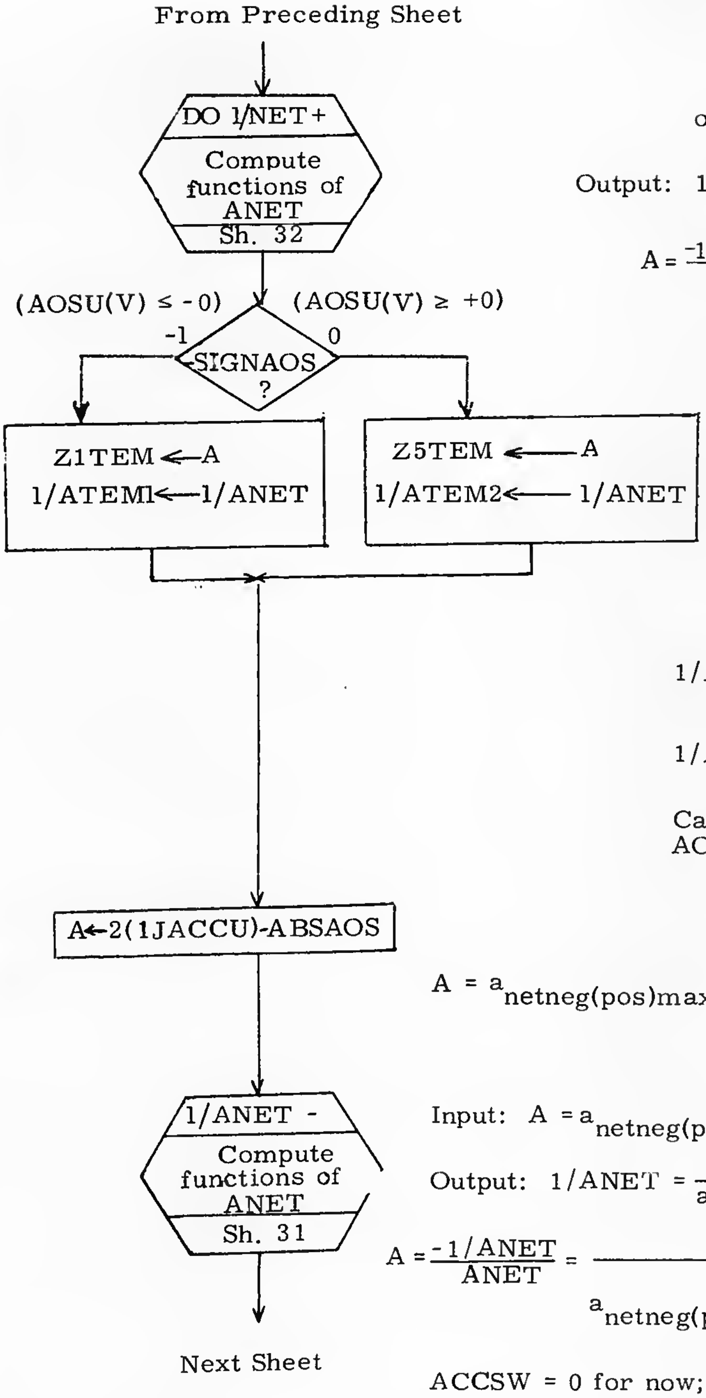

Input: ANET = $a_{netpos(neg)min}$ @ $\pi/2$,

or = $\dfrac{a_{netpos(neg)min}}{a_{coastneg(pos)}}$ @ 2^6

Output: 1/ANET = $\dfrac{1}{a_{netpos(neg)min}}$ @ $2^7/\pi$

$$A = \frac{-1/ANET}{ANET} = \frac{-1}{a_{netpos(neg)min} + \dfrac{a^2_{netpos(neg)min}}{a_{coastneg(pos)}}} @ \frac{2^7}{\pi}$$

$$Z1TEM = \frac{-1}{a_{netnegmin} + \dfrac{a^2_{netnegmin}}{a_{coastpos}}} @ \frac{2^7}{\pi}$$

$$Z5TEM = \frac{-1}{a_{netposmin} + \dfrac{a^2_{netposmin}}{a_{coastneg}}} @ \frac{2^7}{\pi}$$

$$1/ATEM1 = \frac{1}{a_{netnegmin}} @ \frac{2^7}{\pi}$$

$$1/ATEM2 = \frac{1}{a_{netposmin}} @ \frac{2^7}{\pi}$$

Calculate parameters for 2 jets: -jets if AOS ≥+0;+jets if AOS jets if AOS ≤-0.

A = $a_{netneg(pos)max}$ @ $\pi/2$

Input: A = $a_{netneg(pos)max}$ @ $\pi/2$

Output: 1/ANET = $\dfrac{1}{a_{netneg(pos)max}}$ @ $2^7/\pi$

$$A = \frac{-1/ANET}{ANET} = \frac{-1}{a_{netneg(pos)max} + \dfrac{a^2_{netneg(pos)max}}{a_{coastpos(neg)}}} @ 2^7/\pi$$

ACCSW = 0 for now; see next sheet.

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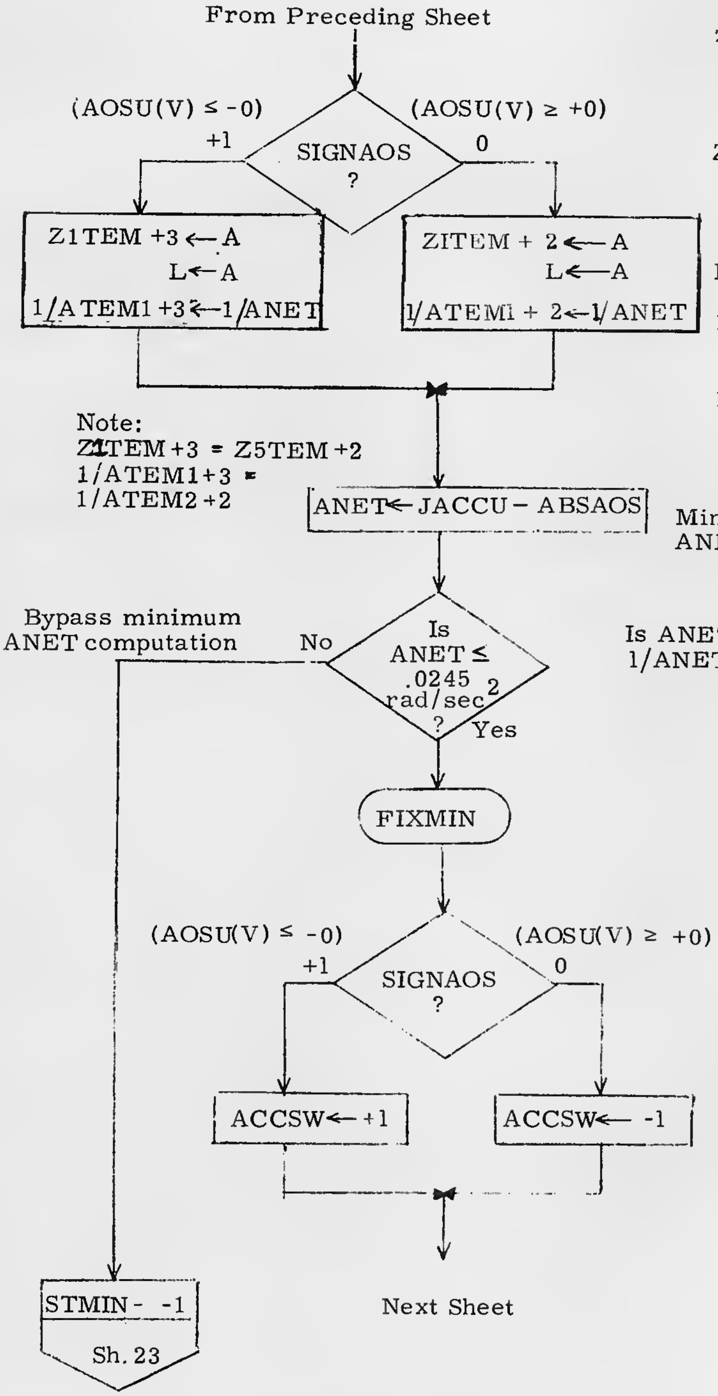

$$\text{Z1TEM} + 3 = \frac{-1}{a_{netposmax} + \frac{a^2_{netposmax}}{a_{coastneg}}} \quad {}^{-} \quad \pi$$

$$\text{Z1TEM} + 2 = \frac{-1}{a_{netnegmax} + \frac{a^2_{netnegmax}}{a_{coastpos}}} @ \frac{2^7}{\pi}$$

May need below; save in L.

$$1/\text{ATEM1} + 3 = \frac{1}{a_{netposmax}} @ \frac{2^7}{\pi}$$

$$1/\text{ATEM1} + 2 = \frac{1}{a_{netnegmax}} @ \frac{2^7}{\pi}$$

Calculate parameters for 1 jet:
-jets if AOS ≥+0; +jets if AOS ≤ -0.

Min-jet net acceleration;
ANET = $a_{netneg(pos)min} @ \pi/2$

Is ANET too small to compute $1/\text{ANET} @ 2^7/\pi$ without overflow?

Set tag to indicate small net acceleration, so that TJETLAW will use maxjets (i. e. 2 jets)
for AOS neg, ACCSW = + 1
for AOS pos, ACCSW = − 1

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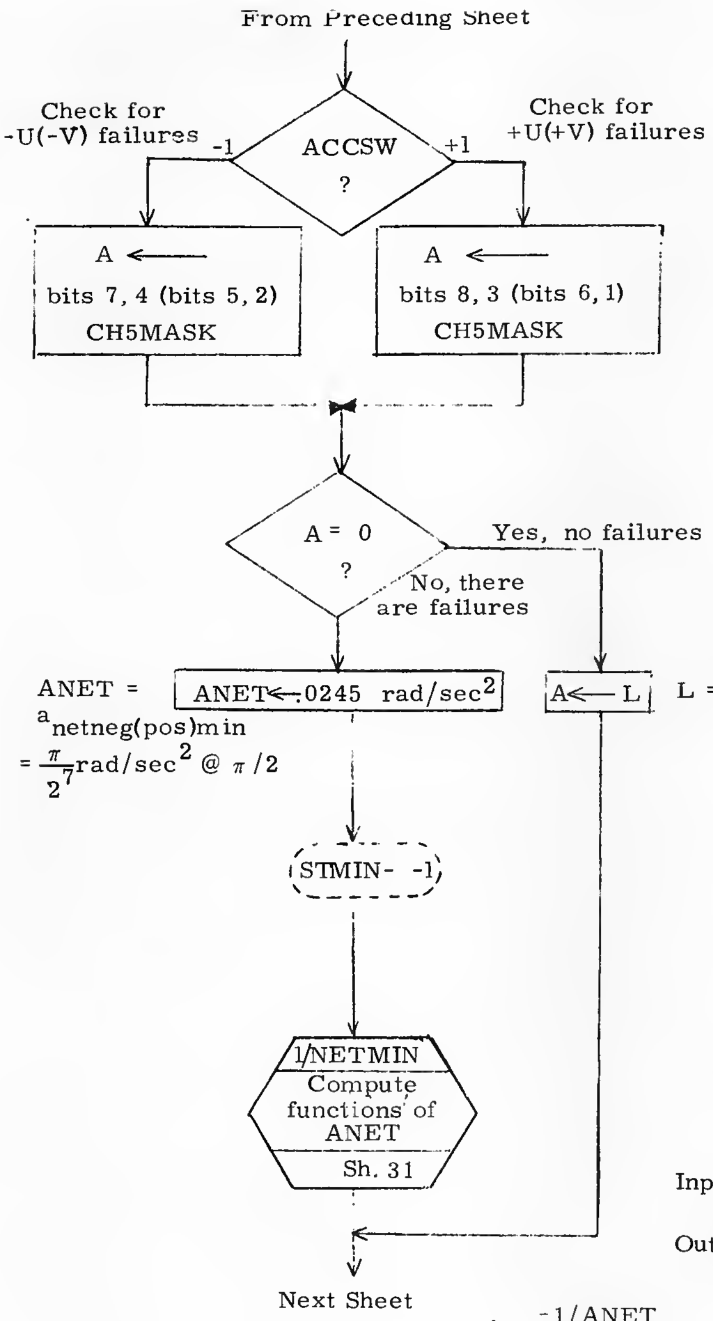

ANET = $a_{netneg(pos)min} = \frac{\pi}{2^7}$ rad/sec^2 @ $\pi/2$

CH5MASK is maintained by RCS failure monitor. Its bits are given the same jet assignments as the bits in channel 5. A bit in CH5MASK which is set indicates that the corresponding jet has been failed.

If no failures, use max-jet (i. e. 2-jet) parameters for this case. If failures, set ANET to minimum and recompute.

$$L = \frac{-1}{a_{netneg(pos)max} + \frac{a^2_{netneg(pos)max}}{a_{coastpos(neg)}}} \text{ @ } \frac{2^7}{\pi}$$

Input: ANET = $a_{netneg(pos)min}$ @ $\pi/2$

Output: 1/ANET = $\frac{1}{a_{netneg(pos)min}}$ at $2^7/\pi$.

$$A = \frac{-1/ANET}{ANET} = \frac{-1}{a_{netneg(pos)min} + \frac{a^2_{netneg(pos)min}}{a_{coastpos(neg)}}} \text{ @ } \frac{2^7}{\pi}$$

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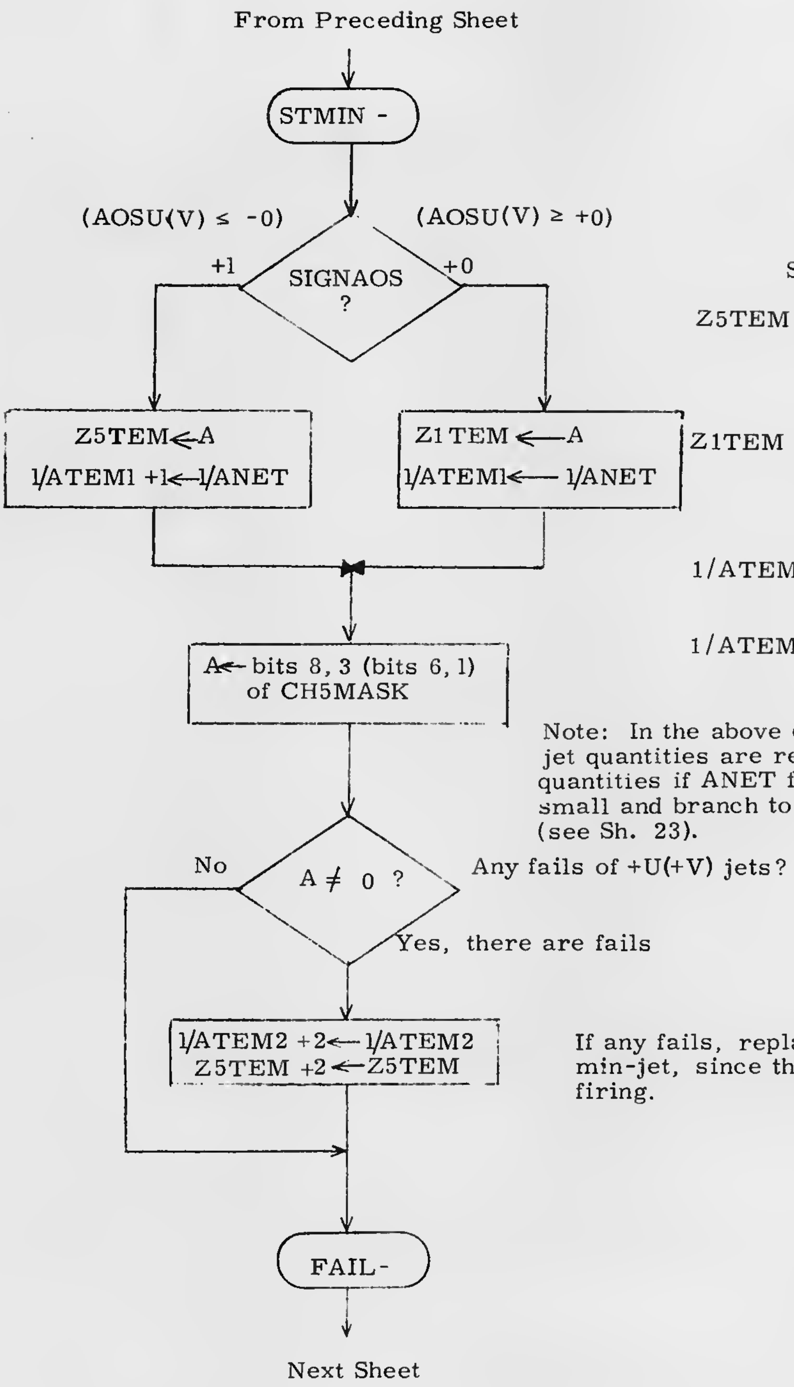

Store output of 1/NETMIN:

$$Z5TEM = \frac{-1}{a_{netposmin} + \frac{a^2_{netposmin}}{a_{coastneg}}} \quad @ \frac{2^7}{\pi}$$

$$Z1TEM = \frac{-1}{a_{netnegmin} + \frac{a^2_{netnegmin}}{a_{coastpos}}} \quad @ \frac{2^7}{\pi}$$

$$1/ATEM1+1 = \frac{1}{a_{netposmin}} \quad @ \frac{2^7}{\pi}$$

$$1/ATEM1 = \frac{1}{a_{netnegmin}} \quad @ \frac{2^7}{\pi}$$

Note: In the above expressions, the min. jet quantities are replaced by max. jet quantities if ANET for one jet was too small and branch to FIXMIN was taken (see Sh. 23).

If any fails, replace max-jet values with min-jet, since there won't be a max-jet firing.

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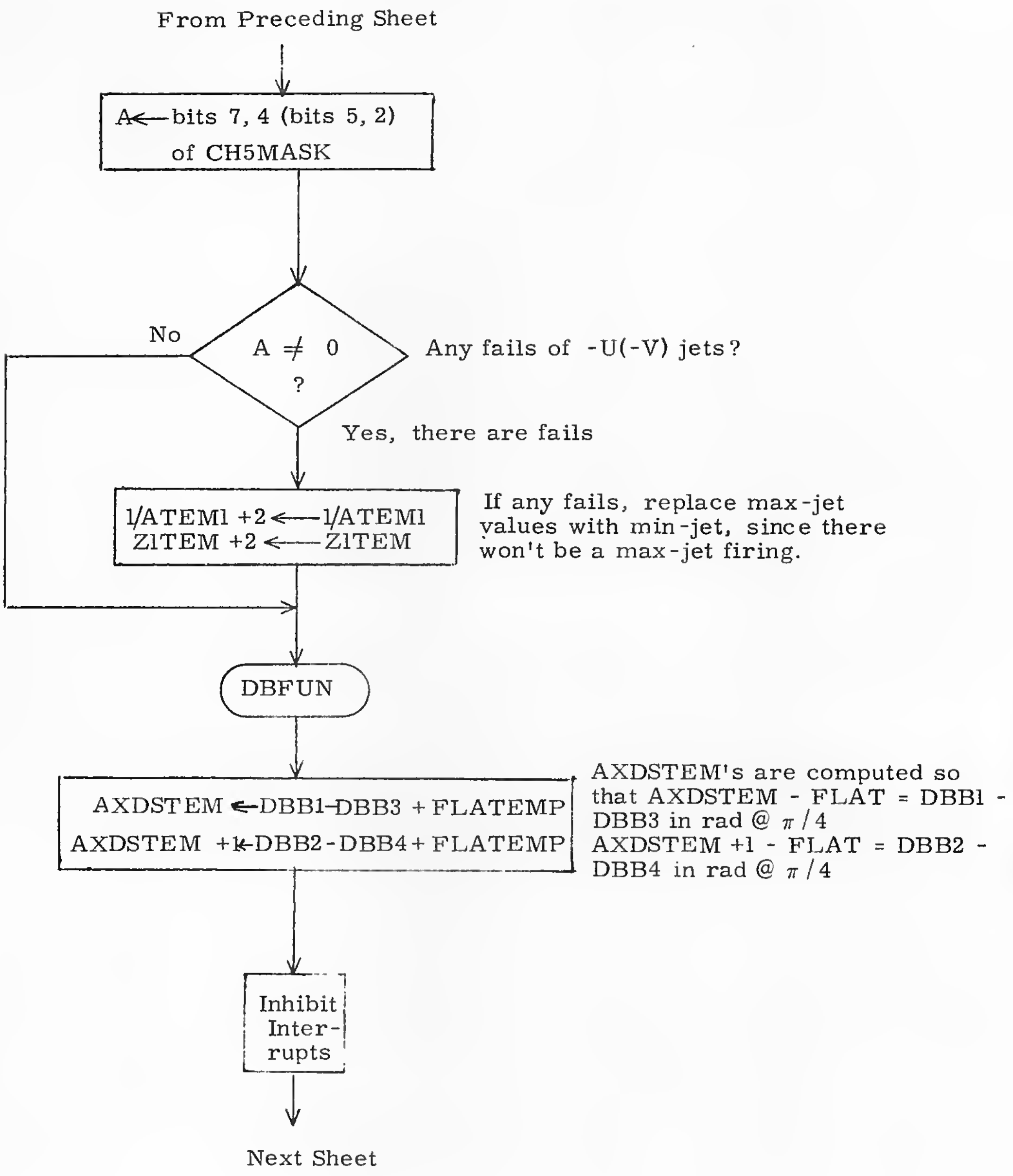
PRGMR		
ANALST	LUMINARY 1D	DOCUMENT NO. FC-3490
DOCMR 3/17/70		
APPR'D 3/17/70	REV 1	SHEET 24 OF 36



Any fails of -U(-V) jets?

If any fails, replace max-jet values with min-jet, since there won't be a max-jet firing.

AXDSTEM's are computed so that AXDSTEM - FLAT = DBB1 - DBB3 in rad @ $\pi/4$
AXDSTEM +1 - FLAT = DBB2 - DBB4 in rad @ $\pi/4$

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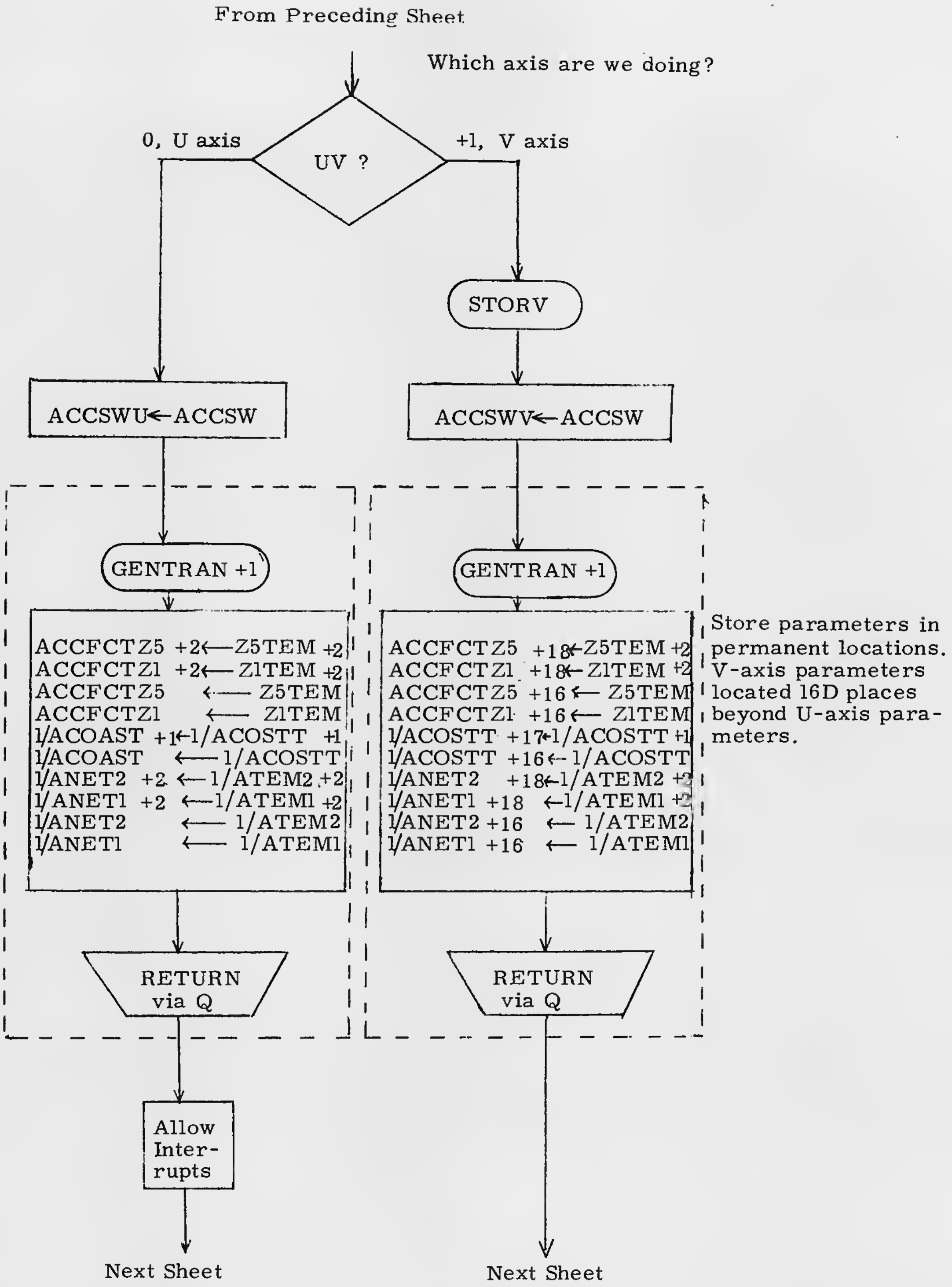

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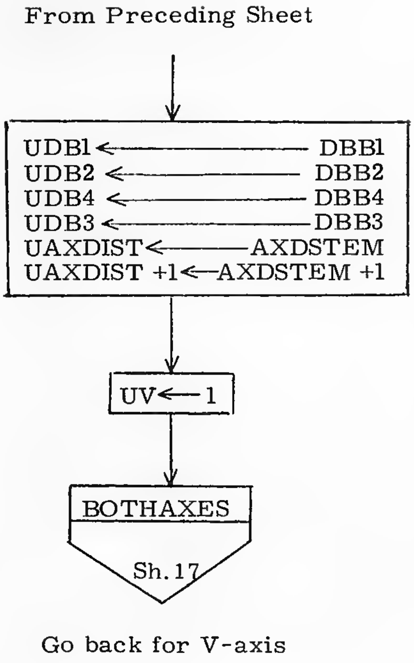

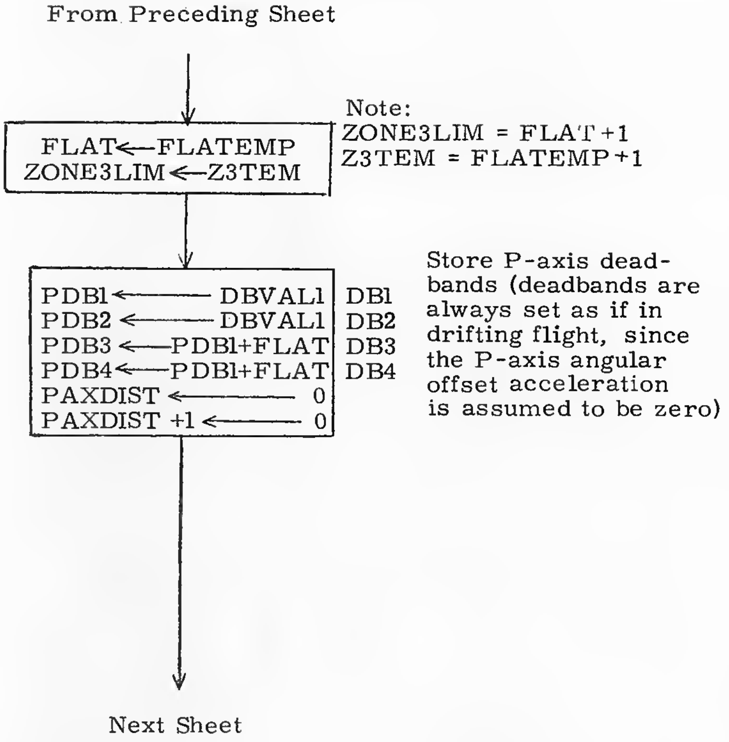

Note:
ZONE3LIM = FLAT +1
Z3TEM = FLATEMP +1

Store P-axis deadbands (deadbands are always set as if in drifting flight, since the P-axis angular offset acceleration is assumed to be zero)

Note:
The above quantities are stored in temporary locations and will be stored in new locations after loop through V-axis is completed.

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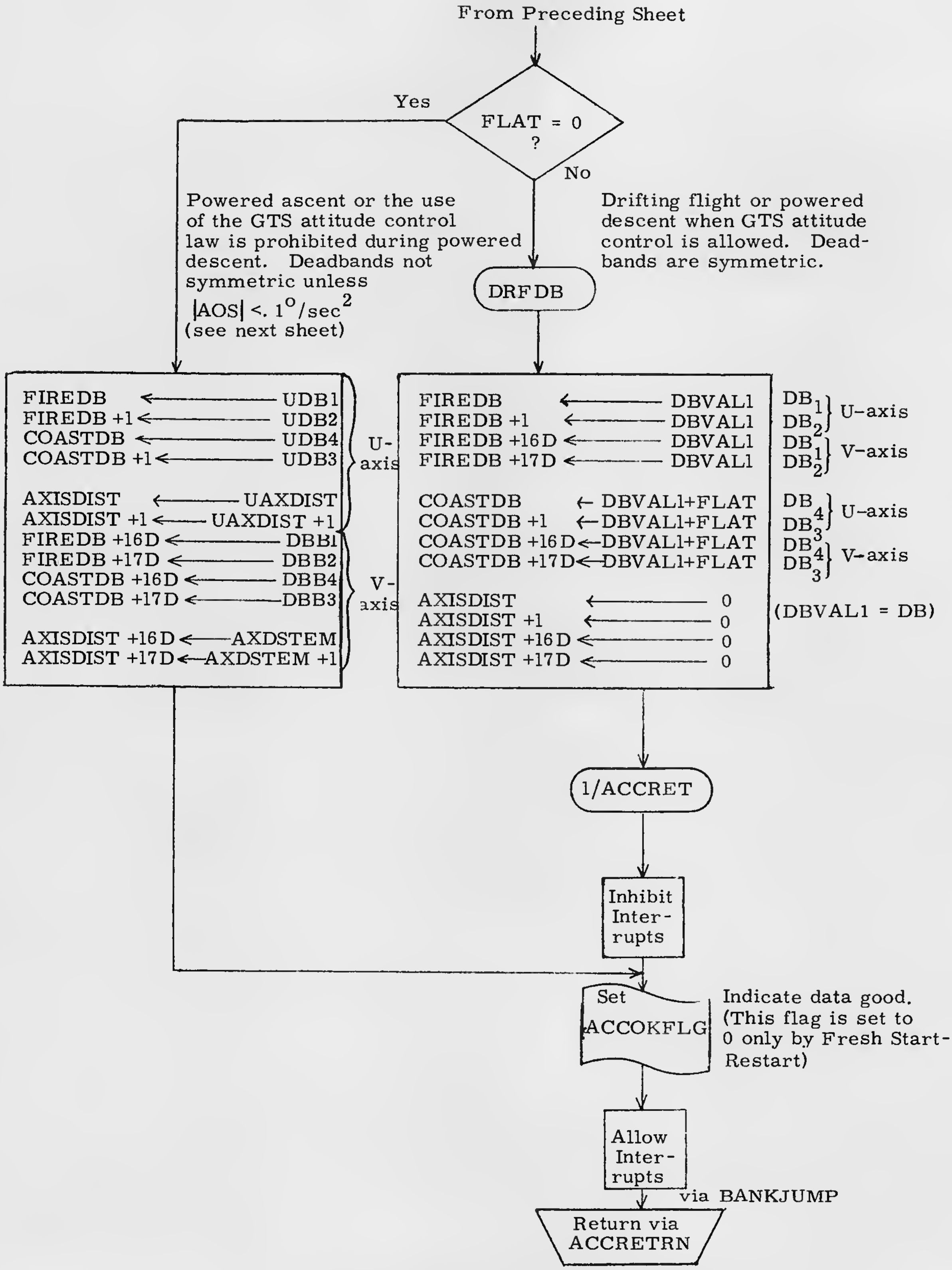
DOCMR RM Enter	3/19/70		
APPR'D RM Enter	3/19/70	REV 1	SHEET 27 OF 36



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ANALST		
DOCMR	R M Estes	3/19/70
APPR'D	R M Estes	3/19/70

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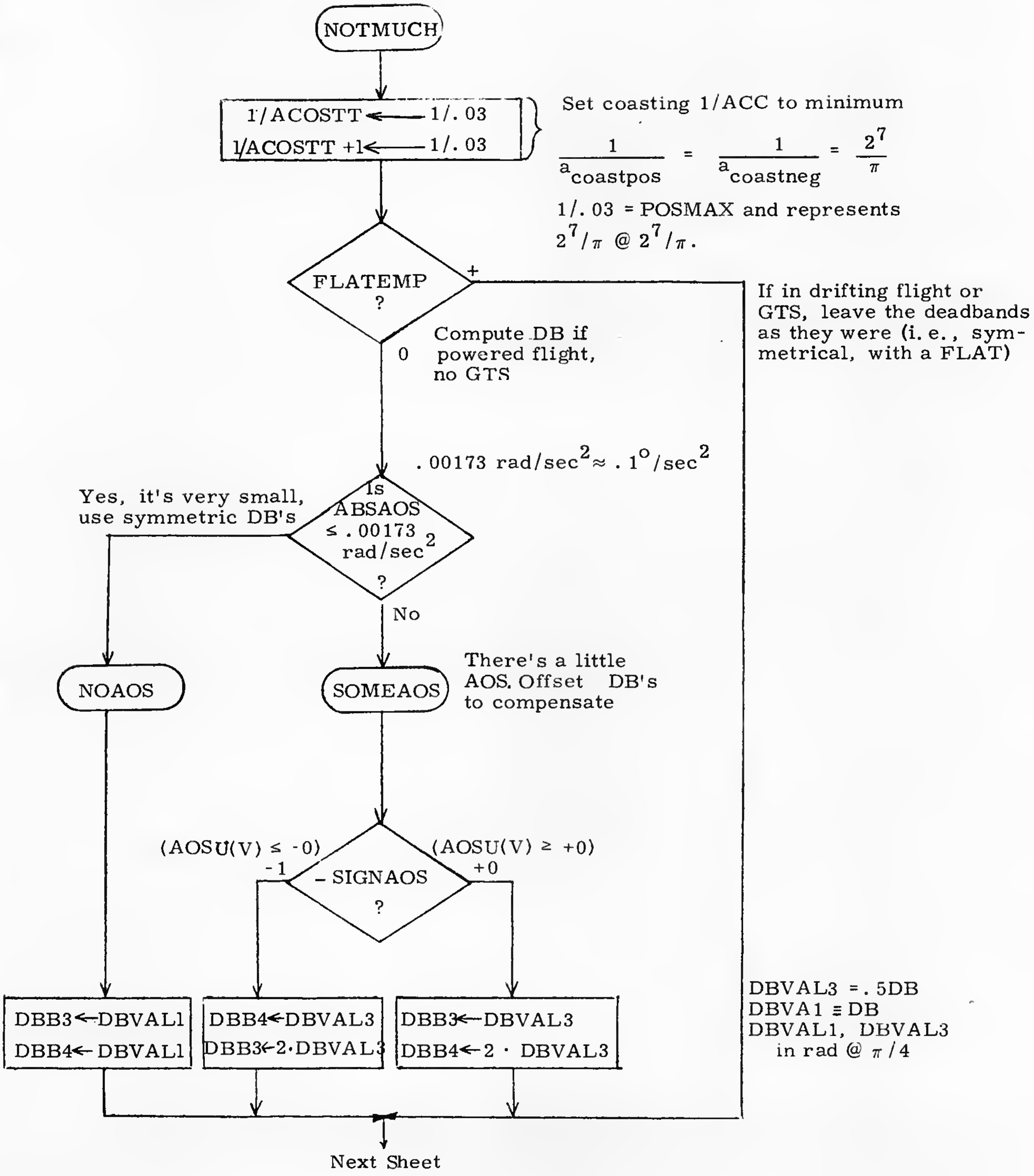

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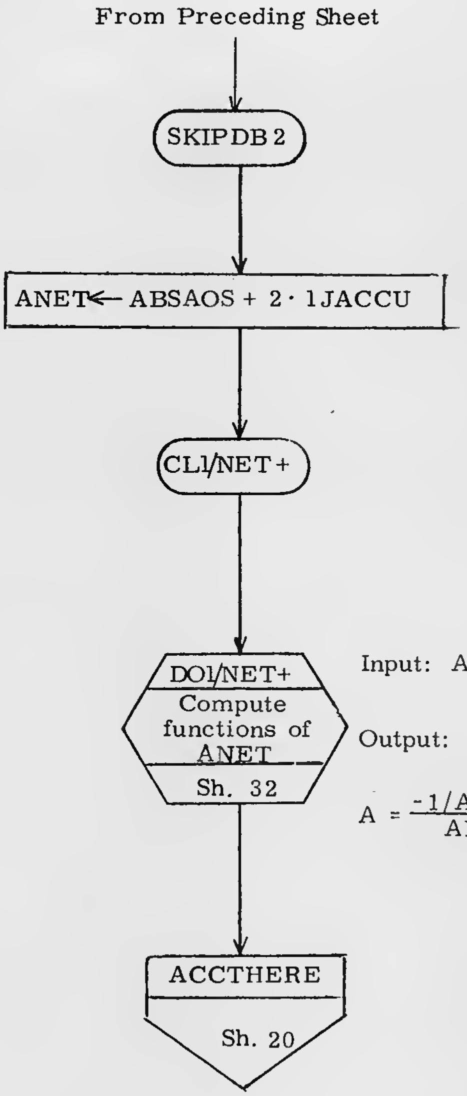

$ANET = a_{netpos(neg)max} @ \pi/2$

Input: $ANET = a_{netpos(neg)max} @ \frac{\pi}{2} = \frac{a_{netpos(neg)max}}{a_{coastneg(pos)}} @ 2^6$

Output: $1/ANET = \frac{1}{a_{netpos(neg)max}} @ 2^7/\pi$

$$A = \frac{-1/ANET}{ANET} = \frac{-1}{a_{netpos(neg)max} + \frac{a^2_{netpos(neg)max}}{a_{coastneg(pos)}}} @ 2^7/\pi$$

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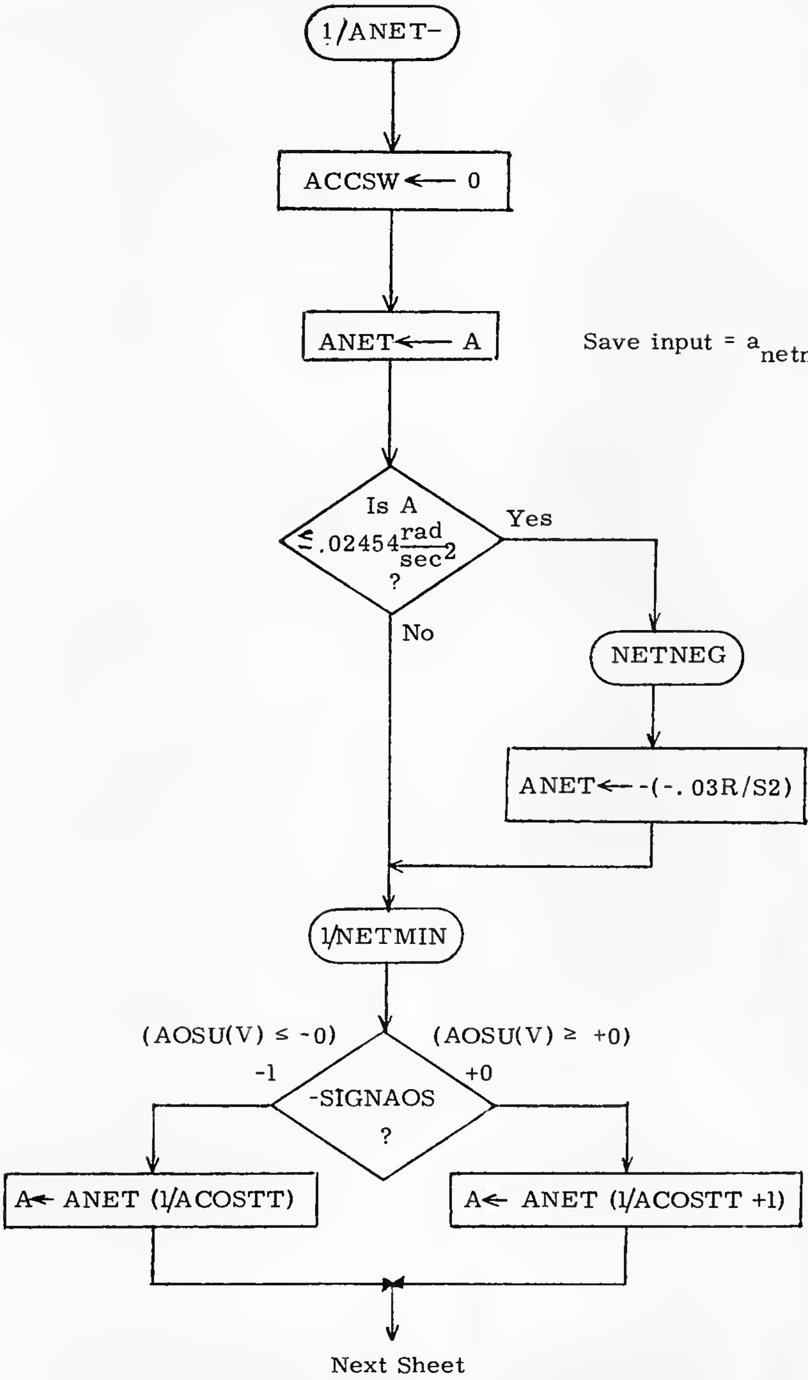
DOCMR	RMM Estes	3/19/70		
APPR'D	RMM Estes	3/19/70	REV 1	SHEET 30 OF 36



Save input = $a_{netneg(pos)max}$ @ $\pi/2$

$-(-.03R/S2) = \pi/2^7$ @ $\pi/2$

$(\pi/2^7 = .02454\ rad/sec^2)$

ANET (1/ACOSTT +1) =

$\frac{a_{netnegmax}}{a_{coastpos}}$ @ 2^6 or

$\frac{a_{netnegmin}}{a_{coastpos}}$ @ 2^6

ANET (1/ACOSTT) =

$\frac{a_{netposmax}}{a_{coastneg}}$ @ 2^6 or

$\frac{a_{netposmin}}{a_{coastneg}}$ @ 2^6

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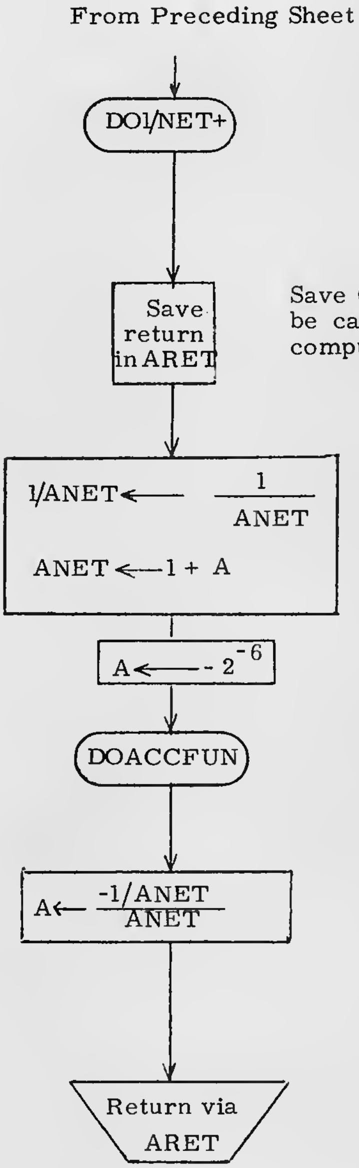
APPR'D	RM Estes	3/19/70	REV 1	SHEET 31 OF 36



Save Q so that subroutine INVERT (Sh. 34) can be called to compute 1/ANET in the following computation

Reciprocal calculated by subroutine INVERT which scales the result at $2^7/\pi$.

@ 2^6 ; ANET location used here for temporary storage.

$-1 @ 2^6 = -2^{-6}$

Input: 1/ANET @ $2^7/\pi$

A containing -1 @ 2^6

Output:

A containing $\frac{-1/ANET}{ANET}$ @ $2^7/\pi$

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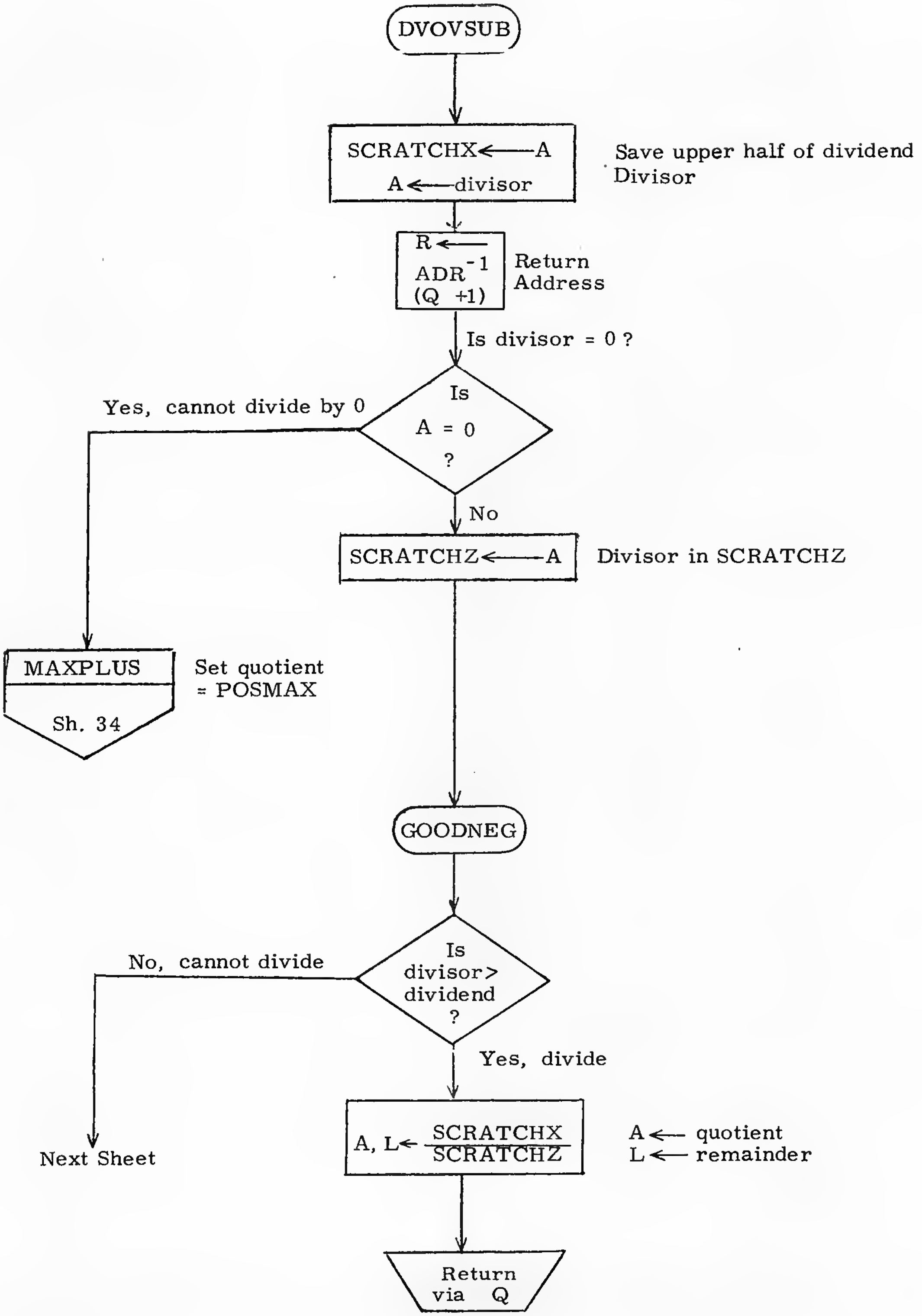
APPR'D RMM Estes	3/19/70	REV -1	SHEET 32 OF 36



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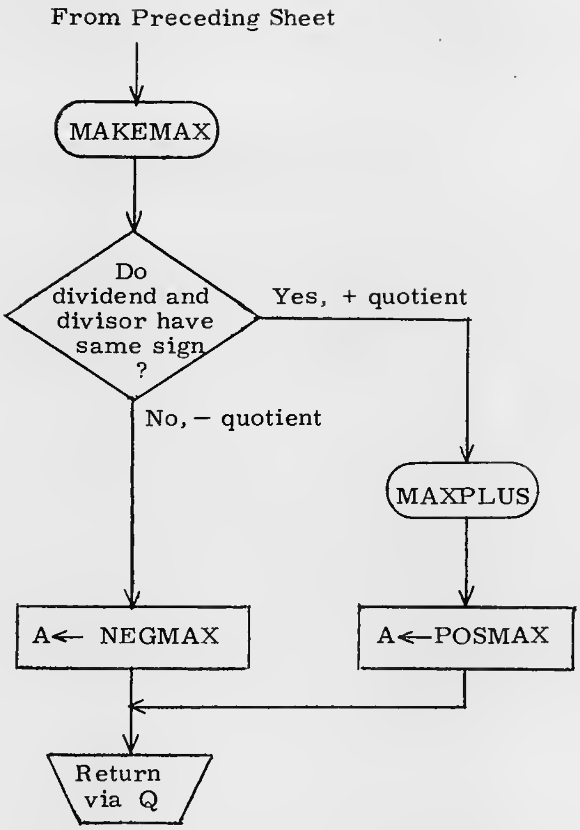
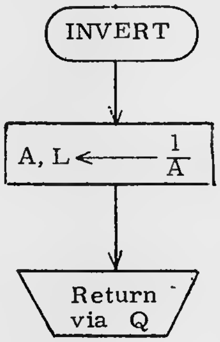


NEGMAX = 40000_8
(as close to -1 as can get)

POSMAX = 37777_8
(as close to +1 as can get)



Input: A @ $\pi/2$

1 @ 2^6
Result @ $\frac{2^7}{\pi}$

Output : $\frac{1}{A}$ (i. e. inverse of input)

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SUBROUTINES CALLED WHICH ARE FLOWED ON OTHER FLOWCHARTS

Subroutine Name	Where Flowed	Description	Where Called
ROT-TOUV	FC-3470	Convert to U-, V- axes	Sh. 15
TIMEGMBL	FC-3480	Gimbal drive	Sh. 14

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ANALST		
DOCMR	RM	3/19/70
APPR'D	RM	3/19/70

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FLAGS

Name	Meaning When Set	Meaning When Clear	Where Set	Where Cleared	Where Tested
ACCOKFLG Flag 13 bit 3	Control authority values from 1/ACCS usable	Restart or Fresh Start since last 1/ACCS; outputs suspect	Sh. 28		
APSFLAG Flag 10 bit 13	Ascent stage	Descent stage			Sh. 3
CSMDKFLG Flag 13 bit 13	CSM docked	CSM not docked to LM			Sh. 3
DRIFTDFL Flag 13 bit 8	Assume 0 offset drifting flight	Use offset acceleration estimate			Sh. 15
USEQRFLG Flag 13 bit 14	Gimbal unusable. Use jets only.	Trim gimbal may be used.			Sh. 14

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INDEX

Major entries

Each major entry is followed by (1) the number and name of the flowchart in which it is flowed, (2) the word ENTRY, and (3) the sheet on which the entry begins.

Example: KEYRUPT1 FC-3110 Keyrupt and Uprupt ENTRY 4

This means that KEYRUPT1 is flowed in FC-3110, Keyrupt and Uprupt, starting on sheet 4.

Subroutines

The name of each subroutine called in one flowchart and flowed in another is followed by (1) the number and name of the flowchart in which it is called, (2) the word CALLED, and (3) the sheet(s) on which it is called.

Example: AXISGEN FC-3520 P57 CALLED 35, 40

This means that AXISGEN is a subroutine called on sheets 35 and 40 of FC-3520, P57, and flowed in some other flowchart.

Flag bits

The name of each flag bit is followed by the number and name of the flowchart in which the flag is set, cleared, or tested. The letters S, C, and T and the numbers following them indicate on which sheet(s) the flag is set, cleared, or tested.

Example: AVFLAG FC-3720 P32/P72 (CSI) S-2 C-2

This means that AVFLAG is set on sheet 2 and cleared on sheet 2 of FC-3720, P32/P72 (CSI).

```
*NBSM*   FC-3320                    ENTRY   11
*NBSM*   FC-3520                    CALLED 12,39
*NBSM*   FC-3600                    CALLED 42
*NBSM*   FC-3900                    CALLED 31
*SMNB*   FC-3320                    ENTRY   11
*SMNB*   FC-3435                    CALLED 5
*SMNB*   FC-3520                    CALLED 20
*SMNB*   FC-3600                    CALLED 35,41
*SMNB*   FC-3960                    CALLED 7
ABTKLEAN FC-3010                    CALLED 5
ABTKLEAN FC-3970                    CALLED 5
ABTTGFLG FC-3970                    S-10
ACCOKFLG FC-3440                                                  T-13
ACCOKFLG FC-3490                    S-28
ACCOMP   FC-3355                    ENTRY   10
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ACC4-2FL FC-3470                                                  T-48
ACC4-2FL FC-3950                    S-3
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ACDT+C12 FC-3470                    CALLED 3
ACDT+C12 FC-3480                    ENTRY   17
ACMODFLG FC-3600                    S-17           C-15           T-18
ACTIVE   FC-3720                    CALLED 17
ACTIVE   FC-3730                    CALLED 2
ACTIVE   FC-3740                    CALLED 15
ADVANCE  FC-3720                    ENTRY   10
ADVANCE  FC-3730                    CALLED 2
AGSINIT  FC-3250                    ENTRY   2
ALARM    FC-3010                    CALLED 19
ALARM    FC-3140                    ENTRY   4
ALARM    FC-3210                    CALLED 12,29,36,37,50,51,52
ALARM    FC-3220                    CALLED 2,3,13,20
ALARM    FC-3310                    CALLED 7
ALARM    FC-3355                    CALLED 38
ALARM    FC-3470                    CALLED 23,49,74,78
ALARM    FC-3510                    CALLED 24
ALARM    FC-3520                    CALLED 8,28
ALARM    FC-3530                    CALLED 10,19,20,22,25,30
ALARM    FC-3600                    CALLED 33,52,64
ALARM    FC-3730                    CALLED 3
ALARM    FC-3800                    CALLED 2
ALARM    FC-3810                    CALLED 9
ALARM    FC-3900                    CALLED 12,19,26
ALARM    FC-3935                    CALLED 5,11
ALARM    FC-3960                    CALLED 13,22
ALARM1   FC-3140                    ENTRY   8
ALARM2   FC-3140                    ENTRY   4
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ALM/END  FC-3435                    CALLED 2
ALM/END  FC-3780                    CALLED 2
ALM/END  FC-3790                    CALLED 2
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```

```
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ANTENFLG FC-3980                                                T-2
AORBSFLG FC-3470                S-42            C-42            T-31,39
AORBTFLG FC-3470                                                T-48,58
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AOTMARK  FC-3510                CALLED 25
AOTMARK  FC-3520                CALLED 31
AOTMARK  FC-3530                ENTRY  2
AOTSTALL FC-3220                ENTRY  35
AOTSTALL FC-3500                CALLED 5
AOTSTALL FC-3520                CALLED 31
A-PCHK   FC-3355                ENTRY  39
APSESW   FC-3360                S-25            C-25
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APSFLAG  FC-3490                                                T-3
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APSIDES  FC-3760                CALLED 13
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ARCTRIG  FC-3310                ENTRY  4
ARCTRIG  FC-3600                CALLED 8,37
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ATOPCSM  FC-3350                ENTRY  7
ATOPCSM  FC-3355                CALLED 34,39
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ATOPLEM  FC-3355                CALLED 34,39
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AVFLAG   FC-3730                S-1             C-1
```

```
AVFLAG    FC-3740          S-2          C-2
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AXISGEN   FC-3510          CALLED 28
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```

```
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CCSHOLE  FC-3440        CALLED 29
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CDHMVR   FC-3730        ENTRY  5
CDRVE    FC-3210        ENTRY  4
CD*TR*G  FC-3320        ENTRY  2
CD*TR*G  FC-3420        CALLED 9
CD*TR*GS FC-3320        ENTRY  2
CDUINC   FC-3150        ENTRY  9
CDULOGIC FC-3150        ENTRY  3
CDULOGIC FC-3320        CALLED 3
CDULOGIC FC-3430        CALLED 21
CDULOGIC FC-3530        CALLED 15,16,31,32
CDULOGIC FC-3600        CALLED 41,53
CDU*NBSM FC-3320        ENTRY  10
CDU*NBSM FC-3780        CALLED 8
CDU*SMNB FC-3320        ENTRY  9
CDU*SMNB FC-3520        CALLED 26
CDU*SMNB FC-3600        CALLED 25
CDU*SMNB FC-3810        CALLED 5
CDU*SMNB FC-3810        CALLED 6
CDU*SMNB FC-3910        CALLED 3
CDUTODCM FC-3420        CALLED 6
CDUTODCM FC-3430        ENTRY  21
CDUTRIG  FC-3320        ENTRY  2
CDUTRIG  FC-3435        CALLED 4
CDUTRIG  FC-3510        CALLED 17,34
CDUTRIG  FC-3520        CALLED 20,21,23,37,40,46   6,46
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CHANG1   FC-3935        CALLED 20
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CHEKBITS FC-3440        ENTRY  20
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CHKPOOH  FC-3100        ENTRY  2
CHKPOOH  FC-3400        CALLED 2
CHKPOOH  FC-3410        CALLED 2
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CHKSDATA FC-3510        ENTRY  46
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CKMID2   FC-3355        ENTRY  37
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```

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CMOONFLG	FC-3640			T-7
CMOONFLG	FC-3720			T-2
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COARSE	FC-3510	CALLED 11		
COARSE	FC-3520	CALLED 16,38		
COATRIM	FC-3520	ENTRY 37		
COGAFLAG	FC-3360	S-23	C-23,34	
COMFAIL	FC-3850	CALLED 13		
COMMINIT	FC-3950	ENTRY 45		
COMMINIT	FC-3970	CALLED 8		
COMPTGO	FC-3720	ENTRY 24		
COPYCYC	FC-3850	ENTRY 19		
COSINE	FC-3320	CALLED 4		
CPHIFLAG	FC-3310	S-7		T-7
CREWMANU	FC-3410	ENTRY 2		
CSI/A	FC-3720	ENTRY 12		
CSMCONIC	FC-3350	ENTRY 13		
CSMCONIC	FC-3400	CALLED 3		
CSMCONIC	FC-3600	CALLED 22,50		
CSMDKFLG	FC-3440	S-5	C-5	T-6,8,9
CSMDKFLG	FC-3470			T-12,38,57,62
CSMDKFLG	FC-3490			T-3
CSMDKFLG	FC-3960			T-3
CSMPREC	FC-3250	CALLED 3		
CSMPREC	FC-3350	ENTRY 12		
CSMPREC	FC-3760	CALLED 15		
CSMPREC	FC-3780	CALLED 3		
CSMPREC	FC-3840	CALLED 3		
CSMSTORE	FC-3760	ENTRY 15		
CSMVEC	FC-3605	ENTRY 3		
CULTFLAG	FC-3510	S-41	C-41	T-37
CURTAINS	FC-3140	ENTRY 4		
CURTAINS	FC-3500	CALLED 5,10		
CURTAINS	FC-3510	CALLED 20,25,49		
CURTAINS	FC-3520	CALLED 31,41		
CUTOFF	FC-3950	ENTRY 39		
C13STALL	FC-3440	ENTRY 40		
C13STALL	FC-3470	CALLED 35		
C13STALL	FC-3900	CALLED 7		
C33TEST	FC-3210	ENTRY 45		
DAPATTER	FC-3440	ENTRY 38		
DAPDISP	FC-3440	ENTRY 2		
DAPIDLER	FC-3010	CALLED 8		
DAPIDLER	FC-3440	ENTRY 13		
DAPT4S	FC-3210	ENTRY 57		
DBSELFLG	FC-3440			T-19
DBSL2FL	FC-3440			T-19
DCMTOCDU	FC-3420	CALLED 8		
DCMTOCDU	FC-3430	ENTRY 19		
DELAYJOB	FC-3050	ENTRY 6		

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DELAYJOB FC-3250            CALLED 3
DELAYJOB FC-3280            CALLED 4,5
DELAYJOB FC-3600            CALLED 9,18
DELAYJOB FC-3720            CALLED 7
DELAYJOB FC-3770            CALLED 13
DELAYJOB FC-3810            CALLED 5
DELCOMP  FC-3420            CALLED 7,8
DELCOMP  FC-3430            ENTRY  16
DELTIME  FC-3360            ENTRY  26
DESCBITS FC-3530            CALLED 18
DESCBITS FC-3940            ENTRY  6
DESIGFLG FC-3600                          C-2,3,33,40,43,49 T-39,46
DESIGFLG FC-3980            S-2           C-2,9         T-2,5
DIDFLAG  FC-3930            S-12          C-11          T-12
DIFEQ+0  FC-3355            ENTRY  28
DIFEQ+1  FC-3355            ENTRY  28
DIFEQ+2  FC-3355            ENTRY  33
DIMOFLAG FC-3350            S-4,23        C-3,5,11,13,14,24,27
DIMOFLAG FC-3355                          C-38          T-10,13,33
DIMOFLAG FC-3600            S-13,20,73,80 C-12,20,21,72,80
DIMOFLAG FC-3610                          C-3
DISDVLVC FC-3720            ENTRY  9
DISPEXIT FC-3940            CALLED 2
DLY2     FC-3040            ENTRY  7
DMENFLG  FC-3600            S-72          C-80
DMP      FC-3320            CALLED 17,19,20
DMPSUB   FC-3320            CALLED 13,14,18,20
DNTMFAST FC-3210            ENTRY  51
DOACCFUN FC-3490            ENTRY  32
DORREPOS FC-3210            ENTRY  22
DOT6RUPT FC-3440            ENTRY  28
DO1/NET+ FC-3490            ENTRY  32
DOW..    FC-3355            ENTRY  41
DOW..1   FC-3355            ENTRY  42
DOWNENT2 FC-3050            ENTRY  2
DOWNFLAG FC-3050            ENTRY  3
DPMODE   FC-3150            ENTRY  14
DRIFTDFL FC-3440            S-18
DRIFTDFL FC-3470                                        T-17,47,63,85
DRIFTDFL FC-3490                                        T-15
DRIFTDFL FC-3840            S-20          C-9
DRIFTDFL FC-3970                          C-3
DRIFTFLG FC-3040                                        T-20
DRIFTFLG FC-3210            S-44                        T-44
DRIFTFLG FC-3220                          C-8
DRIFTFLG FC-3230                                        T-12
DRIFTFLG FC-3500            S-4
DRIFTFLG FC-3510                          C-19
DRIFTFLG FC-3850            S-14          C-2
DRIFTSUB  FC-3230           ENTRY  11
DSKYFLAG FC-3110            S-5
DSKYFLAG FC-3210                                        T-5
DSPOUTSB FC-3210            ENTRY  63
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DVBYCOSM FC-3960            ENTRY  39
D6OR9FLG FC-3350            S-23          C-3,5,24
D6OR9FLG FC-3355                                        T-34
```

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D6OR9FLG FC-3600                    S-13,20,73    C-12,20,21,72,80
ENDEXT   FC-3770                    CALLED 14
ENDIMU   FC-3220                    ENTRY  34
ENDMANUV FC-3430                    CALLED 4
ENDMARK  FC-3530                    CALLED 13
ENDRRMON FC-3210                    ENTRY  57
ENDTNON  FC-3210                    ENTRY  40
ENEMA    FC-3010                    CALLED 5
ENEMA    FC-3970                    CALLED 5
ENGINOF1 FC-3010                    CALLED 25,28
ENGINOF2 FC-3950                    CALLED 38
ENGINOF2 FC-3840                    ENTRY  13
ENGOFF   FC-3950                    ENTRY  36
ENGOFF1  FC-3950                    ENTRY  38
ENGONFLG FC-3210                                  C-33
ENGONFLG FC-3840                    S-8           C-23
ENGONFLG FC-3960                                                T-15
ENGONFLG FC-3970                    S-4
ENGOFTSK FC-3820                    CALLED 3
ERADFLAG FC-3330                                                T-11,12
ERADFLAG FC-3510                                  C-5
ERADFLAG FC-3520                                  C-44
ERADFLAG FC-3610                                  C-5
ETPIFLAG FC-3740                    S-3           C-3           T-4,11
EXTVBACT FC-3530                    S-2           C-33          T-2
FALTON   FC-3010                    CALLED 24
FALTON   FC-3090                    CALLED 15
FALTON   FC-3100                    CALLED 2
FALTON   FC-3120                    CALLED 9,10,13
FALTON   FC-3400                    CALLED 2
FALTON   FC-3410                    CALLED 2
FALTON   FC-3600                    CALLED 17
FALTON   FC-3770                    CALLED 2
FALTON   FC-3970                    CALLED 15
FBR3     FC-3355                    ENTRY  29
FINALFLG FC-3700                    S-3
FINALFLG FC-3720                    S-8                         T-4,8
FINALFLG FC-3730                                                T-4
FINALFLG FC-3710                    S-4
FINALFLG FC-3740                                  C-28          T-25
FINALFLG FC-3760                                  C-14
FINDCDUW FC-3810                    CALLED 8
FINDCDUW FC-3810                    CALLED 9
FINDCDUW FC-3900                    CALLED 26
FINDCDUW FC-3950                    CALLED 33
FINDCDUW FC-3960                    ENTRY  3
FINDVAC  FC-3430                    CALLED 14
FIXDELAY FC-3040                    ENTRY  7
FIXDELAY FC-3210                    CALLED 18,19,20,23
FIXDELAY FC-3220                    CALLED 12
FIXDELAY FC-3600                    CALLED 19,47
FIXDELAY FC-3780                    CALLED 2
FIXDELAY FC-3840                    CALLED 9,13
FIXDELAY FC-3935                    CALLED 8
FLAP     FC-3950                                                T-44
FLAP     FC-3970                    S-11                        T-13
FLASHOFF FC-3100                    CALLED 4
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FLATOUT	FC-3840	CALLED 18		
FLATOUT	FC-3900	ENTRY 39		
FLIP	FC-3930	ENTRY 3		
FLGWRD11	FC-3140		C-16	
FLPC	FC-3950	S-21		T-21
FLPI	FC-3950	S-3	C-11	T-28
FLRCS	FC-3950	S-39		T-12,17,33,34
FLRCS	FC-3970		C-6	
FLTRSUB	FC-3960	ENTRY 23		
FLUNDISP	FC-3840	S-19	C-9,17,19	
FLUNDISP	FC-3900			T-26
FLUNDISP	FC-3950			T-34
FLUNDISP	FC-3970		C-6	
FLVR	FC-3950	S-3	C-30	T-28
FLVR	FC-3970	S-10		
FREEFLAG	FC-3345	S-2	C-2	T-2
FREEFLAG	FC-3500			T-7
FREEFLAG	FC-3510	S-47	C-47	T-28
FREEFLAG	FC-3520	S-14	C-14	T-15,34
G+N,AUTO	FC-3420	ENTRY 11		
G&N,AUTO	FC-3840	CALLED 11		
GAMCOMP	FC-3355	ENTRY 24		
GCOMPSUB	FC-3230	ENTRY 10		
GCOMPZER	FC-3520	CALLED 17		
GENTRAN	FC-3050	ENTRY 9		
GENTRAN	FC-3605	CALLED 2		
GEOM	FC-3360	ENTRY 35		
GETDAT	FC-3530	ENTRY 5		
GETDT	FC-3820	ENTRY 3		
GET.LVC	FC-3710	CALLED 3		
GET.LVC	FC-3760	ENTRY 12		
GET.LVC	FC-3800	CALLED 5,6		
GET+MGA	FC-3720	CALLED 7		
GET+MGA	FC-3760	ENTRY 11		
GETERAD	FC-3330	ENTRY 9		
GETX	FC-3360	ENTRY 27		
GLOCKMON	FC-3210	ENTRY 53		
GLOKFAIL	FC-3310	S-7		
GODSPR	FC-3510	CALLED 19		
GOFLASH	FC-3510	CALLED 3,7,15,24,42,44,47,48		
GOLOADLV	FC-3100	ENTRY 4		
GOMARKF	FC-3120	CALLED 4,5,6		
GOMARK3R	FC-3440	CALLED 12		
GOODEND	FC-3220	ENTRY 34		
GOODEND	FC-3530	CALLED 14		
GOPERF1	FC-3510	CALLED 7,22,29		
GOPERF4R	FC-3510	CALLED 2		
GOPIN	FC-3440	ENTRY 37		
GOPROG	FC-3010	ENTRY 15		
GOPROG2	FC-3140	CALLED 13,18		
GOXDSPF	FC-3240	CALLED 3		
GOXDSPFR	FC-3440	CALLED 4,8,11		
GPMATRIX	FC-3210	ENTRY 57		
GTS	FC-3470	CALLED 44		
GTS	FC-3480	ENTRY 2		
GUESSW	FC-3360			T-13,17
GUESSW	FC-3760	S-4	C-6	

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GUIDINIT FC-3900          CALLED 3
GUIDINIT FC-3950          ENTRY  42
GUILDRET FC-3900          ENTRY  5
GUILDRET FC-3940          CALLED 3
GVDETER  FC-3520          ENTRY  11
GYCOARS  FC-3510          ENTRY  19
GYROTRIM FC-3520          ENTRY  39
HAVEGUES FC-3760          ENTRY  4
HAVEGUES FC-3810          CALLED 13
HBAD     FC-3930          ENTRY  7
HFAILFLG FC-3935          S-31          C-17
HFLSHFLG FC-3930                                      T-3
HFLSHFLG FC-3935          S-31          C-17
IBNKCALL FC-3060          ENTRY  5
ICDUFAIL FC-3210          ENTRY  31
IDLEFLAG FC-3140          S-16
IDLEFLAG FC-3820          S-3                         T-2
IDLEFLAG FC-3840          S-19          C-9,19
IDLEFLAG FC-3950          S-37                        T-19
IDLEFLAG FC-3970                        C-6
IFAILOK  FC-3220          ENTRY  17
IGNFLAG  FC-3840          S-8           C-7,9         T-16
IMPULSW  FC-3810          S-9
IMPULSW  FC-3820                        C-3           T-2
IMPULSW  FC-3840          S-22          C-9,21        T-9
IMUBAD   FC-3210          CALLED 42
IMUBAD   FC-3220          ENTRY  34
IMUCAGE  FC-3210          ENTRY  33
IMUCHK   FC-3500          ENTRY  2
IMUCHK   FC-3520          CALLED 2
IMUCOARS FC-3220          ENTRY  6
IMUCOARS FC-3500          CALLED 10
IMUFAIL  FC-3210          ENTRY  31
IMUFINE  FC-3220          ENTRY  15
IMUFINE  FC-3500          CALLED 10
IMUFINED FC-3220          ENTRY  16
IMUGOOD  FC-3220          ENTRY  34
IMUMON   FC-3210          ENTRY  25
IMUOP    FC-3210          ENTRY  35
IMUPULSE FC-3150          CALLED 11
IMUPULSE FC-3220          ENTRY  21
IMUPULSE FC-3230          CALLED 10
IMUPULSE FC-3510          CALLED 20,49
IMUPULSE FC-3520          CALLED 42
IMUSE    FC-3210                        C-36          T-36,39,42
IMUSE    FC-3220          S-33
IMUSE    FC-3250                                      T3
IMUSE    FC-3500          S-2
IMUSE    FC-3600                        C-2
IMUSTALL FC-3220          ENTRY  35
IMUSTALL FC-3230          CALLED 11
IMUSTALL FC-3250          CALLED 3
IMUSTALL FC-3500          CALLED 10
IMUSTALL FC-3510          CALLED 20,49
IMUSTALL FC-3520          CALLED 41
IMUZERO  FC-3220          ENTRY  2
IMUZERO  FC-3250          CALLED 3
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IMUZERO2 FC-3220         ENTRY  4
INCORP1  FC-3600         CALLED 83
INCORP2  FC-3600         CALLED 83
INFINFLG FC-3360         S-30        C-30        T-19,23
INITALGN FC-3520         S-9         C-10        T-34,35,38,43
INITCDUW FC-3960         ENTRY  2
INITCDUW FC-3970         CALLED 6
INITVEL  FC-3710         CALLED 3
INITVEL  FC-3740         CALLED 19
INITVEL  FC-3760         ENTRY  4
INITVEL  FC-3800         CALLED 6
INSTALL  FC-3120         CALLED 8
INTEGRV  FC-3350         ENTRY  15
INTEGRV  FC-3600         CALLED 12,21
INTEGRV  FC-3610         CALLED 3
INTEGRV2 FC-3355         CALLED 36
INTEGRVS FC-3350         ENTRY  14
INTEGRVS FC-3610         CALLED 3
INTEGRVS FC-3640         CALLED 4
INTEGRVS FC-3740         CALLED 23
INTEGRVS FC-3760         CALLED 7
INTEGRVS FC-3780         CALLED 5
INTEGRVS FC-3900         CALLED 20
INTFLAG  FC-3350                     C-19        T-17
INTGRATE FC-3355         ENTRY  9
INTINT   FC-3720         CALLED 4,16,17,
INTINT   FC-3730         CALLED 2
INTINT2C FC-3720         ENTRY  16
INTINT3P FC-3730         ENTRY  2
INTPRET  FC-3320         CALLED 9
INTSTALL FC-3010         CALLED 26
INTSTALL FC-3350         ENTRY  17
INTSTALL FC-3600         CALLED 3,6,12,14,21
INTSTALL FC-3605         CALLED 2
INTSTALL FC-3610         CALLED 3
INTSTALL FC-3640         CALLED 3,5
INTSTALL FC-3740         CALLED 22
INTSTALL FC-3760         CALLED 6
INTSTALL FC-3780         CALLED 4,5,6
INTSTALL FC-3900         CALLED 19
INTWAKE  FC-3350         ENTRY  18
INTWAKE  FC-3355         CALLED 40
INTWAKE  FC-3605         CALLED 3
INTWAKEU FC-3120         CALLED 13
INTWAKEU FC-3350         ENTRY  20
INTWAKEO FC-3350         ENTRY  18
INTWAKEO FC-3600         CALLED 14
INTWAKEO FC-3640         CALLED 6
INTYPFLG FC-3350         S-13        C-3,5,12,24,27  T-15
INTYPFLG FC-3600                     C-12,20,21,73,80
INTYPFLG FC-3610                     C-3
INTYPFLG FC-3640                     C-4
INTYPFLG FC-3740         S-22        C-22
INTYPFLG FC-3760                     C-7
INTYPFLG FC-3900         S-20
INVFLAG  FC-3840         CALLED 20
IRIGX    FC-3230         ENTRY  5
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IRIGY    FC-3230                    ENTRY  7
IRIGZ    FC-3230                    ENTRY  8
ISITAUTO FC-3420                    ENTRY  11
ISITAUTO FC-3430                    CALLED 9
ISWCALL  FC-3060                    ENTRY  6
ISWRETRN FC-3060                    ENTRY  6
ITERATOR FC-3360                    ENTRY  37
ITSWICH  FC-3730                    S-4
ITSWICH  FC-3740                    S-4          C-4,5          T-5,11
ITURNON  FC-3210                    ENTRY  29
JOBSLEEP FC-3050                    CALLED 8
JOBSLEEP FC-3220                    CALLED 23,35
JOBWAKE  FC-3050                    CALLED 8
JOBWAKE  FC-3220                    CALLED 24,34
JOBWAKE  FC-3350                    CALLED 19
JTLST    FC-3440                    ENTRY  32
JTLST    FC-3470                    CALLED 70
JUSTTRIM FC-3520                    ENTRY  41
KALCMAN3 FC-3420                    CALLED 4
KALCMAN3 FC-3430                    ENTRY  5
KEPLERN  FC-3355                    CALLED 32
KEPLERN  FC-3360                    ENTRY  3
KEPPREP  FC-3350                    CALLED 16
KEPPREP  FC-3355                    ENTRY  30
KEYRUPT1 FC-3110                    ENTRY  4
KILLTASK FC-3600                    CALLED 23,84,85
KILLTASK FC-3840                    CALLED 18,20
LALOTORV FC-3330                    ENTRY  7
LALOTORV FC-3510                    CALLED 16
LAMBERT  FC-3360                    ENTRY  11
LAMBERT  FC-3760                    CALLED 6
LAMENTER FC-3360                    ENTRY  36
LAMPTEST FC-3210                    ENTRY  28
LANDISP  FC-3930                    ENTRY  6
LANDJUNK FC-3910                    ENTRY  2
LASTBIAS FC-3230                    ENTRY  15
LASTBIAS FC-3850                    CALLED 2
LAT-LONG FC-3330                    ENTRY  2
LAT-LONG FC-3510                    CALLED 14
LAT-LONG FC-3610                    CALLED 5
LAT-LONG FC-3910                    CALLED 2
LEGAL?   FC-3970                    ENTRY  15
LEMCONIC FC-3350                    ENTRY  13
LEMCONIC FC-3400                    CALLED 3
LEMCONIC FC-3435                    CALLED 3
LEMCONIC FC-3510                    CALLED 13
LEMCONIC FC-3600                    CALLED 22
LEMPREC  FC-3250                    CALLED 2
LEMPREC  FC-3350                    ENTRY  12
LEMPREC  FC-3510                    CALLED 30
LEMPREC  FC-3520                    CALLED 5
LEMPREC  FC-3710                    CALLED 2
LEMPREC  FC-3760                    CALLED 15
LEMPREC  FC-3780                    CALLED 3,4
LEMPREC  FC-3800                    CALLED 6
LEMPREC  FC-3900                    CALLED 3
LEMPREC  FC-3950                    CALLED 5
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LEMSTORE FC-3760              ENTRY  15
LEMVEC   FC-3605              ENTRY  3
LETABORT FC-3840              S-10
LETABORT FC-3910                            C-2
LETABORT FC-3930                                          T-4
LETABORT FC-3950                            C-41
LETABORT FC-3970                            C-13          T-15
LIMITSUB FC-3935              CALLED 15
LIMITSUB FC-3960              ENTRY  25
LINUS    FC-3420              CALLED 10
LMOONFLG FC-3350              S-9           C-9           T-10
LMOONFLG FC-3600                                          T-73
LMOONFLG FC-3605                                          T-2
LMOONFLG FC-3770                                          T-11
LOADTIME FC-3150              ENTRY  2
LOADTIME FC-3250              CALLED 2
LOADTIME FC-3350              CALLED 2,26,27
LOADTIME FC-3355              CALLED 37
LOADTIME FC-3400              CALLED 3
LOADTIME FC-3435              CALLED 3
LOADTIME FC-3510              CALLED 22,44
LOADTIME FC-3520              CALLED 4,26,44,46,48
LOADTIME FC-3600              CALLED 16,20,24,31,50,84,85
LOADTIME FC-3610              CALLED 2
LOADTIME FC-3750              CALLED 2
LOADTIME FC-3770              CALLED 6
LOADTIME FC-3780              CALLED 3,4
LOADTIME FC-3790              CALLED 3,7
LOADTIME FC-3950              CALLED 36,42
LOADTIME FC-3970              CALLED 7
LOCSAM   FC-3500              CALLED 13
LOCSAM   FC-3510              ENTRY  30
LODSAMPT FC-3110              CALLED 4,6
LOGSUB   FC-3950              ENTRY  50
LOKONSW  FC-3600              S-30,31       C-30,85       T-42
LONGCALL FC-3040              ENTRY  19
LOSCMFLG FC-3600              S-49          C-15,31,32,43,84 T-22,43
LOSCMFLG FC-3980              S-3,5         C-2,3,10      T-3,5
LPOS2FLG FC-3935              S-26
LRALT    FC-3930              CALLED 6
LRBYPASS FC-3140              S-16
LRBYPASS FC-3280                                          T-8
LRBYPASS FC-3850                                          T-4
LRBYPASS FC-3900                            C-2
LRBYPASS FC-3930                                          T-5
LRBYPASS FC-3935                                          T-6,9
LRBYPASS FC-3970              S-4
LRHJOB   FC-3930              ENTRY  6
LRHTASK  FC-3930              ENTRY  5
LRINH    FC-3935              S-2           C-3,4,10      T-17,24
LRPOSFLG FC-3935              S-7
LRPOS2   FC-3935              ENTRY  7
LRVELFLG FC-3600                            C-63          T-94
LSORIENT FC-3510              ENTRY  6
LSORIENT FC-3520              CALLED 5
LSPOS    FC-3355              CALLED 7,12
LSPOS    FC-3435              CALLED 4
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LSPOS	FC-3510	CALLED 30		
LUNAFLAG	FC-3330			T-2,8,10,11
LUNAFLAG	FC-3510	S-5		
LUNAFLAG	FC-3520	S-44		
LUNAFLAG	FC-3610	S-5	C-4	
LUNAFLAG	FC-3910	S-2		
LUNLAND	FC-3940	ENTRY 2		
LUNPOS	FC-3355	CALLED 6		
MAKECADR	FC-3050	CALLED 8		
MAKECADR	FC-3060	ENTRY 4		
MAKECADR	FC-3220	CALLED 35		
MAKECADR	FC-3420	CALLED 2		
MAKECADR	FC-3510	CALLED 34		
MAKECADR	FC-3600	CALLED 24		
MARKRUPT	FC-3530	ENTRY 18		
MARKTYPE	FC-3530	ENTRY 21		
MATMOVE	FC-3500	CALLED 8		
MATMOVE	FC-3510	ENTRY 50		
MATMOVE	FC-3520	CALLED 3,37,42		
MAXCHK	FC-3710	CALLED 3,4		
MFREF	FC-3520	ENTRY 48		
MGLVFLAG	FC-3760	S-12	C-11	
MIDAVFLG	FC-3350	S-27	C-28	
MIDAVFLG	FC-3355			T-33
MIDFLAG	FC-3355	S-2	C-2	T-5,11,41
MID1FLAG	FC-3355			T-37
MIDTOAV1	FC-3350	ENTRY 26		
MIDTOAV1	FC-3840	CALLED 3		
MIDTOAV2	FC-3350	ENTRY 26		
MIDTOAV2	FC-3830	CALLED 2		
MID1FLAG	FC-3350	S-26	C-26	
MINIMP	FC-3440	ENTRY 37		
MINIRECT	FC-3355	ENTRY 43		
MINIRECT	FC-3600	CALLED 14		
MINIRECT	FC-3640	CALLED 5		
MKREJ	FC-3530	ENTRY 25		
MKRELEAS	FC-3530	ENTRY 14		
MODEEXIT	FC-3220	ENTRY 36		
MOONFLAG	FC-3140			T-17
MOONFLAG	FC-3350	S-8,11,21	C-8,21	T-7,9,14
MOONFLAG	FC-3355	S-44	C-44	T-6,12,14, 20,32,40, 41,44
MOONFLAG	FC-3610	S-3	C-3	
MOONFLAG	FC-3640	S-7	C-7	
MOONFLAG	FC-3740	S-23	C-23	
MOONFLAG	FC-3760	S-7	C-7	
MOONFLAG	FC-3900	S-20		
MPACVBUF	FC-3320	CALLED 9,10		
MPACVBUF	FC-3980	CALLED 7		
MR.KLEAN	FC-3140	CALLED 15		
MUNFLAG	FC-3210			T-14
MUNFLAG	FC-3840			T-3
MUNFLAG	FC-3850		C-14	T-4,8,11
MUNFLAG	FC-3900	S-2		
MUNFLAG	FC-3950	S-3		
MUNGRAV	FC-3840	CALLED 3		

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MUNGRAV   FC-3900            CALLED 4
MUNGRAV   FC-3935            CALLED 16
MUNGRAV   FC-3950            CALLED 6
MUNRETRN  FC-3935            ENTRY  9
MXM3      FC-3420            CALLED 7,8
MXM3      FC-3430            ENTRY  23
NBDONLY   FC-3040            CALLED 18
NBDONLY   FC-3230            ENTRY  14
NBSM      FC-3320            ENTRY  8
NB2CDUSP  FC-3960            ENTRY  27
NCOARSE   FC-3500            ENTRY  4
NCOARSE   FC-3510            CALLED 11,21
NCOARSE   FC-3520            CALLED 38
NDELVFLG  FC-3720            S-10
NEEDLER   FC-3440            ENTRY  25
NEEDLFLG  FC-3440            S-38            C-38            T-21
NEED2FLG  FC-3440                                            T-21
NEWIFLG   FC-3350            S-14,39
NEWIFLG   FC-3355                            C-5             T-5
NEWMODEA  FC-3010            CALLED 33
NEWMODEX  FC-3120            CALLED 3,13
NEWMODEX  FC-3900            CALLED 6
NEWMODEX  FC-3940            CALLED 3
NEWSTATE  FC-3360            ENTRY  36
NEXTCOL   FC-3355            ENTRY  36
NJETSFLG  FC-3440            S-6             C-6
NJETSFLG  FC-3810                                            T-2
NOATTOFF  FC-3210            CALLED 39,41
NOATTOFF  FC-3220            ENTRY  38
NODOFLAG  FC-3140                            C-14
NODOFLAG  FC-3250            S-2             C-3
NODOFLAG  FC-3350            S-3             C-6
NODOFLAG  FC-3640            S-2             C-6
NOLRREAD  FC-3850                                            T-20
NOLRREAD  FC-3930                                            T-5
NOLRREAD  FC-3935            S-27            C-28            T-10
NOMINIMP  FC-3440            ENTRY  37
NORMSW    FC-3360                            C-34            T-35
NORMSW    FC-3760            S-5             C-4
NORMSW    FC-3800                                            T-6
NORMSW    FC-3810                                            T-7,10,13
NORMUNIT  FC-3150            ENTRY  12
NORMUNIT  FC-3960            CALLED 5,6
NORMUNX1  FC-3150            ENTRY  12
NORRGMON  FC-3210            ENTRY  17
NORRMON   FC-3210                                            T-14
NORRMON   FC-3600            S-28,85         C-15,28,31
NOR29FLG  FC-3850            S-14
NOR29FLG  FC-3935                                            T-6
NOR29FLG  FC-3980                                            T-11
NOTERFLG  FC-3900                            C-2
NOTERFLG  FC-3935            S-5             C-23
NOTERFLG  FC-3940            S-5
NOTHROTL  FC-3800                            C-3
NOTHROTL  FC-3840            S-21,22         C-21            T-9
NOTHROTL  FC-3900                            C-2
NOTIME    FC-3355            CALLED 37
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NOUPFLAG	FC-3600	S-10		T-56
NOUPFLAG	FC-3605		C-3	
NO511FLG	FC-3935	S-27		T-10
NTARGFLG	FC-3740	S-25		T-25
NVSUB	FC-3100	CALLED 3		
N89DISP	FC-3510	ENTRY 14		
N89DISP	FC-3520	CALLED 45		
OANB	FC-3510	CALLED 44		
OANB	FC-3520	CALLED 27		
OANB	FC-3530	ENTRY 31		
OCCOS	FC-3510	ENTRY 31		
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OLDESFLG	FC-3980	S-3	C-2	T-3
ONESTO2S	FC-3960	ENTRY 38		
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ORBWFLAG	FC-3350		C-21	T-23
ORBWFLAG	FC-3355		C-38	
ORDERSW	FC-3360			T-37,38
ORIGCHNG	FC-3355	ENTRY 44		
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OTHPREC	FC-3770	CALLED 7		
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OURRCFLG	FC-3470	S-36	C-27	T-26,28,43,50
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PASSIVE	FC-3730	CALLED 2		
PASSIVE	FC-3740	CALLED 16		
PASTIT	FC-3530	ENTRY 9		
PAXIS	FC-3440	CALLED 12		
PAXIS	FC-3470	ENTRY 2		
PDSPFLAG	FC-3100			T-3
PDSPFLAG	FC-3420	S-10		T-10,11
PDSPFLAG	FC-3600	S-26	C-26	
PERIAPO	FC-3720	CALLED 14		
PERIAPO	FC-3760	ENTRY 13		
PERIAPO1	FC-3710	CALLED 3		
PERIAPO1	FC-3720	CALLED 17		
PERIAPO1	FC-3740	CALLED 7		
PERIAPO1	FC-3760	ENTRY 13		
PFAILOK	FC-3210	CALLED 44		
PFAILOK	FC-3220	ENTRY 18		
PFLITEDB	FC-3440	ENTRY 19		
PFLITEDB	FC-3800	CALLED 3		
PFLITEDB	FC-3900	CALLED 22		
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PINBRNCH	FC-3080	CALLED 15		
PINBRNCH	FC-3120	CALLED 2		
PINBRNCH	FC-3440	CALLED 37		
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PIPASR	FC-3850	ENTRY 6		
PIPFAIL	FC-3210	ENTRY 49		
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PIPFREE   FC-3850                     CALLED 14
PIPSRINE  FC-3520                     CALLED 17,18
PIPUSE    FC-3220                     ENTRY  19
PIPUSE1   FC-3220                     ENTRY  19
PJETSLEC  FC-3470                     ENTRY  40
PLANET    FC-3500                     ENTRY  11
PLANET    FC-3510                     CALLED 26,27,45
PLANET    FC-3520                     CALLED 26,32,33
PLITEDB   FC-3950                     CALLED 11
POLY      FC-3360                     CALLED 26,29
POLY      FC-3950                     CALLED 50
POODOO    FC-3140                     ENTRY  5
POODOO    FC-3355                     CALLED 23
POODOO    FC-3530                     CALLED 2
POODOO1   FC-3040                     CALLED 8,19
POODOO1   FC-3140                     ENTRY  7
POOHFLAG  FC-3350                     S-3
POOHFLAG  FC-3355                                                        T-4
POSTJUMP  FC-3060                     ENTRY  3
POWRSERS  FC-3900                     CALLED 43
PRECIFLG  FC-3350                     S-5,12          C-4
PRECIFLG  FC-3355                                     C-40               T-4
PRECSET   FC-3720                     CALLED 2,10
PRECSET   FC-3740                     CALLED 5
PRECSET   FC-3750                     CALLED 2
PRECSET   FC-3760                     ENTRY  15
PRERADAR  FC-3850                     CALLED 20
PREREAD   FC-3850                     ENTRY  2
PRIOCHNG  FC-3240                     CALLED 2
PRIOCHNG  FC-3420                     CALLED 10
PRIOCHNG  FC-3435                     CALLED 7
PRIOCHNG  FC-3440                     CALLED 2
PRIOCHNG  FC-3600                     CALLED 3,17
PRIOCHNG  FC-3770                     CALLED 2
PRIOCHNG  FC-3780                     CALLED 6
PRIOCHNG  FC-3900                     CALLED 8
PRIOCHNG  FC-3935                     CALLED 23
PRIOCHNG  FC-3970                     CALLED 12
PRIODFLG  FC-3100                                                        T-3
PRIODSPR  FC-3140                     CALLED 12
PRIOLARM  FC-3140                     ENTRY  3
PROCKEY   FC-3210                     CALLED 6
PROG20    FC-3600                     ENTRY  11
PROG21    FC-3610                     ENTRY  2
PROG22    FC-3600                     ENTRY  11
PROG25    FC-3620                     ENTRY  2
PROG52    FC-3510                     ENTRY  2
PRONVFLG  FC-3100                                                        T-3
PSTHIGAT  FC-3935                     S-27
PTOACSM   FC-3350                     ENTRY  8
PTOALEM   FC-3350                     ENTRY  10
PTOALEM   FC-3605                     CALLED 2
PULSEFLG  FC-3440                     S-38            C-38
PULSEFLG  FC-3470                                                        T-22,50
PULSEFLG  FC-3840                                     C-10
PULSEFLG  FC-3910                     S-2
PULSEFLG  FC-3970                                     C-3
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P12INIT  FC-3970                CALLED 13
P12LM    FC-3950                ENTRY  2
P12NIT   FC-3950                ENTRY  44
P12RET   FC-3950                ENTRY  10
P20FLGON FC-3730                CALLED 1
P20FLGON FC-3750                CALLED 2
P21FLAG  FC-3610                S-4                         T-3
P25FLAG  FC-3600                              C-2           T-2,24
P25FLAG  FC-3620                S-2                         T-3
P25FLAG  FC-3900                              C-2
P3XORP7X FC-3720                ENTRY  24
P30      FC-3700                ENTRY  2
P31      FC-3710                ENTRY  2
P32      FC-3720                ENTRY  2
P33      FC-3730                ENTRY  1
P34      FC-3740                ENTRY  2
P35      FC-3750                ENTRY  2
P40AUTO  FC-3840                ENTRY  11
P40AUTO  FC-3850                CALLED 11
P40AUTO  FC-3970                CALLED 11
P40LM    FC-3800                ENTRY  2
P40SXT4  FC-3800                ENTRY  4
P40SXT4  FC-3810                CALLED 4
P41LM    FC-3810                ENTRY  2
P42LM    FC-3820                ENTRY  2
P47LM    FC-3830                ENTRY  I
P51      FC-3500                ENTRY  2
P57      FC-3520                ENTRY  2
P57OPT0  FC-3520                ENTRY  21
P57OPT1  FC-3520                ENTRY  23
P57OPT2  FC-3520                ENTRY  25
P57OPT3  FC-3520                ENTRY  24
P63DISPS FC-3900                ENTRY  27
P63LM    FC-3900                ENTRY  2
P66PROFL FC-3900                              C-27          T-48
P66PROFL FC-3940                S-4
P70      FC-3970                ENTRY  2
P70A     FC-3930                CALLED 5
P70A     FC-3970                ENTRY  2
P70P71FL FC-3970                S-6
P7071FLG FC-3950                                            T-16,24,32
P71      FC-3970                ENTRY  2
P71A     FC-3930                CALLED 4
P71A     FC-3970                ENTRY  2
P72      FC-3720                ENTRY  2
P73      FC-3730                ENTRY  1
P74      FC-3740                ENTRY  2
P75      FC-3750                ENTRY  2
P76      FC-3640                ENTRY  2
QERRCALC FC-3440                CALLED 23
QRAXIS   FC-3470                ENTRY  43
QTPROLOG FC-3320                ENTRY  5
QUICTRIG FC-3320                ENTRY  6
QUICTRIG FC-3850                CALLED 10
QUICTRIG FC-3935                CALLED 18
QUICTRIG FC-3960                CALLED 6
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QUICTRIG  FC-3980           CALLED 7
QUIKDSP   FC-3210           ENTRY  60
QUITFLAG  FC-3350                         C-2           T-2
QUITFLAG  FC-3355                                       T-2
R-TO-RP   FC-3330           CALLED 3
R-TO-RP   FC-3355           CALLED 16
RADSTALL  FC-3220           ENTRY  34
RADSTALL  FC-3280           CALLED 6
RADSTALL  FC-3600           CALLED 30,31,59
RADSTALL  FC-3930           CALLED 6
RADSTALL  FC-3935           CALLED 5,27
RADSTALL  FC-3980           CALLED 4,11,12
RCDUFAIL  FC-3600                                       T-66,68,71
RCDUOFLG  FC-3600                                       T-18,54,71
RCSMONIT  FC-3210           ENTRY  8
RDCDUS    FC-3510           ENTRY  9
RDRUSECK  FC-3935           ENTRY  6
READCDUK  FC-3420           CALLED 5
READCDUK  FC-3430           ENTRY  23
READRFLG  FC-3980                         C-12          T-10
READVEL   FC-3935           S-22
RECTIFY   FC-3350           CALLED 14,16
RECTIFY   FC-3355           ENTRY  43
RECTOUT   FC-3355           ENTRY  40
REINTFLG  FC-3120           S-8
REINTFLG  FC-3355           S-34,39
REDFLAG   FC-3900           S-29          C-2,7,28      T-9,28
REDFLAG   FC-3940                         C-5
REFMF     FC-3520           ENTRY  46
REFMF     FC-3910           CALLED 3
REFSMFLG  FC-3220                         C-8           T-33
REFSMFLG  FC-3250                                       T-2
REFSMFLG  FC-3500           S-8
REFSMFLG  FC-3510           S-12,21       C-19
REFSMFLG  FC-3520           S-43          C-11          T-6,7,25
REFSMFLG  FC-3720                                       T-7
REINTFLG  FC-3120           S-8
REINTFLG  FC-3140                         C-14
REINTFLG  FC-3350           S-17          C-19          T-17,18
REINTFLG  FC-3355           S-34,39
REINTFLG  FC-3640           S-5
RELDSP    FC-3010           CALLED 27,33
RELDSP    FC-3080           CALLED 15
RELDSP    FC-3970           CALLED 15
RELINUS   FC-3420           ENTRY  10
REMARK    FC-3530           ENTRY  27
REMODE    FC-3600           ENTRY  45
REMODFLG  FC-3600           S-33          C-46          T-39,47,50
REMODFLG  FC-3980           S-2
RENDWFLG  FC-3350                         C-21          T-4,5,23
RENDWFLG  FC-3355                         C-38
RENDWFLG  FC-3600           S-81          C-5,10        T-36,43,47
RENDWFLG  FC-3950                         C-12
RENDZFLG  FC-3950                         C-3
REPOSMON  FC-3600                                       T-36,43,47,66
REPOSMON  FC-3980           S-2    C-4
RESTORDB  FC-3440           ENTRY  18
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RESTORDB FC-3600              CALLED 3,26
RESTORDB FC-3800              CALLED 4
RESTORDB FC-3950              CALLED 41
RESUME   FC-3110              CALLED 8,9,10
RGOODEND FC-3935              CALLED 7
RHCSFLG  FC-3440                                          S-7
RNDREFDR FC-3210              CALLED 34,36
RNDREFDR FC-3220              ENTRY  8
RNDVZFLG FC-3210                            C-36          T-12
RNDVZFLG FC-3420                                          T-10
RNDVZFLG FC-3600              S-15          C-2        T-2,19,23,36,54
RNDVZFLG FC-3620                            C-2
RNDVZFLG FC-3900                            C-2
RNGEDATA FC-3930              S-7
RNGEDATA FC-3935                            C-12          T-13
RNGSCFLG FC-3600              S-90          C-59          T-60
RNGSCFLG FC-3930                            C-7
RNGSCFLG FC-3980                            C-12          T-12
RODFLAG  FC-3940              S-4                         T-3
ROT-TOUV FC-3490              CALLED 15
ROTATE   FC-3720              ENTRY  10
ROTFLAG  FC-3950                            C-29,32       T-30,31
RPCOMP1  FC-3950              ENTRY  49
RPCOMP2  FC-3950              ENTRY  49
RPQFLAG  FC-3350              S-14
RP-TO-R  FC-3330              CALLED 8
RP-TO-R  FC-3350              CALLED 11
RP-TO-R  FC-3510              CALLED 5
RP-TO-R  FC-3520              CALLED 48,49
RP-TO-R  FC-3900              CALLED 3
RP-TO-R  FC-3950              CALLED 42
RPQFLAG  FC-3355              S-23          C-14          T-6,7
RRAUTCHK FC-3210              ENTRY  10
RRCDUCHK FC-3210              ENTRY  12
RRDESEND FC-3600              ENTRY  2
RRGIMON  FC-3210              ENTRY  14
RRLIMCHK FC-3210              CALLED 16
RRNB     FC-3600              ENTRY  53
RRNBSW   FC-3600              S-33          C-23,35       T-40,42
RROUT    FC-3600              ENTRY  48
RROUT    FC-3980              CALLED 9
RRRANGE  FC-3600              ENTRY  62
RRRANGE  FC-3980              CALLED 11
RRRDOT   FC-3600              ENTRY  62
RRRDOT   FC-3980              CALLED 11
RRRSFLAG FC-3600              S-59          C-59
RRSONLY  FC-3210              CALLED 23
RRSONLY  FC-3600              ENTRY  47
RRTONLY  FC-3210              CALLED 23
RRTONLY  FC-3600              ENTRY  47
RRTONLY  FC-3980              CALLED 4
RRTURNON FC-3210              ENTRY  18
RRZEROSB FC-3210              ENTRY  19
RVSW     FC-3360                                          T-23
RVSW     FC-3600                            C-13
RVSW     FC-3720              S-14,15
RVSW     FC-3730                            C-8
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RVSW      FC-3740              S-6
R-TO-RP   FC-3520              CALLED 45,47
R-TO-RP   FC-3910              CALLED 3
R02BOTH   FC-3220              ENTRY  33
R02BOTH   FC-3400              CALLED 3
R02BOTH   FC-3510              CALLED 2
R02BOTH   FC-3600              CALLED 15
R02BOTH   FC-3620              CALLED 2
R02BOTH   FC-3800              CALLED 2
R02BOTH   FC-3810              CALLED 2
R02BOTH   FC-3820              CALLED 2
R02BOTH   FC-3830              CALLED 2
R02BOTH   FC-3900              CALLED 2
R02BOTH   FC-3950              CALLED 2
R04       FC-3280              ENTRY  2
R04FLAG   FC-3280              S-2             C-5             T-2,3
R04FLAG   FC-3600                              C-15
R10,R11   FC-3850              CALLED 9
R10,R11   FC-3930              ENTRY  2
R10FLAG   FC-3930                                              T-11,12,16
R10FLAG   FC-3950              S-3
R10FLAG   FC-3970              S-4
R12RDFLG  FC-3935                                              T-20
R29       FC-3980              ENTRY  2
R31CALL   FC-3780              ENTRY  2
R33       FC-3240              ENTRY  2
R36       FC-3790              ENTRY  3
R51       FC-3510              ENTRY  22
R51P63    FC-3900              CALLED 22
R52       FC-3510              ENTRY  42
R54       FC-3520              CALLED 34
R55       FC-3510              ENTRY  48
R59       FC-3520              ENTRY  25
R60LEM    FC-3400              CALLED 4
R60LEM    FC-3410              CALLED 2
R60LEM    FC-3420              ENTRY  2
R60LEM    FC-3510              CALLED 45
R60LEM    FC-3600              CALLED 26
R60LEM    FC-3800              CALLED 4
R60LEM    FC-3900              CALLED 23
R61FLAG   FC-3600              S-24            C-24            T-27
R62DISP   FC-3410              ENTRY  2
R65LEM    FC-3620              CALLED 3
R77       FC-3280              ENTRY  2
R77END    FC-3280              ENTRY  5
R77FLAG   FC-3280              S-2             C-5             T-6,8
R77FLAG   FC-3600                                              T-65
R77FLAG   FC-3935                                              T-6
SBANDANT  FC-3435              ENTRY  3
SCNDSOL   FC-3720              ENTRY  22
SELECTMU  FC-3720              CALLED 3
SELECTMU  FC-3730              CALLED 1
SELECTMU  FC-3750              CALLED 2
SELECTMU  FC-3760              ENTRY  14
SERVICER  FC-3850              ENTRY  9
SETCOARS  FC-3210              CALLED 54
SETCOARS  FC-3220              ENTRY  7
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SETISSW  FC-3210                ENTRY  31
SETISSW  FC-3220                CALLED 5,17,18,19,20
SETMINDB FC-3600                CALLED 26
SETMINDB FC-3800                CALLED 4
SETMINDB FC-3810                CALLED 2
SETMINDB FC-3950                CALLED 40
SETRRECR FC-3600                CALLED 36
SETRRECR FC-3980                CALLED 2
SETTRKF  FC-3210                CALLED 13,21
SGNAGREE FC-3150                ENTRY  3
SGNAGREE FC-3355                CALLED 3
SGNAGREE FC-3510                CALLED 46
SHIFTR1  FC-3710                CALLED 3,4
SHIFTR1  FC-3760                ENTRY  10
SHORTMP  FC-3950                CALLED 51
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SIGNMPAC FC-3150                ENTRY  14
SIGNMPAC FC-3355                CALLED 4
SIGNMPAC FC-3370                CALLED 9
SIGNMPAC FC-3430                CALLED 7,16,17,18,19
SIGNMPAC FC-3935                CALLED 14
SINE     FC-3320                CALLED 4
SLAP1    FC-3010                ENTRY  2
SLOPESW  FC-3360                S-12,14       C-37          T-19,37
SNUFFBIT FC-3470                                            T-63
SNUFFER  FC-3440                S-40          C-40
SNUFFOUT FC-3440                ENTRY  39
SOLNSW   FC-3360                S-14,20,22,24 C-12,15,25
SPARCSIN FC-3960                ENTRY  37
SPCOS    FC-3160                ENTRY  2
SPCOS    FC-3210                CALLED 58,59
SPCOS    FC-3320                CALLED 7
SPSIN    FC-3160                ENTRY  2
SPSIN    FC-3210                CALLED 57,58
SPSIN    FC-3320                CALLED 6
SPSRCS   FC-3470                ENTRY  80
SRCHOPTN FC-3600                S-49          C-15          T-18,43,49
SR30.1   FC-3770                ENTRY  15
STARTDAP FC-3440                ENTRY  14
STATEFLG FC-3140                              C-14
STATEFLG FC-3350                S-3,5,24      C-3
STATEFLG FC-3355                S-37          C-2,40        T-39
STATEFLG FC-3600                S-20,72,73,80
STATEINT FC-3350                ENTRY  2
STATINT1 FC-3350                ENTRY  2
STCLOK1  FC-3840                ENTRY  12
STCLOK2  FC-3900                CALLED 21
STEERING FC-3820                ENTRY  2
STEERSW  FC-3810                              C-9           T-9
STEERSW  FC-3850                S-12          C-11
STEERSW  FC-3900                                            T-25
STOPRATE FC-3430                ENTRY  14
STOPRATE FC-3600                CALLED 3
STOPRATE FC-3820                CALLED 2
STOPRATE FC-3850                CALLED 13
STOPRATE FC-3900                CALLED 26,46,49
STOPRATE FC-3950                CALLED 35
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STOPRATE FC-3960                  CALLED 22
STRTGYRO FC-3220                  ENTRY  24
SUBDIVDE FC-3470                  CALLED 8,9,10
SUBDVDE  FC-3440                  ENTRY  36
SUPDACAL FC-3060                  ENTRY  4
SUPERSW  FC-3060                  ENTRY  7
SURFDISP FC-3520                  ENTRY  42
SURFFLAG FC-3350                                                T-4,5,10
SURFFLAG FC-3530                                                T-11,21
SURFFLAG FC-3600                                  T-5,18,20,21,36,81
SURFFLAG FC-3610                                                T-4
SURFFLAG FC-3850                                                T-9
SURFFLAG FC-3910                  S-2
SURFFLAG FC-3950                                  C-12
SURFJOB  FC-3530                  ENTRY  27
SURFLINE FC-3520                  ENTRY  34
SVDWN1   FC-3605                  CALLED 3
SWANDISP FC-3840                  S-10
SWANDISP FC-3850                                  C-14
SWCALL   FC-3060                  ENTRY  2
SWRETURN FC-3060                  ENTRY  3
SWRETURN FC-3230                  CALLED 8
S30.1    FC-3700                  ENTRY  4
S32.1F1  FC-3720                  S-13            C-12          T-13
S32.1F2  FC-3720                  S-12            C-19          T-19
S32.1F3A FC-3720                  S-12                          T-19
S32.1F3B FC-3720                  S-19,20
S32/33.X FC-3720                  ENTRY  9
S32/33.1 FC-3720                  ENTRY  6
S32/33.1 FC-3730                  CALLED 4
S33/34.1 FC-3730                  CALLED 3
S33/34.1 FC-3740                  ENTRY  9
S34/35.1 FC-3750                  CALLED 2
S34/35.2 FC-3740                  ENTRY  17
S34/35.2 FC-3750                  CALLED 3
S34/35.5 FC-3750                  CALLED 3
S40.1    FC-3800                  ENTRY  5
S40.1    FC-3810                  CALLED 2
S40.2,3  FC-3800                  ENTRY  7
S40.2,3  FC-3810                  CALLED 2
S41.1    FC-3810                  ENTRY  5
S41.1    FC-3830                  CALLED 5
S52.2    FC-3510                  ENTRY  17
S52.3    FC-3510                  ENTRY  13
TASKOVER FC-3040                  ENTRY  16
TESTLOOP FC-3355                  ENTRY  2
TESTXACT FC-3100                  ENTRY  3
TESTXACT FC-3120                  CALLED 2
TESTXACT FC-3240                  CALLED 2
TESTXACT FC-3280                  CALLED 2
TESTXACT FC-3410                  CALLED 2
TESTXACT FC-3435                  CALLED 2
TESTXACT FC-3440                  CALLED 2
TESTXACT FC-3600                  CALLED 4,7
TESTXACT FC-3770                  CALLED 2
TESTXACT FC-3780                  CALLED 2
TESTXACT FC-3790                  CALLED 2
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TESTXACT FC-3935              CALLED 2
TFFCONIC FC-3370              ENTRY  3
TFFCONMU FC-3370              ENTRY  3
TFFCONMU FC-3770              CALLED 16
TFFRP/RA FC-3370              ENTRY  4
TFFRP/RA FC-3770              CALLED 16
TFFSW    FC3370               S-5           C-5           T-5
TGOCOMP  FC-3970              ENTRY  7
THETCOMP FC-3950              ENTRY  48
THISPREC FC-3770              CALLED 7
THISPREC FC-3790              CALLED 4
THROTUP  FC-3970              ENTRY  16
TICKTEST FC-3770              ENTRY  14
TIMECHK  FC-3430              ENTRY  15
TIMEGMBL FC-3470              CALLED 45
TIMEGMBL FC-3480              ENTRY  13
TIMEGMBL FC-3490              CALLED 14
TIMERAD  FC-3360              ENTRY  24
TIMERAD  FC-3720              CALLED 2
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TIMETHET FC-3720              CALLED 14
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TIMETHET FC-3740              CALLED 7
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TPAGREE  FC-3820              CALLED 3
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TRACKFLG FC-3700              S-2
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TRG*SMNB FC-3935          CALLED 24
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UPFLAG   FC-3050          ENTRY  3
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VARDELAY FC-3930          CALLED 14
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VECPOINT FC-3420          ENTRY  5
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VN1645   FC-3720               ENTRY  7
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V37FLAG  FC-3935                                            T-6
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ZATTEROR FC-3900                      CALLED 27
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Group 23A	S. MacDougall	DL7-205	(15)
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	Gustafson	Muller	
	Higgins	Pu	
	Kachmar	Reber	
	Klumpp	Robertson	
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	Eyles	Moore	
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	Bernikowich	Volante	
	Dunbar	White	
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