

Real Time Computer Complex

Apollo Programming Systems

BOOK: MISSION SYSTEMS

GENERAL

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Mission Systems

Volume 2

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IBM**RTCC APOLLO PROGRAMMING SYSTEMS**

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REENTRY COMPUTATIONS SUBSYSTEM
FUNCTIONAL SPECIFICATIONS FOR THE MISSION SYSTEMS
LUNAR MISSION SIMULATION PROGRAM

INTRODUCTION

The purpose of the Reentry Computations subsystem is to provide trajectory planning and prediction for the reentry and recovery of the Apollo spacecraft through the following three functional capabilities.

- The retrofire planning function provides maneuver and reentry planning for return-from-Earth orbit.
- The spacecraft setting function provides a lookahead study aid for the retrofire or return-to-Earth planning functions.
- The reentry prediction function provides trajectory and impact prediction beginning 90 minutes prior to the reentry threshold time during Reentry phase, in the Low-Speed Mode I/II Launch Abort phase, and in the Mode III Launch Abort phase.

The detailed requirements for these functions have been received from several sources: the TR170 document, NASA internal notes, NASA transmittals, and from interpretations of these requirements through requirements review meetings with NASA Flight Software Branch (FSB). This functional specification presents the design, organization, and function of the programs necessary to satisfy these requirements.

The programs necessary to perform these tasks have been organized under four OS/360 programming tasks which are activated manually by switch settings, manual entry devices (MED's), and push button indicators (PBI's), and are automatically based on events such as trajectory updates and time cycles. The four tasks are as follows:

1. RTSDBMP - retrofire planning
2. RTSSCS - spacecraft setting
3. RTASPECT - reentry trajectory
4. RTSDEAD - reentry display

Following a discussion of each of the above tasks and their associated load modules will be the supporting detailed MED formats. Three orbit/reentry service programs are presented separately in the final section.

Approval	Approval
<i>M. Bunde 7/8/68</i>	<i>G. Kelly 7/8/68</i>

RETROFIRE PLANNING

The retrofire planning function is controlled by a task (RTSDBMP) operating only during the Orbit phase of the mission. This task is initially activated upon completion of an Orbit phase trajectory update by a queue from EMSTRAJ. RTSDBMP initializes the automatic retrofire computations based on primary and contingency targets, which are pre-stored for up to thirty revolutions. It then interfaces with the Mission Plan Table (MPT) to determine a maneuver-free time period in the vicinity of the first guess time. It finally interfaces with the orbit ephemeris and performs the actual computations and iterations. Upon completion of computations, RTSDBMP will activate the reentry display task for updating of the displays. After each primary and contingency computation, a time interrupt is requested so the computations for the next revolution will occur as the current revolution target falls within a time increment of current time. The primary and contingency targets are updated as required by a manual input.

A retrofire maneuver computation for a specified target can be manually initiated at any time in the Orbit phase. This computation requires the same interfaces with the MPT, the orbit ephemeris, and the reentry display task. The manual solution is deleted rather than recomputed on trajectory updates. No periodic recomputation is performed.

The results of the computations are displayed on the Retrofire Digitals, the Retrofire Separation Table, the Retrofire External ΔV /Lambert Parameters, and the Entry Interface Evaluation D/TV displays. The targets for the automatic computations are displayed on the Retrofire Target Table. In addition to these displays, a comprehensive print of each retrofire solution occurs on the on-line output.

The manual inputs defined to change the variables in the retrofire planning are the following:

1. To update the retrofire planning target table

R20, VEH, CODE, AREA, LAT, LONG, REV;

The CODE is P for primary target, C for contingency, and H for an update to the table header.

2. To update separation/shaping maneuvers for Type II

R30, VEH, COLUMN, GETISH, ΔT_{sep} , THRUSTER, ΔV , ΔT , ROLL, PITCH, YAW, ΔT_{ull} , NO. RCS THRUSTERS, GIMBAL;

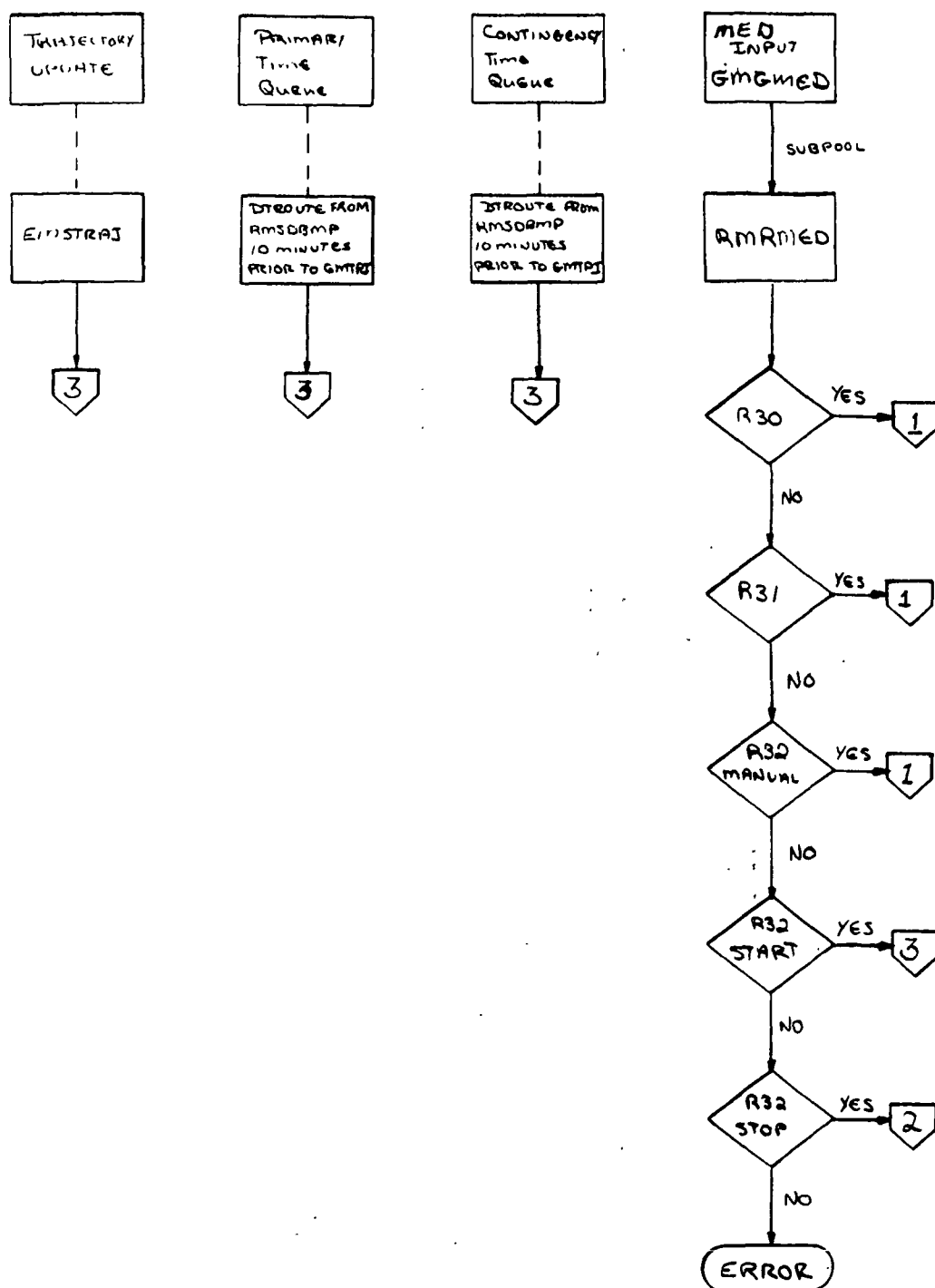


Figure 1. Retrofire Planning Functional Flow

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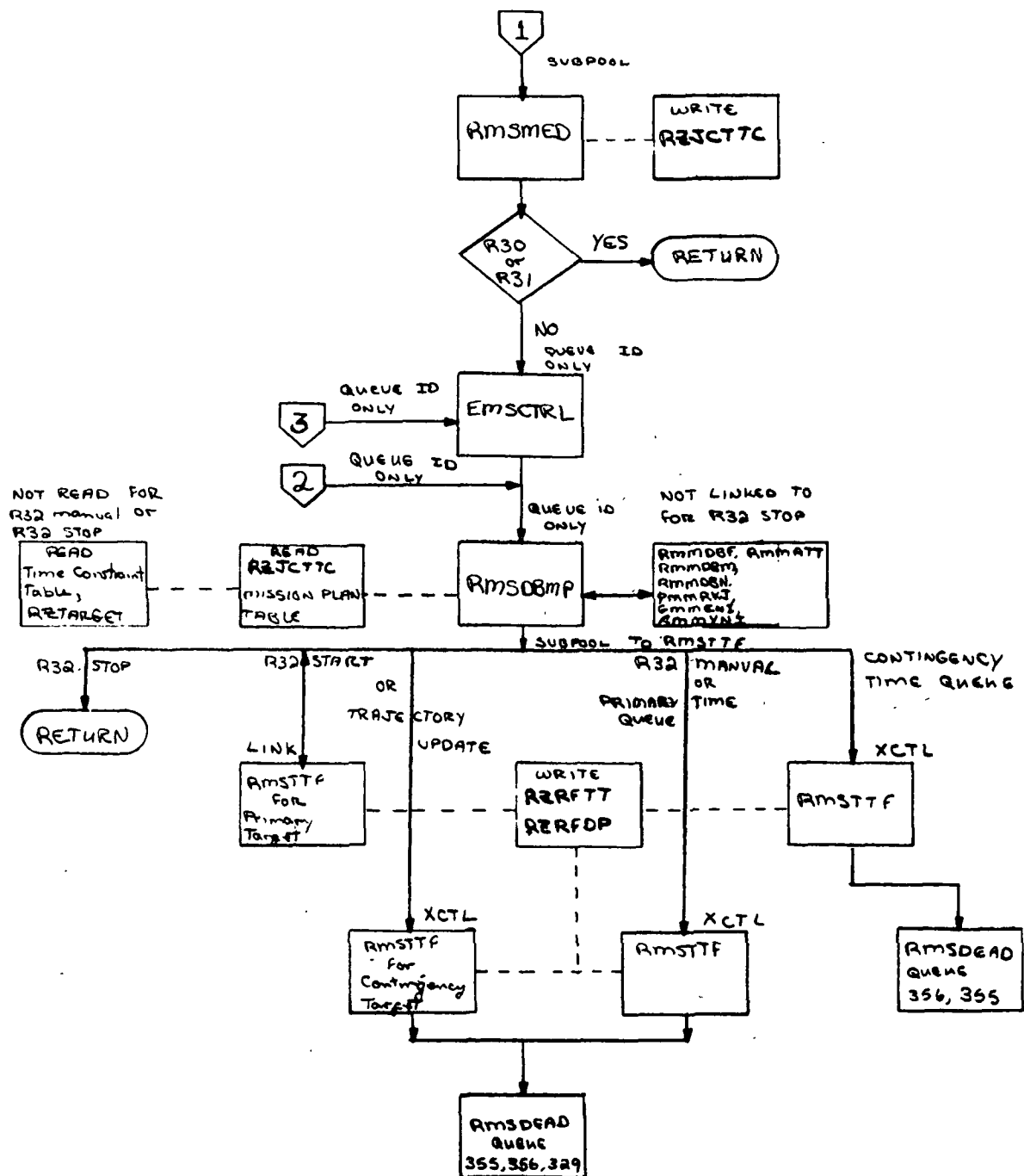


Figure 1. Retrofire Planning Functional Flow

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3. To update retrofire maneuver and entry variables

R31, VEH, COLUMN, THRUSTER, MODE, ΔV , ΔT , ROLL, PITCH, YAW, ΔT_{ull} , NO. RCS THRUSTERS, REFSMAT ID, GIMBAL ID, INITIAL BANK ANGLE, G-LEVEL, FINAL BANK ANGLE;

4. To manually request a retrofire plan

R32, VEH, CODE, REV, REV-ZONE, LAT, LONG, FIRST GUESS TIME, MISS DISTANCE;

The CODE in the R32 MED is used to START or STOP the automatic computations as well as to specify the type of retrofire plan when the R32 is being used to request a manual solution.

Refer to the detailed MED descriptions of this functional specification for checking optional/limited or missing item logic.

Retrofire Planning Control Module - RMSDBMP

RMSDBMP is the supervisor control program for the Deorbit Computations Task, RTSDBMP, from an Earth orbit. Deorbit maneuvers are computed as a result of trajectory updates, automatic time queues and input R32 MED's. Processing information is obtained from the R30, R31, and R32 MED's.

RMSDBMP calls the retrofire boundary computations program, RMMDBF, for: maneuver time limits and anchor time for generation of the two-hour "working" ephemeris, and a first-guess GMTI if one is not input. The retrofire maneuvers computation program, RMMDBM, is then called for the maneuver parameters that are used to integrate a trajectory to impact. RMSDBMP controls a convergence loop between the integrators and RMMDBN until convergence on the target is achieved, or until an error condition is encountered. The final deorbit computation data is passed to the retrofire output control program, RMSTTF, for conversion and data table storage.

Current design decisions and limitations are (1) a four-hour maximum free-flight integration from command/service module (CM/SM) separation to EI, (2) a 90-minute maximum reentry integration from EI to impact, (3) no maneuver or fraction of a maneuver being executed below EI, (4) computations being terminated if available fuel is exceeded, and (5) no more than three targets being attempted on automatic time queues, trajectory updates and R32 starts.

Retrofire Input Control - RMSMED

RMSMED receives a subpool containing time-to-fire parameters from the MED decoder and stores the data in the data table RZJCTTC. If the MED input is an R32 manual, a queue is issued to RMSDBMP via EMSCTRL causing a manual target update.

Retrofire Output Control - RMSTTF

RMSTTF receives subpools of deorbit computation data from RMSDBMP. It then formats data for the data tables RZRFPD and RZRFTT and a subpool for RMGTTF, the on-line print routine. The formatting includes the conversion to the proper units. RMSTTF uses the following modules.

- PIEXDV to compute the biased and unbiased LVLH external ΔV 's for the primary and manual targets. The input is the unit thrust vector multiplied by the total ΔV and the rev. vector at GMTI of retrofire.
- PIFAAP to compute the height of apogee and perigee at retrofire for the primary and manual target. The input is the burnout vector of retrofire.
- PIFAAP to compute the height of vacuum perigee at separation/shaping. The input is the burnout vector of separation/shaping.
- EMMDYNEL to compute the true anomaly of separation/shaping. The input is the vector at GMTI of separation/shaping.
- EMMDYNEL to compute the true anomaly of retrofire and the height above the oblate Earth at retrofire. The input is the vector at GMTI of retrofire.

Retrofire Planning Boundary Computation - RMMDBF

RMMDBF computes the boundary times within which time-to-fire iteration is done, assuming that a sufficient non-hyperbolic ephemeris is available. If the GMTI is input, time right (TR) will be 20 minutes ahead of GMTI, and time left (TL) will be 1.9 hours (114 minutes) before TR. If the GMTI is not input, an iteration will be performed to determine the time of the target longitude crossing to .001 radian (.06 degrees or 3.5 miles), which is TR. GMTI is set 20 minutes prior to TR with a Service Propulsion System (SPS) thruster; 30 minutes prior with a Reaction Control System (RCS) thruster. TL is 1.9 hours (114 minutes) prior to TR.

Tests for various constraints are then implemented. The interval (TL, TR) must be within the ephemeris, or adjustments will be made. Mission Plan Table maneuvers may cause adjustments to TR and/or error indications if they are within three

minutes of GMTI. For automatic time-to-fire, an adjustment to TR may be made if it is within 10 minutes of present time.

In the case of a Type II separation maneuver, the propulsion initiate (TI) will be a ΔT_{SEP} (manually input) before GMTI for a maximum ΔT_{SEP} equal to 84 minutes.

TI is also constrained by Mission Plan Table maneuvers and present time. For a Type II shaping maneuver, the TI is input and must only be in the ephemeris and before GMTI.

The final TL, TR interval must be at least 18 minutes.

Retrofire Maneuvers Computations - RMMDBM

RMMDBM is a mathematical program that computes a retrofire plan that would give a suitable reentry through the Earth's atmosphere and impact at a specified target. The retrofire plan can be either a single maneuver or a series of two maneuvers. To do this, RMMDBM uses impulsive approximations for maneuvers, Keplerian or two-body free-flight motion to 400,000 ft., and a curvefit approximation of the trajectory from 400,000 ft. to the Earth's surface. RMMDBM is subject to external constraints on both the maneuver and the entry profile. RMMDBM has some internal restrictions:

- The trajectory must not become hyperbolic.
- A first guess at GETI is needed in some instances when the orbit is highly elliptical, and the apogee is quite high.
- Other mission maneuvers should not be within a five minute time span of the expected time of the retrofire maneuver.
- There must be at least five minutes separating the two maneuvers of a two maneuver deorbit plan.

Retrofire Convergence - RMMDBN

On a bank-then-reverse-bank entry into the Earth's atmosphere, RMMDBN computes an approximate time to reverse the bank to land near the specified target. On all entries, RMMDBN compares the integrated impact point to the specified target. If the miss distance exceeds three and four-tenths nautical miles in either latitude or longitude, RMMDBN computes corrections to the maneuver parameters. Control is then given to RMSDBMP to call the integrators for a new impact point. This process is repeated until convergence or until 10 iterations have taken place. On entries where the velocity and flight-path angle at 400,000 ft. have to be within

a certain tolerance of a NASA set or target curve, RMMDBN checks the integrated 400,000 ft. velocity and flight-path angle. Deviations above the tolerance limit are corrected by computing changes to the maneuver parameters. RMMDBN has no program limitations other than those described for RMMDEM.

The miss distance is compared against a manually input value. If this miss distance in either latitude or longitude is not exceeded, then this solution is accepted based on the secondary convergence criterion.

Thrust Direction and Body Attitude Routine - RMMATT

RMMATT computes the unit thrust direction and the CSM body axis given either of the two following inputs: (1) a yaw, pitch, and roll sequence to be measured from the local vertical, local horizontal axes and defining the thrust direction (defining the X-body direction for RCS thrusting), and (2) a pitch, yaw, and roll sequence to be measured from a corresponding inertial measurement unit (IMU) alignment (REFSMMAT) and defining the body axis in inertial space. Additional computations done by RMMATT include: a computation of the inner middle, and outer gimbal sequence if input from (1) is used; a computation of a yaw, pitch, and roll sequence relating the body axis to the local vertical, local horizontal if input from (2) is used; and a computation of the desired alignment for the retrofire maneuver. RMMATT outputs engine trim angles if the thruster is SPS. The engine trim angles are either computed by PIMGBL or are special system parameters dependent upon an input indicator.

Retrofire On-line Printing - RMGTTF

RMGTTF receives the results of a successful retrofire plan from RMSTTF, formats the information, and does an RTPUT to the on-line printer. See Figure 2.

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XX/XX/XX/XX.XX *** (RMGTTF) (CONTINGENCY) TIME-TO-FIRE PARAMETERS TYPE (A) COMPUTATION
(SHAPING MANEUVER) MANUAL
(-SEPARATION MNVR) PARAMETERS VEH=CSM AREA=XXX.XX WT=XXXXXX.XX SCS MNVR GETI=XXX/XX/XX.XX THR=+R2
(DT) CONSTRAINT=DV DV=XXXXXX.XX DT=XXX.XX DT ULL=XX.XX X QUADS SP5
INPUT ATT-ROLL=+XXX.XX PITCH=+XXX.XX YAW=+XXX.XX TRIM ANGLE IND(C) +R4
LVLH BODY-ROLL=+XXX.XX PITCH=+XXX.XX YAW=+XXX.XX TRIM ANGLES--PITCH=+XXX.XX YAW=+XXX.XX
IMU-----ROLL=+XXX.XX PITCH=+XXX.XX YAW=+XXX.XX DT SEP=XXX/XX/XX.XX TRUE ANOMALY AT GETI (SEP)=XXX.X
--RETRO MANEUVER PARAMETERS VEH=CSM AREA=XXX.XX WT=XXXXXX.XX (XDV) MNVR GETI=XXX/XX/XX.XX THR=+R2
(DT) CONSTRAINT=DV DV=XXXXXX.XX DT=XXX.XX DT ULL=XX.XX X QUADS POSTBURN WT=XXXXXX.XX
INPUT ATT-ROLL=+XXX.XX PITCH=+XXX.XX YAW=+XXX.XX TRIM ANGLE IND(C)
LVLH BODY-ROLL=+XXX.XX PITCH=+XXX.XX YAW=+XXX.XX TRIM ANGLES--PITCH=+XXX.XX YAW=+XXX.XX
IMU-----ROLL=+XXX.XX PITCH=+XXX.XX YAW=+XXX.XX HT AT RETRO=XXXXXX.X TRUE ANOMALY AT GETI (RET)=XXX.X
REFSMAT ID=XXXXXX XX=+X.XXXXXXXX XY=+X.XXXXXXXX XZ=+X.XXXXXXXX
YX=+X.XXXXXXXX YY=+X.XXXXXXXX YZ=+X.XXXXXXXX
ZX=+X.XXXXXXXX ZY=+X.XXXXXXXX ZZ=+X.XXXXXXXX
LVLH XDV (TRUE) VGX=+XXXXXX.XX VGY=+XXXXXX.XX VGZ=+XXXXXX.XX
VECTOR AT GETI (RETRO) X=+X.XXXXXXXX Y=+X.XXXXXXXX Z=+X.XXXXXXXX XV=+X.XXXXXXXX YV=+X.XXXXXXXX ZV=+X.XXXXXXXX
ENTRY PARAMETERS CM/SM SEP GET=XXX/XX/XX.XX CM AREA=XXX.XX CM WT=XXXXXX.XX KFAC=X.XX
ENTRY PROFILE=( ) INITIAL BANK=(+XXX.XX) (N/A) G-LEVEL=X.XX FINAL-BANK=RL055 BAL GETRB=XXX/XX/XX.XX
TARGET LAT=XX/XX/XXS LONG=XXX/XX/XXW E REV-ZONE=XXXXXX
IMPACT LAT=XX/XX/XXS LONG=XXX/XX/XXW E GETI=XXX/XX/XX.XX VEI=XXXXXX.XX GEI=+XX.XX
MAX IP LAT=XX/XX/XXS LONG=XXX/XX/XXW E GET=XXX/XX/XX.XX MAX G=XX.XX GET OF MAX G=XXX/XX/XX.XX
MIN IP LAT=XX/XX/XXS LONG=XXX/XX/XXW E GET=XXX/XX/XX.XX

```

Figure 2. Retrofire Planning On-Line Print

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MED Format Table

MED Code: R20 Task: RTSDEAD
 Purpose: Update miscellaneous displays EP: RMSDEAD
 Load Module: RMRMED QNAME: NA
 QUEID: 10

Desc.	Item	1	2	3	4	5	6
Item Name		Veh	Update code	Area	Targ/Recovery Lat.	Targ/Recovery Long.	(Beginning) Rev
Input Format		EBCDIC	EBCDIC	EBCDIC	LAT	LONG	FXP
Input Units		Note 1	EBCDIC Note 2	EBCDIC	DD:MM:SS ^N _S	DDD:MM:SS ^E _W	integer
Program Units		Note 1	Integer Note 2	EBCDIC	rad)	rad	integer
Scale Factor		NA	NA	NA	MCCRPD	MCCRPD	NA
Checking Option		Exact.	Exact	None	-90 ≤ x ≤ 90	0 ≤ x ≤ 360	MINMAX 1-999
Missing Item Option		Error	Error	Insert blanks Note 3	Insert - 750 Note 3	Insert - 750 Notes 3, 4	Insert 0 Note 5
Item Destination		RTSDEAD via SUBPOOL 1					

Programmer:

Initial Logic:

Final Logic:

Illegal Phases: Condition for Launch, Launch

Notes: 1. CSM 2. P = Prim. Targ. Table = 1

LFM C = Cont. Targ. Table = 2

H = Targ. Table header = 3

Z = Recovery zones = 4

T = Recovery Targ. selection = 5

A = Recovery ascending node = 6

G = Groundtrack Digital = 7

3. Error if item 2 = P, C, Z1-Z6.

4. Error if item 2 = T, G

5. Error except when item 2 = Z1-Z6

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Z1-Z6 = Recov. zones 1-6, respectively = 8-13



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MED Format Table

MED Code: K20, cont'd
 Purpose:
 Load Module:
 Task:
 EP:
 QNAME:
 QUEID:

Desc.	Item	7							
Item Name		Ending Rev							
Input Format		FXP							
Input Units		integer							
Program Units		integer							
Scale Factor		NA							
Checking Option		MINMAX 1-999							
Missing Item Option		Insert 0 Note 6							
Item Destination		RTSDEAD							A

Programmer:
 Initial Logic:
 Final Logic:
 Illegal Phases:
 Notes: 6.. Error if item 2 = A or Z.

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MED Format Table

MED Code: R30

Task: RTSDBMP

Purpose: Save separation/shaping maneuver

EP: RMSMED

QNAME: NA

Load Module: RMRMED

QUEID: 2

Desc.	Item	1	2	3	4	5	6
Item Name		Veh	Column indicator	GETISH	ΔT SEP	Thruster	Δv
Input Format		EBCDIC	EBCDIC	HHH:MM:SS. TH Hours	HHH:MM:SS. TH	EBCDIC	FLP
Input Units		Note 1	EBCDIC Note 2	GET	hours	EBCDIC Note 5	ft/sec.
Program Units		Note 1	Integer Note 2	GMT	hours	integer Note 5	Er/hr.
Scale Factor		NA	NA	NA	NA	NA	MCCEHF
Checking Option		Exact	Exact	MIN = 1 sec	MIN = 5 min.	Exact I	MIN = 0
Missing Item Option		Error	Insert 'PCM'	Insert 0 Notes 3, 4	Insert Svsp 10 min.	Error	Insert '0' Note 6
Item Destination		RTSDBMP	via SUBPOOL				

Programmer:

Initial Logic:

Final Logic:

Illegal Phases: All except Orbit, Prelaunch II

Notes: 1. CSM 2. P = 1 3. Input accepted only if item 2 = 'M'

5. S = SPS = 33

C1 = RCS + 2 = 1

C2 = RCS + 4 = 2

C3 = RCS - 2 = 3

C4 = RCS - 4 = 4

6. One of Δv , ΔT but not both must be input.
 $\Delta v = 0$ or $\Delta T = 0$ allowed only when GETISH is input.

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PC = 2

PM = 3

C = 4

CM = 5

M = 6

PCM = 7



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MED Format Table

MED Code: R30, cont'd
Purpose:

Task:
EP:
QNAME:
QUEID:

Load Module:

Desc.	Item	7	8	9	10	11	12
Item Name		ΔT	ROLL	PITCH	YAW	$\Delta T_{\text{tullage}}$	No. of RCS thrusters
Input Format		FLP	FLP	FLP	FLP	FLP	FXP
Input Units		secs.	deg.	deg.	deg.	secs.	Integer Note 7
Program Units		hrs.	rad	rad	rad	hrs.	Integer Note 7
Scale Factor		MCCHPS	MCCRPD	MCCRPD	MCCRPD	MCCHPS	NA
Checking Option		MIN = 0	$-180 \leq x \leq 360$	$-90 \leq x \leq 90$	$-180 \leq x \leq 360$	MIN = 0	NA
Missing Item Option		Insert 0 Note 6	Error	Error	Error	Insert sysp 15 secs.	Insert 4
Item Destination		RTSDBMP	via SUBPOOL 1				

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 7. 2 or 4 only



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MED Format Table

MED Code: R30, cont'd.

Purpose:

 Task:
 EP:
 QNAME:
 QUEID:

Load Module:

Desc.	Item	13							
Item Name		GIMBAL INDICATOR							
Input Format		EBCDIC							
Input Units		EBCDIC Note 8							
Program Units		Integer Note 8							
Scale Factor		NA							
Checking Option		Exact							
Missing Item Option		INSERT 'C'							
Item Destination									

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 8. S = Insert Sysparam = 1

C = Compute = -1

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MED Format Table

MED Code: R31 Task: RTSDBMP
 Purpose: Save maneuver and entry parameters EP: RMSMED
 for retrofire QNAME: NA
 Load Module: RMRMED QUEID: 1

Desc.	Item	1	2	3	4	5	6
Item Name		Veh	Column indicator	Thruster	Mode	ΔV	ΔT
Input Format		EBCDIC	EBCDIC	EBCDIC	EBCDIC	FLP	FLP
Input Units		Note 1	EBCDIC Note 2	EBCDIC Note 3	EBCDIC Note 4	ft./sec.	secs.
Program Units		Note 1	Integer Note 2	Integer Note 3	Integer Note 4	Er/hr.	hrs.
Scale Factor		NA	NA	NA	NA	MCCEHF	MCCHPS
Checking Option		Exact T	Exact T	Exact T	Exact T	MIN = .01 FPS	MIN = .01 secs.
Missing Item Option		Error R	Error	Error	Error	Insert 0 Note 5	Insert 0 Note 5
Item Destination		RTSDBMP via SUBPOOL 1					

Programmer:

Initial Logic:

Final Logic:

Illegal Phases: All except Orbit, Prelaunch II,

Notes: 1. CSM *2. P1 = 1 P1GB = 7 C1G = 13 3. S = SPS = 33
 P2 = 2 P2GB = 8 C2G = 14 C1 = RCS + 2 = 1
 P1B = 3 C1 = 9 C1GB = 15 C2 = RCS + 4 = 2
 P2B = 4 C2 = 10 C2GB = 16 C3 = RCS - 2 = 3
 P1G = 5 C1B = 11 M = 17 C4 = RCS - 4 = 4
 P2G = 6 C2B = 12

*P = Primary

C = Contingency

M = Manual

1 = Without SEP/SHAP

2 = With SEP/SHAP

B = Ballistic

G = G-level

MED Format Table

MED Code: R31, cont'd
Purpose:

Task:
EP:
QNAME:
QUEID:

Load Module:

Desc.	Item	7	8	9	10	11	12
Item Name		ROLL	PITCH	YAW	ΔT ullage	No. of RCS thrusters	REFSMMAT
Input Format		FLP	FLP	FLP	FLP	FXP	EBCDIC
Input Units		deg.	deg;	deg	secs.	Integer Note 6	EBCDIC Note 7
Program Units		rad.	rad.	rad.	hrs.	integer Note 6	integer Note 7
Scale Factor		MCCRPD	MCCRPD	MCCRPD	MCCHPS	NA	NA
Checking Option		$-180 \leq x \leq 360$	$-90 \leq x \leq 90$	$-180 \leq x \leq 360$	MIN = 0	NA	EXACT
Missing Item Option		Error	Error	Error	Insert sysp 15 secs.	Insert 4	Insert 'CUR'
Item Destination		RTSDBMP via SUBPOOL 1					

Programmer:
Initial Logic:
Final Logic:
Illegal Phases:

- Notes: 4. I = Inertial = 1 6. 2, 4 only 7. CUR = 1 DMT = 6
EP = Guided = 4 PCR = 2 DOD = 7
5. $\Delta V, \Delta T$ cannot TLM = 3 LCV = 8
both be input. OST = 4 DES = 9
With RCS Thrusters, one of $\Delta V, \Delta T$ must be input.
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MED Format Table

Task:
EP:
QNAME:
QUEID:

MED Code: R31, cont'd
Purpose:

Load Module:

Desc.	Item	13	14	15	16	
Item Name		Gimbal Indicator	Initial bank angle	Prescribed G-level	Final bank angle	
Input Format		EBCDIC	FLP	FLP	FLP	
Input Units		EBCDIC Note 8	deg.	G-units	deg.	
Program Units		integer Note 8	rad.	Er/hr. 2	rad.	
Scale Factor		NA	MCCRPD	MCEACG	MCCRPD	
Checking Option		Exact	$-360 \leq x \leq 360$	MIN = 0	$-90 \leq x \leq 90$	
Missing Item Option		Insert 'C'	Insert sysp 0°	Insert sysp .2G	Insert sysp: 55°	
Item Destination		RTSDBMP via SUBPOOL 1				

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 8. S = Insert Sysparm = 1

C = Compute = -1



MED Format Table

MED Code: R32

Purpose: Planning trigger

Load Module: RMRMED

Task: See final logic

EP:

QNAME:

QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name		Veh	Code	Rev	Rev-Zone	Lat of targ.	Long of targ.
Input Format		EBCDIC	EBCDIC	FXP	EBCDIC	LAT.	LONG.
Input Units		Note 1	EBCDIC Note 2	integer	EBCDIC	DD:MM:SS ^N	DDD:MM:SS ^N
Program Units		Note 1	Integer Note 2	integer	EBCDIC	rad.	rad.
Scale Factor		NA	NA	NA	NA	MCCRPD	MCCRPD
Checking Option		Exact	Exact	MINMAX 1-999	None	MINMAX -90 ≤ x ≤ 90	MINMAX 0 ≤ x ≤ 360
Missing Item Option		Error	Error	Note 4	Note 4	Insert -750	Note 4
Item Destination		RTSDBMP/RTASPECT					
		RTSDBMP via PARAMETER LIST					

Programmer:

Initial Logic:

Final Logic: RTATTACH RTSDBMP on 'STOP', 'M1-M2GB'; RTATTACH ETMSCTRL otherwise

Illegal Phases: All except Orbit, Prelaunch II

Notes: 1. CSM 2. START = 1 = QID 10
STOP = 2 = QID 2

M1, M2, M1B, M2B, M1G, M2G, M1GB, M2GB = 1 - 8 = QID 6

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MED Format Table

MED Code: R32,cont'd

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	7	8				
Item Name		First Guess	Miss Distance				
Input Format		HOURS	FLP				
Input Units		GET	NM				
Program Units		GMT	Er				
Scale Factor		NA	NA				
Checking Option		MIN = 0	MINMAX 0 - 1500 NM				
Missing Item Option		Insert = 0	Insert 25 NM				
Item Destination		RTSDBMP	via PARAMETER LIST				▲

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 3. ΔV , ΔT may not both be input

4. Error if item 2 = M-TYPE

SPACECRAFT SETTING

The spacecraft setting function is a lookahead study aid only for retrofire and return-to-Earth planning. A spacecraft setting data table will be defined that will be capable of containing a single reentry maneuver definition and a complete set of reentry constraints, which will be separate from the mission committed reentry constraints.

A spacecraft setting can be initialized by a transfer of a reentry plan from either retrofire planning or return-to-Earth planning primary or manual solutions. The capability will also exist to manually input a spacecraft setting. The maneuver definition may be a ΔV , ΔT or Lambert steering parameters. Weight, area, and configuration will remain unchanged on a direct transfer by return-to-Earth or retrofire planning. Current MPT values will be used at the input maneuver time in the case of a manual input. On manual input of the Lambert steering quantities, the total ΔV , ΔT and IMU attitudes will be displayed on the proper spacecraft setting displays. A spacecraft setting will not change automatically with a main ephemeris update.

Since the spacecraft setting will be displayed on the retrofire digitals for low-speed cases and on the high-speed entry digitals for high-speed cases, the manual input will specifically designate the type being input. The ephemeris that can subsequently be generated by a manual input requires a threshold time, which will be a required item on the manual input. The spacecraft setting maneuver and reentry constraints will be printed on line in a format analogous to the reentry trajectory output. All reentry displays will be applicable except for present position and time updates.

The manual inputs to change the spacecraft setting are the following:

1. To direct transfer of a return-to-Earth (high speed) or time-to-fire (low speed) solution to spacecraft setting

R65, VEH, SOURCE, COLUMN;

- For low speed
VEH = CSM, SOURCE = T
COLUMN = P = primary, M = manual
- For high speed
VEH = CSM, LM, SOURCE = R
COLUMN = P = primary, M = manual

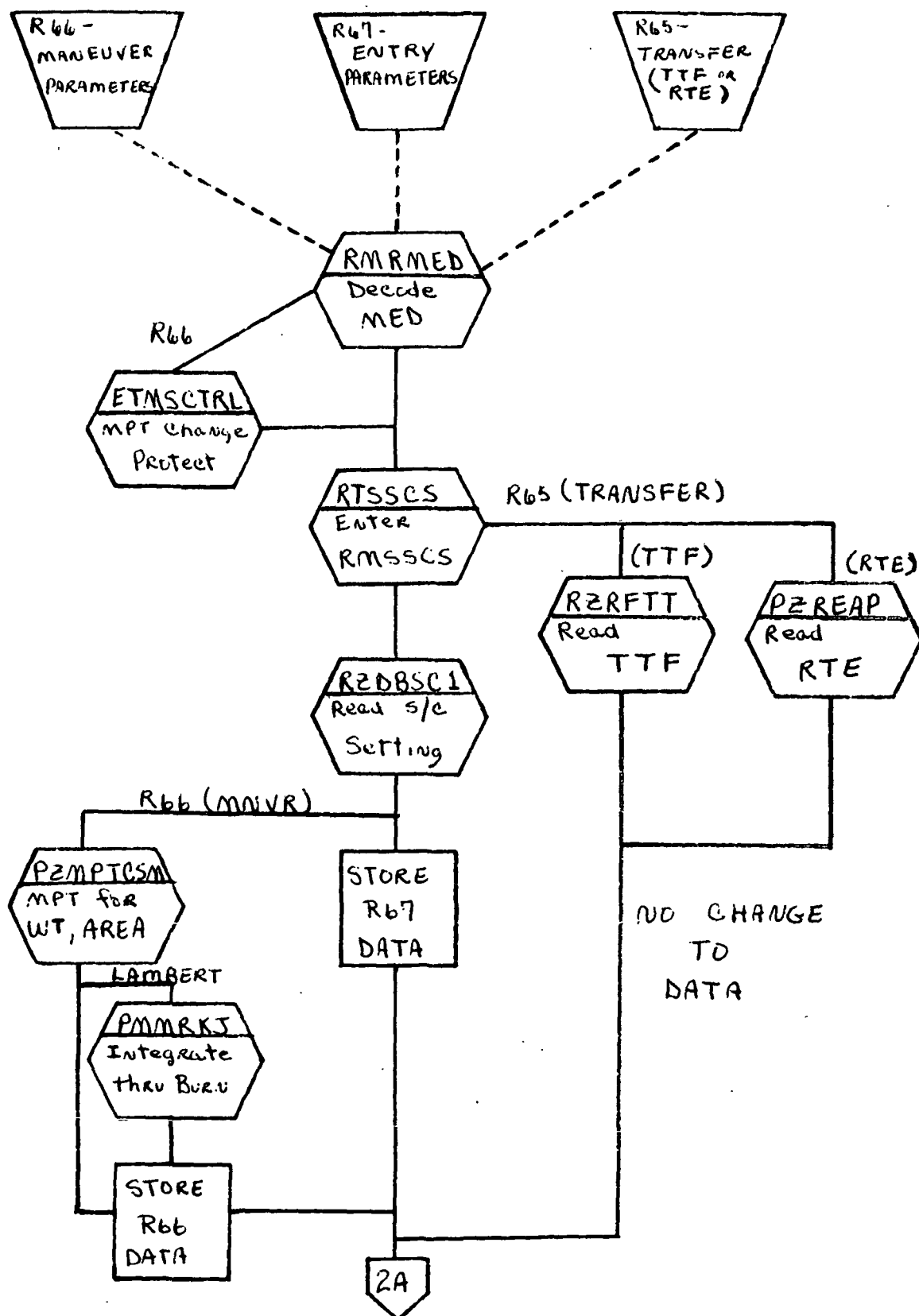


Figure 3. Spacecraft Setting Functional Flow

(Sheet 1 of 2)

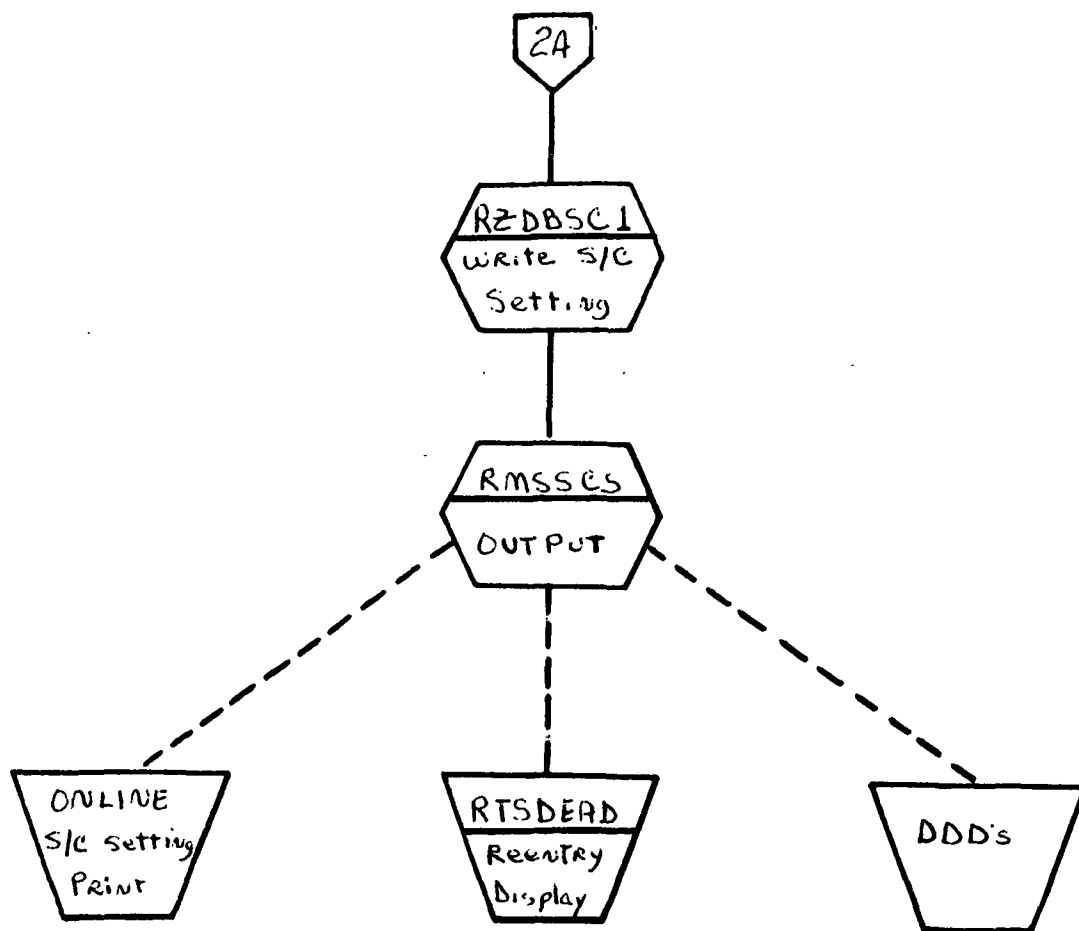


Figure 3. Spacecraft Setting Functional Flow

(Sheet 2 of 2)

2. To manually change maneuver parameters in spacecraft setting

R40, /P1, ΔV , ΔT /;

P1 = Indicator of SCS maneuver

ΔV or ΔT (not both) = Value to be used in the maneuver definition

R40, /P5, X, Y, Z, ΔT_{OF} , C/;

P5 = Indicator of Lambert maneuver (high speed only)

X, Y, Z = Lambert target vector

ΔT_{OF} = Lambert time of transfer

C = Lambert cross product steering constant

The R40 MED must be input prior to the following:

R66, VEH, SOURCE, GETI, THRUSTER, MODE, IND, ROLL, PITCH,
YAW, ΔT_{ULL} , NO. OF RCS THRUSTERS, ΔT OF 10% DPS

THRUST LEVEL, REFSMAT ID, CONFIGURATION,
DOCKING ANGLE, GIMBAL IND, TYPE;

- For low speed

VEH = CSM, SOURCE = T

GETI = Time of main engine on

THRUSTER = SPS, \pm RCS

MODE = I (inertial or SCS), EP (internal ΔV)

IND = 1

ROLL, PITCH, YAW are IMU ECI attitudes

ΔT_{ULL} = ΔT of ullage

Number of RCS thrusters = 2, 4

Configuration = U(CSM)

GIMBAL Indicator = C(compute), S(system parameter)

Type = 1, 2

- For high speed

VEH = CSM, LM, SOURCE = R

THRUSTER = SPS, \pm RCS, DPS

MODE = I (inertial or SCS), EP (external ΔV), L (Lambert)

IND = 1 = SCS or XDV, 5 = Lambert

Configuration = U (CSM), D (CSM-LM), A (CSM-LM ascent stage only)

All others are the same as for low speed

3. To manually change entry parameters in spacecraft setting

R67, VEH, SOURCE, ENTRY, LAT, LONG, INITIAL BANK ANGLE, G-LEVEL, FINAL BANK ANGLE, TIME TO REVERSE BANK, REV, REV-ZONE, CONSTANT G, LONG FOR CONSTANT G, ROLL DIRECTION;

- For low speed
VEH = CSM, SOURCE = T
ENTRY = BAL (ballistic), MAX (max. lift), LGN (G&N), BRB (bank reverse bank), BNK (constant bank), GBL (initial bank to xG's then ballistic) GMX (initial B to xG's then maximum lift), GRB (initial B to xG's then reverse bank), GBK (initial B to xG's then constant bank)
- For high speed
VEH = CSM, LM , SOURCE = R
ENTRY (primary only) = HB1 (constant G throughout entry)
HB2 (lift down to xG's then ballistic), HB3 (ballistic),
HB4 (lift up to xG's then ballistic), HB5 (max. lift)

ENTRY (primary with backup) = HGN1, HGN2, HGN3, HGN4, HGN5
Primary is G&N where 1 to 5 signify the HB1 to HB5 modes, respectively, described above, as backups.

Notes:

1. The last three entry parameters are for high-speed constant-G entry only (HB1 or HGN1).
2. The initial bank angle and G-level are non G&N. That is, these values are applicable to modes, primary or backup, that require the values other than G&N, which uses system parameter values.

Spacecraft Setting Control - RMSSCS

RMSSCS processes manual entries for the planned reentry as well as the direct transfer of planned Return-to-Earth or time-to-fire solutions for reentry to the spacecraft setting table RZDBSC1. The lookahead data is displayed and printed on line preceding deorbit trajectory generation. The following decisions are then made.

1. Transferred data will go unchanged to spacecraft setting.
2. The burn or entry portion of the solution may be changed independently by manual input.

3. All coordinate systems (matrices) and components (vectors) will be Earth-centered inertial (ECI).
4. External ΔV components will not be input manually to spacecraft setting; however, a total ΔV may be input while specifying an external ΔV type burn, which would cause a subsequent computation of the three components, the resultant being treated as an external ΔV maneuver.
5. Only one source, return-to-Earth or time-to-fire, will be processing at one time; hence, spacecraft setting data will be one or the other only.
6. ΔT of the burn will be displayed instead of GMTL (landing time) on the Retro High-Speed Entry Digitals display.
7. Spacecraft setting will not update the External Delta V Lambert display.
8. On manual input of the Lambert steering quantities, after integration, total ΔV , ΔT and IMU attitudes will be displayed.
9. There is no automatic spacecraft setting.
10. There is only one spacecraft setting table servicing return-to-Earth and time-to-fire in the primary and manual columns.
11. Entry profile (EP) for high speed has been defined.
 - HGN - G&N entry
 - HB1 - Constant G-level throughout entry
 - HB2 - Lift vector down to xG's then roll
 - HB3 - Ballistic throughout entry
 - HB4 - Lift vector up to xG's then roll
 - HB5 - Lift vector up throughout entry
12. The third character of the "THR" code designating the configuration has been defined.
 - A - CSM docked with ascent stage of LM only
 - D - CSM docked with both stages of the LM
 - U - CSM undocked
13. The backup entry profile may be changed, as other entry parameters, by an entry MED (R67).
14. All backup entry profiles (HB1 through HB5) will be available for use. HB1 will include both a direct input of the constant G or an iteration to a constant G that will impact an input target longitude.

S/C SETTING ONLINE PRINT

```

XX/XX/XX/XX.XX **b** RMSCS- CURRENT S/C SETTING...XXX TYPE X COMPUTATION TA=XXX/XX/XX.XX
BURN PARAMETERS ***VEH=XXX AREA=XXX.XX WT=XXXXX.XX XXX MNVR GETI=XXX/XXX/XX.XX THR=XXX
CONSTRAINT=XXXX DV=XXXXX.XX DT=XXX.XX DTULL=XX.XX X QUADS
LVLH BODY-ROLL =+XXX.XX PITCH=+XXX.XX YAW=+XXX.XX TRIM ANGLE IND X
IMU-----ROLL =+XXX.XX PITCH=+XXX.XX YAW=+XXX.XX
REFSMAT ID=XXXXXX XX=+X.XXXXXXXX XY=+X.XXXXXXXX XZ=+X.XXXXXXXX
YX=+X.XXXXXXXX YZ=+X.XXXXXXXX
ZX=+X.XXXXXXXX ZY=+X.XXXXXXXX ZZ=+X.XXXXXXXX
LAMBERT X=+XXXXXXXXXXXXX.X Y=+XXXXXXXXXXXXX.X Z=+XXXXXXXXXXXXX.X DT OF=XXX/XX/XX C=+X.XX
VECTOR AT GETI (RETRO) X=+X.XXXXXXXX Y=+X.XXXXXXXX Z=+X.XXXXXXXX
XV=+X.XXXXXXXX YV=+X.XXXXXXXX ZV=+X.XXXXXXXX GMTI=XXX/XX/XX.XX
ENTRY PARAMETERS*** KFAC=X.XX
ENTRY PROFILE=XXX INITIAL BANK=+XXX.XX X.XXG'S FINAL BANK=+XXX.XX GETRB=XXX/XX/XX.XX
TARGET LAT=XX/XX/XXS LONG=XXX/XX/XXW LANDING AREA=XXXXXX

```

Figure 4. Spacecraft Setting On-Line Print



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MED Format Table

MED Code: R40

Purpose: Specify spacecraft setting burn params

Task: NA

EP: NA

QNAME: NA

QUEID: NA

Load Module: RMRMED

P1

P5

Desc.	Item	1	P1 ₁	P1 ₂	P5 ₁	P5 ₂	P5 ₃
Item Name		Burn Params	ΔV	ΔT	X	Y	Z
Input Format		REMOTE	FLP	FLP	FLP	FLP	FLP
Input Units		See P1, P5	ft./sec.	secs.	ft.	ft.	ft.
Program Units		See P1, P5	Er/hr.	hrs.	Er	Er	Er
Scale Factor		See P1, P5	MCCEHF	MCCHPS	MCCERF	MCCERF	MCCERF
Checking Option		None	MIN = 0	MIN = 0	None	None	None
Missing Item Option		Error	Insert '0' Note 1	Insert '0' Note 1	Error	Error	Error
Item Destination							

Initial Logic:

Final Logic: Store data for use when R66 MED is input.

Illegal Phases: Launch, Condition for Launch

Notes: 1. ΔV , ΔT may not both be input, but at least one must be input.

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MED Format Table

MED Code: R40, cont'd

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: RMRMED

P5, cont'd

Desc.	Item	P5 ₄	P5 ₅				
Item Name	ΔT	TRANSFER	STEERING CONSTANT				
Input Format	HHH:MM:SS. TH		FLP				
Input Units	flp. hrs.		NA				
Program Units	flp. hrs.		NA				
Scale Factor	NA		NA				
Checking Option	MIN = 0		None				
Missing Item Option	Error		Insert '1'				
Item Destination							

Initial Logic:

Final Logic:

Illegal Phases:

Notes:



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MED Format Table

MED Code: R65 Task: RTSSCS
 Purpose: Direct transfer to spacecraft setting EP: RMSSCS
 Load Module: RMRMED QNAME: NA
 QUEID: 0

Desc.	Item	1	2	3		
Item Name		Veh.	Data Source	Column indicator		
Input Format		EBCDIC	EBCDIC	EBCDIC		
Input Units		Note 1	EBCDIC Note 2	Note 3		
Program Units		Note 1	Note 2	Note 3		
Scale Factor		NA	NA	NA		
Checking Option		Exact	Exact	Exact		
Missing Item Option		Error	Error	Error		
Item Destination		RTSSCS via	SUBPOOL 1			

Programmer:

Initial Logic:

Final Logic:

Illegal Phases: Launch, Condition for Launch

Notes: 1. CSM 2. T - Time to Fire 3. P = Primary
 LEM R - Return to Earth M = Manual

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MED Format Table

MED Code: R66
 Purpose: Direct input of maneuver to spacecraft setting
 Load Module: RMRMED
 Task: ETMSCTRL
 EP: EMSCTRL
 QNAME: EQ2CTL
 QUEID: 10

Desc.	Item	1	2	3	4	5	6
Item Name		Vehicle	Data Source	GETI	Thruster	Mode	Burn param. indicator
Input Format		Veh	EBCDIC	HHH:MM:SS, TH	EBCDIC	EBCDIC	FXP
Input Units		EBCDIC	Note 2	hours	Note 3	Note 4	Note 5
Program Units		Note 1	Note 2	flp. hours	Note 3	Note 4	Note 5
Scale Factor		NA	NA	NA	NA	NA	NA
Checking Option		Exact	Exact	MIN = 0	Exact	Exact	None
Missing Item Option		Error	Error	Error	Error	Error	Error
Item Destination		RTSSCS via Subpool 1					

Initial Logic: Reject MED if R40 MED to define burn params has not been input.

Final Logic:

Illegal Phases: Launch, Condition for Launch

 Notes: 1. CSM 2. T = Time to Fire 3. S = SPS = 33 4. I = Inertial = 1
 LEM R = Return to Earth C1 = RCS2 = 1 EP = Guided = 4
 C2 = RCS4 = 2 L = Lambert = 3
 C3 = RCS-2 = 3
 C4 = RCS-4 = 4
5. $1 = \Delta V$, ΔT ; 5 = Lambert

Must be same as the P-code on R40 MED.

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MED Format Table

MED Code: R66, cont'd
Purpose:

Task:
EP:
QNAME:
QUEID:

Load Module:

Desc.	Item	7	8	9	10	11	12
Item Name	Roll	Pitch	Yaw	ΔT_{ullage}	No. of RCS thrusters	ΔT of 10 PCT thrust	
Input Format	FLP	FLP	FLP	FLP	FXP	FLP	
Input Units	deg.	deg.	deg.	secs.	Note 7	secs.	
Program Units	rad.	rad.	rad.	hrs.	Note 7	hrs.	
Scale Factor	MCCRPD	MCCRPD	MCCRPD	MCCHPS	NA	MCCHPS	
Checking Option	MINMAX $-180 \leq x \leq 180$	MINMAX $-90 \leq x \leq 90$	MINMAX $-180 \leq x \leq 180$	MIN = 0	MIN = 2	None	
Missing Item Option	Note 6	Note 6	Note 6	Insert sysp. 15 secs.	Insert '4'	Insert sysp. '0'	
Item Destination	RTSSCS via Subpool 1						

Initial Logic:

Final Logic:

Illegal Phases:

Notes:

6. Error if mode is inertial or guided. 7. 2 or 4 only
All or none must be input.



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MED Format Table

MED Code: R66, cont'd

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	13	14	15	16	17
Item Name	REFSMMAT	Configuration	Docking angle	GIMBAL indicator	Maneuver type	
Input Format	EBCDIC	EBCDIC	FLP	EBCDIC	FXP	
Input Units	Note 8	Note 9	Deg.	Note 10	Note 11	
Program Units	Note 8	Note 9	Rad.	Note 10	Note 11	
Scale Factor	NA	NA	MCCRPD	NA	NA	
Checking Option	Exact	Exact	None	Exact	Exact	
Missing Item Option	Insert 'CUR'	Insert 'U'	Insert sysp. '0'	Insert 'C'	Insert '1'	
Item Destination	RTSSCS via	Subpool 1				

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 8. CUR = 1 DMT = 6 9. A = Docked with LEM 10. S = Insert sysparam = 2
 PCR = 2 DOD = 7 ascent stage only C = Compute = 0
 TLM = 3 LCV = 8 D = Docked with both LEM stages 11. 1 or 2
 OST = 4 LEM stages
 MED = 5 U = Undocked

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MED Format Table

MED Code: R67 Task: RTSSCS
 Purpose: Direct Input of Entry Parameters to S/C EP: RMSSCS
 Setting QNAME: NA
 Load Module: RMRMED QUEID: 4

Desc.	Item	1	2	3	4	5	6
Item Name		Veh	Data Source	Entry mode	LAT.	LONG.	Initial bank angle
Input Format		EBCDIC	EBCDIC	EBCDIC	LAT.	LONG.	FLP
Input Units		Note 1	EBCDIC Note 2	EBCDIC Note 3	DD:MM:SS ^N	DDD:MM:SS ^N	deg.
Program Units		Note 1	integer Note 2	integer Note 3	rad.	rad.	rad.
Scale Factor		NA	NA	NA	MCCRPD	MCCRPD	MCCRPD
Checking Option		EXACT	EXACT	EXACT	MINMAX $-90 \leq x \leq 90$	MINMAX $0 \leq x \leq 360$	MINMAX $-360 \leq x \leq 360$
Missing Item Option		Error	Error	Error	Ignore Note 4	Ignore Note 4	Insert sysp. 00
Item Destination		RTSSCS via Subpool 1					

Initial Logic:

Final Logic:

Illegal Phases: Launch, Condition for Launch

Notes: 1. CSM 2. T = Time to fire 3. BAL (Ballistic) = 1
 LEM R = Return to earth MAX (Max. lift) = 2
 LGN (Guided) = 3
 * BRB (Bank/Reverse bank) = 4
 BNK (Constant bank) = 5



MED Format Table

MED Code: R67 cont'd.

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	7	8	9	10	11	12
Item Name		Prescribed G-level	Final bank Angle	Time to reverse bank	REV	REV-ZONE	Constant G-level
Input Format		FLP	FLP	HOURS	FXP	EBCDIC	FLP
Input Units		G-units	deg.	GET	integer	EBCDIC	G-units
Program Units		Er/hr. 2	rad.	GET	integer	EBCDIC	Er/hr. 2
Scale Factor		MCEACG	MCCRPD	NA	NA	NA	MCEACG
Checking Option		MIN = 0	$-90 \leq x \leq 90$	MIN = 0	MINMAX 1-999	NA	MIN = .001
Missing Item Option		Insert syp. .20	Insert 55° Note 7	Insert 0	Ignore	Ignore	Ignore
Item Destination		RTSSCS	via Subpool 1				→

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 3. cont'd.

GBL (Bank to G-level, then ballistic) = 6

GMX (Bank to G-level, then max. lift) = 7

*GRB (Bank to G-level, then BRB) = 8

GBK (Bank to G-level, then BNK) = 9

HB1 (Constant G) = 10

HB3 (Ballistic) = 11

HB5 (Lift vector up) = 12

HGN1 (Guided, Constant G) = 13

HGN2 (Guided, Lift vector down to

X G's) = 13

* One of the item pairs (45 or (89) must be input with this entry mode.



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MED Format Table

MED Code: R67, cont'd.
Purpose:

Task:
EP:
QNAME:
QUEID:

Load Module:

Desc.	Item	13	14			
Item Name		λ T for Constant G	Roll Direction			
Input Format		DDD:MM:SS ^{1/2}	EBCDIC			
Input Units		LONG.	EBCDIC Note 6			
Program Units		rad.	integer Note 6			
Scale Factor		NA	NA			
Checking Option		$0 \leq x \leq 360$	EXACT			
Missing Item Option		Note 5	Insert '-1'			
Item Destination						

Initial Logic:

Final Logic:

Illegal Phases:

- Notes: 3. (cont) HGN3 (Guided, Ballistic Backup) = 16
 HGN4 (Guided, Lift vector up to X G's) = 13
 HGN5 (Guided, Lift vector up) = 13
 HB2 (Lift vector down to X G's, 180° BNK) = 16
 HB4 (Lift vector up to X G's, 0° BNK) = 16

4. Both must be input if entry
mode is LGN, HGN1-5.

5. Must be input if entry mode is HB1
or HGN1 and constant G is omitted.

6. N(North) = +1
S(South) = -1

7. Must be input if entry mode
is BNK, GBK.



REENTRY PREDICTION

The reentry trajectory prediction data is provided by the Reentry Trajectory Control Task, RTASPECT. Processing by RTASPECT controls two major, operationally separate capabilities: the "lookahead" and entry/abort function. Output of each operation will be reentry displays, ephemeris and on-line prints.

Lookahead

Processing is initiated via the R10 MED, deorbit option. Each request is distinct and will not affect future processing. A threshold time (ephemeris start plus one hour) is required. Threshold time for lookahead processing does not key automatic deorbit queues. The anchor will be obtained from the orbit ephemeris at an anchor fetch time, if entered; otherwise, at burn initiate time.

Trajectory computations are based on the current spacecraft setting (SCS) (symbolic table \$RNTYIN). A SCS may be transferred from a return-to-Earth (RTE) or time-to-fire (TTF) or a manually entered (R66/67) MED. The deorbit burn is sufficiently well defined for input to the orbit integrator, PMMRKJ; and the entry profile fully defined for the entry integrator, RMMYNI. The entry constraints table (symbolic \$RCONSTS) contains the entering vehicle area, weight, K-factor and CSM separation criteria (ΔT or specific time). These values will not be duplicated in the SCS or elsewhere in the system. Acquisition (station contacts) information will be generated, but no acquisition messages will be transmitted. Nominal position data will be generated for plotboard display. Output data is obtained from the integrator output tables and from the SCS table. Data will be displayed in the PRE column of D/TV displays.

Entry Abort

Entry — Entry processing must be initiated manually by entering a threshold time and generating an entry trajectory via the R10 MED. This should be done in Orbit phase (or no phase for restarts). Once a threshold time is set, automatic deorbit queues will occur in Orbit phase for current time within 90 minutes of threshold. The anchor vector source for a nominal trajectory is specified on the R10 trigger or on the P83 at phase change. The vector options are orbit ephemeris, high-speed radar, high-speed telemetry, and restart (last entered P14).

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Trajectory computations are based on the Mission Plan Table (MPT) deorbit maneuver and the reentry constraints table. The deorbit maneuver, if present, is flagged in the header block of the MPT. The entry profile specified in the constraints table must be consistent with the burn source (i.e., high-speed entry profiles must be specified for RTE maneuvers and low-speed EP for TTF maneuvers). In Orbit phase the MPT deorbit maneuver and the constraints EP are initialized only by transfer from a spacecraft setting, RTE or TTF table. In entry phase the maneuver may be confirmed with the M60 and the entry profile with the R11.

For primary guidance (G&N) entries, backup entry parameters will be computed. For low-speed entries, the backup mode is assumed constant bank to a G-level then bank - GMTRB (GRB). For high-speed entries, one of the five high-speed backup modes (HB1-5) must be specified.

Anchor vectors may be specified manually for both the nominal and current trajectories. A nominal trajectory is generated on deorbit (using MPT orbit ephemeris vector), phase change (orbit to reentry or restart), or trigger (R10 MED). A current trajectory is generated on PBI. The entry ephemeris will be anchored on the last specified nominal or current vector, except that following a confirmation MED (M60, R11, R12), both nominal and current trajectories will be recomputed, and the ephemeris will reflect the current anchor vector. The detailed maneuver parameters in the MPT will reflect the entry ephemeris if the burn is included.

Acquisition data will be generated and transmitted. Nominal position data for plotboard display will be generated for any nominal trajectory generation. Anchor vectors will be transmitted to the auxiliary computer room (ACR) except for regeneration of trajectories using an old anchor.

Columnar D/TV displays will reflect nominal trajectories in the POST column (for Orbit phase in the PRE column) and current trajectories in the TRK column. They will display trajectory information based on the latest telemetry vector obtained on two-minute time cycle in the telemetry column. The telemetry processing will be solely for display; therefore no ephemeris or acquisition will be computed nor will the vector be transmitted to the ACR.

Abort — Processing will be available for the low-speed abort phases. Abort I and II entry definition will be initialized on phase change. No maneuvers will be available, and the entry profile will be ballistic (BAL) or maximum

lift (MAX), respectively. The ephemeris will be generated from anchor time to impact using the 'current' vector passed by launch. PBI-selected anchors will be processed similarly. Output data will be available in the low-speed portion of the Abort I and II display table for either vector source.

Abort III processing is initiated when the Mode Select Switch is set to Mode III, and the Abort/Hold/Orbit (A/H/O) switch is set to abort. The launch computed maneuver will be automatically transferred to the MPT and the 'maneuver' vector selected. CM/SM separation time will be computed as a Δt from maneuver cutoff. The EP will be defined as a G&N (LGN) entry. Targets will be selected by switch as Atlantic or Indian Ocean. Trajectory data will be displayed in the PRE column. If a current vector is available and free-flight, it will be selected as a nominal anchor, the maneuver in the MPT will be ignored, and a new trajectory will be generated. This will be displayed in the POST column. Selection of a maneuver vector with maneuver, or a current vector without maneuver is available using the R10 MED. The MPT maneuver can be confirmed using the M40 and M60 MED's. Other processing will be the same as for entry.

Restart — The restart capability in Abort III or Reentry allows for a zero delta-V maneuver to be entered in the MPT on entry of the P81 MED. Preceding the P81 MED should be the P80, P10, P12, and the P13 or P14 MED's. The P13 or P14 vector will be passed to RTASPECT, and processing will be the same as for normal Entry/Abort III.

The manual inputs required to control the reentry/abort trajectory generation are the following:

1. To select data source and threshold time:

R10, VEH, DATA SOURCE, THRESHOLD TIME, ANCHOR VECTOR
FETCH TIME;

Data Source = ORB, HSR Vector ID, TLM Vector ID, RESTR, PRE, TRA, DEORB, where DEORB initiates the lookahead from the spacecraft setting, and the other options specify anchor vector source for use in the nominal ephemeris generation.

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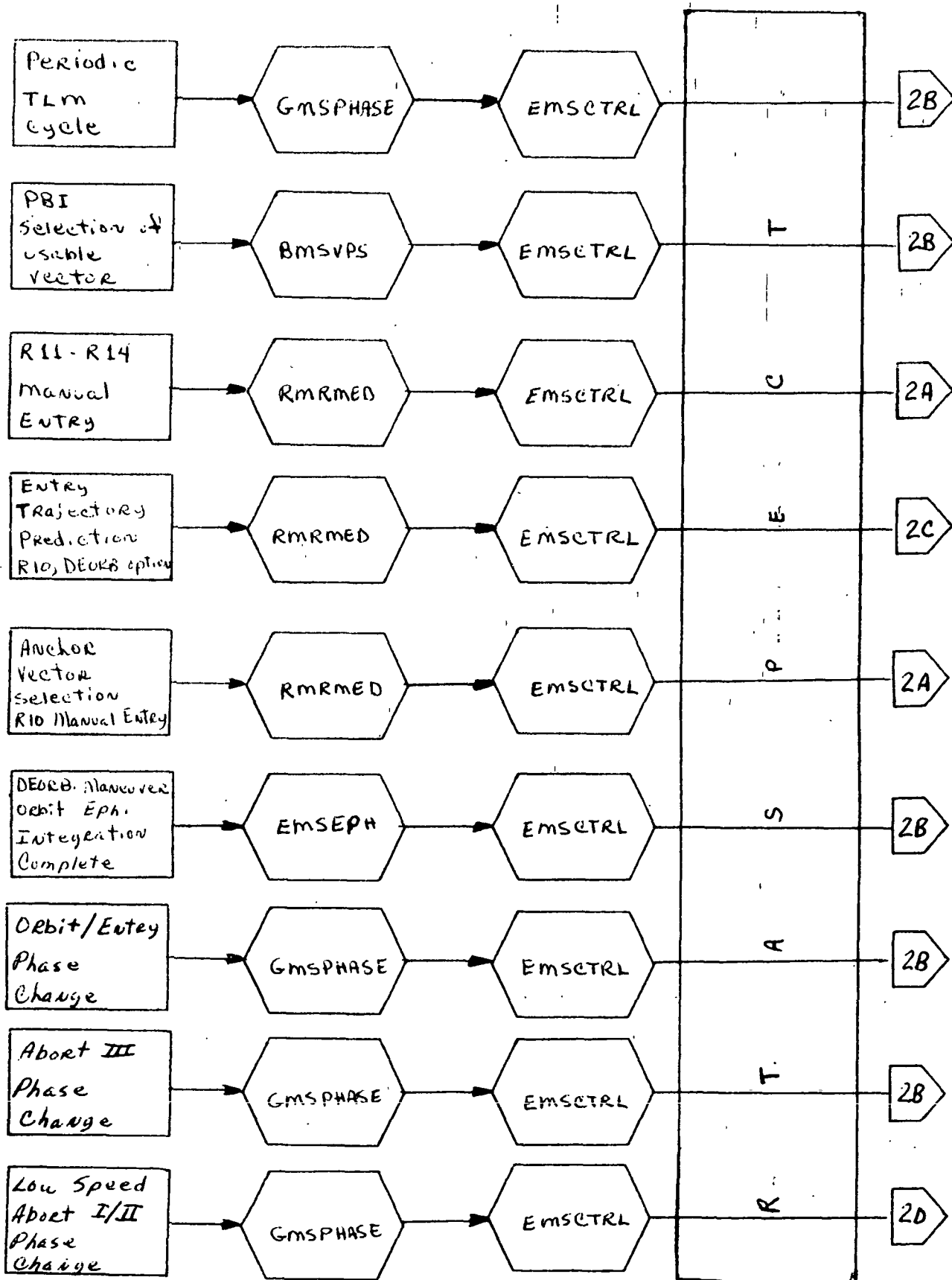


Figure 5. Reentry Trajectory Functional Flow

(Sheet 1 of 2)

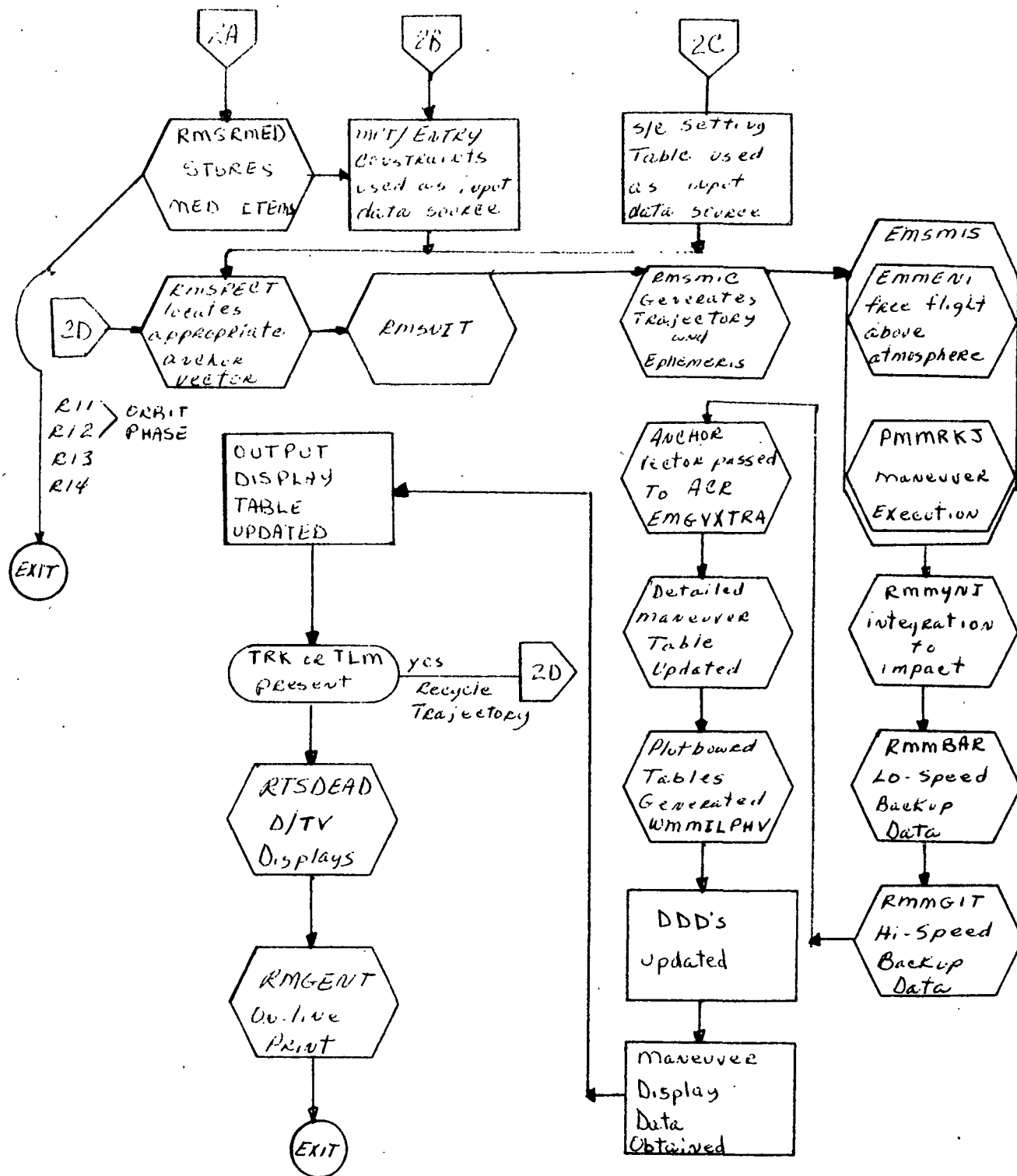


Figure 5. Reentry Trajectory Functional Flow

(Sheet 2 of 2)

2. To specify a double space entry profile

R11, VEH, ENTRY MODE, ϕ_T , λ_T , INITIAL BANK ANGLE, G-LEVEL, FINAL BANK ANGLE, GETRB, REV, REV-ZONE, CONSTANT G-LEVEL, λ_T for constant-G, ROLL DIRECTION;

Entry Mode = The lift vector control. This mode includes the high-speed primary and backup mode concatenations. Initial bank angle and G-level are for the non-G&N modes. For the HGN1 mode, the constant G-level, λ , and roll direction will apply to the backup trajectory. For HGN1 and HB1, if the constant G is not input, an iteration will be performed for the λ_T . For LGN, BRB, and GRB, the bank angle and time to reverse will be computed if not input for the $(\phi, \lambda)_T$ specified.

3. To specify separation parameters

R12, VEH, CM AREA, CM WEIGHT, CM/SM SEPARATION TIME, ΔT OF SEPARATION PRIOR TO EI;

For low-speed entry modes, the ΔT of CM separation from cutoff of the retrofire maneuver is used. The ΔT prior to EI is used for the high-speed entry modes. An input separation time will override.

4. To save miscellaneous entry parameters

R13, VEH, K-FACTOR, CM AREA, CM WEIGHT, LAD, LOD;

These parameters are saved in the reentry constraints table or as system parameters and will be used on any succeeding trajectory generation.

R13 will not effect a trajectory update.

5. To save miscellaneous parameters

R14, VEH, BANK ANGLE BIAS, G&N INITIAL BANK ANGLE, AVG. FLIGHT TIME, ϕ ABORT III 3200, ϕ ABORT III 8200, λ ABORT III 8200;

These parameters are saved in the reentry constraints table or as system parameters and will be used on any succeeding trajectory generation.

R14 will not effect a trajectory update.

Reentry/Abort Trajectory Control Module - RMSPECT

All processing requests for the RTASPECT task enter RMSPECT, and the processing required is determined and initiated. RMSPECT provides the following control:

1. Anchor vector control
2. Updating of the reentry constraints table
3. Communication with other modules in the task
4. Formatting the Reentry Display Table
5. Maintenance of the task resource table.

Trajectory Generation Control Module - RMSNIT

RMSNIT is linked from RMSPECT and provides the interface to RMSMIC for the numerical integration required for the trajectory. RMSNIT will perform the required coordinate transformations, will link RMSMIC, will interface with the MPT, and will return the maneuver and reentry parameters to RMSPECT for the output table. RMSNIT will also provide the GMT of CM/SM separation based on the high-speed or low-speed entry definition unless manually overridden. RMSNIT will also control the DDD's for the task.

Reentry Trajectory MED Control - RMSRMED

RMSRMED is linked by RMSPECT and will cross-check and store the data from the R10 - R14 MED's.

Reentry Runge-Kutta Numerical Integrator - RMMYNI

RMMYNI is used to produce the reentry and lookahead ephemeris and reentry display information such as impact point, entry conditions, blackout times, ephemeris quantities, second entry quantities, etc. There are ten lift modes included in RMMYNI.

1. Zero lift
2. Maximum lift
3. G&N reentry
4. Bank angle - time to reverse bank angle
5. Constant bank angle
6. Bank angle to a G-level then zero lift

7. Bank angle to a G-level then maximum lift
8. Bank angle to a G-level then bank angle-time to reverse bank angle
9. Bank angle to a G-level then another bank angle to impact prediction (IP)
10. Bank angle to a G-level then constant G

Reentry Backup Guidance Convergence - RMMBAR

RMMBAR is the backup guidance convergence and control program. It controls the computation of a bank angle and a time-to-reverse bank angle to come within three nautical miles of a target. RMSPECT queues RMMBAR passing a vector at EI, a target, and an entry mode.

When RCMBAR receives control, maximum-lift and zero-lift impact points are determined. RMMBGC is then called to generate the crossrange and downrange equation coefficients in addition to the first-guess at the bank angle (BA) and time-to-reverse bank angle (TRB). RCMBAR takes these first guesses and calls RMMYNI for the impact point. Control is then passed to the bank-and-reverse bank corrector, RCMBUG, where a miss distance is computed. In RCMBUG the initial guess values are "corrected" an amount determined by dividing the previous error by the proper partial derivative.

After each correction to the BA and TRB, control is returned to the RCMBAR to obtain the impact point. One to a maximum of ten iterations are taken to obtain the recommended BA and TRB. When the miss distance is less than three nautical miles, or the iteration counter is greater than ten, or the corrector is not converging, RMMBAR outputs the current values and returns to RMSPECT.

The following formulation and design limitations are for RMMBAR.

1. Maximum-lift integration must impact (no skip-outs).
2. Footprint length must be less than 180° .
3. Orbit must not be hyperbolic (inconsistent results).
4. Convergence is difficult if velocity is above 34,000 fps.
5. Convergence is extremely difficult if the footprint length is above 3500 nautical miles.
6. Convergence can sometimes be achieved in these cases, but the results are not predictable or guaranteed to converge.

Reentry Backup Guidance First Guess - RMMBGC

RMMBGC is the Backup Guidance Coefficient and First-Guess Computations program. RMMBGC uses the semimajor axis and the time from sensible atmosphere to maximum-lift impact to decurve-fit 25 coefficients for use in computing

a bank angle and time-to-reverse bank for low-speed backup guidance. RMMBGC then uses the crossrange and downrange distance to the target and partial derivatives as well as the coefficients for the downrange and cross range equations to arrive at a first guess for bank and reverse bank.

Currently the curve-fits represent velocities ranging from 20,000 fps to 34,000 fps with maximum footprint lengths of 3500 nautical miles. Present formulation will not handle hyperbolic orbits.

Constant G Iteration Routine - RMMGIT

RMMGIT iterates on an input target longitude to arrive at the constant G at which that target may be hit. (Constant G means the G-level that the vehicle attempts to maintain until sufficient energy is depleted so the remaining flight will remain at lower G-levels.)

Trajectories using maximum and minimum constant G's (presently, five and two G's) will be generated initially to determine a longitudinal footprint. If the input target longitude is within the footprint, an iteration will be performed until the maximum iteration (10) or convergence (3 miles) occurs.

$$\Delta g_i = \frac{\Delta \lambda_i}{\lambda_i}$$

$$\Delta \lambda_i = \lambda_i - \lambda_T$$

where λ_i is the integrated impact; λ_T is the target

$$\Delta \lambda_i = \frac{\partial}{\partial g_i} (\Delta \lambda_i)$$

$$g_{i+1} = g_i - \Delta g_i = g_i - (\Delta \lambda_i) \left(\frac{1}{\lambda_i} \right)$$

The corrected G is not allowed to go beyond the limits (two and five G's) since previous tests have determined the target to be within the footprint.

Upon completion, either the appropriate error or significant computed values are printed on line.

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```

DD/HH/MM/SS.CC :DD: (RMGENT) AAAAAAAAAAAAAA TRAJECTORY BBBBBBBBBB DATA SOURCE=CCC VECTOR SOURCE=DDDDXXX
:MANEUVER PARAMETERS VEH=CSM/LEM AREA=XXX.XX WT=XXXXX.XX EEE MNVR GETI=HHH/MM/SS.CC THR=FFF
DV=SXXXX.XX DT=XXX.XX DT ULL=XX.XX X QUADS
ELAPSED TIME=SHHH/MM/SS.CC TRIM ANGLE IND=G
LVLH BODY-ROLL=SXXX.XX PITCH=SXXX.XX YAW=SXXX.XX TRIM ANGLES--PITCH=SXXX.XX YAW=SXXX.XX
IMU ATT---ROLL=SXXX.XX PITCH=SXXX.XX YAW=SXXX.XX
REFSMAT ID=HHHHH XX=XX.XXXXXXXX XY=XX.XXXXXXXX YZ=XX.XXXXXXXX
YY=XX.XXXXXXXX YY=XX.XXXXXXXX YZ=XX.XXXXXXXX
ZX=XX.XXXXXXXX ZY=XX.XXXXXXXX ZZ=XX.XXXXXXXX
1LAMBERT GUIDANCE LPX=XXXXXXXXXXXXXXXXX LPY=XXXXXXXXXXXXXXXXX LPZ=XXXXXXXXXXXXXXXXX DTLAM=HHH/MM/SS.CC C=SX.XX
1UPLINK XDV COORDS VGX=SXXXX.XX VGY=SXXXX.XX VGZ=SXXXX.XX
ECI VECTOR AT GMTI=DD/HH/MM/SS.CC SX.XXXXXXXX SX.XXXXXXXX SX.XXXXXXXX SX.XXXXXXXX SX.XXXXXXXX SX.XXXXXXXX
:ENTRY PARAMETERS CM/SM SEP GET=HHH/MM/SS.CC CM AREA=XXX.XX CM WT=XXXXX.XX KFAC=X.XX
ENTRY PROFILE=III INITIAL BANK=SXXX.XX G-LEVEL=X.XX FINAL BANK=SXXX.XX GETRB=HHH/MM/SS.CC
TARGET LAT= DD/MM/SSJ LONG=DDD/MM/SSK REV-ZONE=LLLLLL
IMPACT LAT= DD/MM/SSJ LONG=DDD/MM/SSK GET=HHH/MM/SSXCC GETE=HHH/MM/SS.CC VEI=XXXXX.15 GEI=SXX.XX
MAX 1P LAT= DD/MM/SSJ LONG=DDD/MM/SSK GET=HHH/MM/SS.CC MAX G=XX.XX GET OF MAX G=HHH/MM/SS.CC
MIN 1P LAT= DD/MM/SSJ LONG=DDD/MM/SSK GET=HHH/MM/SS.CC BOI =HHH/MM/SS.CC BOE =HHH/MM/SS.CC
MAX 2IP LAT= DD/MM/SSJ LONG=DDD/MM/SSK GET=HHH/MM/SS.CC BOI2=HHH/MM/SS.CC BOE2=HHH/MM/SS.CC
MIN 2IP LAT= DD/MM/SSJ LONG=DDD/MM/SSK GET=HHH/MM/SS.CC III MISS DISTANCE=XXXXX.XXNM
MM IP LAT= DD/MM/SSJ LONG=DDD/MM/SSK GET=HHH/MM/SS.CC MM MISS DISTANCE=XXXXX.XXNM
EPH.TIME LEFT=DD/HH/MM/SS.CC TIME RIGHT=DD/HH/MM/SS.CC CONSTANT XX.XX G ROLL DIRECTION=J
THRESHOLD TIME MINUS ONE HOUR=DD/HH/MM/SS.CC
TRAJECTORY GENERATION NO.XXX

```

NOTES:

A - ABORT MODE I, ABORT MODE II, ABORT MODE III, REENTRY
B - GENERATION, PREDICTION
C - RTE, TTF
D - (PBI VECTOR ID), INSE, PRE, TRA, RES
E - XDV, SCS, LAM
F - SPS, *C2, *C4, APS, DPS, *L2, *L4
G - I, C
H - (GOST ID), GRR
I - BAL, MAX, LGN, BRB, BNK, GBL, GMX, GRB, GBK, HB1, HB2, HB3, HB4, HB5, HGN
J - N, S
K - E, W
L - (TTF ID), (MED ID)
M - GRB, HB1

1 - PRINTED ACCORDING TO MNVR TYPE

Figure 6. Reentry Trajectory On-Line Print



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MED Format Table

MED Code: R10 Task: RTASPECT via ETMSCTRL
 Purpose: Data source and threshold time selector EP: EMSCTRL
 Load Module: RMRMED QNAME: EQICTL
 QUEID: 10

Desc.	Item	1	2	3	4	5	6
Item Name		Veh	Data Source	Threshold time	Anchor vector fetch time		
Input Format		EBCDIC	EBCDIC	HOURS	HOURS		
Input Units		Note 1	Note 2	GET	GET		
Program Units		Note 1	Note 2	GMT	GMT		
Scale Factor		NA	NA	NA	NA		
Checking Option		Exact	Exact	Note 3 MIN = 0	MIN = 0		
Missing Item Option		Error	Error Note 4	Note 6	Note 5 Ignore		
Item Destination		RTASPECT	VIA SUBPOOL 1				

Programmer:

Initial Logic:

Final Logic:

Illegal Phases: Abort I/II, condition for Launch, Launch

Notes: 1. CSM 2. ORB = 215 TRA = 3 3. If zero is input, threshold time is cleared.

HSR ID = 5 DEORB = 154 4. 'PRE', 'TRA' allowed only in Abort III. 'ORB'

TLM ID = 0

allowed only in Reentry. Deorbit allowed only in orbit.

RESTR = 2

5. Input valid only when Item 2 is 'ORB', 'DEORB'

PRE = 4

6. Must always be input except in Abort 3. Must be omitted in Abort 3.

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MED Format Table

MED Code: R11

Purpose: Confirm entry profile

Task: RTASPECT via ETMSCTRL
 EP: EMSCTRL
 QNAME:EQICTL
 QUEID: 111

Load Module: RMRMED

Desc.	Item	1	2	3	4	5	6
Item Name		Veh	Entry mode	ϕ T	λ T	Initial bank angle	Prescribed G-level
Input Format		EBCDIC	EBCDIC	DD:MM:SS ^N	DDD:MM:SS ^N	FLP	FLP
Input Units		Note 1	EBCDIC	Lat.	Long.	deg.	G-units
Program Units		Note 1	integer Note 2	rad.	rad.	rad.	Er/hr. ²
Scale Factor		NA	NA	NA	NA	MCCRPD	MCEACG
Checking Option		Exact	Exact	$-90 \leq x \leq 90$	$0 \leq x \leq 360$	$-360 \leq x \leq 360$	MIN = 0
Missing Item Option		Error	Error	Ignore Note 3	Ignore Note 3	Insert syp. 0°	Insert syp. .2G
Item Destination		RTASPECT	via subpool 1				

Initial Logic:

Final Logic:

Illegal Phases: Condition for Launch, Launch, Abort I/II

Notes: 1. CSM 2. BAL (Ballistic) = 1 GBL (Bank to G-level, then ballistic) = 6
 MAX (Max. lift) = 2 GMX (Bank to G-level, then max. lift) = 7
 LGN (Guided) = 3 GRB (Bank to G-level, then BRB) = 8
 BRB (Bank/Reverse bank) = 4 GBK (Bank to G-level, then BNK) = 9
 BNK (Constant bank) = 5 HB1 (Constant G) = 10

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MED Format Table

MED Code: R11, cont'd.

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	7	8	9	10	11	12
Item Name		Final Bank Angle	Time to Reverse Bank	Rev	Rev-Zone	Constant G-level	AT for Constant-G
Input Format		FLP	HRS.	FXP	EBCDIC	FLP	DDD:MM:SS ^{FF}
Input Units		deg.	GET	integer	EBCDIC	G-units	Long.
Program Units		rad.	GET	integer	EBCDIC	Er/hr. ²	rad.
Scale Factor		MCCRPD	NA	NA	NA	MCEACG	NA
Checking Option		$-90 \leq x \leq 90$	MIN = 0	MINMAX 1 - 999	None	MIN = .001	$0 \leq x \leq 360$
Missing Item Option		Insert 55° Note 6	Insert 0	Ignore	Ignore?	Ignore	Note 4
Item Destination		RTASPECT					→

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 2. cont'd.

HB3 (Ballistic) = 11

HB5 (Lift vector up) = 12

HGN1 (Guided, Constant G) = 13

HGN2 (Guided, Lift vector down to X G's) = 13

HGN3 (Guided, Ballistic Backup) = 13

HGN4 (Guided, Lift vector up to X G's) = 13

HGN5 (Guided, Lift vector up) = 13

HB2 (Lift vector down to X G's, 180° BNN)

= 16

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MED Format Table

MED Code: R11, cont'd.

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	13						
Item Name		Roll Direction						
Input Format		EBCDIC						
Input Units		EBCDIC Note 5						
Program Units		integer Note 5						
Scale Factor		NA						
Checking Option		Exact						
Missing Item Option		Insert '-1'						
Item Destination								

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 2. cont'd.

HB± (Lift vector up to X G's, 0° BNK) = 16

4. Must be input if entry mode is HB1, HGNI, and const. G omitted.

5. N (North) = + 1

S (South) = - 1

6. Must be input if entry mode is BNK or GBK.

3. Both or neither must be input.

Both must be input if entry mode is LGN, HGN 1-5



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MED Format Table

MED Code: R12

Task: RTASPECT via ETMSCTRL

Purpose: Specify CM/SM separation parameters

EP: EMSCTRL

QNAME:EQ1CTL

Load Module: RMRMED

QUEID: 112

Desc.	Item	1	2	3	4	5	6
Item Name		Veh.	Veh. Area	Veh. wt.	CM/SM sep. time	ΔT sep. for low speed	ΔT sep. for high speed
Input Format		EBCDIC	FLP	FLP	HOURS	Note 2 FLP	Note 3 FLP
Input Units		Note 1	sq. ft.	lbs.	GET	secs.	secs.
Program Units		Note 1	sq. ft.	lbs.	GMT	hrs.	hrs.
Scale Factor		NA	NA	NA	NA	MCHPS	MCHPS
Checking Option		Exact	MINMAX 50 - 175	MINMAX 9000-20000	MIN = 0	MIN = 0	MIN = 0
Missing Item Option		Error	Ignore	Ignore	Insert = 0	Insert susp. 2 min.	Insert susp. 10 min.
Item Destination		RTASPECT	via Subpool 1				

Initial Logic:

Final Logic:

Illegal Phases: Condition for Launch, Launch, Abort I/II

Notes: 1. CSM

2. Δt from cutoff of CM/SM sep.3. Δt from CM/SM sep. to EI.



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MED Format Table

MED Code: R13

Purpose: Save miscellaneous parameters

Load Module: RMRMED

Task: RTASPECT via ETMSCTRL
 EP: EMSCTRL
 QNAME: EQICTL
 QUEID: 113

Desc.	Item	1	2	3	4	5	6
Item Name		Veh.	K-factor	Entry veh. area	Entry veh. wt.	LAD Max L/D	LOD L/D Final phase
Input Format		EBCDIC	FLP	FLP	FLP	FLP	FLP
Input Units		Note 1	flp	sq. ft.	lbs.	flp	flp
Program Units		Note 1	flp	sq. ft.	lbs.	flp	flp
Scale Factor		NA	NA	NA	NA	NA	NA
Checking Option		Exact	MINMAX 0 - 10	MINMAX 50 - 175	MINMAX 9000-20000	MIN = 0	MIN = 0
Missing Item Option		Error	Ignore	Ignore	Ignore	Ignore	Ignore
Item Destination		RTASPECT via Subpool 1					4

Initial Logic:

Final Logic:

Illegal Phases: None

Notes: 1. CSM



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MED Format Table

MED Code: R13, cont'd

Purpose:

Task:
EP:
QNAME:
QUEID:

Load Module:

Desc.	Item	7							
Item Name		Altitude of EMS (G&N)							
Input Format		FLP							
Input Units		FEET							
Program Units		Er							
Scale Factor		MCCERF							
Checking Option		MINMAX 25K - 400K							
Missing Item Option		Ignore							
Item Destination		RTASPECT							

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes:



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MED Format Table

MED Code: R14 Task: RTASPECT via E1MSC1RL
 Purpose: Save Misc. Parameters EP: EMSCTRL
 Load Module: RMRMED QNAME: EQ1CTL
 QUEID: 114

Desc.	Item	1	2	3	4	5	6
Item Name	Veh	Bank Angle	G&N Init.	Avg. Flight Time	Lat. Abt 3200 NM	Long. Abt 3200 NM	
Input Format	EBCDIC	FLP	FLP	FLP	LAT	LONG	
Input Units	Note 1	deg	deg	sec	DD:MM:SS ^N	DDD:MM:SS ^N	
Program Units	Note 1	rad.	rad.	hours	rad	rad	
Scale Factor	NA	MCCRPD	MCCRPD	MCCHPs	NA	NA	
Checking Option	Exact	None	None	MIN = 0	-90 ≤ x ≤ 90	0 ≤ x ≤ 360	
Missing Item Option	Error	Ignore	Ignore	Ignore	Ignore Note 2	Ignore Note 2	
Item Destination	RTASPECT via SUBPOOL 1						

Programmer:

Initial Logic:

Final Logic:

Illegal Phases: None

Notes: 1. CSM

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MED Format Table

MED Code: R14 (cont'd)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: RMRMED

Desc.	Item	7	8						
Item Name		Lat. Abt 3 8200 NM Targ.	Long Abt 3 8200 NM Targ.						
Input Format		DD:MM:SS ^N _S	DDD:MM:SS ^E _W						
Input Units		Lat	Long						
Program Units		rad.	rad.						
Scale Factor		NA	NA						
Checking Option		-90 ≤ x ≤ 90	0 ≤ x ≤ 360						
Missing Item Option		Ignore Note 2	Ignore Note 2						
Item Destination		RTASPECT							

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 2. Both or neither should be input.

REENTRY DISPLAYS

Display programs provide the results of the retrofire planning, spacecraft setting, and reentry prediction capabilities. These display programs and various aids needed to produce the previously mentioned results are controlled by the Reentry Display Supervisor Task.

Reentry Display Supervisor Task - RTSDEAD

During an Abort or Reentry phase, RTSDEAD initiates queues to the projection and X-Y plotboard task and the Orbit Display Supervisor after the generation of nominal data, a reentry ephemeris update, and on six second time traps. Also, queues are issued to generate and transmit site acquisition data to remote sites after trajectory updates.

There is one MED used to activate the recovery zones, recovery target, detection, recovery ascending node, and groundtrack digital display as well as to update the retrofire planning target table: R20, VEH, UPDATE CODE, AREA, LAT, LONG, BEG. REV, END REV;.

An MSK request for a display is honored in all phases. Table 1 shows the phases during which the displays are applicable. In addition, it shows how the displays may be updated. Three displays, which have IFN equal to 8, are updated by launch programs in Prelaunch, Condition for Launch, Launch, and High-Speed Abort Phases. In all other phases, they are updated by reentry programs. The rest of the displays have an IFN equal to 6 and are always updated by reentry programs. If a display has a clock (also noted in comments), and if it is being viewed in a phase, other than one for which it applies and in which time queues occur, time alone will update. (See examples 3 and 4 below.)

Some examples of the displays and how they may be updated are given below.

1. MSK 271 will update automatically in Abort III, Orbit or Reentry phases when nominals are generated, an ephemeris update occurs, or a telemetry vector is processed. It will update its clock and present position data in the same phases on a time queue.
2. MSK 335 will update by MED only in any phase.
3. MSK 356, if being viewed in reentry phase, will update its clock.
4. MSK 271, if being viewed in Abort I phase, will update its clock, but not the present position data.



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Table 1. Reentry Displays

DISPLAYS	PHASE					TIME QUEUES					Update by MED	COMMENTS		
	Low-Speed Abort			Reentry	Nom./ Ephem. Update	Telemetry P/M	TTF C	SCS	Return to Earth	6 Sec.			12 Sec.	P.P Data
	I	II	III											
Guidance 271 - Entry Digitals External DV/ 329 - Lambert Param. 331 - Abort Mode I/II Digitals 332 - RFO Entry/ Abort Digitals 333 - Time to Freefall vs. Range to Impact	X	X	X	X	X	X	X			X	X	X	clock clock clock-IFN=8	
335 - Retrofire Target Table	All Phases Valid												X	Analog-IFN=8
Entry 338 - Interface Evaluation 347 - Groundtrack Digitals 349 - Deorbit Predicted Site Acquisition	X	X	X	X	X	X	X	X	X	X	X		X	Analog-IFN=8
354 - Retro Elapsed Times 355 - Retrofire Separation 356 - Retrofire Digitals		X	X	X	X	X	X	X	X	X	X			clock clock clock, SCS reflects TTF data only
367 - High-Speed Entry Digitals				X	X				X					SCS reflects return-to- Earth data only
1453 - Recovery Zones 1454 - Recovery Target Selection 1505 - Recovery Ascending Node				X	X								X X X	
1620 - Entry Trim Aerodynamics	All Phases Valid												X	
2004 - Reentry Testing	X	X	X	X	X					X	X	X	X	clock

* Six second queues occur in Abort and Entry phases; twelve second queues occur in Orbit Phase.

Abbreviations:

NOM./EPHEM UPDATE - Reentry nominals or ephemeris update occurs
 TELEM - Telemetry vector processed
 TTF P/M - Time to fire - primary/manual target computed
 TTF C - Time to fire - contingency target

SCS - Spacecraft setting queue
 RET - Return-to-Earth queue
 IFN - Internal format number

Reentry Display Control Module - RMSDEAD

The controlling load module of the task interprets the input to the task and determines which load modules or tasks to queue. On time traps, which occur at six second intervals in Abort/Reentry and at 12 second intervals at 90 minutes prior to the threshold time, it provides present position data based on the present position vector. Present position height, latitude, and longitude are computed by the subsatellite position routine, GLSSAT. LIMRAN computes arc range to impact. LLBRTD computes the time at entry interface providing the orbit is not hyperbolic, from which time to freefall is determined.

The following displays are updated by RMSDEAD and are identified by an IFN of six.

<u>MSK</u>	<u>PROGRAM</u>	<u>NAME</u>
271	RMDGEDD	Guidance Entry/Abort Digitals
329	RMDRXDV	Retrofire External ΔV /Lambert Parameters
332	RMDREAD	Entry/Mode III Digitals
335	RMDTARG	Retrofire Target Table
347	RMDGTDL	Groundtrack Digitals
349	RMDDPSA	Deorbit Site Acquisition
354	RMDRET	Retro Elapsed Times
355	RMDRTSEP	Retrofire Separation
356	RMDDBMP	Retrofire Digitals
367	RMDHSED	High-Speed Entry Digitals
1453	RMDRTSD	Recovery Zones
1454	RMDRTSD	Recovery Target Selection
1505	RMDASCND	Recovery Ascending Node
1620	RMDTADD	Entry Trim Aerodynamics
2004	RMDEAPP	Reentry Testing-available on GSCCATS (for testing purposes) only.

The next three displays are updated by Launch programs in Prelaunch, Condition for Launch, Launch, and High-Speed Abort phases. In all other phases, they are updated by Reentry Computations' programs. They are identified by an IFN of eight.

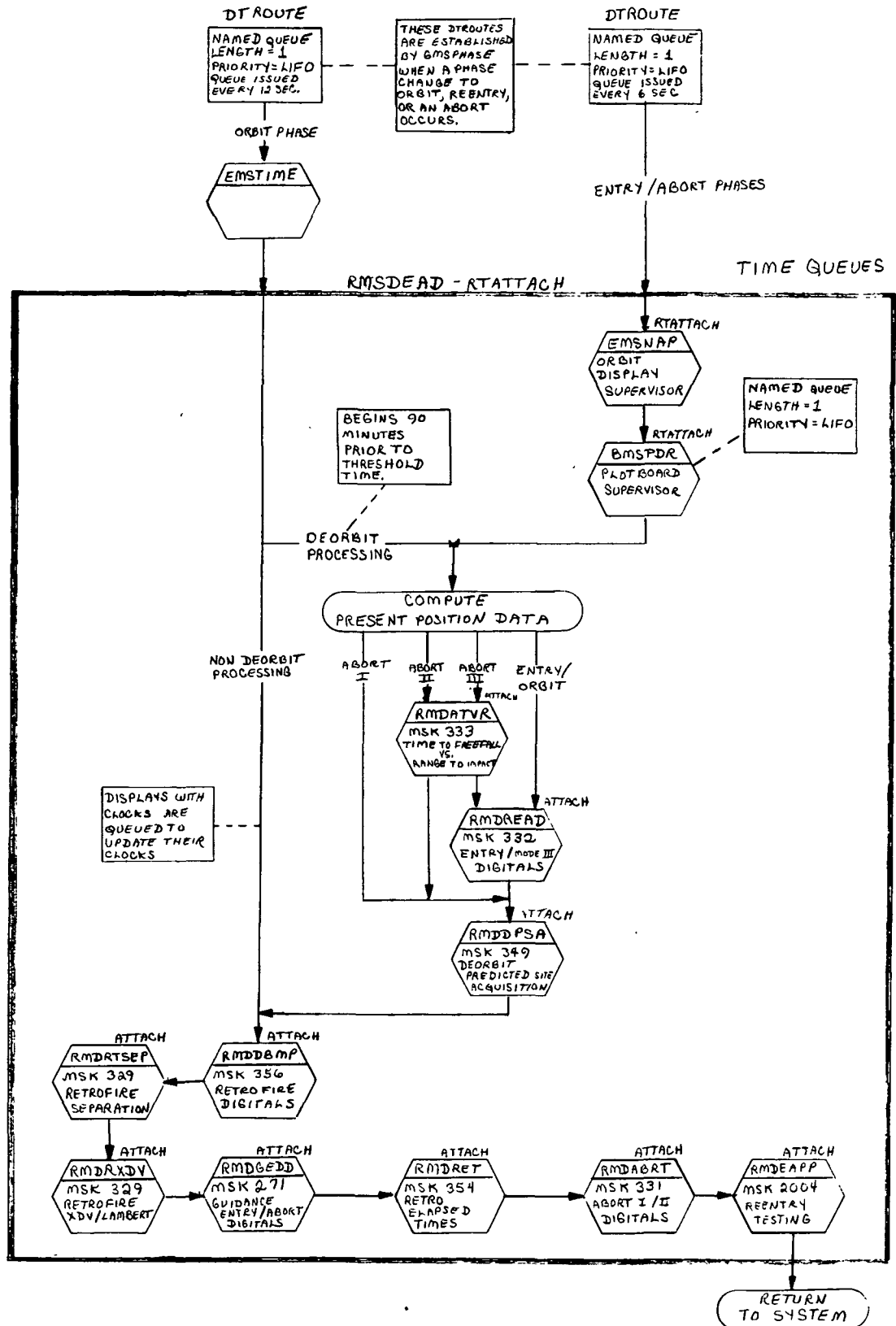
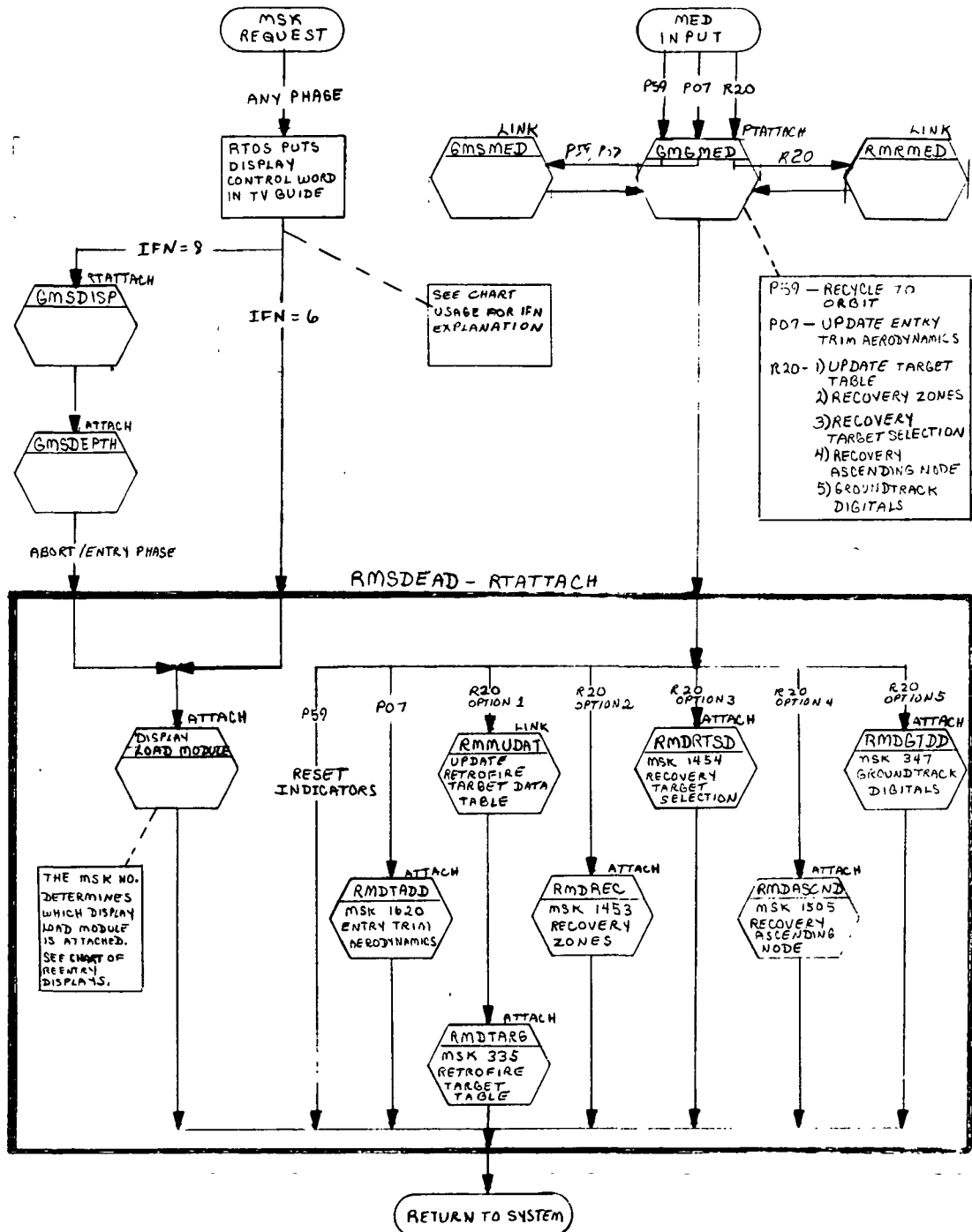


Figure 7. Reentry Displays



NOTE:

ATTACH TO DISPLAY LOAD MODULE IS MADE ONLY IF THE DISPLAY IS BEING VIEWED.

Figure 7. Reentry Displays

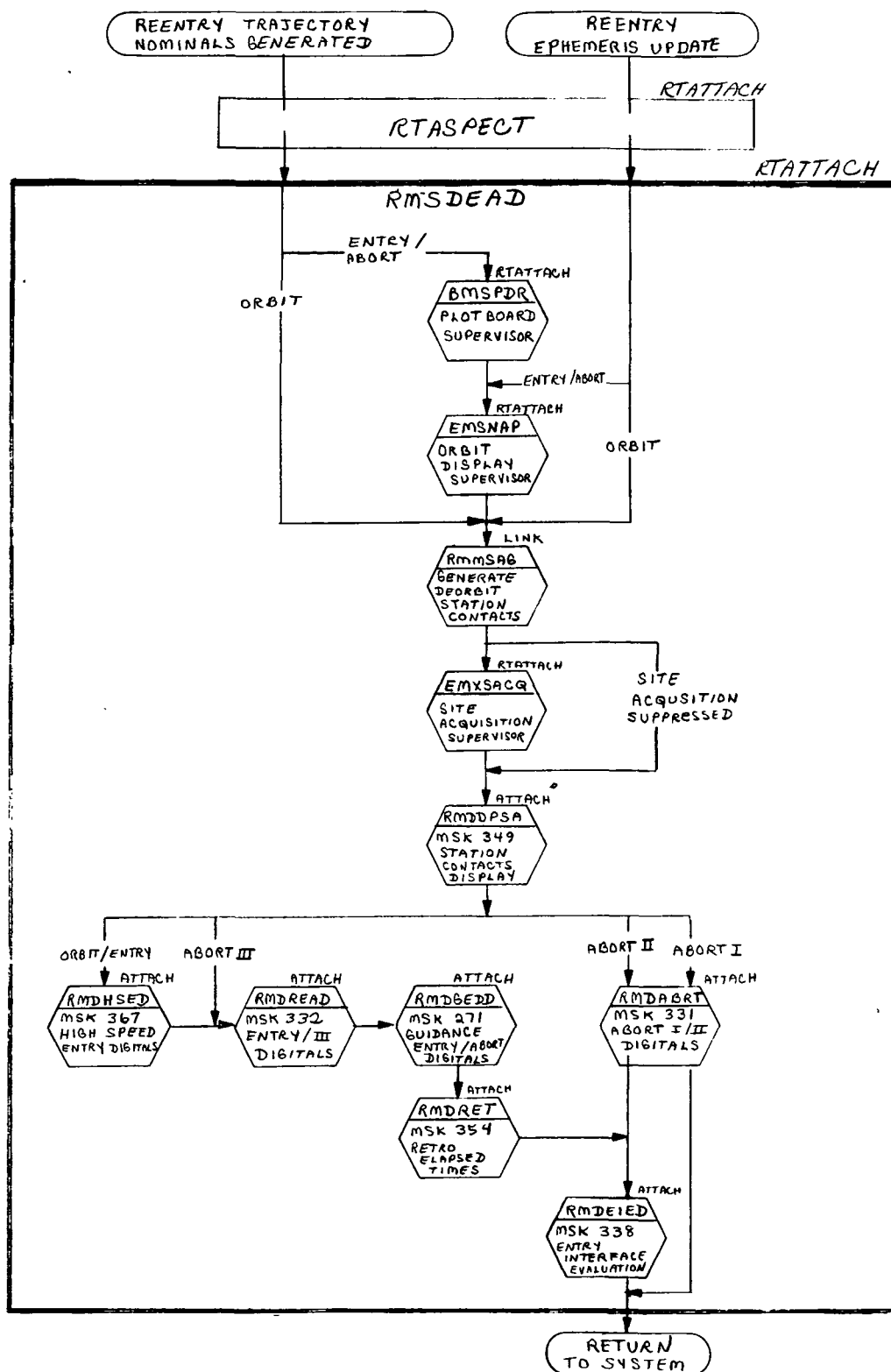


Figure 7. Reentry Displays

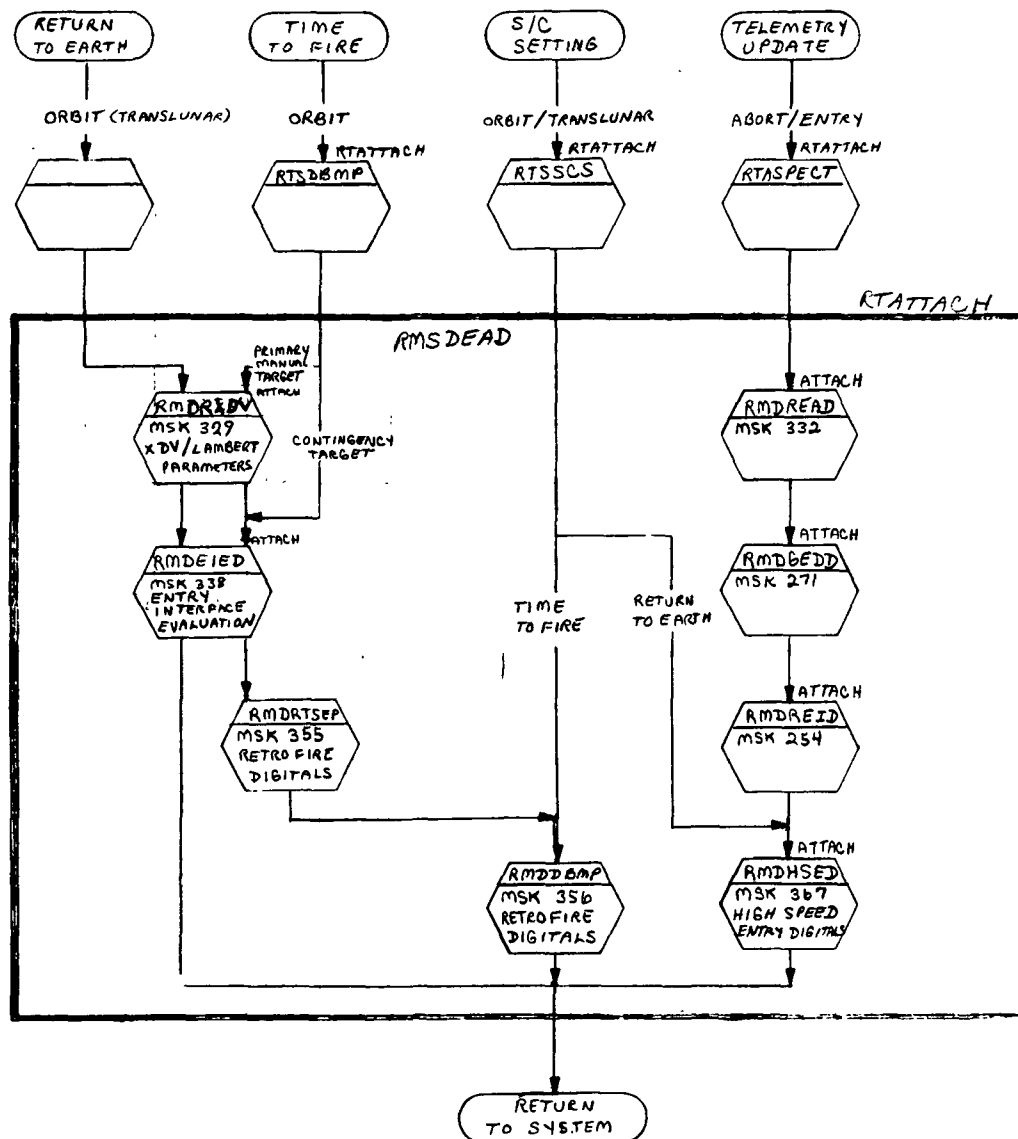


Figure 7. Reentry Displays

<u>MSK</u>	<u>REENTRY PROGRAM</u>	<u>NAME</u>
331	RMDABRT	Abort Mode I/II Digitals
333	RMDATVR	Time to Freefall vs. Range to Impact
338	RMDEIED	Entry Interface Evaluation

Reentry Station Contacts Generator - RMMSAG

After a reentry trajectory generation or update, this program generates the ascending and descending times of the stations that will make contact with the spacecraft during an abort or reentry by passing the ephemeris to the Orbit Station Contacts program, EMGENGEN. It determines the rev. of contact for each station by using RMMEACC to compute Cape crossing times. The resulting data is stored in the data table, RZRESTAL, to be used by the Deorbit Predicted Site Acquisition display and the Site Acquisition Task.

Target Table Updating Processor - RMMUDAT

RMMUDAT updates the Target Table, RZTARGET. It is queued by RMSDEAD on entry of an R20 MED. Either the header or one of the data blocks, 2 through 30 depending on the rev. number, will be updated. If this rev. number exceeds the rev in the header block by more than one, an on-line message will be printed.

Deorbit Predicted Site Acquisition - RMDDPSA

The Deorbit Predicted Site Acquisition display program outputs to D/TV the station contact data generated by RMMSAG on a display request and after a reentry ephemeris generation or update. It computes and displays Δt of passing on a time trap during reentry processing. Station information will be maintained after loss or contact, and the display will page if necessary to present data for all stations.

Reentry Testing - RMDEAPP

A reentry testing program available for testing purposes only, RMDEAPP displays the present position vector and data computed by RMSDEAD for the other display programs and the projection and X-Y plotboard task, BTSPDR.

Retrofire Digitals - RMDDBMP

RMDDBMP monitors computed deorbit information for selected landing sites (primary, contingency, and manual) and displays parameters from a manually input spacecraft setting. The data tables used are RZRFD P and RZDBSCI.

Retrofire Separation Table - RMDRTSEP

RMDRTSEP displays the separation/shaping parameters for the primary, contingency and manual landing sites. The data table used in RZRFD P.

Retrofire Target Table Display - RMDTARG

RMDTARG will display up to 22 landing areas and corresponding latitudes and longitudes for primary and contingency targets. These target parameters will be displayed starting from the current revolution. The initial targets are taken from the data table RZTARGET and may be changed by the R20 MED. The display is updated on a Cape crossing and MED input.

External ΔV /Lambert Parameters - RMDRXDV

RMDRXCV presents digital data for retrofire maneuver planning and provides key parameters used for building command loads related to the retrofire maneuver. This display will be available in Orbit phase. An indicator will be tested to determine the data to be displayed: time-to-fire or return-to-Earth. This indicator is set by the planning area being used. Since, procedurally, both areas will not be active at the same time, the display will reflect the latest solutions from whichever area is in process.

Guidance Entry Digitals Display - RMDGEDD

This program displays spacecraft attitudes for various event times during Abort III, Deorbit, and Reentry phases. Updates occur after a display request, trajectory update, six-second time cycle during Abort and Reentry and on a 12-second time cycle during Deorbit. The display has four columns: preburn, postburn, tracking, and telemetry.

In addition to the attitudes at separation, 300K ft., the specified G-level, and reverse bank, the following items are displayed:

1. Retro elapsed time of separation
2. Pitch from local horizontal at separation
3. Bank angle corrected to reflect the bank angle bias
4. Retro elapsed time of reverse bank
5. Station ID

The following items are displayed from the telemetry input of the entering vehicle.

1. Command Module Computer (CMC) values of program, verb and noun
2. CMC values of the three DSKY registers
3. CMC flash signal

Additional header information contains the time to free fall and the latitude and longitude of 400K ft.

The following table shows each set of attitudes that are displayed for each entry profile, and the bank angle used in the computation of the attitudes. The attitudes at 300K feet, specified G-level and reverse bank reflect the effect of the bank angle bias.

Entry Interface Evaluation Display - RMDEIED

RMDEIED is an analog display of velocity versus gamma points at entry interface. Primary, contingency, and manual data during orbit and deorbit processing is taken from RZRFPD; primary and manual data is taken from PZREAP during return-to-Earth processing; reentry data is taken from RZC1READ during Reentry and Abort II, III, and is also displayed in the first two cases. The display during Orbit phase is based on an indicator that is set by retrofire or return-to-Earth planning. Procedurally, these two planning functions will not be active at the same times; consequently the latest setting of the indicator alone will determine the solutions displayed.



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Table 2. Spacecraft Attitudes

Lift Option	Entry Profile	Bank angle at ¹ Separation	Bank Angle at 300K feet ³			Bank angle at G-level	Bank angle at Reverse
1	Zero Lift - BAL	None	NA ²			NA	NA
2	Max. Lift - MAX	None	= 0 - Bias			NA	NA
3	G & N - LCN	None	Time (300K) Initial - Bias		Time (Guid. Init.) NA	Final - Bias	-Final - Bias
4	Bank-RB-BRB	None	Time (300K) Final - Bias		Time (Rev. Bnk) - Final - Bias	NA	-Final - Bias
5	Const. Bank-BNK	None	Final + Bias			NA	NA
6	Bank-zero-GBL	None	Time (300K) Initial - Bias		Time (G-level) NA	NA	NA
7	Bank-Max.-GMX	None	Time (300K) Initial - Bias		Time (G-level) = 0 - Bias	= 0 - Bias	NA
8	Bank-BRB-CRB	None	Time (300K) Initial - Bias	Time (G-level) Final Bias	Time (Rev. Bnk) - Final Bias	Final - Bias	-Final - Bias
9	Bank-Bank-CBK	None	Time (300K) Initial - Bias		Time (G-level) Final - Bias	Final - Bias	NA
10	Bank-Const. G-HB1	None	Time (300K) Initial - Bias		Time (G-level) NA	NA	NA
11	Zero Lift-HB3	None	NA			NA	NA
12	Max. Lift-HB5	None	= 0 - Bias			NA	NA
13	G & N - HCN	None	Time (300K) Initial - Bias		Time (Guid. Init.) NA	NA	NA
16	Bank-zero-HB2/HB4	None	Time (300K) Initial - Bias		Time (G-level) NA	NA	NA

NOTES

1. Attitudes at separation are computed assuming the following spacecraft alignment:

X-body axis, X_b , is along the negative velocity direction.Y-body axis, Y_b , is along the positive angular momentum direction.Z-body axis, Z_b , is equal to $X_b \times Y_b$.

2. NA means not applicable for this entry profile, attitudes are blanked.

3. If the entry profile is G&N, the time at 300K feet is compared to the time of guidance initiate. If 300K feet occurs earlier, the initial bank angle plus bias is used. If the guidance initiate time is earlier, the attitude at 300K feet is not applicable.

* If a column of the display is updated on a vector after any of the events (e.g., separation), the attitudes for that event will be blanked.

RFO Entry/Mode III Digital Display - RMDREAD

RMDREAD displays digital data for trajectory monitoring based on a reentry ephemeris. This display is queued after each trajectory update to the reentry ephemeris during Orbit, Entry (high and low speed), and Abort III phases. For high-speed entries, the displayed valued "GETRB" will become GET of initiate roll, "BANK" will become the initial lift vector orientation (deg. tenths rather than roll left/right XXX deg.), "BN" (burn code) will be blanked, and "ENT CODE" (entry code) will correspond to "EP" (entry profile) on the Spacecraft Setting. This display is also queued on six-second (Abort III, Entry) and 12-second (Orbit) time traps for ϕ , λ , height of present position.

Present position data is passed in a parameter list. All other data is taken from RZC1READ.

Retro High-Speed Entry Digital Display - RMDHSED

RMDHSED will display digital data for monitoring a high-speed entry. The display is available in Orbit, Translunar, Lunar Orbit, Trans-Earth, and Entry phases. Data displayed in the preburn, postburn, tracking and telemetry columns will be taken from RZC1READ. Spacecraft setting and lambert target parameters are taken from the Spacecraft Setting Table, RZCDSC1. Spacecraft setting data on this display will be available only for high-speed entries.

If "EP" (primary entry profile) is HB1, 2, 3, 4 or 5, then "BU" (backup entry profile) will be blanked in the spacecraft setting section of the display.

The quantity "GMTL" on the spacecraft setting section will actually be a ΔT of the maneuver.

This display is queued on a spacecraft setting update and a trajectory update.

Retro Elapsed Time Display - RMDRET

RMDRET displays backup quantities and event times elapsed from GMTPI. The GMTPI is obtained from RZC1READ if it is available there; otherwise, it is taken from RZRCNS, the Reentry Constraints Table. All other data is taken from RZC1READ. The display is queued after a trajectory update on a six-second time trap in Entry and Abort III and phases on a 12-second time trap in the Orbit phase.

For high-speed entries, the displayed quantity "BANK" will become the initial lift vector orientation (deg. tenths rather than roll left/right XXX deg.), and "RETRB" will become RET of initiate roll.

Apollo Entry Trim Aerodynamics Display - RMDTADD

RMDTADD will display up to 20 mach numbers with corresponding trim angles, coefficients of lift and drag, and a ratio of lift over drag for each lift, drag quantity. Shift in X- and Z-direction and reference length bank angle bias are displayed from SYSPARAM MCZBAB. All other data is displayed from MHACLD SYSPARAM. This display is available in all phases. Bank angle bias is updated by the R14 MED; all other quantities; by the P07 MED.

T_{FF} versus R_{IP} Analog Display - RMDATVR

RMDATVR displays an analog plot of free-fall time to entry interface versus range to predicted impact point from launch pad. All data for this display is passed in a parameter list from RTSDEAD. It is available in Aborts II and III. In other phases, "NO DATA" is displayed. When T_{FF} is past entry interface, "T_{FF} PAST EI" is displayed, and the display is frozen. When T_{FF} is bad, "NO T_{FF} GIVEN" is displayed. When T_{FF} or R_{IP} is off display scale, "OUT OF RANGE" is displayed. The data is updated on a six-second time trap.

RFO Abort Mode I/II Digital Display - RMDABRT

RMDABRT displays digital data for monitoring Modes I and II low-speed aborts. Height of present position, ϕ , and λ are updated every six seconds and are passed in a parameter list from RTSDEAD. All other data is taken from LZXSAPM. Transferred vector data and high-speed data are stored in the table by Launch; low-speed data is stored by RMSPECT, the Reentry Trajectory Supervisor. The display is queued on a low-speed trajectory update and six-second time trap.

Recovery Target Selection Display - RMDRTSD

This program computes and displays groundtrack data for any requested 40 degrees of longitude for a requested rev. The following MED is used to queue the display:

R20, VEHICLE NAME, T,,, BEGINNING LONGITUDE, REV;

The display is available in Earth Orbit phase until the time of groundtrack reversal. Any data requested past this point will not be computed. Valid rev. numbers for input are present rev. to present +22nd rev. The display has four pages.

The following error messages are displayed.

1. If MED has not been input -

"ENTER MED R20, VEH, T,,, LONG, REV;"

2. If data is not available for requested vehicle -

"DATA NOT AVAILABLE FOR (VEH REQUESTED)"

3. If requested rev. is invalid -

"MED OUTDATED, REENTRY USING REV (first valid) - (last valid)"

4. If update is in process -

"TRAJECTORY UPDATE IN PROCESS - RE-REQUEST DISPLAY"

5. If longitude crossing routine could not converge, an asterisk is displayed by the longitude, and the following message displayed at bottom of screen -

"ALTERNATE LONG - UNABLE TO CONVERGE ON INPUT LONG"

6. If a point after groundtrack reversal is requested -

"GROUNDTRACK REVERSED - NO SOLUTION AVAILABLE"

7. When all data has been displayed -

"END OF RECOVERY TARGET SELECTION TABLE"

The display is updated by an MSK request only.

Recovery Zone Display - RMDREC

This program displays the recovery zones for each revolution requested that is within 500 nautical miles of the predicted groundtrack. The following MED is used to queue the display:

R20, VEHICLE, Z,,,,, BEG REV, END REV;

The display is available in Earth Orbit phase until the time of groundtrack reversal. Any data requested past this point will not be computed. Valid rev. numbers for input are present rev. to present +22 rev. This is a multi-page display.

The recovery zone definitions are stored in data table RZC1ZNE. They may be updated by use of the R20 MED as follows:

R20, VEH, Z, AREA, LATITUDE N/S, LONGITUDE E/W;

The data table will be a circular table; each entry of the above MED will be entered into the next position in the table.

Information will be displayed for each zone that lies within 225 nautical miles of the groundtrack. If fewer than two zones meet this qualification during one rev, the two zones which lie nearest the groundtrack will be displayed unless the farther of the two lies farther than 500 nautical miles of the groundtrack. For this case, the zone closest to the groundtrack will be displayed, provided it is within 1,000 miles of the groundtrack.

The following information is displayed with each zone.

1. Zone ID
2. Revolution number
3. Bearing from center of zone to point of closest approach to groundtrack
4. Distance from point of closest approach to zone
5. Time of closest approach
6. Latitude and longitude of point of closest approach
7. Latitude and longitude at times one minute before and one minute after time of closest approach.

The display is updated by MSK request only.

Recovery Ascending Node Display - RMDASCND

This program displays the time (GET and GMT) of the ascending node, the longitude of the node, and the right ascension for the current rev. and each rev. within the requested span. The following MED is used to provide inputs to the display:

R20, VEH, A,,,, BEG REV, END REV;

The display is available in Earth Orbit phase until the time of Earth groundtrack reversal. Any data requested past this time will not be computed. Valid revs. for input are current rev. to current +22. A maximum of 10 revs. plus the current rev. will be displayed.

This program is updated on a MSK request only.

Ascending Node, Right Ascension Routine - RMMASCND

This program computes the time and longitude of the ascending node referenced to Greenwich and the inertial right ascension referenced to Aries. The time of the ascending node is accurate to at least two seconds. Inputs to the program consist of a time-to-begin iteration and an ephemeris in the Earth-centered true coordinate system. The time-to-begin iteration must be within the ephemeris times. The ephemeris must not be hyperbolic. For the above cases, an error code is returned. If an ascending node correct within two seconds cannot be found in 10 iterations, the values computed in the tenth iteration (time, longitude and right ascension) are returned along with a delta time between the last iterations.

Groundtrack Digital Display - RMDGTDL

RMDGTDL displays subsatellite information for a designated vehicle to aid in determining recovery areas. This display is initialized only by a MED input. On entry of a veh, rev, and longitude via the R20 MED, the display program will compute one-degree increments of longitude for the next 40 degrees beginning with the input rev. number. With each longitude thus generated will be computed and displayed a latitude, GET, GMT, and true anomaly of the vehicle at the GMT. This is a paging display, yielding a maximum of two pages (20 lines per page).

The display is available only in Earth Orbit and Lunar Orbit phases. No automatic updates are provided. An appropriate error message is displayed if any procedural or processing error is encountered.

ORBIT/REENTRY SERVICE ROUTINES

These programs are provided in the Reentry Computations subsystem, but are primarily used by other subsystems. The programs are not logically connected; hence no flow diagram is presented. The telemetry/trajectory interface programs, which are a part of this section, are to be provided.

Master Numerical Integration Control - RMSMIC

This program was designed and developed to satisfy the integration needs of the Digital Command and Reentry Departments, thereby eliminating the need for integration control logic in the many separate programs that require integrations.

RMSMIC interprets a job code that may be between 1 and 11. Each job code defines a complete job as described in the user's guide. The job may be further constrained by the anchor time, time left, and time right.

RMSMIC will use the Miscellaneous Numerical Integration Control Program, EMSMISS, for all free-flight and straight mission plan table integrations until entry interface is reached. The integration will then be completed by going to the entry integrator (RMMYNI). The two ephemerides will be placed into the same coordinate system and patched together. The header will be updated and the pointers reset. The user may ask for an ephemeris in any or all of five coordinate systems. One call to RMSMIC will in most cases satisfy the complete integration needs of a user. Example: When linked with a job code of 4, RMSMIC will generate and store an entry ephemeris. It will also output CM/SM separation values, impact information, minimum, maximum, second minimum, and second maximum entry information before returning to the caller. The entry ephemeris is limited to four hours or 215 vectors and will contain no more than seven maneuvers.

This program will also do independent burns by calling the appropriate burn integrator, PPMRKJ or PMMSIU. The user may pass his burn parameters in an input list, or he may specify a job that will do a direct burn using perturbed mission plan table parameters.

RMSMIC will interface with both the high-and low-speed back up guidance programs. Back up parameters will be returned to the entry supervisor, RMSPECT.



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Table 3. RMSMIC Job Codes

Job Output	1	2	3	4	5	6	7	8	9	10	11
Returns free-flight vector at time right	x	x									
Returns free-flight ephemeris between requested times, which must contain seven vectors.		x									
Returns ephemeris that includes mission plan maneuver.			x								
Includes maneuvers in integration and returns vector at time right. Returns burn parameters.			x								
Includes maneuvers in integration from anchor time to first specified time. Then, integrate a free-flight ephemeris.											x
Stores entry ephemeris and returns all entry parameters including backup values.						x					
Integrates backward (free-flight only) and returns vector at time left.							x				

JOBS PERFORMED BY RMSMIC

- 1: Free-flight integration with a vector returned at the requested time.
- 2: Generate a free-flight ephemeris between the requested times. Ephemeris must contain at least seven vectors.
- 3: Generate an ephemeris between the requested times that included mission plan maneuvers.
- 4: Generate and store reentry mission ephemeris including maneuver times. (Maximum length of ephemeris is 4 hours or 215 vectors.) Generate all required entry parameters including backup values.
- 5: Include mission maneuvers in integration and return a vector at the requested time.
- 6: Integrate backward (free-flight only) and output a vector at the requested time. This job performs above entry interface only.
- 7: Reentry lookahead. Generate deorbit ephemeris and all required deorbit parameters as a pre-mission entry study aid. Ephemeris and data generation based on current Space Craft setting.
- 8: Special differential corrections job. Integrate through a maneuver storing the ephemeris and vehicle weights at a fixed delta-T. Re-integrate the maneuver with a perturbed weight. Reset the weight and integrate the maneuver once more with a perturbed mass flow rate.
- 9 Deleted
- and 10:
- 11: Include maneuvers in integration from anchor time to first specified time. Then, integrate a free-flight ephemeris.

Cape Crossing Computations - RMMEACC

This program is used to generate a table of cape crossing times for either the Earth or moon, beginning with the start of the ephemeris and continuing for 24 revs., or until the ephemeris ends, or until a groundtrack reversal is reached. This update is part of the process of the trajectory update. The independent task PTMANC (Maneuver Control Supervisor Task) issues an XCTL to EMSTRAJ (Trajectory Update Control load module) which issues a link to RMMEACC.

The ephemeris table to be used is determined from three input codes — vehicle ID (CSM), reference frame (Earth/moon), and the ephemeris type (orbit/reentry). The starting rev. number is input by the calling program.

The longitude crossing routine, RLMTCL is used to compute the crossing times. If RLMTLC cannot converge, a miss distance and rev. number will be printed on line.

Longitude Crossing Subroutine - RLMTLC

The minimum time to consider (or, if it is later, the ephemeris begin time) is used to interpolate for the initial vector. From this vector, the geographic longitude is computed using the formula

$$\lambda = \tan^{-1} (\gamma/X) - \omega t_i$$

where ω = Rotational rate of the Earth

The difference in this longitude and the requested longitude is determined (forward direction only this time). Based on the velocity component of the vector at hand, the time required to travel to the target longitude is calculated, assuming mean motion and equatorial component travel only. This process is repeated, if necessary, until the longitude of the time arrived at is within .0001 radians of the target longitude, or until ten iterations are achieved. The only difference in the successive iterations is that the smallest longitudinal difference is used rather than forward travel.

2.1.9 TRAJECTORY DETERMINATION SUBSYSTEM FUNCTIONAL SPECIFICATION
FOR THE MISSION SYSTEMS LUNAR MISSION
SIMULATION PROGRAM

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TRAJECTORY DETERMINATION SUBSYSTEM FUNCTIONAL SPECIFICATION
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SIMULATION PROGRAM

INTRODUCTION

A structural definition of the Trajectory Determination Subsystem is a definition of its parts, the program modules. These modules carry out all the input, output, control, and mathematical tasks involved in the subsystem's goal: support of the Lunar Mission Simulation Program (LMSP). Support of LMSP includes three major functions:

1. Determining the orbit of a given vehicle by mathematically processing low-speed radar data.
2. Providing centralized control of the various vectors available for computations.
3. Providing an evaluation tool whereby vectors may be compared before they are committed for use in various mission computations.

All of the modules are structured for the accomplishment of one or more of these functions. Manual input modules permit extensive control over the execution of this subsystem. The manual control features in orbit determination (OD), a part of the first major function, complement the automatic control capabilities. The result is a responsive, flexible, and usable subsystem.

Trajectory Determination also provides support features. Special computations are available upon manual request in support of orbit determination. For other subsystems, special vector control services are performed when required. The modules for carrying out support functions are called utility programs.

To make defining all the module types most understandable, this document has been divided into three units. Unit One describes the modules for the first major function: processing low-speed radar data. The second unit is a combined discussion of the second major function, vector control, and the third, vector comparison. Unit Three describes and explains the support programs. Each unit includes first a general description of functional requirements. This is followed by a more detailed design discussion of the applicable program modules in terms of functional flow. The design discussion also includes a section which clarifies requirements.

Approval	Approval
<i>Neon H. McFarland</i> <i>Said Stanley</i>	<i>George W. Fuller</i>

It should be noted here that all integration requests for this subsystem go through RMSMIC, the Master Integrator Control Program, and operate under the control of EMSCTRL, the Mission Control Supervisor. This will prevent any Trajectory Determination integration being performed during a trajectory update and thus prevent the use of an inconsistent mission plan table.

This description of the purpose and design of the Trajectory Determination Subsystem expresses IBM's understanding of the requirements to be satisfied for LMSP.



LOW-SPEED RADAR PROCESSING

The processing of low-speed radar is the most complex of the three major functions of the Trajectory Determination Subsystem. It is, therefore, discussed singly, apart from other major and support functions. To simplify discussion, this unit has been divided into four sections which consist of groups of related program modules. The sections are (1) low-speed input, (2) low-speed control, (3) low-speed math, and (4) low-speed output. Low-speed input, control, and output are discussed as logical units; low-speed math is a module-by-module discussion. Each section begins with a general description of its requirements during low-speed radar processing and follows with a detailed discussion of the section's design and the specific functions of its parts. Figures 1 through 5 are flowcharts of the entire unit.

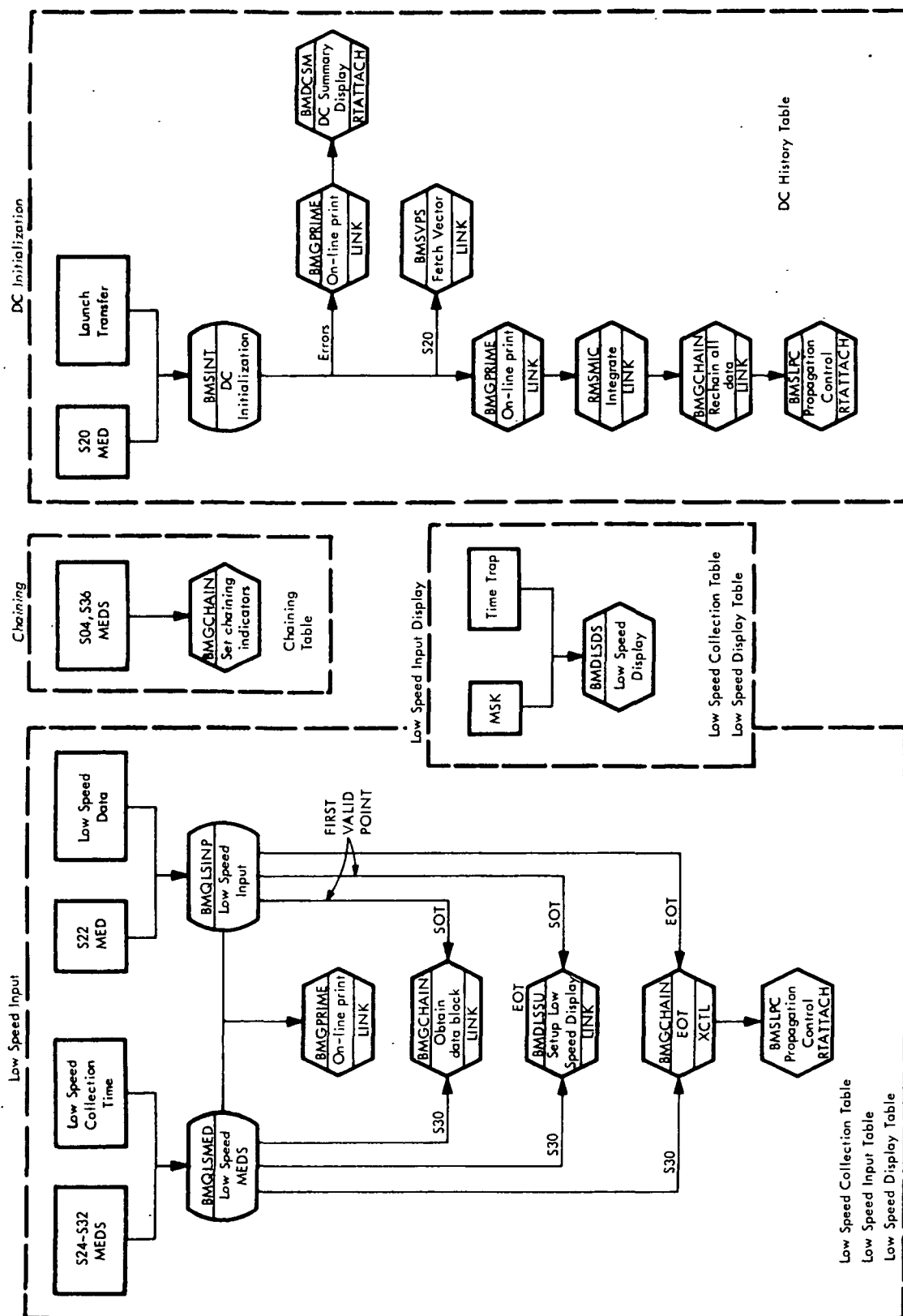


Figure 1. Low-Speed Input Chaining and Differential Correction (DC) Initialization

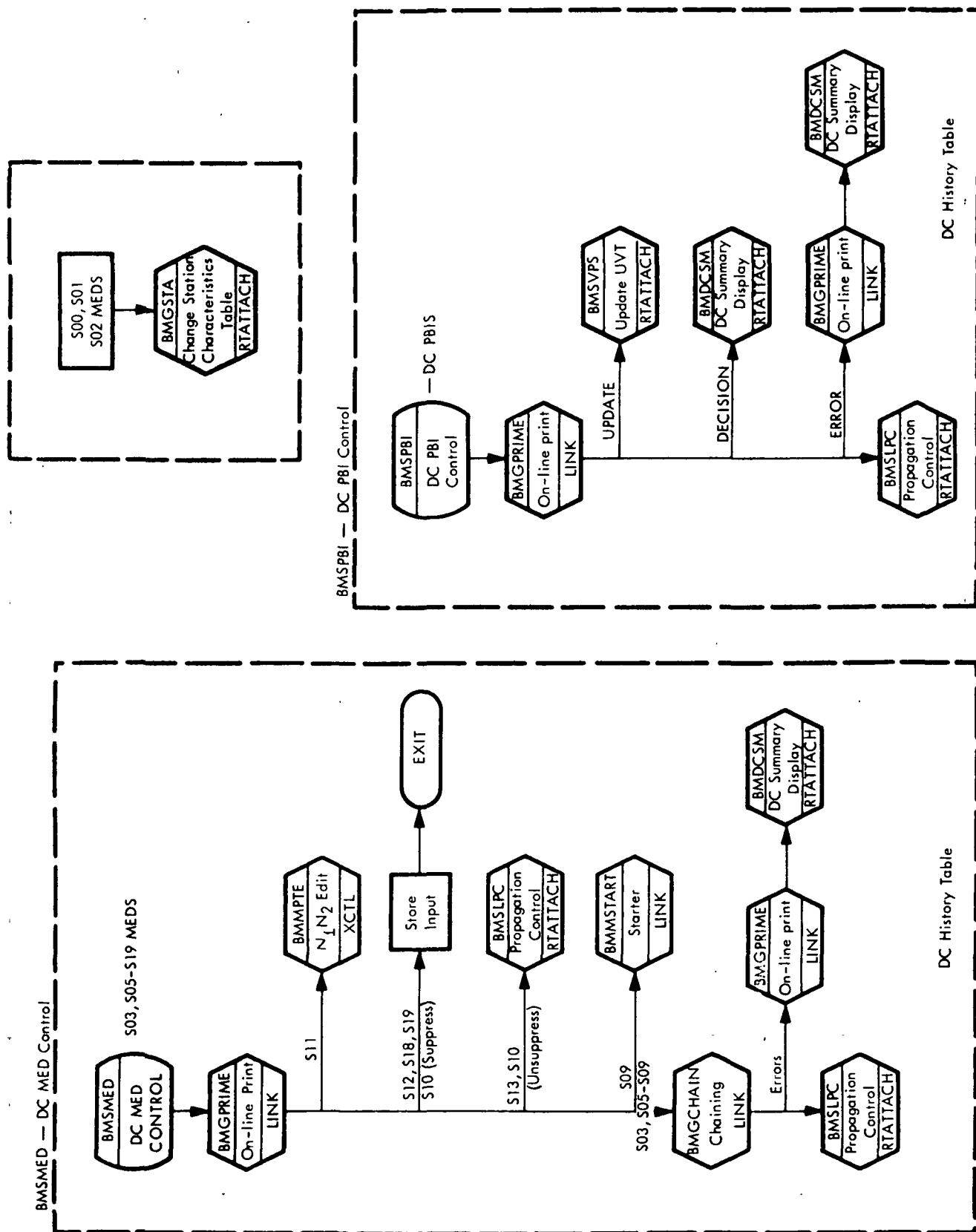


Figure 2. MED Controls

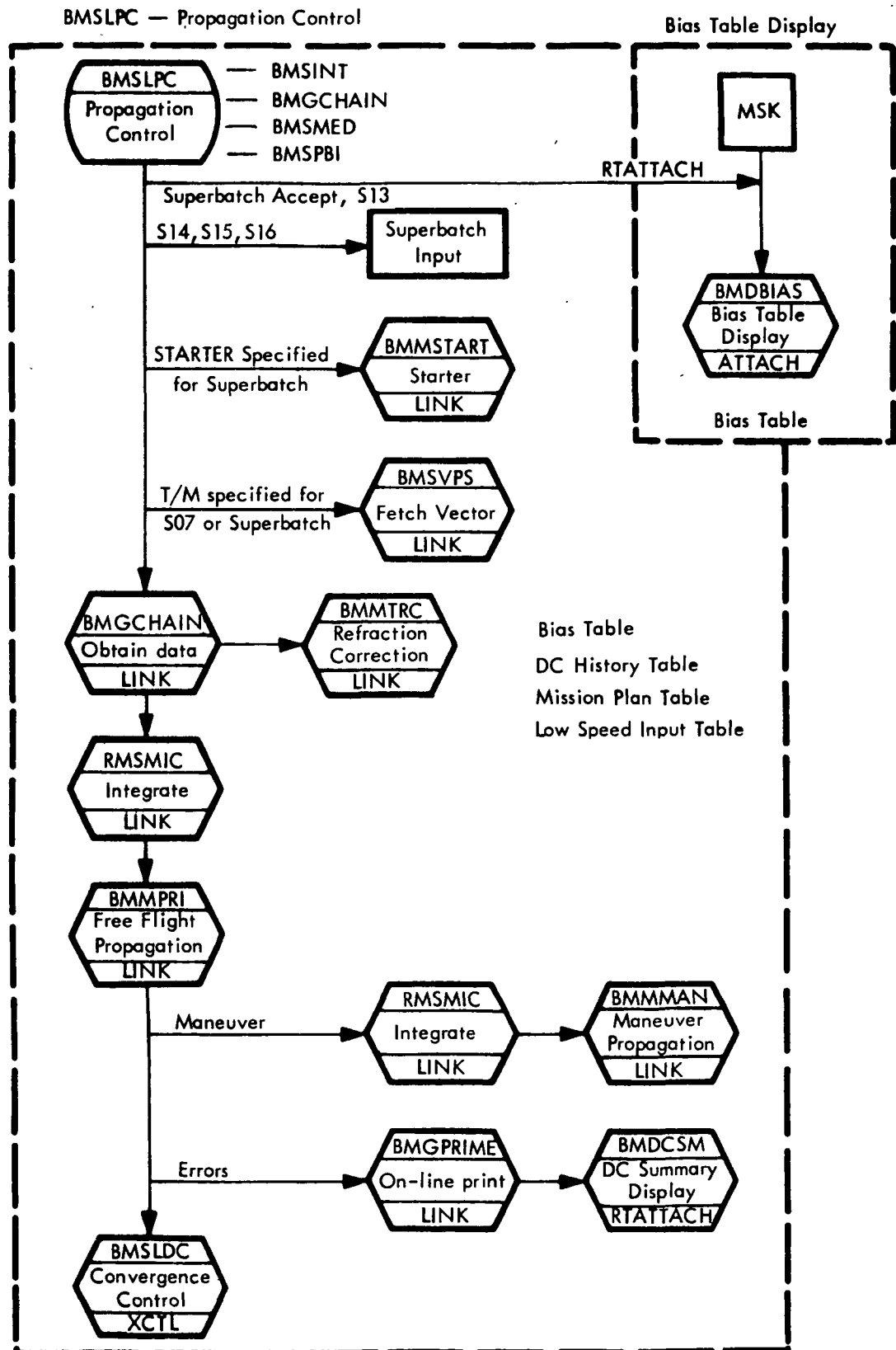


Figure 3. Propagation Control

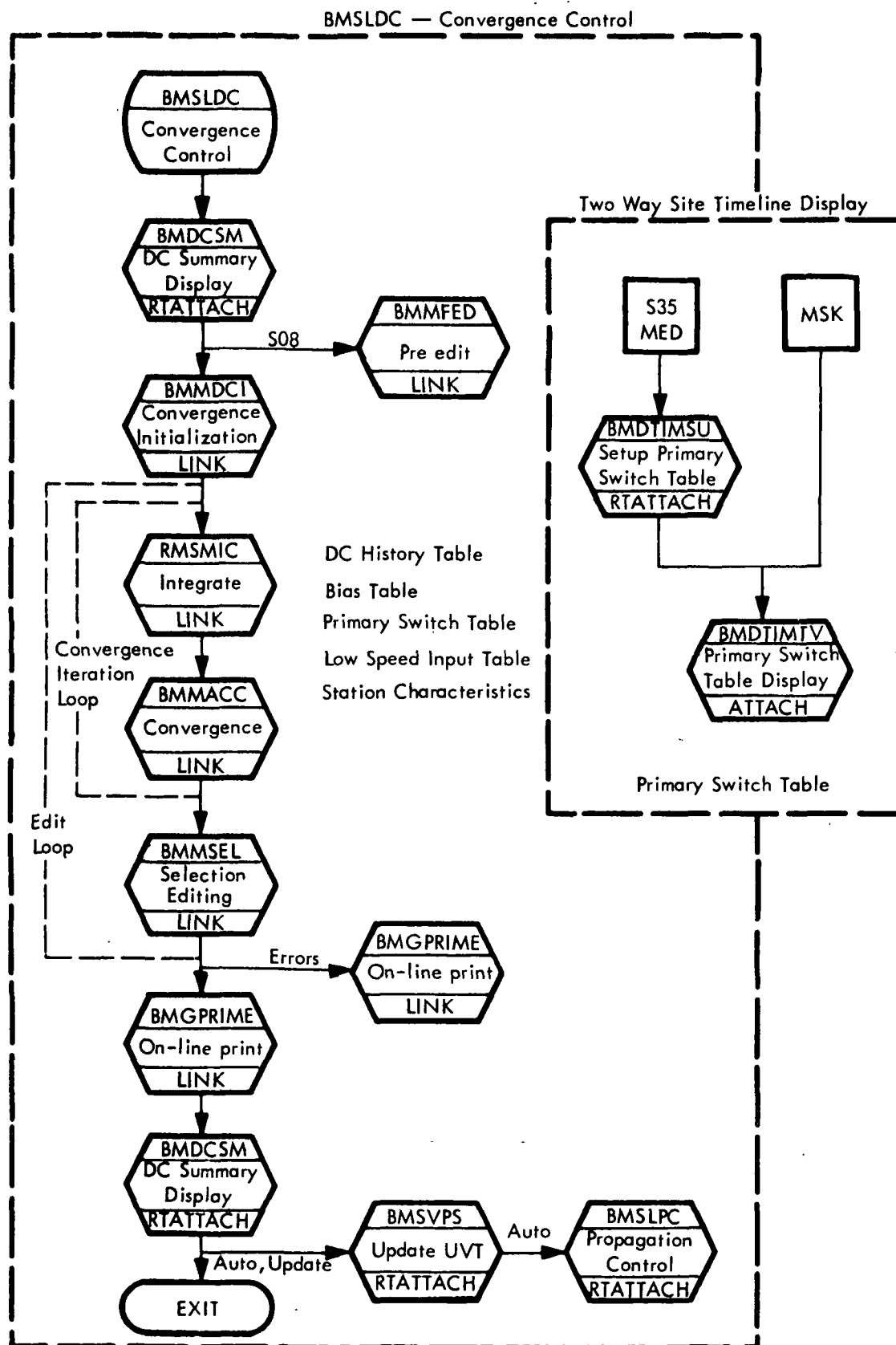


Figure 4. Convergence Control

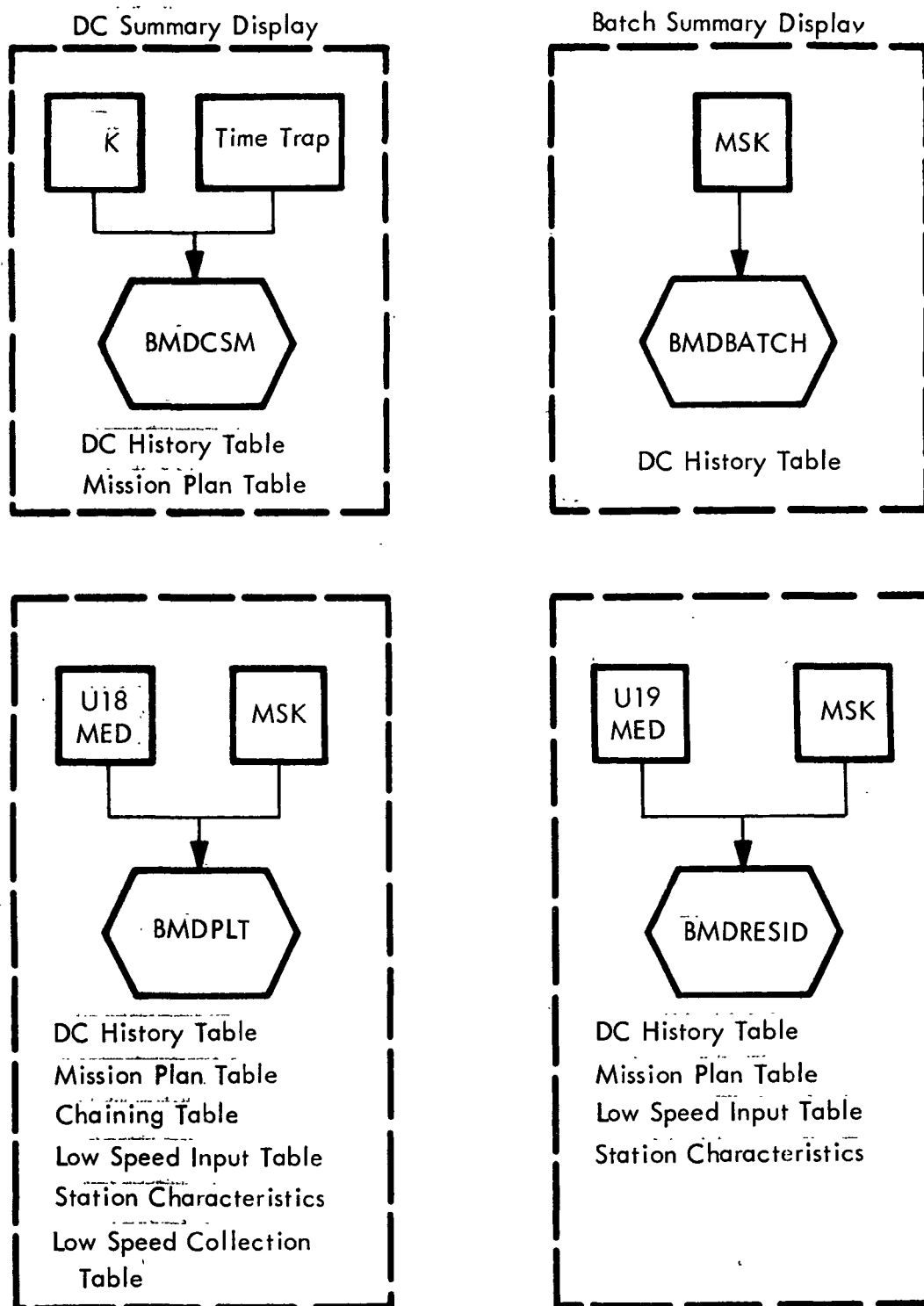


Figure 5. DC Displays Controlled under ETISPLAY

LOW-SPEED INPUT

General Requirements

The low-speed input section is responsible for the processing of all low-speed radar data prior to orbit determination (OD). Incoming data is not routed to the low-speed input unit for a specific vehicle until twenty seconds after receipt of the S-IVB cutoff event or until the mission phase is switched from launch to orbit or abort. Upon receipt of data, the low-speed input unit unpacks and converts the data from its teletypewriter format into fixed and floating point numbers, checks for validity and, if the data is acceptable, applies various corrections to it. Fourteen items must be validity checked:

1. Station/vehicle/beacon ID
2. Format
3. Time sequence
4. Valid teletypewriter (TTY) characters
5. Minimum elevation
6. On-track indicator (C-Band only)
7. Non-destruct doppler mode (S-Band only)
8. Range/range-rate quality indicator (S-Band only)
9. Range/frequency indicator (S-Band only)
10. Test indicator (S-Band only)
11. Angle/data quality indicator (S-Band only)
12. Auto track indicator (S-Band only)
13. Range quality indicator (S-Band only)
14. Range-rate data quality indicator (S-Band only).

The modifications to the data frame are (1) a constant added to the data frame time and (2) a change vehicle/beacon ID.

The following items are the corrections applied to the data frames:

1. Local vertical
2. Site-dependent range biases
3. Beacon-dependent range biases (C-Band only)
4. Frequency-dependent range biases (S-Band only)
5. Azimuth deviation (C-Band only).

A data batch save area is obtained for each new vehicle/site received by the low-speed input unit. The input unit can accommodate up to fifteen batches of transmitting data at a given time (twenty batches for collected data). Acceptable data types are

1. C-Band
2. Two-way S-Band (XY angle (30' and 85' antennas) and hour angle, declination)
3. Three-way S-Band (XY angle (30' and 85' antennas) and hour angle, declination).

One-way data is not saved, nor is data with a vehicle ID of zero. The collection of a data batch is complete when the input unit receives an end-of-transmission indication (actual or simulated) for the specified batch. Following the end-of-transmission indication, the entire data batch is available for refraction correction.

The collection process can be altered by the use of manual entry devices (MED's). These MED's can be used to change the characteristics of the radar sites, specify editing criteria to exclude or alter data, or change the method of passing collected data to differential correction (DC). Listed below are the MED's and their collection process function.

1. S00 - Changes station characteristic indicators
2. S01 - Changes station characteristic values
3. S02 - Changes station location
4. S22 - Forces end of transmission
5. S24 - Adds time to data time tags
6. S25 - Adds range correction
7. S26 - Changes vehicle/beacon ID
8. S27 - Specifies limits on batch size
9. S28 - Specifies minimum elevation
10. S29 - Specifies time between observations
11. S30 - Duplicates a radar batch
12. S32 - Starts or stops three-way processing

Each of the above MED's are discussed more fully under "Design Discussion". In addition, the last unit, "INPUT/OUTPUT SUPPORT" describes the format of each MED.

External output from the low-speed radar input unit is by digital display drivers (DDD), on-line print messages, and the Low-speed Input Display. A "data in transmission" DDD is turned on when data is being received for that vehicle; it remains on until all sites have ended transmission for that vehicle. On-line

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print messages include start of transmission, end of transmission (EOT) and those mentioned in "Design Discussion". The exact format of these messages is also given. The status of the low-speed input unit is shown on the Low-Speed Input Display, which is discussed under "Low-Speed Output".

Design Discussion

The low-speed input unit consists of four main load modules: (1) Low-Speed Input Processor (BMQLSINP), (2) Low-Speed MED Processor, (BMQLSMED), (3) Modify Station Characteristics (BMGSTA), and (4) Low-Speed Display Data Table Setup (BMDLSSU). In addition, the load modules BMGCHAIN/Low-Speed Data Chaining Processor; BLMREF/Radar Correction Subroutine, and BMGPRIME/On-line Print Module are extensively used. Figure 6 shows the general interfacing of these modules.

All low-speed radar input and the S22 MED, which simulates a radar input EOT message, are processed by BMQLSINP. Module BMDLSSU is queued three times during the period of a station's transmission in order to provide data for the Low-Speed Input Display at start of transmission, first valid data frame, and end of transmission. Upon receipt of valid data, BMGCHAIN is queued to provide storage and an identifying batch number for the data. It is again queued at end of transmission to signify that the low-speed input unit has completed its task and the data is available for differential correction. Start and end-of-transmission print messages or error messages are obtained by queuing BMGPRIME. Local vertical and azimuth deviation corrections, as required, are applied to each valid data frame by calling BLMREF.

The Low-Speed MED Processor (BMQLSMED) provides three main functions for the low-speed input unit: initialization, data routing, and MED processing. The mission control supervisor is responsible for queuing BMQLSMED so that the initialization and data routing functions may be performed. All parameters and tables required by the low-speed input unit are initialized by BMQLSMED. This module also does the starting or stopping of the routing of low-speed radar data for collection. Its third main function is to process various MED inputs to the low-speed input unit. All of these MED's, except one, require no interfacing with other modules. MED's S24-S29, and S32 set indicators and values that will be used by BMQLSINP to collect and process low-speed radar data and by BMDLSSU to provide data for the Low-Speed Input Display. If any errors are detected within the MED parameters, BMGPRIME is queued to print an error message.

The use of MED S30 necessitates interfacing with three other modules of the low-speed input unit. BMGPRIME is queued to either print an error message, if an error is found within the MED parameter, or a message stating that a radar batch has been duplicated. A queue to BMDLSSU is required to provide display information for the new and old radar batch. BMGCHAIN is queued twice: once to obtain a new block and batch number and again to indicate collection processing is complete on the duplicated batch.

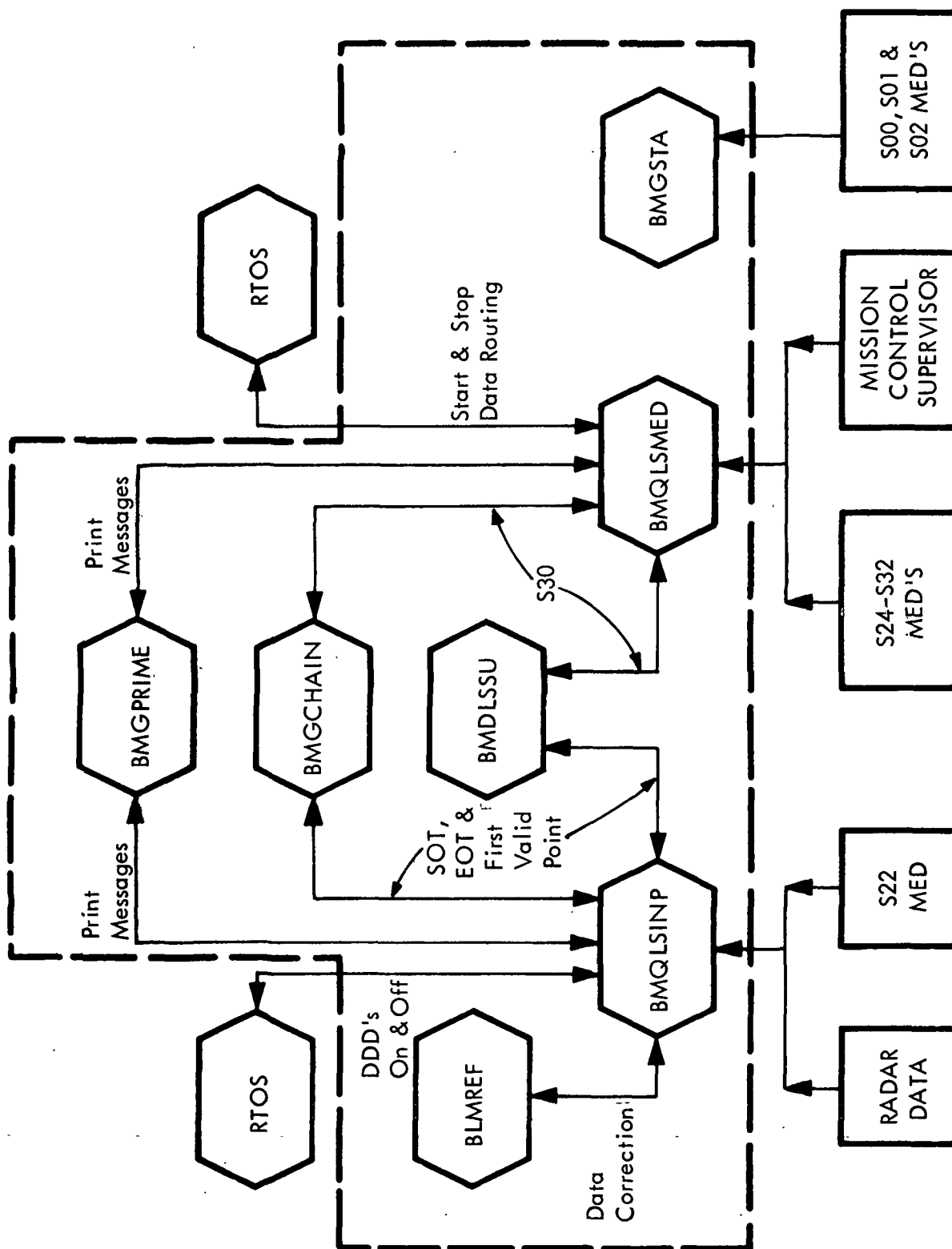


Figure 6. Low-Speed Input Unit

Values within the station characteristics table are altered by BMGSTA, as specified in MED's S00, S01, and S02. If an error is found by BMGSTA, BMGPRIME is queued to print an on-line error message.

The function of BMDLSSU is to provide data for the Low-Speed Input Display. Queues are received from either BMQLSINP or BMQLSMED; their receipt results in modifying the data table from which data is displayed. BLMREF is a library subroutine called by BMQLSINP to apply local vertical corrections to all valid data and deviation corrections to valid C-Band data. The method for applying these corrections is found in NASA Internal Note #67-FM-51.

Low-Speed Input Processor (BMQLSINP)

All initialization required by Load Module BMQLSINP is done by the Low-Speed MED Processor (BMQLSMED) at the time of mission control initialization. During mission phase, BMQLSINP has no restrictions.

Input Queues — One queue is received when the S22 MED is input.

This queue is treated as if a station had sent an end-of-transmission message. (See output queues and error checks - S22 MED). Another queue is received from RTOS when the conditions specified by BMQLSMED in its initialization of data routing are met. When received, the input data frames are checked, corrected, and collected. (See error checks - collection storage available).

Output Queues — When a data frame is recognized as being from a new station, three queues may be issued:

1. BMDLSSU is queued to update the data table for the Low-Speed Input Display to reflect the new acquisition.
2. BMGPRIME is queued to print the start-of-transmission message:

DD:HH:MM:SS.CC **SE**) BMQLSINP (XXXB RADAR START
OF TRANSMISSION, VEHICLE N, PASSIVE/ACTIVE

where: XXXB = station name and band type

N = Vehicle number

ACTIVE = 2-way station

PASSIVE = 3-way station

3. The data transmitting DDD associated with the vehicle is queued to be turned on, if it is currently off.

Local vertical corrections for all data and azimuth deviation corrections for C-Band are made to a data frame by calling BLMREF. When a data frame is recognized as being the first valid point from a new station, two queues are generated:

1. BMGCHAIN is queued to obtain the next storage block and batch number.
2. BMDLSSU is queued to update the data table for the Low-Speed Input Display to reflect the time and batch number.

When an end of transmission is recognized (either from the data frame or the S22 MED), four queues may be issued:

1. BMDLSSU is queued to update the data table for the Low-Speed Input Display to reflect the end of transmission of that station.
2. BMGPRIME is queued to print the end of transmission message:

DD:HH:MM. CC **SE**)BMQLSINP(XXXB RADAR END OF TRANS-
MISSION, VEHICLE N XX OBS., YY DOPPLER, ZZ DEGREES,
PASSIVE/ACTIVE

where: XXXB = station name and band type
N = vehicle number
XX = number of observations saved
YY = number of doppler points saved
ZZ = maximum elevation

ACTIVE = two-way station
PASSIVE = three-way station

3. The data transmitting DDD associated with the vehicle is queued to be turned off if no other stations are transmitting for that vehicle.
4. BMGCHAIN is given control since the collection process is now complete for this batch.

Clarification of Requirements — The time sequence validity check is made by comparing the difference between the times of the current and the last data frames to the specified time between observations. In order to be valid this difference must be equal to or greater than the specified time. This time is initialized as six seconds but may be altered with the S29 MED. Refraction corrections are not made to valid data by BMQLSINP or any other module within the Low-Speed Input section because this is a function of Low-Speed Control.

When a station switches from two to three way or three to two way, the first point indicating the "different mode" will trigger EOT for the "old mode" before being discarded. The next point received will be the first point eligible for the "new mode" batch of data. If a site indicates "one way", and an EOT is inserted, the information about that transmission will be retained on the Low-Speed Radar Input Display. If a switch occurs from one way to two or three way, the automatic EOT will be inserted as indicated. This will be handled in the same manner if the switch is from two or three way to one way.

Additional Processing and/or Capabilities not in Requirements — Additional corrections applied to low-speed data include a correction added to the data time tag, range bias correction and vehicle/beacon ID change. These values are specified by MED S24, S25, and S26, respectively. Additional validity checks on each data frame include minimum elevation and valid vehicle/beacon ID. The value of minimum elevation is initialized as 3° but may be altered with the S28 MED.

Error Checks — Any data frame not passing all validity checks is not saved, and BMQLSINP ends all further processing of this data frame. It should be noted that an S-Band data frame can have a bad range and still be valid if the elevation is equal to or greater than 10°. The number of data frames received and saved is provided on the Low-Speed Input Display.

If an S22 MED is received for a station not currently transmitting, BMGPRIME is queued to print the error message:

DD:HH:MM:SS.CC **SE**) BMQLSINP (STATION NOT TRANSMITTING.

If collection storage is not available, BMGPRIME is queued to print the message:

DD:HH:MM:SS.CC **SE**) BMQLSINP (TOO MANY STATIONS TRANSMITTING.

This message is printed when a data frame is received for the new station and until collection storage is available. Data received from the new station during this period is not saved.

Operational Procedure — When the message given in the third error check appears, collection storage can be made available by entering the S22 MED (preferably on the oldest transmitting station).

Figure 7 is a functional flowchart of BMQLSINP.

Low-Speed MED Processor (BMQLSMED)

BMQLSMED has no mission phase restrictions. Its initialization is the first of the eleven input queues given below.

Input Queues —

1. Initialization - Queue from mission control supervisor for initialization of tables necessary to the low-speed input unit.
2. Start Routing - Queue from mission control supervisor to start routing all low-speed radar data to BMQLSINP.
3. Stop Routing - Queue from mission control supervisor to stop routing all low-speed radar to BMQLSINP.
4. S24 MED - Queue to specify a time to be added to data time tags.
5. S25 MED - Queue to specify a correction to be added to future incoming ranges.
6. S26 MED - Queue to change the interpretation of an input ID.
7. S27 MED - Queue to specify limits (minimum and maximum) on batch size.
8. S28 MED - Queue to specify the minimum acceptable elevation.
9. S29 MED - Queue to specify the minimum time between observations collected in a batch.
10. S30 MED - Queue causing a partially complete batch to be available for refraction correction, while also keeping the batch open for the addition of future incoming data.
11. S32 MED - Queue to set the three-way processing indicator ON or OFF.

Output Queues — BMGPRIME is queued to print an on-line error message when an error is found in the beacon or frequency number entered in the S25 or S26 MED (see "Error Checks").

When the S30 MED is received, the following output queues are generated:

1. BMGCHAIN is queued to supply a new batch and block number for the duplicated batch and to signal EOT on the old batch.

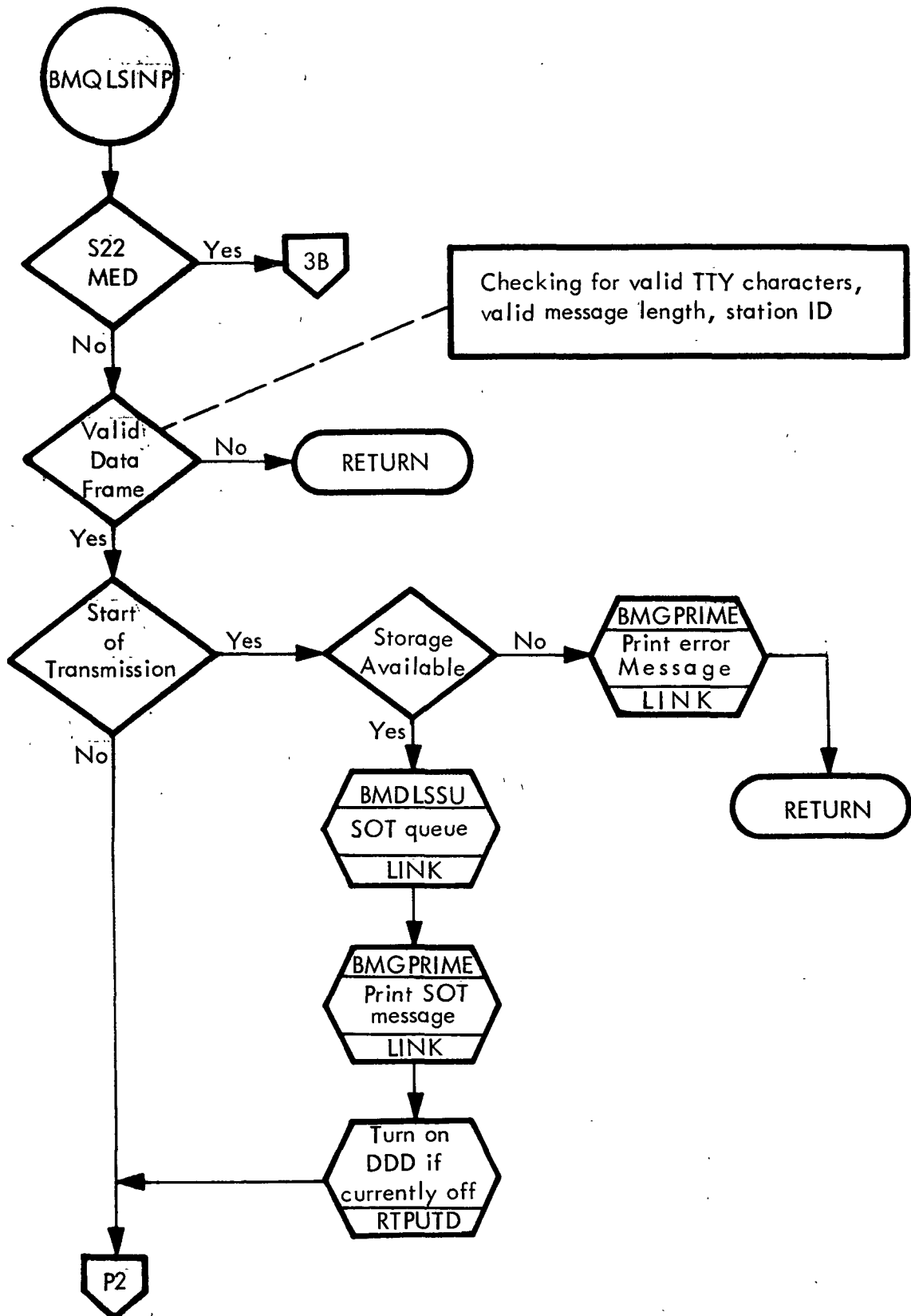


Figure 7. BMQLSINP Flowchart

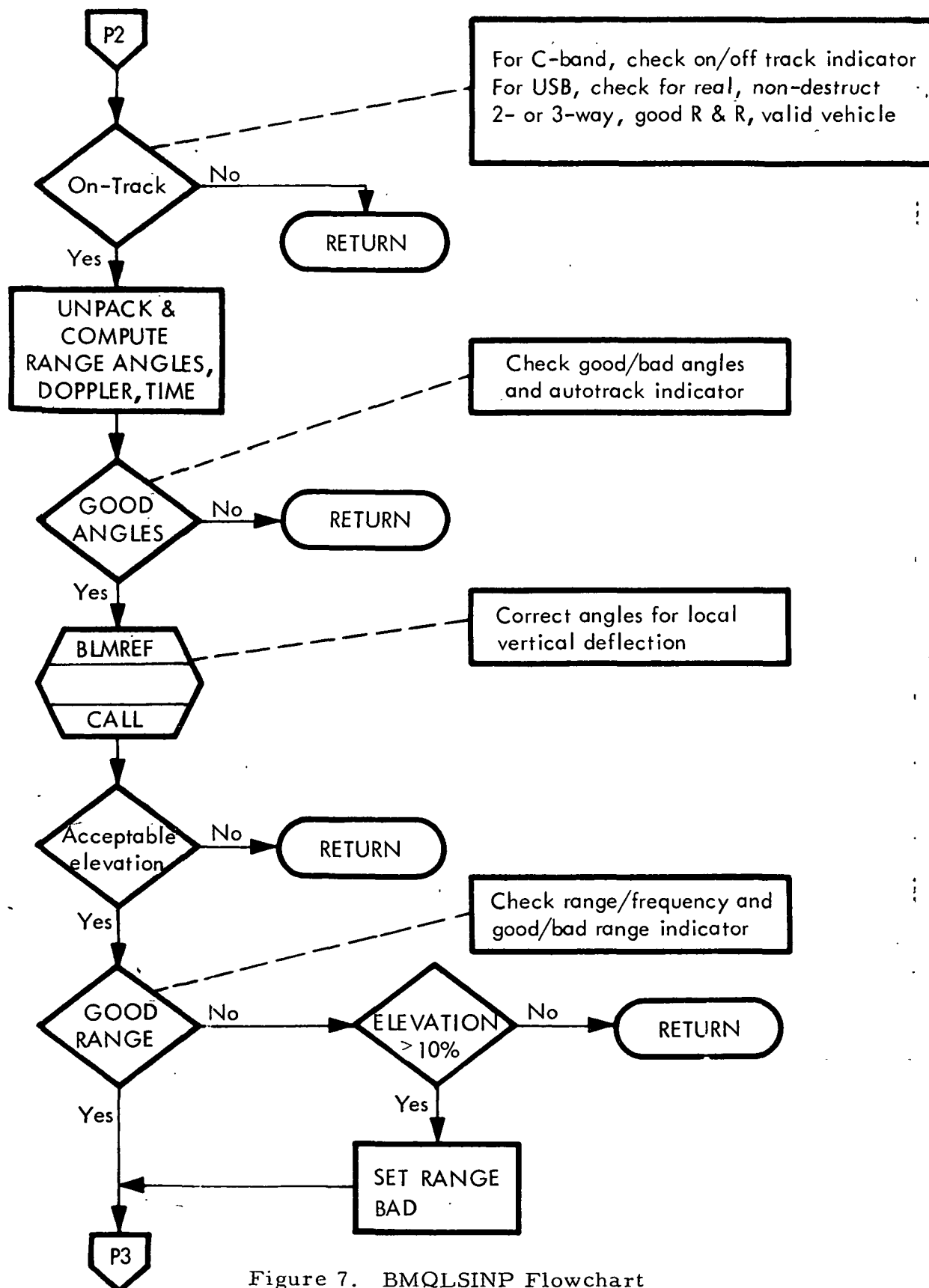


Figure 7. BMQLSINP Flowchart

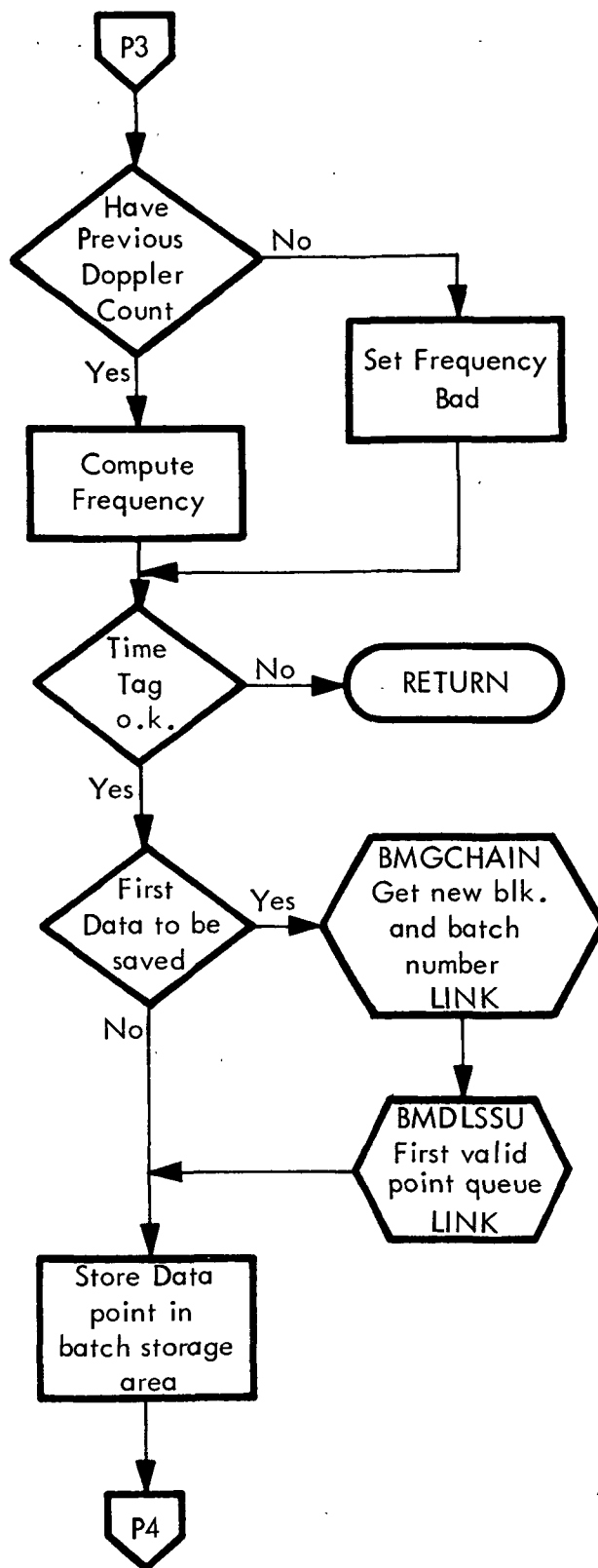


Figure 7: BMQLSINP Flowchart

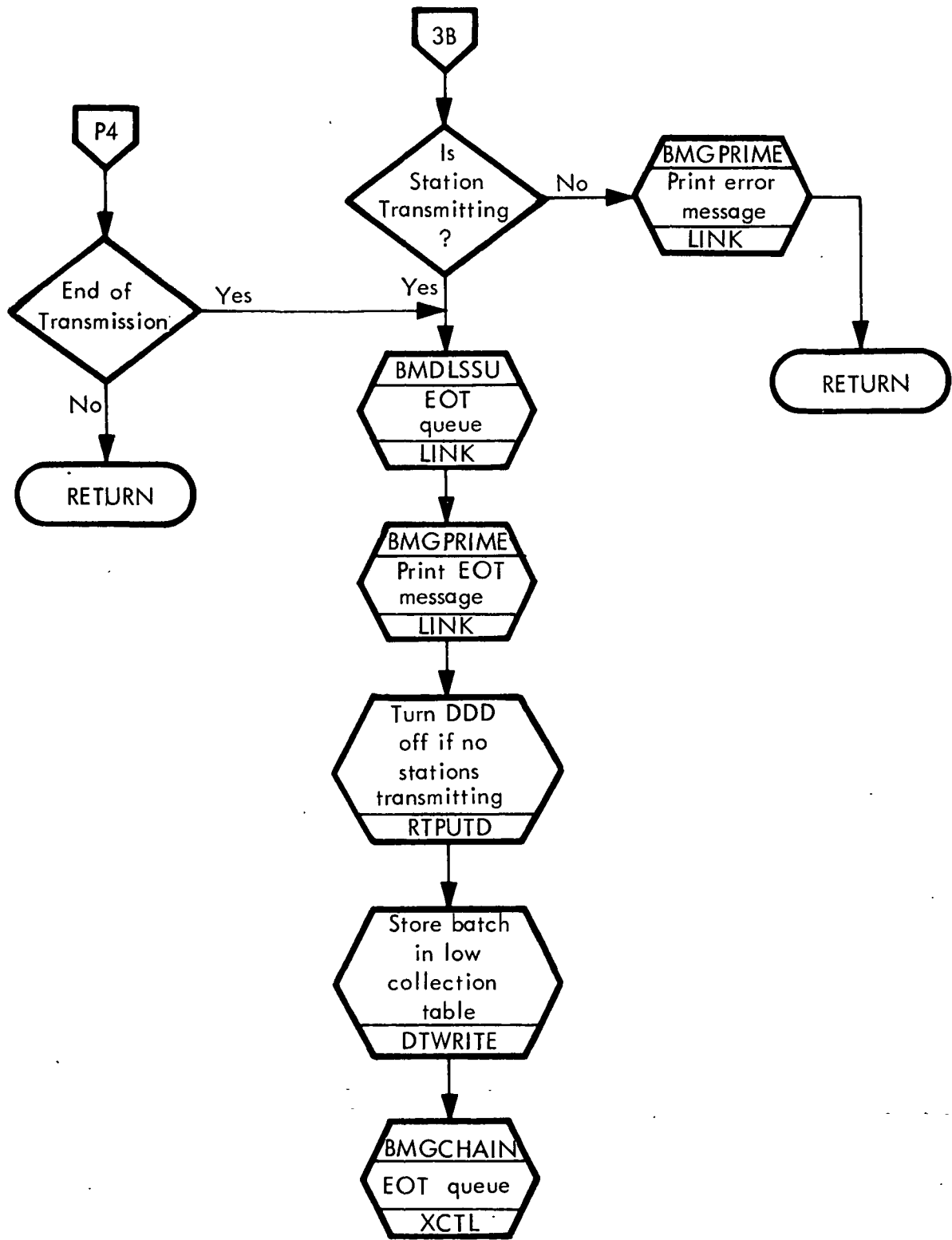


Figure 7. BMQLSINP Flowchart

2. BMDLSSU is queued to provide new information for the Low-Speed Input Display.
3. BMGPRIME is queued to print the duplicate batch message:
DD:HH:MM:SS. CC **SE**) BMQLSMED (DUPLICATE BATCH FOR
XXXB, VEHICLE N, YY OBSERVATIONS. *

*XXXB = Station name and band types
N = Vehicle number
YY = Number of observations saved

Clarification of Requirements — In the MED's that require a vehicle code (S22, S24, S26, S27, S28, S29, S30, S32), that code will be the first parameter entered after the MED code. If the vehicle code is a missing item for the S22 or the S26, the assumed vehicle number is zero.

Error Checks — A check is made by the S30 MED to verify that the station/vehicle combination is currently transmitting. If not, BMGPRIME is queued to print the following message:

DD:HH:MM:SS. CC **SE**) BMQLSMED (STATION NOT TRANSMITTING.

If it is transmitting, but fewer than the minimum number of points specified for a batch have been saved, BMGPRIME is queued to print the following error message:

DD:HH:MM:SS. XX **SE**) BMQLSMED (NO DATA SAVED FOR
REQUESTED STATION.

If an illegal beacon or frequency number is entered, the S25 and S26 MED's cause the following message to print by BMGPRIME:

DD:HH:MM:SS. XX **SE**) BMQLSMED (BEACON NUMBER TOO LARGE.

A flowchart of module BMQLSMED immediately follows (Figure 8).

Modify Station Characteristics (BMGSTA)

No initialization is required for this module. It will operate in all phases when an S00, S01, or S02 MED is entered. An input queue is received for each of the following MED codes:

1. S00 - Modify station capability indicators
2. S01 - Change station characteristic values
3. S02 - Change station location

BMGPRIME is queued to print error messages, which are the only output queues (See "Error Checks").

Clarification of Requirements — The values which may be changed with the S01 MED are listed below.

<u>Item No.</u>	<u>Description</u>
18	Local vertical deflection in longitude
19	Local vertical deflection in latitude
20	Azimuth deviation from true north
21	Refraction modulus
23	Range granularity
24	Angular granularity
25	Decay constant (K)
26	Sigma coefficient #1
27	Sigma coefficient #2
28	Sigma coefficient #3
29	Sigma coefficient #4
32	Transmitter frequency #1
36	Transmitter frequency #2
37	Maximum slant range
38	Range bias

Additional Capabilities not in Requirements — The capability to move a station, changing latitude, longitude, or height, is provided by BMGSTA in the S02 MED.

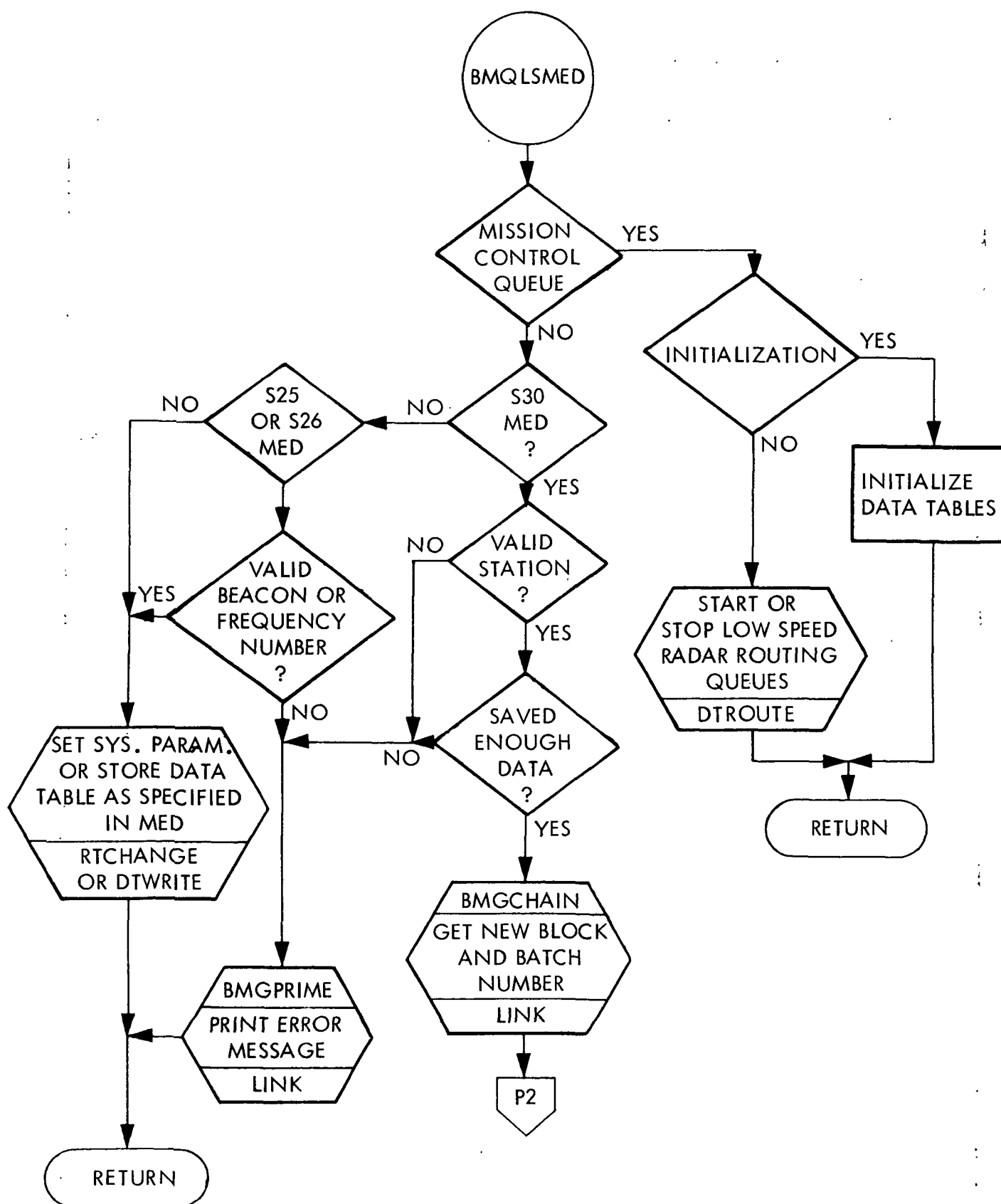


Figure 8. BMQLSMED Flowchart

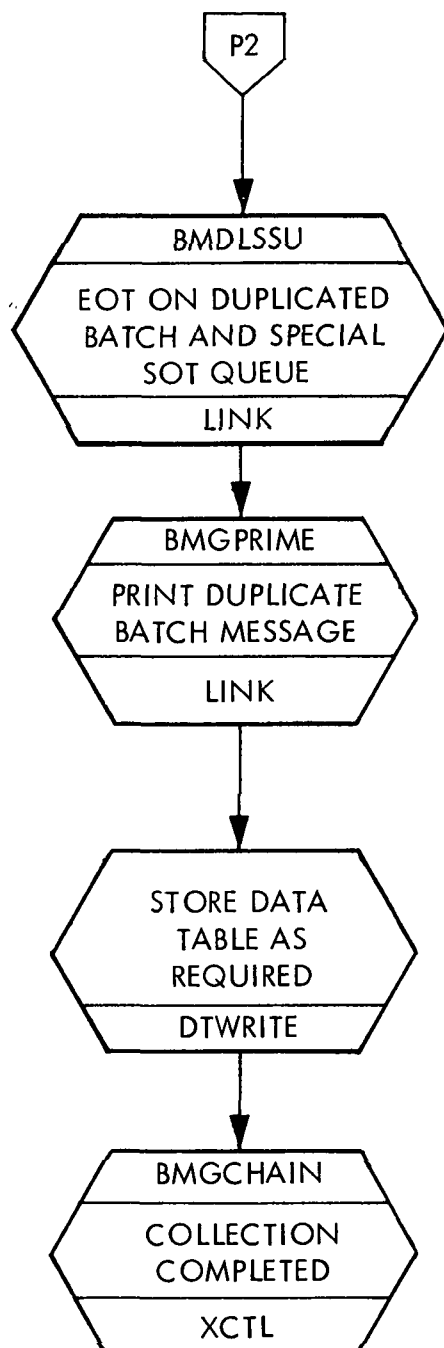


Figure 8. BMQLSMED Flowchart

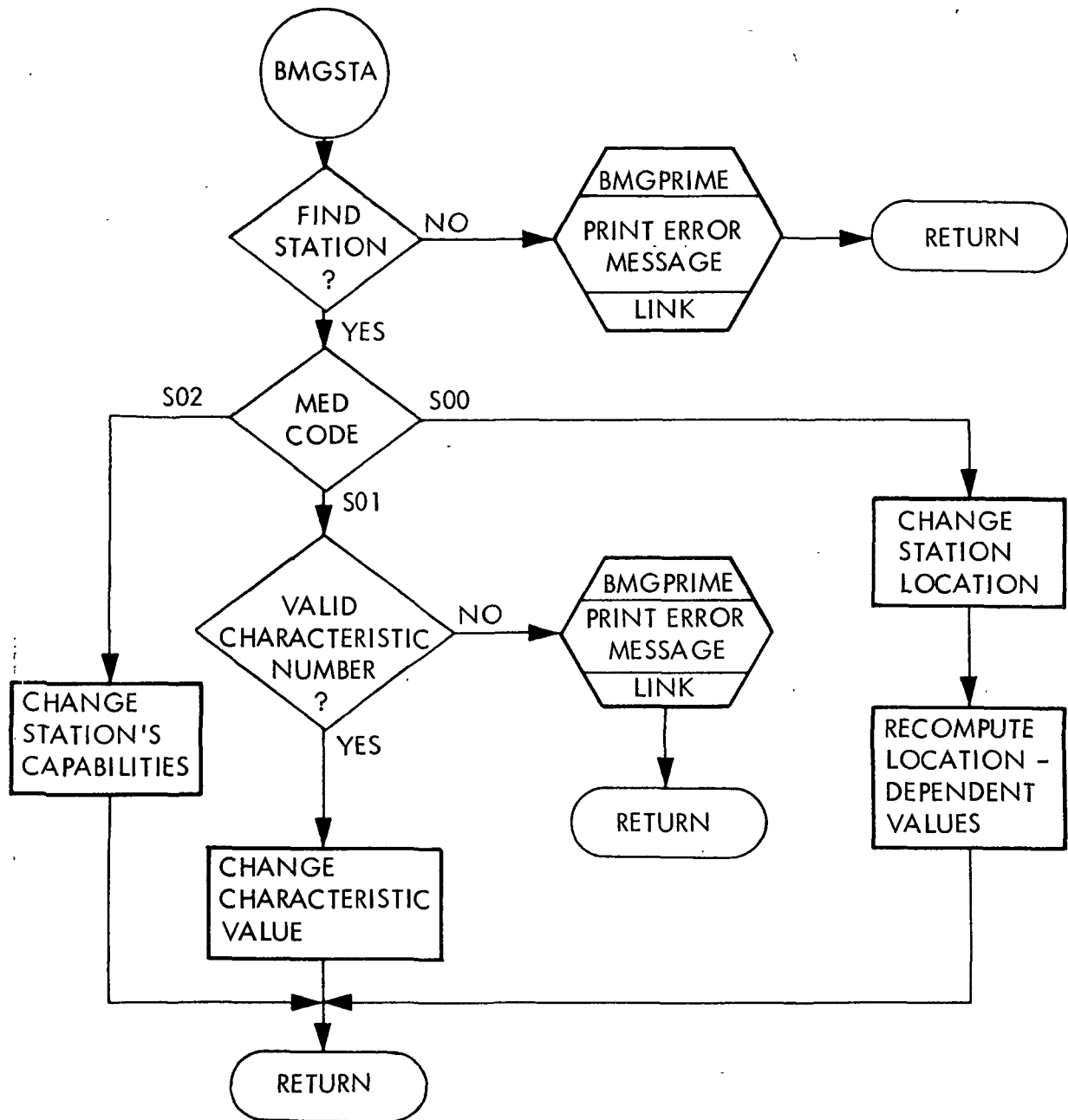


Figure 9. BMGSTA Flowchart

Error Checks — If the station name entered in either the S00, S01, or S02 is not found in the station characteristics table, the following message is printed by BMGPRIME before BMGSTA returns control to the system:

DD:HH:MM:SS. CC **SE**) BMGSTA(ILLEGAL CHARACTERISTIC NUMBER

Figure 9 is a flowchart of module BMGSTA.

Low Speed Display Data Table Setup (BMDLSSU)

No initialization is required for BMDLSSU; no mission phase checks are made.

Input queues — A queue is received from BMQLSINP when a station begins transmission. The STATION (without batch number) is entered into the low-speed input display data table with the current Greenwich Mean Time (GMT) as the STATION ANCHOR TIME, since no valid data frames have been collected. The chain of stations in the data table is ordered on STATION ANCHOR TIME with the latest time first. In addition to the asterisk, which identifies the STATION as transmitting (T), the following values are placed in the data table for future display:

1. Vehicle (VEH)
2. Number of observations transmitted (N_T)
3. Vehicle/beacon ID (ID)
4. Number of observations saved (N_{DC}) - (C-Band only)
5. Number of positional observations (N_{ANG}) - (S-Band only)
6. Number of doppler observations (N_{DC}) - (S-Band only)
7. Doppler mode (MODE) - (S-Band only)
8. Observation rate (RATE) - (S-Band only)

Values that do not apply to that radar band are blanked.

The second type of queue occurs when the first valid (i. e., collected) data frame is processed by BMQLSINP. At this time, BMDLSSU is queued. The STATION with the assigned batch number is entered in the data table in place of the STATION entered as a result of the start-of-transmission

queue. The previously entered STATION ANCHOR TIME is replaced by the GMT of the first valid data frame. The chain of stations is then reordered, if necessary, based on the new STATION ANCHOR TIME.

A third queue is received from BMQLSINP when a station ends transmission. The same changes are made as on a start-of-transmission queue (see first queue). In addition, the transmission indicator (T) is set to a blank.

When a request is made to duplicate a batch from a transmitting station, a fourth queue is received from BMQLSMED. A new entry is placed in the data table for the duplicated batch with a new batch number assigned. The STATION ANCHOR TIME is the same as the transmitting station. In addition to setting the transmitting indicator (T) to a blank, the same values (as in the first queue) are placed in the data table as for a new entry on a start-of-transmission queue.

Output queues — No output queues are generated by this load module (See "Clarification of Requirements").

Clarification of Requirements — Because only twenty stations are shown on Low-Speed Input Display, the data table maintained by BMDLSSU only retains the twenty most current entries (based on STATION ANCHOR TIME). No distinction is made between transmitting or non-transmitting stations. Upon receiving an input queue, BMDLSSU changes only the values in the data table, not the displayed quantities. The displayed quantities will reflect the changes on its next update or generate cycle.

Error Checks — No error checks are made because this module orders data that has already been verified as valid.

Figure 10 is a functional flowchart of BMDLSSU.

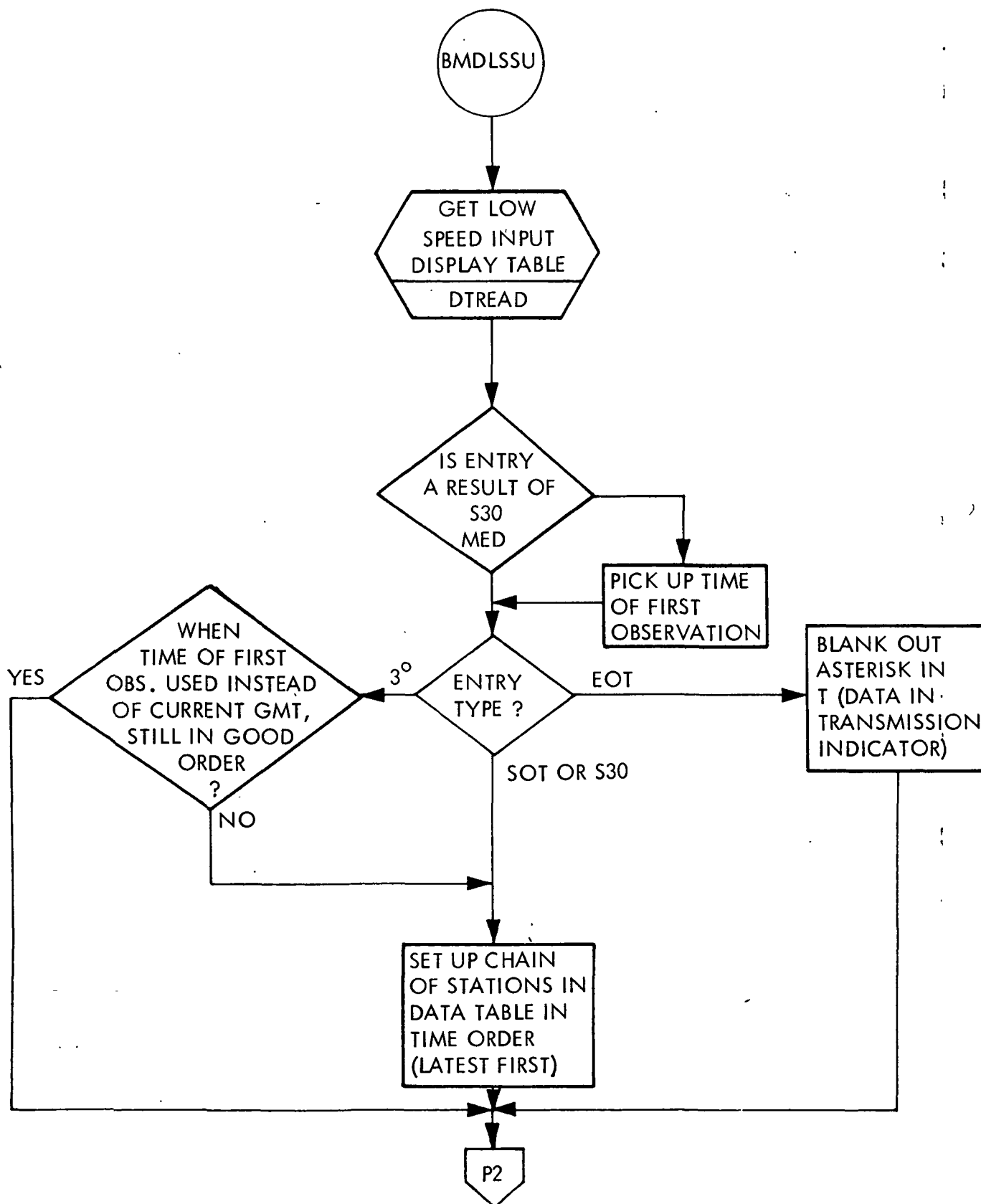


Figure 10. BMDLSSU Flowchart

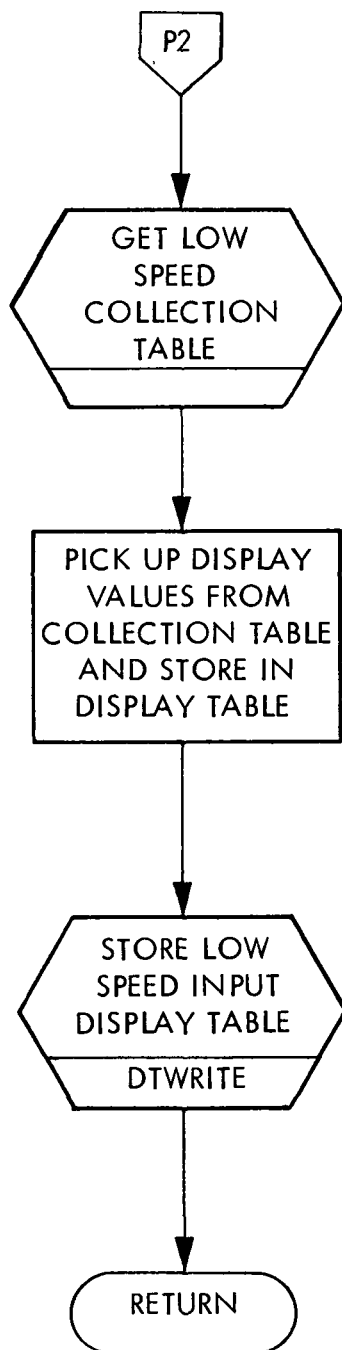


Figure 10. BMDLSSU Flowchart

LOW-SPEED CONTROL

General Requirements

After a batch of radar data is collected, it may be used in the orbit determination process. This processing is acceptable in the following phases:

1. All low-speed aborts
2. Low-speed prelaunch II
3. Low-speed orbit
4. Low-speed trans-earth
5. Low-speed trans-lunar
6. Reentry.

Several sources provide the required input. The radar data is obtained from the low-speed input table, BZLSINPT. The starting vector is obtained from either the launch transfer, a P13, P14, or P06 MED, the Usable Vector Table, the Evaluation Vector Table, or the DC History Table. The covariance matrix is obtained from either the DC History Table, pre-mission initialized parameters or MED-initialized parameters.

Batches of data are processed sequentially. The Propagation Control Program obtains the next sequential batch of data from the chaining program. No low-speed data is used during maneuvers. Chaining will eliminate this maneuver data by creating a new data batch which contains only non-maneuver observations.

Riley conditioning is performed on the covariance matrix prior to propagation for an SS2, SS3, or multistation solution. The anchor state vector (ECI) is integrated backward free-flight and forward through maneuvers to the time of the first observation of the next data batch. If either propagation limit falls within 1.1 Earth radii of the Earth's center, the K factor is modified, and an integration is performed to obtain the drag-perturbed vector needed for secant drag partials in free-flight propagation of the covariance matrix. Powered-flight propagation of the covariance matrix requires special integration and is discussed under Low-Speed Math.

Upon completion of propagation, control is passed to the DC Control Program. This program sends pre-DC information to the DC Summary Display, performs initialization of parameters, and controls to some extent the actual differential correction process. An ECI free-flight ephemeris is obtained over the entire

data arc for the computation of residuals. The convergence program provides an update to the state vector and covariance matrix and determines if the solution is converging or diverging. When either the maximum number of iterations is reached or either convergence or divergence is achieved, the DC control program requests "selection editing". If no additional editing is required, an accept or reject decision is made based on the value of the figure of merit and the percentage of points edited.

Output parameters are computed from the new solution, and post-DC information is sent to the DC Summary Display and the on-line printer. If in manual mode, the "waiting" indicator is set, and the program becomes dormant. If in automatic mode, the DC Control Program passes control back to the Propagation Control Program for processing the next batch of data.

This has been a description of the most simplified form of DC processing. Manual intervention plays an important and significant role in the differential correction process. Entries are made via either a pushbutton indicator (PBI) or a send/receive teletypewriter (MED).

Pushbutton indicators (PBI's) are divided into three categories: decision, mode, and modification. A vehicle PBI (CSM or LM) must be depressed with each entry. No entry will be accepted if the DC is in a suppressed condition.

1. Decision - The ACCEPT PBI may be used in the manual mode to accept a DC solution. The PBI Control Program sets the accept indicator, turns off the "waiting" DDD, and passes control to the Propagation Control Program for processing the next batch of data.

The REJECT PBI may be used in the manual mode to reject a DC solution. In this case, the PBI Control Program moves the propagated state vector and covariance into the solution slot of the DC history table. The reject indicator is set, the "waiting" DDD is turned off, and control is passed to the Propagation Control Program for processing the next batch of data.

2. Mode - Any mode PBI may be entered with a PBI or with only the vehicle PBI. Depression of the MANUAL PBI will cause the program to wait on controller action following the next differential correction. The program is initialized in the manual mode. The "auto" DDD will be turned off and the "manual" DDD turned on. Depression of the AUTO PBI allows the program to proceed based upon program decision logic. The "manual" DDD will be turned off and the "auto" DDD turned on. For

both the MANUAL and AUTO PBI, control is passed to the Propagation Control Program. Depression of the NO-UPDATE PBI will result in no change in the DC slot of the Usable Vector Table (UVT). The "no update" DDD will be turned on, and the "update" DDD turned off. The program is initialized in the no update mode. Depression of the UPDATE PBI determines if an accepted DC vector may be used to update the ephemeris. If this PBI is depressed only with the vehicle PBI, then the last accepted DC vector for that vehicle will cause that vector to be entered in the DC slot of the Usable Vector Table. The "no update" DDD is turned off and the "update" DDD is turned on.

3. Modification - The "waiting" DDD is turned off on each entry. The modification PBI's can be further categorized as follows: SS, K gamma, K alpha, K rho, MOD F and FORCE. In all cases, the modification affects only the current set of data.

The SS (covariance) category contains four PBI's. Depression of the SS1, SS2, or SS3 PBI causes the current covariance to be ignored and a DC to be performed on the current batch of data using the PBI selected covariance. The matrix diagonal elements are set to infinity for SS1; pre-mission initialized values are used for SS2; and MED initialized values are used for SS3. The SS3 values are zero until initialized by MED. Depression of the MULTITATION PBI will cause a normal multistation solution to be performed on the current batch of data. This will override previous usage of manual controls on the current batch of data.

Depression of either K gamma PBI will cause the input covariance matrix to be multiplied by a constant (even if the input covariance is SS2 or SS3) and a subsequent DC performed on the current batch of data. If entered several times, the value will be multiplicative. The current value used for K gamma LARGE is ten, and that for K gamma SMALL is five.

Depression of either K alpha PBI will cause the a priori station weights to be multiplied by a constant and a subsequent DC performed on the current batch of data. The current value used for K alpha LARGE is five and for K alpha SMALL is three.

Depression of the K rho PBI's cause a repropagation, and the variances for μ and drag are set to zero for K rho ZERO and are multiplied by two for K rho LARGE.

The MOD F PBI modifies the coefficient of the Riley conditioning term using the following formula:

$$\text{covariance (I, I)} = \text{MODF} \times \text{Riley}^2 \times \text{Vector (I)}^2 + \text{covariance (I, I)}.$$

A value of zero is used for MOD F ZERO, and a value of ten is used for MODF LARGE. A DC is subsequently performed on the current batch of data.

The FORCE PBI causes the program to perform another convergence iteration on the batch of data awaiting a decision. No selection editing is performed.

MED's, in general, change a variable parameter, cause reprocessing, or both. Reprocessing causes the "waiting" DDD to be turned off, if it is on. No reprocessing MED's are allowed in automatic mode.

1. Insert Late Reporting Station - Through the use of this MED a late reporting station can be time sequenced into the post-DC chain. This does not cause rechaining. The DC Program begins a repeat from the batch specified in the MED; so to process the inserted batch, the controller must repeat from a batch with a time tag prior to the inserted batch. This MED may be used for repeating by omitting the batch to be inserted.
2. Exclude/Include - This option may be exercised on data in the post-DC chain or with data still transmitting. If excluded, a station may be processed only by using the include option. This MED does not have recycle or repeat capability.
3. Change Coefficients for Maneuver Uncertainties - The maneuver uncertainty coefficients may be changed by the MED. The modified uncertainties are printed on-line during the maneuver propagation. The DC process begins a repeat from the batch specified in the MED.
4. Specify DC Edit Coefficients - Three standard deviations is the nominal value used in DC editing. The editing coefficient for each element may be changed by the MED and used in the first DC performed in the repeat.
5. Recycle - This MED will cause data to be rechained in time order, taking into account any maneuvers that may have occurred. The vector ID and

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and covariance ID are optional, and the vector may have a later time tag than the data to be processed. The covariance matrix will assume the time tag of the vector and, thus, will probably have to be propagated. This MED must be able to access the following vector tables for the specified vector: (1) the Usable Vector Table, (2) DC History Tables, and (3) the P14 or P13 initialization vector table. If the vector ID and COVARIANCE options are entered, then rechaining will not be done, only a repeat.

6. Specify Pre-edit Criteria - A MED may be entered so that after computation of the residuals (and subtraction of appropriate biases), the pre-edit program will "tag" all points with residuals greater in value than the entered values. These points may be "untagged" during the DC edit.
7. DC Starter - When the starter MED is entered, the program will obtain a starting vector from the specified data batch and subsequently perform a single station solution on the data using the starting vector as the uncorrected input vector.
8. Suppress/Resume DC - Input of the STOP DC MED will cause no processing to take place on data collected for the specified vehicle. Data will continue to be collected, but no processing will take place until the MED is reentered with START DC.
9. N_1/N_2 Edit - Upon entry of the time pre-edit MED, the program will immediately "tag" the indicated type of observations for the given time interval.
10. Input SS3 Variances - The SS3 matrix diagonal is determined using values specified in the MED.
11. Update Table of Biases - This MED allows the controller to either delete or place (or change) a value in the table of biases for unified S-band (USB) data.
12. Superbatch-BEGIN - This MED is necessary to initialize for superbatch processing on a particular vehicle. It indicates that a series of MED's will follow to define the superbatch.
13. Superbatch Exclude - This is an optional entry. This MED, entered following the "BEGIN" entry, will cause the specified batches not to be

considered in the superbatches solution. Should a later "BEGIN" entry be made, the previously excluded batches would not be excluded unless this MED was entered again.

14. Superbatch Biases - This is an optional entry. This MED specifies the type of bias to solve for a particular radar station (or stations). Any combination of one, two, or three biases may be solved. When the superbatches solution is accepted, the computed bias value will automatically be stored in the bias table.
15. Superbatch Batches - This entry defines the stations to be used for the superbatches, the input vector, and covariance matrix. If "NOMINAL" is entered for the vector, then the program will choose the vector and covariance matrix immediately prior to the first batch in the superbatches as it was input to the superbatches DC. If a T/M vector or "STARTER" is entered, then a covariance matrix code must also be entered. If "STARTER" is used for the vector input, then the program will use all two-way data inclusive between the beginning and ending stations to compute a start vector. The covariance matrix will assume the time tag of the input vector. This is necessarily the last MED used to initialize superbatches processing.
16. Eliminate Angles in DC - This entry causes angles of the observations for the specified vehicle not to be used in all subsequent DC's; however, residuals for the angles will still be computed for display on the Batch Residual Plot and the Residual Summary Statistics displays.
17. Use Nth Range - This MED causes the USB range observations for the given vehicle to be downweighted. The weight given to range will effectively be that of using only every Nth range. The a priori weight-given range will be

$$\frac{1}{N} * \frac{1}{\alpha^2 \sigma_R^2}$$

where σ_R is the range sigma, α is the value for the alpha switch, and N is the Nth range option.

18. Low-Speed Initialization Time - This MED will cause the DC routine to be initialized with "INSERT" time defined as the input GMT; all stations following will be rechained. Entry of a restart vector will not affect

the DC routines unless this particular MED is entered. The specified GMT can be before or after the time tag of the restart vector. The vector ID may be a vector from the Usable Vector Table, P14 (or P13) initialization vector table, the DC history table, or the launch transfer table.

19. Two-Way Site Timeline - This MED specifies the time at which a USB station became (or will become) active. The entry is placed in the two-way site table. It cannot be deleted from the table, but it can be changed.
20. Duplicate Batches for Another Vehicle - This MED is intended to be used while two vehicles are docked so that low-speed radar data can be used in DC's for both vehicles. It takes batches of data from one vehicle and creates duplicate batches, which it inserts into the pre-DC chain of the other vehicle at the proper place in time. As many as five batches may be duplicated with one MED. They may be in either the pre- or post-DC chain of the first-named vehicle, and they must have ended transmission.

Design Discussion

BMSINT

There are three ways in which the DC Initialization Program can be entered: (1) from GMSCTRL at launch-to-orbit transfer, (2) from RMSPECT at launch to abort transfer, and (3) from the MED decoder on an S20 MED. The S20 starting vector will be obtained as specified by the vector ID in the MED.

If PREBURN or CURRENT is the vector ID specified in the S20 MED, the starting vector will be obtained from the Launch Transfer Table. If NOMINAL is specified, the last P13 or P14 vector is obtained. Otherwise, the vector is taken from either the Usable Vector Table or the DC History Table. If the PREBURN or CURRENT vector ID is specified on the S20 MED and no GMT is input, a launch transfer is simulated. The Launch Transfer Table will be interrogated and integration performed as described below. BMSINT will no longer be called as a result of an M01 MED entry. If a GMT option is specified with the PREBURN or CURRENT vector ID, the S20 integration logic will be used. Backward integration will be performed in the following situations:

1. When the launch transfer vector is pre-burn and greater than low-speed collection time, integrate back to low-speed collection time.
2. When the launch transfer vector is current and greater than GMT of the secondary propulsion system (SPS) cutoff, integrate back to GMT of cutoff.
3. When the launch transfer vector is current and less than GMT of SPS cutoff, integrate back to low-speed collection time.
4. When the launch transfer table contains a zero maneuver, and the launch transfer vector (pre-burn or current) is greater than low-speed collection time, integrate back to low-speed collection time.
5. When the time specified in the S20 MED is less than the time tag of the vector specified, integrate back to the specified time, ignoring maneuvers in the Mission Plan Table (MPT).

If an integration error occurs for launch transfer, the DC will initialize with the transferred vector. For the S20, the DC will not be initialized, and MISHAP 11 will be displayed. In the case of the S20, integration may be forward as well as

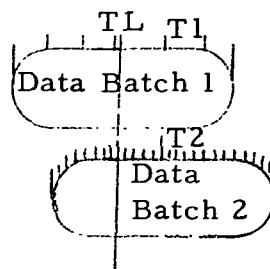
backward. Forward integration will consider maneuvers, but all backward integration will be free flight. Integration will be in the ECI coordinate system. If the starting vector (launch transfer or S20) is time tagged during a burn, the burn is ignored.

For acceptable entries to BMSINT, the data for the specified vehicle will be put into the pre-DC chain. Absolutely no entries will be accepted by BMSINT if DC processing is suppressed for the vehicle specified. Figure 11 shows the S20 MED logic used by BMSINT.

BMGCHAIN

The chaining Program receives several types of entries.

1. Communication with Low-Speed Input - When the input program receives an acceptable observation from a station and no data block is reserved for the new batch, a data block is requested from BMGCHAIN. Data which is still transmitting cannot be overlayed. If no free blocks exist, BMGCHAIN uses the oldest block in the pre-DC chain of either vehicle. If there are no blocks in either pre-DC chain of either vehicle. Data is not automatically discarded by a maximum time. (For this reason the controller should always force an EOT on data which apparently will never receive a transmitted EOT.) The post-DC chain contains a maximum of 30 blocks per vehicle. For any EOT, manual or transmitted, the input program passes BMGCHAIN an indication, and the data becomes available for the DC process.
2. Data Available - If the DC process is in an idle state when the data-available entry is received, BMSLPC requests the next batch of data between t_{left} and t_{right} . For a no-maneuver situation, t_{left} will be the insertion time discussed in BMSINT, and t_{right} will be a very large number. If t_{left} falls within a batch, the observations later than t_{left} will be moved into a new data block and become a new batch. The new batch must contain at least six observations; otherwise, it will never be formed. BMGCHAIN saves the time tag of the data returned and always returns to BMSLPC the next sequential batch of data. If t_{left} falls within several batches of data, the batches will be processed (split) in the order of time of first observation. The following condition may exist.



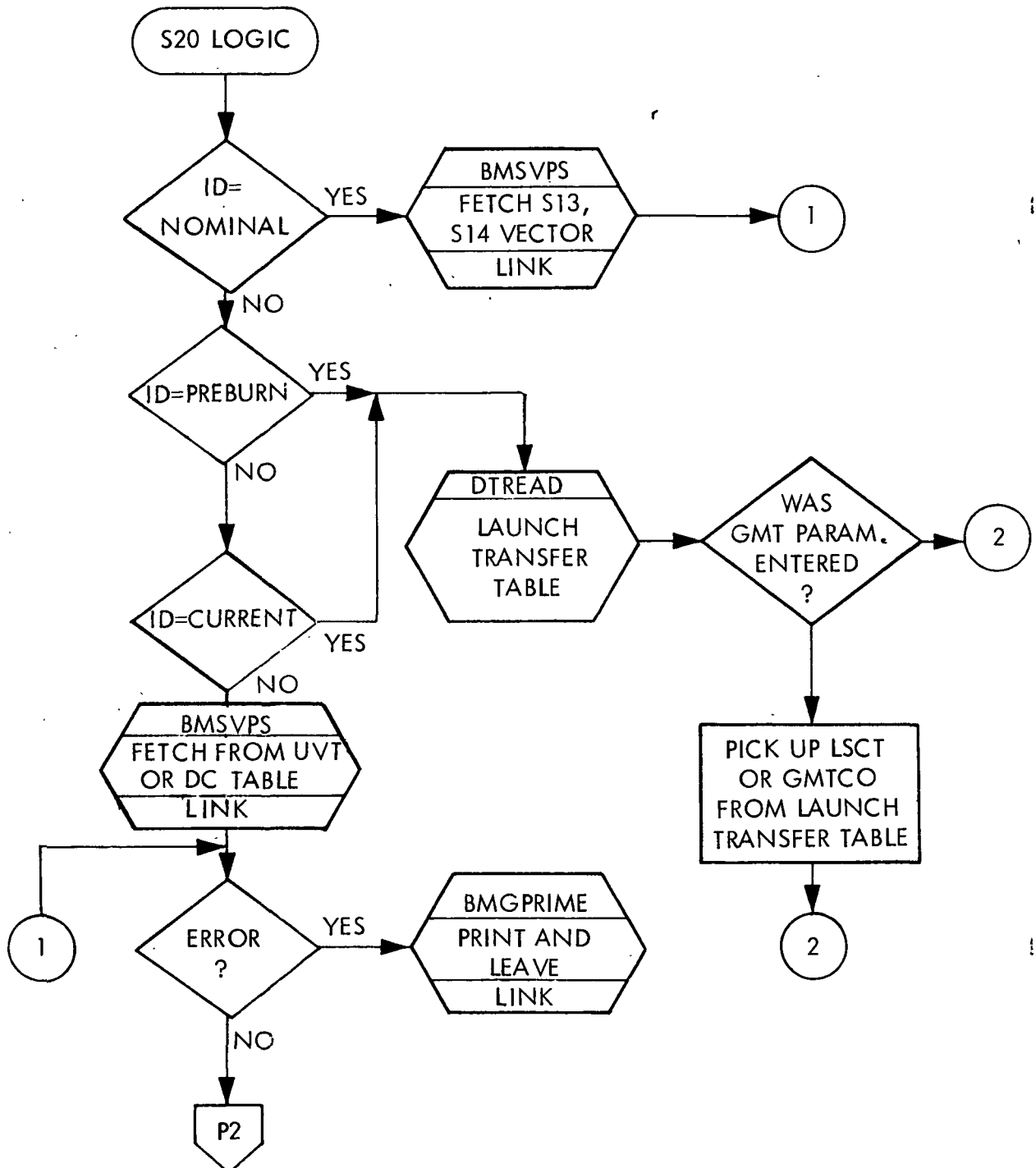
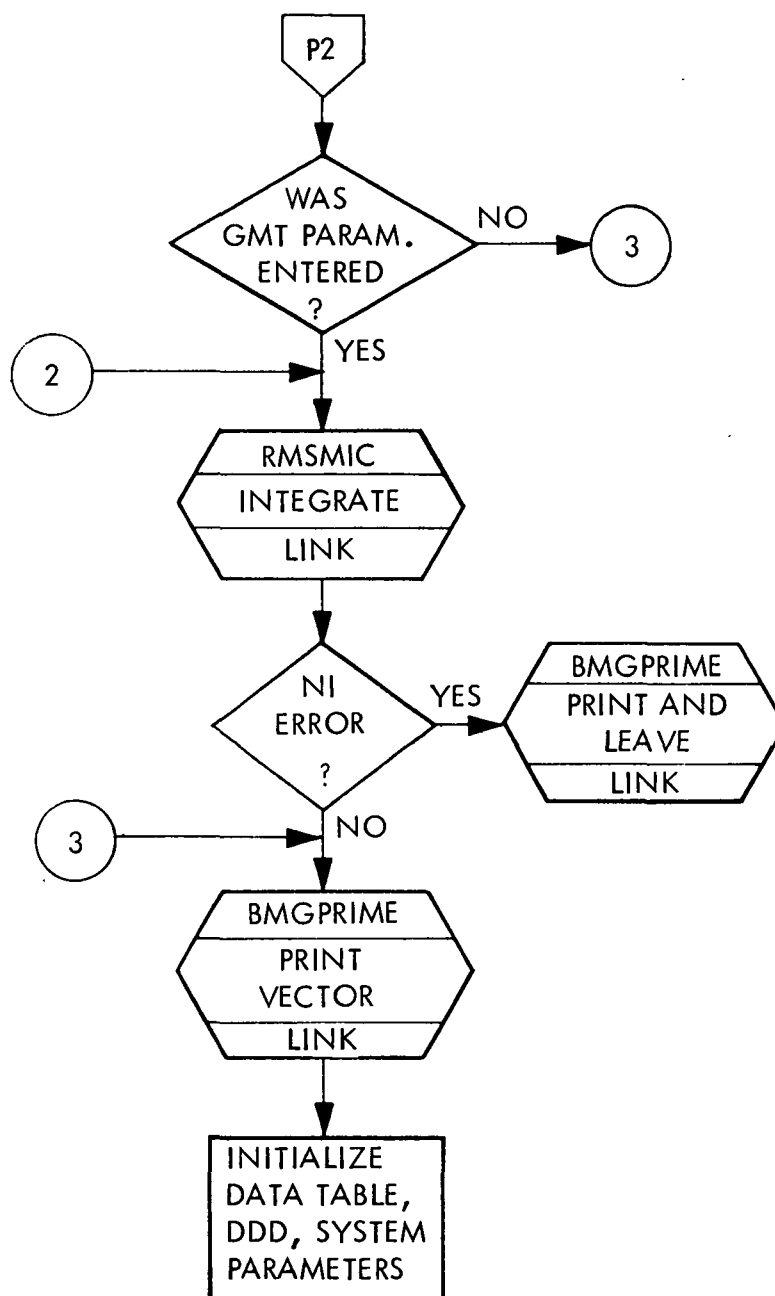


Figure 11. S20 MED Logic Used by BMSINT
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Figure 11. S20 MED Logic Used by BMSINT
(Sheet 2 of 2)

If the data rate for batch 1 is thirty seconds and the rate for batch 2 is six seconds, batch 1 will be split first because it first started saving data. When batch 2 is split, only observations after time T_1 will be saved and, thus, up to four of the observations in batch 2 will not be used. This is necessary to maintain sequential processing. Refraction correction is handled in the following manner: When a new batch is created by a start of transmission queue from low-speed input, BMGCHAIN will set an indicator for that batch in BZCHAIN to on, meaning that the data batch has not been corrected for refraction. After EOT, when BMSLPC queues BMGCHAIN with a data request, the data batch which is selected will be corrected for refraction before it is returned to BMSLPC, and the refraction indicator will be turned off for that batch. If the data is split, BMGCHAIN will queue BMMTRC to correct the mother batch before splitting it. The refraction indicator will be set off for both the mother and the offspring batches. If the mother batch cannot be corrected, BMGCHAIN will split the data, then queue BMMTRC to refract the offspring and turn only its refraction indicator off.

If data is selected which cannot be corrected for refraction, a message will be printed on-line stating that the batch has not been corrected, and the refraction indicator will be left on. The data will be returned to BMSLPC for use in the DC process, however.

In the case of maneuvers, all above statements are true. The times for chaining, t left and t right, are obtained from the mission plan table. BMSLPC compares the time of the current anchor vector with the beginning time of each maneuver until a maneuver begin time is greater than the vector time. The maneuver begin time becomes t right for chaining, and the end time of the previous maneuver becomes t left. BMGCHAIN creates a new data batch using only observations within the specified time. The DC is performed on the data, and BMSLPC requests the next data batch using the mission plan table times once again. This process continues until BMGCHAIN returns an indication to BMSLPC stating that no more data exists in the specified time interval, but more data does exist. BMSLPC then goes to the next maneuver and repeats the procedure. BMSLPC continues through the mission plan table until either data is available in a specified time span or until no more data exists. An extremely large number is used for t right after the last maneuver.

After the data is obtained, BMSLPC integrates to the time of the first observation. This can include integration through one or more maneuvers. For guided maneuvers, the DC process can possibly obtain a maneuver-end time different from the one in the mission plan table. If the time of the

first observation of the data to be processed is less than the DC maneuver end time, BMSLPC will request rechain from the previous data batch. Then the data will be resplit by BMGCHAIN using the DC maneuver end time at t left. This situation may never occur, but it is possible.

3. Repeat/Rechain - The rechain entry, alias recycle, causes all data with time tags greater than the specified batch to be put into the pre-DC chain. If the mother batch of a split batch still exists, the split batch is discarded. The batch specified may be any batch in the DC history chain. The data is then obtained for the DC by using the data request entry to BMGCHAIN. BMGCHAIN will check the refraction indicator when it selects the data and not re-correct any previously corrected data. If a split batch is rechain and resplit, and if the mother batch is already corrected, the new split batch will not be re-corrected. The rechain may be used to try again to correct and re-DC the post-DC chain data which has not been corrected. The rechain should be used if a history maneuver definition changes.

The repeat is used for general reprocessing. Upon receiving a repeat batch number, BMGCHAIN returns the next batch of data in the post-DC chain. On a repeat data queue from BMSLPC, BMGCHAIN will neither do any refraction correction nor check the refraction indicators.

4. MED's - Three MED's affect the chaining table. An insert late reporting batch moves the specified batch from the pre-DC chain into the post-DC chain. If the batch should be split by maneuvers, then a rechain should be used instead. The include/exclude MED results in data batches being tagged or untagged. These batches may be in the post, pre or transmitting chain. If data in the post chain is excluded and a repeat is performed, the batches in the DC history table may differ from the batches in the post-DC chain. An excluded batch in the post chain will remain there until a rechain is performed. It must be remembered, however, that if a split batch is excluded, the mother batch is excluded on a rechain. This is necessary because on a rechain split data is released. The include/exclude MED cannot enter if the DC is suppressed for the specified vehicle.

The duplicate batches for another vehicle will operate as described in the description of general requirements. If any batch cannot be found or has not ended transmission when the MED is entered, an error message will be printed on line naming the erroneous batch number. Other batches named in the same MED will be duplicated. This MED must be used with discretion; there is a limit to the number of batches of data the low-speed input table can hold. It is suggested that a batch be used in the DC for one

vehicle to make sure it is usable before it is duplicated for the other vehicle. Split data batches can be duplicated. BMGCHAIN will not accept the duplicate batches for another vehicle MED while the DC is suppressed for the vehicle into whose chain the batch is going.

5. End of High-Speed Pass - BMGCHAIN receives an entry at the end of each high-speed pass. BMGCHAIN then sends a data-available entry to BMSLPC for each vehicle for which DC processing is not suppressed. (DC processing is initialized suppressed for vehicle 2.)

BMSLPC

Propagation Control receives two types of entries: check for data available and manual intervention. If the DC history table is initialized and the entry is not the result of a superbatch MED, the "DC in progress" digital display driver (DDD) is turned on, and results of the previous DC are read into the program. If the entry was the result of a decision or a data available check, the propagation is performed as described in the "General Requirements" section.

BMSLPC reacts to modification PBI's and MED's. Described below are the effects of modification PBI's when more than one is entered per batch.

1. $K\Gamma$ - Causes input covariance to be multiplied by a constant.
 - a. $K\Gamma$; $K\Gamma$ - Multiplicative.
 - b. $K\alpha$; $K\Gamma$ - Same as $K\Gamma$ only.
 - c. $K\rho$; $K\Gamma$ - Perform $K\Gamma$ on resultant covariance from $K\rho$.
 - d. $MODF$; $K\Gamma$ - Perform $K\Gamma$ on resultant covariance from $MODF$.
 - e. $SS1, SS2, SS3, MS$; $K\Gamma$ - Perform $K\Gamma$ on resultant covariance from SS_n / MS .
2. $K\alpha$ - Causes a priori station weights (R, A, E, D) to be multiplied by a constant.
 - a. $K\Gamma$; $K\alpha$ - Perform $K\alpha$ using resultant covariance from $K\Gamma$.
 - b. $K\alpha$; $K\alpha$ - Same as $K\alpha$ only.
 - c. $K\rho$; $K\alpha$ - Perform $K\alpha$ using resultant covariance from $K\rho$.
 - d. $MODF$; $K\alpha$ - Perform $K\alpha$ using resultant covariance from $MODF$.
 - e. $SS1, SS2, SS3, MS$; $K\alpha$ - Perform $K\alpha$ using resultant covariance from SS_n / MS .

3. $K\rho$ - Causes a repropagation with the sigma values μ and drag set to zero or is multiplied by a constant.
 - a. $K\Gamma$; $K\rho$ - Repropagate covariance, no $K\Gamma$ effects.
 - b. $K\alpha$; $K\rho$ - Repropagate covariance, no $K\alpha$ effects.
 - c. $K\rho$; $K\rho$ - Same as $K\rho$ only.
 - d. MODF; $K\rho$ - Repropagate covariance, with MODF effects.
 - e. SS1, SS2, SS3, MS; $K\rho$ - Repropagate covariance, no SS_n/MS effects.
4. MODF - Modifies the coefficient of the Riley conditioning term by zero or by a constant.
 - a. $K\Gamma$; MODF - Repropagate covariance, no $K\Gamma$ effects.
 - b. $K\alpha$; MODF - Repropagate covariance, no $K\alpha$ effects.
 - c. $K\rho$; MODF - Repropagate covariance with K_p and MODF effects.
 - d. MODF; MODF repropagate covariance (not multiplicative).
 - e. SS1, SS2, SS3, MS; MODF - Repropagate covariance using MODF effects.
5. SS1, SS2, SS3, MS - Selected covariance causes effects of all $K\Gamma$, $K\alpha$, $K\rho$ to be wiped out.

MED's have the following effects on BMSLPC.

1. Rechain - BMSMED resets the current block number to match the batch specified. BMSLPC treats a rechain entry exactly the same as a data-available entry.
2. Repeat - For all repeats, BMSMED resets the current block number to match the repeat batch specified. (In the case of starter the repeat batch is not specified but must be determined by BMSMED.) BMSLPC saves the appropriate information, editing coefficients for S06, pre-editing criteria and indicator for S08 or the starting vector, starter indicator, and SS1 indicator for S09. For an S03, S05, S06, S08, or S09 entry, the repeat indicator is set, and transfer is made to the basic DC logic. For both repeat and rechain the K rho, K alpha, K gamma, Force and MODF PBI's are initialized to normal settings.
3. Repeat Using Specified Vector and Covariance - BMSMED sets the current block number as in the normal repeat. BMSLPC obtains the specified vector and covariance and uses these as though they were the previous results.

4. Table of Biases - BMSLPC updates the bias table as specified by the S13 MED. Then it requests an update for the Bias Table Display and exits.
5. Superbatch (SB) MED's - For the S14 (SB initialize) and the S15 (SB exclude) BMSLPC saves the information and exits. For the S16 (biases to be solved) the station specified must be in the station characteristics. If any of the stations specified are not in the station characteristics, the legal station ID's are saved, and an error message is printed for the illegal stations. Subsequent entry of the S15 MED deletes the previous station ID's which have been saved.

The MED which initiates superbatch processing is the S17 MED. Specified in the MED input are the begin and end batches. A superbatch of one batch may be created by entering the same batch ID as the begin and end batches. The begin and end batches must be in the DC history table (MISHAP 14), and neither batch can be in the excluded batches list (MISHAP 13); otherwise, the MISHAP number will be displayed and BMSLPC will exit. For a legal superbatch BMSLPC creates a list of included batches and sets the end batch as the repeat batch to be used if the superbatch is accepted. Also specified in the S17 MED input is the starting vector ID and covariance to be used for the superbatch. If STARTER is specified as the vector ID, BMSLPC will request a starting vector from BMMSTART. BMMSTART will use all two-way data in the list of included batches to determine a starting vector.

Since there is no vehicle code in the superbatch MED's, all inputs will assume the vehicle specified by the last S14. This makes it impossible for initialization of a superbatch on both the LM and CSM.

BMSLDC

BMSLDC receives only one entry: control from BMSLPC. BMSLDC initializes the decision indicator, sets pre-DC information for the DC Summary Display, and then checks the FORCE indicator. If the FORCE indicator is on, the number of iterations, edits, and the last corrected vector are obtained in order to perform an additional iteration. If the FORCE indicator is off, the superbatch indicator is checked. For non-superbatch (batch-to-batch) the number of biases to solve is set to minus one. BMMDCI is then called to perform convergence initialization. Error conditions from BMMDCI are explained in the Low-Speed Math section. It should be noted here that an inversion error results in a single station solution.

An iteration loop consists of obtaining a seven-vector minimum ECI ephemeris over the data span and computing a corrected state vector and associated covariance matrix. The corrected state vector is used as input for the next iteration's ephemeris. The iteration loop continues until BMMACC achieves convergence or divergence or until BMSLDC reaches the maximum number of iterations. The maximum number of iterations is five for superbatches and ten for batch-to-batch. There is no limit on the number of FORCED iterations. By MED request, pre-editing can be performed during the first iteration of a batch-to-batch process. Also by MED request, biases can be solved for USB stations during superbatches processing. An error return from either the integrator or BMMACC results in a recommend reject decision and a MISHAP number.

Upon completion of the iteration loop, the superbatches indicator is checked. For superbatches, the processing is finished, and the accept indicator is set. For batch-to-batch processing, BMMSEL is called to perform selection editing. BMMSEL returns two indicators. The first indicates if additional observations were "tagged" or "untagged", and the second indicates if more than 75% of the observations are "tagged". BMSLDC checks the BMMSEL indicators in the following order:

1. If the figure of merit is greater than fifty and the maximum number of edits is reached, reject is recommended.
2. If the figure of merit is greater than fifty but the maximum number of edits is not reached, perform another edit loop.
3. If the figure of merit is less than fifty and no additional observations were "tagged" or "untagged", accept is recommended if less than 75% of the observations are tagged, and reject is recommended if more than 75% are tagged.
4. If the figure of merit is less than fifty, additional observations were "tagged" or "untagged" and the maximum number of edits is reached, the decision is based on the per cent of observations tagged (as described in item 3 above).
5. If the figure of merit is less than fifty, additional observations "tagged" or "untagged", but the maximum number of edits not reached - perform another edit loop.

After determining a decision, the results of the DC are printed on line. BMSLDC computes the magnitude of the vector correction and the output trace, and converts the diagonal of the output covariance to U, V, W coordinates. The DC History Table is updated, and the results are passed to the Summary Display. If the processing was batch-to-batch, the edited low-speed data is written into BZLSINPT.

In manual mode the waiting indicator and DDD are set, the DC-in-Progress DDD is turned off, and the program becomes dormant.

For an accept recommendation in automatic update mode, the output state vector is passed to the Usable Vector Table. For any reject recommendation in automatic mode, the input vector and covariance become the output vector and covariance. For all DC's in automatic mode, the DC-in-Progress DDD is turned off, and a decision entry is passed to BMSLPC.

BMSPB I

No PBI's for a DC-suppressed vehicle will be accepted by the PBI control module. Here is a list of illegal combinations:

1. No more than two mode PBI's can be accepted.
2. Both vehicles will not be accepted.
3. Both AUTO and MANUAL modes will not be accepted.
4. Both UPDATE and NO-UPDATE modes will not be accepted.
5. Both ACCEPT and REJECT decisions will not be accepted.
6. More than one modification PBI will not be accepted.
7. A decision and a modification PBI will not be accepted.
8. A mode and a modification PBI will not be accepted.
9. One of the vehicle PBI's must be set.
10. A mode PBI must be accompanied by a decision PBI unless the DC is idle.
11. Only the combination VEHICLE and MODE will be accepted when the DC is idle.
12. In returning from AUTO mode to MANUAL mode, none of the PBI's from ACCEPT through FORCE may be depressed.
13. In transferring to AUTO mode, a decision PBI must be depressed or else the DC must be idle.

The only acceptable PBI's while operating in AUTO mode are MANUAL, UPDATE, NO UPDATE, or a combination of MANUAL and either UPDATE or NO UPDATE.

1. If in either the manual or auto mode, the DC is idle (not waiting on a decision), and the UPDATE PBI is entered; the last accepted DC vector is passed to the Usable Vector Table (UVT).
2. If the ACCEPT/UPDATE combination is entered while waiting on a decision, the current vector is passed to the UVT.
3. If the REJECT/UPDATE combination is entered while waiting on a decision, the current solution will be rejected, and the last accepted DC is passed to the UVT.
4. If the UPDATE PBI is entered as a legal combination with other PBI's, the DC will operate in the UPDATE mode even though no accepted DC vector exists.
5. While operating in the UPDATE mode, any decision to ACCEPT will cause that vector to be passed to the UVT.

BMSPBI uses four MISHAP numbers:

1. MISHAP 49 - Manual mode required
2. MISHAP 54 - DC Table not initialized.
3. MISHAP 57 - No action on DC PBI input.
4. MISHAP 58 - No accepted DC can be found for UVT update.

If the DC is suppressed for the specified vehicle, no MISHAP number is displayed.

BMSMED

For MED's which specify a repeat or recycle batch (S03, S05-S08), BMSMED first determines that the batch specified is in the DC History Table. Then the appropriate information is passed to BMGCHAIN. If no error is returned from Chaining, BMSMED passes the information to Propagation Control and exits.

For the starter MED (S09), the batch from which to compute the starting vector is entered. If BMSMED finds the batch is in the DC History Table, then BMMSTART is called. Upon an error free return from BMMSTART, BMSMED determines the previous DC batch before the specified batch and passes control to BMSPCL.

For N_1/N_2 Edit control is passed to BMMTPE. This MED does not result in control eventually being passed to BMSPCL.

For all MED's which initialize tables or superbatch processing, control is passed directly to BMSPCL. For the eliminate-angles MED and the Nth-range-interval MED, BMSMED sets an indicator and exits. For the input SS3-variances MED, BMSMED squares the variances, saves them for an SS3 PBI input, and exits.

BMSMED is the program that turns on and off the SUPPRESS DC indicator. When the STOP DC MED is entered, BMSMED sets the suppress indicator for that vehicle. No MED's for the suppress vehicle will be accepted. (The vehicle for superbatch MED's is determined by interrogating the task resource table.) Upon entry of the START DC MED, BMSMED passes control to BMSLPC if the DC is not waiting on a decision.

No MED's will be accepted for a vehicle that is in automatic mode.

BMSMED uses MISHAP numbers:

1. MISHAP 49 - Manual mode required.
2. MISHAP 51 - Repeat to a station in the future. (This occurs if the current batch is the repeat batch.)
3. MISHAP 52 - Requested maneuver does not exist (S05).
4. MISHAP 53 - Error from BMMSTART.
5. MISHAP 54 - DC table not initialized.

If the DC is suppressed for the specified vehicle, no MISHAP number is displayed.

LOW-SPEED MATH

The math needed in low-speed radar processing is included in the modules described in this section. Each module is approached twice. The general requirements are first given; then in a second coverage, the modules are discussed in detail.

General Requirements

BMMTRC

Refraction computations are performed by module BMMTRC. It receives a batch of refracted low-speed radar data and then returns the data, corrected for refraction. This data may be in the form of C-band, S-band two-way doppler, and S-band three-way doppler. Three types of S-band data are acceptable: X/Y_{30} , X/Y_{85} , and HA/DEC. The formulation used for refraction correction is that specified by MSC Internal Note No. 67-FM47-274.

BMMPRI

Free-flight propagation of the covariance matrix is performed by module BMMPRI. The model dynamic biases considered are the uncertainties in the gravitational parameter, μ , and drag. The uncertainty in μ is always considered, but drag is only considered if either end point in the propagation interval falls within 1.1 earth radii of the Earth's center. The mean conic state transition matrix, analytic partials of position and velocity with respect to μ , and numeric partials of the state with respect to drag are used to propagate the covariance matrix for free flight. The formulation used may be found in MSC Internal Note No. 67-FM-51.

BMMMAN

The covariance matrix is propagated through maneuvers (fifteen minutes or less) via module BMMMAN. The variables used in propagation through the maneuver are broken down into three groups: state, guidance, and engine parameters - a total of ten variables (R , V , α , p , ω , $\dot{\omega}$). α corresponds to the direction of thrust with respect to the platform; p corresponds to the sensed acceleration; ω and $\dot{\omega}$ correspond to the weight and weight flow rate, respectively. The position and velocity at any time t_i , $(R, V)t_i$, are expressed as analytic functions of

$(R, V, \alpha, p, \omega, \dot{\omega})_{t_{i-1}}$. All the partials except those involving ω and $\dot{\omega}$ (the engine parameters) are computed analytically. To compute the analytic partials requires a nominal eighteen-second ECI trajectory through the burn and vehicle weight corresponding to each vector, a vector and corresponding weight at the end of ullage if ullage exists, and a vector and corresponding weight at the end of tailoff. The engine partials (secant partials) are computed by calling the integrator three times, the first to generate the nominal trajectory, the second to generate trajectory with ω perturbed, and a third to generate a trajectory with $\dot{\omega}$ perturbed. The variances for $\alpha, p, \omega, \dot{\omega}$ are those specified in Transmittal #7655, April 25, 1967. The formulation used may be found in MSC Internal Note No. 67-FM-51.

BMMDCI, BMMACC

BMMDCI performs initialization services for BMMACC. It is called at the beginning of the differential correction process. BMMACC computes a correction to an initial estimate of vehicle position and velocity (state vector) and an updated state covariance matrix from a batch of observations. To do this, it uses an initial estimate of vehicle position and velocity at anchor time (t_0), the relative weight of this data (expressed as a covariance matrix), an ECI ephemeris of the state vectors covering the interval of observations based on the same orbit as the anchor vector, and a batch of observations. During the processing of a superbatches, BMMACC can also solve for three bias elements, such as any three of two-way Doppler biases, three-way Doppler biases, and the Unified S-Band System (USBS) range bias.

The Convergence Program can process the following types of data:

1. Range (C-band, Deep Space Instrumentation Field (DSIF), USBS).
2. Azimuth and elevation (C-band).
3. Right ascension and declination (DSIF).
4. X and Y angles from 30-foot antennas (S-band).
5. X and Y angles from 85-foot antennas (S-band).
6. Continuous count two- and three-way Doppler (DSIF and USBS).

MCS Internal Notes No. 67-FM-51 and No. 67-FM41-241 contain the equations for computing the ground observations (azimuth, elevation, X and Y angles, declination, hour angle, range, and Doppler), their partials, and the topocentric coordinate system in which the measurements are made. The observations and associated partials are computed for use in the differential correction technique. The position vectors of the vehicle and the transmitting station needed to form the computed observations are calculated using the light time delay iterative technique.

The correction to the state is in the ECI coordinate system. The observational residuals and the partials of the observations with respect to the state at the time of the observations are computed directly from the ECI ephemeris. The state transition matrix is also based on the ECI ephemeris. For the angular observables, RNP matrices are utilized as an intermediate transformation to convert from true topocentric to the ECI system.

If the correction to the state affects only the eighth significant digit or less, the problem is said to have converged. If the correction to the state is in the seventh significant digit or larger, the quadratic form "f" of the last iteration (f_j), must be checked against f_{j-1} from the previous iteration. If $f_j > f_{j-1}$, the solution is diverging; and if $f_j \leq f_{j-1}$, the solution is in the process of converging.

BMMSEL

During the performance of a batch-to-batch differential correction the selection editing program, BMMSEL, is called at the end of each convergence loop. The program computes the RMS and average values for each observational element and edits elements which have residuals greater than K times the corresponding computed standard deviation. K is nominally 3.0 but may be changed by MED. Elements which have previously been "tagged" as edited can be "untagged".

If additional elements are edited, BMMSEL sets the modified indicator. BMMSEL then computes the total percentage of observations edited. If the percentage is greater than 75%, a recommend-reject indicator is set. Otherwise, the recommend-accept indicator is set.

BMMSTART

Upon MED request, BMMSTART provides an initial state vector for the DC program. The data used is specified by the MED input and may be either a single batch or a superbatches. All computations are in the ECT coordinate system, but the starting vector is returned in the ECI coordinate system. The average and RMS values of the residuals are also returned for display purposes. There is no automatic data editing. The formulation is that specified by MSC Internal Note No. 67-FM-51.

BMMTPE

BMMTPE performs the editing specified by the N_1/N_2 Edit MED. This editing is completely independent of the DC processing and is performed on the batch

specified by the MED. The batch may be in either the post- or pre-DC chain, but must have ended transmission. The MED input also specifies the observational component to be edited and the time span for this editing.

BMRSDC

BMRSDC performs pre-editing and computes residual statistics for display purposes. It receives an ECI ephemeris, interpolates for a vector at the time of each observation using the speed of light delay interpolation, and converts the vectors to local coordinates as specified by MSC Internal Note No. 67-FM41-241. Biases are used if available. On a pre-edit request, if the difference between the computed observational element and the real observational element is greater than the value specified by MED, BMRSDC "tags" the element. On a residual statistics request, BMRSDC computes the residuals just as it does for pre-edit and determines the RMS and average values for each data batch. If the request is for the Batch Residuals Plot Display, the residuals are scaled also.

Design Discussion

BMMTRC

BMMTRC computes refraction correction at the request of BMGCHAIN for a data-available request from BMSLPC and at the request of BMDPLT for the look-ahead feature of the batch residuals plot. When processing C-band data and Earth orbit/reentry two-way S-band data, the observed values are used directly to compute refraction corrections. Corrections for the range and angles are computed by library subroutine BLMREF. Doppler is corrected as specified in the formulation. There are no error returns in the above logic.

When processing translunar, lunar, and transearth two-way S-band data and all three-way S-band data, corrections for the range and Doppler are computed from the observables and an ECI ephemeris. To obtain this ephemeris, BMMTRC uses the last accepted DC vector with a time tag prior to the data. (The insertion vector is acceptable.) If no acceptable vector is available, an error indicator is set, the data remains uncorrected, and BMMTRC returns to the calling program. The ephemeris is generated over the data time span and considers maneuvers. If the time of the first observation in the data falls within a maneuver, the begin-burn time of the maneuver is used as t left in requesting the ephemeris.

Interpolation is performed by BLMLPR, which considers the speed of light and maneuvers. For three-way data BMMTRC interrogates the primary switch table. If the time of the first observation precedes the first time in the primary switch table, an error indicator is set, and the data is not corrected. An error from either integration or interpolation results in no correction to the data.

BMMPRI

BMMPRI is called by BMSLPC (propagation control) to propagate the covariance matrix in free flight. The following equations are used:

$$\Gamma_F = \frac{\partial S_F}{\partial S_O} \Gamma_O \frac{\partial S_F^T}{\partial S_O} + \frac{\partial S_F}{\partial q} \Gamma_{qO} \frac{\partial S_F^T}{\partial q} + \frac{\partial S_F}{\partial S_O} P \frac{\partial S_F^T}{\partial S_q} + \frac{\partial S_F}{\partial q} P_O^T \frac{\partial S_F^T}{\partial S_O}$$

$$P_F = \frac{\partial S_F}{\partial S_O} P_O + \frac{\partial S_F}{\partial q} \Gamma_{qO}$$

	$x \ y \ z \ \dot{x} \ \dot{y} \ \dot{z}$	$\mu \ D$
x	$\Gamma_o(6 \times 6)$	P_o (6x6)
y		
z		
\dot{x}		
\dot{y}		
\dot{z}		
μ	P_o^T (2 x 6)	$\mu \ D$
D		Γ_{qo} (2x2)

where

1. S_o = State vector at t_o
2. S_F = State vector at t final
3. Γ_o = Covariance matrix of state vector t_o
4. Γ_F = Covariance matrix of state vector t final
5. P_o = Covariance matrix of state vector and model dynamic biases
6. Γ_q = Covariance matrix of model dynamic biases
7. $\frac{\partial S_F}{\partial S_o}$ = State transition matrix; partial derivatives of the final state with respect to initial state
8. $\frac{\partial S_F}{\partial q}$ = Partial derivative of final state with respect to model dynamic biases.

There are no error returns for this program.

BMMMAN

BMMMAN is called by the propagation control module BMSLPC to perform powered-flight propagation on the covariance matrix. It is the responsibility of BMSLPC to request the special integrations, to obtain the proper variances

based on the thruster code, and to verify that the duration of the maneuver is fifteen minutes or less. The maneuver uncertainties modified by the coefficients in the mission plan table will be printed on line by BMMMAN. There are no error returns for this program.

BMMDCI

BMMDCI is called by BMSLDC to perform several initialization services for convergence processing. For both batch-to-batch and superbatches, BMMDCI inverts the covariance matrix of the uncorrected state vector. If the inversion error is greater than 10^{-4} , the error is printed, MISHAP 15 is displayed, and a single station differential correction is performed. BMMDCI obtains available biases for all batch-to-batch processing and for all batches in the superbatches whose biases are not to be solved.

If biases are to be solved (only possible for superbatches), the stations specified must be included in the superbatches; otherwise, MISHAP 24 will be displayed, and reject DC recommended.

For three-way data BMMDCI interrogates the primary switch table and determines if a switch occurred during the data batch. If the time of the first observation for the three-way data precedes the first time in the primary switch table, MISHAP 23 is displayed, and reject DC recommended.

BMMACC

BMMACC is called by BMSLDC for each convergence iteration. Before performing any computations, BMMACC evaluates the ephemeris. MISHAP 17 is displayed if less than 6 vectors are available and MISHAP 18 is displayed if the ephemeris is determined to be invalid. This test is essentially one of computing $r \times v$ vectors for each state vector in the ephemeris and examining their individual and relative magnitudes. MISHAP 19 is displayed if all the input data has been edited. For all three errors a reject-DC decision is recommended.

In BMMACC a batch-to-batch DC is treated as a superbatches of one. Several manual inputs affect the convergence processing. The K alpha PBI which modifies the station weights is actually applied by BMMACC. (K alpha is illegal for superbatches processing.) Entry of the MED to eliminate angles in the DC will cause BMMACC to ignore angles in the convergence processing. Entry of the Nth-range MED will cause BMMACC to modify the range weight for USB stations. (Range is ignored in three-way data.) If biases are to be solved, BMMACC

solves for them. For stations whose biases are not being solved, BMMACC uses the bias values supplied by BMMDCL. If bias values are available, the biases are applied to the computed observations before calculating residuals.

The computations performed by BMMACC include the following figure-of-merit calculation.

$$\text{FOM} = \frac{\sum_{j=1}^J \frac{1}{\sigma_j^2} \sum_{i=1}^{N_j} (\Delta\rho)_{ij}^2}{\sum_{j=1}^J N_j}$$

where

J = Number of observational elements

N = Number of valid observations for each element

σ_j = Apriori standard deviation of each element

$\Delta\rho$ = ith residual of the jth element.

Upon completion of the convergence computations, BMMACC calculates the covariance matrix of the new anchor state by inverting the updated inverse of the uncorrected state vector. If the inversion error is greater than 10^{-4} , the error is printed, MISHAP 66 is displayed, and the decision is determined by the figure-of-merit (FOM) value.

BMMSEL

BMMSEL is called by the convergence control program BMSLDC for the purpose of performing selection editing. The residuals used by BMMSEL are computed by BMMACC. BMMSEL computes the RMS and average values and the number of rejections for each observational component. For all three-way data the range component is ignored. If the eliminate-angles indicator is set, the angle components are ignored. If BMMSEL encounters a residual greater than 10^{30} , MISHAP 16 is displayed, and a reject decision is recommended for the current DC.



BMMSTART

BMMSTART is called by BMSMED for a single-batch starter vector and by BMSLPC for a superbatch-starter vector. Only two-way C- or S-band data is acceptable, and at least two complete observations must be available.

If only three-way data is available, or if two complete two-way data observations are not available, or if an error occurs in the coordinate conversion (ELVCNV), BMMSTART returns an error indicator to the calling program. BMMSTART also returns an error indicator if sufficient working core storage is not immediately available. The amount of storage required ranges from 8096 bytes for one batch to 75,336 bytes for thirty batches. An error from BMMSTART causes MISHAP 53 to be displayed on the DC Summary Display.

BMMTPE

The N_1/N_2 Edit Program is called by BMSMED upon receipt of an S11 MED. N_1/N_2 Edit is the only method of editing data in a superbatch. Each batch must be edited individually. A message will be printed on line if the batch specified cannot be found or if the observational component type is not available in the batch specified.

BMRSDC

BMRSDC is called by the convergence control program, BMSLDC, for data pre-editing and by two display programs, BMDRESID and BMDPLT, for computing residual statistics. The speed-of-light delay is considered in the ephemeris (ECI) interpolation. If the request is for the Vector Residual Summary Display, maneuvers are considered; otherwise the ephemeris is assumed to be ECI, free flight.

Biases are used, when available, in the residual computations. If waiting on a superbatch decision, the biases solved in the superbatch computation override the values in the Bias Table for the DC Residual Summary Display. The other requests use only values from the Bias Table.

No range residuals are returned for three-way data. However, the range is always computed for possible use in angle computations and is the average of the ranges from the transmitting station and receiving station to the vehicle, plus the range bias (if available) of the receiver. The "eliminate angles" indicator is ignored. If data has been edited by the DC, N_1/N_2 edit or pre-edit, residuals for those

observational elements are not included in the RMS and average computations.

The residual values for the Residual Plot Display are normally scaled by the computed RMS. If a U18 MED is entered specifying the scaling factors, the RMS is computed, but the residuals are scaled by the MED values. The Residual Plot Display also requires the time span of the pass. The earlier of either the time of the range or the time of the doppler of the first observation is used for the time span calculation.

There are four error returns from BMRSDC. Error 1 occurs if the maneuver times subroutine, ELFECH, returns an error. Error 2 occurs if the coordinate conversion subroutine, ELVCNV, returns an error. Error 3 occurs if the speed-of-light delay interpolation subroutine returns an error. Error 4 occurs if the subroutine to calculate doppler frequency, BLMDFQ, returns an error. The subroutine's error code is also returned with the error code from BMRSDC. No results are returned if any error is encountered, but an appropriate message will be printed on line and displayed.

Flowchart 12 contains the basic logic for BMRSDC.

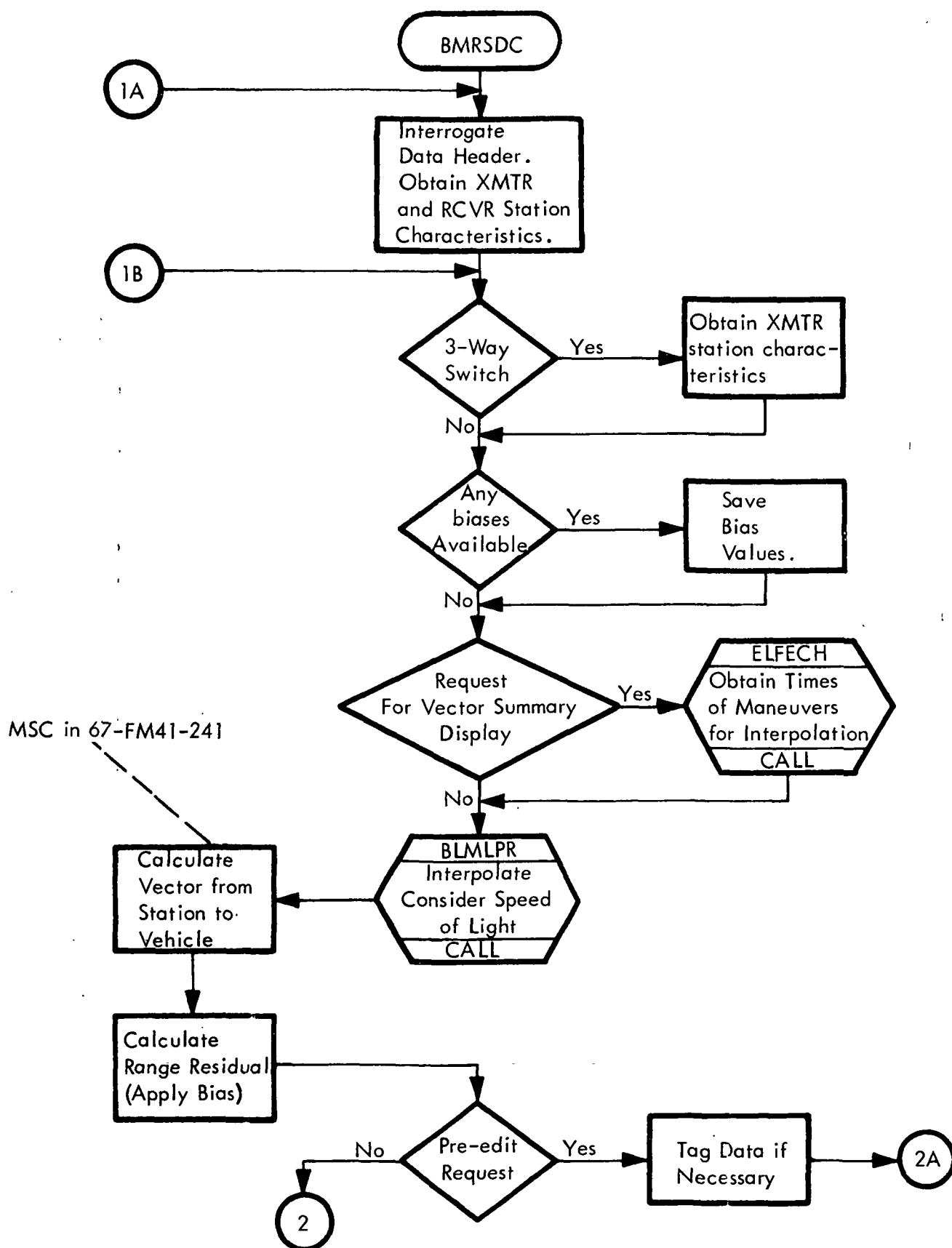


Figure 12. BMRSDC Flowchart

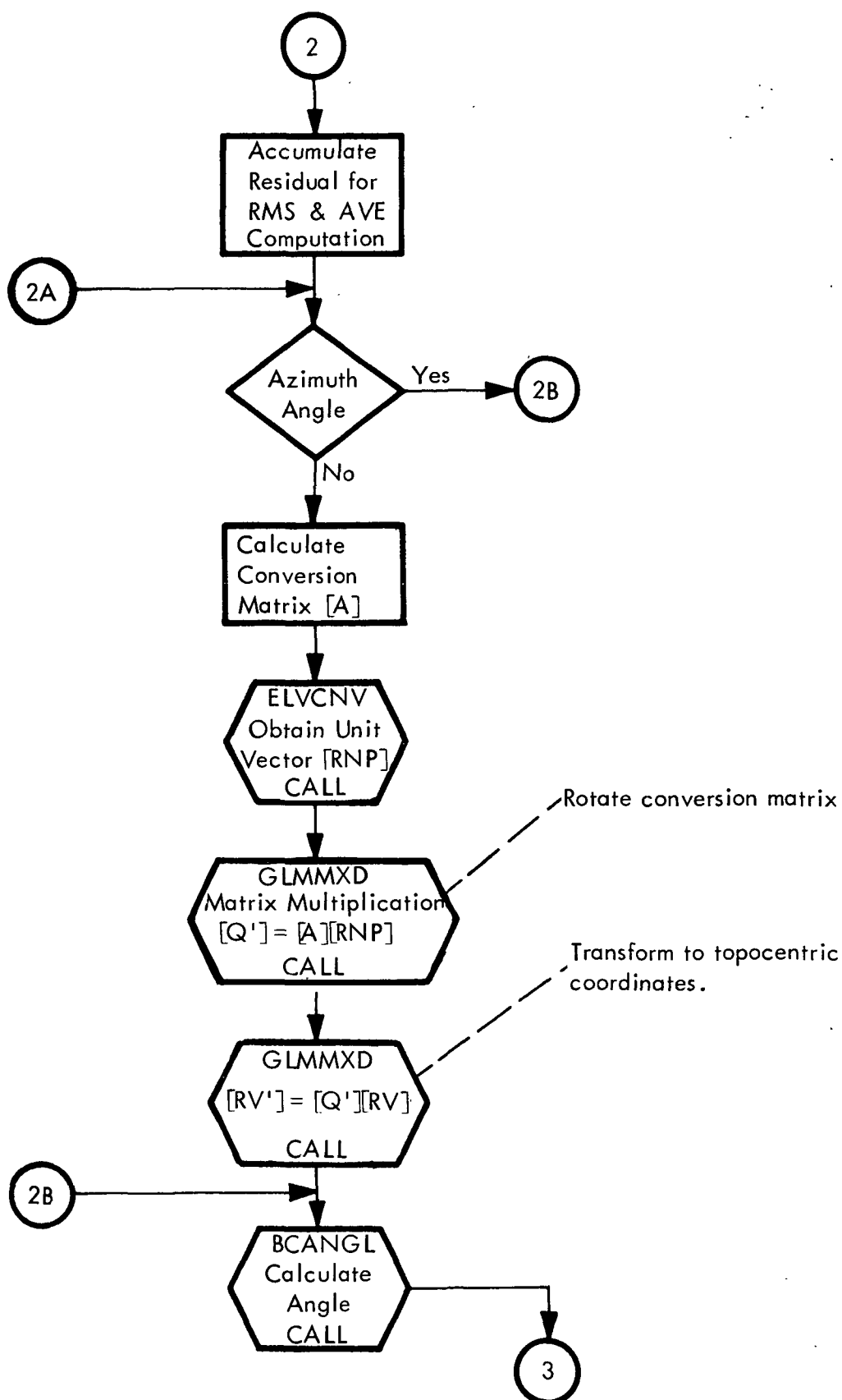


Figure 12. BMRSDC Flowchart

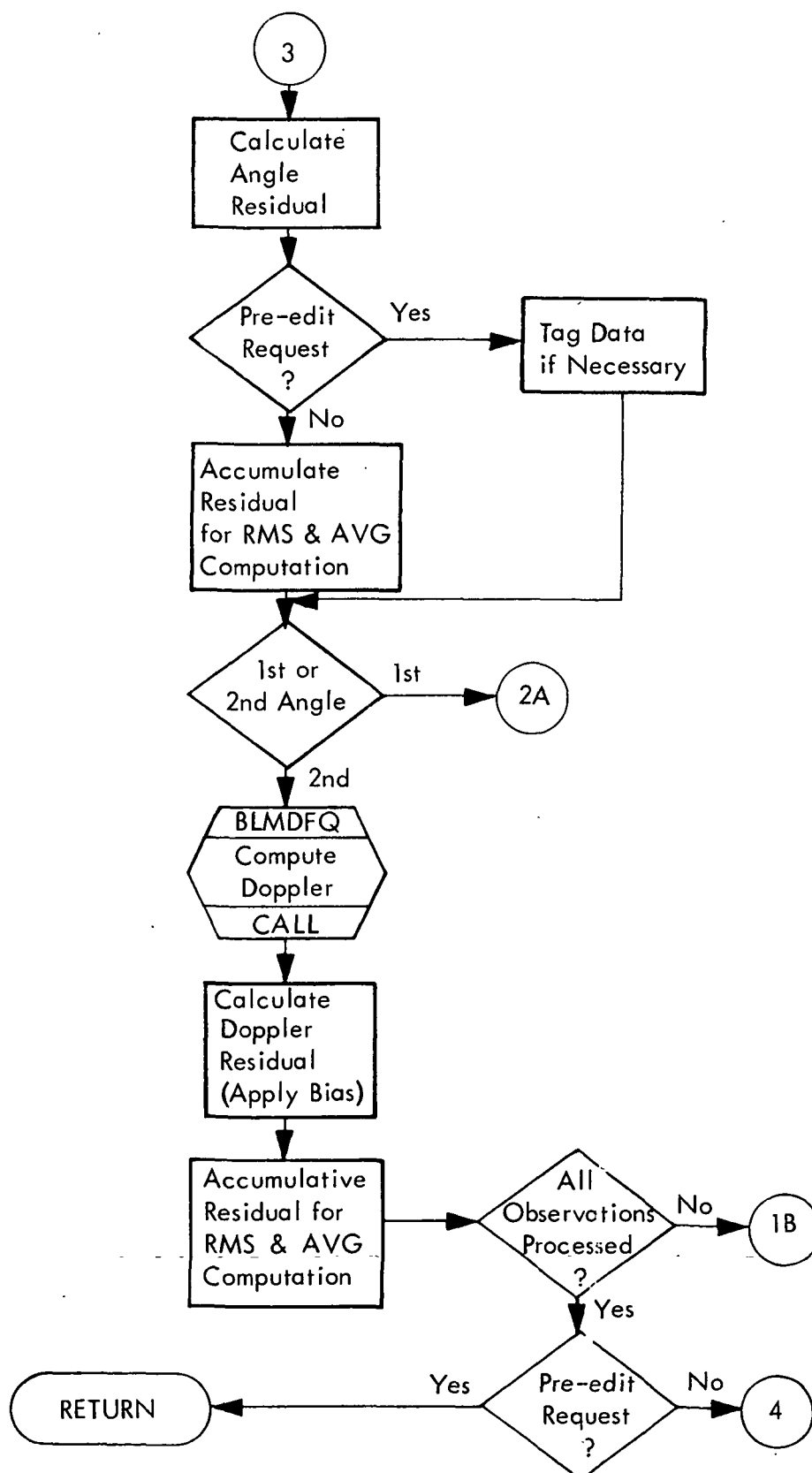


Figure 12. BMRSDC Flowchart

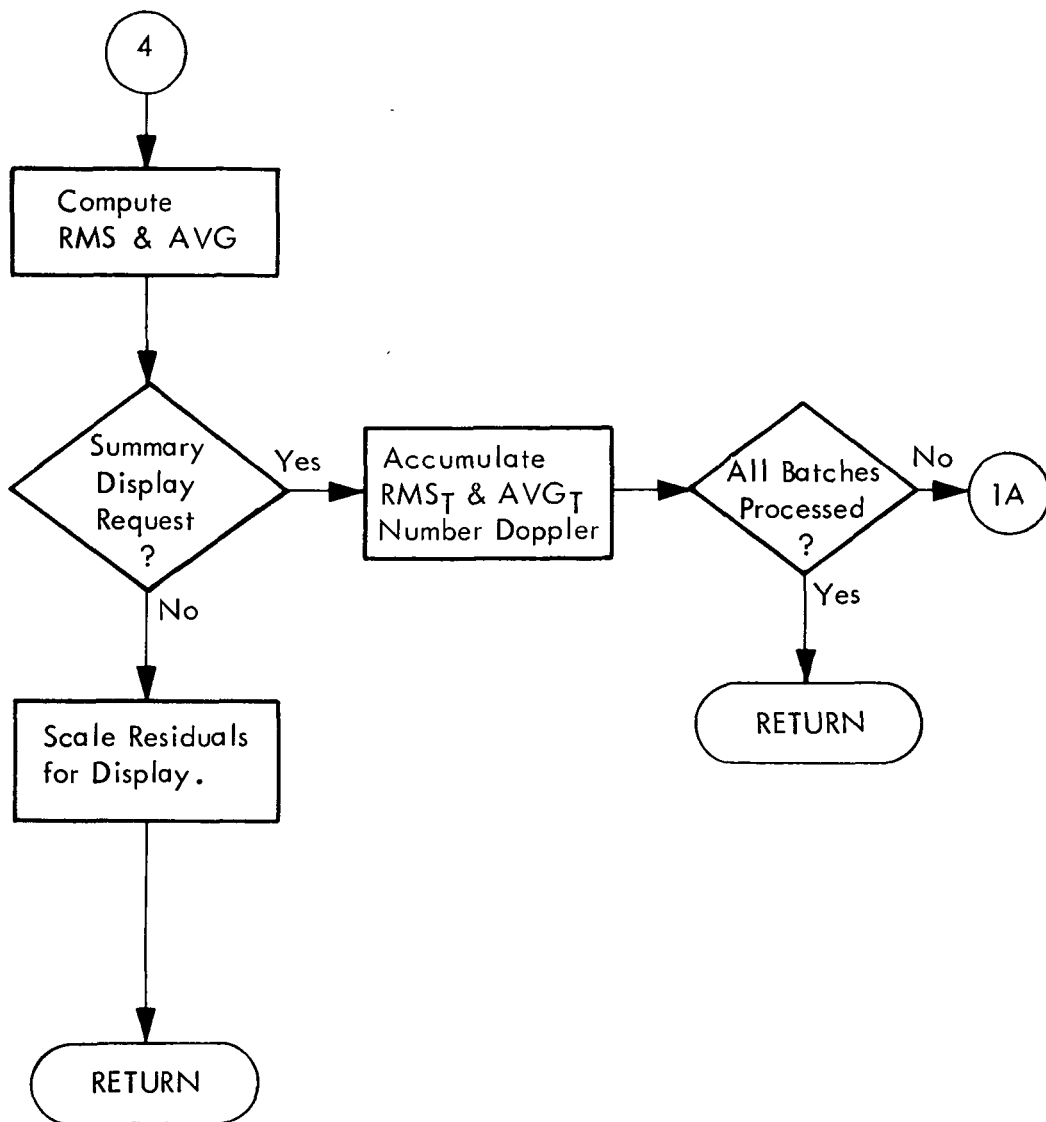


Figure 12. BMRSDC Flowchart

LOW-SPEED OUTPUT

The low-speed output section is a collection of programs responsible for providing digital-to-television (D/TV) displays that enable the controller to evaluate and use the Low-Speed Radar Processing function. The displays within this section provide information concerning the input radar data and radar sites, computational results from the OD process, and statistical data for comparing OD solutions. In this section requirements of the output programs are given, followed later by a detailed design discussion of each program.

General Requirements

The programs which comprise the low-speed output section are listed in the table below. Included in the table are the manual selection keyboard's (MSK's) required for generating the display and the program's requirement sources.

Table of Low-Speed Output Programs

Program	MSK No.	FCR No.
Low-Speed Input Display	1618	L511
Two-Way Site Timeline Display	1589	L419
CSM Table of Biases	1582	L415
LM Table of Biases	1583	L416
CSM Batch Residuals Plot	1580	L413
LM Batch Residuals Plot	1581	L414
CSM Residual Summary - I	1570	L403
CSM Residual Summary - II	1517	L404
LM Residual Summary - I	1572	L405
LM Residual Summary - II	1573	L406
Vector Residual Summary - I	1574	L407
Vector Residual Summary - II	1575	L408
CSM Batch Summary - I	1576	L409
CSM Batch Summary - II	1577	L410

Program	MSK No.	FCR No.
LM Batch Summary - I	1578	L411
LM Batch Summary - II	1579	L412
CSM DC Summary - I	1584	L563
LM DC Summary - II	1585	L563

Other requirement sources are

1. PHO-TR170A, Volume 2 (through change 43)
2. RTCC Transmittal #8612, #7642.

The following discussion presents the general processing requirements of each display module contained in this section.

Low-Speed Display

The Low-Speed Display is primarily intended to provide information on the activity of low-speed radar prior to the OD process. In addition to the name of the transmitting station and the vehicle being tracked, whether or not the station is still transmitting and other similar values, quantities are displayed to reflect the status of the collection process. These quantities show editing criteria, such as minimum acceptable elevation and rate of collection, and provide an indication of data quality by displaying the number of data frames received and the number of data frames that have been saved.

Two-Way Site Timeline Display

This display provides information on the activity of S-Band radar stations. The data in the timeline table is used in refraction and convergence processing for determining the transmitting station when processing three-way data.

Tables of Biases

The CSM/LM Table of Biases Display provides information on stations which were three-way/two-way combinations and on biases used on the two-way S-Band range and Doppler observations.

Batch Residual Plots

The CSM/LM Batch Residuals Plot is used to evaluate the quality of low-speed radar data and to provide information on the editing criteria used (time, σ level or absolute level).

Residual Summaries

The CSM, LM, and Vector Residual Summaries provide a method of comparing groups (batches or superbatches) of low-speed radar observations or comparing and evaluating selected vectors.

Batch Summaries

The CSM/LM Batch Summaries display information on low-speed radar that has completed OD processing. In addition to information such as the number of observations collected and rejected in the solution, the display shows the status of the PBI indicators as used in the OD process.

DC Summaries

The CSM/LM DC Summaries provide information for evaluating and selecting the vector resulting from the OD process, as well as information for evaluating the low-speed radar data that was used in the solution. Numerous mathematical results from the OD process are displayed in order to aid in evaluating the resulting vector and the input radar data. In addition, information of the last executed and next upcoming maneuver is displayed.

Figures 13 and 14 show the functional flow of the low-speed output.

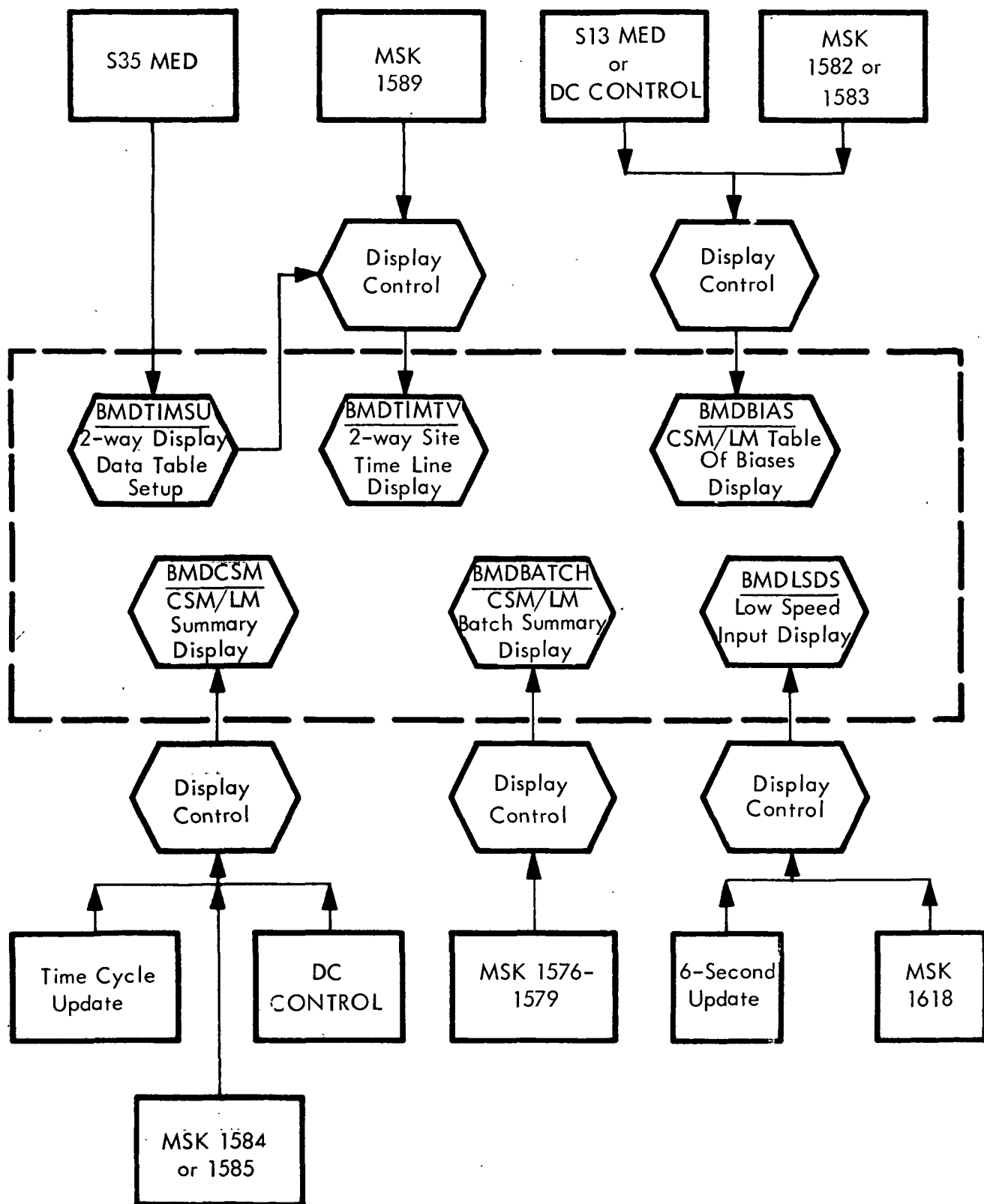


Figure 13. Low-Speed Output

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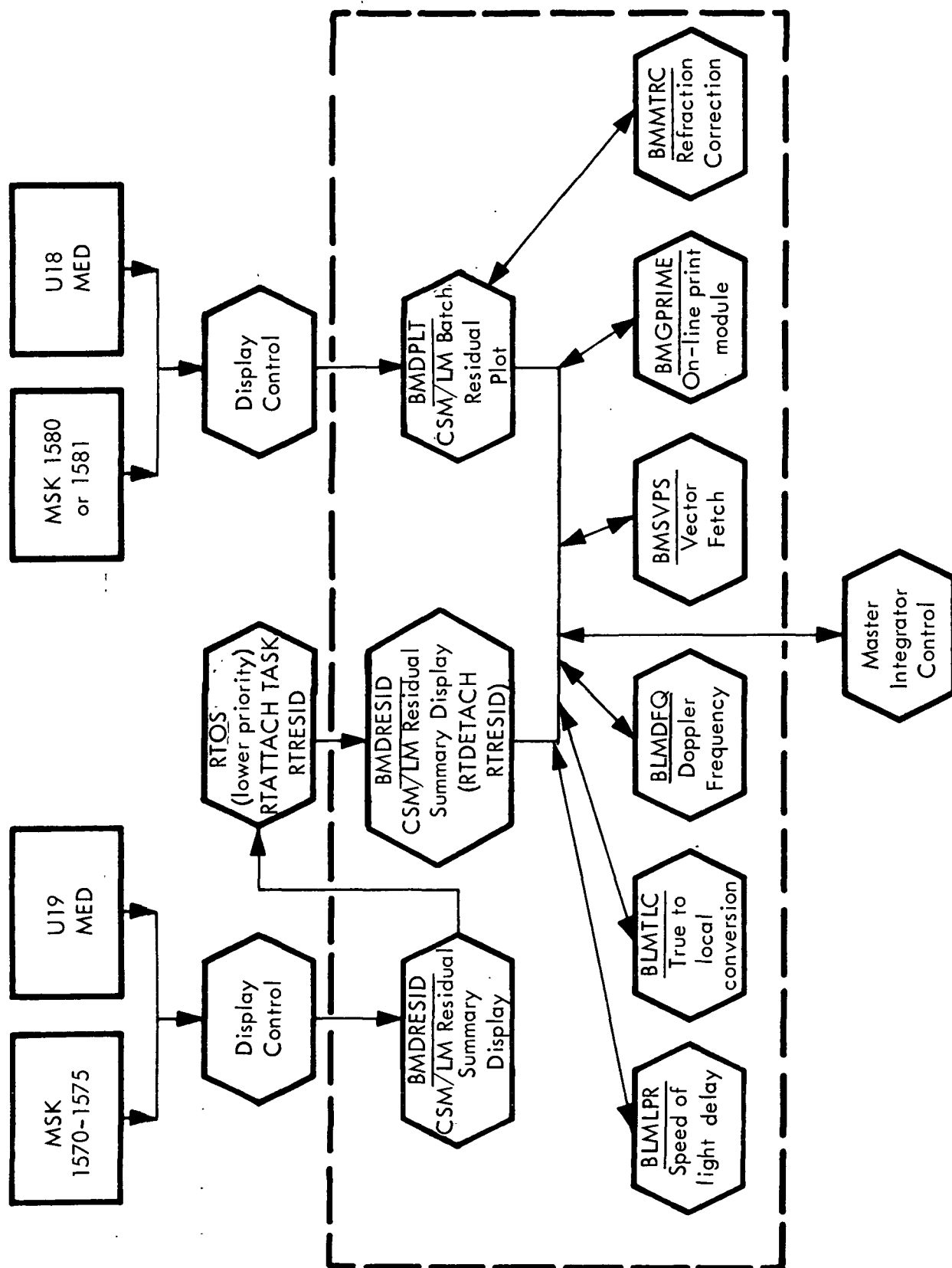


Figure 14. Low-Speed Output

Design Discussion

Low-Speed Input Display (BMDLSDS)

No initialization is required for this display. No check is made for the mission phase.

Input and Output Queues — MSK requests and queues on a six-second time trap from the display supervisor result in reading the low-speed display data table and low-speed collection table, formatting the data, and updating the display. All queues result in data being output on the D/TV.

Clarification of Requirements — Multipoint will always be expressed in seconds. No quantities will be updated on the display until the six-second cycle is initiated or an MSK request is made.

N_T is the total number of observations received. For C-Band, the N_{DC} equals the number of observations; for S-Band it is the number of Doppler observations saved. In addition, for S-Band, N_{ANG} is displayed showing the number of positional observations.¹ ID is the input ID used as an index to pick up vehicle and beacon numbers for each data frame. There are two sets of input ID's, one for C-Band and the other for unified S-band. The ID's are displayed for each transmitting station on the Low-Speed Input Display. The status of the vehicle-beacon table used to interpret the ID's is also displayed in the form of "ID is A, B", where A is the vehicle number assigned to the given ID, and B is the assigned beacon number. Beacon 0 indicates skin tracking.

The Low-Speed Input Display has no error checks. Illustrated in Figure 15 is the functional flow of this display.

Two-Way Site Timeline Display (BMDTIMTV)

Initialization is not required for BMDTIMTV; Mission Phase checks are not made. All input queues are a result of either an MSK request (1589) or an output queue from BMDTIMSU after an S35 MED. In each case, the timeline data

¹ Ship S-Band has no doppler, therefore, N_{DC} will display a zero. The number of observations available for differential correction is under N_{ANG} .

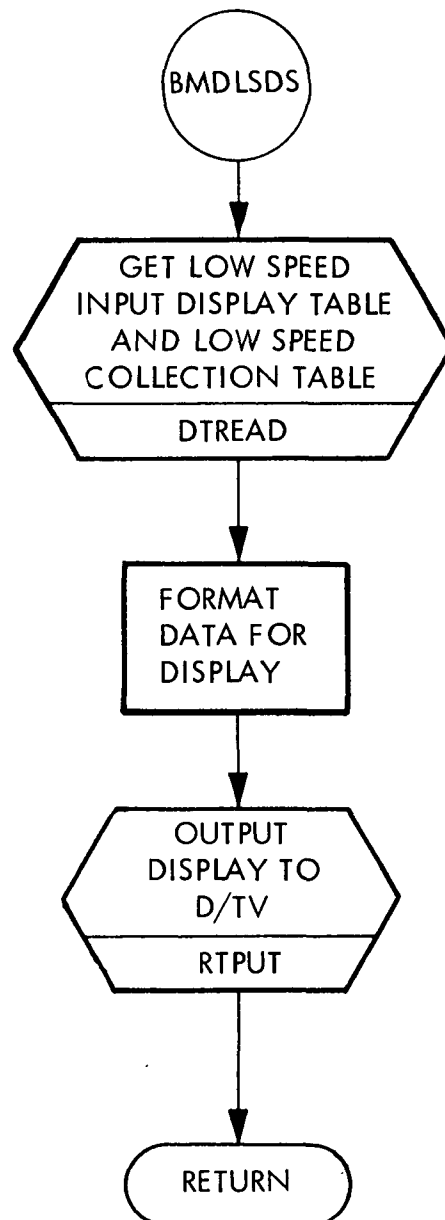


Figure 15. Low-Speed Input Display

table is read, and the data formatted. After formatting, the data is output to the D/TV. A functional flowchart (Figure 16) illustrates BMDTIMTV.

CSM/LM Table of Biases Display (BMDBIAS)

BMDBIAS requires no initialization. No check is made for the mission phase.

Input queues result from the entry of an S13 MED and the acceptance of a super-batch solution that solved for biases and an MSK request. All queues result in reading the appropriate biases data table, formatting the data, and putting the data to the D/TV. Output queues occur when formatted data is output to the D/TV. Figure 17 illustrates this display.

Two-Way Display Data Table Setup (BMDTIMSU)

BMDTIMSU requires no initialization. No mission phase checks are made.

Input Queues — The only input queue is a result of the S35 MED. The time-line data table block indicated by the vehicle ID in the MED parameter is obtained; the station and GMT (also MED parameters) are entered in the table; and the table is reordered based on GMT (oldest to current).

Output Queues — After the table has been reordered and written, the Two-way Site Timeline Display module (BMDTIMTV) is queued via the display control supervisor to update the display.

Error Checks — The station name entered via the MED is searched for in the station characteristics table. If the station is not found, BMGPRIME is queued to print the on-line message:

```
DD:HH:MM:SS.CC **SE** )BMDTIMSU( STATION NOT FOUND IN GZSTCH.
```

Figure 18 is a functional flowchart of BMDTIMSU.

CSM/LM Batch Residual Plot (BMDPLT)

The initialization of BMDPLT requires the input of the U18 MED before any computations can be performed. The display's only mission phase restriction

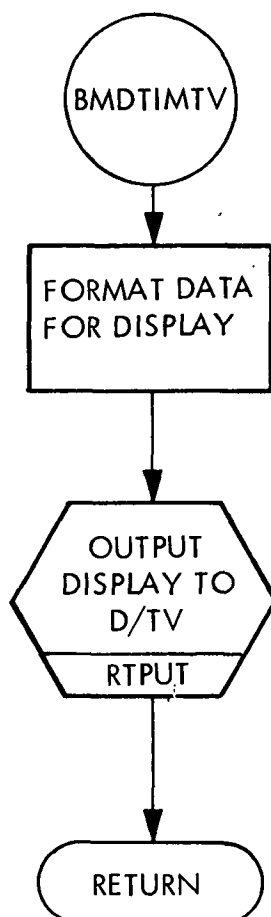


Figure 16. Two-Way Site Timeline Display

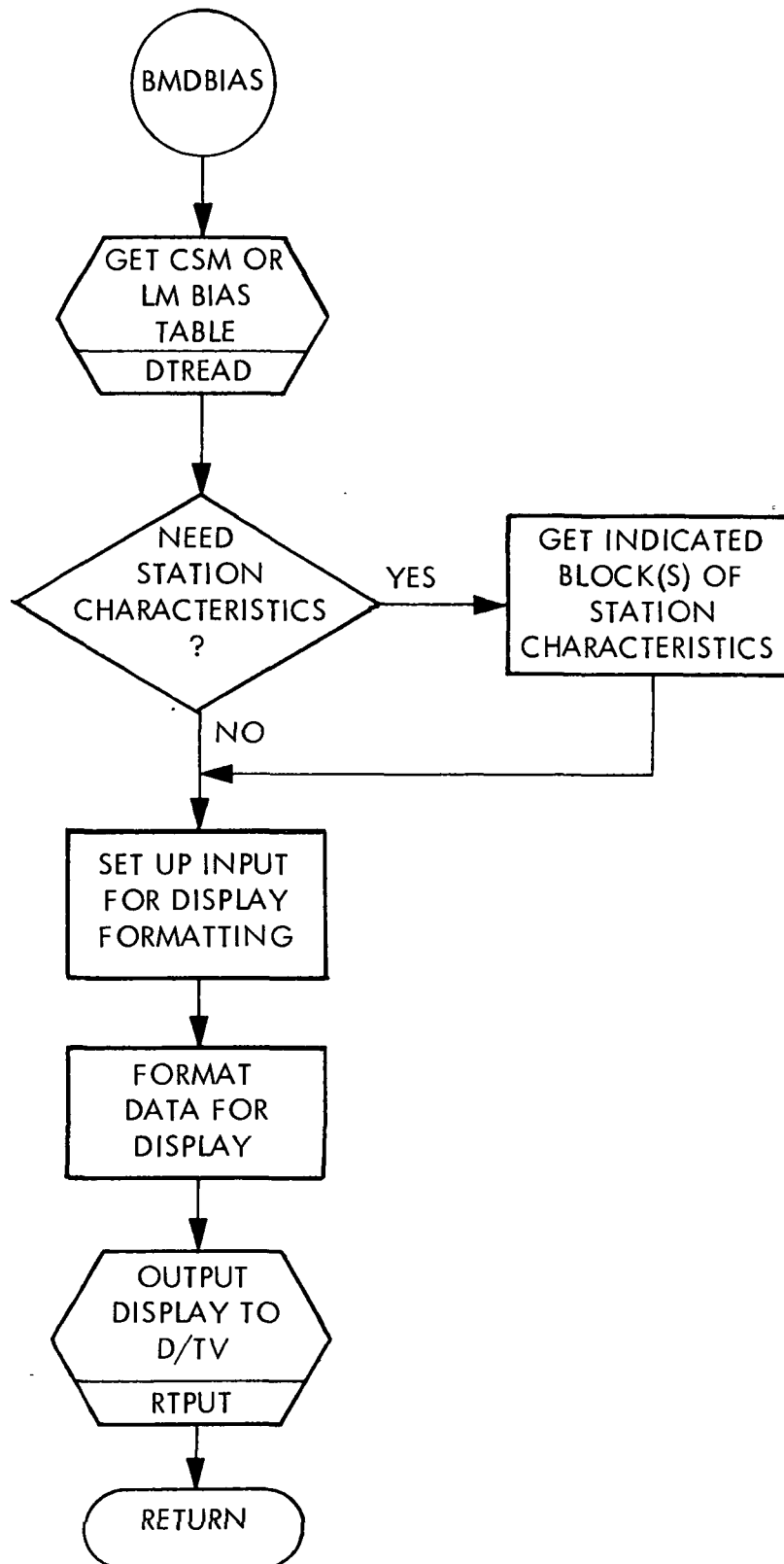


Figure 17. CSM/LM Table of Biases Display

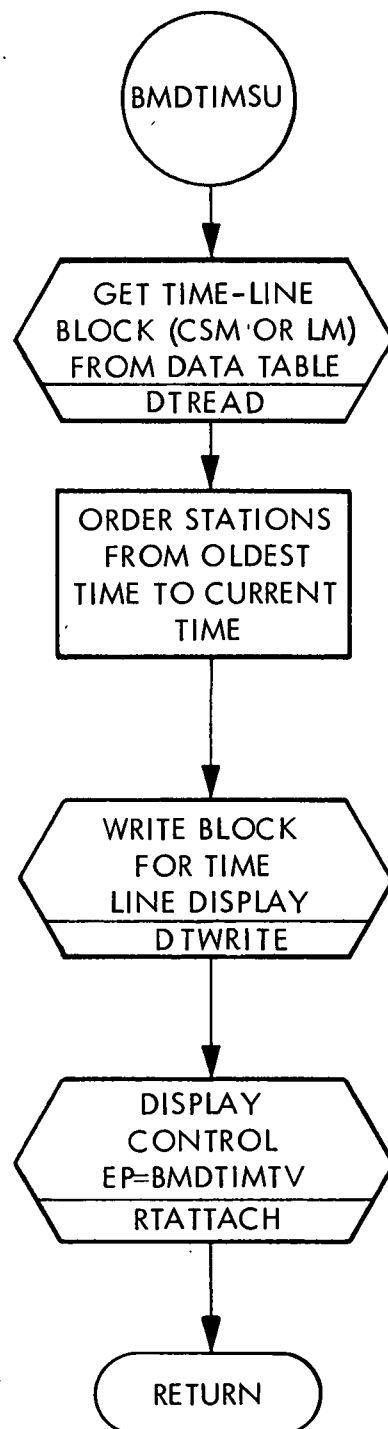


Figure 18. Two-Way Display Data Table Setup

is not being allowed in prelaunch I, condition for launch, launch, or any of the high-speed phases.

Input Queues — The input queues are the MSK entries and the U18 MED.

1. MSK Entries — The entry of MSK 1580 results in the generation of the CSM residuals plot for the batch previously specified in the last U18 entry. The entry of MSK 1581 results in the generation of the LM residuals plot for the batch previously specified in U18 entry.
2. The U18 MED entry results in the generation of the residual plot for the specified vehicle/batch combination, if the display is being received.

Output Queues — Error messages are passed to the general print program BMGPRIME. Formatted data is output to the D/TV display.

1. BMGPRIME is queued to print on-line error messages
2. The master integrator control program is queued to provide an ephemeris.
3. BMSVPS is queued to provide, if required, a vector requested in the U18 MED.
4. Formatted data is output to the D/TV display.
5. The refraction correction module, BMMTRC, is queued to correct the data, if the batch requested has not been corrected for refraction.
6. BMRSDC is queued to compute the residuals for each observation.

Clarification of Requirements — A refraction error does not stop processing. The batch will be processed without correcting refraction. If refraction corrections are applied, they are not permanent and are only used for this display.

In reentry and abort phases, the U18 MED is invalid. The input or output batch vector from the last DC is used to compute residuals on that data batch.

Error Checks — The CSM/LM Batch Residual Plot has seven error checks.

1. Wrong Phase — If an MSK request is made in an illegal phase, the following message is displayed:

ILLEGAL PHASE.

2. Initialization — If an MSK is requested before the U18 MED has been entered, the following message is displayed:

INITIALIZE BY ENTERING A U18 MED.

3. Invalid Data Batch Requested — If an invalid data batch is requested, BMGPRIME is queued to print the error message:

DD:HH:MM:SS.CC **SE)BMDPLT (BATCH(ES) XXX
UNAVAILABLE FOR U18 MED

where XXX is the requested batch. In addition, a "BATCH NOT FOUND" message is displayed.

4. Valid Vector Specified in U18 MED — If a vector is specified which cannot be found, BMGPRIME is queued to print:

DD:HH:MM:SS.CC **SE** (BMDPLT(XXXXXXXX NOT
AVAILABLE

where XXXXXXXX is the ID of the requested vector, and a "VECTOR NOT FOUND" message is displayed.

5. Backward NI Through Non-Zero ΔV Maneuver — If backward NI through a non-zero ΔV maneuver is necessary to compute residuals, BMGPRIME receives a queue to print:

DD:HH:MM:SS.CC **SE**) BMDPLT(ILLEGAL REQUEST FOR
BACKWARD INTEGRATION, VEHICLE X

where X is the vehicle number, and an "NI ERROR" message is displayed.

6. Refraction Error — If an error indicator is returned by the refraction processor BMMTRC, BMGPRIME is queued to print the following error message:

DD:HH:MM:SS.CC **SE**) BMDPLT(-BATCH XXX FOR VEHICLE
Y NOT REFRACTED, ERROR NUMBER ZZZ

where XXX is the requested batch, Y is the vehicle number, and ZZZ is the error number returned by BMMTRC.

7. NI Error — An error return from the NI Control Program, RMSMIC, results in queuing BMGPRIME to print an error message. In addition, "NI ERROR" is displayed on the D/TV.

Figure 19 is a functional flowchart of this program.

Residual Summary Statistics (BMDRESID)

BMDRESID is initialized by entering the U19 MED before requesting MSK's 1574 and 1575. All mission phases are invalid except Earth orbit.

Input Queues — All input queues are MSK entries.

1. MSK 1570 results in the generation of the CSM Residual Summary I (up to 20 batches).
2. MSK 1571 results in the generation of the CSM Residual Summary II (up to 10 batches).
3. MSK 1572 has the same result as MSK 1570 except for the LM.
4. MSK 1573 has the same result as MSK 1571 except for the LM.
5. U19 MED results in the generation of vector residuals for the Vector Residuals Summary I and II Display for the specified vehicle.
6. MSK 1574 and 1575 results are given under "Clarification of Requirements".

Output Queues — Error messages are passed to the general print program, BMGPRIME. Formatted data, including error messages, is output to the D/TV.

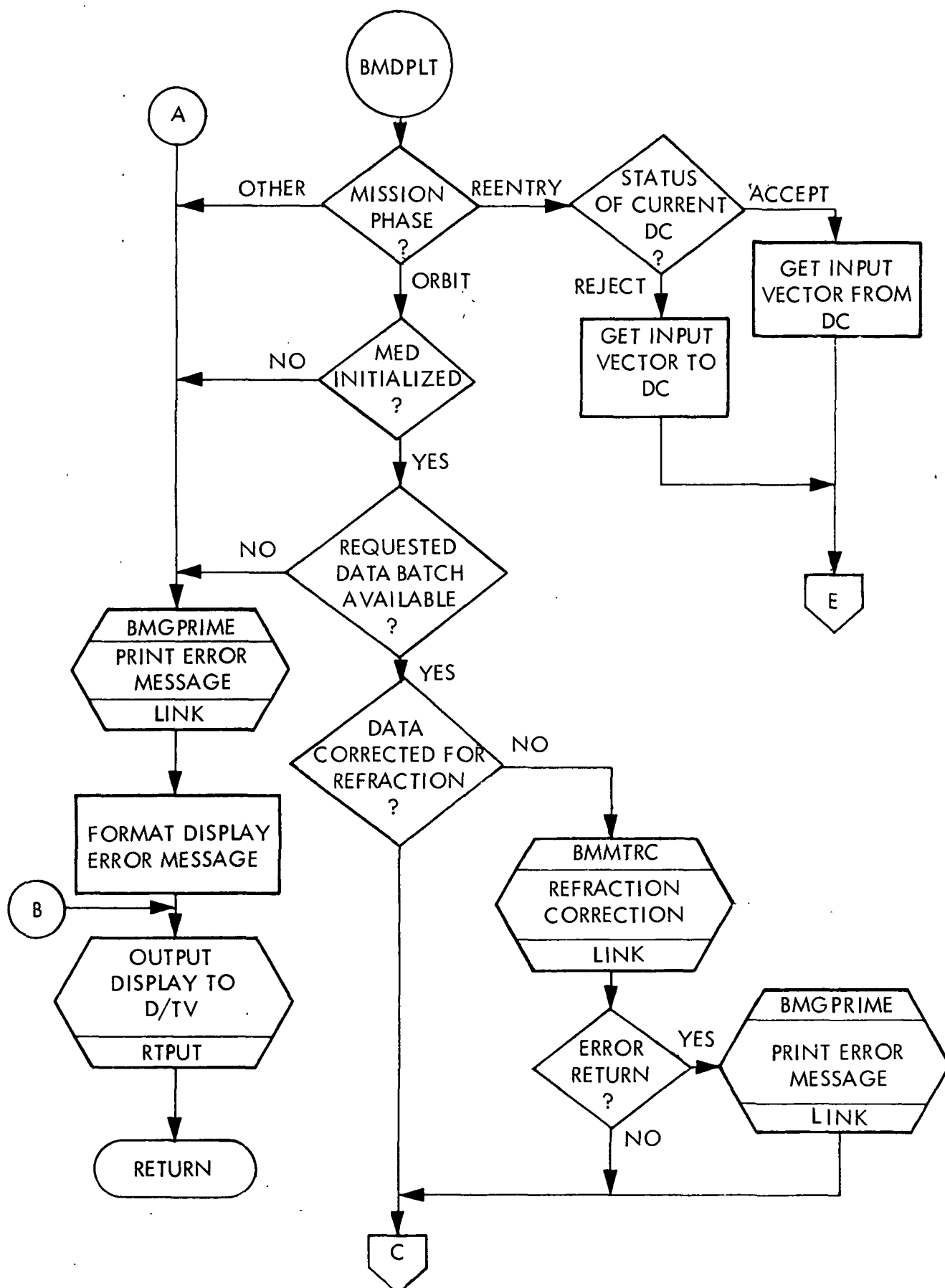


Figure 19. CSM/LM Batch Residual Plot

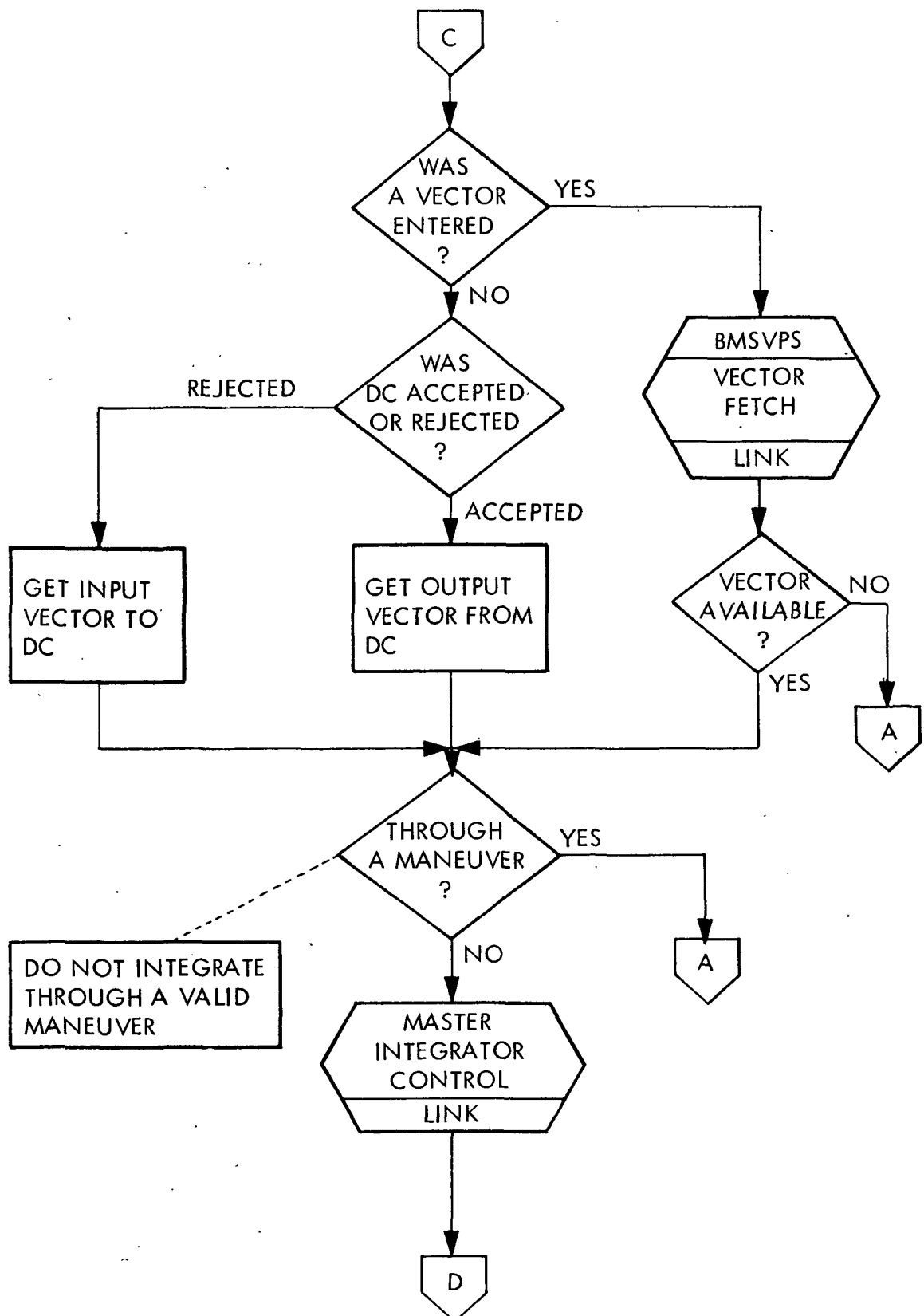


Figure 19. CSM/LM Batch Residual Plot.

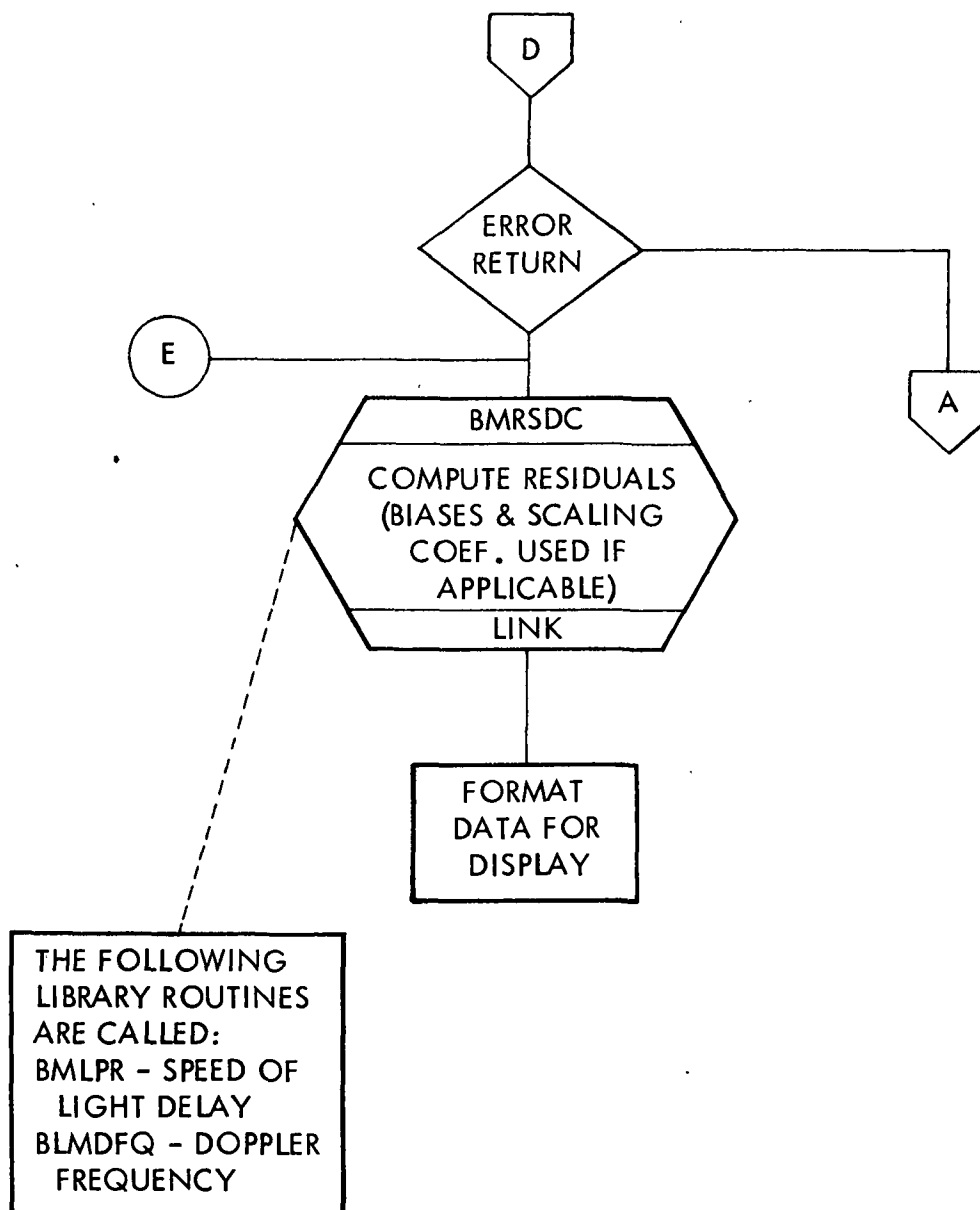


Figure 19. CSM/LM Batch Residual Plot

Clarification of Requirements — Batches timetagged more than 48 hours before the time of the most current station in the post-DC chain will not be displayed. The calculation of ΔT is the time span from the anchor time of each station in the post-DC chain to the anchor time of the most current station in the post-DC chain.

If a batch number is entered in the U19 MED, the anchor vector used to generate the ephemeris will always be the output vector of the station with a batch number that was entered.

When the U19 MED is entered, residuals for the latest twenty batches in the post-DC chain will be computed and displayed if MSK 1574 is currently active. If more than twenty batches exist in the post-DC chain, residuals may be obtained for those batches by requesting MSK 1575 after entry of the U19 MED.

Blanks will be displayed for Doppler RMS and average for a C-Band station. They will also be displayed for range RMS and average for a three-way S-Band station. For each entry from the display control program, BMDRESID lowers its execution priority by creating a new task which operates at a lower priority. This was necessary due to the excessive time required for computations. The lower priority permits other tasks to share the computer with BMDRESID during its computation period, thus producing a more efficient system.

Residuals are only computed for batches within a free-flight trajectory. Free-flight trajectories are determined by the contents of the mission plan table; however, a mission plan table entry of a $0.0\Delta V$ maneuver is considered free flight.

Error Checks — If any of the error conditions listed below are encountered, BMGPRIME is queued to print the indicated error message, and the indicated D/TV error message is formatted.

1. If BMDRESID is queued in an illegal phase, BMGPRIME prints

DD:HH:MM:SS.CC PHASE ERROR, OPTION (), VEHICLE N

where N is the vehicle number. The formatted D/TV error message is "D/TV: WRONG PHASE".

2. If no stations (batches) are available for residual computations, BMGPRIME prints

DD:HH:MM:XX.CC *SE**) BMDRESID(NO STATIONS AVAILABLE
D/TV: NO STATIONS AVAILABLE.

3. If the U19 MED has not been entered to properly initialize the input table used by BMDRESID, BMGPRIME prints

```
DD:HH:MM:XX.CC ** **) BMDRESID( TABLE NOT INITIALIZED
D/TV:  TABLE NOT INITIALIZED.
```

4. If an error return is received from the integrator control program, BMGPRIME prints

```
D/TV:  NI ERROR.
```

(See "Additional Formats" in the discussion of the On-line Print Module, BMGPRIME.)

5. If the DC history block has not been initialized, BMGPRIME prints

```
DD:HH:MM:SS.CC **SE**) BMDRESID( DC TABLE NOT
INITIALIZED FOR VEHICLE N
```

where N is the vehicle number. The formatted error message is "D/TV: NO DC YET".

6. If the requested vector is not found, BMGPRIME prints

```
DD:HH:MM:SS.CC **SE**) BMDRESID( AAAAAAA NOT AVAILABLE
D/TV:  AAAAAAA NOT AVAILABLE
```

where AAAAAAA is the vector ID.

A functional flowchart, Figure 20, of BMDRESID is included on the following pages.

Batch Summary (BMDBATCH)

The differential correction history block must be initialized for the requested vehicle (see "Error Checks"). There are no phase restrictions.

Input Queues — All queues are from the display control supervisor as a result of an MSK input (1576-1579). Based on the MSK input, the selected page of the Batch Summary for the selected vehicle is displayed after the data has been obtained and formatted.

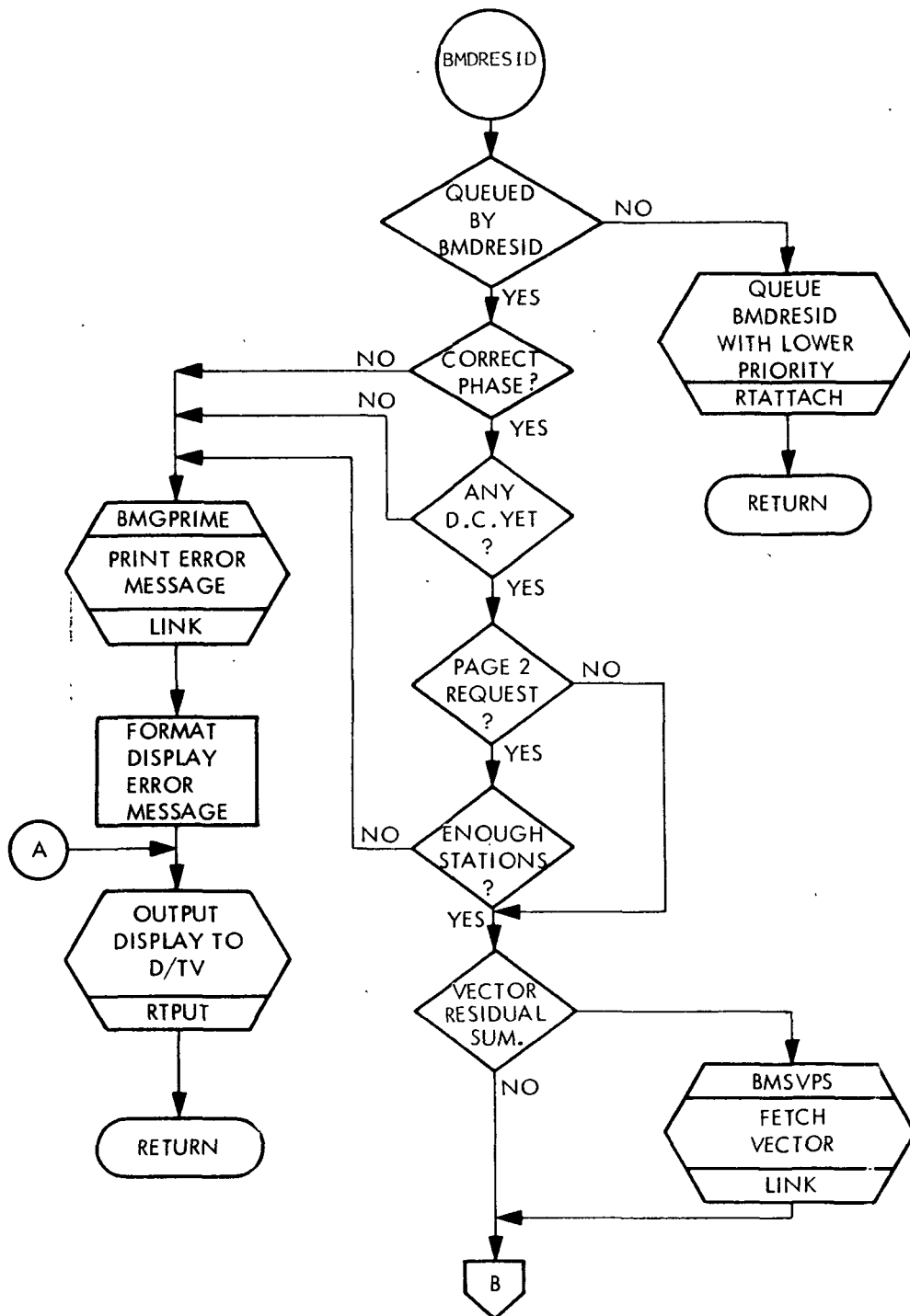


Figure 20. Residual Summary Statistics
(Sheet 1 of 2)

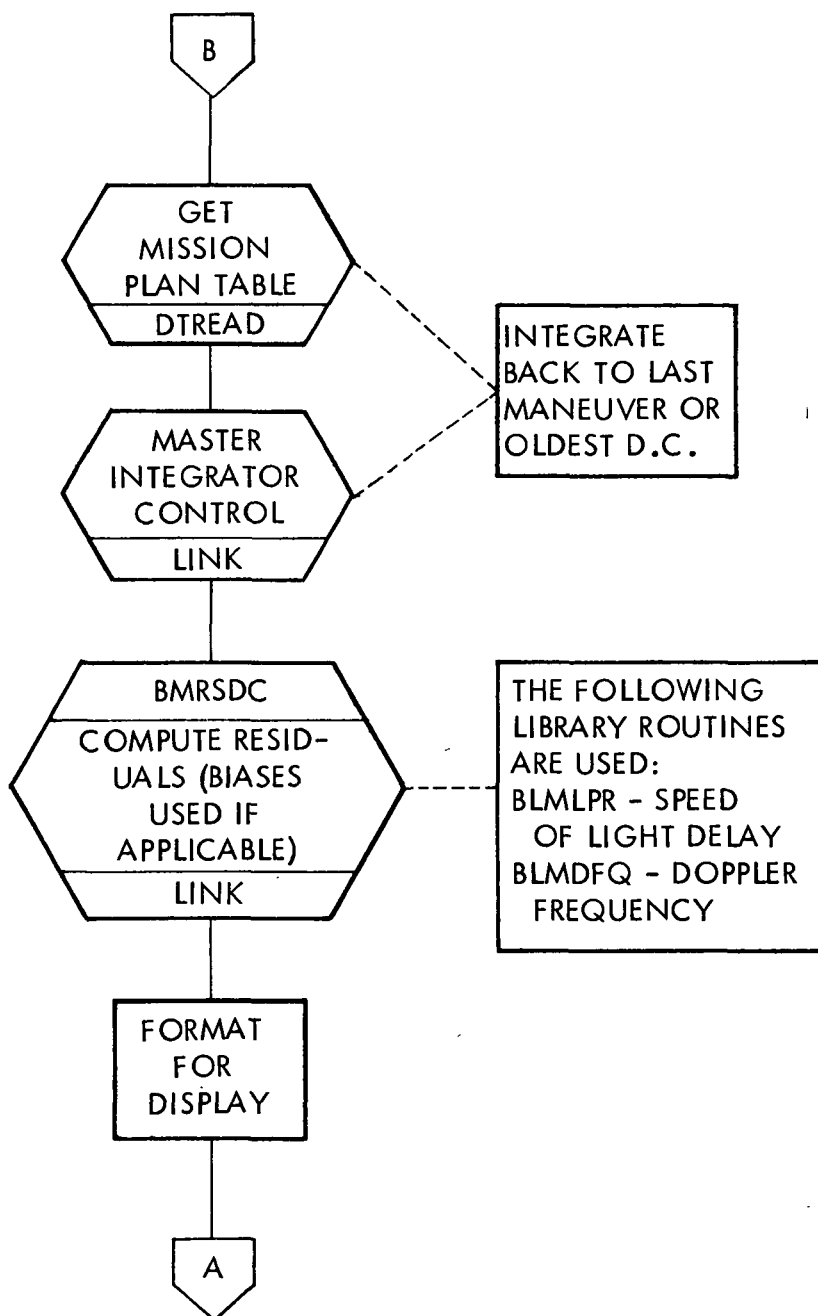


Figure 20. Residual Summary Statistics

Output Queues — For error conditions, BMGPRIME is queued to print an on-line error message, and a message is output to the display (see "Error Checks"). If no errors are found, the formatted output is displayed.

Clarification of Requirements — For a superbatch solution all values reflect the batch-to-batch results for the last batch in the superbatch except Γ , α , ρ , F and S. These represent the values used in the superbatch solution.

Error Checks — If the differential correction history block has not been initialized, BMGPRIME is queued to print the error message:

```
DD:HH:MM:SS:CC **SE** )BMDBATCH( DC TABLE NOT INITIALIZED
FOR VEHICLE N.
```

where N = requested vehicle. The message, "NO DC YET", is displayed in the D/TV.

If no stations are available, BMGPRIME is queued to print the error message:

```
DD:HH:MM:SS:CC **SE** )BMDBATCH( NO STATIONS AVAILABLE.
```

The message, "NO STATIONS AVAILABLE" is displayed in the D/TV.

Figure 21 is a functional flowchart of BMDBATCH.

DC Summary (BMDCSM)

The DC Summary requires no initialization. No check of mission phase is made.

Input Queues — Although all queues to BMDCSM are from the display control supervisor, they originate from three sources: (1) MSK request (1584 = CSM, 1585 = LM), (2) time cycle update, and (3) DC control.

1. MSK Request — When queued due to an MSK request (1584 or 1585), the generate cycle of BMDCSM formats the registration marks and MSK number, formats those items in the time cycle update queue (see item 2) and determines if there is a history DC for that vehicle. If there is not a history DC, an output message is formatted (see "Error Checks"). If there is a history DC, BMDCSM formats those items in the program-decision queue (see 3 e).

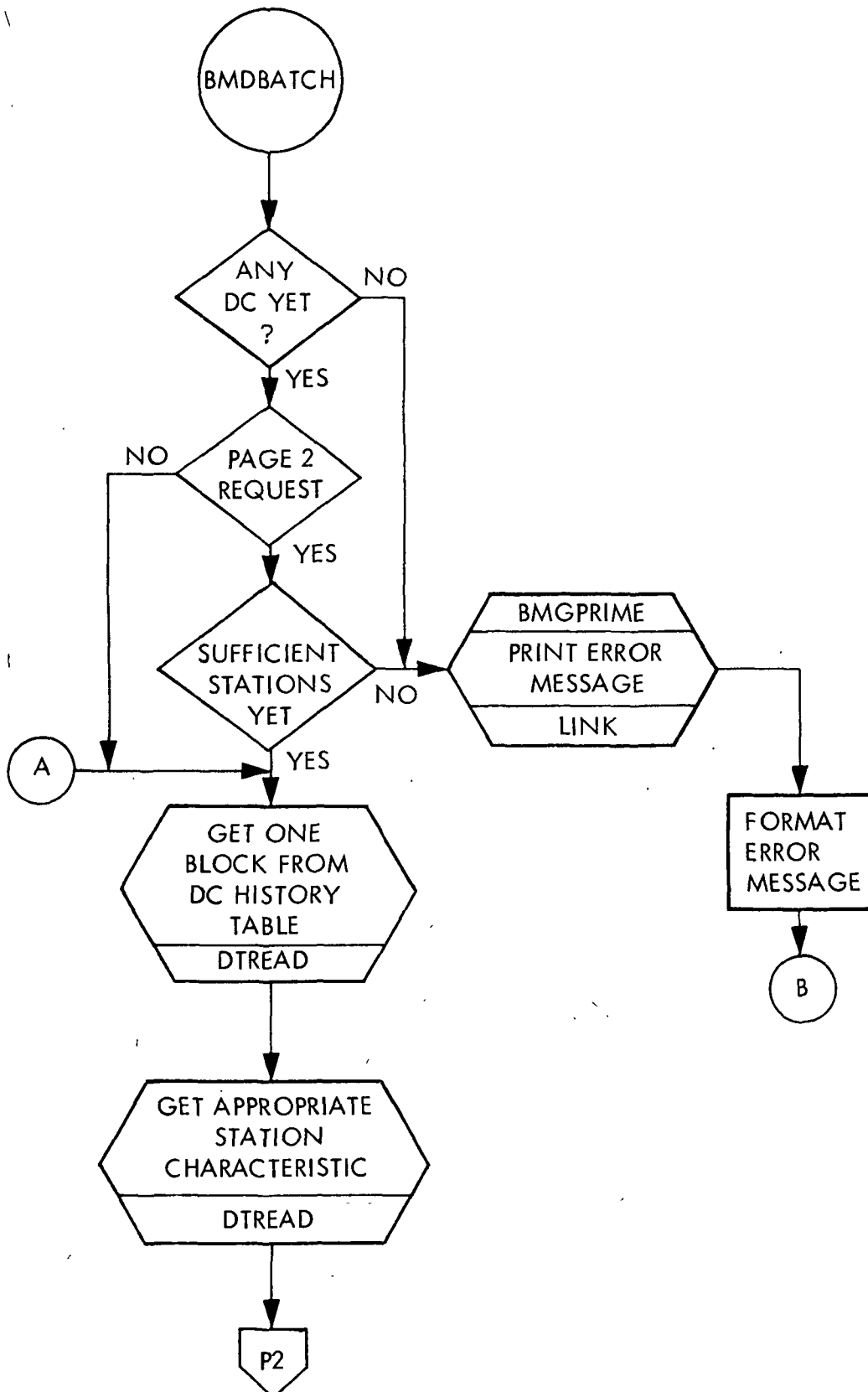


Figure 21. Batch Summary

(Sheet 1 of 2)

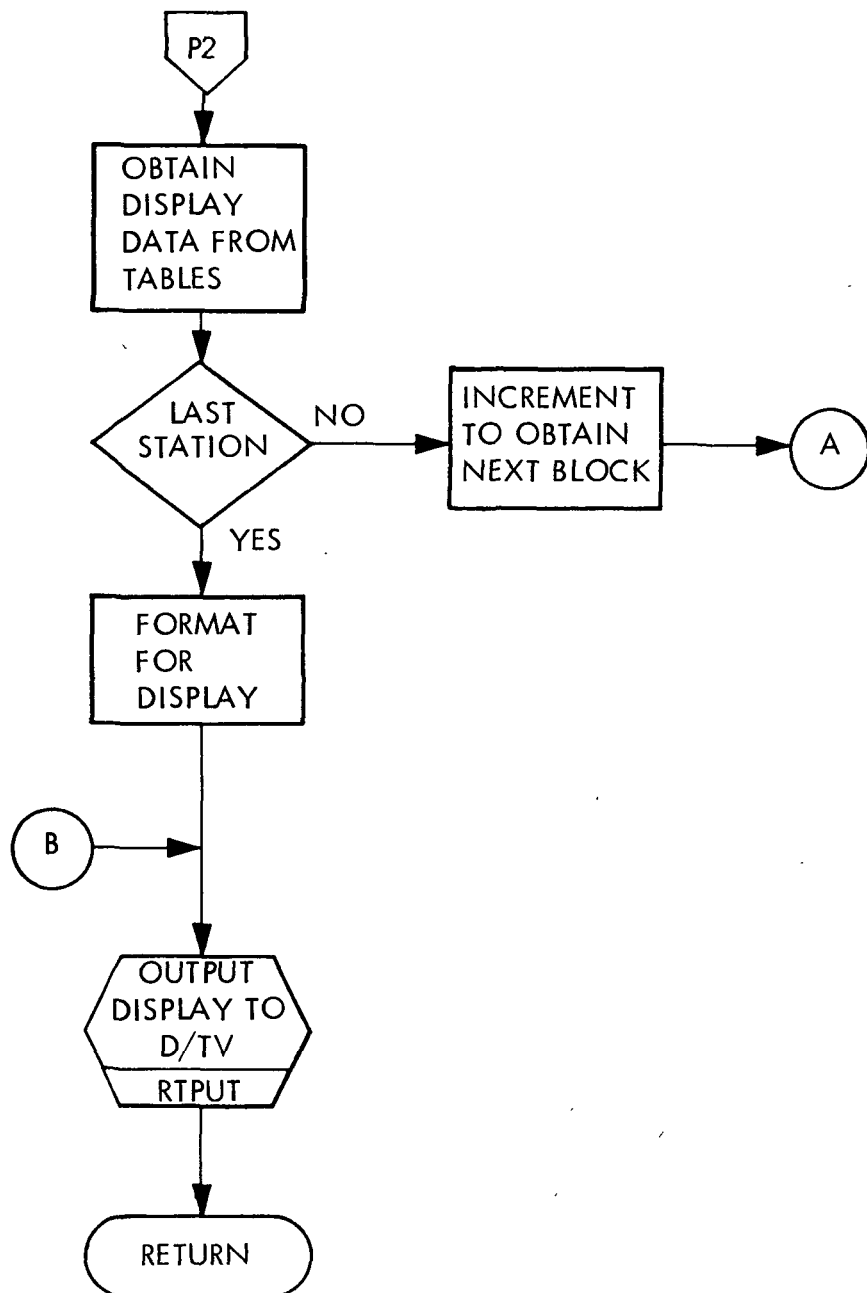


Figure 21. Batch Summary

(Sheet 2 of 2)



2. Time Cycle Update — When a time cycle queue is received (every twelve seconds in orbit and every six seconds in abort or reentry), the current GMT and GET is formatted in addition to the following items:

- a. ΔT_I (if no future maneuver is in the Mission Plan Table).*
- b. Maneuver column items (last executed maneuver in the Mission Plan Table) GMT, GET, CODE, ΔV , ΔT_B , $K\theta$, K_A and K_M .

These items are blanked if no maneuver is in the Mission Plan Table.

3. DC Control — BMDCSM is queued by DC control on five events: error condition, manual decision made, batch-to-batch DC in process, superbatches DC in process and program decision made.
 - a. Error condition — The MISHAP number is formatted.
 - b. Manual decision made — The DECISION (ACCEPT or REJECT) is formatted.
 - c. Batch-to-batch DC in process — The in-process indicator, SSSBNNN IN PROCESS (see "Clarification of Requirements" for definition of SSSBNNN), is formatted.
 - d. Superbatch DC in process — The message SUPERBATCH IN PROCESS for the in-process indicator is formatted.
 - e. Program decision made — The following items are formatted.

<u>Item</u>	<u>Note</u>
MISHAP	
ΔT_P	4
E_{MAX}	1
FOM	
ITER	2
EDIT	1
SS	

*See "Note 2", page 91.

<u>Item</u>	<u>Note</u>
α	1
$K_I, K_e, K_F, T_I, T_\theta, Q$	
In-process Indicator	3
STATION	4
GMT	4
DECISION	5
EDIT	6
σ	7.9
RMS	8,9
NO. OBS.	9
$DC\sigma$	1,9
EDITED	1,9
VALUE	1,9
RMS	9
AVG	9
$V, \sigma, \psi, \theta, \lambda, h, \Delta V, \Delta\sigma, \Delta\psi,$ $\Delta\theta, \Delta\lambda, \Delta h, \Delta a, \Delta e$	
Δi	
$\Delta\omega_\rho$	11
$\Delta\Omega$	
Δv	11

<u>Item</u>	<u>Note</u>
$\Delta u, \Delta v, \Delta w, \Delta \dot{u}, \Delta \dot{v}, \Delta \dot{w}, \Delta R_i,$ $\Delta V_i, \sigma u, \sigma v, \sigma w, \sigma \dot{u}, \sigma \dot{v}, \sigma \dot{w},$ $H_A, \Delta H_A, H_P, \Delta H_P$	
BIAS	10

Note 1: Blanked if a superbatch solution.

*Note 2: Formatted after ITER if DC was converging and (1) ITER ≥ 5 for a superbatch solution, or (2) ITER ≥ 10 for a batch-to-batch solution.

Note 3: This item blanked.

Note 4: See "Clarification of Requirements".

Note 5: "WAITING" if in manual mode; "ACCEPT" or "REJECT" if in automatic mode.

Note 6: Blanked if starter or pre-edit not used in solution.

Note 7: Blanked unless pre-edit used.

Note 8: Blanked unless pre-edit or starter on a superbatch used (for starter, two-way and three-way will be blanked).

Note 9: For a batch-to-batch solution, the following values are blanked:

C-Band and ship S-Band: Two-way and three-way
Land S-Band, two-way: Three-way
Land S-Band, three-way: Two-way, range.

Note 10: If range bias applied BIAS = R0, three-way = blank, ID(3) = blank.

If two-way Doppler bias is applied, BIAS = D2, three-way = blank, ID(3) = blank.

If three-way Doppler bias is applied, BIAS = D3, two-way = blank.

Note 11: If $e < .001$, $\Delta \omega_p$ and Δv are blanked.

Output Queues — All formatted values are output to the D/TV.

Clarification of Requirements — The total time of the pass, ΔT_p , will be the batch-collection time for batch-to-batch processing. For superbatch processing, ΔT_p will be the difference between the time at the end of the last batch and the time at the beginning of the first batch.

STATION will be SSSBNNN, where

SSS = Station name (last name if a superbatch).
B = Band type (X if a superbatch).
NNN = Batch number (last batch number if a superbatch).

GMT (under STATION) will be the time at the beginning of the batch (first batch if a superbatch). The following formulation was provided by NASA to compute a and e :

$$1/a = 2/r - v^2/\mu$$

$$e = 1/a \frac{(\bar{r} - \bar{v})^2}{\mu} + [1 - r(1/a)]^2$$

where

r = Radius magnitude
 v = Velocity magnitude
 μ = Gravitational constant
 \bar{r} = Radius vector
 \bar{v} = Velocity vector.

Error Checks — If no history DC is available, the message "DATA NOT AVAILABLE" is formatted and output to the D/TV. If an invalid queue is received, BMGPRIME is queued to print the error message:

DD:HH:MM:SS.CC **SE**)BMDCSM(ILLEGAL INPUT XXXX

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where XXXX = invalid queue ID received. If an error condition occurs when computing the orbital elements, the message "ORBITAL ELEMENTS CANNOT BE COMPUTED" is formatted and displayed under the RESIDUAL STATISTICS portion of the display.

Figure 22 illustrates the functional flow of BMDCSM.

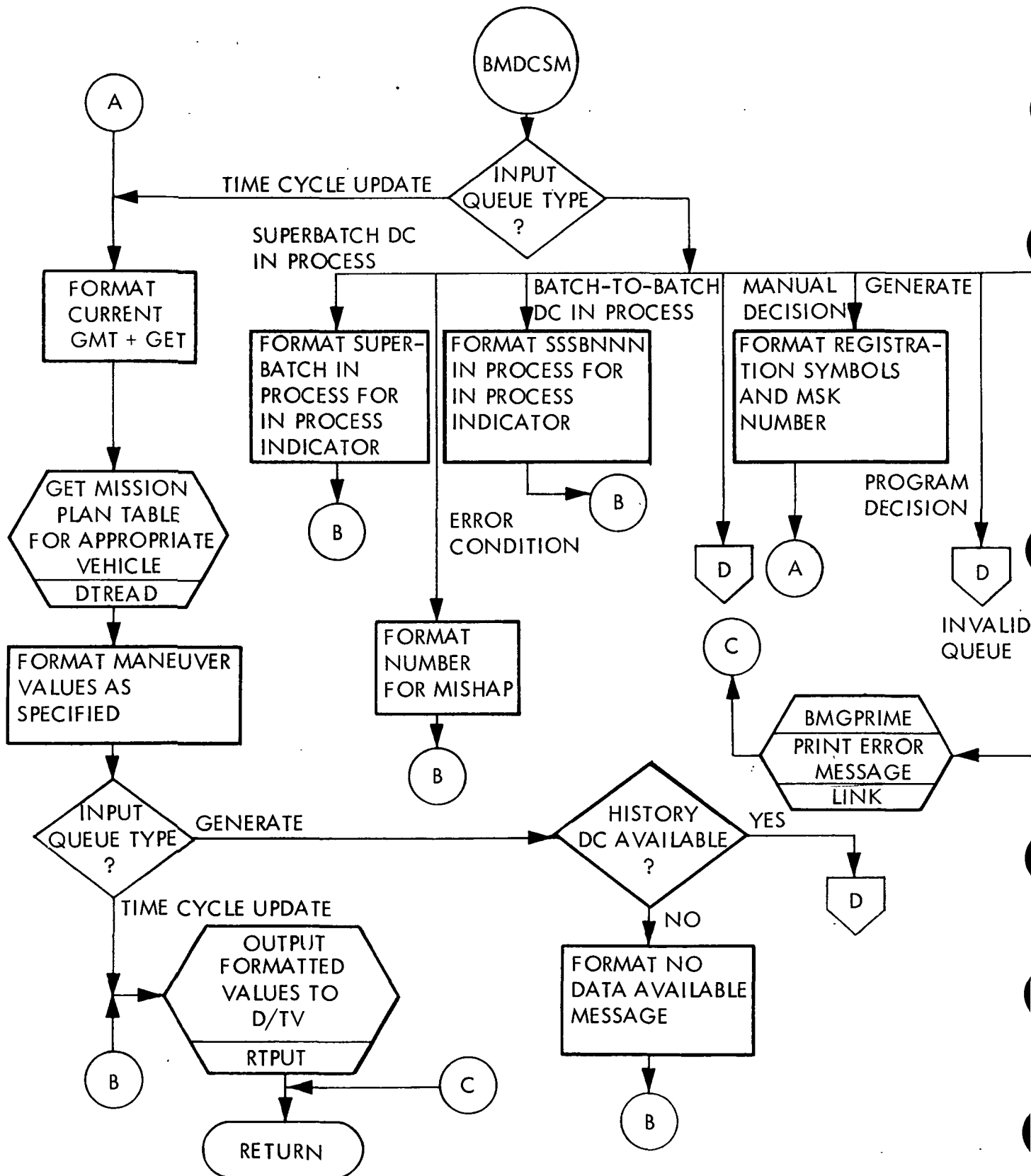


Figure 22. DC Summary

(Sheet 1 of 2)

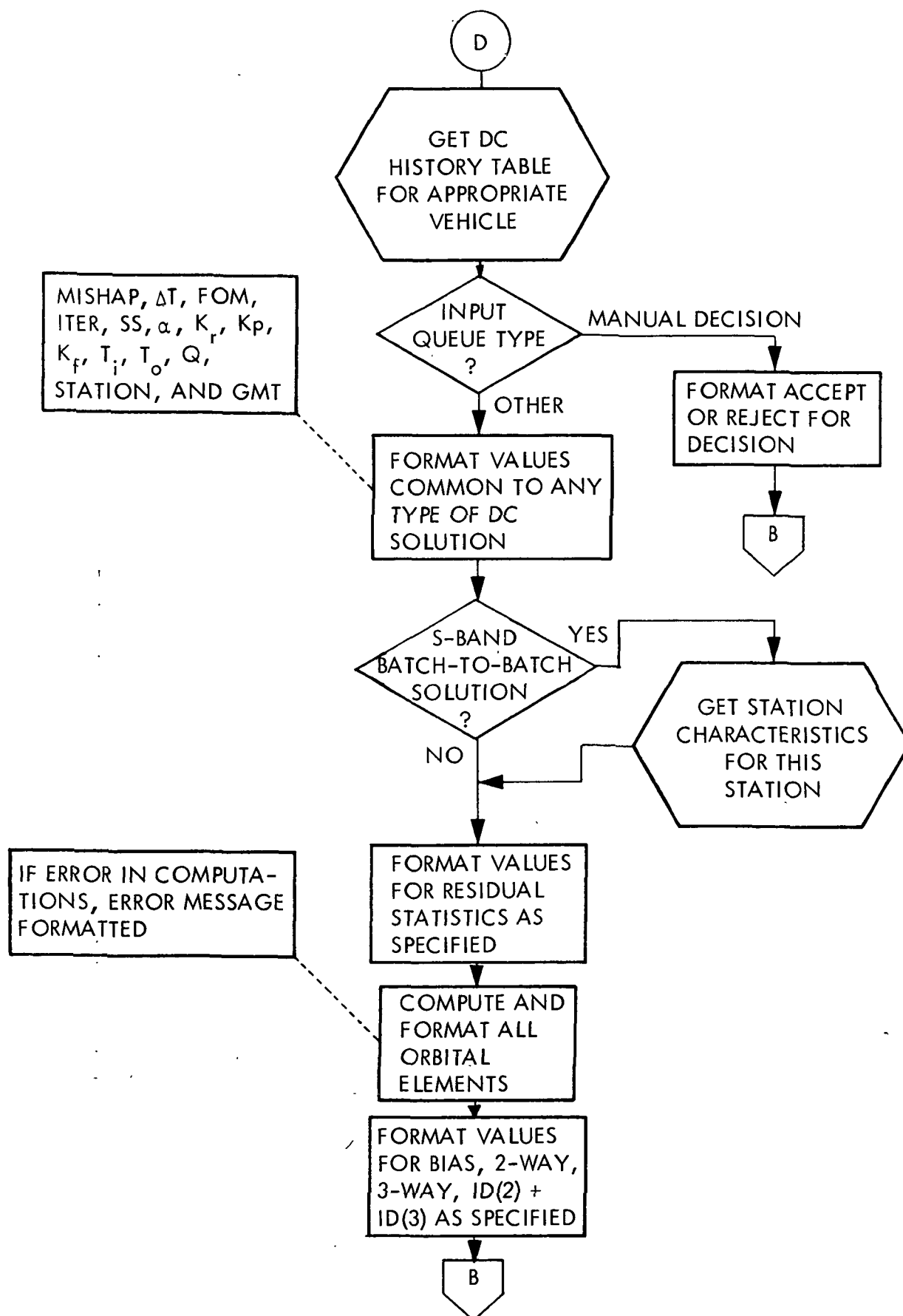


Figure 22. DC Summary

VECTOR CONTROL AND COMPARISON

GENERAL REQUIREMENTS

The vector control and comparison unit is responsible for collecting specified vectors into several vector storage areas (slots). These vectors can come from the available telemetry pool of available telemetry vectors, the differential correction unit, orbit high-speed processing, and from a MED input. For the purpose of vector evaluation, the unit will compare vectors within the unit, vectors from the differential correction unit, and ephemeris vectors.

Vector control will cause vectors to be moved into the evaluation vector and usable vector slots by use of the vector control panel pushbutton indicators (PBI), the DC logic control PBI (update inputs), and termination of orbit high-speed processing. Both the evaluation vector and the usable vector slots may be manually filled by a MED. Vector comparison is accomplished by specifying the desired vectors for evaluation by MED input. The local spherical and classical elements are computed for the initial vector and convert the vector to the UVW system. The differences between the elements of this base vector and the elements for the subsequent vectors specified in the MED are then computed. The MED's involved are

1. Vector Comparison Display MED (S80).
2. Vector Panel Summary MED (to load vector slots) (S84).

Output from the vector control and comparison unit is by D/TV display and on-line print messages. The status of the various evaluation and usable vector slots, as well as the results of vector comparisons, are shown on D/TV displays. On-line prints include all usable vectors, PBI inputs, and appropriate error messages. In addition, an error condition in vector comparison will be indicated on the comparison D/TV display.

DESIGN DISCUSSION

The vector control and comparison unit consists of four load modules:

1. Vector Control Module (BMSVPS)
2. Vector Comparison Module (BMSVEC)
3. Vector Panel Summary (BMDVPS)
4. Vector Comparison Display (BMDVEC).

In addition, the On-line Print Module (BMGPRIME) is used. Figure 23 shows the interface of these modules as well as all unit inputs and outputs.

All vector control panel PBI entries are processed by BMSVPS. These entries can cause:

1. Movement of available telemetry vectors to the Evaluation Vector Slots.
2. Movement of evaluation vectors to the Usable Vector Slots.
3. Movement of any usable vector to cause an ephemeris update. BMSVPS will also collect the High-Speed Radar Short-Arc or Smoothing Vector (whichever is available) and the Averaged Telemetry Cut-off Vector at termination of Orbit High-Speed processing. Upon activation of the update PBI on the DC Logic Control Panel, the last accepted DC vector for the vehicle specified will be moved to the appropriate DC Usable Vector Slot. Any usable vector can be moved to cause an ephemeris update by use of the Vector Control Panel PBI.

BMSVPS will also process the S84 MED, which can be used to initialize any of the vector slots. This MED has a remember capability and thus can be input in segments.

The vector comparison module, BMSVEC, will fetch the vectors specified in the S80 MED and cause the vectors to be integrated, if necessary, to the comparison time specified in the MED. The local spherical elements, the classical elements, and the UVW coordinates will be computed for the base (first) vector specified in the S80 MED. The differences between the elements of this vector and the second, third, and fourth vectors (if input) will then be computed. From one to four vectors can be specified for comparison. BMSVEC queues the display supervisor, which in turn queues BMDVEC to display the results of the comparison.

BMDVEC will generate a D/TV display of the base vector elements and the element differences for the comparison vectors. If an error condition was encountered in the comparison computations, an error message will be displayed on the Vector Comparison Display.

The load module, BMDVPS, will display the time tags of all telemetry vectors available in the telemetry collection pool. The vector identification, the time tag of each evaluation, and the usable vectors will be displayed. Ephemeris anchor vector ID's and times are shown, as well as GMT of ullage on and GMT of tailoff for the last executed maneuver.

A unit flowchart (Figure 23) is provided on the following page.

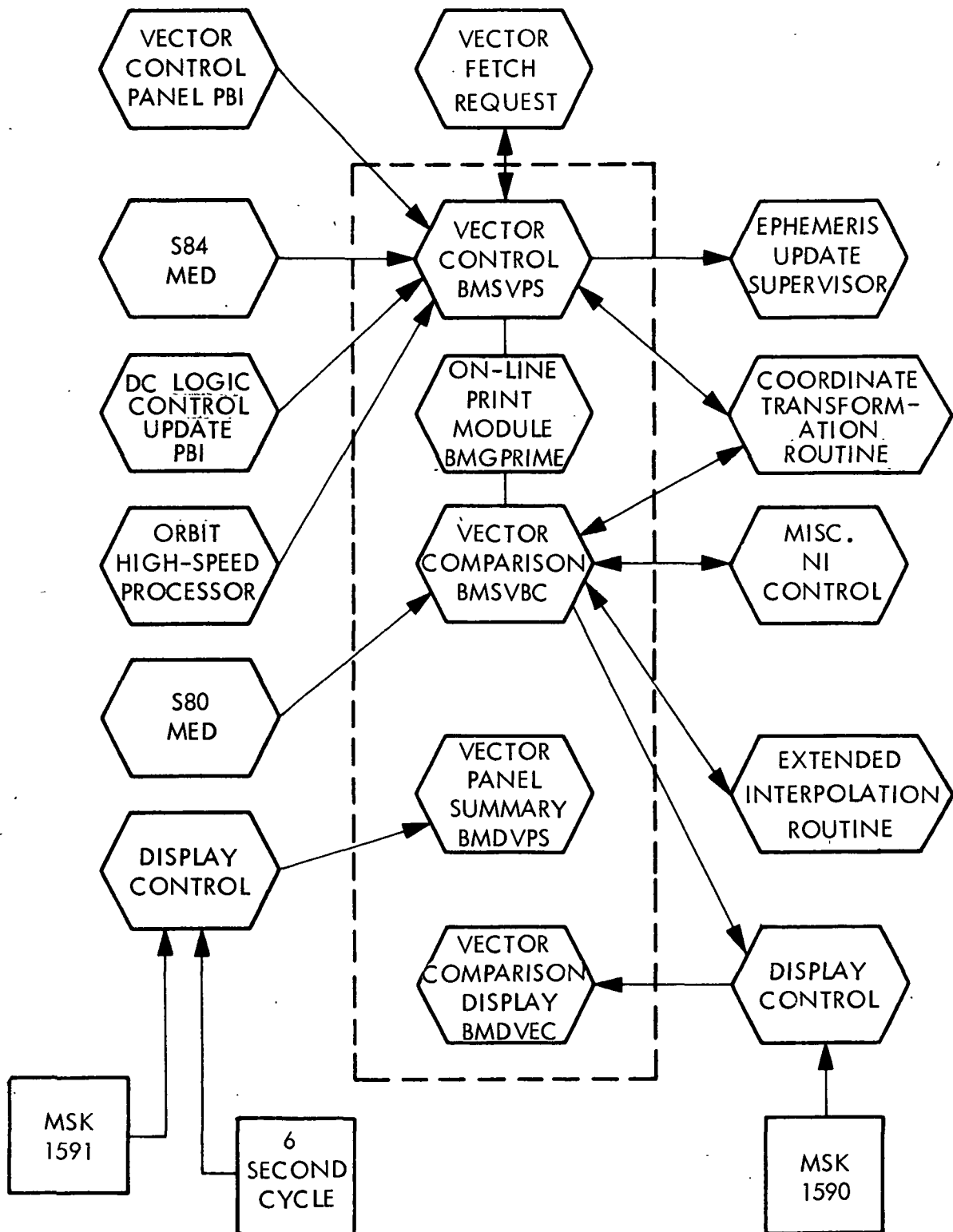


Figure 23. Vector Control and Comparison Unit

Vector Control Processor (BMSVPS)

The initialization required by BMSVPS is accomplished upon the first entry of the load module.

Mission Phase

This module will accept queues resulting from PBI inputs in all low-speed processing phases. It is available to fetch vectors and for S84 MED processing in any phase.

Input Queues

BMSVPS has four input queues.

1. A queue is received when a Vector Control Panel PBI entry is made. The PBI request is decoded and the vector movement requested is made (see "Mission Phase").
2. BMSVPS is queued when the update PBI on the DC Logic Control PBI is entered. The last accepted DC vector for the vehicle specified is moved to the Usable Vector Slot for that vector (See "Mission Phase").
3. A queue is received at termination of orbit high-speed processing. This queue will designate the types of vectors available for transfer to the Usable Vector Slots. BMSVPS will move the specified vectors to the appropriate Usable Vector Slots.
4. Each entry of the S84 MED will cause BMSVPS to be queued. Missing MED items are ignored since this MED has a remember capability. When all the MED items have been accumulated for a particular vehicle, the vector just entered will be moved to the vector slot designated by the vector ID entered in the MED. The memory capability will then be re-initialized for subsequent vector inputs.

Outputs Queues

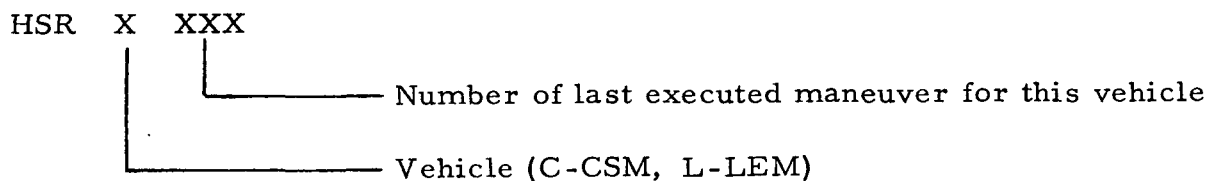
The following output queues are possible.

1. Each Vector Control Panel PBI entry will cause the vector movement requested in the PBI message. If the message cannot be decoded or the vector movement requested cannot be done, BMGPRIME is queued to print an error message. In either case, the PBI message is printed on line by BMGPRIME (see item 1 of "Additional Formats" under "On-Line Print Module BMGPRIME").

2. If vector movement is to a Usable Vector Slot, BMGPRIME is queued to print the vector on line as a possible anchor vector (see item 6 of "Clarification of Requirements" under "On-Line Print Module BMGPRIME").
3. If the PBI request is to move a usable vector to cause an ephemeris update, the Ephemeris Update Supervisor is queued, and the designated vector is passed to that processing unit.

Clarification of Requirements

High-speed radar vectors are identified as follows:



Only certain PBI inputs are allowed for various requests.

1. To move a vector to an evaluation slot, the "To Evaluation Slot" button must be depressed in addition to one of each of the following sets of buttons:
 - a. CMC, LGC, AGS, IU
 - b. CSM, LM (other)
 - c. High-Speed, Low-Speed.
2. To move a vector to a usable slot, the "To Usable Slot" button must be depressed in addition to one of each of the following sets of buttons:
 - a. CMC, LGC, AGS, IU
 - b. CSM, LM (other).
3. To move a vector to an update processor, the "To Ephemeris Update" button must be depressed in addition to one of each of the following sets of buttons:
 - a. CMC, LGC, AGS, IU, HS Radar, DC
 - b. CSM, LM (other).

The S84 MED will have a remember capability. Items of the MED can be input on successive entries. The various parameters will be accumulated until a MED entry is made that will include the last item(s) necessary to complete the memory cell for the vehicle being processed. Items may be changed prior to entering all MED parameters by reentering the item(s). The cell for a particular vehicle will have its memory capability renewed when all items have been input and properly decoded.

Telemetry vectors will not be rotated through a matrix whose time tag is later than the vector time (if not time is associated with the matrix, it will always be used). An on-line error message will be printed as mentioned above in item 1 of "Output Queues".

Upon rotation of telemetry vectors through the appropriate conversion matrix, a test will be made of the position components. If the position is less than one radius for the reference body, the vector will not be further processed. An on-line error message will be printed as mentioned above in item 1 of "Output Queues".

If a telemetry vector is entered by use of the S84 MED and it contains a vector number identical to a number presently assigned to that vector type, the vector number will be incremented by one. This action will be indicated by an on-line message (Code 9) printed by BMGPRIME as described below (see "Error Checks").

Additional Processing and/or Capabilities

Vector fetch and coordinate system transformation services are provided by BMSVPS for users of usable vectors. Evaluation vector Slots can be initialized by the S84 by entering a valid evaluation vector identification.

Error Checks

In addition to the error checks mentioned above, many additional checks are made by BMSVPS; BMGPRIME is then queued to print the following error message:

DD:HH:MM:SS.CC**DY**)BMSVPS(ERROR NUMBER XX

where XX is one of the codes listed below.

<u>Code</u>	<u>Error Description</u>
1	An unrecognizable queue ID was detected.
2	Not used.
3	Not used.
4	The PBI request made was not a valid request (missing information, two sources indicated, etc.).
5	Request to move vector to Usable Slot cannot be honored because there is no vector in the corresponding Evaluation Slot.
6	Request to move vector to ephemeris update cannot be honored because there is no vector in the corresponding Usable Slot.
7	Not used.
8	Test of PBI message header failed; improper message was routed to module.
9	Unidentifiable vector ID in the S84 MED.
10	Vector to be moved to ephemeris update could not be transformed to ECI coordinates.
11	Telemetry vector requested by PBI cannot be furnished this mission.
12	Not used.
13	Not used.
14	The matrix to rotate the telemetry vector requested is not available.
15	Request is for a telemetry vector that is not available in the collection slot for this type vector.
16	Invalid vehicle code from high-speed processor.
17	Invalid vector source code from high-speed processor.

If any of the above error conditions occur, no vector movement will take place.

Operational Procedure

When the error message ("Output Queues", item 1) is printed, the PBI input should be reentered with the correct indicators depressed.

Figure 24 is a flowchart of this load module.

Vector Comparison Processor (BMSVEC)

Initialization of BMSVEC is required via the S80 MED. BMSVEC is available during all low-speed mission phases.

Input Queue

There is one input to BMSVEC, This queue results from entry of the S80 MED which can contain parameters requesting comparison of from one to four vectors. These vectors can be any combination of vectors from the following sources: the Usable Vector Slots, the Evaluation Vector Slots, the Differential Correction history table and the orbit or reentry/abort ephemeris. Each vector is transformed to the coordinate reference specified in the S80 MED and integrated to the comparison time requested.

Output Queues

An output queue to BMDVEC is generated after the following has been performed. After any necessary integrations have been completed, the vectors with time tags equal to comparison time are used to compute the following quantities for each vector:

H_A - Height of apogee

H_P - Height of perigee

Local Spherical Elements

V - Velocity

γ - Flight-path angle

ψ - Heading

φ - Latitude

λ - Longitude

h - Height

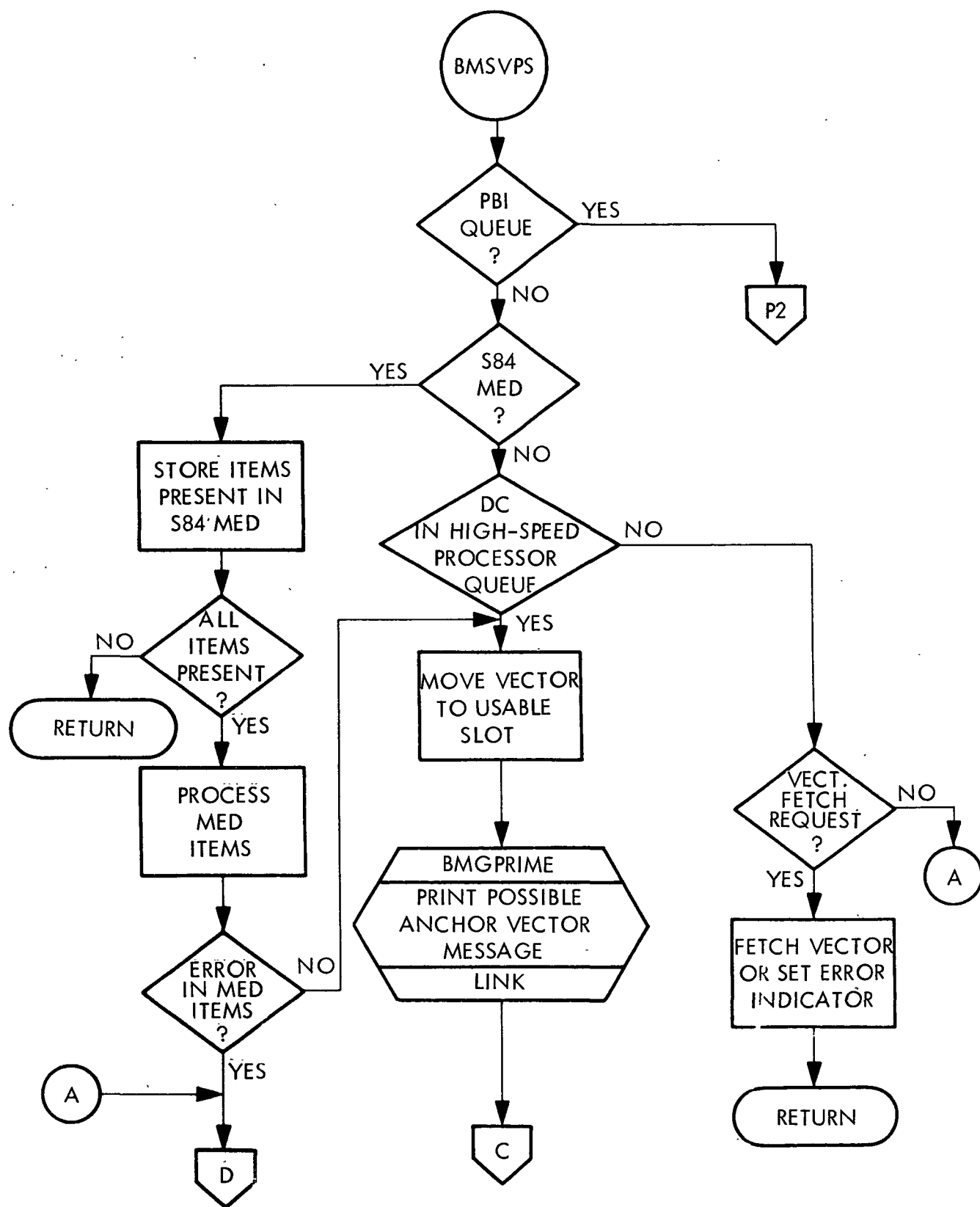


Figure 24. Vector Control Processor

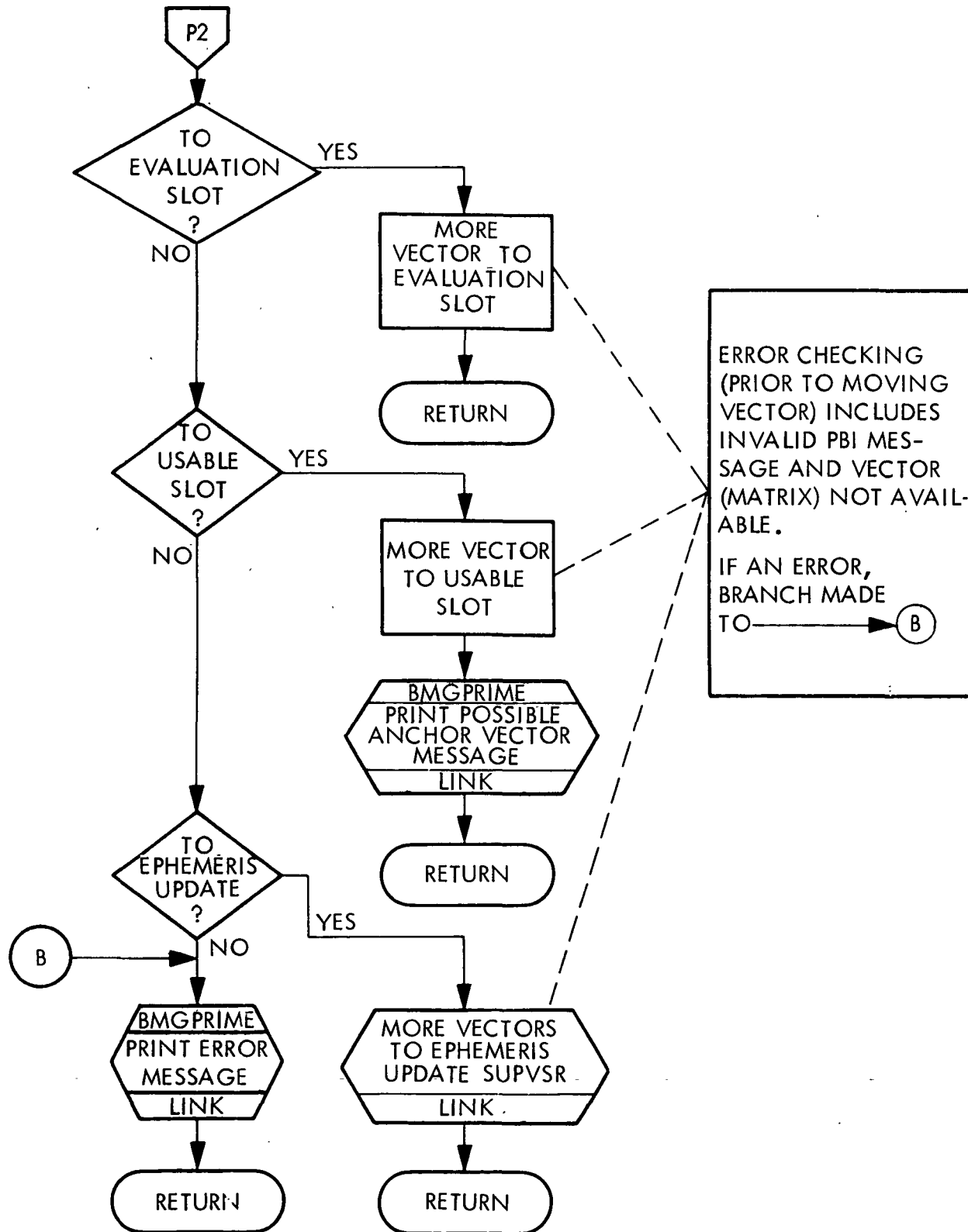


Figure 24. Vector Control Processor

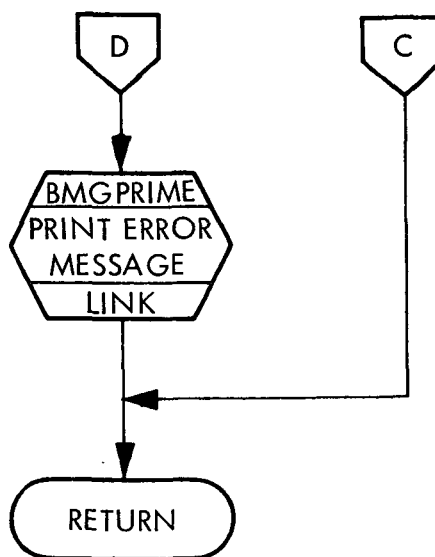


Figure 24. Vector Control Processor

Classical Elements

a - Semimajor axis

e - Eccentricity

i - Inclination

 ω_p - Argument of perigee Ω - Right ascension of the
ascending node u - True anomalyCoordinates in U, V, W system

$$U = r \cdot \hat{U}$$

$$V = r \cdot \hat{V}$$

$$W = r \cdot \hat{W}$$

$$U = \bar{v} \cdot \hat{U}$$

$$V = \bar{v} \cdot \hat{V}$$

$$W = \bar{v} \cdot \hat{W}$$

The \hat{U} , \hat{V} , \hat{W} system is defined by using the base vector (the first requested in the S80) to calculate unit vectors. Output queues to request vector fetch services from BMSVPS and for vector integration are generated if necessary.

Clarification of Requirements

Although a comparison time within a maneuver is an error condition for vectors which must be integrated, an interpolation for an ephemeris vector at a comparison time within a maneuver will not produce an error message.

If the vector time tag is equal to the comparison time that is within a maneuver, no integration is necessary, and no error message is produced.

The Miscellaneous NI Control Program is used for orbit integration forward with maneuvers in the mission plan table considered, or backward with no maneuvers. The following NASA-provided formulation will be used to compute the semimajor axis and eccentricity:

$$\frac{1}{a} = \frac{2}{r} - \frac{v^2}{\mu}$$

$$e = \sqrt{\frac{1}{a} \left[\frac{(\vec{r} \cdot \vec{v})^2}{\mu} \right] + \left[1 - r \left(\frac{1}{a} \right) \right]^2}$$

(This formulation will provide for non-elliptic vectors.)

BMSVEC requires no additional processing and/or capabilities.

Error Checks

BMSVEC error checks are described below.

1. If a vector must be integrated backward through a maneuver, BMGPRIME is queued to print the following error message:

DD:HH:MM:SS. TH**DY**)BMSVEC(ILLEGAL REQUEST FOR
BACKWARD INTEGRATION, VECTOR N

where N is a number (1-4) representing the vector in the S80 MED.

2. If a vector cannot be found, BMGPRIME is queued to print the following message:

DD:HH:MM:SS. TH **DY**)BMSVEC(CANNOT FIND VECTOR N

where N is the number as described in item 1.

3. If any error condition is detected by the integrator, an appropriate message is printed on line by BMGPRIME (see item 2 of "Additional Formats" under "On-line Print Module").
4. If the cross product of the position and velocity components of a vector are zero, or if the time of the vector or the comparison time is within a maneuver and integration must be performed, BMGPRIME will be queued to print an error message.

Figure 25 illustrates the functional flow of module BMSVEC.

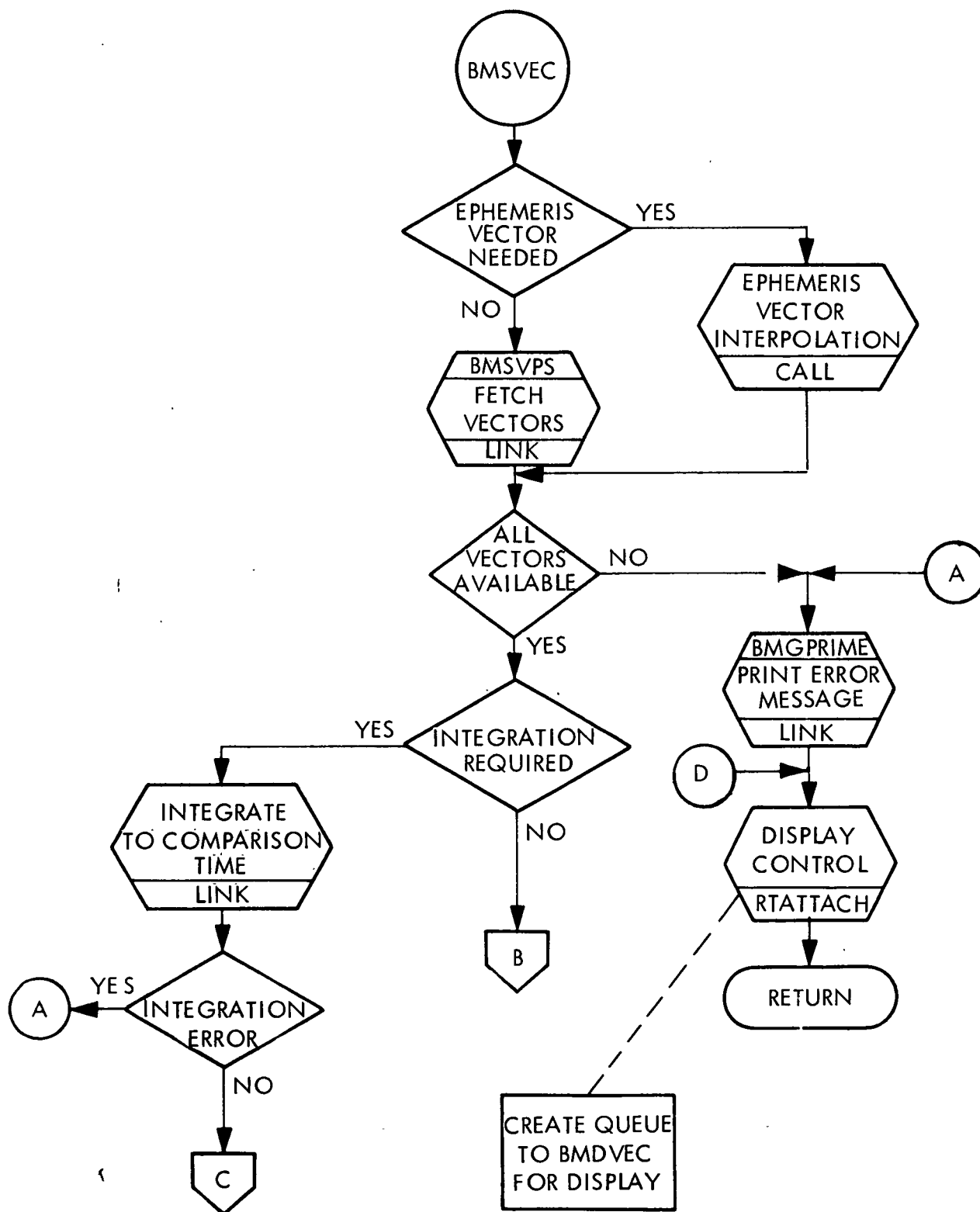


Figure 25. Vector Comparison Processor

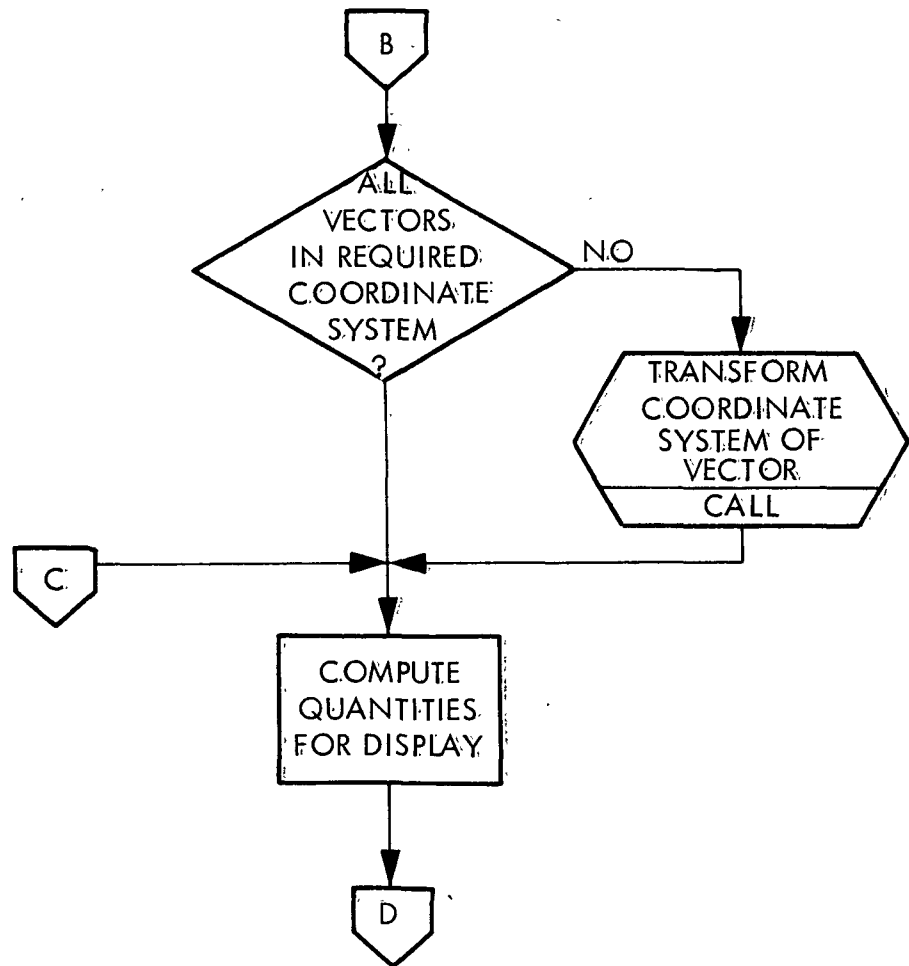


Figure 25. Vector Comparison Processor

Vector Panel Summary Processor (BMDVPS)

No initialization is required for BMDVPS. This load module is available in all mission phases and in no phase.

Input Queues

A queue is received upon entry of display request 1591 which will cause generation of the entire Vector Panel Summary Display. A queue is received every six seconds while the Vector Panel Summary is being displayed. This queue will result in an update of all the display items.

Output Queue

BMDVPS will output the ephemeris anchor vector identifications, anchor vector times, and current GMT. It will also display the vector identification and time for each vector in a Usable Vector Slot and each vector in an Evaluation Vector Slot. GMT of ullage tailoff are displayed for the last executed maneuver for both vehicles. The time tags of all available telemetry vectors will also be displayed.

Clarification of Requirements

The GMT of ullage will be computed as follows:

$$GMTUL = GMTLO + GETI - \Delta T_{UL} + 1 \text{ sec.}$$

where:

GMTUL = GMT of ullage
GMTLO = GMT of liftoff
GETI = GET of burn initiate
 ΔT_{UL} = time of ullage.

One second represents the nominal ΔT of buildup and overlap, which may vary for different types of maneuvers.

There are no error messages output by this processor. If a display quantity is blank, this means that quantity is not available for display. Figure 26 is a flowchart of BMDVPS.

Vector Comparison Display Processor (BMDVEC)

No initialization of the Vector Comparison Display Processor is required (see "Error Checks"). BMDVEC is available during all low-speed mission phases.

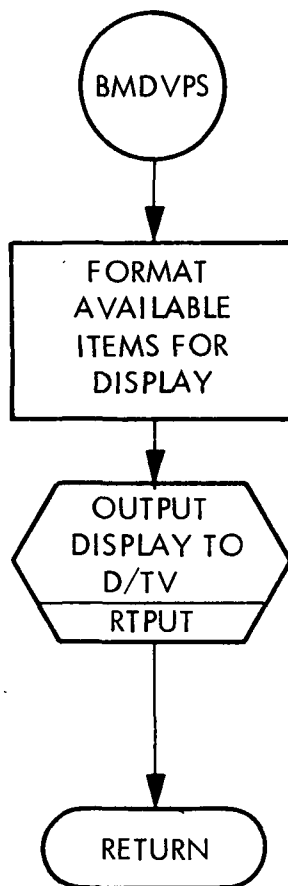


Figure 26. Vector Panel Summary Processor

Input Queues

BMDVEC is queued when display request 1590 is entered. This will cause generation of the entire display. BMDVEC is queued upon completion of comparison computations made by BMSVEC.

Output Queues

If the vector comparison output area of BMSVEC has been initialized, the quantities computed are displayed by BMDVEC upon receiving each queue.

Clarification of Requirements

BMDVEC will display the local spherical, classical and UVW coordinates for the base vector. The differences between the base vector elements and the elements for the other comparison vectors (if any) will also be displayed. The vector identification and time will be displayed over each column of computed elements. The header of the display will include the vehicle ID and the comparison time (GMT and GET). If the eccentricity for a vector is less than 0.001, the values for the argument of perigee (ω_P) and true anomaly (ν) are left blank. If the eccentricity for a vector is greater than 1, height of apogee will not be displayed.

Error Checks

If the vector comparison output area of BMSVEC has not been initialized, the message "TABLE NOT INITIALIZED" is displayed by BMDVEC. If an error was encountered by BMSVEC in computing the display quantities, the message "ERROR - REFER TO ONLINE" is displayed.

Figure 2.7 is a functional flowchart of this module.

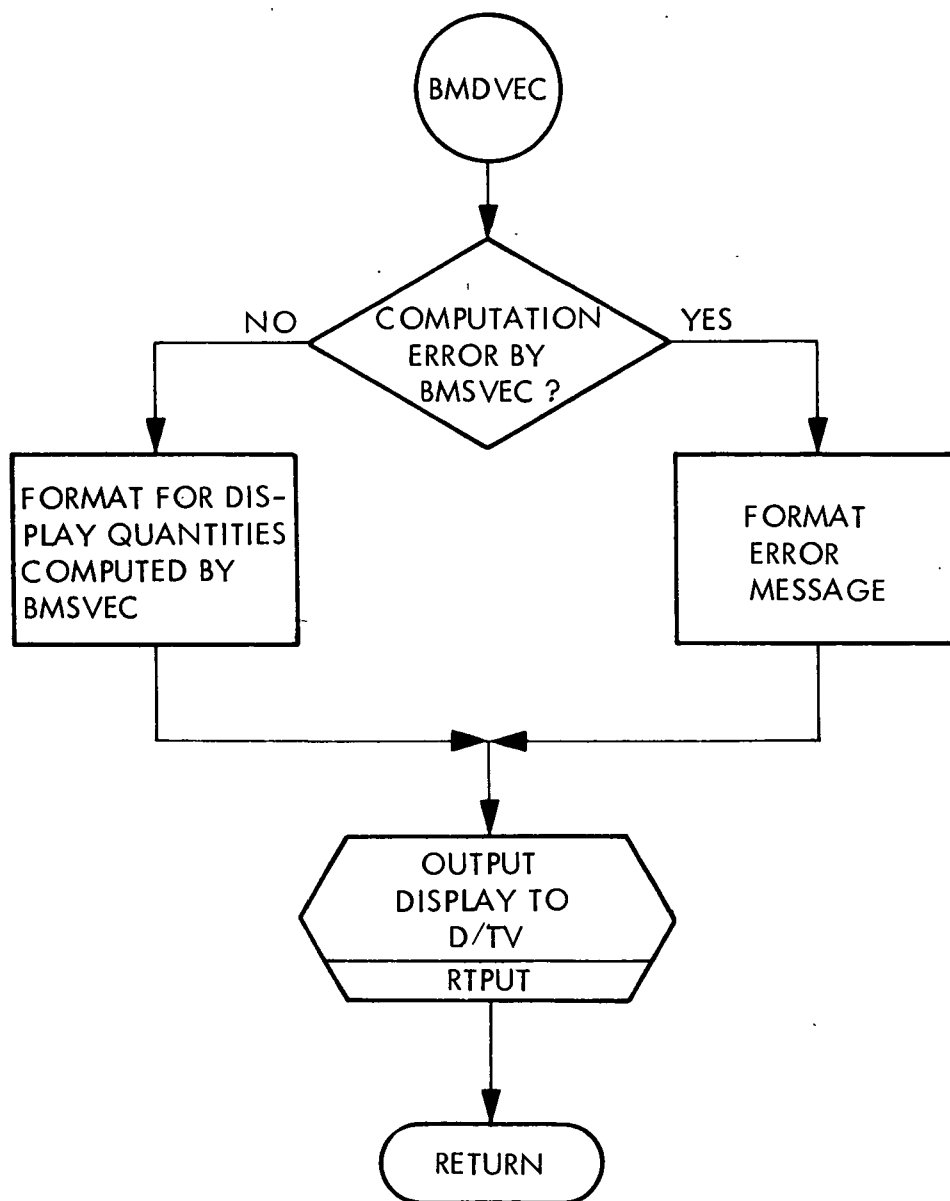


Figure 27. Vector Comparison Display Processor

INPUT/OUTPUT SUPPORT

The Input/Output Support unit is responsible for providing input and output support for Low-Speed Radar Processing and for Vector Control and Evaluation.

GENERAL REQUIREMENTS

Input support is provided by processing manual entry device (MED) messages that have been input by the RTCC controller. Processing of a MED message includes (1) checking the message content for validity, and (2) determining what program is to receive the MED information and returning this information to the MED control program for conversion and routing. Output support is provided by an on-line message-writing program that will format and output on-line information or error messages upon request.

DESIGN DISCUSSION

The Trajectory Determination MED module (BMQDCMED) contains the MED format tables for Low-Speed Radar Processing and Vector Control and Evaluation that tell the mission control MED decoder how to convert and check the "S" MED's. It also contains user exits for special checking of specific manual inputs.

When an "S" MED is entered, the mission control MED decoder brings BMQDCMED into core and finds the correct format table by which to check the MED. After all items of the MED have been checked and any user exits taken for special checking, control is returned to the mission control MED decoder with an indication of any errors found in the input parameters. The mission control MED decoder will then queue the appropriate load module indicated by BMQDCMED and pass the converted and formatted data to it.

The On-line Print Module (BMGPRIME) contains all of the print formats for Low-Speed Radar Processing and Vector Control and Evaluation. The module queueing BMGPRIME determines which format is to be printed and supplies BMGPRIME with the queueing module's name, console identification, and any variables which are to be included in the print message. BMGPRIME then formats and outputs the message to the on-line printer.

Figures 28 and 29 are functional flowcharts of the Input/Output Support unit.

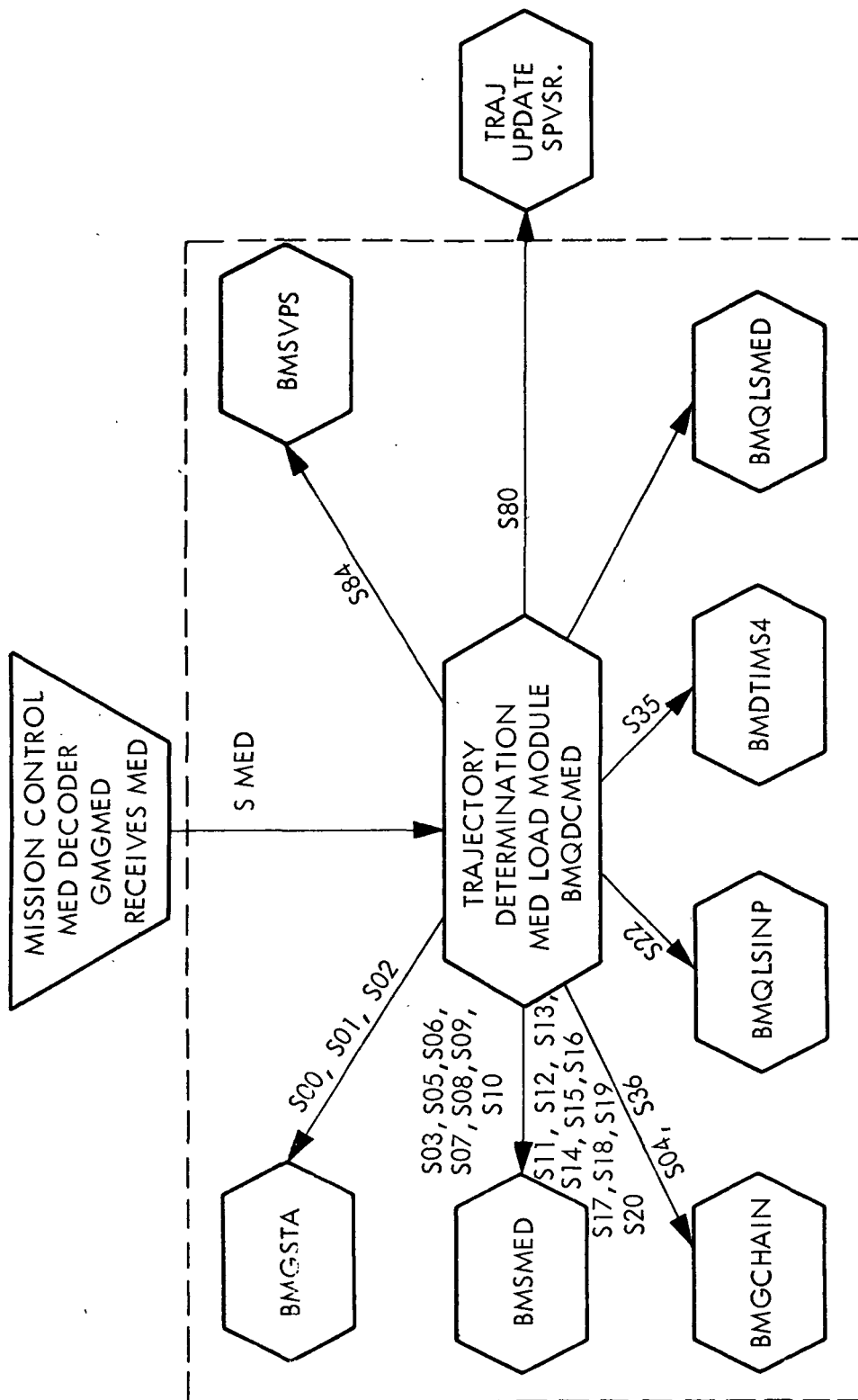


Figure 28. Input/Output Support

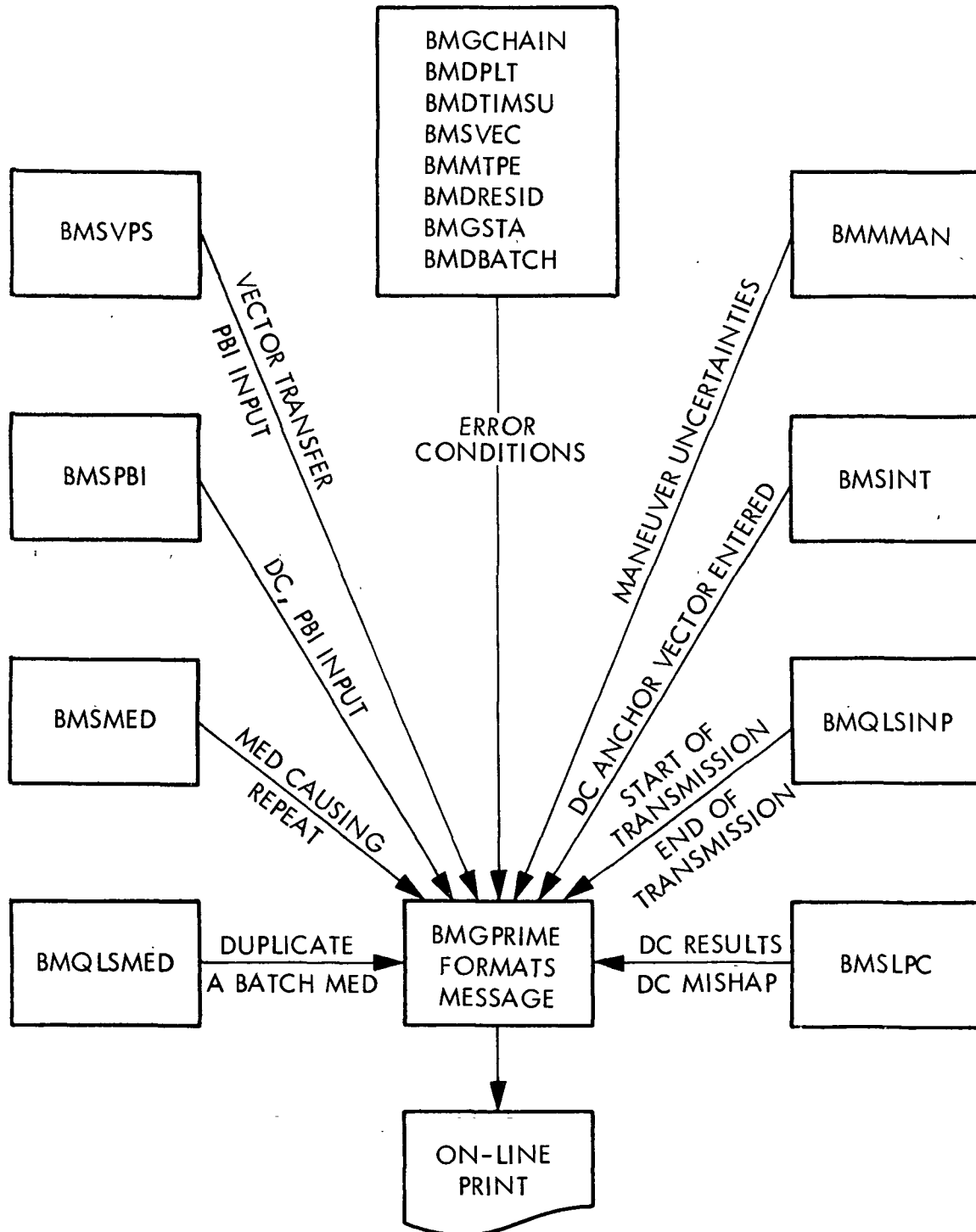


Figure 29. Input/Output Support

Trajectory Determination MED's (BMQDCMED)

BMQDCMED requires no initialization. It is available in all phases.

Input Queues

A queue from the mission control MED decoder, on receiving any "S" MED, passes the input parameters to BMQDCMED.

Output Queues

Output Queue Table

MED	Module Queued	Purpose
S00	BMGSTA	Change station characteristics indicator
S01	BMGSTA	Change station characteristics values
S02	BMGSTA	Change station location
S03	BMSMED	Insert late reporting station
S04	BMGCHAIN	Exclude and/or include post-DC station
S05	BMSMED	Modify uncertainty level of a maneuver
S06	BMSMED	Specify editing multiplier
S07	BMSMED	Rechain DC
S08	BMSMED	Pre-edit weight modification
S09	BMSMED	Starter
S10	BMSMED	Suppress/Resume DC
S11	BMSMED	N_1 / N_2 edit
S12	BMSMED	Input SS^3 diagonal variances
S13	BMSMED	Table of biases
S14	BMSMED	Superbatch begin
S15	BMSMED	Superbatch exclude
S16	BMSMED	Superbatch biases

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MED	Module Queued	Purpose
S17	BMSMED	Superbatch batches
S18	BMSMED	Eliminate angles
S19	BMSMED	Use Nth range
S20	BMSINT	Low-speed initialization time
S22	BMQLSINP	Force end of transmission
S24	BMQLSMED	Add GMTLO to data time tags
S25	BMQLSMED	Add range correction
S26	BMQLSMED	Change vehicle-beacon ID for low-speed radar data
S27	BMQLSMED	Specify limits on batch size for low-speed radar
S28	BMQLSMED	Minimum elevation for acceptable low-speed radar data
S29	BMQLSMED	Specify time between low-speed radar observations
S30	BMQLSMED	Duplicate a low-speed radar batch
S31	BMQLSMED	Low-speed angle check
S32	BMQLSMED	Start or stop three-way processing
S35	BMDIMSU	Supply data for two-way site timeline
S36	BMGCHAIN	Make duplicate batches for another vehicle
S80	EMSCtrl	Specify vector comparison parameters
S84	BMSVPS	Initialize vector slots in Vector Control Task



Clarification of Requirements

Given below are descriptions of each Trajectory Determination MED. The kind of information included with each explanation is as follows:

- Line 1 - Title of MED
- Line 2 - Fields within the MED
- Line 3 - Printed format of MED
- Line 4 - Detailed description of format.

1. S00 - CHANGE STATION CHARACTERISTICS INDICATORS
2. S00, STATION, COMMAND, RADAR, TELEMETRY, VOICE;
3. S00, AAAA, N, N, N, N;
4. N = 0 sets indicator off, N = 1 sets indicator on. If parameters 2, 3, 4, or 5 are missing, no change. -1 inserted if parameters 2, 3, 4, or 5 are missing.

1. S01 - CHANGE STATION CHARACTERISTIC VALUES
2. S01, STATION, WORD NUMBER, /FORM ID, VALUE/;
3. S01, AAAA, NN, /PN, NNNN, NN OR DDD:MM:SS N/S/;
4. "FORM ID":

P1 value is of the form DDD:MM:SS E/W.

P2 value is of the form DDD:MM:SS N/S

P3 value is of the form NNNN.NN.

Word number is 3 to 40.

1. S02 - CHANGE STATION LOCATION
2. S02, STATION, LATITUDE, LONGITUDE, HEIGHT;
3. S02, AAAA, DD:MM:SS N/S, DDD:MM:SS E/W, SNNNN. NNNN
4. If parameters 2, 3, or 4 are missing, insert -1000. Height is in meters.

1. S03 - INSERT LATE REPORTING STATION
2. S03, VEHICLE, REPEAT, LATE;
3. S03, AAA, NNN, NNN;
4. "REPEAT" and "LATE" are batch numbers. S03 is illegal in prelaunch condition, launch, high-speed and lunar ascent and descent.
"VEHICLE" = CSM/LEM.

1. S04 - EXCLUDE AND/OR INCLUDE POST D. C. STATIONS
2. S04, VEHICLE, /EXCLUDE, ..., EXCLUDE/, /INCLUDE, ..., INCLUDE/;

3. S04, AAA, /NNN,...,NNN/, /NNN,...,NNN/,
 4. "EXCLUDE" and "INCLUDE" are batch numbers. Maximum excluded plus included is eight ; minimum is one. S04 is illegal in prelaunch, condition, launch, high-speed and lunar ascent and descent. "VEHICLE" = CSM/LEM.
-
1. S05 - MODIFY MANEUVER UNCERTAINTY LEVEL
 2. S05, VEHICLE, REPEAT, MANEUVER, ATTITUDE, ACCELEROMETER MAGNITUDE;
 3. S05, AAA, NNN, NN, NN.NN, NN.NN, NN.NN;
 4. "MANEUVER" is indicated by its number in the mission plan table. Attitude, accelerometer and magnitude are uncertainty values ≥ 0 . S05 is illegal in prelaunch, condition, launch, high-speed and lunar ascent and descent. "VEHICLE" = CSM/LEM.
-
1. S06 - SPECIFY EDITING MULTIPLIER
 2. S06, VEHICLE, REPEAT, RANGE, DOPPLER, AX, EL;
 3. S06, AAA, NNN, NN.NN, NN.NN, NN.NN, NN.NN;
 4. "RANGE", "DOPPLER", "AX" and "EL" are sigma multipliers (0.0 - 50.0) S06 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent. "VEHICLE" = CSM/LEM.
-
1. S07 - RECHAIN D. C.
 2. S07, VEHICLE, REPEAT, VECTOR, COVARIANCE;
 3. S07, AAA, NNN, AAAAAAA, N;
 4. "VECTOR" is vector ID; "COVARIANCE" is 1, 2, 3, or 4. S07 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent. "VEHICLE" = CSM/LEM.
-
1. S08 - SPECIFY PRE-EDIT CRITERIA
 2. S08, VEHICLE, REPEAT, RANGE, DOPPLER, AX, EL;
 3. S08, AAA, NNN, NNNNN. NN, NNN. NN, NNN. NN, NNN. NN
 4. "RANGE", "DOPPLER", "AZ" and "EL" are edit criterion. S08 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent. "VEHICLE" = CSM/LEM.
-
1. S09 - D. C. STARTER
 2. S09, VEHICLE, STARTER BATCH NUMBER;
 3. S09, AAA, NNN;
 4. S09 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent. "VEHICLE" = CSM/LEM.

1. S10 - SUPPRESS/RESUME D. C.
 2. S10, VEHICLE, SUPPRESSION INDICATOR;
 3. S10, AAA, AAA;
 4. Indicator = ON/OFF; "VEHICLE" = CSM/LEM.
-
1. S11 - N1/N2 EDIT
 2. S11, VEHICLE, EDIT BATCH, TLEFT, TRIGHT, OBSERVATION TYPE
 3. S11, AAA, NNN, N. NN, N. NN, A,
 4. "TRIGHT" must be greater than "TLEFT" and both must be between 0.0 and 1.0. "OBSERVATION TYPE" = R, D, A, or E. S11 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent. "VEHICLE" = CSM/LEM.
-
1. S12 - INPUT SS³ VARIANCES
 2. S12, U, V, W, UDOT, VDOT, WDOT;
 3. S12, NNNN. N, NNNN. N, NNNN. N, NNNN. N, NNNN. N;
 4. "U, V, W" in yards = "UDOT", "VDOT", "WDOT" in ft. /sec. S12 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent.
-
1. S13 - UPDATE TABLE OF BIASES
 2. S13, VEHICLE, STATION 1, BIAS TYPE, VALUE, STATION 2;
 3. S13, AAA, AAA, AA, NNNN. NN, AAA;
 4. "BIAS TYPE" = R, D2, D3. If it is D3, then parameter 5 must be specified. S13 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent. If a value is missing, -1000. should be inserted. "VEHICLE" = CSM/LEM.
-
1. S14 - SUPER BATCH BEGIN
 2. S14, VEHICLE;
 3. S14, AAA;
 4. S14 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent. "VEHICLE" = CSM/LEM.
-
1. S15 - SUPER BATCH EXCLUDE
 2. S15, BATCH, , BATCH;
 3. S15, NNN, , NNN;
 4. Maximum of ten batches; S15 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent.
-
1. S16 - SUPER BATCH BIAS
 2. S16, BIAS TYPE, STATION, D2 STATION, BIAS TYPE, STATION, D2 STATION, BIAS TYPE, STATION, D2 STATION;

3. S16, AA, AAA, AAA, AA, AAA, AAA, AA, AAA, AAA;
 4. "BIAS TYPE" = R, D2, or D3. If it is D3, then D2 station must be specified. S16 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent.
-
1. S17 - SUPERBATCH BATCHES
 2. S17, BEGIN BATCH, END BATCH, VECTOR, COVARIANCE;
 3. S17, NNN, NNN, AAAAAAA, N;
 4. "VECTOR" is vector ID, nominal, starter. "COVARIANCE" is 1, 2, or 3. If missing then vector must be AAA. S17 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent.
-
1. S18 - ELIMINATE ANGLES IN D. C.
 2. S18, VEHICLE, INDICATOR;
 3. S18, AAA, N,
 4. "INDICATOR" = +1 (use) or -1 (eliminate). S18 is illegal in prelaunch, condition, launch, high-speed and lunar ascent and descent.
"VEHICLE" = CSM/LEM.
-
1. S19 - USE Nth RANGE
 2. S19, VEHICLE, N-OPTION;
 3. S19, AAA, NNN;
 4. S19 is illegal in prelaunch, condition, launch, high-speed, and lunar ascent and descent. "VEHICLE" = CSM/LEM
-
1. S20 - LOW SPEED INITIALIZATION TIME
 2. S20, VEHICLE, GMT, VECTOR;
 3. S20, AAA, HHH:MM:SS, AAAAAAA;
 4. S20 is illegal in prelaunch, condition, launch, high-speed and lunar ascent and descent. "VEHICLE" = CSM/LEM.
-
1. S22 - FORCE END OF TRANSMISSION
 2. S22, VEHICLE, STATION;
 3. S22, AAA, AAA;
 4. "STATION" must end in C or S. When vehicle is missing, vehicle 0 is indicated. "VEHICLE" = CSM/SIU/LEM.
-
1. S24 - ADD TIME TO DATA TIME TAGS
 2. S24, VEHICLE, GMT;
 3. S24, AAA, DD:HH:MM:SS;
 4. "GMT" may be + or -. S24 is illegal in all high-speed phases.
"VEHICLE" = CSM/SIU/LEM.
-
1. S25 - ADD RANGE CORRECTION
 2. S25, RANGE CORRECTION, BEACON OR FREQ. NUMBER, BAND TYPE;

3. S25, ±NNNN. NNN, A, NNN;
4. "BAND TYPE" = C or S.

1. S26 - CHANGE VEHICLE - BEACON ID FOR LS RADAR DATA
2. S26, VEHICLE, ID, BEACON, BAND;
3. S26, AAA, NN, NNN, A;
4. "BAND TYPE" = C or S. When vehicle is missing, vehicle 0 is indicated.
"VEHICLE" = CSM/SIU/LEM.

1. S27 - SPECIFY LIMITS ON BATCH SIZE FOR LS RADAR DATA
2. S27, VEHICLE, MINIMUM, MAXIMUM;
3. S27, AAA, NN, NN,
4. $6 \leq \text{"MINIMUM"}; \text{"MAXIMUM"} \leq 80$. If minimum is missing, insert 6.
If maximum is missing, insert 80. "VEHICLE" = CSM/SIU/LEM.

1. S28 - SPECIFY MINIMUM ELEVATION
2. S28, VEHICLE, ELEVATION;
3. S28, AAA, NN;
4. $1^\circ \leq \text{"ELEVATION"} \leq 90^\circ$;
"VEHICLE" = CSM/SIU/LEM.

1. S29 - SPECIFY TIME BETWEEN OBSERVATIONS
2. S29, VEHICLE, TIME;
3. S29, AAA, NNNN;
4. "TIME" is in seconds and must be a multiple of six. "VEHICLE" = CSM/SIU/LEM.

1. S30 - DUPLICATE A RADAR BATCH
2. S30, VEHICLE, STATION;
3. S30, AAA, AAAA;
4. "STATION" must end in C or S. "VEHICLE" = CSM/SIU/LEM.

1. S31 - LOW SPEED ANGLE CHECK
2. S31, VEHICLE, ACTION;
3. S31, AAA, AAA;
4. "ACTION" = Yes or no; "VEHICLE" = CSM/SIU/LEM.

1. S32 - START OR STOP 3-WAY PROCESSING
2. S32, VEHICLE, ACTION;
3. S32, AAA, AAAAA;
4. "ACTION" = Start or stop; "VEHICLE" = CSM/SIU/LEM.

1. S35 - TWO - WAY SITE TIMELINE
2. S35, VEHICLE, STATION, GMT;
3. S35, AAA, AAA, HHH:MM:SS. TH;
4. "VEHICLE" = CSM/LEM.

1. S36 - DUPLICATE BATCHES FOR ANOTHER VEHICLE
 2. S36, PRESVEH, DUPVEH, /BATCH, . . . , BATCH/;
 3. S36, AAA, AAA, /NNN, . . . , NNN/;
 4. Maximum of five batches is permitted. S36 is illegal in all high-speed phases. "PRESVEH" and "DUPVEH" = CSM/SIU/LEM.
-
1. S80 - SPECIFY VECTORS FOR COMPARISON
 2. S80, VEHICLE, GMT, REFERENCE, VECTOR, VECTOR, VECTOR, VECTOR;
 3. S80, AAA, HHH:MM:SS. TH, A, AAAAAAA, AAAAAAA, AAAAAAA, AAAAAAA:
 4. "REFERENCE" = E(Earth), (M)(moon). S80 is illegal in all high-speed phases. If reference is missing, insert 0. "VEHICLE" = CSM/LEM.
-
1. S84 - VECTOR PANEL SUMMARY ENTRY
 2. S84, VEHICLE, X, Y, Z, XDOT, YDOT, ZDOT, GMT, ID, REFERENCE;
 3. S84, AAA, NN.NN, NN.NN, NN.NN, NN.NN, NN.NN, NN.NN, HHH:MM:SS. TH AAAAAAA, AAA,
 4. Values are in Earth radii and Earth radii/hour. "REFERENCE" = ECI, ECT, MCI, MCT, EMP. If items 2 through 10 are missing, insert 7FFFFFFF(hex). "VEHICLE" = CSM/LEM.

Error Checks

Error checks are made on each item in the MED. The MED is either accepted or rejected. If an error is found in the special logic provided by BMQDCMED, a return is made to the mission control MED decoder indicating an error has been found.

Error numbers indicated by the mission MED decoder are listed below.

<u>Error Number</u>	<u>Description</u>
01	Illegal format code
02	Error detected by special checking in BMQDCMED
03	Checking error (MIN, MAX, etc.)
04	Illegal character
05	Missing parameter
06	No semicolon to end MED
07	Error within recursive item type
08	User format error
09	Slashes in other than special item type
10	Error in time conversion
11	Latitude/longitude error
12	Error in item skip
13	Special item type and no slashes
14	Hex or octal convert error
15	Remote item format error
16	MED entered in invalid phase

The form of the error message printed on line and on the MED is

ERR xx PRM xx SBP xx RMP xx.

The message printed when there is no error in the MED is "OK".

Figure 30 is a functional flowchart of BMQDCMED.

On-line Print Module (BMGPRIME)

BMGPRIME requires no initialization. The module is available in all phases.

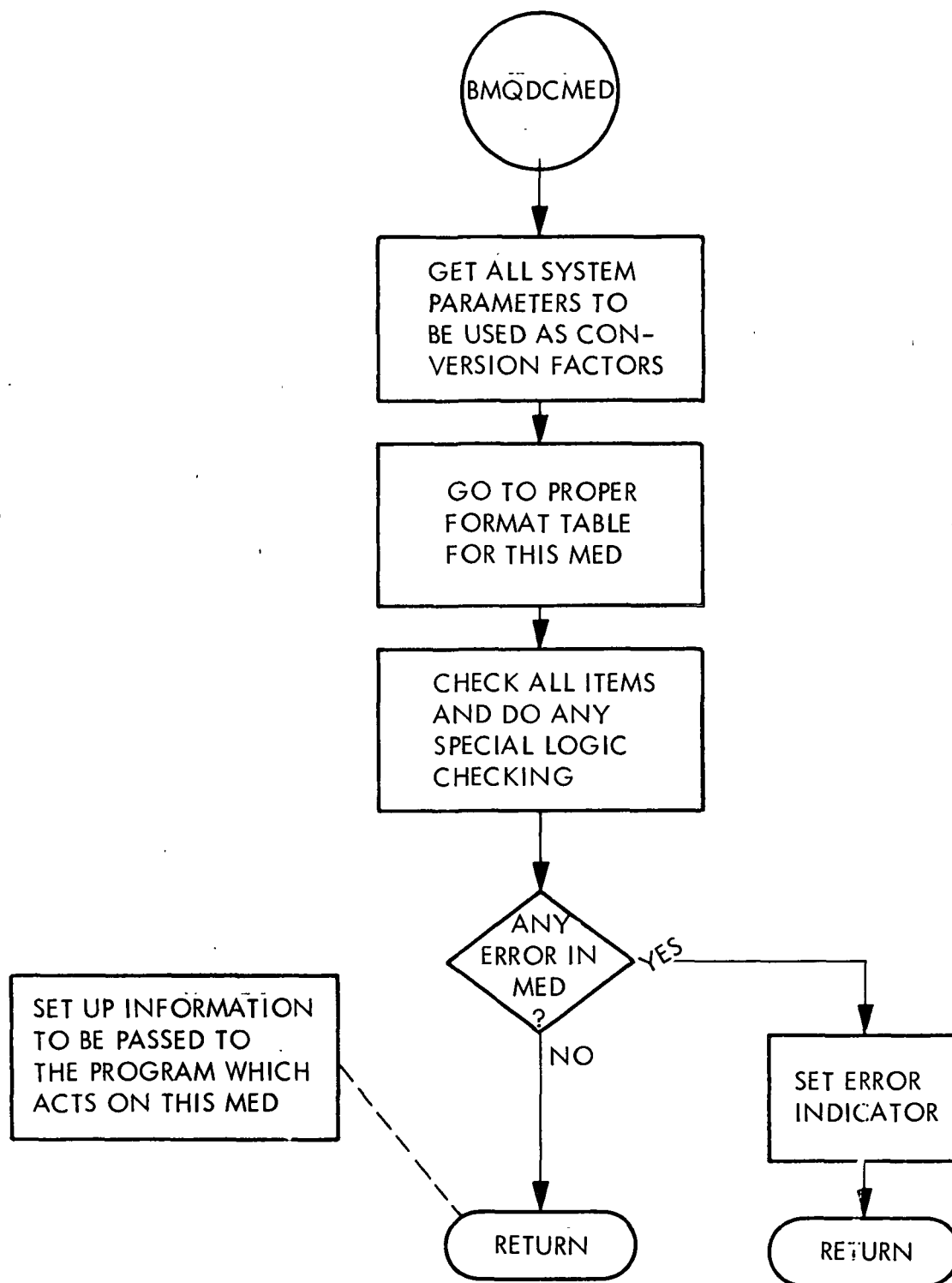


Figure 30. Trajectory Determination MED Module

Input Queues

The On-line Print Module includes the input queues listed below.

1. At the start of transmission of a radar station, a queue is received from BMQLSINP requesting the start-of-transmission message.
2. At the end of transmission of a radar station, a queue requesting the end-of-transmission message is received from BMQLSINP.
3. When a batch of data is duplicated by BMQLSMED, it queues BMGPRIME to print the duplicate batch message.
4. After a differential correction (DC) is completed, a queue is received from BMSLPC and the DC results are printed.
5. Queues are received from BMSVPS and BMSPBI to print vector panel or DC PBI inputs.
6. BMSVPS queues BMGPRIME to print the vector when one is transferred to the usable vector table.
7. A queue is received from BSMED when a MED is entered which causes a repeat.
8. The maneuver propagation uncertainties are printed on a queue from BMMMAN.
9. When a new DC anchor vector is received by BMSINT, it queues BMGPRIME to print the vector.
10. Queues are received from BMSVPS, BMGCHAIN, BMQLSINP, BMQLSMED, BMDPLT, BMDTIMSU, BMSVEC, BMSPBI, BSMED, BMSINT, BMSLPC, BMMTPE, BMDRESID, BMDBATCH, and BMGSTA to print error messages.

Output Queues

An RTPUT to the printer is done to output the message.

Clarification of Requirements

Each message has the format:

DD/HH/MM/SS. CC **CO**)LMNAME(- Message -

where "CO" is the identifying code of the console to which the message is to be read, if there is a console; or blank if there is no console.

Given below are the required messages.

1. DC Results - Load module BMSLPC; no console.

This print consists of five or six lines. The format is variable, depending on the value of some of the variables in the format. Line 1 contains the following elements:

AAAANN - Station ID

VEH X - Vehicle number

XXXX OBS - Number of observations

XXXX DOPPLER - Number of doppler points

MS, SS1, SS2, or SS3 - Single station/multistation indicator. Only 1 is printed.

ACCEPT AUTO or REJECT AUTO - Accept/reject decision, printed only if in auto mode.

XX EDIT - Number of edit loops

XX ITER - Number of iteration loops.

Line 2 contains the corrected anchor vector in Er and Er/hr. and the time of the vector. The format is

$S = \pm \underline{XX. XXXXXXXXXXX} \pm \underline{XX. X} \dots\dots\dots T = \underline{DD/HH/MM/SS.}$

Line 3 contains the corrections to the anchor vector in Er and Er/hr. and the maximum elevation of the batch:

$DS = \pm \underline{XX. XXXXXXXXXXX} \pm \underline{XX. X} \dots\dots\dots EMAX = \underline{XX} DEG.$

Line 4 contains the UVW covariance in yards and ft./sec. and the vehicle weight:

GU = \pm XXXXXXXX. XXX \pm XX. VEH WT = XXXXXX. X.

Line 5 contains the following elements:

FOM = XXXXXXXXXXX. XXX - figure of merit

TRACE = \pm X. XXE \pm XX - trace of corrected covariance

KRHO X - $K\rho$; not printed if 0, 1 = small, 2 = large

KALPHA X - $K\alpha$; not printed if 1, 3 = small, 5 = large

KGAMMA X - $K\Gamma$; not printed if 0, 1 = small, 2 = large

MODF = XXXX - coefficient for Riley factor; not printed if 1.

Line 6 contains the biases solved. It is not printed if no biases were solved. The format is

BIASES S1/S2 XXXX. X S1/S2 XXXX. X S1/S2 XXXX. X

S1/S2 is the station nos. If S1 = 0, the bias is for range.

If S1 = S2, it is for two-way Doppler.

If $0 \neq S1 \neq S2$ it is for three-way doppler.

2. Start of Transmission — Load module BMQLSINP; no console.

XXXX RADAR START OF TRANSMISSION,

VEHICLE X PASSIVE/ACTIVE

The first variable is the four-letter station name.

3. End of Transmission — Load module BMQLSINP; no console

XXXX RADAR END OF TRANSMISSION, VEHICLE X,
XX OBS., XX DOPPLER, XX DEG., PASSIVE/ACTIVE

4. Maneuver Uncertainties — Load module BMMMAN; no console.

MANEUVER UNCERTAINTIES SIGMA(A) = ±. XXXE±XX
SIGMA(P) = ±. XXXE±XX SIGMA(W) = ±. XXXE±XX

5. Vector Transfer — Load module BMSVPS; no console.

XXXXXXXXX NOW A POSSIBLE XXXX ANCHOR VECTOR,
SITE = XXXX REF = XXX T = XX/XX/XX/XX.XX

X = ±XX.XXXXXXXXXX Y = ±XX.XXXXXXXXXX Z = ±XX.XXXXXXXXXX
X = ±XX.XXXXXXXXXX Y = ±XX.XXXXXXXXXX Z = ±XX.XXXXXXXXXX

The first variable is the vector ID, the second is the vehicle name. SITE, the station ID, is not printed if it is included in the vector ID. REF is the coordinate system of the vector.

6. DC PBI Input — Load module BMSPBI; no console.

DC PBI ENTRY XXXX XXXXXX XXXXXX XXX FOR VEHICLE X

This message may be followed by either of two other messages:

MANUAL DECISION ACCEPT/REJECT
UPDATE/ NO UPDATE ON XXXXXXXXX

The final variable is the four-letter station name.

NO ACTION ON DC PBI INPUT

Additional Formats

BMGPRIME has the following additional formats.

1. Informational Formats — None of these will have a console ID.

- a. Repeat MED — Load module BSMED.

DC MED SXX ENTERED TO REPEAT FROM BATCH NNN FOR
VEHICLE X

- b. DC Anchor Vector load module BMSINT.

DC ANCHOR VECTOR FOR VEHICLE
N AT XX/XX/XX/XX.XX

±XX.XXXXXXXXXX ±XX.XXXXXXXXXX ±XX.XXXXXXXXXX
±XX.XXXXXXXXXX ±XX.XXXXXXXXXX ±XX.XXXXXXXXXX

- c. Duplicate Batch (S30 MED) - Load module BMQLSMED.

DUPLICATE BATCH FOR XXXX,
VEHICLE X XX OBSERVATIONS

The first variable is the four-letter station name.

- d. Vector Panel PBI Input — Load module BMSVPS

VD PBI INPUT XXXXXX XXXXXX XX ACCEPTED

If the PBI input is invalid, an error message will be printed with the console ID SE.

VP PBI INPUT XXXXXX XXXXXX XX REJECTED
ERROR NUMBER XXX

2. Error Prints — Twenty-eight error prints are possible.

- a. Error returns from the integrator control program.

Load module: BMDPLT, BMSLPC, BMSINT, or BMDRESID.
Console: SE

MISC. NI ERROR XXXX, OPTION YY, VEHICLE Z

ENTRY NI ERROR XXXX, OPTION YY, VEHICLE Z

BURN NI ERROR XXXX, OPTION YY, VEHICLE Z

EPHEMERIS FETCH ERROR XXXX, OPTION YY, VEHICLE Z

INTERPOLATION ERROR XXXX, OPTION YY, VEHICLE Z

PHASE ERROR, OPTION YY, VEHICLE Z

VECTOR ROTATION ERROR, OPTION YY, VEHICLE Z

BAD INPUT TO RMSMIC, OPTION YY, VEHICLE Z

SPACECRAFT BELOW EI, OPTION YY, VEHICLE Z

"ERROR" is the error number returned to the integrator control program from the applicable routine. OPTION is a number from one to eleven indicating the type of integration requested from the integrator control program. The phase error print is also used with option = 0, to indicate a phase error encountered when there has been no call to integrator control.

All of these prints are used by BMSVEC with VECTOR X substituted for the vehicle number. This vector number refers to the position of the vector in the S80 MED.. The console ID is DY in this case.

- b. ILLEGAL REQUEST FOR BACKWARD INTEGRATION,
VEHICLE X
Load module: BMSLPC, BMDPLT
Console: SE

This message is also used by BMSVEC with VECTOR X instead of the vehicle number. The console ID then is DY.

- c. ERROR NUMBER XXX
Load module: BMSVPS
Console: DY

- d. ILLEGAL INPUT XXXXXX.....
Load module: BSMED, BMSPBI, BMGPRIME, and BMSLPC
Console: None

The illegal data is printed out in hexadecimal. The length is variable and is determined by the queuing module.

- e. Bad batch number(s) in MED.
Load module: BSMED, BMSPBI, BMMTPE, BMGCHAIN and BMDPLT.
Console: None or SE

BATCH(ES) XXX XXX...UNAVAILABLE FOR AAA MED
AAA = the MED code

f. STATION NOT FOUND IN GZSTCH

Load module: BMDTIMSU, BMGSTA, BMQLSINP, BMQLSMED
Console: SE

g. Superbatch processing errors

Load module: BMSLPC
Console: SE

BIAS(ES) REQUESTED FOR STATIONS NOT IN SUPERBATCH.
MANEUVER WITHIN SUPERBATCH VEHICLE X
SUPERBATCH BEGIN OR END IS EXCLUDED FROM SUPERBATCH
REQUESTED SUPERBATCH BATCH XXX NOT IN POST-DC CHAIN
S13 or S16 MED STATION IS NOT FOUND IN GZSTCH

h. THREE - WAY BATCH IS BEFORE 1ST TIME IN PRIMARY SWITCH
TABLE, VEHICLE X

Load module: BMSLPC
Console: SE

i. Covariance inversion error. This message has two forms depending
on the module requesting it.

Load module: BMSLPC or BMSLDC
Console: SE

COVARIANCE INVERSION ERROR ±XXXX±XX. WILL DO SINGLE
STATION. VEHICLE X. "WILL DO SINGLE STATION" is not printed
for BMSLDC.

j. BAD RESIDUALS IN SELECTION EDITING. VEHICLE X

Load module: BMSLPC
Console: SE

k. Error returns from BMMACC to BMSLPC.

Load module: BMSLPC
Console: SE

BMMACC ERROR - GARBAGE IN EPHEMERIS. VEHICLE X
BMMACC ERROR - LESS THAN 6 VECTORS IN EPHEMERIS.

VEHICLE X
BMMACC ERROR - ALL DATA TAGGED INVALID. VEHICLE X

l. TOO MANY STATIONS TRANSMITTING

Load module: BMQLSINP

Console: SE

m. STATION NOT TRANSMITTING

Load module: BMQLSINP, BMQLSMED

Console: SE

n. BEACON NUMBER TOO LARGE

Load module: BMQLSMED

Console: SE

o. NO DATA SAVED FOR REQUESTED STATION

Load module: BMQLSMED

Console: SE

p. AAAAAAA NOT AVAILABLE

Load module: BMDPLT, BMDRESID

Console: SE

AAAAAAA is a vector ID

q. CANNOT FIND VECTOR X

Load module: BMSVEC

Console: DY

The vector number refers to the position in the S80 MED.

r. REQUESTED DATA TYPE NOT PRESENT

Load module: BMMTPE

Console: SE

s. MANUAL MODE REQUIRED

Load module: BMSMED

Console: SE

t. REPEAT TO A STATION IN THE FUTURE

Load module: BMSMED

Console: SE

u. REQUESTED MANEUVER DOES NOT EXIST

Load module: BMSMED

Console: SE

v. STARTER PROCESSING ERROR NUMBER XX

Load module: BSMED

Console: SE

x. DC TABLE NOT INITIALIZED FOR VEHICLE N

Load module: BMSPBI, BMDRESID, or BMDBATCH

Console: SE

y. NO ACCEPTED DC CAN BE FOUND FOR UVT UPDATE

Load module: BMSPBI

Console: SE

z. Refraction error

Load module: BMGCHAIN, BMDPLT

Console: SE

BATCH XXX FOR VEHICLE X NOT CORRECTED FOR REFRACTION,
ERROR NUMBER XXX

The error number is returned by BMMTRC.

aa. INVALID CHARACTERISTIC NUMBER

Load module: BMGSTA

Console: SE

bb. NO STATIONS AVAILABLE

Load module: BMDRESID, BMDBATCH

Console: SE

cc. TABLE NOT INITIALIZED

Load module: BMDRESID

Error Checks

The format number is checked for validity. If it is invalid, the illegal input message is printed with the illegal format number.

2.1.10 MISSION PLANNING SUBSYSTEM FUNCTIONAL SPECIFICATION
FOR THE MISSION SYSTEMS LUNAR MISSION
SIMULATION PROGRAM



MISSION PLANNING SUBSYSTEM FUNCTIONAL SPECIFICATION
FOR THE MISSION SYSTEMS LUNAR MISSION
SIMULATION PROGRAM

INTRODUCTION

Mission planning includes planning and controlling all maneuver computations needed for the Lunar Mission Simulation Program (LMSP). Three subsystems are involved in the task: (1) 500 Apollo Flight Plans, (2) Rendezvous Planning, and (3) Maneuver Control. All are within the Mission Planning Subsystem.

The functional specifications are discussions of these three units. Another unit describes utility programs not included in the subsystems.

Thus, this document has four major parts:

1. 500 Apollo Flight Plans Subsystem
2. Rendezvous Planning Subsystem
3. Maneuver Control Subsystem
4. Mission Planning Utility Programs.

Approval	Approval
<i>G. Ayres H. W. E. Shuma</i> <i>B. E. James</i>	<i>R. O. Sogard</i>



500 APOLLO FLIGHT PLANS SUBSYSTEM

The 500 Apollo Flight Plans Subsystem for the lunar landing mission simulation in Earth reference can be logically broken into two major sections of computation: "Return-to-Earth Abort Planning" and "Translunar Injection Planning". Both sections operate under the independent task PTFLTPLN, and both are entered via EMSCNTRL to alleviate system load problems. The mathematical processes involved are independent but use many common modules. Both fall into the category of flight controller study aids and are available only on a manual request basis. The methods of constructing analytical approximations to the precise solution are independent in the two procedures, but a common iteration technique called the generalized iterator (PMMFIT) is used in construction of the precise solution. The translunar injection planning study aid's capability for this mission is limited to selecting the set of targeting parameters that will result in the second S-IVB burn achieving the appropriate energy for reaching a specified height of apogee using the minimum amount of fuel. The return-to-Earth abort planning has a variety of options. Flight controllers may look at conic solutions in the form of an analog plot, intermediate discrete solutions in the Abort Scan Table and finally, precision solutions in the return-to-Earth digitals. End conditions are satisfied by iteration on one maneuver only in both sections.

RETURN-TO-EARTH ABORT PLANNING (REAP)

The REAP section is a mission planning study aid which can be initiated only by manual request. It provides abort planning capability between the trans-lunar injection (TLI) simulation and the deboost into circular parking orbit. As a study aid it has few interfaces with the rest of the mission system. The essential interfaces are (1) fetching a vector from the main ephemeris, (2) providing information for command load generation, (3) defining a maneuver for insertion into the Mission Plan Table, and (4) providing information to initialize the spacecraft study aid.

The objective of abort planning is to produce a single maneuver for changing the trajectory to one having safe entry-interface conditions and satisfying certain other constraints. Other constraints are dependent on the type of abort requested. The safe entry interface condition is a velocity flight path angle target line at 400,000 feet. Either of two entries may be specified dynamically: (1) a shallow target line that is the nominal for a planned high-speed guidance and navigation (G&N) entry; or (2) a steep target line for the constant G-level backup entry. The second type of entry may also be done from the shallow target line.



Dependent upon the request, the abort maneuver will be computed considering one of three types of impact areas:

1. An Unspecified Area

This means that a safe reentry is guaranteed but no consideration is given to the location of the impact point (it may be quite undesirable).

2. A Primary Target Point (PTP)

This would be defined by a pair of latitude-longitude values.

3. An Alternate Target Point (ATP)

This is actually not a point but is as many as five connected line segments (defined by latitude-longitude pairs) extending generally in a longitudinal direction.

Both the PTP and ATP targets can be defined by manual input. The Return-to-Earth Target Table Display contains up to five PTP and five ATP target names and definitions.

Four general types of abort maneuvers are available.

1. Time Critical Unspecified Area (TCUA)

This is an inplane maneuver producing the trajectory with the earliest possible reentry. The abort is characterized by

- a. Consuming all fuel provided for the maneuver, or
- b. Having the maximum allowable reentry velocity, or
- c. Having the minimum allowable time from maneuver to entry to Entry interface.

2. Fuel Critical Unspecified Area (FCUA)

This is the inplane maneuver requiring the least fuel to obtain a safe entry interface. Note that if the pre-abort trajectory had a safe entry interface, a request for a FCUA abort having the same target line should result in a zero ΔV maneuver. In practice, because of convergence tolerances, a small maneuver will be computed.

Sometimes, as for example in an RCS report, sufficient fuel may not be available to obtain an abort trajectory that will satisfy a target line at 400,000 feet. If a FCUA request is made and insufficient fuel exists, a different set of logic is entered. This new set of logic produces a maneuver using all the fuel available to minimize the error in flight path angle at entry interface. The resulting maneuver will be identified as an extreme fuel-critical unspecified area (EFCUA) abort. Since the reentry target line was not satisfied, the reentry portion of the trajectory must have special handling. This is discussed in the section "Abort Scan Table".

3. ATP Abort

This inplane maneuver produces a trajectory that impacts ATP trace. Multiple solutions are possible. If they exist, they are discrete and, except for possibly the first two, differ by twenty-four hour increments in time of landing.

4. Fuel Critical PTP Abort

An essential input for this type of request is a specification of a maximum allowable miss distance (normally 0 to 400 miles). Since any solution within the allowable miss distance is deemed acceptable, this miss distance is used to minimize the fuel required to perform the maneuver. Note that without the coordinates of the impact point the user has no knowledge of the location of impact other than the fact that it does not exceed the maximum allowable miss distance. Multiple solutions are possible. If they exist they are discrete and, except for possibly the first two or three, differ by increments of twenty-four hours in time of landing.

The position from which the abort is to be performed is obtained by fetching a vector from the main ephemeris at some specified time and propagating this vector with a coast Encke integrator to the time of abort.

The abort computations are separated into three distinct steps, each of which can be initiated only by manual request. They are (1) the trade-off, (2) the Abort Scan Table, and (3) return-to-Earth digitals. Associated with each step in the computations is a display which summarizes the results of that step. The construction of an abort solution may be viewed as combining models of the abort maneuver, the trajectory between maneuver and entry interface, and the reentry trajectory. The three are combined in a way that will satisfy the abort criteria and the solution constraints. The trade-off, Abort Scan Table, and return-to-Earth digital computations are characterized by the models used; the models progress from less precise to more precise solutions.

Tradeoff

Four major questions must be answered by the person involved in abort planning:

1. How much fuel may be expended?
2. When may the maneuver be performed?
3. How soon must splashdown occur?
4. If the target is a PTP, how large a miss is acceptable?

There is a hidden difficulty in answering these questions — the best answer to any one of the above is not independent of the answers to the remaining three. Sometimes by relaxing the acceptable miss by a few miles, the required velocity

decreases by several thousand feet per second; sometimes shifting the time of the maneuver by a few minutes substantially reduces the time of landing or the chance of a miss.

The objective of this step of the computations is to provide the user with an overall picture of the abort situation for either ATP or PTP aborts. The abort situation is defined in terms of the above four parameters (three if the target is an ATP). To this end the user supplies parameter ranges within which his solutions of interest can be found. The REAP section imposes a mesh over the solution region and examines each mesh point for a solution. Those solutions existing are used to produce analog TV displays to assist the user in arriving at an optimum answer to the four questions given above.

As mentioned earlier, multiple solutions having different times of landing may be available for ATP and PTP aborts. As the time of abort is varied, these times of landing tend to vary smoothly where they exist. This leads to a natural grouping of solutions into families of solutions, each having similar times of landing. The Tradeoff Display is a multiple page (up to five) TV display; each page contains the analog information for a different family of solutions. Two display formats are used.

1. The Near-Earth PTP consisting of two analog graphs on each page:
 - a. Characteristic ΔV versus Time of Abort
Five minimum fuel curves parameterized by maximum miss allowable (normally 400, 300, 200, 100, and 0 miles).
 - b. Time of Landing versus Time of Abort
Five time-of-landing curves corresponding to the five curves in item a.
2. Near-Earth ATP consisting of three analog graphs on each page:
 - a. Characteristic ΔV versus Time of Abort
One curve representing the ΔV required for an inplane solution that impacts the ATP trace.
 - b. Time of Landing versus Time of Abort
One time of landing curve corresponding to the curve in item a.
 - c. Latitude of Impact versus Time of Abort
One curve representing the declination of impact. Although latitude is not considered a tradeoff parameter, it is helpful to know this information.

The abort solutions for the Tradeoff Display are constructed by combining an impulsive velocity change, a conic (analytic two-body) trajectory, and polynomial reentry



functions. The reentry functions simulate either a high-speed G&N entry or a constant G-level entry and are valid only if entry interface occurred on one of the two target lines. They provide reentry range, cross range, and Δt as a function of target line, entry profile and entry interface velocity, inclination, azimuth, and latitude. Solutions constructed for the Abort Scan Table or return-to-Earth digitals will be constrained to these conic entry interface conditions.

Abort Scan Table (AST)

The Abort Scan Table Display is essentially a digital scratch pad that may be used to compare up to seven discrete abort solutions. One solution is inserted for each manual AST request. These computations are more precise than the trade-off and less precise than return-to-Earth digital computations. They consist of an impulsive velocity change, an integrated coast trajectory, and unless an EFCUA abort is generated, polynomial reentry functions.

The start of all AST solutions consists of obtaining a single solution from the conic load module PMMEAB, which also provides answers for the Tradeoff Display. If a TCUA or FCUA abort is requested, the user must supply the maximum velocity available for the maneuver and a specific time of abort. If the user requests a discrete PTP or ATP solution, he must also specify the time of landing and (for PTP's) the maximum allowable miss distance. Although the user is not forced to generate a Tradeoff Display prior to requesting an AST entry, it is assumed in the case of ATP and PTP aborts that he has done so, otherwise it is quite likely that he will pick neither optimum nor consistent sets of values for the tradeoff parameters.

This single solution from the conic logic serves as a first guess to an iteration algorithm that constructs a solution with an integrated coast trajectory achieving the entry interface conditions defined by the conic trajectory. This constraining of the integrated trajectory to the conic end conditions makes the iteration scheme. The reader is referred to the section on utility programs for the writeup of the load module PMMFIT. Essentially the iteration consists of adjusting a set of independent variables (the impulsive maneuver) to cause a set of dependent variables (the conic entry interface conditions) to satisfy tolerances prescribed for each dependent variable. Values of the dependent variables corresponding to the intermediate values of the independent variables are calculated by precision trajectory logic (PMMPABTC), which operates under control of the iteration algorithm. The integration is performed by a coarse Encke integrator PMMCEN which is also described in the utilities section.

After the iteration has converged the reentry parameters are obtained from the polynomial reentry functions (unless an EFCUA abort), and the required data is

passed to the Abort Scan Table Display. The REAP unit saves a converged reentry state vector and an impulsive maneuver vector for each displayed solution. These states will serve as the first guess and entry interface constraints for the return-to-Earth digital computations.

If the conic solution was an EFCUA abort, the AST computations are stopped after convergence to entry interface conditions. The solution is displayed omitting quantities dependent on a reentry trajectory. Two of the displayed quantities are velocity and flight path angle at entry interface. These values allow the user to determine where in the reentry corridor the entry occurred and to select an appropriate entry profile. A subsequent request causes the AST computations to pick up the stored reentry state and obtain the reentry parameters from the reentry integrator using the appropriate entry profile. If G&N is specified as the entry profile, a fictitious target is generated. These are added to the incomplete display of the solution.

Return-to-Earth Digitals

The final solution produced by the REAP section — the Return-to-Earth digital solution — consists of an integrated maneuver, an integrated trajectory from the end of the maneuver to entry interface, and an integrated reentry. Two solutions, each the result of a manual request, may be viewed with the Return-to-Earth digital and external ΔV /Lambert displays. Either of these solutions may be transferred into the Mission Plan Table, used to initiate execution of the spacecraft setting study aid, or used to generate a command load.

Computation of a solution is similar to the AST computations in that the same iteration algorithm is used to adjust independent and dependent variables to meet certain constraints on the dependent variables. The major differences can be listed:

1. The first guess is a converged solution being viewed in the AST Display.
2. The constraints at entry interface are taken from the entry interface state of the converged solution.
3. Independent variables are the target parameters for the finite maneuver integrator (PMMRKJ).
4. The reentry parameters are always obtained from an integrated reentry after the iteration converges to the entry interface conditions.

The same precision trajectory logic is used by the iteration algorithm except that now the finite maneuver integrator is used to perform the maneuver instead of making an impulsive velocity change. The user may specify to the Return-to-Earth



digital computations either of two kinds of maneuver guidance: (1) external ΔV , or (2) Lambert and any of four thrusters (SPS, SMRCS, DPS, or LMRCS).

In addition to requesting a solution constructed as described above, the user may manually define a solution by defining, via the manual entry device (MED) a time for a vector fetch, a time of abort, and maneuver targets. This type of manual entry bypasses the iteration logic. The coast Encke integrator is used to propagate the fetched vector to the time of abort. The maneuver is integrated one time using the targets supplied. The coast Encke is used again to propagate the burn-out vector to 400,000 feet at which point the reentry integrator is used to propagate to impact.

Load Module Descriptions

Certain load modules are unique to the REAP section. These modules are described below; their functional flow is illustrated in Figure 1.

1. PMMREAP - This is the overall supervisor that controls the progression of a solution from the Tradeoff Display through the Return-to-Earth Digital Display.
2. PMQREAP - This utility module is used by PMMREAP to sort and order the solutions calculated for a Tradeoff Display and to interface with the Analog Tradeoff Display module.
3. PMMEAB - PMMEAB is the Earth-centered conic logic that controls the generation of conic solutions for the four types of abort.
4. PMMEABTC - This is the conic trajectory computer used by PMMEAB.
5. PMMPAB - This module is the precision logic that controls the iteration algorithm for both AST and Return-to-Earth digital solutions.
6. PMMPABTC - Precision trajectory logic used by the iteration algorithm to compute the values of the dependent variables for given values of the independent variables is contained in this module.
7. PMDRETT - PMDRETT is the Return-to-Earth Target Table Display that displays the name and definition of up to five PTP and five ATP targets.
8. PMDTRDFF - This Return-to-Earth Tradeoff Display is an analog display of the dependence of the tradeoff parameters ΔV available, time of abort, time of landing, and allowable miss distance.

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9. PMDREAST - The Return-to-Earth Abort Scan Table Display allows a comparison of up to seven discrete abort solutions.
10. PMDREDIG - The Return-to-Earth Digital Display presents two final solutions of the Return-to-Earth Abort Planning section.

TRANSLUNAR INJECTION PLANNING

The Translunar Injection Planning section has two purposes: (1) to simulate the nominal S-IVB hypersurface solution for translunar injection and (2) to do mission planning for a dispersed Earth parking orbit. The first purpose gives the flight controllers a monitoring tool where various vectors may be routed through a simulation of the on-board targeting logic without placing the maneuver in the Mission Plan Table. The second assumes that a target update will take place which will require an iteration to attain the specified apogee.

The section is designed to perform the designated computations using any vector available in the Vector Summary Table, in addition to the main ephemeris. Initiation of this section is only available via a MED input. For monitoring the simulation of the on-board targeting logic, the quantities available via the MED are any one of four columns on the display, vector source, and injection opportunity. For generating a plan to a specified apogee, the quantities available via the MED are any one of four columns on the display, vector source, GET of translunar injection ignition and desired apogee altitude. A maximum of four solutions may be displayed on the Translunar Injection Planning Display to provide digital information for the flight controllers. This display will be available during pre-launch and orbit phases or until the execution of the second S-IVB burn. All solutions displayed are candidates for transfer to the Mission Plan Table via the maneuver transfer module (PMMXFR).

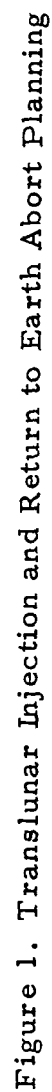
Described below are the load modules contained in the Translunar Injection Planning section.

1. PMMEPP - This load module contains both the control logic and math computations to generate the values for the TLI Planning Display. This routine will interface with the S-IVB hypersurface load module (PMMSP) to get the hypersurface solution for a desired translunar injection opportunity. This routine will also interface directly with the forward iterator (PMMFIT) to perform mission planning to determine the S-IVB maneuver necessary to obtain a specified apogee on the resultant ellipse.
2. PMMSPT - Given a vector from the vector summary table and an injection opportunity, this load module will determine the S-IVB hypersurface solution for the translunar injection maneuver. A more detailed description of this load module is available in the Maneuver Control Subsystem writeup in this document.
3. PMMFPC - This load module is the conic trajectory computer which calculates the S-IVB maneuver to obtain a specified apogee for an analytically determined ellipse. This load module uses a subroutine (PITLIB), which is a calibrated polynomial described via system parameters that



simulate the hypersurface solution for the TLI maneuver. All free flight propagation is accomplished using conic motion; results will be used as a first approximation to the precision trajectory computer.

4. PMMFBS - This load module is the precision trajectory computer that calculates the S-IVB maneuver to obtain a specified apogee for an integrated ellipse. The integrating of the ellipse to the desired apogee is done using the free-flight integrator (PMMCEN). This load module uses a subroutine (PITLIB), which is a calibrated polynomial that simulates the hypersurface solution for the TLI maneuver.
5. PMDTLIPL - This program generates a digital display containing up to four columns of information for evaluating the translunar injection maneuver.





RENDEZVOUS PLANNING SUBSYSTEM

The purpose of the Rendezvous Planning Subsystem for LMSP is to plan and display all impulsive maneuver computations necessary to achieve rendezvous of two vehicles or to achieve desired orbital conditions for either vehicle. This subsystem provides the flight controllers with a real time pre-launch and mid-course maneuver planning capability.

The subsystem is composed of five major parts:

1. General Purpose Maneuvers (GPM)
2. Perigee Adjust Maneuvers (PADJ)
3. Two-Impulse Maneuvers (TI)
4. Docking Initiation Maneuvers (DKI)
5. Coelliptic Sequence Maneuvers (SPQ).

Certain of these parts have been functionally linked. Therefore, in this paper GPM and PADJ are discussed as a single part. The same is true of SPQ and TI.

GENERAL PURPOSE MANEUVER (GPM)/PERIGEE ADJUST MANEUVER

Described below are the load modules for the GPM/Perigee Adjust Maneuver section.

1. PMMGPM - The function of the General Purpose Maneuver Processor is to provide the flight controller with two main capabilities:
 - a. To determine the effect that a specified incremental velocity applied at a given maneuver point (along a given pitch and yaw) will have on the orbit;
 - b. To determine the maneuver required to obtain a specified orbit or orbital change.

The first capability is more commonly known as a flight-controller special-maneuver request and has six options for the maneuver point:

- a. An equatorial (nodal) crossing
- b. A specified longitude
- c. A specified time



- d. A specified height
- e. An apogee crossing
- f. A perigee crossing.

The second capability is divided into eight types with various maneuver point options:

- a. A plane change at a certain equatorial crossing, longitude, time, or height;
- b. A circularization maneuver at a longitude or height;
- c. A maneuver at perigee to adjust apogee or vice-versa;
- d. A maneuver to adjust the height 180° around from the maneuver point at a longitude or time;
- e. A maneuver to shift the ascending node at an optimum time, longitude, time or height;
- f. A maneuver to obtain a specified apogee and perigee at an optimum time, longitude, or height.
- g. A maneuver to shift the ascending node and adjust the height 180° around from the maneuver point at a longitude or time;
- h. A maneuver to shift the line of apsides to the maneuver point and obtain a specified height 180° around from the maneuver point at a time, longitude, or height.

The output of the GPM Processor is a display containing such maneuver information as ΔV , pitch, yaw, maneuver time, maneuver height, etc., and such post maneuver information as apogee and perigee heights, longitude of the ascending node, eccentricity, etc. A table containing the elements before and after the maneuver at the impulsive time is also output so the maneuver may be transferred to the Mission Plan Table, if desired.

2. PMDGPM - The Display Load Module formats all necessary information required on the GPM Display.



3. PMMPAD - The function of the Perigee Adjust Processor is to compute a series of maneuvers, each of which will raise perigee to a specified height while keeping the thrust direction at a constant angle to the horizon. A threshold time, desired perigee height, and a desired time increment are the main inputs; while the main display values are the begin-burn time, the required velocity increment, and the resultant apogee and perigee values for each of the six maneuvers computed. A table containing the elements before and after each of the maneuvers is also provided so that a selected maneuver can be transferred if so desired.
4. PMDPAD - The Display Load Module formats all necessary information on the Perigee Adjust Display.

TWO-IMPULSE (T/I)

The purpose of the Two-Impulse section for the AS-503 mission is to provide the flight controller with a set of two maneuvers that can be transferred to the Mission Plan Table (MPT) to achieve desired orbit conditions of the maneuvering vehicle.

The section works in terms of chaser and target vehicle, and in terms of a transfer initiation time and transfer completion time. The first maneuver computed is a chaser transfer initiation maneuver needed to intercept a point in space which is defined in terms of the target vehicle. This intercept point is defined using phase angle and height difference offsets from the target vehicle at the transfer completion time. The second maneuver of the set, which is done at this intercept point, is a coelliptic maneuver. For example, if the desired offsets are both zero at the transfer completion time, the transfer initiation maneuver will cause the chaser to intercept the target at transfer completion time, and the transfer completion maneuver would be a velocity matching maneuver.

The Two-Impulse section has two major areas to accomplish its purpose: (1) the regular Two-Impulse or Multiple Solution option, and (2) a Corrective Combination or Digital Option.

The regular Two-Impulse request is initiated via MED input. A maximum of thirteen solutions may be displayed on the Multiple Solution Display. If more than thirteen solutions are computed, the thirteen that require the least fuel expenditure are displayed. The flight controller may fix the time of the first maneuver and vary the time of the second maneuver through a time increment; he may hold the second maneuver time fixed and vary the first maneuver time; or he may compute only one solution at the input times. An option also exists to compute the time of the first maneuver in terms of an elevation angle to the target. The time of the second maneuver may also be computed in terms of a target vehicle central angle of travel from transfer initiation time to transfer completion time. These two options are normally used for the terminal phase maneuvers, i. e., zero offsets.

The Corrective Combination area of the Two-Impulse section is normally used to obtain satisfactory coelliptic conditions prior to terminal phase. This may be used when launch dispersion or improper maneuver execution may cause other rendezvous techniques some problems. There are two methods of obtaining the optimum corrective combination solution.

1. The first method requires a range of height differences to be input. A range of times for the transfer completion maneuver are also input, and the phase angle for each time is computed. For each height difference



the range of solutions are computed, and the impulsive solution at each height difference that requires the least amount of fuel expenditure is displayed.

2. The second method involves a series of solutions that also requires a range of height differences at a transfer completion time. For each height difference requested, a range of phase angles at transfer completion time is used, and the optimum solution for each height is displayed. This range of phase angles for each height is computed from a time limit on each side of terminal phase initiation, with an input increment determining the number of solutions attempted. A terminal phase slip time is computed for each solution displayed.

Another display that is driven by this section is the Single Solution Display. The flight controller may view any one solution from either the multiple or corrective combination table. This display contains components in external ΔV coordinates, daylight-darkness information, and pitch and yaw angles so that the window is along a given line of sight, and contains range, range rate and azimuth approach data at requested times.

Should the flight controller desire to insert the solution into the MPT, a direct transfer option of a particular solution, either multiple or corrective combination, is available by MED request.

The load modules described below are parts of the Two-Impulse Maneuvers.

1. PMSTICN - This load module contains both the control logic and math computations necessary to generate either a multiple solution or a corrective combination set, using Lambert's conic fit technique. It also contains the logic necessary to build an elements table for a transfer of any of the above solutions, and contains the logic to compute the two maneuvers and related elements table to pass to the Docking Initiate (DKI) program to achieve rendezvous from the point in the orbit passed from the DKI (usually TPI point).
2. PMSTISS - This load module contains the logic and math computation to build the single solution table for display purposes from either the multiple solution table or corrective combination table. This is determined by the MED input.
3. PMDTIMP - The Display Load Module formats all necessary information required on the Two-Impulse Multiple Solution Display.



4. PMDDTVCC - The Display Load Module formats all necessary information required on the Two-Impulse Digitals Display.
5. PMDTISS - The Display Load Module formats all necessary information required on the Two-Impulse Single Solution Display.

Figure 2 is a flowchart of the functional flow of the Two-Impulse section.

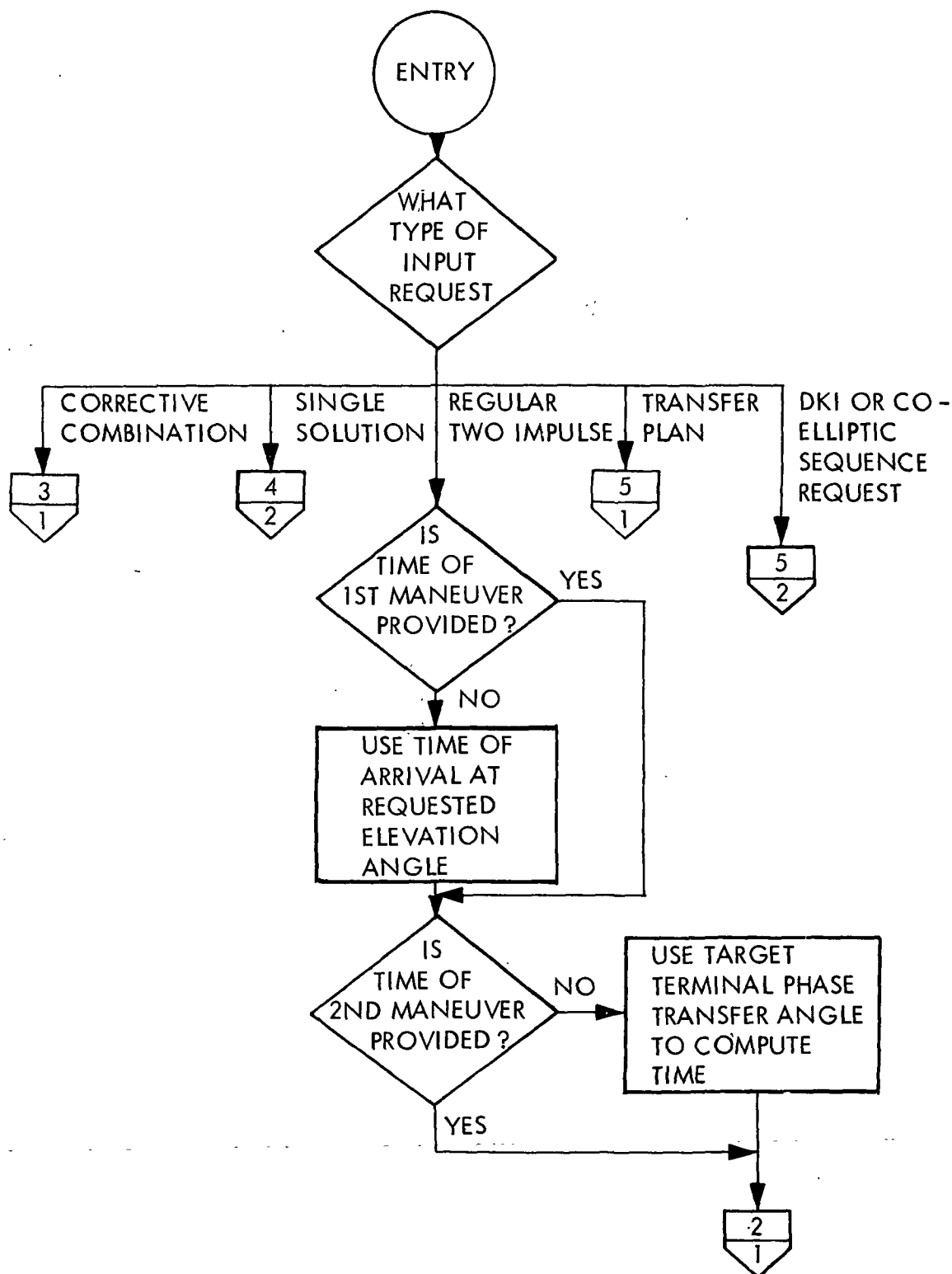


Figure 2. Two-Impulse Maneuvers

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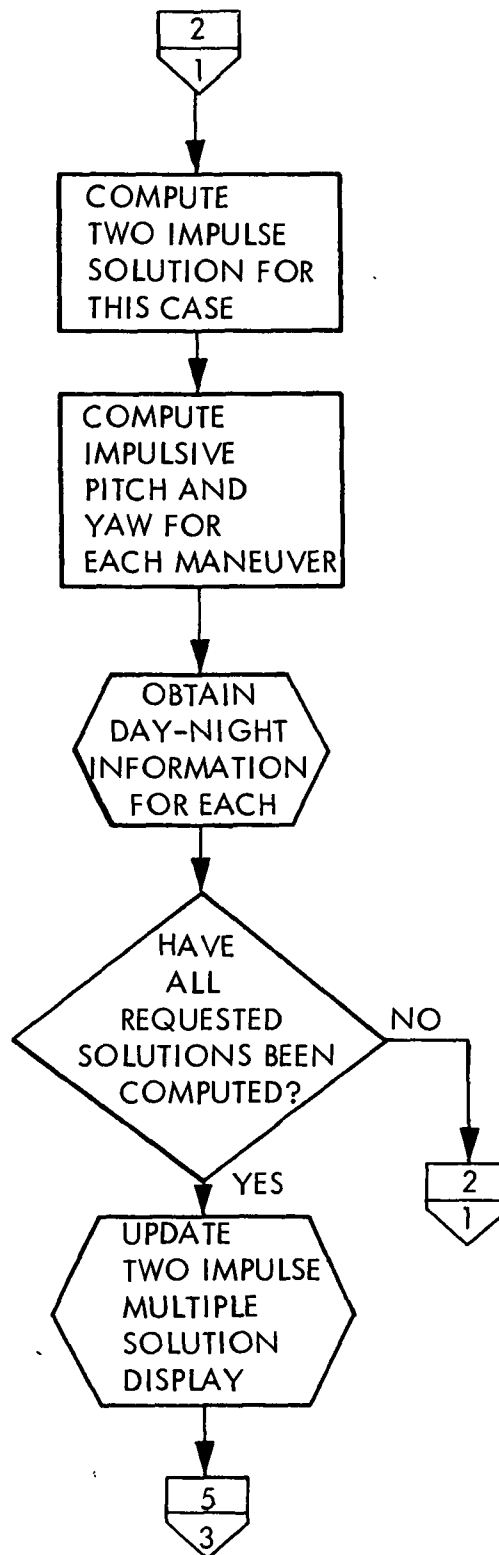


Figure 2. Two-Impulse Maneuvers

(Sheet 2 of 5)

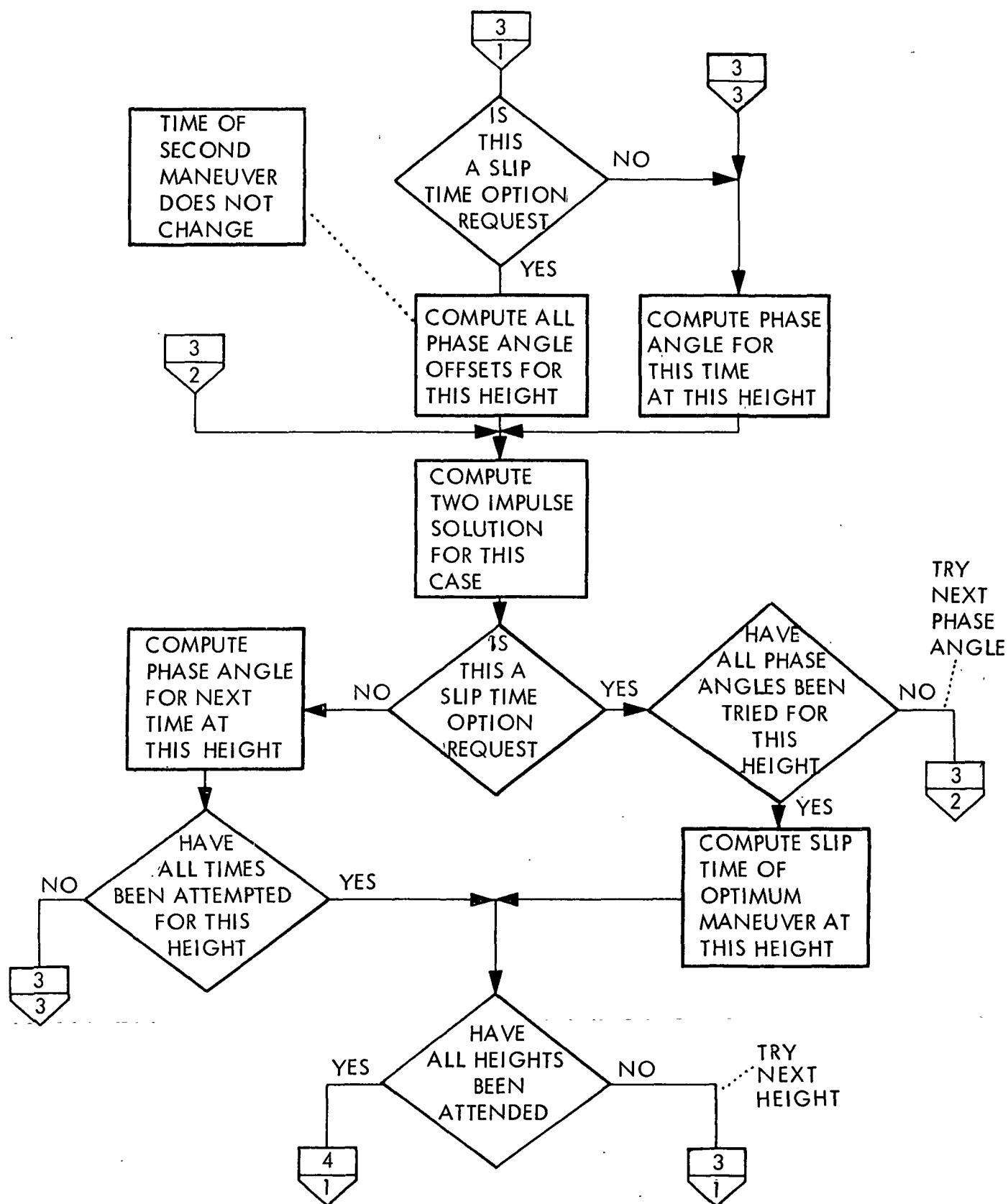


Figure 2. Two-Impulse Maneuvers

(Sheet 3 of 5)

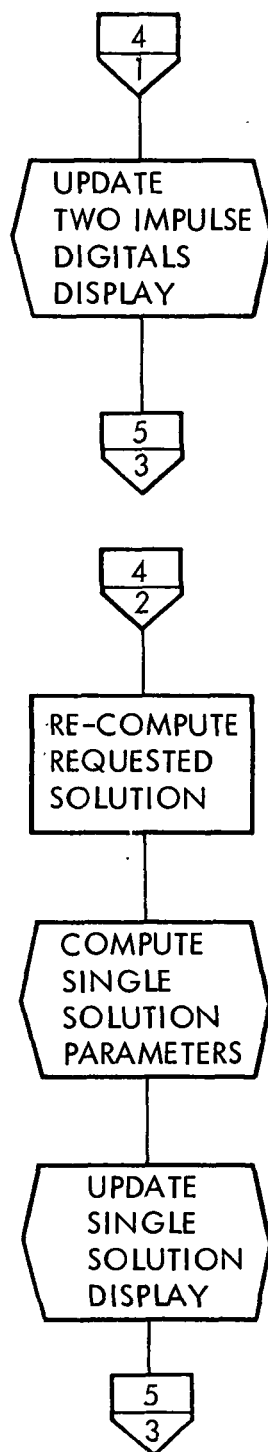


Figure 2. Two-Impulse Maneuvers

(Sheet 4 of 5)

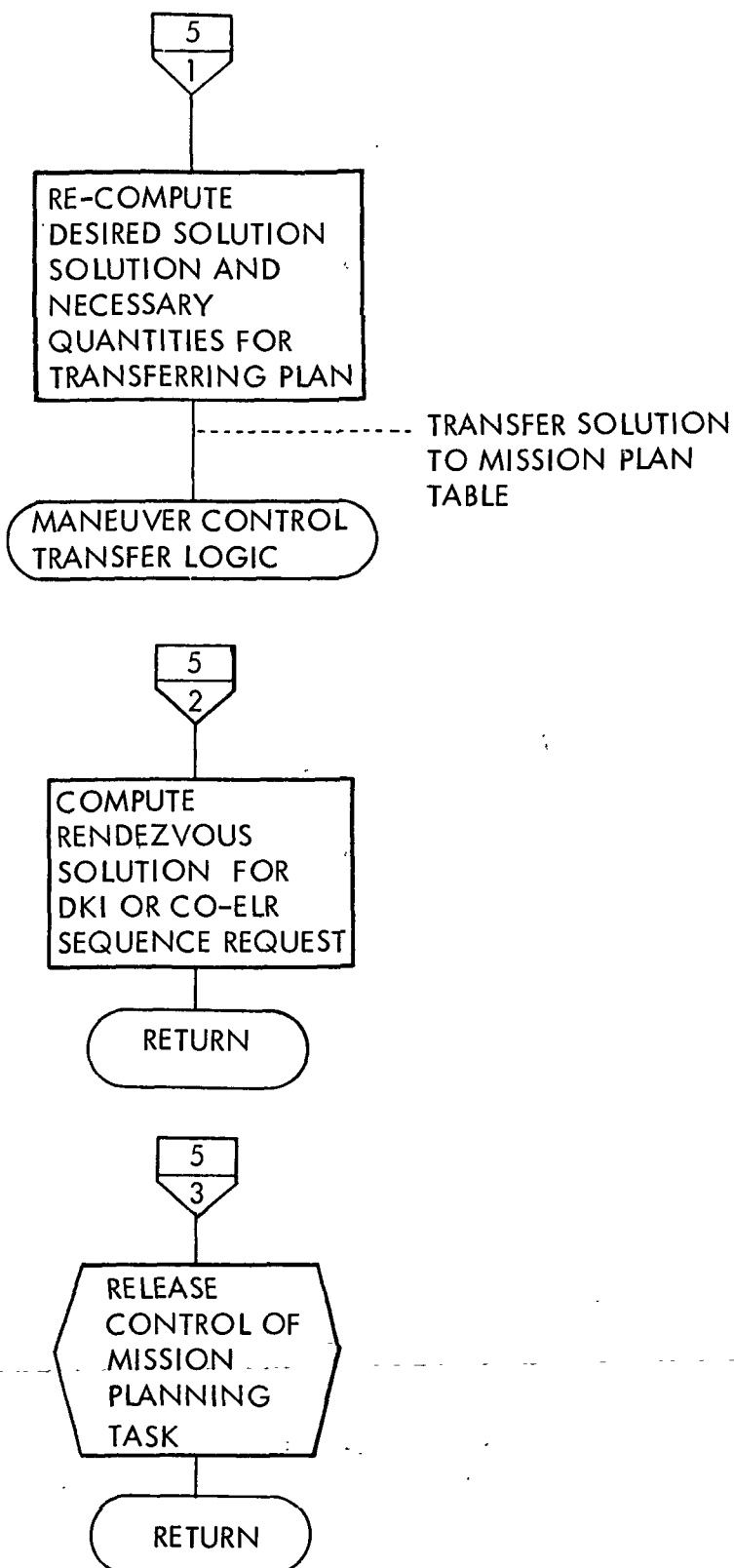


Figure 2. Two-Impulse Maneuvers

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DOCKING INITIATE (DKI)/COELLIPTIC SEQUENCE (SPQ)

The basic function of DKI/SPQ is to compute midcourse impulsive maneuvers for up to seven mission plans; the result of these maneuvers is the rendezvous of the command and service module (DSM) and lunar module (LM) spacecraft.

The technique used to determine the necessary times and velocities for the maneuvers is divided into two major areas of logic: (1) the docking initiate (DKI) and (2) the coelliptic sequence (SPQ). Each method is designed to put the vehicles in a coelliptic orbit so that a terminal phase maneuver (TPI) and a terminal velocity match maneuver (TPF) may be performed to achieve the actual rendezvous. In addition, DKI/SPQ provides the data necessary for the transfer of a particular plan to the Mission Plan Table (MPT).

Docking Initiate

The DKI attains a coelliptic orbit by doing up to four maneuvers: (1) plane change, (2) phase, (3) height, and (4) a coelliptic maneuver that puts the chaser in a coelliptic orbit with the target.

The rendezvous point for the DKI is defined for a specific maneuver counter-line crossing, with the possible constraints as to whether rendezvous occurs in daylight, darkness, or at a longitude crossing. The rendezvous point dictates what phase angle is needed at the coelliptic maneuver point (NSR) for rendezvous to occur. The NSR maneuver is always done, and always occurs at an apogee end of an orbit.

The three other maneuvers are done to get the spacecraft to NSR with a phase angle, height difference, and wedge angle so that subsequent maneuvers will produce rendezvous. These maneuvers are also defined by a maneuver counter line crossing (N_a).

The plane change maneuver point (NPC) is at a common node between two successive counter-line crossings, namely $NPC + .25$, and $NPC - .25$. The height maneuver point (NH) is performed at a perigee counter-line value (i. e., $N_a + .5$).

The phase maneuver can be done at either a perigee or apogee counter line. The point depends upon the phase angle desired at NSR, and how much phase must change to obtain the desired phase at NSR. To distinguish the two phase possibilities, two modes are defined.

1. Upper (Mode 1) for phase at apogee (C1)
2. Lower (Mode 2) for phase at perigee (CH1).

The flight controller has the option to input the maneuver line number, delete the maneuver, or have them scheduled automatically according to ground rules. They may be for Mode 1 or Mode 2; but if Mode 1 fails to produce rendezvous conditions, the program automatically shifts to a Mode 2 in an attempt to produce rendezvous. If this fails, the program terminates processing.

Upon computing a plan, sufficient information is saved so that the plan may be transferred to the Mission Plan Table. The values are saved that will be displayed on the rendezvous evaluation and rendezvous planning displays.

Coelliptic Sequence

The Coelliptic Sequence Program computes the incremental velocities required to meet some relative vehicle positioning at the terminal phase initiation (TPI) point. The maneuvers of the iterative sequence are the concentric sequence initiation maneuver (CSI), the coelliptic maneuver (CDH), and a plane change maneuver (PC), which may or may not be scheduled.

The desired relative positioning at TPI has two options: (1) that the active vehicle have a certain elevation angle to the target, or (2) that a desired differential altitude exist is the coelliptic orbit configuration.

The time of the CSI maneuver, if scheduled, is input. The desired CSI ΔV that will only be horizontal, may be computed with respect to a desired elevation angle at TPI or a desired ΔH at CDH.

There are three options for the computation of the CDH maneuver:

1. Arrival at the apsis may be computed by using the Analytic Ephemeris Generator (AEG),
2. It may be computed after some desired travel angle from CSI,
3. It may be scheduled at an input time.

The CDH maneuver may be deleted if the CSI maneuver is also deleted.

The CSI and CDH maneuvers may be applied in-plane or parallel to the target plane; if a plane change is scheduled, only the in-plane option is available. A plane change may be scheduled for either vehicle and before TPI. The threshold time and subsequent common node to perform the PC are input, or the threshold time may be designated as either the CSI or CDH time. TPI time may be input or computed as a time of target arrival at a desired sunlighting condition or at a desired Earth longitude.

An input flag allows the CSI phase angle to be defined in one of three ways:

1. As the phase angle having smallest absolute value ($-\pi$ to $+\pi$),
2. As the positive phase angle (0 to 2π),
3. As the negative phase angle (0 to -2π).

The constraints checked by this program are in three classifications:

1. Resulting orbits should have minimum perigees,
2. A minimum time should exist between the maneuvers,
3. The total ΔV expenditure should not exceed the ΔV remaining.

If desired, an option is available to recycle the iterator when a constraint violation occurs by redefining the CSI phase angle as the complement of the original value.

Load Module Descriptions

The load modules described below are included in the DKI/SPQ Maneuvers.

1. PMMPHL - The program computes the phase angle needed at the NSR maneuver point to achieve rendezvous at a specified elapsed time into daylight or darkness or to achieve rendezvous at a specified longitude crossing.
2. PMMSCH - The program schedules input maneuver points according to ground rules and sequences them in ascending order. If a phase maneuver is scheduled, then the target vehicle liftoff delay time is computed.
3. PMMITL - The program computes impulsive maneuvers at specified maneuver lines. The maneuvers are computed by an iterative process to converge on a specified phase, height, and co-planar relationships at the circularization (NSR) point.
4. PMMSPQ - The program computes impulsive maneuvers for specified CSI, CDH, PC, and TPI points. See page 25 for further description.
5. PMMMLC - This program computes and defines the chaser vehicle's maneuver line, updates according to specified option, and returns the chaser and target elements at specified time.
6. PMDRET - This program displays times, velocities, maneuver N_a 's, height of apogee and perigee, and phase and height difference for the maneuvering vehicle.

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7. PMDRPT - This program displays up to seven DKI plans, indicating plan modes, maneuvers N_a 's, rendezvous m-lines, plus other quantities used to evaluate a plan.

A flowchart, Figure 3, illustrates the functional flow of the DKI/SPQ Maneuvers.

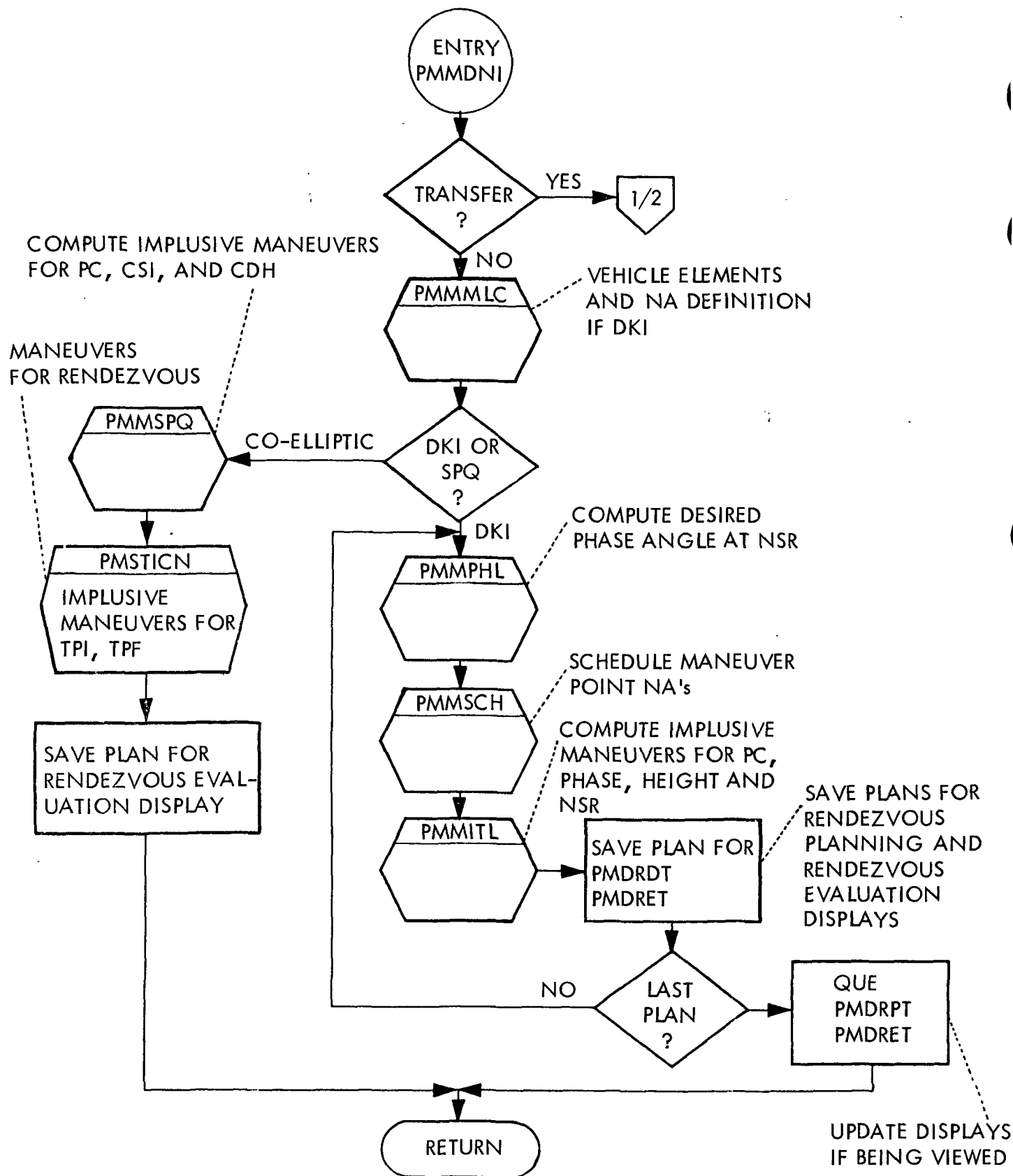


Figure 3. Docking Initiate and Coelliptic Sequence Maneuvers

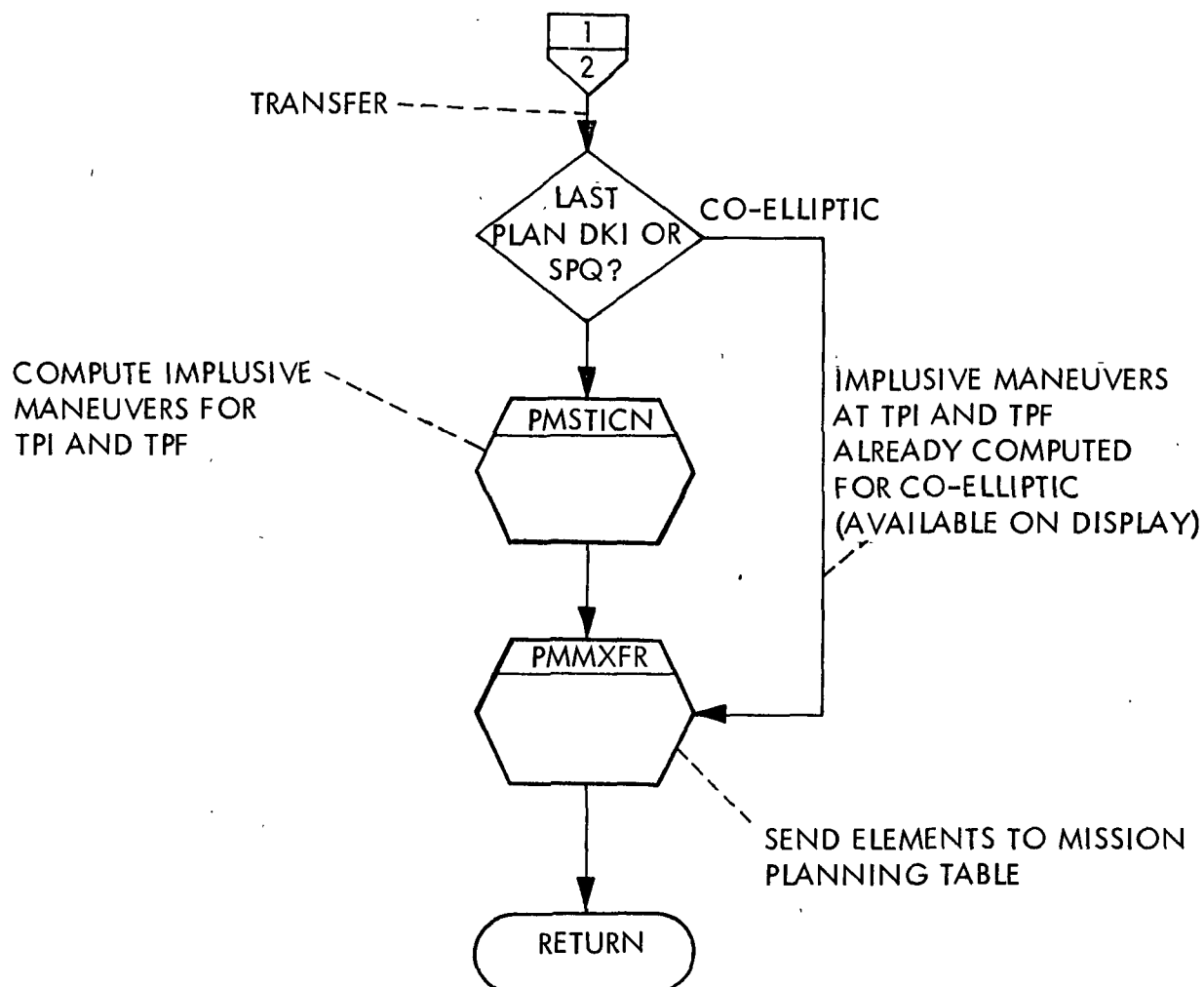


Figure 3. Docking Initiate and Coelliptic Sequence Maneuvers

(Sheet 2 of 2)

MANEUVER CONTROL SUBSYSTEM

The maneuver control subsystem is responsible for processing various inputs related to the computation and insertion of maneuvers into the appropriate vehicle ephemeris and to all trajectory updates that involve maneuvers. The primary function of the subsystem is to control the generation and maintenance of maneuver information in the LM and CSM Mission Plan Tables. The functions of the subsystem also require that it interface with other trajectory-related subsystems. Interfaces exist with the following subsystems:

1. The Launch/High-Speed Abort Subsystem for the Mode III launch abort maneuver and the Mode IV contingency insertion maneuver;
2. The Orbit Trajectory Computations Subsystem for all maneuver computations involved in trajectory generation;
3. The Reentry Computations Subsystem for the deorbit, spacecraft setting, and Mode III launch abort maneuvers;
4. The Rendezvous Planning Subsystem for general purpose maneuvers and rendezvous plans;
5. The Apollo Flight Plans Subsystem for the TLI maneuver and return-to-Earth maneuver.

The main types of processing related to the functions of this subsystem are as follows:

1. Maneuver generation and confirmation
2. Vector routing
3. Maneuver control maintenance
4. I/O related processing.

The load modules are discussed using these four groupings.

LOAD MODULES FOR MANEUVER GENERATION AND CONFIRMATION

The maneuver generation and confirmation modules are responsible for defining all maneuvers in the Mission Plan Tables and for the numerical integration through these periods of powered flight. For these maneuver computations, a decision making module (PMMXFR) is required to interpret MJD data, solve logical ground rules, and collect and route data to the appropriate maneuver processing modules. The finite burn computations for direct input maneuvers or for the confirmation of history maneuvers are performed by the PMMMCD module or the PMMSPT module. The Mode III abort maneuver, the deorbit maneuver, the Mode IV contingency insertion maneuver, the perigee adjust



maneuver, the Return-to-Earth maneuver, and the spacecraft setting maneuver are treated as direct input maneuvers and are processed by PMMMCD. The finite burn computations for the transfer of impulsive maneuvers as computed by the rendezvous planning subsystem are performed by the impulsive maneuver transfer module PMMMPT.

For S-IVB maneuvers using IGM guidance, the initial maneuver that defines data is computed in the pre-thrust targeting module PMMSPT. The powered-flight numerical integration is performed by the module PMMSIU for maneuvers using S-IVB IGM guidance and by the module PMMRKJ for all other maneuvers. Maneuver execution and postburn data are then computed and stored into the appropriate Mission Plan Table by the Detailed Maneuver Table Computations module PMMDMT. The maneuver data from the MPT is then available for display by the display modules. The following is a description of each of these modules.

PMMXFR

The Maneuver Transfer Module is responsible for the solution of ground rules and the control of processing that is required in order to place the following types of maneuvers into the Mission Plan Table:

1. Mode III Launch Abort Maneuver
2. Mode IV Contingency Insertion Maneuver
3. Perigee Adjust Maneuver
4. Direct Input Maneuver
5. General Purpose Maneuver
6. Two-Impulse Maneuver Plan
7. DKI Maneuver Plan
8. Co-Elliptic Sequence Maneuver Plan
9. TLI Study Aid Maneuver
10. Return-to-Earth Maneuver
11. Deorbit Maneuver
12. Reentry Spacecraft Setting Maneuver

A future maneuver can be put directly into the Mission Plan Table by manually inputting the appropriate maneuver that defines data on the applicable direct input MED. PMMSFR routes the MED data, a vector prior to the maneuver, and the necessary maneuver control indicators to either PMMMCD or PMMSPT, depending on the specified guidance mode.



The TLI maneuver using S-IVB IGM guidance is directly input by manually specifying the desired TLI opportunity. The time of restart preparation and the final IGM guidance targets may also be specified. If the final IGM targets are not manually input, the appropriate indicators are routed by PMMXFR to the S-IVB pre-thrust targeting module PMMSPT for the computation of all initial maneuver defining parameters, including ignition time and final IGM targets. If the final IGM targets are input, the necessary data is routed by PMMXFR to PMMSPT for the computation of the remaining initial maneuver-defining parameters.

All other types of maneuvers are directly input by manually specifying the basic finite burn parameters. The necessary data is routed by PMMXFR to the PMMMCD module for the computation of the remaining initial maneuver-defining parameters.

The parameters defining the Mode III abort and Mode IV maneuvers are made available by processing during the launch phase. The Mode III abort maneuver is automatically transferred to the MPT upon entering the launch abort phase. The Mode IV contingency insertion maneuver can be entered into the MPT either automatically or on manual request, depending on the circumstances of the situation. If there is a Mode IV maneuver performed and there are no free-flight post maneuver vectors, then the maneuver is automatically transferred to the MPT. If there are free-flight vectors after the maneuver, then a manual entry is required to put the maneuver into the MPT. In both the Mode III and Mode IV cases, PMMXFR takes the maneuver data generated by the launch processing and includes other necessary information to simulate a direct input maneuver to PMMMCD.

The maneuvers contained in the Perigee Adjust Maneuver Table are impulsive maneuvers, computed assuming a fixed inertial thrust alignment. The alignment is defined by aligning the spacecraft in a "heads down" orientation with the spacecraft X-body axis aligned at the appropriate angle above the "in plane" line of sight to the Earth's horizon. Maneuvers transferred from the perigee adjust table to the Mission Plan Tables will utilize the same initial attitude, the same attitude control mode, and the same thruster as in the Perigee Adjust Processor. The data from the Perigee Adjust Table is arranged to resemble a direct input maneuver, and the initial finite burn computations are done by the PMMMCD module.

All other future maneuvers require finite burn computations by the PMMMPT module. This module performs its computations based on the input of orbital elements before and after the maneuver at the impulsive maneuver time. There are several types of impulsive maneuvers that can be transferred into the Mission Plan Table. They include a General Purpose Maneuver, a Two-Impulse

Rendezvous Plan, a DKI Rendezvous Plan, and a Co-Elliptic Sequence Rendezvous Plan. All of these maneuvers are computed by the Rendezvous Planning Subsystem and are transferred to the MPT via a manual entry. The MED data is routed to the PMMXFR module, which then reads the appropriate maneuver defining elements table or tables and routes all of the data to the PMMMPT module.

The transfer of the Deorbit maneuver, Spacecraft Setting maneuver, and the Return-to-Earth maneuver is accomplished by PMMXFR acquiring the maneuver definition from an appropriate table. The data for the spacecraft setting is stored by the Reentry subsystem. The maneuver data for the deorbit maneuver is generated and stored in a table by the Reentry Subsystem. The Return-to-Earth maneuver is generated and stored by the Apollo Flight Plans Subsystem. After acquiring the maneuver definition, PMMXFR arranges the data to look like a direct input maneuver and then queues the PMMMCD module to have the maneuver input to the MPT.

The transfer of the TLI maneuver is handled in a similar manner to the Spacecraft Setting and Return-to-Earth maneuvers. The maneuver definition is generated by the TLI study aid programs in the Apollo Flight Plans subsystem. After reading the maneuver data out of a table, PMMXFR arranges the data to resemble a direct input TLI maneuver. The data is routed to the PMMSPT module for insertion into the MPT.

Any maneuver in the Mission Plan Table that has a begin-burn time prior to present time may be confirmed by manual input. When confirmation is requested, PMMXFR sets up the MED inputs and queues the appropriate maneuver confirmation program, PMMSPT, for the S-IVB TLI maneuvers and PMMMCD for all others. These modules perform the necessary computations to re-define the maneuver so that the resultant trajectory is consistent with the input maneuver execution parameters. These inputs include the MED data, the last anchor vector prior to the maneuver and the control indicators necessary for placing the maneuvers in the Mission Plan Table.

In all cases, after the initial processing is completed, the anchor vector is routed to PMSVCT where it is brought to present time. The present time vector is then routed to EMSTRAJ to complete the trajectory update.

PMMMCD

The Maneuver Confirmation and Direct Input load module is responsible for the direct input of a future maneuver and for the confirmation of a history (executed) maneuver. In both cases the primary concern is the computation of finite burn parameters for the specified maneuver. The parameters computed are used as inputs to the maneuver integrator. The module is used to process direct input maneuvers for the CSM and LM with all possible thruster and attitude control modes. The module is used to process thruster and attitude control modes. The module is used to process the Mode III and Mode IV maneuvers, the perigee adjust maneuver, the Return-to Earth maneuver, and the deorbit maneuver. In the case of direct input, a new future maneuver is built based upon the input data and transferred into the appropriate Mission Plan Table. In the case of a confirmation, certain quantities for a specified executed maneuver are changed as specified by the inputs, such that the maneuver and the resultant orbit are consistent with the actual execution of the maneuver.

A maneuver can be performed with the following thrusters and attitude modes:

1. CSM

<u>Thruster</u>	<u>Attitude Mode</u>
RCS±X	Fixed inertial, primary external ΔV,
SPS	manual holding body attitude fixed
S-IVB Blowdown Vent	Lambert guidance
	Fixed inertial only

2. LM

<u>Thruster</u>	<u>Attitude Mode</u>
RCS±X	Fixed inertial primary external ΔV,
DPS	manual holding body attitude fixed,
APS	AGS external ΔV, Lambert guidance.

A CSM or LM maneuver can be a single-vehicle maneuver, a docking maneuver, an undocking maneuver, or a docked maneuver. If the CSM and the LM are docked, the maneuver may be placed in either the CSM or LM Mission Plan Table or both. The TLI maneuver can be input to either MPT.

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The basic inputs for a direct input or confirmation are as follows:

1. Thruster and attitude control mode indicators,
2. The ΔV magnitude, or the ΔV along the X-body axis excluding tail-off, or the ΔV along the X-body axis including tail-off, or the Δt , or the \bar{V}_g , or the V_F , V_S , V_D , or the external ΔV vector, or Δt_{OF} , C , \bar{r} , or in the case of a confirmation, the maneuver ΔV residuals.
3. Ignition time of specified thruster,
4. The pitch, yaw, roll in the LVLH or IMU system. Attitudes are not required for the external ΔV or Lambert guidance modes,
5. The Δt of ullage and number of RCS thrusters used for ullage (SPS, DPS, APS maneuvers only),
6. A reference matrix indicator,
7. Vehicle heads up/heads down indicator,
8. The Δt of 10% thrust level for DPS maneuvers,
9. The trim angle indicator for SPS and DPS maneuvers.

In both cases, control is given to PMMMCD from PMMXFR; when the processing has been completed, control is returned to PMMXFR. The PMMXFR module then relinquishes control to PMSVCT, which moves the anchor vector up to present time. A trajectory update is then performed.

PMMMPT

The Mission Plan Table Impulsive Maneuver load module is responsible for the transfer of an impulsive maneuver into the appropriate Mission Plan Table. The maneuver is generated by one of the following sources:

1. General Purpose Maneuver Program
2. Two-Impulse Program
3. DKI Program
4. Co-Elliptic Sequence Program.

This program takes osculating orbital elements before and after an impulsive maneuver and computes the finite burn parameters necessary as inputs to the powered flight numerical integration program. In computing these parameters an iterative process is used to insure an accurate computation for long duration maneuvers. The ability is also provided to allow the begin burn time to be computed in one of three ways:

1. Set begin burn time to the impulsive time
2. Compute an optimum time to begin burn.

A maneuver can be performed with the following thrusters:

1. CSM or LM RCS \pm X (2 or 4 thrusters firing)
2. CSM SPS
3. LM DPS
4. LM APS.

in any of the following attitude control modes:

1. Fixed inertial
2. Primary external $\overline{\Delta V}$
3. Manual holding body orientation fixed
4. Lambert guidance
5. LM AGS external $\overline{\Delta V}$.

The basic input parameters are the following:

1. Osculating orbital elements before and after the impulsive maneuver with both sets of elements given at the impulsive maneuver time
2. Thruster and attitude control mode indicators
3. Δt of ullage and number of ullage thrusters to be used (applicable for SPS, DPS or APS thrusters only)
4. Δt of 10% thrust level for DPS thruster
5. Thruster trim angle indicator.

Maneuvers transferred to the Mission Plan Table by this program may be single vehicle or docked maneuvers; however, no change in the vehicle configuration is allowed.

PMMSPT

The S-IVB Pre-thrust Targeting load module is responsible for the direct input, transfer or confirmation of the S-IVB Translunar Injection (TLI) maneuver with the IGM guidance. The basic functions of this module are as follows:

1. Compute the guidance target parameters
2. Compute certain transformation matrices
3. Store the appropriate maneuver data and indicators in the specified Mission Plan Table.

For the direct input option, the data required is input via the MED and consists of one of three sets:

1. The MED input of the number of the desired injection opportunity
2. The MED input of the number of the desired opportunity and the time of restart preparation
3. The MED input of the desired injection opportunity, the time of restart preparation, and the final target parameters.



For the TLI maneuver transfer option, the data is acquired from a maneuver description table maintained by the TLI study aid programs. The data consists of the time of restart preparation, the desired injection opportunity, and the final target parameters. The required transformation matrices are computed, maneuver indicators are set, and the maneuver is input to the MPT.

The PMMSPT module also provides the confirmation capability for the TLI maneuver when the IGM guidance is used. For the confirmation option, the time of re-ignition and/or the Δt of the maneuver are manually input. There is no recomputation of guidance target parameters as a result of confirmation.

There are other circumstances under which the PMMSPT module performs its basic computations. There are also other special computations. These circumstances and the applicable computations are as follows:

1. When a future TLI IGM maneuver is frozen, the specified vehicle vector at maneuver initiation is stored in the MPT by PMMSPT. If a vector other than the ephemeris vector is specified as the vehicle vector, the maneuver is flagged as an iterable maneuver. An iterable maneuver is one which originated from a direct input of the desired injection opportunity only or from the direct input of the desired injection opportunity and the time of restart preparation.
2. When a future iterable TLI IGM maneuver exists, the maneuver defining parameters are recomputed by PMMSPT on every trajectory update that affects the ephemeris associated with the Mission Plan Table which contains the TLI maneuver.
3. The PMMSPT module is used in the TLI Planning Study Aid. In this environment the input to PMMSPT will consist of the desired injection opportunity only.

PMMSIU

The S-IVB IGM Powered Flight Guidance and Numerical Integration module is responsible for processing the translunar injection maneuver when the S-IVB IGM guidance is specified. The processing requires simulating the TLI guidance program of the S-IVB Instrument Unit and integrating through the maneuver using a fourth order Runge-Kutta technique. This module has the capability of performing either single integration or double integration.

Double integration is used when a maneuver is frozen. Basically, double integration consists of using an input vehicle vector in simulating on-board calculations of thrust directions and computing the output ephemeris using the input ephemeris vector as in single integration, except that the above thrust directions are used. This requires simultaneous propagation of the vehicle and ephemeris vectors through the burn, which suggests the name double integration.

The input to the PMMSIU module includes a flag to indicate if all target parameters required for the integration have been computed. If not, then PMMSIU will calculate the remaining target parameters before doing the integration.

The module outputs the following:

1. An ephemeris table of time, position or position and velocity vectors
2. A standard ephemeris header
3. An auxiliary output table consisting of special vectors and maneuver related quantities
4. A table of time and weights with a 1-1 correspondence with the ephemeris table storage cycle.

Since this module functions as a special purpose maneuver integrator, it has been designed with the following restrictions:

1. The program will perform no backward or free-flight integration
2. The Earth will be the reference body for all integration
3. All vectors returned will be in the same coordinate system as the input vectors.

PMMRKJ

The General Purpose Powered Flight Guidance and Numerical Integration load module is designed to numerically integrate through periods of powered flight for any of the following attitude modes:

1. Inertial
2. Manual holding body orientation inertially invariant
3. Primary external $\overline{\Delta V}$
4. LM AGS external $\overline{\Delta V}$
5. Lambert guidance.



Any of the following thrusters may be used except where noted:

1. CSM RCS \pm X (2 or 4 thrusters)
2. LM RCS \pm X (2 or 4 thrusters)
3. CSM SPS
4. LM DPS
5. LM APS
6. S-IVB blowdown vent (inertial only)

For maneuvers using SPS, DPS or APS thrusters, two or four RCS thrusters for ullage may be specified.

This module has the capability of performing either single or double integration when Lambert guidance is specified. Single integration is always used for all other attitude modes; double integration is used when a Lambert guided maneuver is frozen. Basically, double integration consists of using an input vehicle vector in simulating on-board calculations of thrust directions and computing the output ephemeris using the input ephemeris vector as in single integration, except that the above thrust directions are used. This requires simultaneous propagation of the vehicle and ephemeris vectors through the burn, which suggests the name double integration.

The module outputs the following:

1. An ephemeris table of time, position or position and velocity vectors
2. A standard ephemeris header
3. An auxiliary output table consisting of special vectors and maneuver related quantities
4. A table of time and weights with a 1-1 correspondence with the ephemeris table storage cycle.

PMMDMT

The Detailed Maneuver Table load module is responsible for the following:

1. Maintenance of vehicle areas and weights pertaining to the maneuver
2. Storing integrator outputs, when necessary, into the appropriate MPT
3. Computations of quantities based on the position and velocity vectors at ignition
4. Post maneuver trajectory calculations



The results of these computations are stored in the appropriate Mission Plan Table and are available for display. A restart vector is printed on line at the end of a trajectory update from the burnout vectors of the first future maneuver. Also a vector is printed on line whenever a history maneuver is involved in a trajectory update.

PMMUDT

The PMMUDT module provides the capability to change the vehicle orientation for a future maneuver in the Mission Plan Table. The vehicle orientation can be changed to "heads up" or "heads down". This module also provides the option of specifying whether or not system parameter values for the thruster trim angles are to be used. These computations are queued by a MED entry containing the MPT desired, maneuver number, vehicle orientation indicator, and a trim angle computation indicator. A trajectory update is queued after the PMMUDT computations are completed.



LOAD MODULES FOR VECTOR ROUTING

The primary function of the Vector Routing processing is to select vectors from the current vehicle ephemeris for the purpose of performing an ephemeris update and to initiate trajectory updates as the result of the selection of new vehicle anchor vectors.

PMSVCT

The Vector Routing Load Module will initiate all trajectory updates for the CSM or LM ephemerides. The update may be performed with a vector from the current ephemeris or with a new ephemeris anchor vector. If an iterable S-IVB TLI IGM maneuver exists in the MPT associated with the trajectory update, PMSVCT queues the PMMSPT module for recomputation of the appropriate maneuver defining parameters. The vector is then integrated to present time, reflecting any MPT maneuvers, and routed to EMSTRAJ to complete the trajectory update.



LOAD MODULES FOR MANEUVER CONTROL MAINTENANCE

The Maneuver Control Maintenance Programs are responsible for the general upkeep of the CSM and LM Mission Plan Tables. They set indicators and change data as the result of an internal real time queue or a MED request. These modules are also required to logically solve given sets of ground rules as a part of their task.

PMMFUD

The Freeze/Unfreeze/Delete module solves the ground rules and controls the processing associated with freezing, unfreezing, or deleting maneuvers in the CSM and LM Mission Plan Tables.

The basic function performed by this module related to freezing a maneuver is the determination of the vehicle vector to be used by the powered-flight integrators to perform double integration for IGM or Lambert guidance. It also performs the calculations and/or functions necessary to freeze a fixed inertial maneuver, a manual maneuver, or an external ΔV maneuver. Maneuvers may be frozen with the ephemeris vector or with any of the usable vectors in the Vector Panel Summary (VPS). An iterable IGM maneuver refrozen with the ephemeris vector or frozen with a vector from the VPS will cause a recomputation of the guidance parameters. A trajectory update is performed for all freeze requests except an initial request to freeze with the ephemeris vector.

This program also performs the function of unfreezing maneuvers and maintaining the MPT when deleting executed or non-executed maneuvers. The deletion of executed maneuvers will not cause a trajectory update. The deletion of a non-executed maneuver or the unfreezing of a maneuver will result in a trajectory update being performed.

PMMWTC

The Weight Change Module performs the function of changing the vehicle area, weight, and fuel remaining in the MPT. The following manual inputs may be made:

1. Cross-sectional area of CSM, LM ascent stage, LM descent stage, and S-IVB
2. Total weight of CSM, LM, LM ascent stage, and S-IVB
3. Fuel remaining for CSM (RCS or SPS), LM (RCS, APS, or DPS), and S-IVB.

The input of vehicle area or weight will be stored as the single vehicle area or weight to be applied at the end of the last maneuver prior to present time. (The input of total LM weight will result in a change to LM descent stage weight if that stage is present in the configuration. If the descent stage is not present, the total LM weight will be stored as the weight of the ascent stage.) These new values will then be used to compute a new configuration area or weight and ΔV remaining at the end of that maneuver. A trajectory update is then performed using a vector from the current ephemeris.

An input of fuel remaining will result in those values being stored as the values at the end of the last maneuver prior to present time and the ΔV remaining displayed on the DMT to be recomputed if necessary. The new fuel weights will be carried forward to subsequent MPT maneuvers.

This program also accepts manual inputs of orbit density multiplier (K-factor), initial vehicle configuration, CSM/LM docking angle, and time to begin S-IVB venting.

PMSEXE

The Maneuver Execution load module performs various maneuver control functions related to the execution of maneuvers in the CSM or LM Mission Plan Table. When present time reaches the begin time of a maneuver, a queue is passed to PMSEXE to print on line the burnout vector for the maneuver along with the corresponding area and weight of the vehicle. Flags are set in the MPT to indicate that the maneuver has been executed. A queue is sent to the Supervisor providing it with the time of the next maneuver execution queue. The MPT and DMT displays are updated as a result of releasing control to a display task.

LOAD MODULES FOR I/O RELATED MODULES

The maneuver control input modules consist of two load modules, PMMMED and PMKMED. The PMMMED module is responsible for interpreting and routing data input via the M-code MED's, while the PMKMED is responsible for similar activity for the K-code MED's. Generally, the K-code MED's are used to generate Rendezvous Planning computations while the M-codes result in queues for maneuver control computations.

The maneuver control output modules consist of display modules and on-line print modules. The display programs present summary and detail maneuver-related quantities and post-maneuver quantities to the flight controllers. These displays are automatically updated as a result of any activity which causes any of the display parameters to be changed. The on-line print module will print error messages and other items related to Maneuver Control and Rendezvous Planning processing.

PMMMED

The PMMMED module is responsible for the checking and conversion of data that is manually input via the M-code MED's and the routing of data to the appropriate processing modules. Other functions of this module include storing MED data into tables and changing system parameter values. The following is a description of the Maneuver Control M-code MED's.

- M03 - Changes target parameters for the S-IVB TLI pre-thrust targeting calculations using the IGM guidance.
- M06 - Changes SPS electronic null and DPS hardover system parameters.
- M07 - Changes the system parameter thruster trim angles for orbital maneuvers.
- M10 - Changes the SPS, DPS, APS thruster characteristics.
- M11 - Changes the CSM and LM center of gravity characteristics.
- M40 - Inputs the burn parameters for the direct input MED (M66) and the confirmation MED (M60).
- M49 - Changes the CSM, S-IVB, and LM fuel weights.
- M50 - Changes the CSM, S-IVB, LM and LM ascent weights.
- M51 - Changes the CSM, S-IVB, LM descent, LM ascent areas and K-factor.



- M55 - Changes the initial vehicle configuration in the MPT; changes the GET to begin venting and sets the docking angles.
- M58 - Changes the vehicle body orientation and trim angles for MPT maneuvers
- M60 - Confirms executed maneuvers using CSM or LM guidance.
- M61 - Confirms executed TLI maneuvers using the IGM guidance.
- M62 - Freezes, unfreezes, deletes or history deletes MPT maneuvers.
- M64 - Transfers a perigee adjust maneuver to the MPT.
- M65 - Transfers a GPM to the MPT.
- M66 - Directs input of a maneuver into the MPT.
- M68 - Directs input of a TLI maneuver into the MPT.
- M70 - Transfers a DKI or SPQ plan into the MPT.
- M72 - Transfers Two-Impulse plan into the MPT.
- M74 - Transfers a Return-to-Earth, Time-to-Fire, or Spacecraft Setting maneuver into the MPT.
- M75 - Transfers a TLI maneuver into the MPT.
- M81 - Overrides the Launch to Abort Mode III or Launch to Orbit transfer.

PMKMED

The PMKMED module is responsible for the checking and conversion of data that is manually input via the K-code MED's and the routing of data to the appropriate processing modules. Another function of this module is to store MED data into tables for use by the processing modules. The following is a description of the maneuver control K-code MED's.

- K00 - To generate a DKI plan.
- K01 - To generate an SPQ plan.
- K05 - To initialize for a DKI and/or SPQ plan.
- K10 - To define a maneuver line.
- K20 - To generate a General Purpose Maneuver.
- K21 - To generate a Flight Controller Input GPM.

- K22 - To generate a GPM to adjust apogee and perigee heights with a single maneuver.
- K23 - To generate a GPM to adjust height and shift the node.
- K24 - To generate a GPM to shift apsis and adjust height 180° around.
- K28 - To generate perigee adjust maneuvers.
- K30 - To generate a Two-Impulse Plan.
- K31 - To generate a Two-Impulse Single Solution Display.
- K32 - To generate a Two-Impulse Corrective Combination.

PMDMPT

The Mission Plan Table display module formats maneuver related quantities from the CSM and LM Mission Plan Tables and causes the information to be put to the D/TV system.

PMXSPT

The Maneuver Control Print module prints all on-line messages related to Maneuver Control and Rendezvous Planning processing.

PMDDMT

The Detailed Maneuver Table Display module provides detailed maneuver information for any specified maneuver in either the CSM or LM Mission Plan Table. Two maneuvers may be evaluated by simultaneous display of a DMT for each maneuver. The information displayed is obtained as follows:

1. Maneuver execution parameters, including times, ΔV quantities, vehicle attitudes and weights, are picked up from the appropriate MPT block. IMU attitudes and V_g are computed based on a specified reference matrix. FDAI angles for the LM are computed from IMU attitudes (FDAI and IMU angles will be the same for CSM).
2. Resultant trajectory parameters are also picked up from the appropriate MPT block. When two ephemerides exist at cutoff, rendezvous-related quantities are computed by PMDDMT.



3. Targeting parameters are displayed when applicable. The following are the available guidance types for the indicated on-board computers:
 - a. IU - Translunar injection IGM
 - b. CMC - Lambert or external $\overline{\Delta V}$
 - c. LGC - Lambert or external $\overline{\Delta V}$
 - d. AGS - External $\overline{\Delta V}$.
4. For unfrozen maneuvers where the LM primary external $\overline{\Delta V}$ guidance mode is specified, LM AGS external $\overline{\Delta V}$ target parameters are computed and displayed as backup guidance parameters. The parameters remain unchanged after the maneuver is frozen.

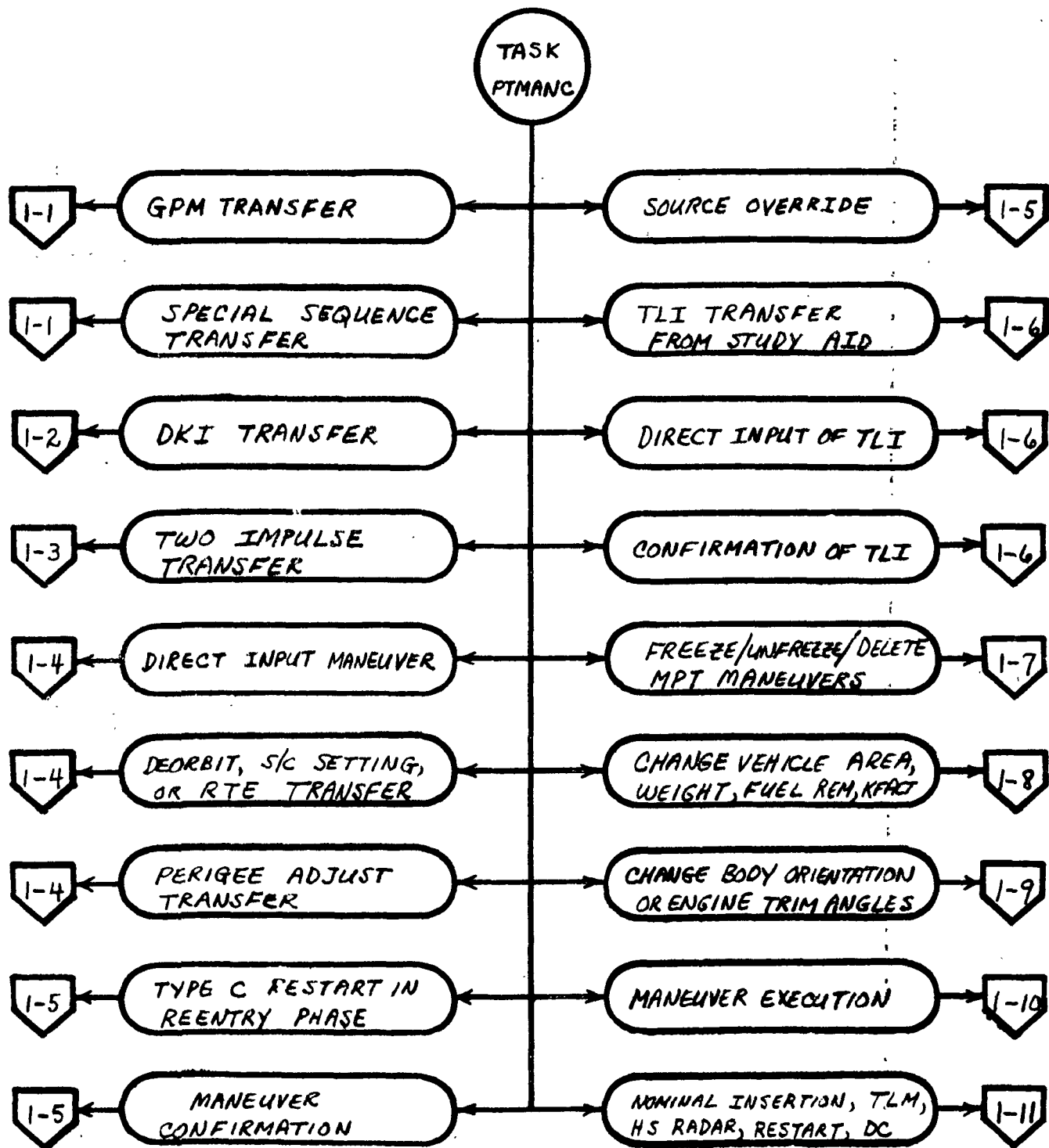


Figure 4. Maneuver Control Subsystem/Task PTMANC

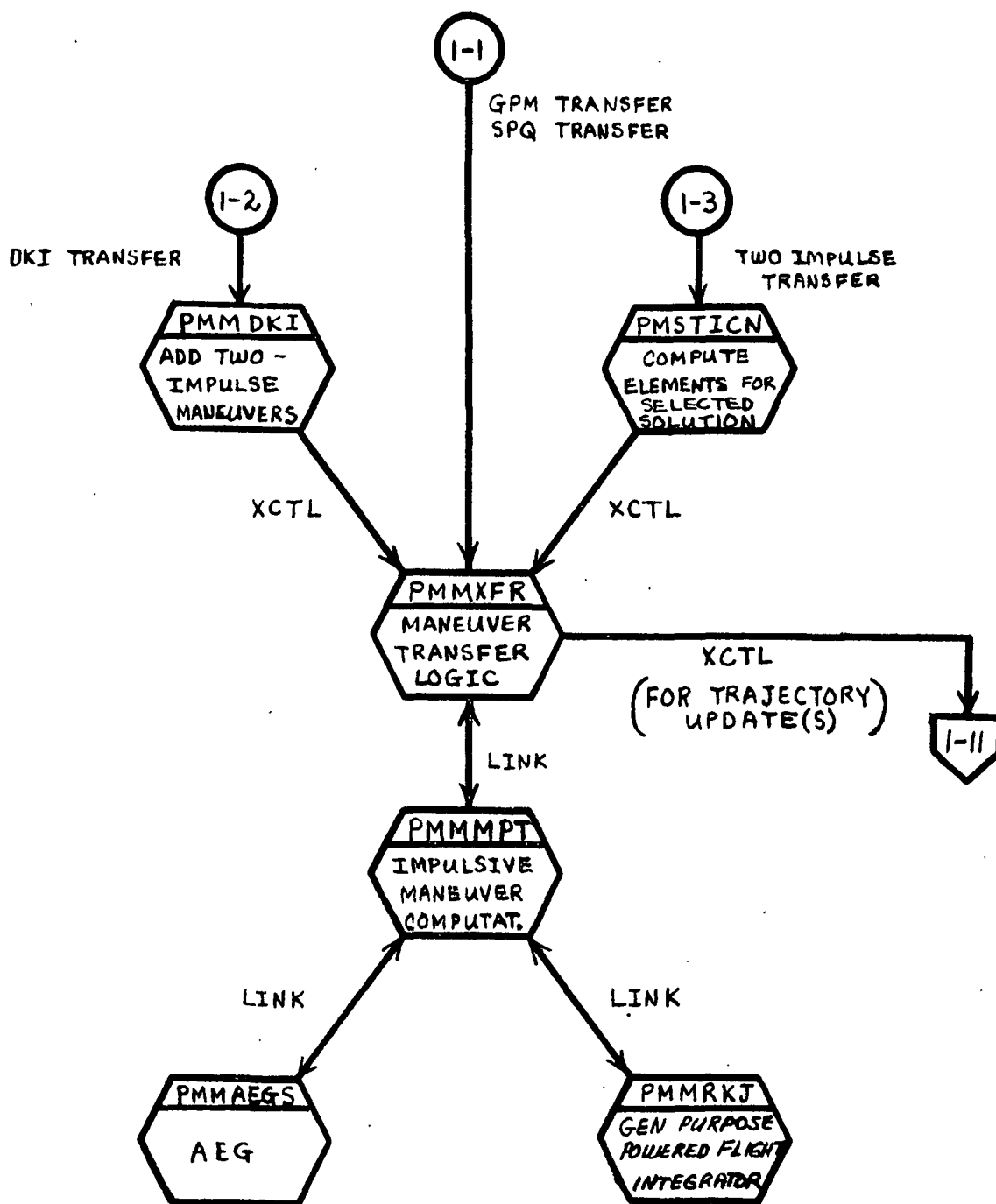


Figure 4. Maneuver Control Subsystem/Task PTMANC

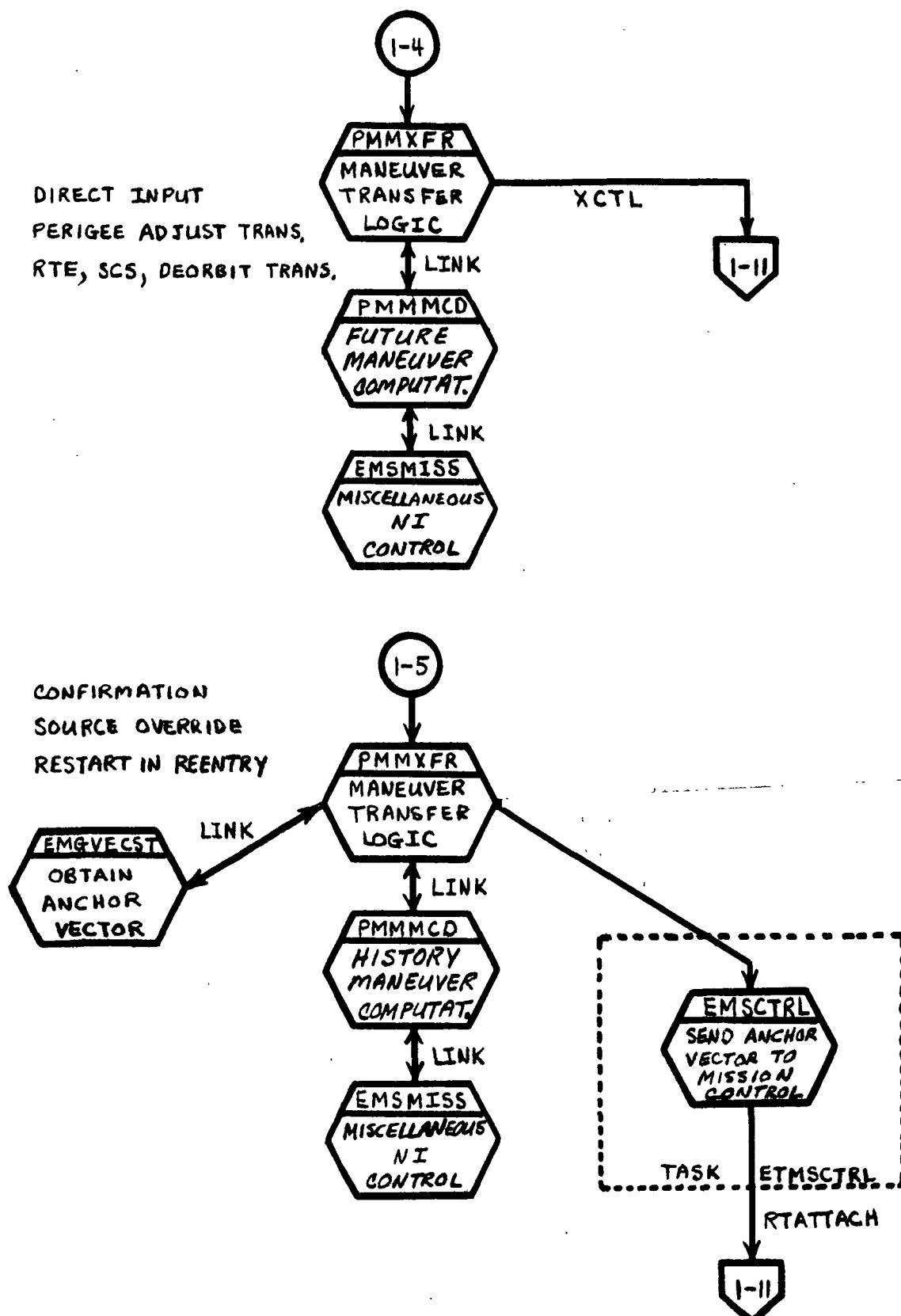


Figure 4. Maneuver Control Subsystem/Task PTMANC

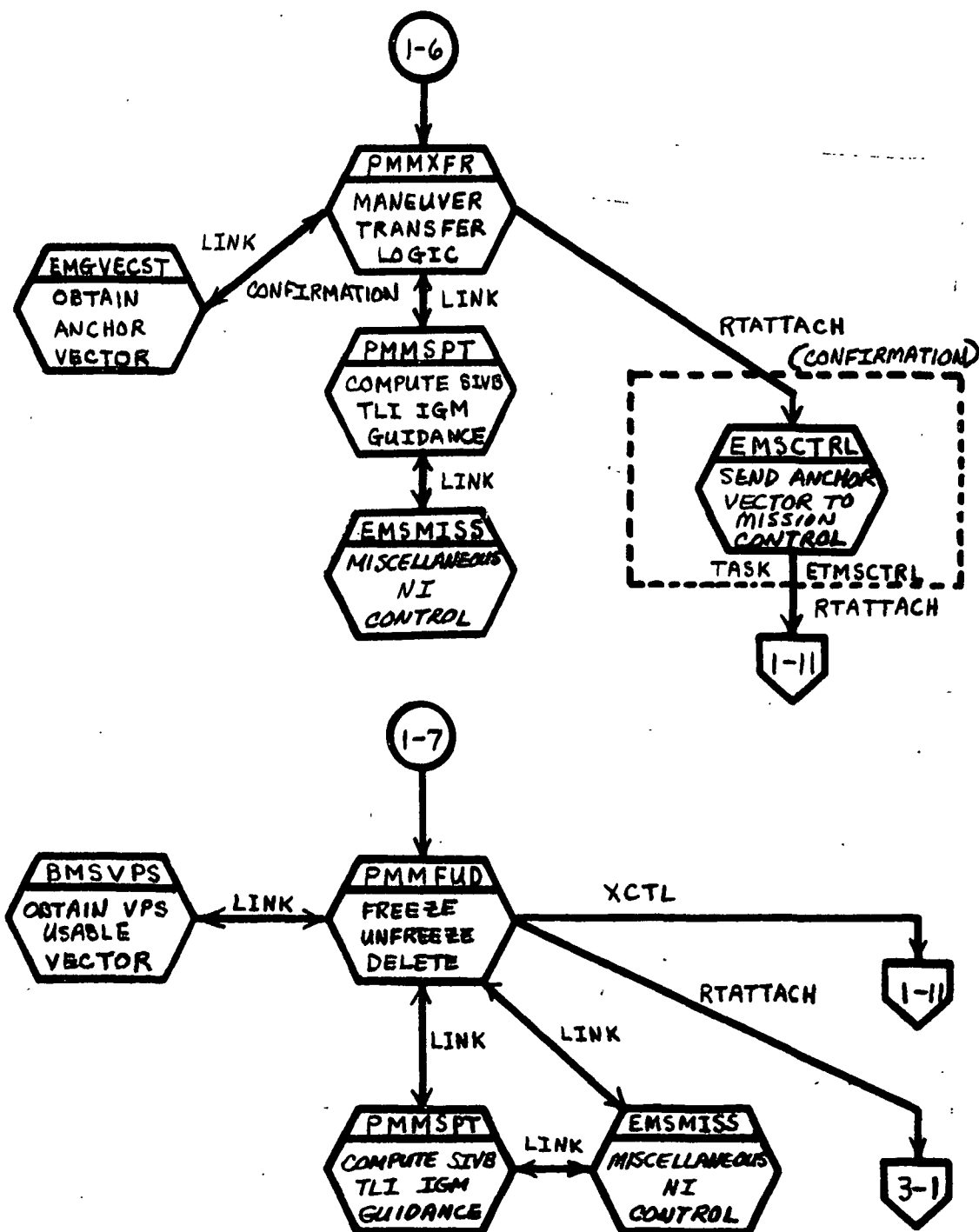


Figure 4. Maneuver Control Subsystem/Task PTMANC

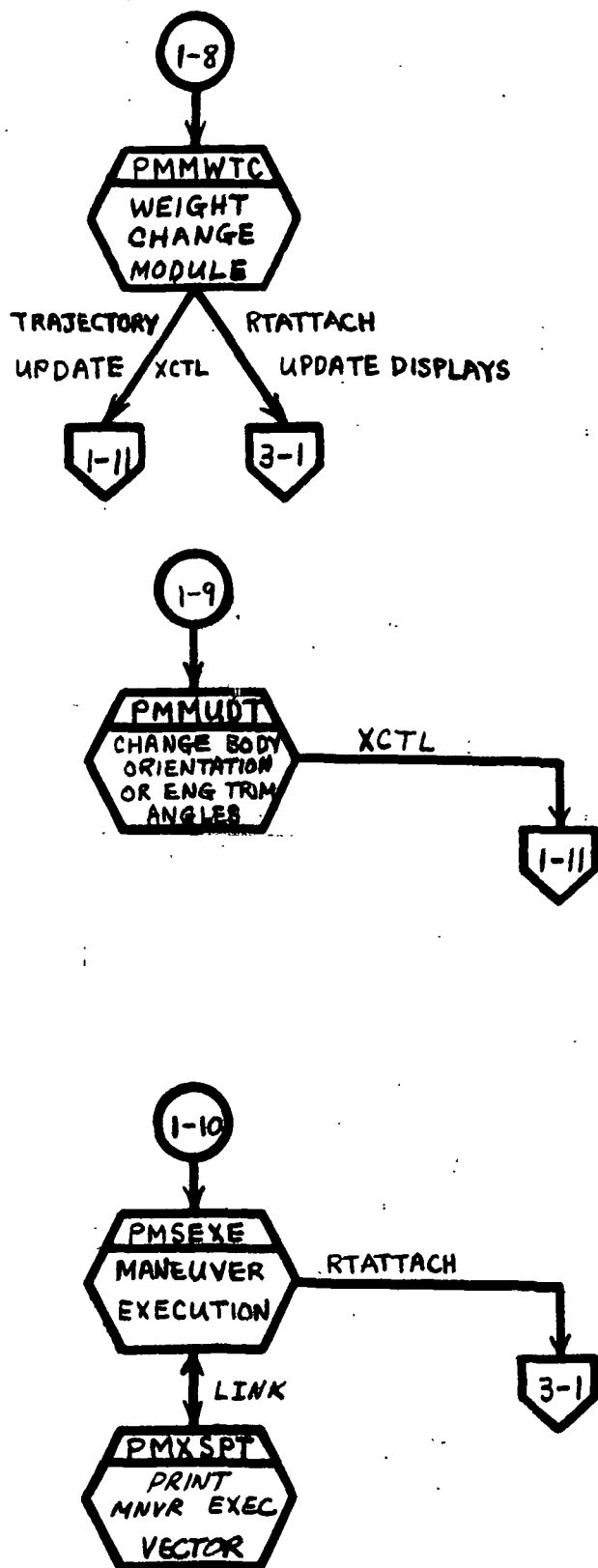


Figure 4. Maneuver Control Subsystem/Task PTMANC

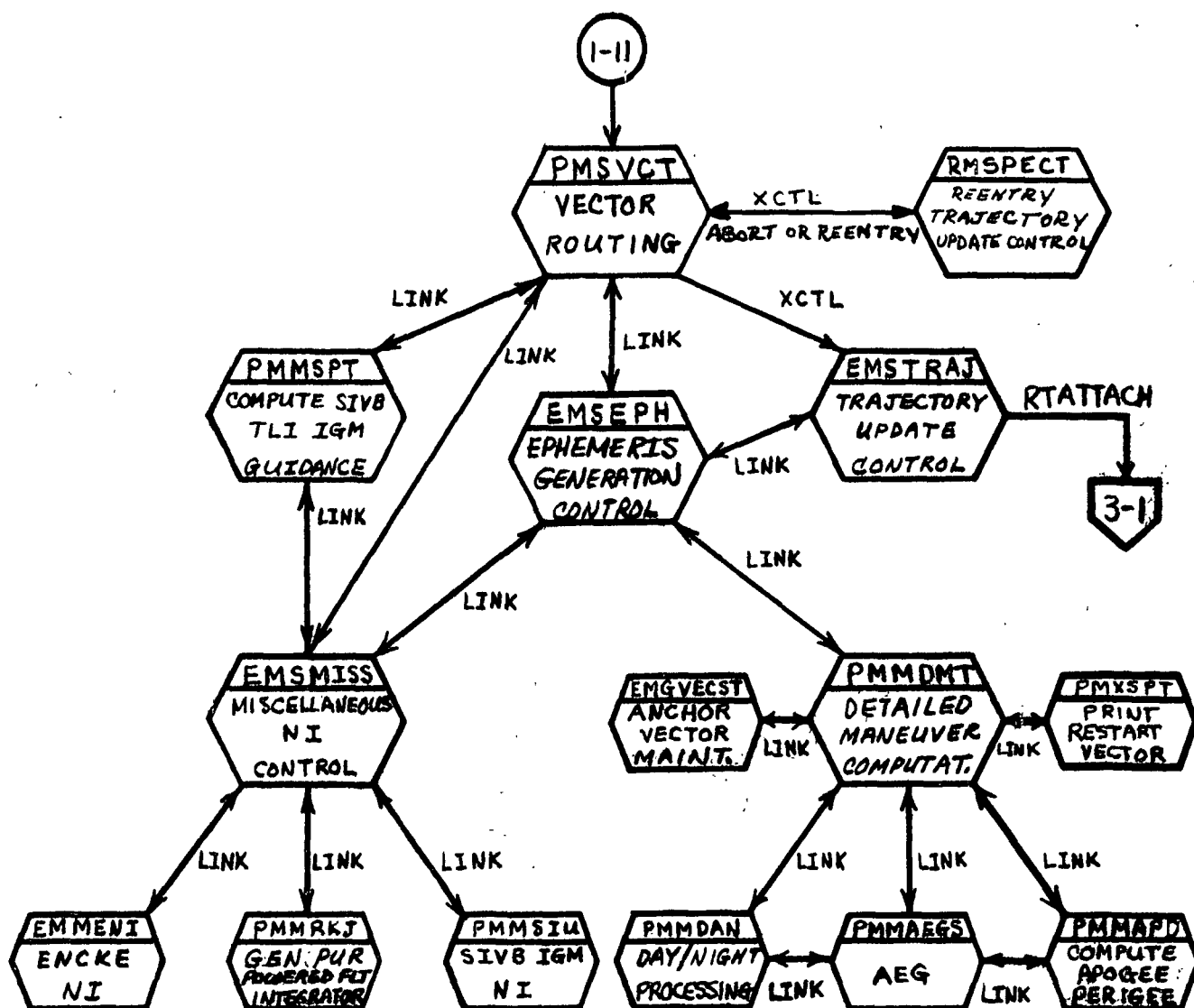


Figure 4. Maneuver Control Subsystem/Task PTMANC

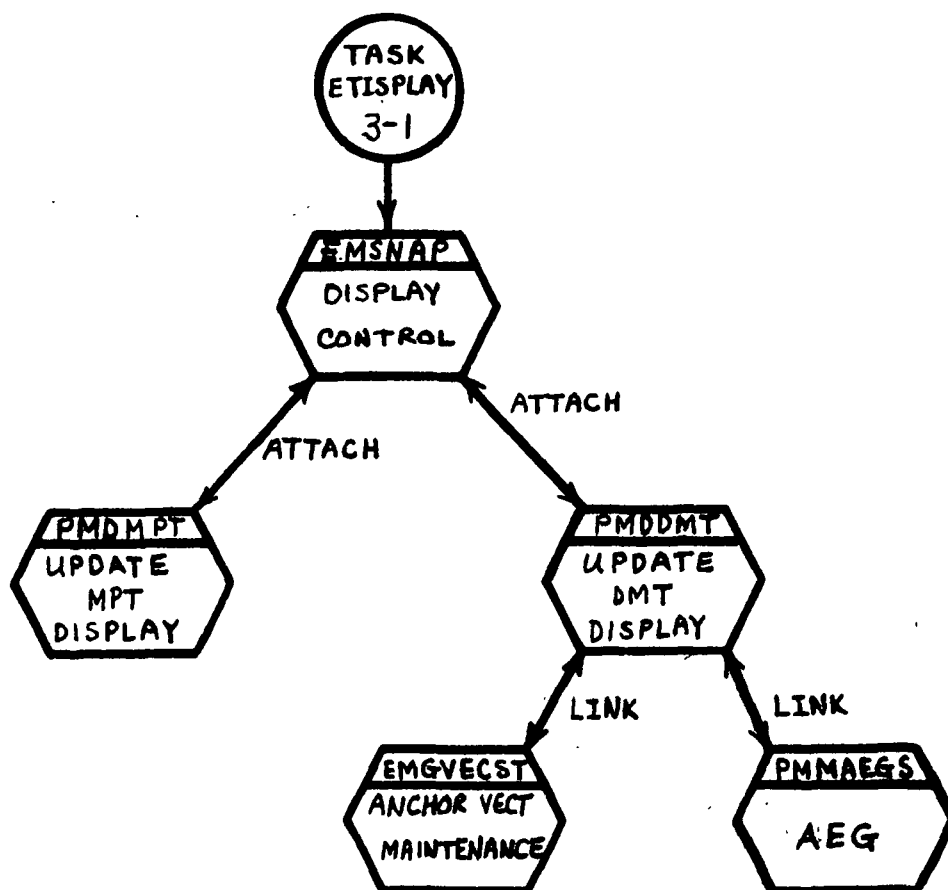


Figure 5. Maneuver Control Subsystem/Task ETISPLAY

MISSION PLANNING UTILITY PROGRAMS

LOAD MODULE DESCRIPTIONS

The Mission Planning Utility Programs include the load modules described below.

PMMAEG

The Earth Satellite Analytic Ephemeris Generator (AEG) load module can be separated into four logical units. The units are (1) initialization of a set of Keplerian elements, (2) updating of the elements, (3) initialization and updating of elements, and (4) processing of multiple blocks. Each of these logical units are discussed in more detail below.

Initialization of Elements

To initialize elements the AEG will compute the osculating and mean elements, the rates, argument of latitude, radius magnitude, and true anomaly. The compilation will be based on a set of input osculating elements at a given time.

Updating of Elements

To update elements, the AEG must have a set of the initialized elements described above. The AEG can update a set of these elements by six different methods. The methods are (1) time, (2) mean anomaly, (3) argument of latitude, (4) maneuver counter line, (5) time match, and (6) position match.

1. Time - Update the initialize input elements to an input time.
2. Mean Anomaly - Update the initialize input elements to the input mean anomaly in the orbit ΔN orbits from the input elements.
3. Argument of Latitude - Update to the input argument of latitude in the orbit ΔN orbits from the input elements.
4. Maneuver Counter Line - Update to a maneuver counter line, which is ΔN lines from the reference.
5. Time Match - Update the input elements to the time associated with output elements of the previous block processed. The AEG also computes the phase angle for output.

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6. Position Match - The AEG can update to position match in two different ways. They are (1) update the input elements to position match with the previous block processed by going backward, and (2) update the input elements to position match with the previous block processed by going forward if the phase angle at time match is greater than 180° , or by going backward if the phase angle at time match is less than 180° . The AEG also returns the time lag, height difference, and phase angle as output at time match. When updating the input elements, the AEG has the option to update with or without drag depending upon the input.

Initialization and Updating of Elements

Depending upon the input, the AEG can take a set of input osculating elements and initialize the elements (described above) and then update the initialize elements (described above) with one entry.

Processing of Multiple Blocks

The AEG can process multiple numbers of input blocks. When updating to a time or position match, multiple block processing must be used. This procedure is necessary because a previous block was probably processed to use this same update option.

PMSVEC

Given either one or two vector times, and a vehicle code for the first or only time, the Rendezvous Planning Vector Fetch Load Module fetches a vector from the corresponding vehicle ephemeris, if available, thus satisfying all criteria concerning maneuvers in the MPT. The logic then converts the vector to Keplerian elements and passes these elements, the corresponding time, and the area, weight and K-factor at that time to the requesting program in a format suitable for use with the Analytic Ephemeris Generator (AEG) Program. If two vector times are requested, two AEG blocks are passed, one for each vehicle involved in the mission. The station ID used to build the current ephemeris is also made available to the user.

At the time of the writing, the General Purpose Maneuver (GPM), Perigee Adjust, Two-Impulse, and Maneuver Line Definition programs were using utility programs.

PMMDAN

Given a set of satellite elements (AEG format), the Day/Night Load Module Program will utilize the AEG to determine the time and nature of the next one or two environmental changes. The routine will use a sun vector at the input time. The sun's rays are considered to be parallel, and no attention is given to reflection, diffusion or semidiameter, or parallax. For the purpose of this program these factors do not introduce significant error.

PMMAPD

Given a set of classical Keplerian elements (ECI or ECT) the Rendezvous Planning Apogee-Perigee Determination load module will compute (using the AEG with or without drag as desired) upcoming apogee and/or perigee quantities such as magnitude(s), time(s) of arrival, related Keplerian elements, and upon request the latitude(s) and longitude(s).

PMMCEN

The Coast Numerical Integrator load module is a free-flight numerical integrator which, when given a state vector, the time associated with it, and an indication of the central body, drives numerical integration of the input state toward a desired ending condition.

The ending condition may be specified by one of three stopping parameters: time, flight path angle, or radial distance. The parameter at stopping has a minimum of twelve digits of agreement with the desired value. In the event the desired value cannot be reached, a maximum integration time is also checked, preventing excessive looping internally.

Integration may be either forward or backward with respect to time and is accomplished by use of an eccentric anomaly-related independent variable (Beta). The integration scheme used is attributed to Encke.

The integrator will function inside the central body by assuming a central force field only, thus making possible iterative procedures which will on occasion drive trajectories into the central body before reaching desired end conditions.

The potential function includes the point mass effects of the sun and moon as well as the first three zonal harmonics and the first tesseral harmonic of the non-spherical earth. No atmospheric drag is included.

PMMFIT

This load module is an iterative scheme to find the optimum mission by satisfying a given set of constraints. The iterative method solves two problems; first, obtaining a mission that satisfies the constraints (select mode) and second, adjusting the initial conditions and control values until a function of these variables achieves a minimum or maximum value (optimizing mode).

The method is completely general; it does not depend on the mission, the initial conditions, control parameters, constraints, or variable to be optimized. The values of the initial conditions and control parameters appear as a vector of independent variables. The values of the constraints and of the variable to be optimized (that is, the variable to be maximized or minimized) appear as a vector of dependent variables. The actual routine that computed the dependent variables from the independent variables is referred to as the trajectory computer. The particular trajectory computer to which this iteration scheme applies defines the mission to be obtained or optimized. For the Translunar Injection Planning, section of LMSP, there are two trajectory computers defined; the first is the conic trajectory computer load module (PMMFPC), and the second is the precision trajectory computer load module (PMMFBS). The Return-to-Earth Abort Planning section also has a precision trajectory computer (PMMPABTC) used in constructing the Abort Scan Table and Return-to-Earth Digital solutions.

PMQAFMED

The Translunar Injection and Return-to-Earth abort processing will be initiated only by manual inputs beginning with the first character of 'F'.

The MED's will be decoded, checked for reasonable values, when possible, and stored in the appropriate data table. Then EMSCTRL will be RTATTACHed with the necessary information to initiate the appropriate processing, when no other processing under EMSCTRL is active.

Other 'F' MED's will control such things as labeling the abort tradeoff display, entering targets into the Return-to-Earth abort target table and deleting plans from the TLI tradeoff display.

SUBROUTINE DESCRIPTIONS

The subroutines described below are included in Mission Planning Utility Programs.

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PIEXDV

The Primary External ΔV Coordinate Transformation subroutine performs a special coordinate transformation on an input velocity increment vector, ΔV . If the input ΔV is in the external ΔV uplink coordinate system the transformed ΔV is in the RTCC inertial coordinate system. The subroutine is designed for the GSM GNCS and LM PGNCs external ΔV computations.

PIMIKC

The inertial to Keplerian Element Conversion subroutine converts position and velocity vectors in the RTCC inertial coordinate system to Keplerian orbital elements. The program can be used for elliptic and circular orbits and cannot be used for parabolic or hyperbolic orbits.

PIMIKC

The Keplerian to Inertial Element Conversion subroutine converts Keplerian orbital elements to position and velocity vectors in the RTCC inertial coordinate system. The program can be used for elliptic and circular orbits and cannot be used for parabolic or hyperbolic orbits.

PIDREF

The Orbit Desired REFSMMAT Computation subroutine computes the orbit phase desired IMU stable member alignment REFSMMAT for the CSM or LM. There is an option for either a heads up or a heads down IMU stable member orientation.

PIDVRS

The Maneuver Confirmation ΔV Residual subroutine is designed to allow confirmation of an executed CSM or LM maneuver when the maneuver ΔV residual in the vehicle RCS control axes are known. The inputs are the ΔV residuals, the IMU attitude angles at the time of the reading of the residuals, the applicable REFSMMAT, the original maneuver ΔV , and a vehicle indicator. The actual maneuver velocity increments ΔV_A are computed and can be used by other programs to confirm the executed maneuver.

PIMGBL

NASA will provide tables for the Thruster Gimbal Angle Computation subroutine. These tables give the vehicle center of gravity location as a function of vehicle weight for each of the following vehicles:

1. CSM
2. LM with Ascent Propulsion System attached
3. LM with Ascent and Descent Propulsion Systems attached.

The capability will exist to update each of these tables in real time. The Thruster Gimbal Angle Computation subroutine will use these tables and the input vehicle configuration code, docking angle, and thruster indicator to compute the center of gravity for the specified configuration and the thruster gimbal angles necessary to align the thrust vector through the center of gravity.

PIAEDV

The LM AGS External ΔV Coordinate Transformation subroutine performs a special coordinate transformation on an input velocity increment vector, ΔV . If the input ΔV is in the LM AGS external ΔV uplink coordinate system the transformed ΔV is in the RTCC inertial coordinate system. If the input ΔV is in the RTCC inertial coordinate system the transformed ΔV is in the uplink coordinate system.

PCLAMB

This subroutine uses Lambert's equations in the universal form to compute the velocity required at a given position vector \mathbf{r}_1 to define a trajectory which passes through \mathbf{r}_1 and another position vector \mathbf{r}_2 with a given time of flight between \mathbf{r}_1 and \mathbf{r}_2 . The routine is designed for circular, elliptic, parabolic and hyperbolic orbits. The equations are for two body motion.

The Lambert subroutine is used in the powered flight guidance modules for Lambert guidance computations and in the PMMDMT module in the computation of the Lambert guidance \bar{V} for the DMT display for the SVIVB TLI maneuver when IGM guidance is specified.

PIFAAP

Given certain input elements (a, e, i, f, u and r in the ECI or ECT system) the Rendezvous Planning Apogee-Perigee subroutine will compute the position magnitudes of apogee and perigee based upon a low eccentricity, first harmonic



approximation. It differs completely from PMMAPD in that it does not use the AEG and does not compute location information.

PIAIPP

Given a reentry state vector, this subroutine computes a geodetic impact point from reentry range function curve fits based on a selected target line and reentry mode.

One of two target lines may be selected: a shallow (primary) line, or a steep (secondary) line. If the shallow line is selected, a choice of two reentry modes is available, G&N or constant g. If the steep target line is selected, only the constant g mode is available.

A pseudo-impact point may be computed for states off either target line by specifying a reentry range bias which is added into the computations before the radius to impact is computed.

2.1.11 REAL TIME OPERATING SYSTEMS

FUNCTIONAL SPECIFICATION FOR THE MISSION SYSTEMS LUNAR MISSION SIMULATION PROGRAM

REAL TIME OPERATING SYSTEM
FUNCTIONAL SPECIFICATION FOR THE MISSION SYSTEMS
LUNAR MISSION SIMULATION PROGRAM

INTRODUCTION

The Real Time Computer Complex - Real Time Operating System/360 (RTCC-RTOS/360) is comprised of a multi-tasking version of Operating System(OS)/360 with necessary additional facilities for RTCC processing. Most of the new facilities were added to OS/360 for one or more of the following reasons:

1. To provide the software support for the handling of real time data
2. To insure fast response system activity. (The mission system has requirements ranging from one-tenth of a second.)
3. To provide support for devices not currently supported by OS/360.

The major functional areas listed below were developed at Houston Operations and added to OS/360 in the formation of RTOS/360.

1. Independent Task Management
2. System Task Capability
3. Queue Management
4. Data and Time Routing
5. Time Management
6. Real Time Input/Output Control System
7. Data Tables
8. Display Formatting Language
9. Real Time Linkages
10. Large Core Storage Support
11. Logging
12. Simulated Input Control
13. Fastime
14. Fail Safe Programs
15. Background Utilities
16. Houston Automatic Spooling Priority (HASP)
17. Statistics Gathering System
18. Job Accounting System

Each of these areas will be described in the sections that follow.

Approval	Approval
<i>F. E. Adams</i>	<i>R. J. Kopp</i> 7-24-68

INDEPENDENT TASK MANAGEMENT

All processing under OS/360 is done in conjunction with tasks that have been defined as "units of work".¹ Some of the characteristics of an OS/360 task are not functionally oriented toward the types of work performed by real time systems. An OS/360 task requires the existence of its "creator" in order to exist, has the protect key of its creator and must have at least one load module executing under it. Its dispatching priority is a function of its creator's priority.

The task concept has been extended within RTOS/360 to include tasks that are independent of their creators. A distinction is therefore made between dependent and independent tasks. (A dependent task is identical to an OS/360 task.) An independent task does not require the existence of its creator in order to exist, has a unique protect key, can be dormant with no load modules executing under it, and assumes its priority from the request it is processing.

How do the characteristics of an independent task render it more especially suited to real time systems? First, a real time system must be able to receive and process varying data loads rapidly and efficiently. An independent task may be defined for each type of data to be processed, and each task must be available to receive work at all times even if the data rate is low or random. The major distinction here between dependent and independent tasks is that the independent task will continue to exist in the system when it has no data to process; during this time it is dormant. When data is received by the system for an independent task, it is sent to the task in the form of a request. Each request has its own priority which in turn becomes the task's dispatching priority while processing that request. If an independent task is processing a request when another request is generated for it, the new request is enqueued according to its priority. Requests in this queue will be given to the task as it completes the processing of higher priority or older requests.

Each independent task is assigned an area in main core called a resource table. This is a private area that can be used by the programs running under the task. Usually, information is stored in this area which is derived from the processing of earlier data. In this way the task can "remember" information through periods of dormancy.

¹ IBM OPERATING SYSTEM/360: Concepts and Facilities

When an independent task becomes active, it is assigned a unique protect key. This protect key is given to all dependent tasks created by the independent task while processing a request. Therefore, a program running under an independent task or its descendents will be protected from all programs controlled by other active independent tasks or their descendents. Since dependent tasks are assigned the same protect key as their creator's, all tasks of a job step in OS/360 have the same protect key. This is not practical in large multiprogramming systems where many tasks handle various types of data. Independent tasks ensure that unique protect keys will be assigned to unique functions.

Figure 1 represents the logical structure of tasks operating as a job step in OS/360.

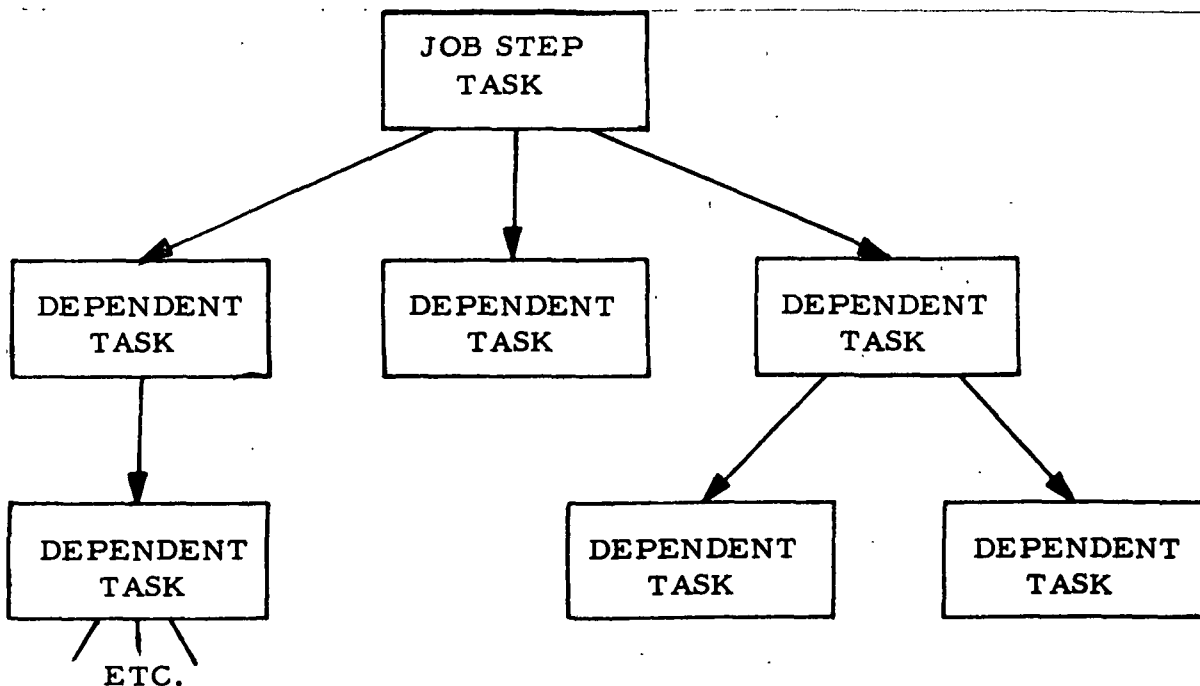


Figure 1. OS/360 Task Structure

This structure is obviously pyramidal in form. All tasks depend either directly or indirectly on the Job Step Task.

The Job Step Task can ATTACH² dependent tasks (subtasks) which in turn can ATTACH task dependent upon them, etc. All tasks compete for system resources (CPU, I/O, etc.), and OS/360 awards those resources according to the priority assigned to each task.

Figure 2 represents the logical structure of tasks operating as a job step in RTOS/360. One can easily see that a new dimension has been added. The Job Step Task and its subtasks exist as in OS/360 while each independent task forms the basis of another set of tasks that operate independently of and parallel to the Job Step Task and each other. This structure is comparable to multi-jobbing in OS/360 with each independent task analogous to the job step task of each active job. However, in RTOS/360 all independent tasks and their subtasks function within a single job step, and all tasks in that job step are awarded the system resources according to their dispatching priority. This means that RTOS/360 provides a single-jobbing, multi-tasking environment.

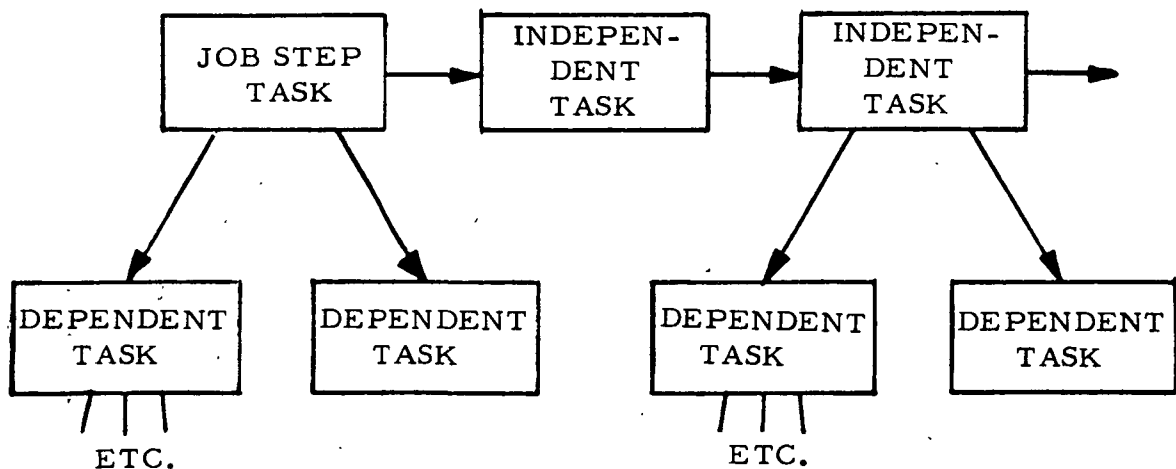


Figure 2. RTOS/360 Task Structure

² ATTACH is an OS/360 service MACRO. Refer to IBM OPERATING SYSTEM/360: Supervisor and Data Management Services.



SYSTEM TASK CAPABILITY

The system task capability provides the system with an efficient means of assigning task responsibility to units of work that are unrelated to an existing task or are performed asynchronously to existing tasks.

A system task differs from an OS/360 defined dependent task and an RTOS defined independent task in the areas of creation and communication. Creation of and communication with dependent and independent tasks is via the ATTACH and RTATTACH system macro. System tasks are created via the SYSTWORK system macro. Supervisor overhead to service a SYSTWORK request is less than 1/25th of the overhead required to service an ATTACH or RTATTACH. The large difference is due to the following:

- All control blocks required for a system task have been pre-allocated and pre-initialized for efficient utilization.
- The entry point for a system task is an absolute location instead of a load module name as is the case for dependent and independent tasks.

The supervisor overhead to service the return from a system task is also less than 1/25th of the overhead required to service the return from a dependent or independent task.

QUEUE MANAGEMENT

If an independent task is processing a work request, all other requests for that task must be held by the system until the task is ready to begin processing a new request. Therefore, RTOS/360 must build and maintain a queue of work requests waiting to be processed by an active independent task. Information concerning each request is held in a Real Time Queue Element (RTQEL).

Figure 3 shows the logical structure of an independent task and its RTQEL's waiting to be processed.

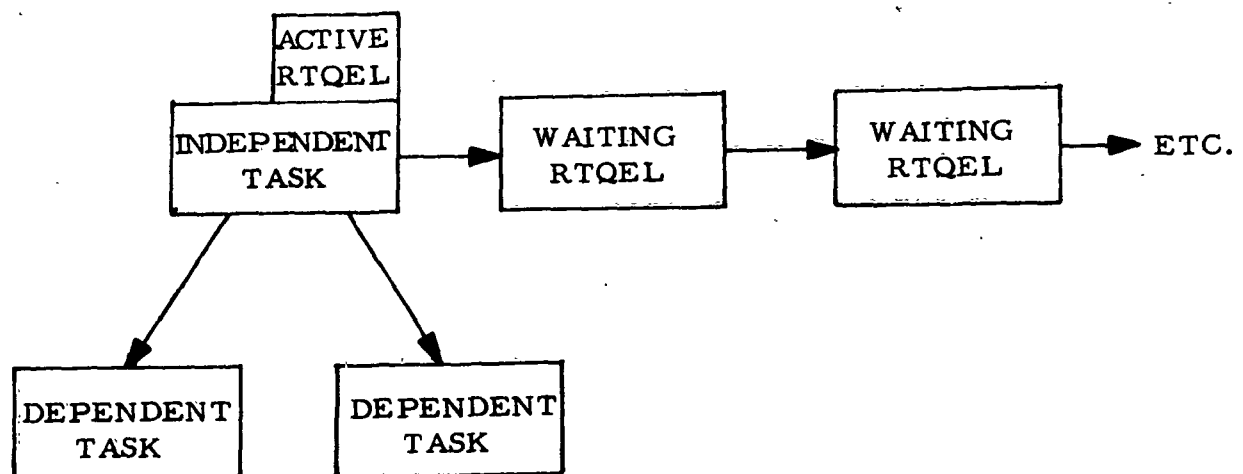


Figure 3. Independent Tasks and RTQEL's

Each active independent task will be processing one work request, and that request is represented by the active RTQEL. All other work requests for the independent task are placed in a queue of waiting RTQEL's. This queue is ordered by dispatching priority; in the case of equal priorities, it is first-in-first-out (FIFO). When the task completes processing the active RTQEL, the top RTQEL in the queue of waiting RTQEL's is made active and is given to the task. If there are no work requests (RTQEL's) waiting for the task, then the task is made dormant and waits in the system for the arrival of new work.

All work requests for independent tasks can be optionally placed under queue management controls by directing each RTQEL into a Real Time Queue (RTQ). Each RTQ is created by a user macro-instruction, which defines the five attributes of the queue:

1. Its unique name identifying the RTQ
2. Its length, which is the maximum number of RTQEL's to be held in the RTQ before an overflow condition occurs
3. The sequence in which RTQEL's are to be removed from the RTQ and given to independent tasks for processing (dispatching priority, FIFO, LIFO)
4. The overflow disposition that identifies the RTQEL to be removed from the RTQ and discarded if the queue overflows (newest, oldest, lowest priority RTQEL)
5. The ability of the RTQ to give RTQEL's to independent tasks (enabled or disabled).

Figure 4 is an example of the logical structure of RTQEL's controlled by an RTQ. The five attributes and other control information pertaining to the RTQ are held in the Real Time Queue Control Block. In the example, the RTQEL's would be given to the independent task in order 1, 2, 3, 4 if they were not controlled by the RTQ. That is the sequence of their relative dispatching priorities. However, the RTQ has a FIFO order attribute; therefore the RTQEL's will be given to the task in the order 3, 1, 2, 4.

If queue management is not used, the RTQEL's for independent tasks in the waiting queues can accumulate indefinitely unless the tasks can process their work requests faster than they are generated. Queue management provides additional controls over the requests in the waiting queues by limiting the maximum number of RTQEL's held for independent tasks. It can also be used to indirectly control the system load by not giving work to an independent task until another independent task has completed processing.

The number and structure of RTQ's is determined entirely by the user. An RTQ can contain work requests for any number of tasks, and any number of RTQ's can contain work requests for the same independent task. The point to be made here is that queue management is very versatile in that it can be used in many ways to regulate the system's work flow.

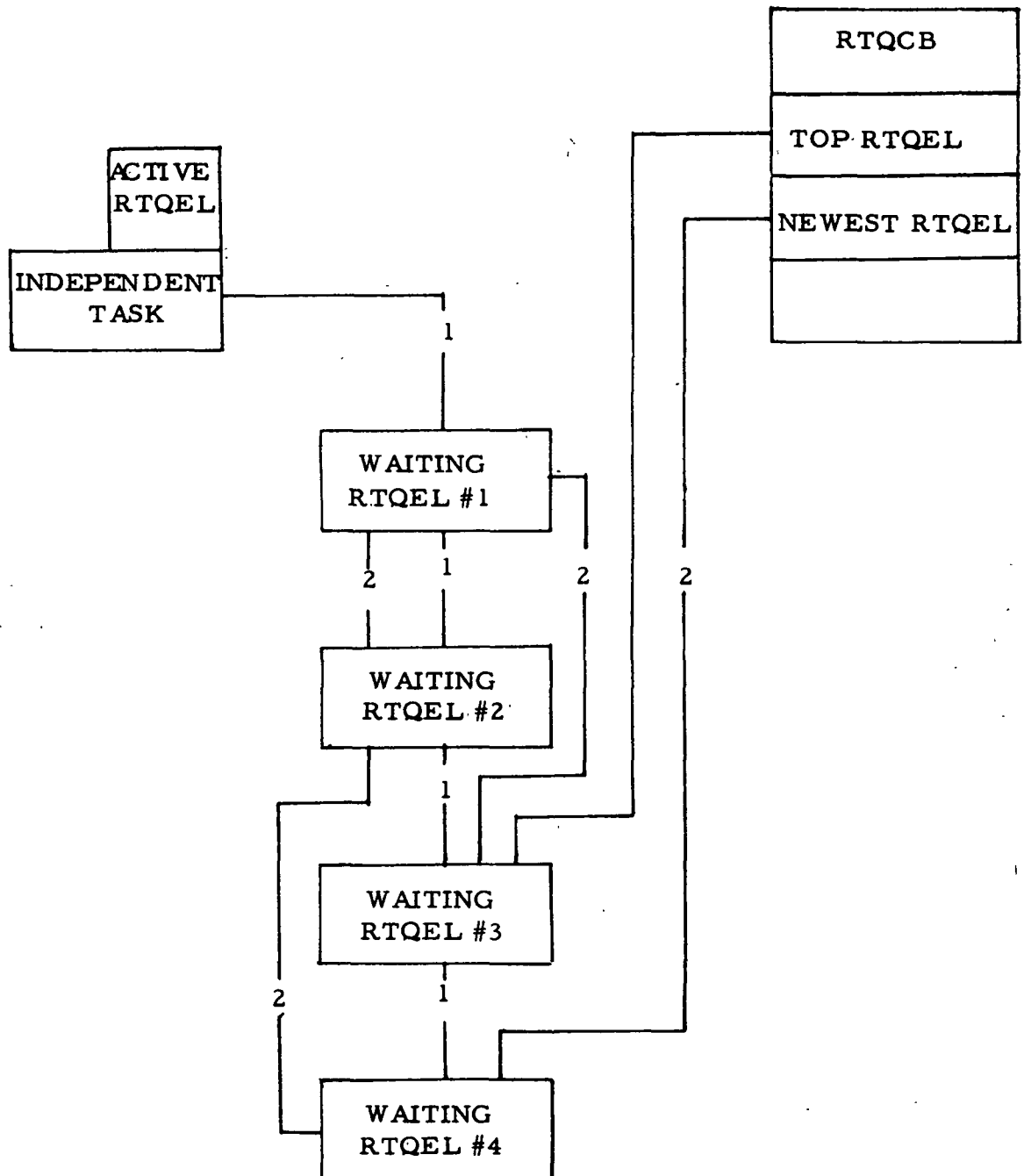


Figure 4. Real Time Queue Element Control

DATA AND TIME ROUTING

While independent tasks were being developed, it was recognized that a mechanism was required that would examine all input data and cause it to be sent to the appropriate independent tasks for processing. This mechanism is called data routing, and it acts as an interface between the hardware interrupt servicing function and the independent task management function in the resident nucleus of RTOS/360. A macro-instruction is used in problem programs to identify to the system the criteria linking a data type to an independent task. When the data routing function receives an input message, it compares the message with the current data definitions. If a match is found, the message is routed to the independent task that will process it. If no match is found, the message is discarded. Data routing can also be instructed to accumulate a number of messages for the same independent task and generate a request for the task only after the number of messages specified by the user have been received. In this case all the accumulated messages will be sent to the independent task as one request.

In real time systems, work requests may be generated according to the passage of time only. For example, an independent task may be created to control a load module that updates the position of a space vehicle every second. The only data necessary to perform this operation is the position of the vehicle at the last second and some orbit and velocity parameters. Since this operation is controlled by an independent task, the necessary data and parameters can be saved in the task's resource table while it is dormant. There will be no input data that will cause requests to be generated for the task processing a request each second, so time routing must be used to generate the required requests.

Time routing, a basic RTOS/360 function, is used to generate work requests for independent tasks on specified time intervals. It functions as an interface between time management and independent task management modules. When a problem program first requests a series of time activations for an independent task, the time routing program sends the request to the time management program specifying the time when the next request is to be generated. Time management performs the necessary operations so that the system will be interrupted by the interval timer, and control will be returned to the time routing function at that time. When time routing is reentered, it calls the independent task management function to create the request for the task. Then the next time of activation is calculated by the time routing function, and that time is once again given to time management.



The data and time routing modules operating under a system task have been constructed so that their function can be combined. It is possible to request the accumulation of messages under data routing with requests generated by time routing on some specified interval. Each request generated will contain all the messages accumulated during the last interval. Also, messages can be accumulated over a timed interval and request generated either when the interval expires or when or when a specified number of messages have been received, whichever event occurs first. If the request is generated at the expiration of an interval, all accumulated messages will be given to the task with the request.



TIME MANAGEMENT

The RTCC System/360 Model 75 computers are equipped with a special high resolution GMT clock and interval timer. To provide support for this special hardware, a time management supervisor was developed for RTOS/360, which functions in parallel with the standard OS/360 time management routines. The time supervisor maintains the system time in a job step pseudo-clock, and it controls the setting and interrupt handling from the GMT hardware to keep time and service interval time-out requests from the routing supervisor and other areas of RTOS/360. Additional functions have been added to the time supervisor that provide optional controls over the job step pseudo-clock.



REAL TIME INPUT/OUTPUT CONTROL SYSTEM

It was necessary to develop facilities in RTOS/360 that would service real time input/output requests rapidly and efficiently, perform special device-dependent data manipulation, and support the special real time input/output (I/O) devices at the RTCC. The real time I/O control system included in RTOS/360 is comprised of five logical parts.

1. A real time access method
2. A real time interrupt servicer and start-stop input routine
3. A digital display device control routine
4. A digital/TV display control routine
5. A graphic display attention control routine

The real time access method is a Supervisor Call program. It performs device-dependent data manipulation and sends output messages to the special real time output devices at the RTCC. Standard sequential System/360 output devices may be substituted for the special RTCC devices through the normal OS/360 use of Data Definition (DD) cards in the user's Job Control Language. This means that either 2400 tapes, 1403, or 1443 printers can be specified simply by altering the UNIT designation on the DD cards, which define real time output data sets.

The real time access method is also used to control the reading of information from the IBM 2250 and 2260 graphic display units. This section of the real time access method functions closely with the graphic display attention control routine, and together these two areas of the real time I/O control system provide RTOS/360 users the ability to read information from the IBM 2250 or 2260 devices. Writing on the display devices is controlled by the real time access method alone. In this case, the displays are handled as normal real time output requests.

The real time interrupt servicer and the start/stop input routine provide software control over the real time input devices at the RTCC. The interrupt servicer passes input data to the data routing function in RTOS/360, which sends the data to the appropriate independent task or tasks for processing. The start/stop input routine starts real time input devices and, under special circumstances (job termination, restart), it is used to halt those devices when they are active.



The digital display control routine has been developed to centralize and simplify the control of the special RTCC devices called digital displays. This control program is entered by user tasks signalling the change of status in one or more of the displays. The current status of the display is updated by the control routine, and then it gives control to the real time access method, which updates the actual hardware display.

The digital/TV display control routine provides software support for the Philco digital/TV display system at the RTCC. This program services all digital/TV display requests, maintains information indicating which displays are currently being viewed and the console viewing them, controls the dynamic allocation of the digital/TV channels, and generates work requests for the user tasks that create and update the actual numbers or figures within each display.

DATA TABLES

During the development of RTOS/360 for the RTCC, it was recognized that an additional facility would be required to handle the large amounts of data accessed by the mission programs. The OS/360 data management methods were too slow to meet RTCC requirements, and they were not able to efficiently support data sharing between independent tasks. Therefore, to resolve these problems and to provide the user's of RTOS/360 an easy method of reading and writing data, a series of control programs were written to support data tables.

Data tables are blocks or arrays of data maintained on direct access devices (2311 disk) in the OS/360 partitioned format. Therefore, data tables can be treated as members of partitioned data sets. However, the main utility of data tables is the additional facilities provided by the data table control programs. The standard OS/360 data management open/close logic has been eliminated thereby increasing the speed at which data can be read or updated. Data can be used commonly by any number of different tasks. The data table programs provide methods of "locking" data tables, which insures data integrity and consistency by delaying any tasks that try to write into a data table until the table is "unlocked". In this way various portions of a table can be read through different requests, and the user is ensured that no update has taken place between requests.

Each data table is identified by its unique EBCDIC name and is defined by its block size and number of blocks. A data table generation program uses these parameters in allocating direct access space for each table, providing the controls required to access it, and storing its initial data in the direct access space provided.

DISPLAY FORMATTING LANGUAGE

There is a large variety of display devices at the RTCC having different internal format requirements. Also, there is a high probability of change in the devices, their internal formats, and the displays shown on them. This changeable character of the display devices increased the need for providing a series of display formatting programs. To meet this need, RTOS/360 programmers designed and developed a versatile display formatting language (DFL), which insulates the applications programmers from the unique characteristics of each display device and the internal format changes resulting from modifications to those devices.

The display formatting process is comprised of two steps. First, the user must define his display by assembling the DFL format macro-instruction. The expansion of this macro-instruction is used to identify the display format to the conversion routines. During execution, the applications programmer can prepare output data for a display by executing the DFL conversion macro-instruction. When the conversion routines complete processing and return control to the calling program, the data is in converted form and ready to be sent to the device specified by a particular DD card in the job control language for the job step. The user can subsequently output the data to the display device via the real time access method portion of real time I/O control system.

The format macro-instruction expands into a "format statement" or character stream when assembled. This character stream provides the display format controls used by the conversion routines in the building of the actual output block for the desired display. The conversion routines build the output block for a particular device. The device is specified by identifying to the conversion routines the DD name of the DD card for the data set. From this information, the conversion routines can identify the particular device that is to receive converted data and therefore will activate the appropriate conversion modules. This means that the DFL package provides complete device independence among those devices supported. (See Figure 5.) Through the simple alteration of DD statements, the user can alter his display devices. This feature can be very valuable when the actual display devices are not readily available. The applications programmers can code and debug their display programs using common or standard devices such as 1403 printers. When the display devices become available, the programs will be ready for actual production work after changing the appropriate DD cards.

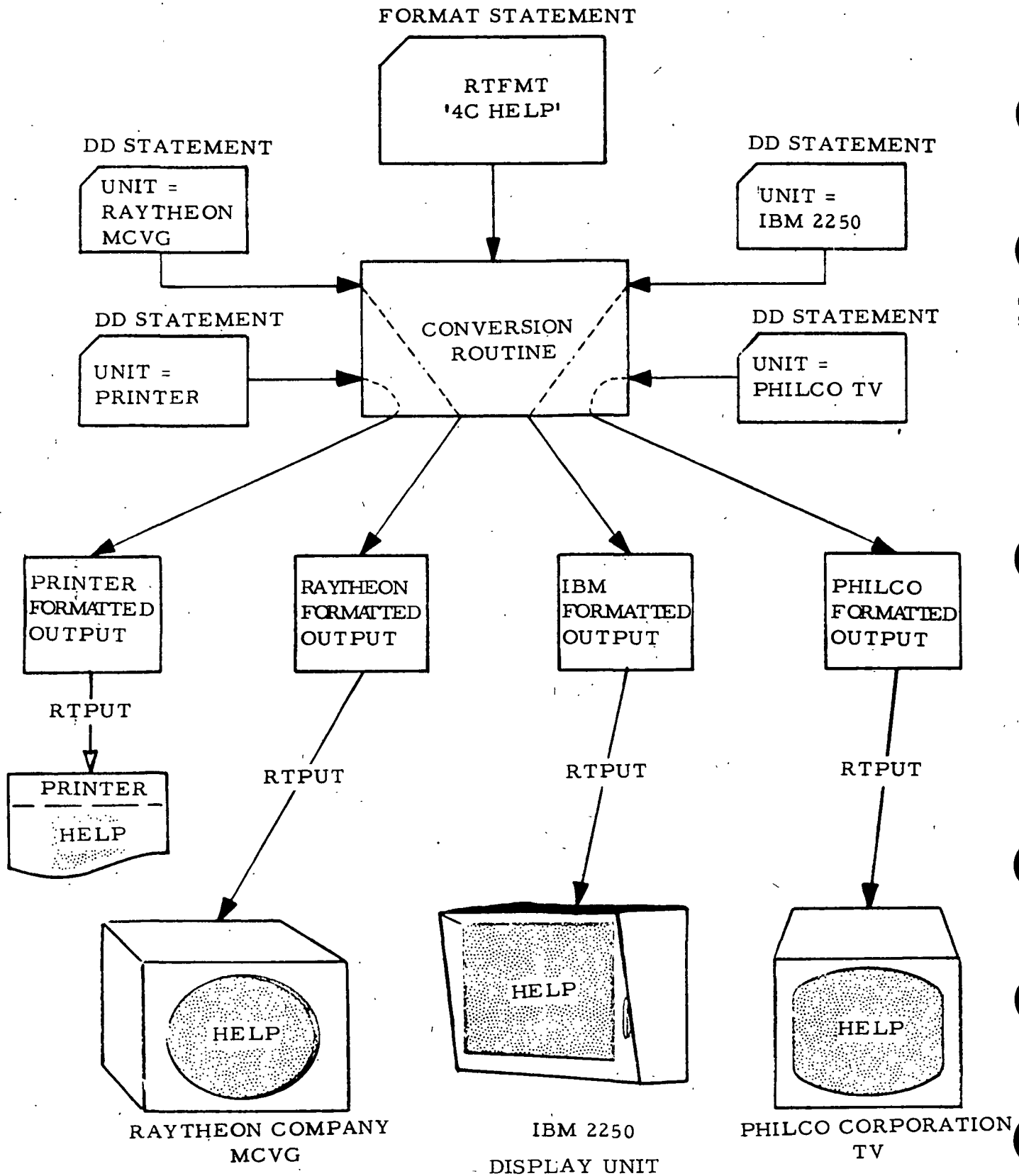


Figure 5. Device Independent Display Language



The devices currently supported by the DFL package are printers: 1403, 1443; cathode ray tubes: IBM 2250, IBM 2260, Raytheon MCVG, Philco RTCC Digital/TV; plotters: RTCC x-y Plotboards, RTCC Scribes; and teletypes. The device independence feature and some of the devices supported by DFL are shown in Figure 5.

REAL TIME LINKAGES

Real time linkages were developed for RTOS/360 to solve two problems encountered in large real time systems. The first problem pertains to the fact that the system library subroutines referenced by the OS/360 load modules must be included within each module when built by the OS/360 linkage editor. This requirement often results in a large duplication of system subroutines present in main core at one time. It is obvious that this duplication can be very wasteful. The amount of main core available is reduced, the amount of main core available is reduced, the amount of time required to load a module is increased, and the amount of space required to hold the module on a direct access device is increased. Real time linkages solve this problem by allowing load modules to reference common resident reentrant library subroutines. It is also true that in large systems it is often convenient to maintain selected items of information (task priorities, constants such as diameter of Earth) at a central source so that these items are available to all active tasks in the system. This problem has also been solved by the real time linkage mechanism.

Real time linkages resolve all of the external references a load module contains for system subroutines or common parameters when the module is loaded into core for execution. The system subroutines and common parameters are loaded into main core during real time initialization and held there for the duration of the job step. Therefore the addresses of these routines and parameters can be inserted into the appropriate external address constant fields contained in a module as it is loaded such that the cost at execution is no greater than if they appeared in the load modules in the normal fashion.

Real time linkages allow parameters such as task priorities to be maintained in a common table. By holding task priorities in a common parameter table, the system can be "tuned" by simply changing those priorities found in that single table rather than performing a reassembly of a large number of programs. Other numerical constants used by a large number of programs can be defined and held as common parameters. This mechanism will ensure the coordinators of the total application system that all programs are using identical constants.

LARGE CORE STORAGE SUPPORT

Each RTCC System/360 Model 75 is equipped with two IBM 2361 Large Core Storage (LCS) units, which provide a total of two megabytes of LCS storage. These units are addressed continuously with main memory, and they have the same characteristics of main memory except for a slower access cycle time. Associated with the LCS units is the IBM 2860 storage channel feature. This feature enables a 2860 Selector Channel to access memory (main and/or LCS) via the Storage Control Unit independently of Central Processing Unit(CPU) accessor. The CPU can start the storage channel, which then proceeds under control of Channel Command Words to transfer the contents of a series of locations in memory to another area in memory. This operation is performed concurrently with CPU operation.

It is not desirable to allow the execution of load modules on the LCS since the LCS units have a relatively slow access cycle time relative to main storage. However, for volume information, which cannot fit in main storage, the access time is much faster on the LCS when compared to external storage devices (direct access). For this reason, the LCS is used as a high-speed dynamically changing residence device for load modules and data tables that are heavily used, but cannot be contained in main storage for the duration of the need for them. A load module or data table will be put on the LCS when it is requested and is not presently on the LCS. As long as the load module or data table is frequently used, it will be retained on the LCS; when it appears that the load module or data table is no longer required on the LCS, it may be replaced with another load module or data table.

It is possible to identify load modules and data tables with such low response requirements that they need never be placed on the LCS; in other words, residence on a direct access device is sufficient. Conversely, some load modules and data tables are very critical; therefore, these may be permanently "locked" on the LCS.

The Large Core Storage Access Method (LCSAM) provides the RTOS control program with a facility of moving blocks of storage from the LCS to main storage or from main storage to LCS. LCSAM will perform the data move either with the normal System/360 instruction set or by performing an I/O operation through the storage channel depending on the size of the block of data.

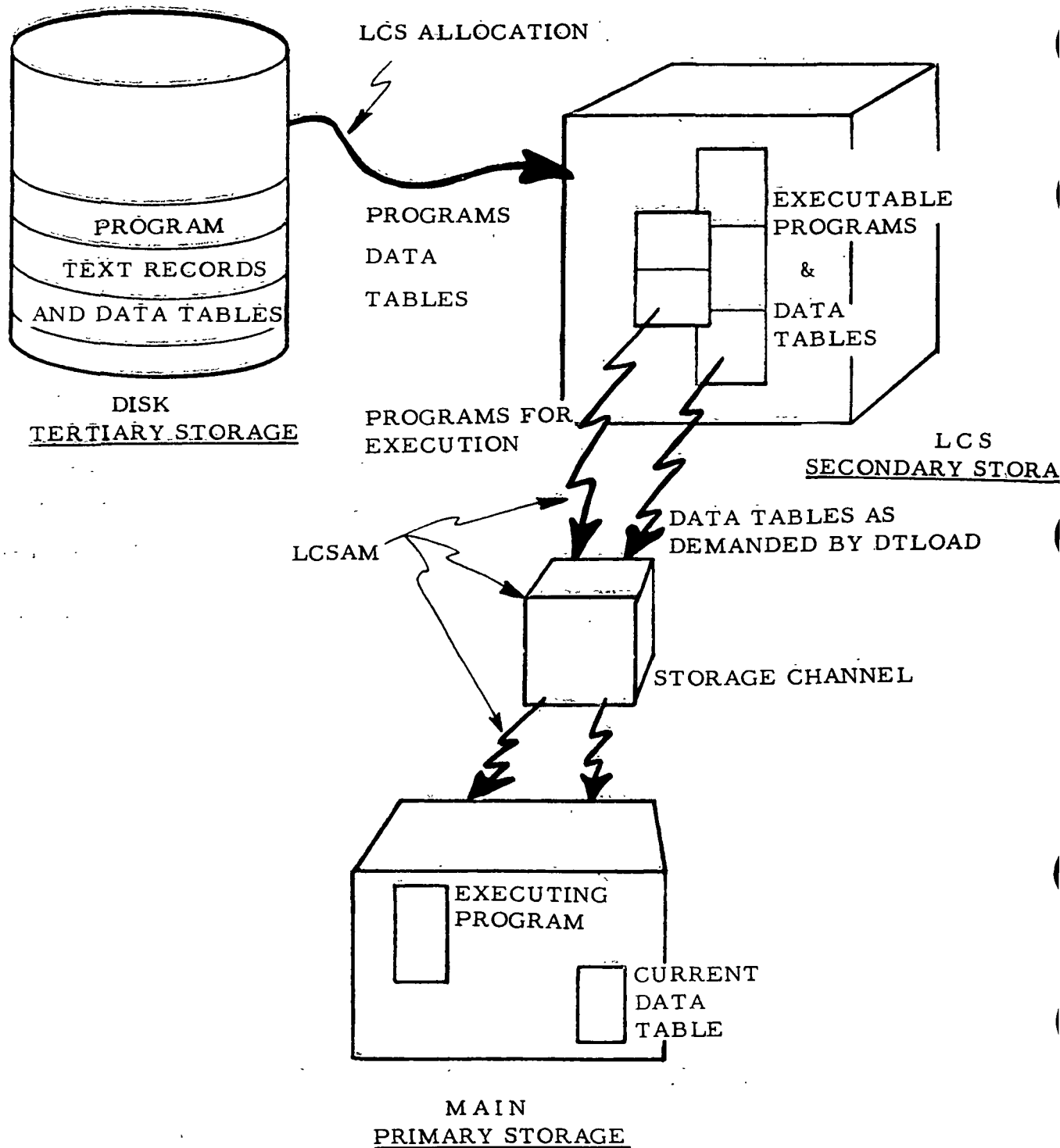


Figure 6. LCS Access Method and LCS Allocation



LOGGING

In most real time applications, it has become important to perform some type of recording activity that saves the data received, transmitted, and processed by the system. This is referred to as logging in RTOS/360. Logging automatically records all real time input and output messages on magnetic tape. Also, a macro-instruction has been provided that will write problem program generated information on the log tape if an applications programmer wants a record of selected data or processing results.



SIMULATED INPUT CONTROL

Simulated Input Control (SIC) provides the ability to send simulated data into the application system. This function has been used at RTCC to check out new programs. Since the SIC programs operate as part of the system for which they are generating data, this function cannot provide an exhaustive test, but it can be used to exercise the user's system in an attempt to eliminate most programming errors.

The SIC programs obtain the simulated input data from cards or tape or both. All data has a time of receipt associated with each message and SIC sends each data message to the data routing function when the time of receipt on the message equals the current job step psuedo-clock time. This in turn generates requests for independent tasks, which will process the data as if it was a real time message. The SIC package is capable of handling simulated data from multiple sequential data sets and sending data from selected data sources in each sequential data set. For convenience, the SIC package has been designed so that magnetic tapes produced by the logging function can be used as SIC input sources without any special editing. The SIC programs will pass over all output messages on the log tape and send only the input messages to the data routing function.



FASTIME

Another special RTOS/360 function that has become very valuable at RTCC is Fastime. Fastime is often used in conjunction with SIC when testing new areas of the user's system. Its only function is to step the job psuedo-clock when there is no system activity. Fastime operates as the lowest priority task in the system so that it is entered when there is no other activity. If the program running under this task determines that there is no further work to be performed before the next routing request, the time management function is signalled to step the psuedo-clock to that time. In this way, many hours of computer time can be saved because the system will not wait for the actual passage of time to generate a time queue if the system becomes inactive. Instead, the time queue will be generated immediately. This function is further enhanced in SIC runs because the SIC programs use time queues in determining the exact moment a message is to be sent to data routing. Therefore in a SIC run, time may be stepped to the time of the next data message. This message will be immediately sent to data routing and then to a task for processing. In this way simulated data messages can be given to tasks as fast as the tasks can process them, thereby reducing the actual computer time to test new programs. Of course, Fastime and simulated input control have no place and are not used when the system is performing its real time production work. These functions are used only in testing new versions of the application system.



FAIL SAFE PROGRAMS

Because of the nature of manned space flights, it is extremely important that RTOS/360 be able to handle abnormal conditions in such a manner that it is virtually impossible for a portion of a flight to go unmonitored because of either a software or hardware failure. Three areas of software support have been developed and included in RTOS/360 to meet this need: selectover, high-speed restart and error recovery.

Selectover is performed by exchanging the Mission Operational Computer (MOC) and the Dynamic Standby Computer (DSC) operational roles without interruption to the input/output data on the real time interfaces and maintaining the integrity of the mission outputs.

The Apollo mission support system, operating under RTOS/360 in a System/360 Model 75 with one megabyte main storage and four megabytes LCS, is restarted in less than 12 seconds on a similar computer system, which may be idle while processing job shop or performing real time test operations. This is accomplished through IBM Channel-to-Channel Adapters (CCA), which link each combination of two out of five machines. An Initial Program Load (IPL) sequence is generated from a remote console to the proper CCA on the operational computer system, simultaneously enabling the CCA path between the two systems, which is otherwise disabled for system security. A special IPL hardware modification enables a restart even if the machine to be restarted is in manual state. All of allocated storage is then transferred over the CCA from the operational system to the selected standby system before resuming in the restarted system. A similar restart can be performed from magnetic tape by creating the tape on an operational computer and carrying it to the standby computer for IPL.

The error recovery package allows the system to recover from errors due to program checks, hardware malfunctions, or abnormal conditions arising within the system itself. As recovery occurs, appropriate messages and recommendations are printed indicating the current status of the system.

A part of the error recovery activity includes device pooling, such that if one I/O device fails, RTOS will automatically (or by external signal) select another device of that type. When the control program detects an error condition or an end-of-tape, or when a user requests a device switch, Alternate Device Support (ADS) is invoked to locate an alternate to replace the primary device. Control programs contain built-in logic allowing recovery from a situation where

an alternate is unavailable. The computer operator is informed on the console typewriter of all device switching operations. Currently, device switching is provided for the 1052 typewriter, tapes, printers, and 2311 discs.

Certain I/O device failures are such that an interrupt to the CPU is never generated to signal the completion of the I/O operation or an error condition. A software time-out facility exists in RTOS/360 that will check once per second to determine if an I/O operation has not completed in a period of time normal for the particular device. When such an occurrence is detected, the I/O operation will be purged and appropriate messages printed. Normal use of the device will be attempted on subsequent requests.

BACKGROUND UTILITIES

Numerous "peripheral" type operations have been implemented in RTOS/360 as background operations, which can be initiated and terminated by the operator at the console typewriter. These background utilities execute asynchronously with the normal job processing. They have been designed such that interference with normal processing is minimal.

The utility operations supported are:

1. Dump a direct access volume to tape
2. Restore a direct access volume from tape
3. Clear a direct access volume
4. Change a direct access volume serial
5. Store mission updates on collection pack
6. Copy a tape
7. Copy and compare a tape
8. Compare two tapes
9. Print a system output tape
10. Print a standalone (RDUMP) dump tape
11. Print a tape in hexadecimal format
12. Label a tape
13. Execute immediate tape commands (rewind, forward space files, etc.)
14. Print (on console) the current status of on-line direct access volume.



HOUSTON AUTOMATIC SPOOLING PRIORITY SYSTEM

The Houston Automatic Spooling Priority (HASP) System is a specialized program co-habiting a single CPU with RTOS/360. It performs the peripheral functions normally associated with off-line support computers by using small amounts of primary CPU time to operate unit record devices while operating in direct communication with the operating system.

These peripheral functions include transferring the job stream to direct access to await execution, collecting job output on direct access, and printing and punching job output from direct access following job execution. Jobs awaiting any stage of processing (print, punch, or execution) are queued on a priority basis so that the effect of a true priority scheduler is gained not only for normal job execution, but for associated peripheral functions as well.

A complete "warm start" capability exists in HASP such that untimely interruptions of the system will cause no loss of queued data. Sophisticated operator communications exist that provide control over the number of input job streams, the number of output devices, and the order of job executions.

STATISTICS GATHERING SYSTEM

The Statistics Gathering System (SGS) provides timing information and execution frequency statistics useful to any programmer who is aiding in the development of a real time system. Any programmer whose load module, subsystem, or system can execute with RTOS/360 may use SGS.

An SGS request card or a Manual Entry Device (MED) may be used to select the desired statistics. This request supplies start and stop times, a keyword option, which selects the statistics to be taken, and a user identification symbol. At the end of each sample interval, the output is recorded for the system with the statistics appearing in an easy to read report form. Each SGS report includes a heading with the user identification, and the start and stop times for the interval over which the sample was taken.

SGS provides several categories of statistics.

1. CPU Performance — This category will show the amount of CPU utilization, the time spent waiting on I/O computer idle time, and the time taken by SGS to collect statistics. CPU performance indicates the computer capacity required for a system or subsystem. Conversely, it is an indication of the capacity available for system growth.
2. Load Module Performance — This category will show the execution frequency, the average execution time, the percent of CPU utilization, and RTOS service requests for each load module. Load Module performance shows any programmer the performance of his load module and its dependent on RTOS Control Program Services.
3. Task Performance — This category will show the independent task executions per interval and per second, plus the percent of CPU utilized by the load modules and RTOS services required by each independent task. These statistics also provide a response time figure which is the elapse time required to execute an independent task. This figure shows whether or not a system is meeting the requirements of real time.



4. RTOS Control Program Services — This category will show the executions per interval for each RTOS service, the average execution time for the service and the percent of CPU utilized by each service. RTOS statistics are most useful to systems programmers.
5. I/O Frequency — This category will provide the frequency-of-use for all I/O devices, and communications lines. I/O frequency is useful to systems programmers.

JOB ACCOUNTING SYSTEM

The Job Accounting System (JAS) consists of a set of programs and modifications that have been added to RTOS/360. JAS automatically generates, through punched cards, a data base for the following three types of reports that are valuable for both accounting and system measurement purposes.

1. Job Shop Analysis Report provides job mix and computer system performance statistics.
2. Computer Utilization Report is used to charge computer time to users.
3. Management Report provides information on program development costs through statistics on the use of the computer by individual programmers.

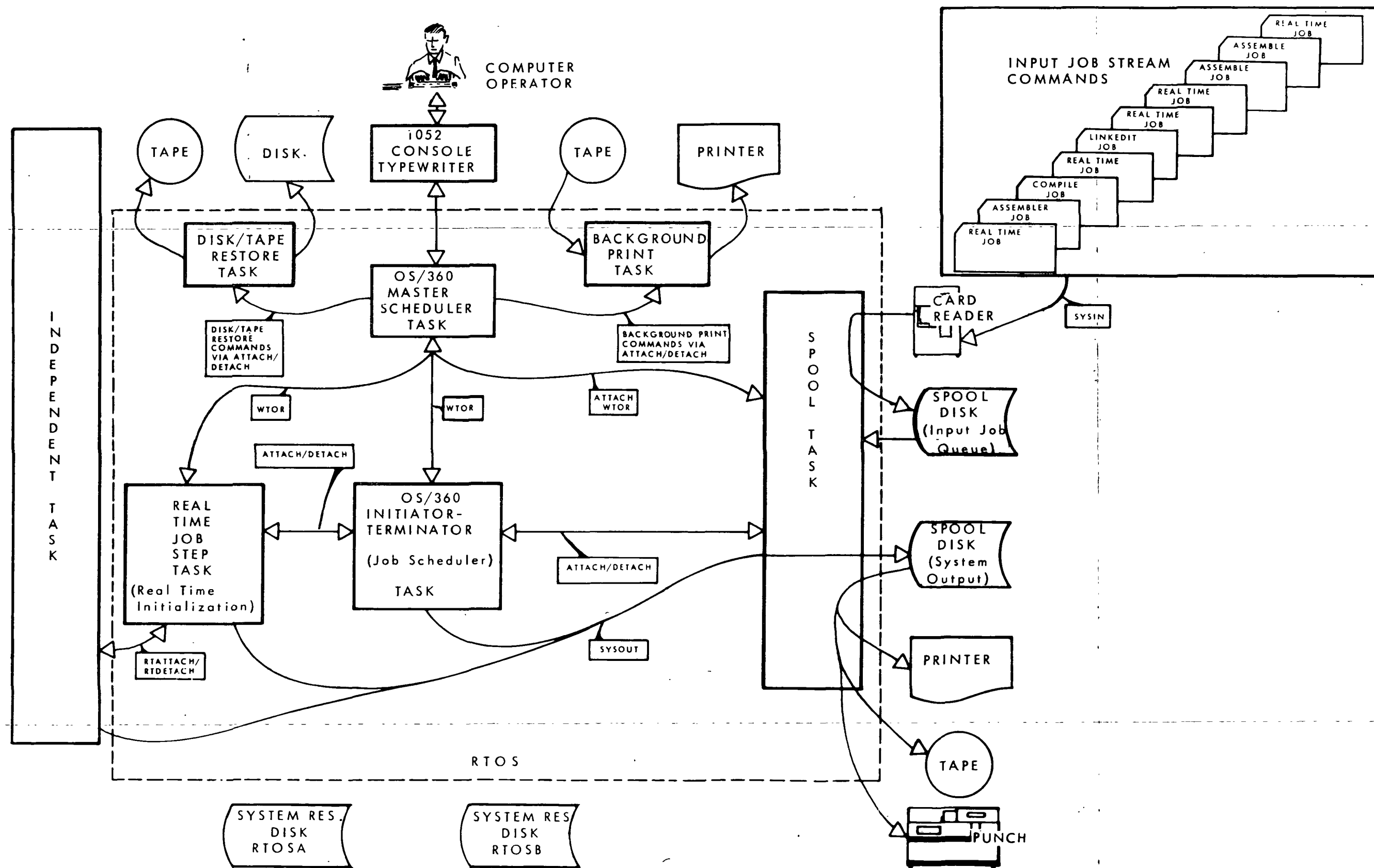


Figure 7. Functional Flowchart of the RTOS Flowchart

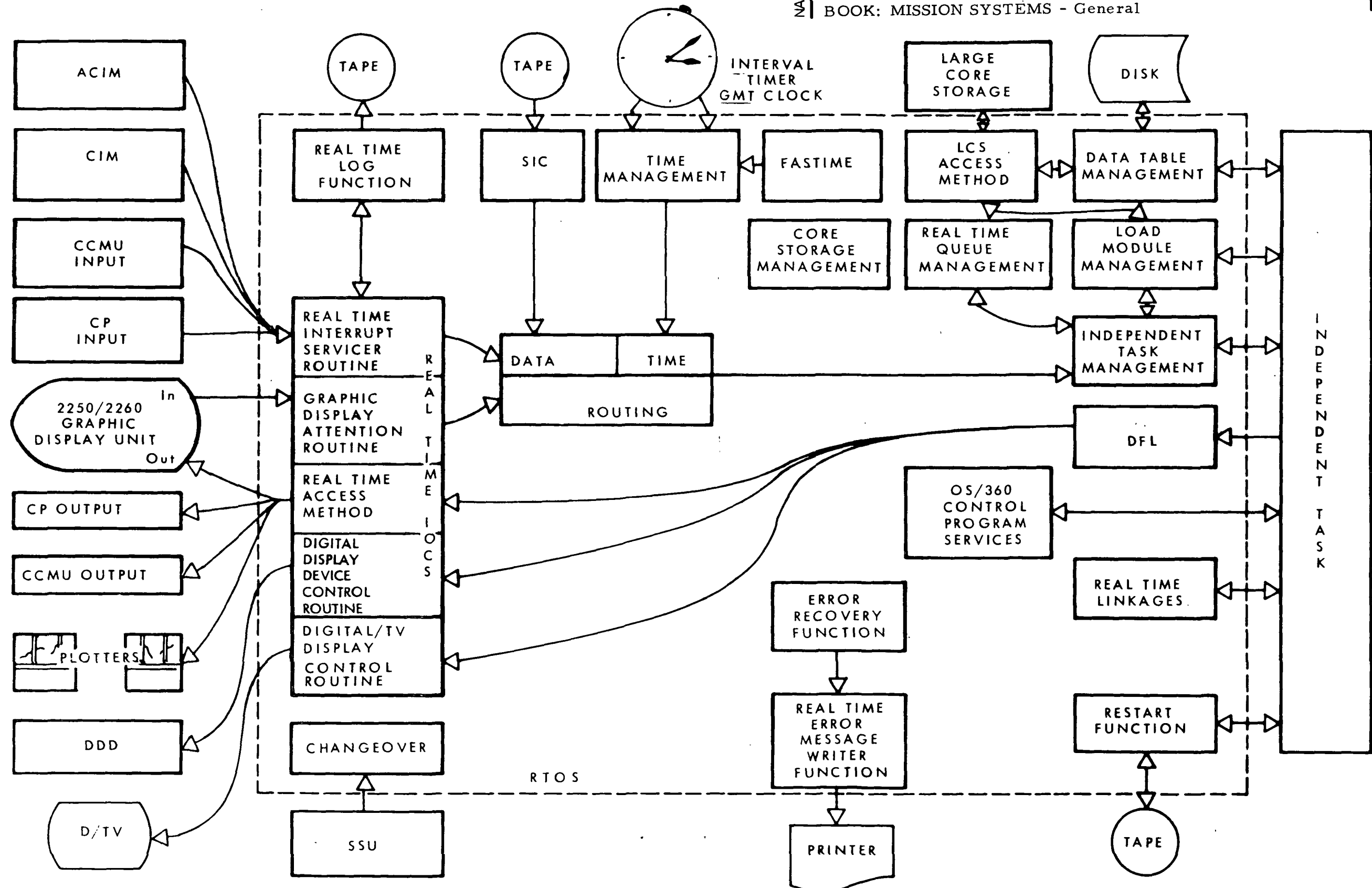


Figure 7. Functional Flowchart of the RTOS (Cont'd)
Flowchart

FUNCTIONAL SPECIFICATIONS FOR MISSION SYSTEMS

LUNAR LANDING PROGRAM

General Program Description

FUNCTIONAL SPECIFICATIONS FOR MISSION SYSTEMS
LUNAR LANDING PROGRAM

LLP SYSTEM OPERATION

The ability of the Lunar Landing Program to successfully control and monitor a lunar landing mission rests upon its ability to process and display large amounts of data in a short time. The mission is monitored by receiving and processing data from the Manned Spaceflight Network and the Mission Control Center at Houston. Processed data is displayed in the form of digital values, analog plots, illumination of significant event indicators, and printouts. Processing is initiated within the system automatically and manually.

Most of the automatic processing is cyclic, based on a given time interval. During Launch, for example, data is collected, manipulated, and displayed in one-second cycles. Automatic processing that is not cyclic will ordinarily be initiated upon receipt of data. Telemetry data holds a high priority in the system and is programmed for this type of processing. As soon as telemetry data is received, it is verified, processed, and displayed. On the other hand, low-speed radar data is collected and batched automatically, but may not be processed and displayed until a later time, depending upon controller inputs.

Manually initiated processing is used to produce a set of numbers given a set of input conditions. An example of manually initiated processing is the trajectory determination calculation, which uses a differential correction algorithm in processing previously gathered and batched radar data. From this calculation, a state vector is obtained, which may be used as a basis for trajectory updates.

For many of the processing functions, both the automatic and manual types of processing are required. An example of this is the trajectory update processing which includes a table of predicted position and velocity vectors, station contacts parameters, and a table of maneuver definitions. Although the trajectory update is generated on manual request, the ephemeris is sampled on a cyclic basis for display updates, acquisition data, and other trajectory parameters.

The Lunar Landing Program is a highly developed program that must be responsive to a wide variety of external or internal controls. External controls are initiated by a controller to provide an interrupt to the CPU. Such controls must be interfaced with the system to be effective and include the manual entry devices (MED's), push-button indicator switch modules (PBI's), logic control switches, and display request switches.

Approval	Approval
<i>J. D. Carlaw</i>	<i>J. H. Harris</i>



Internal controls are inherent in the program structure. Processing organization and control is provided by an independent task structure, and a routing facility provides for a processing unit to be queued when a specific event occurs. Processing requests in the form of queues may be generated within the application program or as a function of routing. The priority queuing system provides for putting processing requests in order, and dispatching priority permits processing units to be initiated in the order of their significance. This combination of features provides resource control at the request level and again at the processing level.

Accurate and consistent time data is essential to the operation of the mission program. The central mission system timing structure is the Master Instrumentation Timing Equipment (MITE), and a pseudo-clock maintains time to the nearest second in response to a signal from the MITE. Current time is synthesized from the output of the pseudo-clock and a stream of ten-millisecond units obtained from the MITE readout. Cyclic processing initiated on interrupts from the interval timer which is incremented in ten-millisecond units and is driven from the MITE.

A number of safeguards are built into the Mission System to minimize the possibility of loss of support during a mission. Two computers are used to support the mission, the Mission Operational Computer (MOC) and Dynamic Standby Computer (DSC). Both computers receive identical input and perform identical processing. However, only the MOC interfaces with the flight controller display equipment. A selectover capability exchanges the functions of the two computers so that the output from the former DSC is designated MOC and interfaces with the display equipment.

A restart facility exists whereby a standby computer may be initialized to the current status of the MOC by transferring the contents of main memory and large core storage (LCS) to the standby computer over a direct channel-to-channel interface. The restart can also be accomplished by recording the memory and LCS contents on a magnetic tape and reading the tape into the standby computer. Certain key resources, such as printers, disks, and tapes, are backed by alternate devices so that if the primary device fails, it will automatically be replaced by the alternate. Should system abnormalities occur, error recovery logic is incorporated into the program to identify an erroneous condition and permit other processing to continue.

The initial residence of the Mission System is on disk storage. A program to be executed in the CPU is initially retrieved from disk and routed through LCS. Programs with critical response times or high usage rates are retained in LCS for rapid access.

IBM RTCC APOLLO PROGRAMMING SYSTEMS

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BOOK: MISSION SYSTEMS - General

Data tables initially reside on the disk and are brought into LCS as they are referenced. These data tables compete with programs for LCS resources. In addition, data tables may be modified dynamically in LCS, and once modified, they reside permanently in LCS.

Two protection features are used to ensure data table reliability. Fetch-protection monitors all access to stored data tables, while store-protection monitors all attempts to modify stored data tables.

MISSION/RTOS SYSTEMS INTERFACE

The LLP comprises two programming systems, the Mission System and the Real Time Operating System (RTOS). The Mission System consists of those programs that are required to collect and process the radar and telemetry data received from the tracking network, respond to the manual inputs initiated by the flight controllers, and format the results of the processed data for presentation to the flight controller on various types of display devices.

The RTOS functions as the controlling monitor by providing the facilities necessary to schedule the execution of the Mission System programs; controlling and sequencing all input/output activity which takes place over the external interfaces, and providing the recovery facilities to ensure system integrity in the event an error is experienced at some point in the hardware or software. Described below are the major functions the RTOS provides:

- The task is the basic element that provides an interface between the RTOS and Mission System, and permits the RTOS to maintain control of the computer facilities. A task is not a program in itself but is defined as a unit of work. One or more programs may be required to execute under one task to provide the processing needed to accomplish a specific unit of work. The tasks are defined and created by the Mission System programs, but the RTOS is responsible for maintaining the necessary control tables that define the status of a task. A task is said to be active if it has outstanding work to perform or dormant if it does not. It is very probable that multiple tasks will be active at the same time. By examining the priority assigned to each task, the RTOS will determine which task should execute. The task priority assignments are made by the Mission System programs. These task control functions are provided by the task management facilities.
- A task can have more than one outstanding work request, but only one work request can be serviced at a time. The queue management facility must ensure that the work request with highest priority is serviced first. Another function of this facility is that of "gating" work requests to one or more tasks. This allows the Mission System programs to control the order and dispatching of work requests, and to define which to disregard if the maximum number of allowable requests should be exceeded.
- The LLP must interface with several different types of external devices which require different servicing methods and different types of data formats. The real time input/output control facilities of the RTOS service the real time I/O requests, perform special device-dependent

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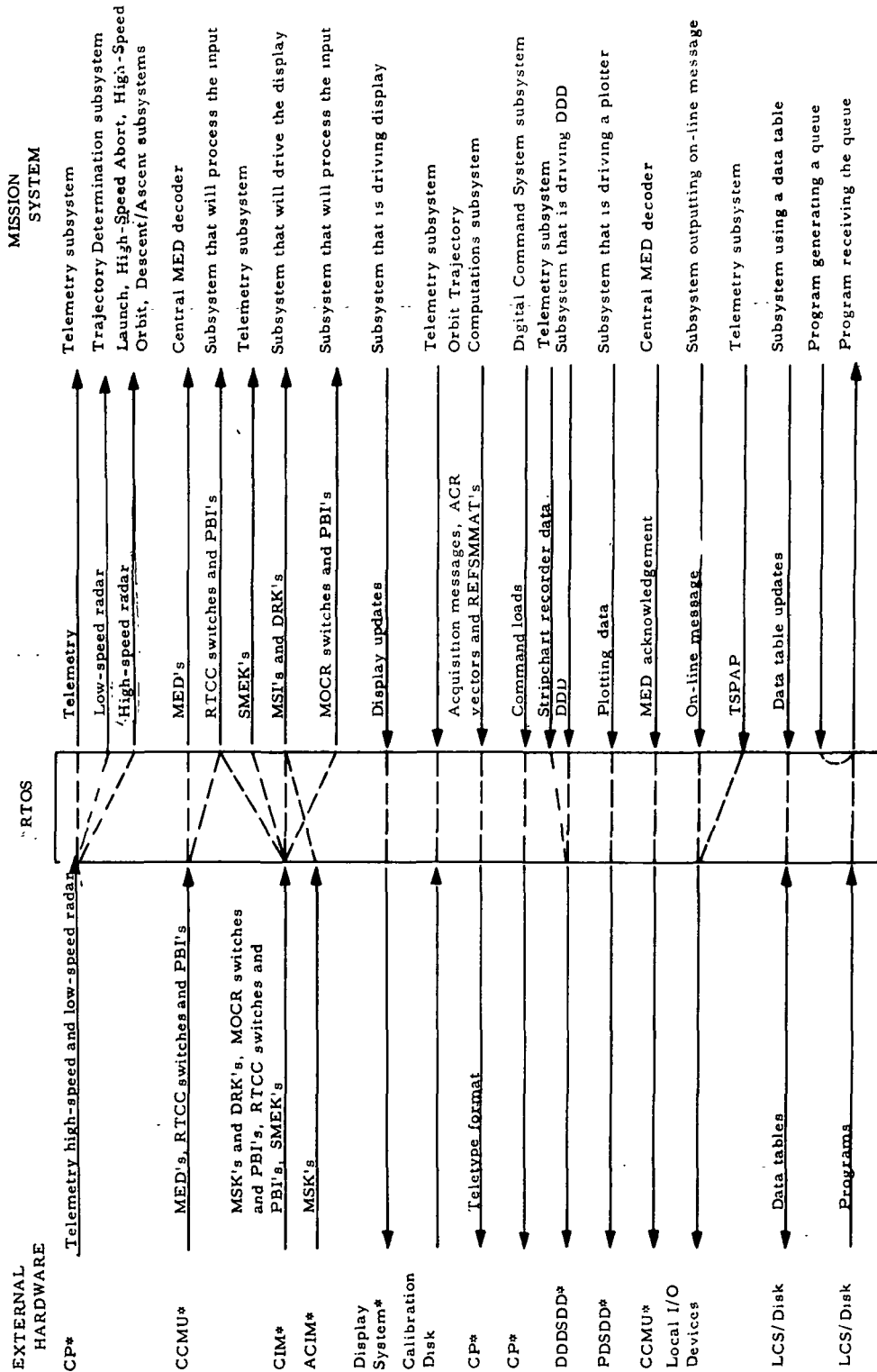
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data manipulations, and provide for special device interfaces. The four major parts of this facility are the real time access method, the real time interrupt services and start-stop input routine, the digital display device control routine, and the Digital/TV display control routine.

- The LLP must be able to present information on a large variety of display devices for monitoring and control. These devices have different internal format requirements which are subject to change. To isolate the Mission System programs from these unique device characteristics, the RTOS provides the Display Formatting Language (DFL) facility. With this facility, the Mission Systems program provides output data in a format that defines the desired result. The DFL is called to convert the data into a format that can be used by the unique device and return control to the calling program, which will initiate the output of the data to the device.
- Computations performed by many of the Mission System programs require references to constants, such as the diameter of the Earth or the thrust characteristics of a spacecraft engine. The nature of these constants is such that some may be required by several different programs, or they may be changed at any time. Allowing different programs to contain the same constant would create many problems, such as ensuring that each program is using the same value when the constant is changed. This problem is solved by the use of system parameters which are retained in main core storage and made available to any program during real time execution. The real time linkage facility of the RTOS will provide a program with the core address of any parameter which it uses. This is done when the program is loaded from disk to core for execution. The facility also provides the necessary linkages that will permit any program to use a system subroutine to perform some mathematical computation. These system subroutines consist mostly of common mathematical routines used by many of the programs. As with system parameters, these subroutines are maintained in main memory for use by any Mission System program at any time.
- A new function in the RTOS is the system recovery facility (SRF) which is designed to provide a high probability of recovery from certain types of system errors such as transient machine checks, inboard I/O errors, and latent and random control program logic failures. Depending on the type of error or failure encountered the SRF attempts to correct, report, and prevent recurrence of the problem.

- Another import function the RTOS performs is that of logging all data on magnetic tape that is either received from or sent to an external source. A method is also provided whereby a Mission System program can instruct the RTOS to log other selected data or processing results. Using nonreal time delog programs, the recorded data can be reduced, formatted, and printed for post-flight analysis.
- Previously mentioned under the Mission Systems Operation section are several other functions which are performed by the RTOS: Restart, Alternate Device Support, high-speed memory and LCS space allocation management, system time management, and computer selectover.
- The general relationships between the RTOS and the Mission System are presented in Figure 1.



*All data to or from the CP, CIM, CCMU, DDSDDD, DISPLAY SYSTEM, PDSDD, and ACIM are logged on the log tape by RTOS.

Figure 1. Mission/RTOS Interface Flowchart

(Sheet 1 of 1)



MISSION SYSTEM STRUCTURE

The LLP Mission System is divided into twelve subsystems, each having a overall task to perform. For example, the Telemetry subsystem provides the total processing capability to monitor the on-board systems of all the vehicles during phases in which they are active. To a large degree, the subsystems operate independently of each other; however, there is substantial communication between them through direct queues and data tables.

Each subsystem has several functional units, and several programs may be required to provide the output of a functional unit. The subsystems that make up the Mission System are outlined below. A detailed description of subsystems design and the programs that make up the subsystems will be found in Sections 2.2.2 through 2.2.12.

MISSION CONTROL SUBSYSTEM

This subsystem provides system initialization, explicit LCS allocation, computer phase switching, restart control, real time delog control, general mission MED and display control, MED and switch input simulation, and real time station characteristics logging.

1. System initialization consists of setting up routing for system inputs, such as data, MED's, switches, TV requests, etc. It initializes data tables; and queues the Telemetry subsystem for its initialization.
2. Computer phase change involves changes in routing definitions, generating queues to other subsystems, and setting internal phase related indicators. On-line printing also is generated to indicate phase change.
3. Manual entry device control consists of receiving and decoding all MED inputs and providing logic and interface control with the other subsystems.
4. Display logic control consists of controlling the generation of phase dependent displays driven by the various subsystems. The TVGUIDE is generated and maintained, and the D/TV status indicators are driven, indicating that only four or fewer display channels are available.
5. Restart control consists of controlling channel-to-channel restarts, writing restart tapes, and initializing and resuming the system after loading IPLable restart tapes.

Miscellaneous other functions involve simulating switch inputs by MED inputs, providing nonreal time delog ability, and writing station characteristics data on log tapes at initialization and log tape switch.

LAUNCH/HIGH-SPEED ABORT/HIGH-SPEED ORBIT SUBSYSTEM

This subsystem processes high-speed trajectory related data. It provides the total processing to monitor the trajectory of a specified vehicle through the Launch phase until Orbit insertion or Abort occurs.

1. The high-speed input processors receive a one-half second cycle queue and process the accumulated data messages from each of the input sources appropriate to any high-speed phase. As the input sources are processed, various parameters are computed and displayed for flight control evaluation. The subsystem will receive and react to various manual inputs, and as specific events occur, DDD's corresponding to those events are driven.
2. During powered flight, Mode II impact points are computed using the launch powered flight integrator.
3. After S-IVB cutoff and Hold phase has been entered, GO/NO-GO calculations are performed on all available data sources except IPS, which is not processed after the cutoff event. For each of the available sources during free flight, contingency insertion maneuvers are computed. Mode III SPS Abort maneuvers are calculated during Hold phase. The calculations for the two target areas (short and long) are controlled by the position of the RFO Range Target PBI.
4. During powered and free flight, the Launch digitals and Launch analogs are updated at a one-half second cycle. At phase transfer, the Launch interface table is established, and the Launch output task queues the next phase. During the Launch phase it is possible, by manual input, to initiate a special logging routine that may be used for post-flight analysis of the data.
5. During High-Speed Abort, parameters which define the best predicted estimate of the impact point are computed and displayed on a six-second time queue.
6. Several other tasks are performed during Launch and High-Speed Orbit. These consist of driving X-Y plotboards, scribes, and spotters, and of formatting and printing high-speed on-line messages.

7. High-Speed Orbit processing is initiated via MED input. Processing is initiated for input data sources similar to that done during Launch phase. Telemetry source selection is accomplished via switch input, while radar site selection is performed via MED input. Powered flight processing continues until the receipt of THRUST to NO EVENT, which queues a vector averaging routine for telemetry vectors and short arc computations for radar data (except tracking ship radar data which is averaged). During the high-speed phase, digital, analog, plotboard, and projection equipment displays are updated on a one-second cycle. Upon the receipt of an MED input, the telemetry and radar cutoff vectors are transferred to the usable vectors and transferred to the usable vector table for later comparison. At termination of High-Speed Orbit processing, Low-Speed Orbit processing is re-initiated.

LUNAR ASCENT/DESCENT SUBSYSTEM

This subsystem is used during the Ascent and Descent phases. It processes powered flight data, calculates Hold phase parameters, generates digital and analog displays, and drives projection and X-Y plotboard equipment during a lunar mission.

1. During Descent/Ascent, input processing is performed on all high-speed trajectory input data sources (PNGCS, AGS, RR, and USB). The input task operates on a one-second time queue for USB data. As USB data is received, the telemetry data tables are read to obtain the last available good telemetry vector, which is used for comparison with the doppler residuals computed for each of the selected MSFN radar sites. Manual entries are processed under the input task.
2. Generation of nominals and D/TV displays are performed under the Descent/Ascent nominal, D/TV, and phase interface task. The digital and analog displays are updated on a two-second cycle. Interface tables and phase control logic are controlled by this task.
3. During the Ascent Hold phase, GO/NO-GO calculations are performed based on the latest averaged telemetry vector (provided by the input task) at cutoff plus x seconds. Free flight processing is then initiated. If an additional maneuver is required, the Hold phase calculations are repeated upon the receipt of THRUST to NO EVENT, and the latest telemetry vectors are averaged. These vectors may be used in the transfer to Lunar Orbit phase.
4. The on-line processor formats and outputs the high-speed events, Φ , λ , and R values, GO/NO-GO parameters, and maneuver information for on-line printing during the Ascent/Descent phase.

ORBIT TRAJECTORY COMPUTATIONS SUBSYSTEM

This subsystem provides the logic needed to build and maintain an ephemeris representing the predicted trajectories for the desired vehicles, compute contact information from that ephemeris, provide certain Orbit phase evaluation displays, and compute and maintain guidance optics and sighting displays and matrices.

1. Ephemeris generation and control includes queue control and anchor vector maintenance, time queue control, trajectory update and numerical integration control, teletype information (to exclude acquisition data), and some on-line prints.
2. Station contacts logic is used to generate contact information for experimental and tracking sites. The computed information is formatted, displayed, and transmitted via teletype to the MSFN stations.
3. Guidance optics and sighting involve RTCC calculations of inertial measurement unit platforms and maintenance of tables of platform alignments. In addition, flight controllers are provided with displays of star sightings and alignments.
4. Evaluation displays logic includes display control, MED decoding, and display of appropriate evaluation parameters.

TRAJECTORY DETERMINATION SUBSYSTEM

The primary function of the Trajectory Determination subsystem is to process the incoming low-speed radar data and produce a vector that represents the best estimate of the spacecraft position and velocity. It also maintains a table of radar and telemetry vectors which are evaluated by comparisons and/or used to update the spacecraft ephemeris.

1. Collection and mathematical processing of low-speed radar data — By collecting incoming low-speed data and applying various corrections (speed of light delays, station granularity constant, azimuth, local, vertical, refraction adjustments), orbit parameters are determined and updated through differential correction techniques. Appropriate residuals (differences between observed and computed values of range, azimuth, elevation, and doppler) and the root mean square and average of these residuals are computed for each station in the post-DC chain. These computations permit evaluations to be made for the data from each station as well as for agreement of past data.

2. Vector control and evaluation — Vector control stores the available telemetry vectors, the differential correction anchor vector, and the high-speed radar vector in the usable and evaluation vector tables. A fetching service is provided to other subsystems which accepts requests for vectors, rotates them to the correct coordinate system, and returns them to the user. Vector evaluation permits comparisons between these vectors and the ephemeris vectors by integrating them to a specified GMT, and computing the local spherical and Keplerian elements and the UVW system components in either the lunar or Earth reference systems. The differences in the elements of the base vector and elements for the subsequent vectors specified are displayed.
3. Rendezvous radar and optics — The location of the landing site is determined by using optical sightings of landmarks near the landing site during Lunar Orbit. During Lunar Stay phase, CSM optics observations of the LM on the moon are used to solve for the LM position. The LM uses its radar to track the CSM, giving the range, range rate, shaft, trunnion, and gimbal angles of the CSM with respect to the LM. The position of the LM on the lunar surface is also computed from these quantities.
4. Platform alignment — Through the processing of rendezvous radar shaft and trunnion angle measurements and a gravity vector, the attitude of the LM platform with respect to the LM body coordinates, and the LM attitude with respect to a local vertical/horizontal coordinate system on the moon can be determined. The LM attitude is essential in computing the ascent trajectory of the LM.

MISSION PLANNING SUBSYSTEM

There are four functional units within this subsystem which are responsible for: (1) maneuver prediction, where proposed maneuvers may be displayed for evaluation; (2) maneuver confirmation, where the maneuver is updated to reflect the actual maneuver performed by the vehicle; (3) maneuver integration, where a proposed maneuver is placed in the predicted ephemeris by taking an initial vector and propagating it through the on-board steering equations; and (4) maneuver control, where checks are made to permit the maneuver to be placed in the predicted ephemeris, replaced in the ephemeris, or deleted from the ephemeris.

1. Maneuver control is responsible for maneuver definition, maintenance of maneuver data as stored in the predicted ephemeris, display of pertinent elements of that data, and vector routing for trajectory updates. Maneuver definition encompasses the transformation of impulsive ma-



maneuvers from study to finite maneuvers, the acceptance of maneuvers directly into the ephemeris (i.e., not as the result of a transfer from a study and confirmation of executed maneuvers). Maneuver integration is accomplished by taking an initial vector and propagating it through the on-board guidance equations for the vehicle until the desired end conditions have been reached. There are two maneuver integrators available for this purpose: the Command and Service Module/Lunar Module maneuver integrator and the S-IVB Iterative Guidance Mode integrator for the TLI (translunar injection) maneuver. Maneuver maintenance logic includes freeze/unfreeze logic where the initial vector for a maneuver and all the steering commands based upon and applied to the current ephemeris vector may be frozen, deletion logic whereby maneuvers may be removed from the ephemeris, and logic to incorporate changes to the vehicle weight and area in the current ephemeris. Post-maneuver computations and displays are also handled through maneuver control.

2. Rendezvous planning provides the logic to generate and display in study aids impulsive special purpose maneuvers, impulsive rendezvous plans, and lunar launch window computations.

The impulsive special purpose maneuver processors provide four types of maneuver planning. The general purpose maneuver processors compute a variety of maneuvers to adjust the height of apogee and/or perigee, to perform an inclination or plane change, to shift the line of nodes or the line of apsides, and to compute general maneuver results based on inputs from a flight controller. The perigee adjust maneuver processors compute up to six maneuvers designed to raise the orbital perigee to a specified point to compensate for improperly executed maneuvers or a non-nominal launch. The two-impulse maneuver processors compute two maneuvers designed to achieve a certain relationship between two vehicles; the first is performed to intercept a point in space defined in terms of the target vehicle, and the second is performed at that intercept point to place the chaser vehicle in an orbit co-elliptic with the target and satisfying the desired relationship. The lunar orbit insertion processors compute a maneuver designed to place the vehicle in a designated orbit around the moon.

DKI (docking initiate) rendezvous and SPQ (co-elliptic sequence) rendezvous plans combine to make up the impulsive rendezvous plans which are available in either an Earth or a lunar sphere of influence. DKI is a series of four computed maneuvers that culminate in certain previously defined end conditions (height difference and phase angle). The DKI

enables the chaser vehicle to decrease or increase its catch-up rate. When this plan is placed into the ephemeris, two additional maneuvers (TPI and TPF) are automatically computed and added to the plan to achieve final rendezvous conditions. In the SPQ rendezvous plans, a series of three maneuvers are computed to culminate in certain end conditions. In addition, TPI and TPF are computed automatically based on these end conditions which result in final rendezvous.

Rendezvous planning also provides the logic to compute the desired lunar launch time and other launch parameters required to place the LM in the proper orbit after launch. In addition, an ascent rendezvous monitor is provided which, on a time cycle during lunar launch (Ascent), recomputes a plan to rendezvous the CSM and LM.

3. Apollo flight plans provides the logic needed to compute and display a flight plan and/or a return-to-Earth abort maneuver. The flight plan computations involve (TLI) and midcourse correction planning. The TLI study aid may be used to compute either a circumlunar trajectory, a maximum apogee given a fixed amount of fuel, or a specified apogee given a fixed amount of fuel, or a specified apogee using minimum fuel. Midcourse planning involves taking the output of an actual TLI or a predicted TLI maneuver, and either correcting a dispersion from the nominal trajectory or determining an alternate flight plan that is within the capability of the spacecraft, where the nominal trajectory is a stored pre-mission trajectory. The return-to-Earth abort computations involve various study aids designed to produce a single maneuver to change the present trajectory to one having safe entry interface conditions and satisfying other constraints, such as fuel available, time to landing available, and impact point. The return-to-Earth processing is designed to work in a post-TLI environment, and may be used to compute trans-Earth midcourse correction maneuvers. In addition, it may compute an abort maneuver regardless of whether it occurs within the moon's sphere of action.

ENTRY/LOW-SPEED ABORT SUBSYSTEM

The Entry subsystem is responsible for (1) time-to-fire or low-speed de-orbit maneuver planning, where proposed de-orbit maneuvers are computed and displayed for evaluation; (2) the generation and maintenance of the entry ephemeris; and (3) the generation and maintenance of the associated entry evaluation displays.



1. Time-to-fire planning includes the computation and display of de-orbit maneuvers during Earth orbit, which cause impact at a prescribed target point. These solutions for stored target points are regenerated automatically upon any change to the current ephemeris and where present time would cause a solution to be outdated. In addition, a manual solution may be generated and evaluated for targets not available to the automatic computations. This planning is designed for use only during Earth orbit.
2. Entry ephemeris generation and control includes both a look-ahead or study aid feature and the generation of an actual entry ephemeris.

The look-ahead or spacecraft setting feature includes the generation of an entry ephemeris and associated evaluation parameters based on a proposed de-orbit maneuver. This de-orbit maneuver may be a time-to-fire solution (low-speed entry), a return-to-Earth solution (high-speed entry), or a manually described maneuver.

The generation of the actual entry ephemeris, however, is always based on a de-orbit maneuver in the Mission Plan Table and is updated to reflect changes to the entry profile, the current ephemeris anchor, or the maneuver definition.

In each case logic is provided for trajectory update control and numerical integration.

3. Evaluation display logic includes the generation of the required entry displays and associated parameters, MED decoding, and the cyclic update of the displays on a time queue where applicable.

PLOTBOARDS

The Plotboard subsystem provides general visual presentation of prescribed parameters. The available plotting devices for LLP are a 10 x 20 projection plotboard, a 10 x 10 projection plotboard, a 6 x 12 projection plotboard, and five X-Y plotboards. The two types of data which may be plotted are nominals and present position. The nominals which may be plotted are world map nominals, generated from the current ephemeris, and maneuver monitor nominals, plotted from Mission Plan Table maneuver data. The present-position plots include radar or telemetry data received during high-speed phases, and present position world map data plotted from the current ephemeris in low-speed phases. The subsystem has two functional units.

The input functional unit accepts inputs from AMSK's, MED's, phase changes, and time queues. Data is then obtained, scaled, and formatted to satisfy the requests. Editing criteria are applied to the data for the nominals to permit a minimum number of points to be plotted while still perserving the nominals.

The output functional unit accepts data from the input unit and initiates the output of data to the applicable devices. In addition, data to the various devices will be interleaved to provide the most efficient output whenever possible. The interleaving of the output data is accomplished by alternating the output among available devices for which work is outstanding.

DIGITAL COMMAND SUBSYSTEM

The Digital Command subsystem generates, formats, and transfers digital command data from the RTCC to the MSFN for subsequent uplink to the spacecraft on-board computing systems. The subsystem is organized into four major functional areas:

1. The manual entry control function accepts, decodes, and routes manual request for generation of digital command data.
2. The load generation function generates digital command loads from manually entered data or from selected trajectory parameters.
3. The display control function provides for appropriate display of digital command data obtained from the load generation function.
4. The load transfer function, upon manual request, formats the generated digital command data and transfers the load to the selected MSFN command site.

TELEMETRY SUBSYSTEM

The Telemetry subsystem is primarily responsible for the processing, recording, and displaying (via D/TV) of MSFN and ALDS data from measuring devices on space vehicles. The subsystem provides the flight controllers and staff support personnel with immediate visual access to information to monitor and evaluate the spacecraft and crew's status in real time. The subsystem is composed of the function units described below.

1. The telemetry control unit manages the Telemetry subsystem through the use of data routing and direct requests. It receives inputs from MSK's,

telemetry console logic modules, and SMEK and ESOS panels, and directs them to other subsystem tasks. It also receives and processes requests for initialization, liftoff corrections, and phase changes; and it maintains the Telemetry Status Table.

2. The high-speed input processing unit is divided into five tasks:
 - a. The SLV high-speed input task receives and processes data from the S-IC, S-II, and S-IVB/IU vehicles. The data is unpacked and calibrated, converted to engineering units in which special computations are performed, limit sensed, and output to D/TV and DDD's.
 - b. The CSM high-speed input task processes data received from the CSM, AGC, and AEROMED vehicles. This data is processed in the same manner as the SLV data.
 - c. The LM high-speed input task processes data received from the LM, LGC, and AGS vehicles. This data is also processed in the same manner as the CSM and SLV.
 - d. The CSM playback input task processes playback data received from magnetic tape which recorded high-speed data from the CSM and AGC. This data is also processed in the same manner as the CSM playback data.
 - e. The LM playback input task processes playback data received from magnetic tape which recorded high-speed data from the LM, LGC, and AGS vehicles. The data is processed in the same manner as the CSM playback data.
3. The nuclear particle detection system unit performs special computations on NPDS CSM data and displays them via D/TV. These computations are initiated by MED input and routed once a minute until stopped by MED request.
4. The guidance display processor unit processes special guidance display plots initiated by PBI action or upon receipt of liftoff. These displays are updated once a second for preset period, and they contain plots and digital data from the Launch/Abort, Orbit Trajectory, and Telemetry subsystems. Two stripchart recorders and the guidance insertion/injection digital display are also driven by this task.
5. The Summary Message Enable Keyboard (SMEK) unit, upon PBI initiation, takes high-speed input data and reformats selected parameters for output

to the D/TV displays and as low-speed rebroadcast messages to the MSFN.

6. The input buffer unit receives raw high-speed input data and reformats it for display via D/TV.

Several utility functions operate in nonreal time. The telemetry pre-processor generates data tables for calibration data, limit sense data, switch selector data, format control lists for D/TV display generation, TV display directories, and DDD data processing. This data is stored on disk and read into LCS when manually requested. The report processor processes the telemetry summary tape and prints the data in a tabulated format. The erasable memory octal dump program processes log tapes and provides a printed format of the erasable memory downlists from the AGC and LGC.

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PROCESSING BY MISSION PHASE

The Lunar Landing Program may be divided into segments or phases that reflect not only the physical aspects of a portion of the mission, but also the type of processing required to support that portion of the mission. Mission subsystems provide processing support as required by mission phase.

Phase sequence need not follow the order outlined in this description. The Mission System may be initialized in any phase except Launch, Condition for Launch, Condition for Launch Sim, High-Speed Abort, Lunar Descent, Lunar Ascent, Condition for Ascent, and Condition for Ascent Sim. It may also be recycled from Condition for Launch to Prelaunch, Condition for Launch Sim to Prelaunch, Reentry to Orbit, Launch to Condition for Launch, Reentry to Trans-Earth, Descent to Lunar Orbit, Lunar Orbit to Translunar, Translunar to Orbit, Trans-Earth to Lunar Orbit, and Condition for Ascent to Lunar Stay.

PRE-PHASE

Initial loading of the mission program and time synchronization of the computers is accomplished before phase selection. Any required initialization, such as loading the telemetry calibration data from disk on entry of initial MED's is accomplished in this phase.

PRELAUNCH

The system is initialized in Prelaunch phase by inputs from the MED. During this phase the Telemetry subsystem processes high-speed telemetry data from the ALDS on a one-second cycle. Telemetry processing will continue throughout the remainder of the mission in all phases. Prelaunch phase will continue until terminated by MED entry to Condition for Launch.

CONDITION FOR LAUNCH

During this phase the Launch subsystem will process high-speed radar and telemetry trajectory data on a half-second cycle. Condition for Launch phase will continue until terminated by any of the following: an MED entry to recycle to Prelaunch, the flight dynamics officer's (FDO) liftoff event sequence override switch (ESOS) set to EVENT, or a liftoff event indication received from the impact predictor (IP) computer at Cape Kennedy, provided that the liftoff ESOS is not set to NO EVENT.

LAUNCH

Launch phase is initiated by either FDO's liftoff ESOS set to EVENT or a lift-off indication from the IP computer at Cape Kennedy. The Launch subsystem will process high-speed radar and telemetry trajectory data and compute Abort impact points, velocity, flight-path angle, downrange distance, and other essential trajectory information. This processing is done on a one-half second cycle.

When a S-IVB cutoff indication is received from either FDO's, ESOS, or telemetry data, the Launch subsystem will go into the Launch-Hold phase and compute the Orbit insertion GO/NO-GO's on all available data sources and Abort Mode III maneuver parameters based upon the position of the retrofire officer's target switch. If the switch is set to the Atlantic Ocean target (short), the maneuver is computed for a fixed time of ignition. If the switch is set to the Indian Ocean target (long), the maneuver is computed based upon a fixed ΔV and variable GET of ignition.

In addition to the abort maneuver computations, a Mode IV maneuver is computed for a fixed time of ignition which is designed to insert the spacecraft into an orbit with a minimum perigee of 75 NM in the event the spacecraft was not orbital at the time of booster shutdown. To monitor one of these maneuvers with the powered flight processing, the thrust switch on the FDO's console is set to THRUST ON. Hold phase processing will be re-initiated when the thrust switch is set to THRUST OFF at cutoff, and a post-maneuver vector computed for transfer to the next phase.

The Launch phase will continue until the FDO's Abort-Hold-Orbit (A/H/O) switch is set to Abort or Orbit.

ORBIT

The processing for this phase is initiated by setting the A/H/O switch to Orbit. Upon entering Orbit phase, the Orbit Trajectory subsystem will obtain a vector and maneuver, if applicable, from the Launch subsystem. Orbit Trajectory then generates an ephemeris and station contact information for the vehicle inserted into Orbit and transmits acquisition data to the remote tracking stations.

The ephemeris may be updated to reflect a change to the anchor vector, the input of new vehicle weights and areas, or the input or deletion of maneuvers from the Mission Plan Table for the appropriate vehicle. A change to the anchor vector may be obtained from a high-speed radar or telemetry vector or a differential corrections radar vector. Vectors are passed to the Orbit Trajectory subsystem via the vector evaluation unit.

The Trajectory Determination subsystem will collect incoming low-speed radar data, edit the data, perform differential corrections, compute residuals, and

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provide a differentially corrected vector to the vector evaluation unit. Super-batching may use up to 30 batches of low-speed radar data to produce a differential corrections (DC) vector.

A table of vectors including DC, high-speed radar, and telemetry vectors is maintained by the vector evaluation unit to perform vector comparisons and, if desired, routed to the Orbit Trajectory subsystem for an ephemeris update.

Orbit Trajectory evaluation displays will be maintained and updated, if applicable, on a 12-second cycle. In addition, a "static" or "live" ephemeris may be generated and maintained for a second vehicle by inputting an anchor vector and an indicator for the ephemeris. If the indicator is static, the ephemeris and station contact information will be generated and maintained; however, no automatic time updates of evaluation displays will be initiated, and no acquisition data will be transmitted to the remote tracking stations. If the indicator is live, processing initiated for the inserted vehicle will also be initiated for the second vehicle. Upon insertion into Orbit phase, acquisition data which will acquire within the next thirty minutes will be transmitted to all remote stations and will be regenerated every thirty minutes.

In Orbit phase the Mission Planning subsystem may be used to compute and display impulsive special purpose maneuvers such as general purpose maneuvers, perigee adjust maneuvers, and the Lunar Orbit insertion. If two ephemerides are available, impulsive rendezvous plans such as the DKI or SPQ rendezvous plans may be computed and displayed. Impulsive two-impulse maneuvers may also be computed and displayed. This subsystem may be used to input maneuvers directly into the respective mission plan table for either vehicle, or to replace any executed maneuvers with the maneuver as it was actually performed. In addition, a lunar flight plan, which includes the translunar injection maneuver, midcourse corrections, and return-to-Earth abort maneuvers, may be computed, displayed, and/or updated.

The guidance optics support functional unit may be used to compute initial platform alignments for the vehicles, update these alignments with telemetered data, maintain a table of the platform alignments, and display the computed values. It may also be used to compute star sighting angles and associated data.

The Reentry subsystem and the Mission Planning subsystem both provide for de-orbit maneuver planning. During Orbit phase, the Reentry subsystem automatically computes CSM de-orbit maneuvers for low energy orbits. It is also possible to compute the de-orbit maneuver manually; the Mission Planning subsystem computes de-orbit maneuvers for high energy orbits upon manual request only. In either case, the de-orbit maneuver so computed may be placed in the spacecraft setting and a look-ahead or study aid entry ephemeris may be generated.

The Plotboard subsystem in low-speed orbit provides world map displays for the 10 x 20 and 6 x 12 projection plotboards and on the SSR X-Y (4). Present position data is plotted on these displays on a 12-second cycle.

The Telemetry subsystem continues to process data from all orbiting vehicles. It provides REFSMMAT, optics data, IU, AGC, and LGC vectors to the Trajectory subsystems.

Orbit phase is terminated by MED input to initiate a new phase.

HIGH-SPEED ORBIT

This phase can be entered from Orbit, Translunar, Lunar Orbit, Lunar Stay or Trans-Earth phases. The processing performed in this phase is usually required when there is a maneuver executed by the spacecraft and monitored by a tracking station. Smoothing vectors are computed and displayed from the high-speed radar until a THRUST OFF indication is received. After THRUST OFF, short-arc vectors are computed from the radar data. A ten-second averaging computation is used to produce a telemetry cutoff vector.

During High-Speed Orbit, the Plotboard subsystem is used to plot present position data on the 10 x 20 and 10 x 10 projection plotters.

When the MED entry to stop high-speed processing is received, the last short-arc radar vector and the telemetry averaged vector are made available to the vector evaluation processors, and the phase which was active before High-Speed Orbit is re-initiated.

TRANSLUNAR

The processing for this phase is initiated by an MED. The Orbit Trajectory subsystem performs the same function as in the Orbit phase, with the exception that 12-second time queues to the FDO digitals are terminated, and are initiated for the space digitals. The FDO digitals, which can be acquired by display request only, will be based on the Earth reference system until a point of nine Earth radii from the moon is reached, at which time it will switch to a lunar reference system. The reverse is true when in the Trans-Earth phase. The Mission Planning and GOST functions remain the same as in the Orbit phase.

The plotboard subsystem performs the same function in this phase as in Orbit phase except that 10 x 20 height vs. longitude (h vs. λ) plot is replaced by an elapsed time vs. distance from the center of the Earth (X vs. Z).

All other subsystems process in the same manner as described in Orbit phase.

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LUNAR ORBIT

The processing for this phase is initiated by MED. Low-speed radar data will be collected and processed by the Trajectory Determination subsystem to determine the CSM-LM Lunar Orbit. CSM optics data is processed to determine the location of the landing site.

The Plotboard subsystem processing is the same as that performed in Orbit phase with the following exceptions: all quantities are related to the moon instead of the Earth, and the SSR X-Y (4) and the 6 x 12 plotboards are not active.

All other subsystems process in the same manner as described for Orbit phase except that the lunar reference system is used.

LUNAR DESCENT

The Descent phase is initiated by an MED input; powered flight processing is initiated by the input of the THRUST ON switch located on the FDO console.

During the Descent phase, four sources of data are processed by the Descent/Ascent subsystem. They are AGS and PNGS telemetry vectors, USB, landing radar, and rendezvous radar data. Telemetry data is processed every two seconds, and USB radar data is processed every second. The USB is interpolated to establish a pseudo range rate which is used to calculate residuals for each of the four (maximum) USB sites. This data is then presented on analog displays for comparison. The second radar source, rendezvous radar, is processed in a manner similar to the USB data. Should an abort occur, there is a phase change to Ascent upon receipt of the abort switch. Upon receipt of the separation switch, the area and weight of the DPS/APS configuration is adjusted to reflect the APS only.

The Plotboard subsystem provides the following plots. The 10 x 10 projection plotboard is divided into two plots: one 5 x 10 plots present altitude above the lunar surface vs. range to go to the target (h vs. R_{GO}), and the other plots wedge angle vs. height of pericynthion (δ vs. hp). The left 10 x 10 of the 10 x 20 projection plotboard plots altitude above the lunar surface vs. altitude rate (h vs. \dot{h}), and the right 10 x 10 will plot either flight path angle vs. velocity (γ vs. V_s) or flight path angle vs. delta-velocity (γ vs. ΔV_s) depending on the scale selected. These plots include both nominal and present position plots except for δ vs. hp in Descent phase, which provides only present position.

Powered flight processing in Descent phase is terminated by entering an MED input to begin Lunar Stay phase.

LUNAR STAY

Lunar Stay phase is initiated by MED input. Mission Planning provides lunar launch targeting and lunar launch window computations during Lunar Stay. The functions of GOST and Orbit Trajectory are the same as those in Orbit phase, with the exception that the moonrise/set display is no longer available.

The Trajectory Determination subsystem will continue to collect low-speed radar data. Rendezvous radar data received by the LM, while tracking the CSM in Lunar Orbit, will be used to determine the position of the LM on the lunar surface. Platform alignment computations will be made from the rendezvous radar data and the gravity vector data received from the LM.

The Plotboard subsystem will terminate Lunar Descent processing at phase entry and will initiate the plotting associated with Orbit or Lunar Orbit phase upon manual request.

The Lunar Stay phase is terminated by an MED entry to Condition for Ascent or Ascent Sim.

CONDITION FOR LUNAR ASCENT

Powered flight processing is initiated by setting the FDO's liftoff switch to EVENT. Input processing of the radar and telemetry data is performed in the same manner as in the Descent phase. Predictions are made as to the insertion vectors, PNGS and AGS or AGS only, depending upon the position of the guidance officer PNGS/AGS switch (i.e., if the PNGS is selected, both vectors are used; if AGS is selected, predictions are made only on the AGS vector). The Mission Planning subsystem provides a rendezvous monitor (ARM) which updates the proposed rendezvous plan on a two-second cycle. The same type of insertion vector predictions and rendezvous computations are performed after an abort in the Descent phase. Upon receipt of main engine cutoff (Thrust Off), the Hold phase calculations are initiated. PNGS and AGS vectors are averaged and displayed. Additional RCS thrust periods may follow main engine cutoff. Each time the thrusters are used, the ARM processor will be passed a new set of averaged vectors. GO/NO-GO computations, delta-velocity of insertion, delta-velocity of apogee, kick maneuver calculations, and the corresponding GET of ignition are made each time the thrust switch is cycled from EVENT to NO-EVENT.

Lunar Ascent phase is terminated after Hold phase calculations are complete and the A/H/O switch is set to ORBIT.

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The processing performed in this phase is the same as in the Translunar phase.

REENTRY

Reentry phase is entered from Orbit or Trans-Earth phase by MED input. In this phase, the Reentry subsystem will compute the entry ephemeris and station contact information for the entering vehicle and will transmit that information to the remote site tracking stations. The required entry data will be displayed on the D/TV and updated on a six-second cycle where applicable. The entry ephemeris will be maintained and updated to reflect changes to the DC anchor vector, the TM anchor vector, de-orbit maneuver, preburn and postburn weights, or entry mode. Receipt of a new anchor vector from any source available in the vector evaluation unit will also be reflected in the entry ephemeris as a change to the DC anchor.

In Reentry phase, the vector evaluation unit will perform as in Orbit phase, except that vectors for ephemeris updates will be routed to the Reentry subsystem instead of the Orbit Trajectory subsystem, and the reentry integrator will be used to perform vector comparisons.

The Trajectory Determination subsystem will perform as in Orbit phase, except that it will use the reentry integrator in addition to the orbit integrator in making computations.

HIGH-SPEED ABORT

This phase is initiated by PBI inputs from the FDO and retrofire officer during the Launch-Hold phase. A vector is passed from Launch and integrated down to impact. All necessary reentry parameters are available on the D/TV displays. Tracking will continue as long as high-speed telemetry or radar trajectory data are coming into the system.

High-Speed Abort has two subphases: Mode I when the launch escape tower is used to abort the spacecraft and Mode II when the abort occurs after the launch escape tower has been jettisoned. There is no maneuver capability in the High-Speed Abort phase.

LOW-SPEED ABORT

Low-Speed Abort has Mode I, Mode II, and Mode III subphases. Modes I and II are entered from High-Speed Abort Modes I and II, respectively, by MED entry. Mode III Abort is entered by entry of the required PCK's by the flight dynamics officer and the retrofire officer. Processing in the Mode III subphase is the same as in Reentry phase. Abort Modes I and II are processed the same as in Reentry phase, except that the ephemeris may be updated only through the vector evaluation unit.

The Mission Planning subsystem may be used to confirm the Mode III maneuver.

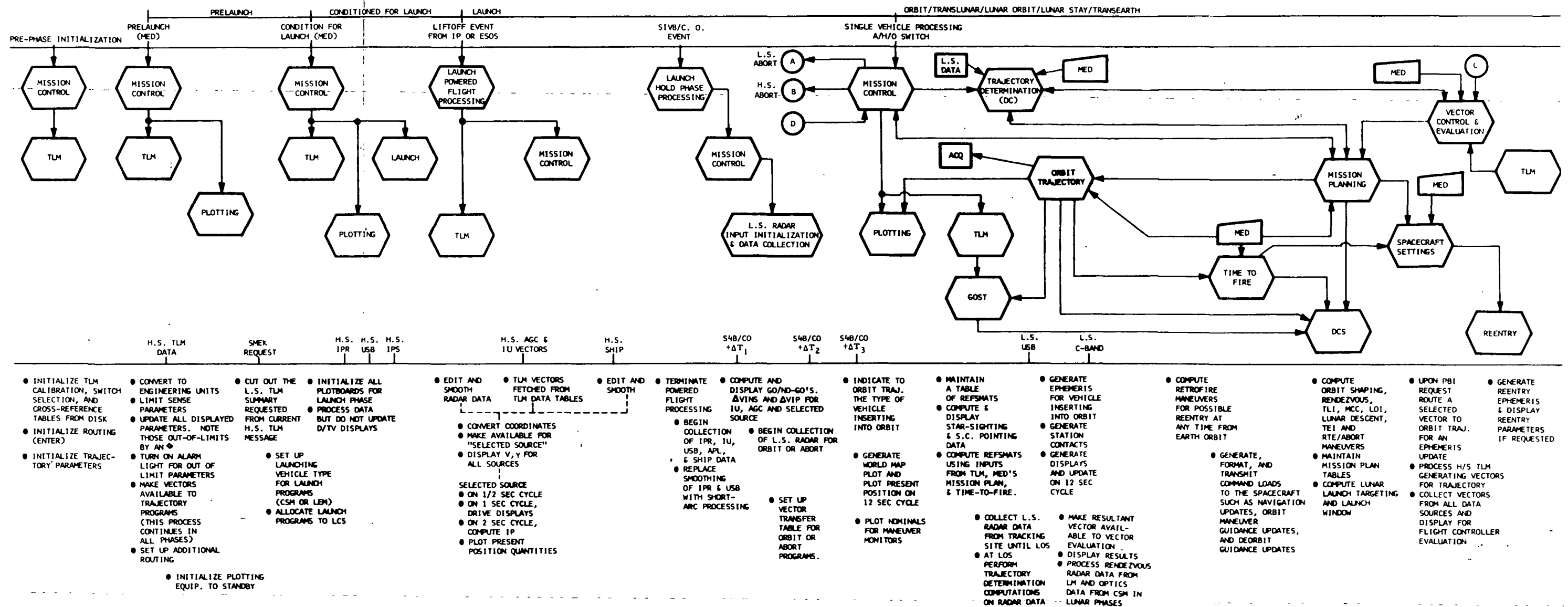


Figure 2. RTCC Mission System Profile Flowchart

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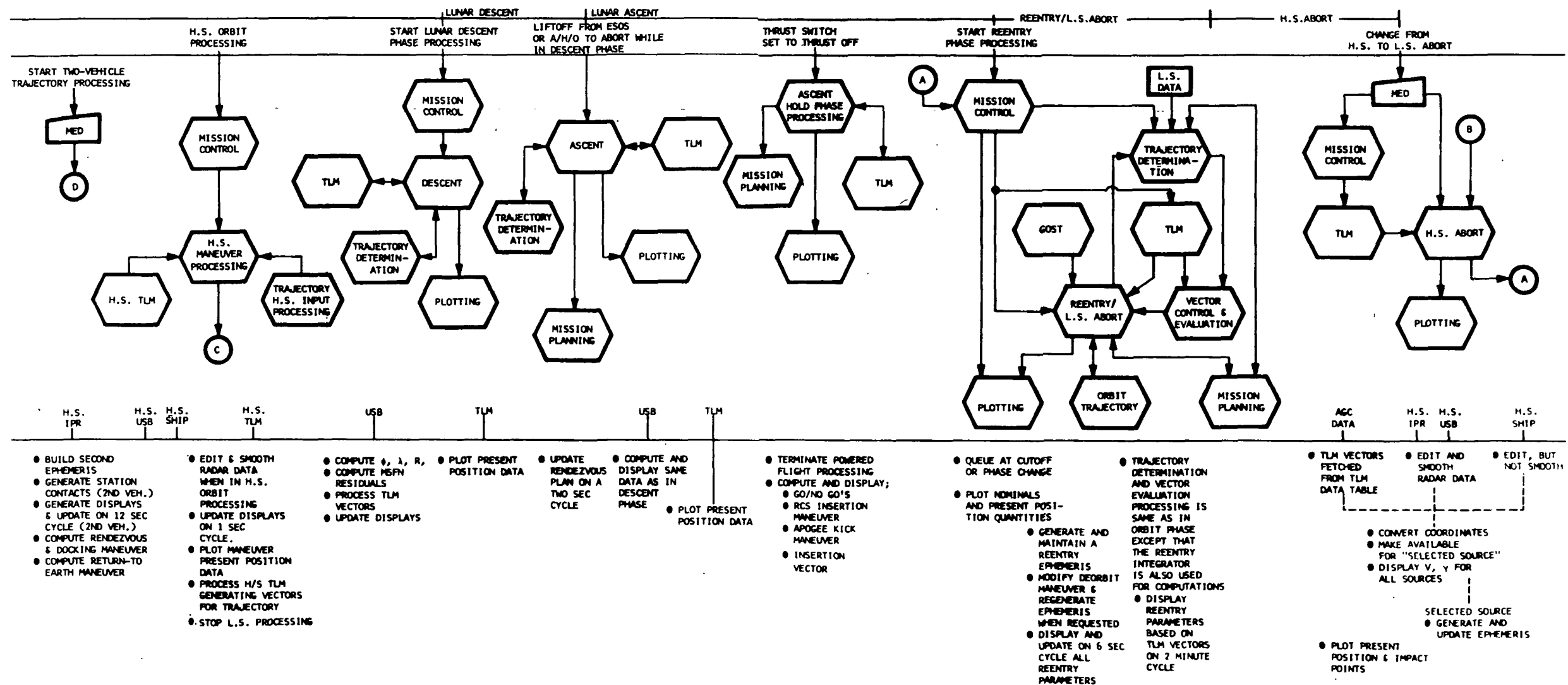


Figure 2. RTCC Mission System Profile Flowchart

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2.2.2 MISSION CONTROL FUNCTIONAL SPECIFICATIONS FOR THE
MISSION SYSTEMS LUNAR LANDING PROGRAM

MISSION CONTROL FUNCTIONAL SPECIFICATIONS
FOR THE MISSION SYSTEMS LUNAR
LANDING PROGRAM

INTRODUCTION

The Mission Control Subsystem consists of eight functional units:

1. Mission Initialization and Phase Control
2. Central MED* Decoding Control
3. Restart Control
4. Real Time Delog
5. General Mission MED
6. General Mission Display Control
7. MED and Switch Input Simulation
8. Real Time Station Characteristics Logging

These eight program functions operate under six tasks. Listed below are the six tasks and the Mission Control functions which operate under each task.

1. GTPHASE — Initialization and Phase Control
General Mission Display Control
General Mission MED Decoding
Hardware Switch Simulation
2. GTGMED — Restart Control
General Mission MED Decoding
Central MED Decoding Control
3. GTDELQG — Real Time Delog
4. GTGCARD — MED and Switch Input Simulation
5. GTPRINT — Load Module GMSPRINT (included in Initialization and Phase Control)
6. GTLGSTCH — Station Characteristics Logging

A ninth functional unit, General Purpose Delogging, is also included in the Mission Control Subsystem. It is not, however, part of the real time system.

*Manual Entry Device

Approval	Approval
<i>Paul C. Payne</i>	<i>John M. Sienkowsky</i>

INITIALIZATION AND PHASE CONTROL

When the Mission System is first cycled up, the initialization function is called to set up initial routing and the display MSK internal format number table. (See Figure 1.) Upon a MED entry, the Phase Control function initializes the Mission System in the phase that is specified. Further phase changes are also handled by the Phase Control function. (See Figure 2.)

The load modules included in the Initialization and Phase Control function and a brief description of each are given below.

GMSINT

This load module is the first to execute after the Lunar Landing Program (LLP) is cycled up and after the Real Time Operating System (RTOS) finishes its initialization. GMSINT establishes the routing control blocks of several subsystems, executes routing instructions to RTOS for inputs from the communications processor (CP), restart switches, MED's and MSK's, starts six-second time traps to the general mission display supervisor, queues the Telemetry Subsystem for initialization, queues GMSFILL to initialize the data tables, queues Digital Command Subsystem to increment load sequence number, and log out equipment status words for D/TV.

GMSFILL

This load module is called by the initialization load module (GMSINT) to initialize the display MSK tables with format numbers and names.

GMSPHASE

This load module provides the logic for the control of mission phase initialization and phase switching. All queues to GMSPHASE are from the "P" class MED decoder with the following exceptions: (1) queues to initiate a phase change from Launch to Orbit, High-Speed Abort, or Mode III Low-Speed Abort, (2) a phase change from Condition for Launch to Launch, (3) a phase change from Descent to Ascent, (4) a phase change from Condition for Ascent to Ascent, and (5) a phase change from Ascent to Lunar Orbit. The Launch Subsystem generates these queues to GMSPHASE.

Upon entry of a phase change request, GMSPHASE executes any error checking logic necessary, updates the phase system parameter, turns on the phase digital display drivers (DDD), queues the phase change print

processor to print the new phase on the on-line printer, executes any necessary data routing changes, and generates all necessary queues to other subsystem programs.

GMSPRINT

GMSPRINT is called by GMSPHASE to print on-line messages. Messages passed to it are converted into Display Formatting Language (DFL) and then will output to the on-line printer.

GMSWAQ

GMSWAQ provides the logic for interfacing between Telemetry (TLM) and Launch for the Launch-Trajectory - TLM events. It then processes the event sequence override switch (ESOS) inputs from the flight dynamics officer's (FDO) console when the mission phase is other than Condition for Launch or Launch. After the phase change from Prelaunch I to Condition for Launch, GMSWAQ passes a history of TLM events to the Launch Subsystem. During Condition for Launch and Launch phases, it passes all changes in TLM events to Launch as they occur. During any other phase, it only maintains a history of TLM events.

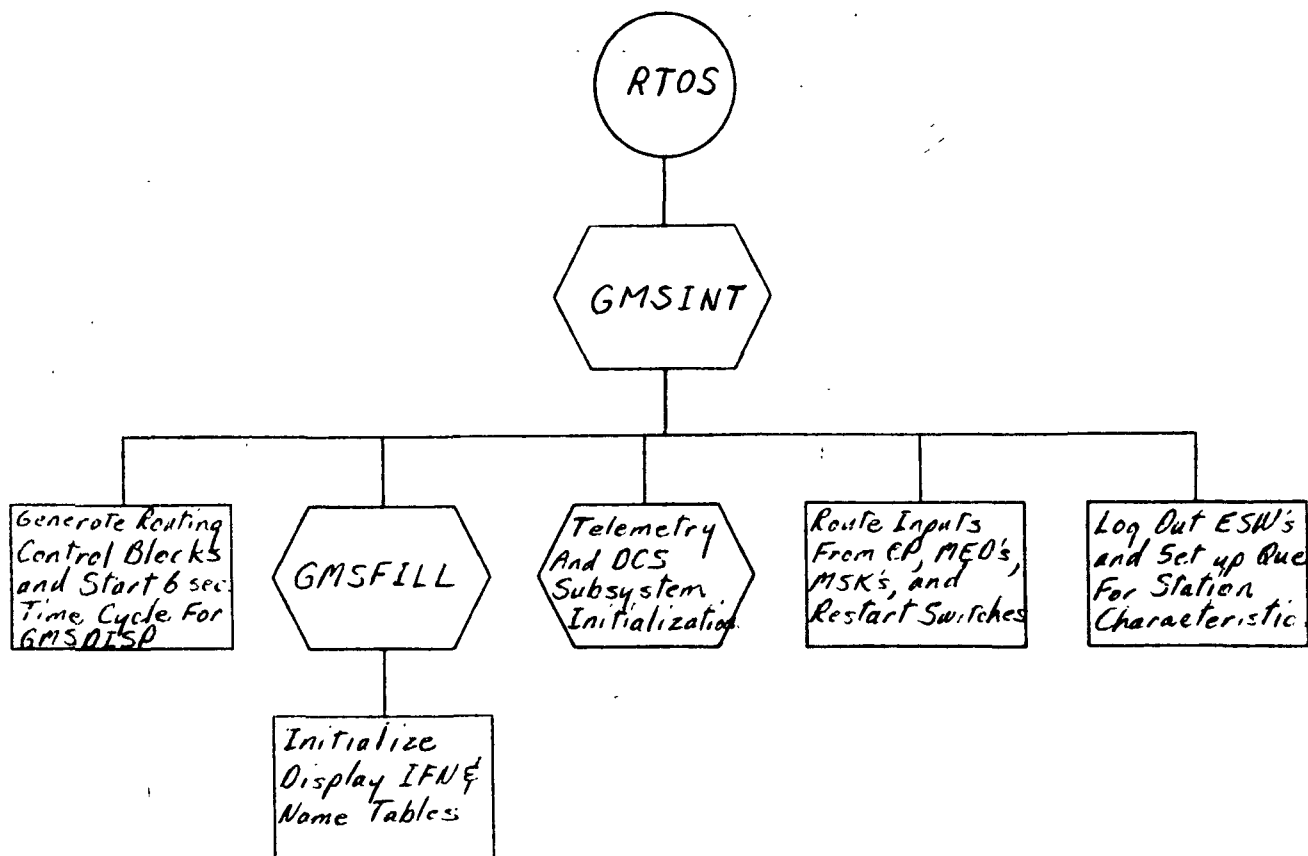


Figure 1. Initialization Control Flowchart

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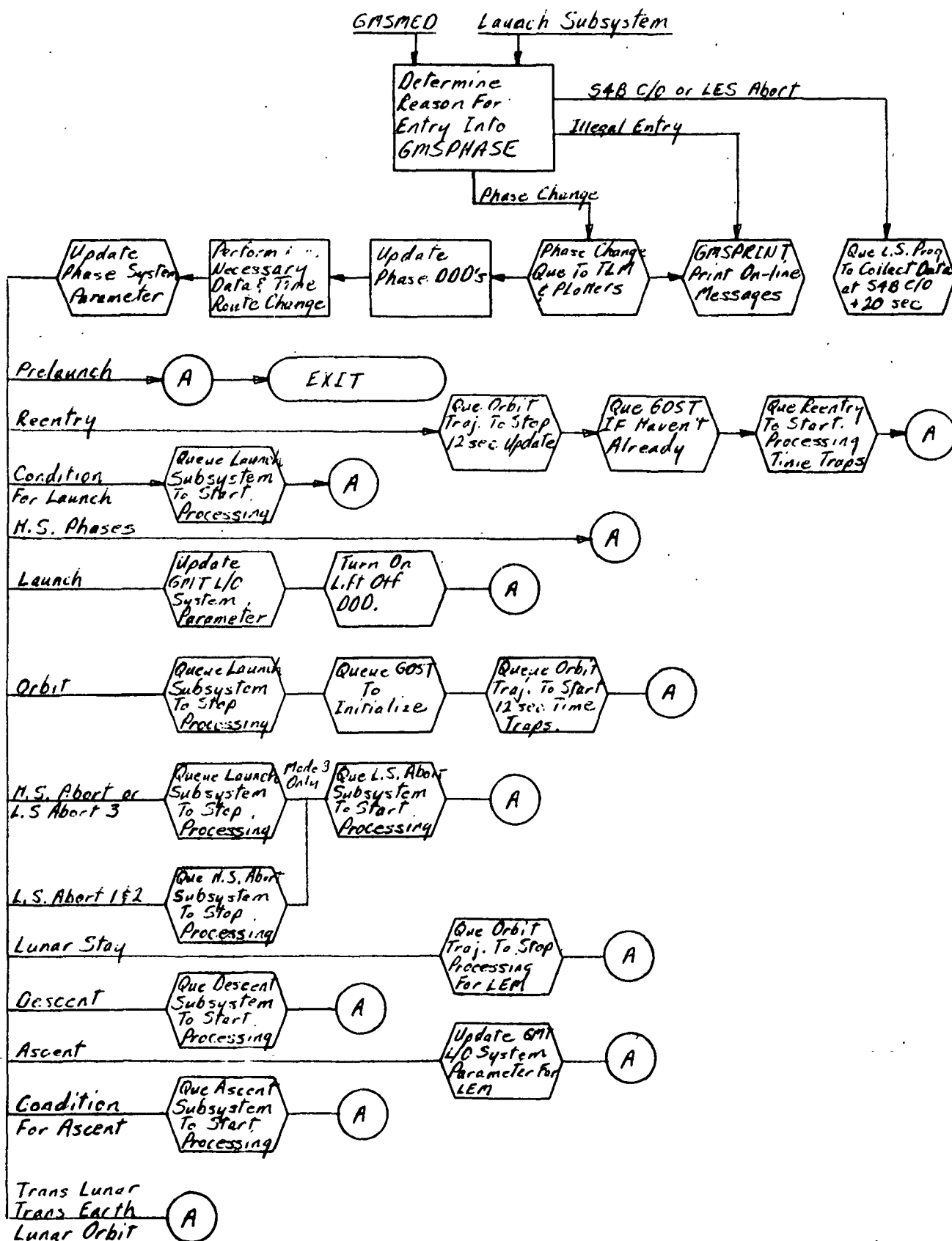


Figure 2. Phase Control Flowchart

HARDWARE SWITCH SIMULATION

The Hardware Switch Simulation function is to provide a backup in the event that certain hardware switches should fail during the mission.(See Figure 3.) A history is kept of the following switch inputs to maintain a current status during all phases of the mission:

- Wedge angle
- PCK
- Data select, sub-selected source
- Data selected, selected source
- ESOS
- AMSK

The load module is described below.

GMSWITCH

GMSWITCH simulates and maintains a history of the following hardware switches: PCK, ESOS, wedge angle, selected source, sub-selected source, and AMSK requests.

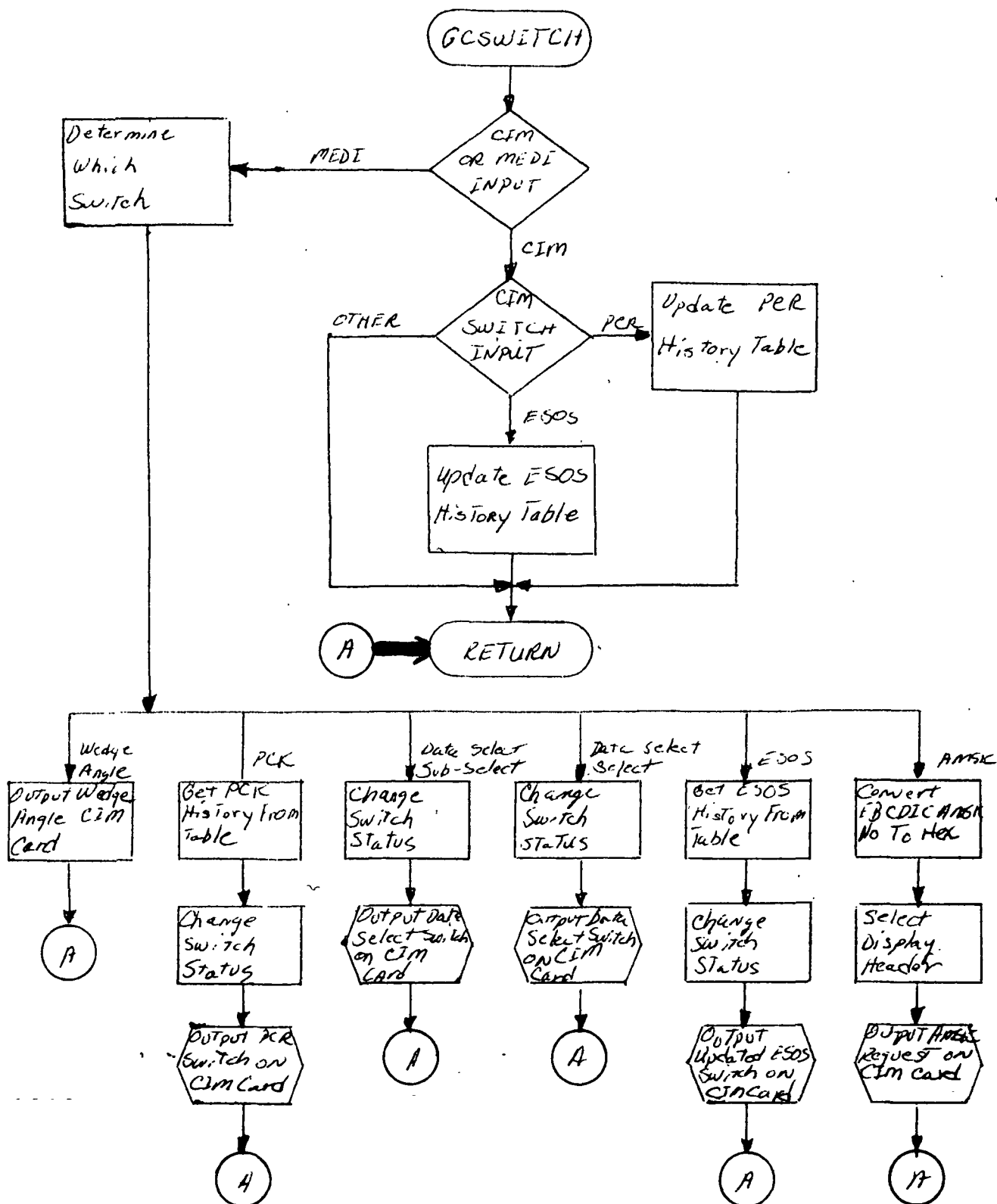


Figure 3. Hardware Switch Simulation Flowchart

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CENTRAL MED DECODING AND CONTROL

The Central MED Decoding Control function fields all MED inputs, and provides logic and interface control with the subsystems that assist in decoding the MED entries and initiating any required processing. (See Figure 4.)

The Central MED Decoding and Control function includes one load module.

GMGMED

This load module fields all MED's entered into Mission Systems. According to the MED code class, which is determined from the first character in the input, GMGMED LINKs to a second load module, which is provided by the subsystem, in order to obtain a definition of each item on the MED. The definition explains how the MED items should be decoded. It also explains what subsystem-provided load module should be queued to initiate the processing required because of the MED entry. After phase checking, error checking, and converting all items on the input MED, GMGMED RTATTACHes the specified subsystem load module, and passes the converted and formatted data to it.

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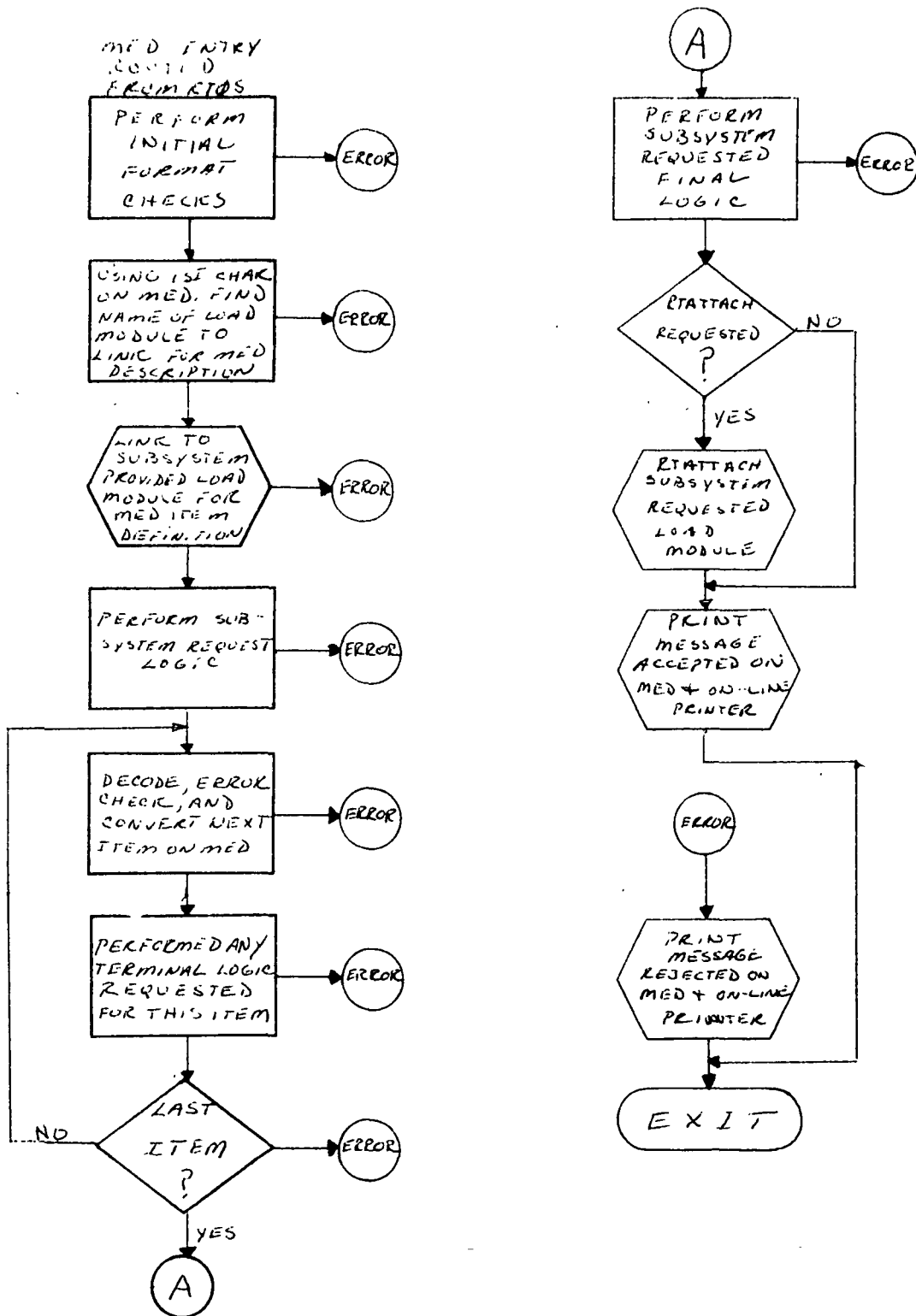


Figure 4. Central MED Decoding and Control Flowchart

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REAL TIME DELOG

The Real Time Delog function includes one load module.

GMSDELQG provides a real time delog to the on-line printer of the computer input multiplexor (CIM), auxiliary computer input multiplexor (ACIM), manual entry device input (MEDI), or communications command and telemetry system (CCATS or CP) subchannel messages. GMSDELQG also processes and prints on line data that is not routed by any other routing block from the CIM, ACIM, and MEDI subchannels.

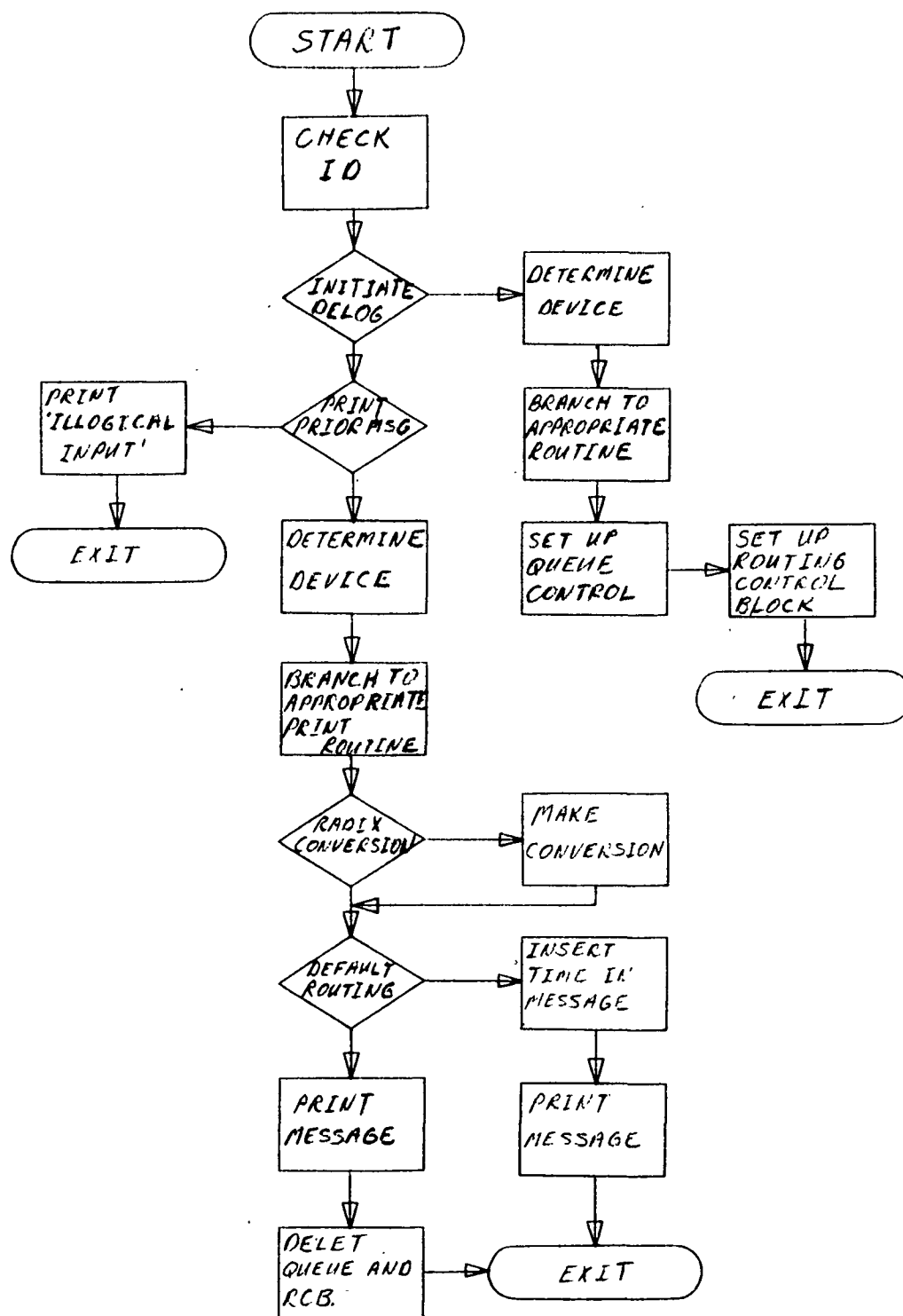


Figure 5. GMSDELQG Flowchart

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RESTART CONTROL

The Restart Control function controls channel-to-channel restarts, writing of restart tapes and initialization of initial program loadable (IPL) restart tapes. (See Figure 5.) During the course of a mission, it may be expedient to cycle up another computer with the LLP, operating with the same information as in the active Mission Operational Computer (MOC). If so, a channel-to-channel restart may be used if the necessary hardware is available. (This is a core-to-core transfer of information.) Otherwise, a restart tape can be written on the MOC that will contain a copy of all presently stored information. This tape is IPLed into the new computer and executed. At this point, the status of both computers is the same.

The following two load modules are part of the Restart Control function.

GMSREMED

This load module provides the restart MED item with definitions used by GMGMED to decode a restart MED entry. It also provides the load module (GMLRESRT) to be queued by GMGMED after the restart MED entry, and contains the logic for the MED resume.

GMLRESRT

This load module provides the capability to execute channel-to-channel restart tapes and to write Type A and B restarts. When called to write a Type A restart tape, GMLRESRT queues RTOS to stop all processing and begin writing; at completion, RTOS notifies GMLRESRT, but no instruction to resume processing is issued to RTOS. If a Type B restart tape is being written, a resume instruction is then issued to RTOS. When GMLRESRT receives a restart end from the MED or switch input, it issues a resume processing instruction to RTOS. Channel-to-channel restart is executed as in Type B tape restarts (i. e., the MOC executes a resume after data transfer is complete). When a Type A or B restart tape is IPLed, processing is suppressed until a MED or switch entry initializes the resume macro with the necessary options.

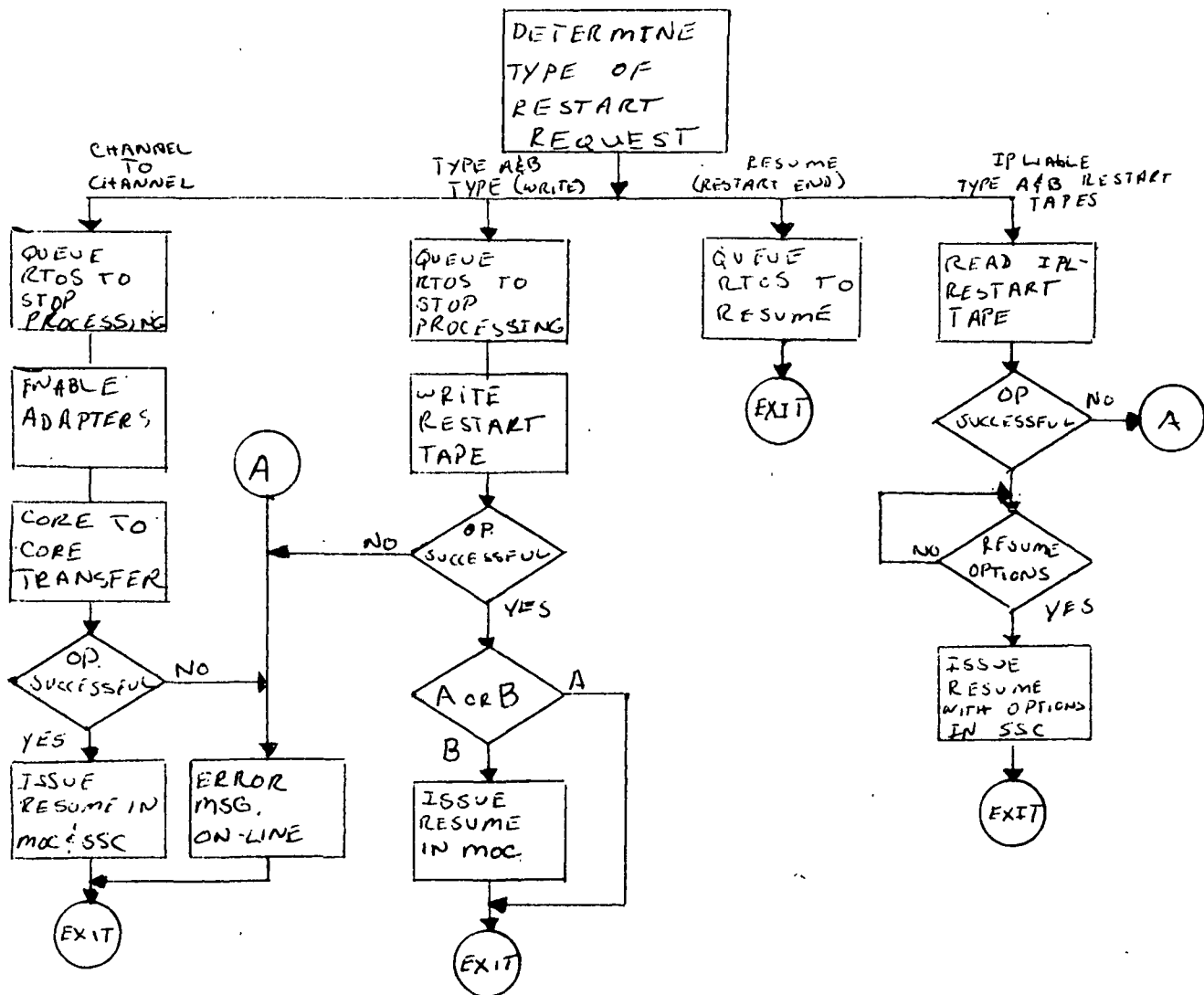


Figure 6. Restart Control Flowchart

GENERAL MISSION MED DECODER

The General Mission MED Decoder function defines to the Central MED Decoder "D" and "P" class MED's and provides the logic that controls the processing performed when a "P" class MED is entered into the computer. (See Figure 6.)

Described below are the load modules for the General Mission MED Decoder.

GMGPMED

This load module provides the "P" code MED item definitions to be used by GMGMED to decode and error check a "P" code MED entry; when necessary, this module performs supplementary error checking. GMGPMED also provides the load module that should be queued by GMGMED after decoding and accepting a "P" code MED.

GMSMED

GMSMED is queued by GMGMED after decoding most of the "P" code MED entries. At this time, depending on which "P" code MED was entered, GMGMED updates appropriate system parameters, stores converted MED-entered data into data tables, and/or routes any necessary queues to various subsystem programs. In some cases, GMSMED performs further error checking on the MED entry.

GMGDMED

GMGDMED provides the "D" code MED item definitions to be used by GMGMED. If the "actual" bit has been set by the P77 MED, the Testing D-code MEDS will be rejected if entered and no queue will be sent to GMSRMMED.

GMSRMMED

GMSRMMED processes data input in any of the "D" code MED's.

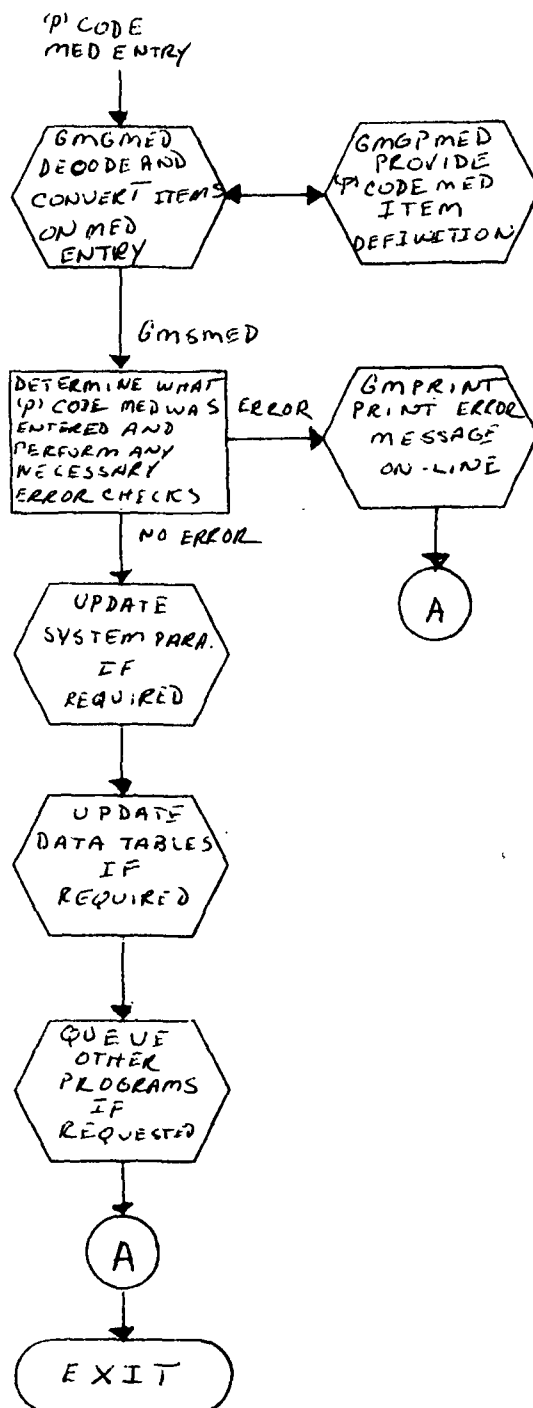


Figure 7. General Mission MED Decoder Flowchart

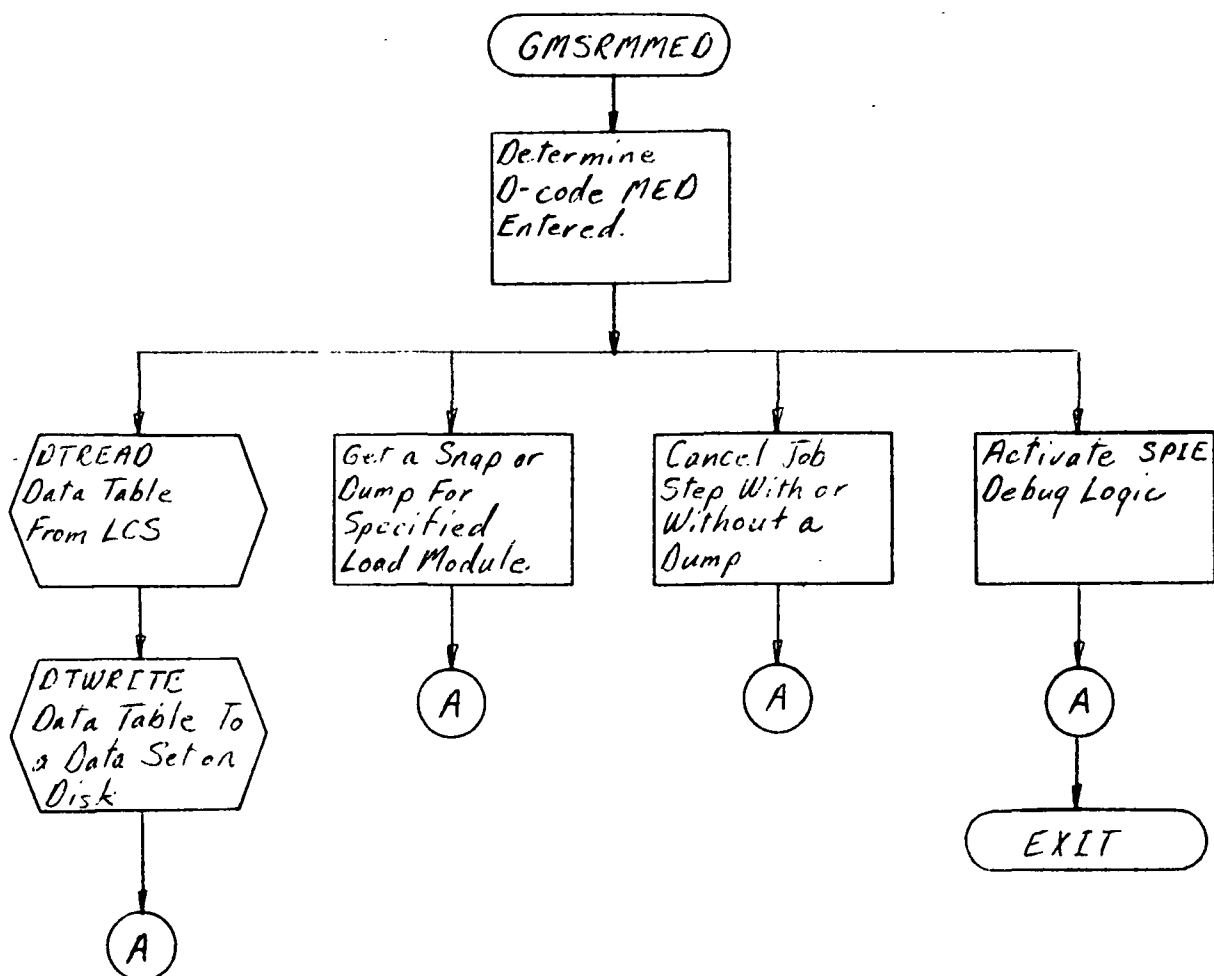


Figure 7. General Mission MED Decoder Flowchart

GENERAL MISSION DISPLAY CONTROL

The General Mission Display Control function provides the logic to control the generation of displays that are driven by different subsystem load modules. The module choice depends on the mission phase used and the displays to be updated on a six-second cycle. The formatting, output, and updating of the TV-GUIDE display is also handled by this function. (See Figure 7.)

The three load modules given below are part of the General Mission Display Control function.

GMSDISP

This load module provides three types of services for several mission display programs. It queues display programs on display requests, queues displays programs that are requested by an internal format number (IFN), and displays programs on six-second time updates. These services are described in greater detail below.

- Display Request — On a display request for a format with an IFN of the form 08XX, GMSDISP is queued with a generate entry. A search is performed on the IFN to determine the appropriate display module name. A dependent task is then created with an ATTACH to the module, followed by a WAIT for ensuring completion of the dependent task before it exits by a RETURN.
- IFN Update — A specific display may be updated by queuing GMSDISP with the IFN. GMSDISP searches the TVGUIDE to ascertain whether the desired display is being viewed. Then a dependent task is created with the display module as the entry point for each desired format in the TVGUIDE. Finally, a WAIT is issued to ensure completion of all dependent tasks before exiting by a RETURN. Logic can handle several update messages of IFN's in a single queue.
- Time Update — GMSDISP is queued on a six-second time cycle in all phases. Those displays that need updating on the time cycle are kept in an internal table. GMSDISP searches the TVGUIDE, and for each format that needs updating, a dependent task is created with the display module as the entry point. In addition, the digital-to-television (D/TV) status indicators are updated during the time cycle. Red indicates that two or fewer D/TV channels are available; amber indicates that four or three are available; off indicates that more than four channels are available.



GMSDETPH

This load module is queued by GMSDISP when a request is made for a phase-dependent display. A check is made of the mission phase system parameter. If the present phase is Prelaunch I, Condition for Launch, Launch, or High-Speed Abort, the request is routed to the Launch/High-Speed Abort Subsystem. If in any other phase, the request is routed to the Reentry/Low-Speed Abort Subsystem. The TVGUIDE control word is passed to the subsystem as a parameter.

GMDTVGID

The function of this load module is to generate and update the TVGUIDE display on a six-second cycle. This display shows the MSK numbers and title being viewed on each of the 52 TV channels; it also shows the numbers of users latched to each channel and the number of the lowest numbered console latched to the channel. GMDTVGID examines the IFN in each of the 52 entries in the TVGUIDE table. (IFN of zero indicates that no display is being viewed on the channel; IFN of 255 indicates that the channel is down.)

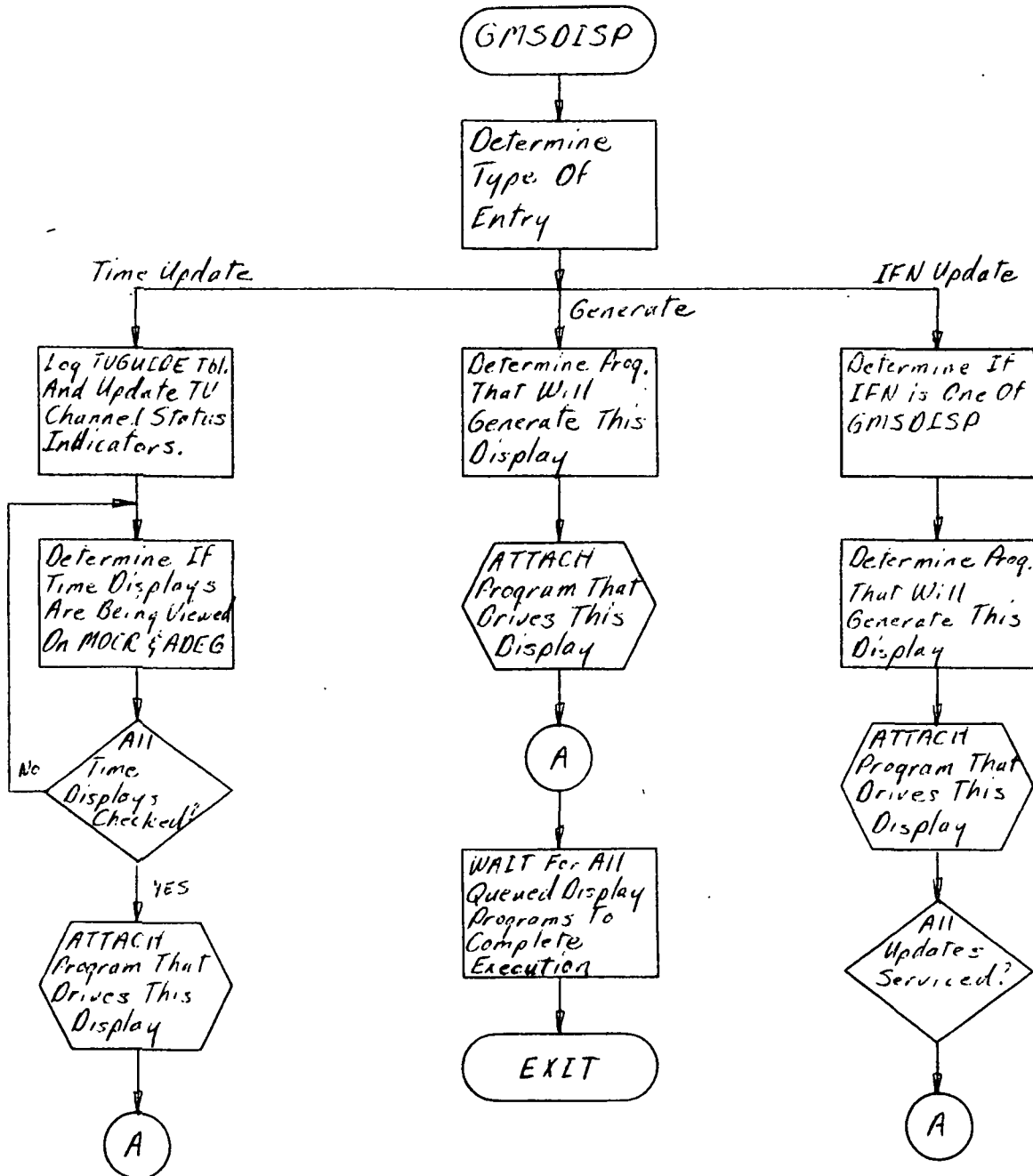


Figure 8. General Mission Display Control Flowchart

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MED AND SWITCH INPUT SIMULATOR

The MED and Switch Input Simulation function provides the ability to simulate the entry of an MED or console switch into the computer by reading specially formatted punched cards from the on-line card reader. After reading the card and error checking it for correct format, the input is routed to RTOS. RTOS processes the input as if the input actually came from a MED or console switch. (See Figure 8.)

The load module for the MED and Switch Input Simulator is described below.

GMGCARD

This load module is queued by GMGMED after decoding a P66 MED entry. GMGCARD then reads MED and Switch Simulation cards from the card reader until a \$\$ or /* card is encountered. It also checks the cards for correct format. If the cards are error free, the input is formatted again, as required by RTOS, adding such things as headers. The cards are then routed to RTOS to be processed as if the actual MED or Switch had been entered.

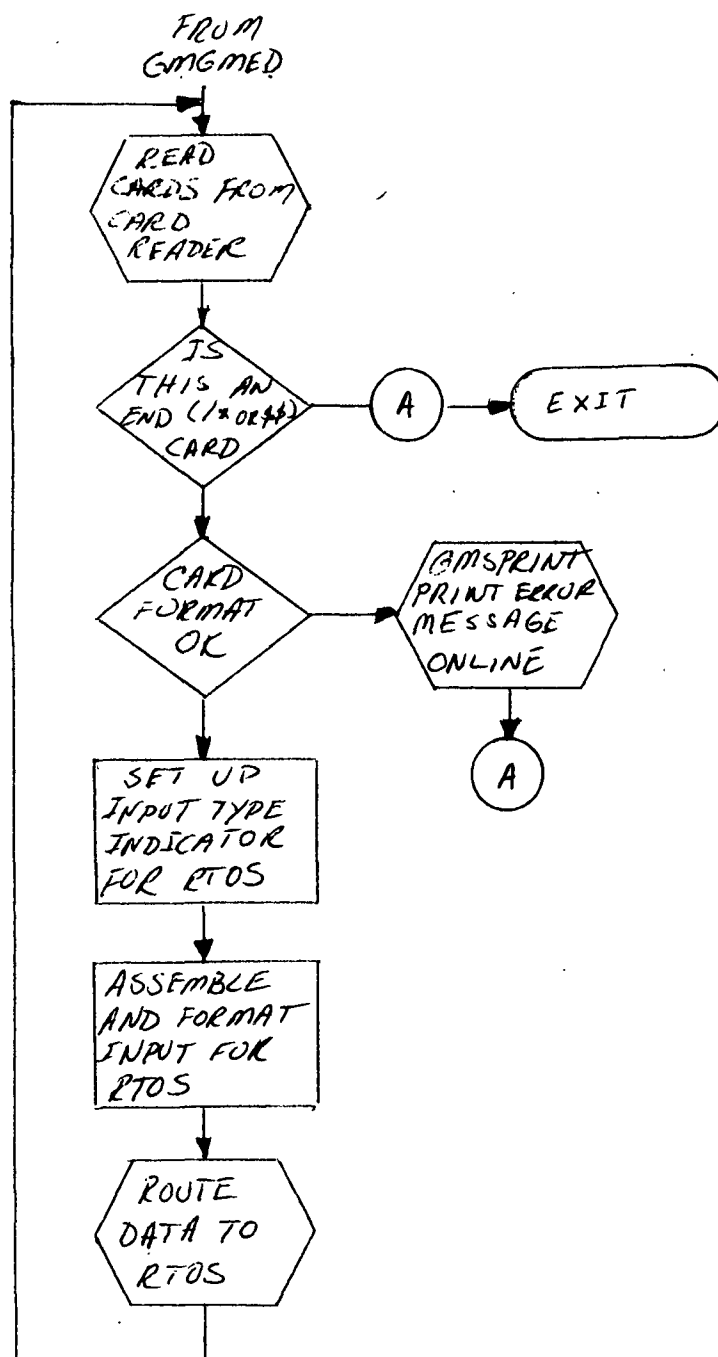


Figure 9. MED and Switch Input Simulator Flowchart

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STATION CHARACTERISTIC LOGGING

The function of Station Characteristic Logging is to write the station characteristics on the log tape at initialization and on each log tape used during the mission. Following is a brief description of the load module.

GMLGSTCH

GMLGSTCH reads the station characteristics table and writes each block onto the log tape at initialization and any time the log tape is changed.

GENERAL PURPOSE DELOG

This function consists of several types of delog programs designed to run non-real time and to operate under one control program. The type of delog desired is specified to the control program by using control cards read from the card reader or using entries made at the console typewriter. Multiple types of delogs can be requested at one time and multiple log tapes can be processed during a single execution.

Listed below are the load modules included in the General Purpose Delog function.

1. QMDELOG

This module (1) processes the delog control cards, (2) builds request blocks for the requested load modules, (3) loads the requested load modules, (4) provides conversion routines for time, octal and decimal numbers, (5) reads and interprets each log record, and (6) provides a print routine. (See Figure 9.)

2. QMDDDR

QMDDDR decodes the DDD output into each of the following: "A" name, groupset address, lamp control bit(s), width, status, and bits that are "on". The printout occurs only on a change of status.

3. QMDTIMES

Load module QMDTIMES provides a means of delogging at specified times only.

4. QMDPLOTR

This module decodes all plotting gear output into hex, device, word type, unit, color, raster position x and y, symbol size, slide number, plot control, and xy channel indicators.

5. QMDDTVR

QMDDTVR reproduces a tube image of the requested display. An image can be produced only with the specified size characters or for a specified time.

6. QMDMEDR

Load module QMDMEDR prints all MED inputs and outputs.

7. QMDCIMR

This module decodes all computer input multiplexor (CIM) inputs into hex and type of inputs. It also permits the appropriate bit decoding, according to type.

8. QMDCPINR

QMDCPINR provides an octal dump of all CP input.

9. QMDPRINR

This module prints all the printer or RTLOG output.

10. QMDTLTYP

This load module simulates a teletypewriter (TTY) printer for teletype output.

11. QMDTTYR

QMDTTYR provides an octal dump of all TTY output.

12. QMDRNSOR

This module decodes all D/TV commands into time, hex, operation code, raster position x and y, size, character, delta x and y, channel number, console, monitor, and slide number.

13. QMDHSINR

Load module QMDHSINR provides the ability to dump any subchannel in hex. It also provides a formatted hex dump of high-speed TLM data.

14. QMDDCSR

This module prints Digital Command System (DCS) command loads.

15. QMDLSDLG

QMDLSDLG provides a formatted delog of low-speed TLM data.

16. QMDHEXR

This module prints any log record in hex.

17. QMDTVER

This delog will show each MSK display being viewed at a requested time, and which console(s) are viewing them. Primary use is during Flight Controller Simulations when all TV channels are tied up, and it is desired to find out which console personnel has a TV channel latched via MSK or DRK request.

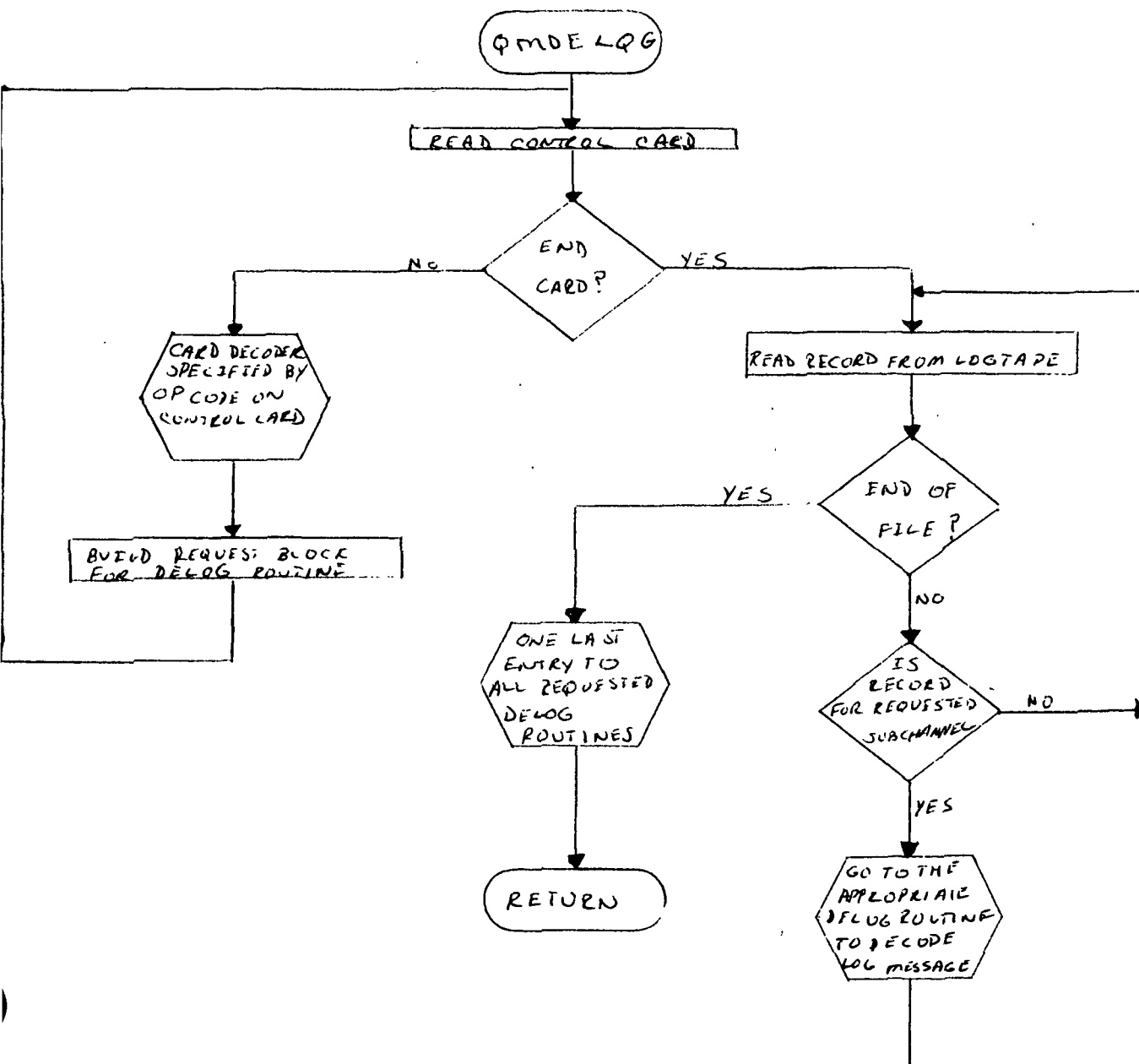


Figure 10. General Purpose Delog Flowchart

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2.2.3 TELEMETRY SUBSYSTEM FUNCTION SPECIFICATIONS
FOR MISSION SYSTEMS LUNAR
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TELEMETRY SUBSYSTEM FUNCTIONAL SPECIFICATION
FOR MISSION SYSTEMS LUNAR
LANDING PROGRAM

INTRODUCTION

The Telemetry subsystem, a program unit of the Real Time Computer System, provides processed network telemetered data and related information for flight control and staff support personnel. This subsystem offers vehicle measurements and computer-derived quantities in a variety of visual formats. Time-critical evaluation and post-flight analysis of flight crew status, spacecraft systems, and launch vehicle systems are made possible through the use of telemetry processing.

With those responsibilities, the Telemetry subsystem has four basic design goals, which will be attained by the Lunar Landing Program design.

Basic Goals

1. The time interval between data receipt and data presentation must satisfy the users' requirements. Data flow from spacecraft to observer must not be restricted in computer handling.
2. The data must maintain the required degree of accuracy and must be continually available for inspection.
3. Since mission objectives and space experiments vary from mission to mission, the subsystem's structure must experience minimum impact as changes are incorporated.
4. The subsystem design must provide a means of expansion. New and unique requirements should be implemented easily without affecting the existing routines.

Lunar Landing Program Design

1. New processing techniques provide a means of reducing the computer time intervals.
2. Improved data selection methods offer greater subsystem control.
3. Tabular processing controls and automated table generation methods allow dynamic responses to new and changing requirements.
4. A modular subsystem structure allows a means of expansion.

Approval	Approval
Ed Premit	Garth E. Bagley



The contents of this functional specification are divided into five sections. The first section generally describes telemetry processing. Those methods that are incorporated in the telemetry functions are discussed in the second section. This section also describes the Lunar Landing Program design for a dynamic definition of telemetry requirements. The third section is a functional structure of the LLP Telemetry subsystem. Each functional unit (task) is described in detail. The subsystem services required by one or more functional units are highlighted in the fourth section. Methods, characteristics, and limitations are presented for these services. The final section outlines the utility programs that support the real time processors and that extend the total telemetry capability.



GENERAL TELEMETRY PROCESSING

Telemetry processing can be divided into two categories: high-speed vehicle processing, constituting the major portion of telemetry considerations and manual controls, dictating the execution of special functions. Each of these categories may be further divided into three phases: input, intermediate, and output.

HIGH-SPEED VEHICLE PROCESSING

High-speed data processing is governed by station contact consideration. Cyclic processing is initialized for both the type of vehicle and the type of data upon receipt of the first valid frame, and processing continues until the data contains a Last Frame Indicator (LFI). When the LFI is detected, processing for that vehicle/data type is terminated and reset for the next station contact.

Each on-board transmitting source is designated as a particular vehicle type,¹ and several vehicles have two data modes: live, containing a current time-tag, and playback, containing a previous time-tag. The telemetry processors distinguish the two modes and vehicle types from the input data header. So live and playback data can be processed simultaneously, the two data modes are handled separately.

The input phase validates the input header, computes the data receipt rate, determines the processing code (initial, cyclic, or last frame), updates the appropriate vehicle data base header, and drives the source/status indicators. The data frame is then unpacked and calibrated or scaled into units that fulfill internal processing requirements. The input phase supplies the bulk of the vehicle data base. Data quality and redundancy are determined, and each input parameter's status is indicated.

The intermediate phase operates on the data, adding to the data base those quantities and indications not directly represented in the input stream. Examples of this phase are: special computations needed to satisfy the output requirements, comparisons of input and computed quantities for pre-defined limits, and special event detection.

The output phase selectively accesses the appropriate vehicle data base(s) to generate a variety of visual outputs. Digital television constitutes the largest

¹The CCATS/RTCC interface defines vehicle type.

single output medium with various types of graphical, tabular, and system status displays. Digital indicators and readouts are another major output medium. The output phase also consists of stripchart recordings, teletype rebroadcasts, and summary logs for off-line report generation. Mission event notification, required by other subsystems, is also performed during this phase.

MANUAL CONTROLS

Manual controls extend the capabilities of the Telemetry subsystem by specifying additional output and by directing the logic flow. Telemetry users select these controls for which the processing elements have pre-defined procedures.

The input phase decodes the request, checks the validity of the input, determines if the request may be performed, and either queues the proper processing element or updates the appropriate control table. Two functions accept manual controls. The control function handles SMEK requests, television display selection, and all pushbutton indicator (PBI) inputs. The manual entry device (MED) function decodes entries made from this source.

Depending upon the input, the intermediate phase of manual controls has a wide range of processing. However, discussion may be limited to three broad areas: summary message enable keyboard (SMEK), pushbutton indicator (PBI), and manual entry device (MED).

For SMEK processing, a selected set of quantities is retrieved from the high-speed data base(s), placed in a prescribed sequence, and passed to the output function. Each SMEK request is executed serially from intermediate to output phases.

Processing for PBI's involves setting an indicator or flag in a control table and making the update available to the responsible element(s). These elements examine the control tables at prescribed intervals and execute the required logic. Selected inputs require an immediate action; a queue is built, and control is passed directly to the routine. Examples of this procedure are start plot queues, display selection requests, load calibration and limit tables queues, and vehicle shutdown queues.

The intermediate and output phases for MED involve either updating the appropriate constants table, updating a control table, or generating a special queue to the indicated processing routine. The MED processing is a low-response type of input; therefore its execution is on an available-time basis.

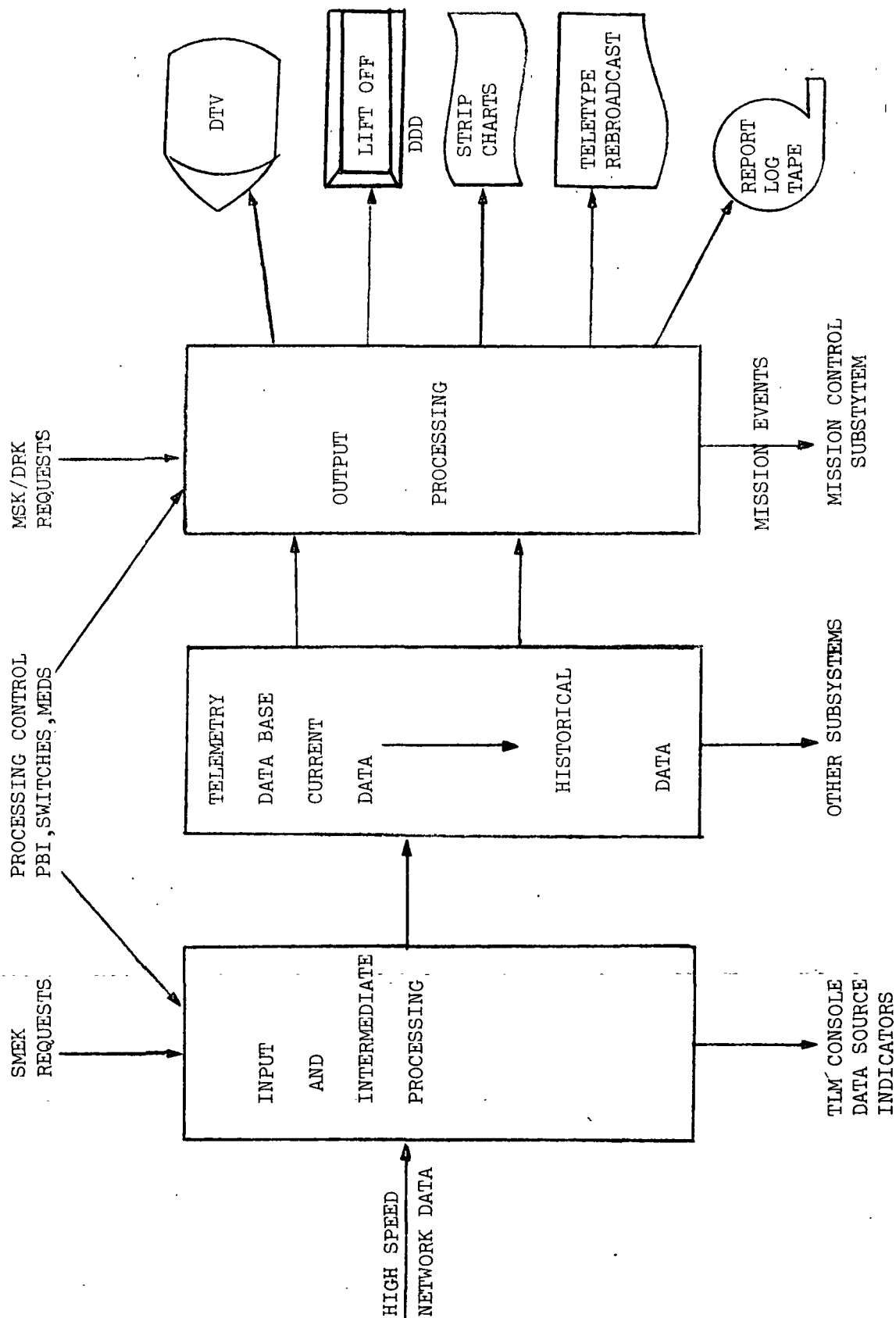


Figure 1. Telemetry Data Flow

GENERAL SUBSYSTEM DESIGN

The major role of telemetry programming, both in the real time routines and in the support programs, is data conversion and data formatting. The volume of data, the amount of unit processing, and the time interval allotted makes the efficiency of on-line routines especially important.

Telemetry programs are further characterized by extensive decision logic, whereby the operations performed at any given time are subject to control by data content, data quality, and manual selection. Object code efficiency, extensive bit manipulation, and RTOS interface combine to dictate the use of Assembler language programming.

However, the instability of data formats and processing requirements necessitates a compiler-like data description and reference capability. Macros and a common data base definition are two methods employed to achieve the required flexibility. Tabular processing controls and program modularity satisfy the changing requirements environment.

MACRO USAGE

Macros are an OS/360 Assembler tool, which invoke a compiler-type capability. The Telemetry subsystem uses this tool in three general areas: table mapping, table generation, and standard logic expansion.

Mapping a data structure involves assigning labels and allotting space to the individual data items. By defining the telemetry data bases in macro form, all users may access a data base item symbolically. Item displacements and item boundary alignments are resolved by macro definitions. A common table map may be introduced into many programs by referencing the macro library element. When the table map changes, the user programs are re-assembled thus obtaining the new table attributes. Examples of the mapping facility are data base definitions, Telemetry Status Table references, message logs definitions, and limit definitions.

Macros provide a convenient method of defining a table structure. A prototype statement defines all necessary types of entries without specifying the particular entries. Through pre-processed input or through programmer-coded statements, the specific entries are assembled, using the prototype statement and its logic, thereby generating table contents. Many sets of input may be assembled and will produce the same table structure with different contents. This method requires the additional effort of defining the table structure, but it is offset by the rapid, error-free generation of tables. Many inputs are generated by the pre-processor programs (refer to Utility Programs); therefore the number of programmer-coded statements is minimized. Format Control Tables for digital television,

Digital Display Tables, Switch Selector Tables, and various table initializations are examples of this process.

The availability of a user-oriented macro library can supply common and standardized services for a multitude of programming situations. Common execution logic is coded and verified independently of user routines, incorporated into the macro library, and then expanded upon request into user routines. As changes warrant, the master copy may be updated, verified, and reassembled into the routines. This procedure reduces individual program errors and establishes a logic standard. The most prevalent usages of this service are as follows:

1. Module and routine interface - saving and restoring registers, establishing program addressability and save areas, and building calling sequences
2. Standard high-speed module logic - vehicle logic, which must be contained in all high-speed processing modules
3. Management of program control flags - automated bit and byte assignment and compiler-like references
4. Time conversion - converted RTOS time units into a variety of floating-points formats (hours, hours and minutes, and seconds, etc.)

TELEMETRY DATA BASE

Telemetry processing is characterized by its compilation and utilization of a finite, special-purpose data base. Using a telemetry definition, a data base is the collection of quantities necessary to satisfy all intermediate and output functions. The data base method allows all functions to reference a common homogeneous set of parameters and provides a compatible output generation. The data base obtains its source from all defined telemetry parameters, special computations derived from telemetry inputs, and certain required constants. Several types of data bases are found in the Telemetry subsystem. These types are discussed below.

High-Speed Vehicle Data Bases

The high-speed vehicle data bases (intermediate data arrays) consist of the latest measurements received from a particular vehicle/data type source. The current structure defines one data base for each transmitting source and data type, live or playback. Space is allotted in the vehicle data base for every measurement that appears in the high-speed data stream and for the results of all intermediate or special input processes.

All defined parameters may not appear in the input frame by line format definition; therefore, only the active or valid inputs replace their previous readings. References to the vehicle data base yield all of the current samples.

Playback vehicle data bases are identical in structure, update, and labels to their live counterparts. The distinguishing factor is the data type which "feeds" these arrays.

The first part of the high-speed data base is the header, which contains the line format number, the vehicle identification code, the telemetry site, the live or playback indicator, the bit rate indicator, the processing codes, and the control bits to reflect the data's status and quality. Two time words are associated with the header. The GMT of Assembly is the time of message generation. For CSM, LM, AGC, LGC, AGS, and S-IVB-IU, this time is "tagged" at the remote site; and for SIC, S-II, and AMD, the time is tagged at RTCC input. The GMT of Receipt is the time at which the message queue is generated for the telemetry processor. Also retained in the header portion are the total number of bytes allocated, the communications processor label and time words, the telemetry message label, and the "burst-calibration" codes.

The second part of the high-speed data base is the body, which contains slots for all defined telemetry quantities. Vehicle data inputs are converted into specified engineering units. The body contains analog parameters, scaled quantities, time quantities, logical and bilevel representations, computed values, and displayed MED values. Parameter units indicate the type and form of space allocated. The analog values, computed values, and MED values are defined in short form, floating-point units. The scaled and time quantities are expressed in long form (eight bytes), floating-point units. Bilevels are grouped into eight or sixteen bit groups and saved in binary fullwords. Logicals also occupy fullwords in binary form. Parameters are labeled by internal name and mapped by macros.

The third part of the high-speed data base contains each parameter's status indication. Each slot in the body has an associated status indicator. Parameters that occupy more than one fullword (four bytes) have an additional unused status indication. The mapping algorithm is as follows:

$$\text{STATUS} = \text{LNG} + \text{DSP}_i/4$$

where STATUS — Displacement in bytes to PARAMETER_i status indicator

LNG — Displacement in bytes to status array

DSP_i — PARAMETER_i displacement in the body.

This algorithm is illustrated in Table 1. Each parameter's status indicator contains eight bits, and each bit reflects a particular condition. The possible conditions are as follows:

1. Missing — A computed output could not be performed due to faulty input data, non-initialized computation, or magnitude errors.
2. Off Scale High/Low — The parameter's input PCM count is outside the calibration range.
3. Dead — The parameter is not currently being received by telemetry (not defined in the current line format or on-board downlist).
4. Static — The input measurement is defined to be "high bit rate," but the data is transmitted in "low bit rate".
5. Nochange — The parameter's input count is not changing, therefore the engineering value remains constant.
6. Limit — The current engineering value is outside the prescribed limits for this parameter.

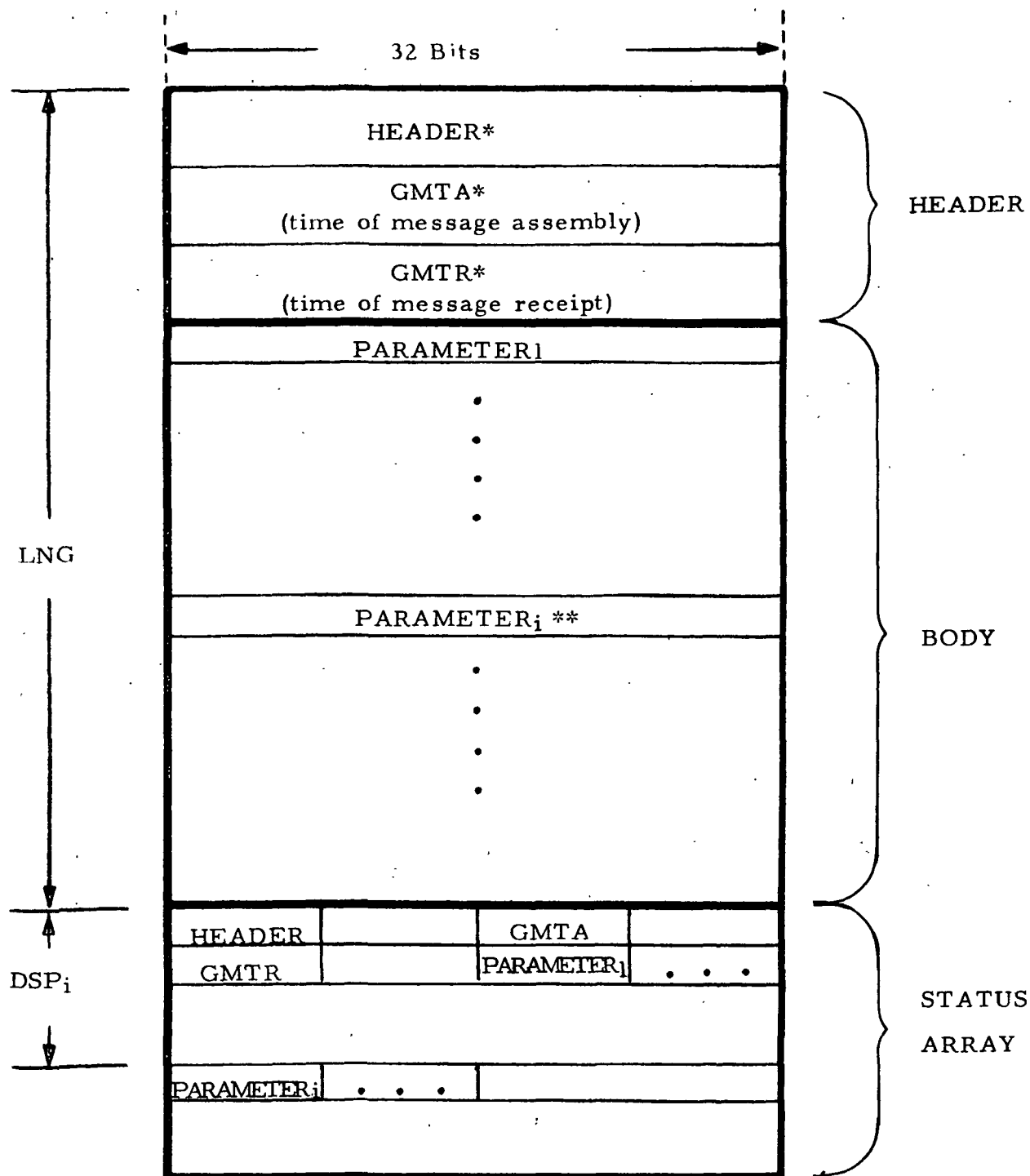
A description of these conditions may be found in the fourth action, Subsystem Services, under Data Conversions, Computations, and Data Limit Sensing.

Summary Message Log

The second type of telemetry data base is the summary message log. These logs are similar in structure to the high-speed data arrays. They contain a header with time quantities, a selected subset of parameters received in the high-speed input stream, and associated status indicators. Many subsets are defined, each containing a unique format number. A message log represents one format with the latest "n" messages. A new message will result in the oldest one being lost when the maximum has been reached for that format. The selection of parameters is determined by their presence on the paging-tabs type displays. "N" is fixed at fifteen, but re-establishment is possible if the demand warrants.

Special Purpose Data Logs

Special purpose data logs constitute the third type of data base and satisfy special functions such as system plot tables, guidance tables, rebroadcast tables, and switch selector tables.



* - This quantity occupies a doubleword

** - Parameters may occupy single or doubleword

Table 1. Intermediate Data Array Mapping Algorithm

TABULAR PROCESSING CONTROL

Tabular processing control specifies what actions are to be performed by a routine via table elements. These elements consist of control codes, processing constants, and pointers to related information. This technique can be used effectively when well-defined actions are performed on items of a data structure. The operation performed on each element need not be the same, but there should be significant subsets of elements requiring the same process.

Each table element specifies either explicitly or implicitly what operation is to be utilized, what input data item is to be used, and where the results are to be placed. Each element may also provide, directly or indirectly, the necessary processing constants. The routine generally scans the table, element by element, and responds to the indicated action. In this manner, the execution logic is divorced from specific descriptions of the process, the control table may be revised or replaced without disturbing the logic of the routine, new and varied operations may be included with minimum effort, and real time processing can be altered by dynamically replacing the routine's control table. This capability exists for cross-reference/calibration tables, limit sense tables, and switch selector tables.

The following various types of processing are subject to this technique.

1. High-speed input frame unpacking and calibrating
2. Limit sensing
3. Digital television output formatting
4. Teletype rebroadcast formatting
5. Report generation formatting.

Computations and digital display drivers (DDD) pose unique problems which make these routines difficult to implement. Computation descriptions vary extensively, and each one contains unique logic. DDD's require complex definitions and unique "loading" methods, which discourage the use of this technique.

Process control tables are generated either by the pre-processor utility program or by the macro facility of the OS/360 Assembler. The detailed requirements, generally supplied by the customer, provide the necessary input for pre-processor generation of these tables. All tables are initialized in large core storage (LCS), and selected tables reside on an on-line disk. The disk resident tables can be loaded into LCS by PBI command. Tables which reside on this disk are (1) cross-reference (calibration), (2) limit sense, and (3) switch selector.

As the need arises, additional types of control tables may be placed on this disk.

PROGRAM MODULARITY

Program modularity is an essential technique used by Telemetry. The Telemetry subsystem's definition of program modularity is the isolation of executable program logic into functional elements. Each element performs a distinct non-redundant service. These elements may exist as a library routine, a macro, a load module, or a section of logic within a load module. The overall telemetry structure can be modified as requirements dictate.

Library routines are typical examples of modular programming that operate under the caller's control and perform their designated function without consuming the caller's storage. Generally, these routines are reentrant, allowing many users to utilize their function. Telemetry services performed by library routines are (1) message verification, (2) data conversion, (3) specialized subroutines used by computations, (4) data limit sensing, (5) DDD's, and (6) digital television.

For the Lunar Landing Program, the Telemetry subsystem limits the majority of mission-dependent logic to the computations load modules and to remote sections of logic. This factor provides expedient checkout, quicker mission turn-around, and efficient maintenance.

FUNCTIONAL STRUCTURE

The Telemetry subsystem consists of ten functional units defined by work scope. Subsystem control, high-speed telemetry, summary message generation, and special display processing are the major functions. The high-speed telemetry function requires five independent tasks, and the special display processing function requires three independent tasks. The magnitude of responsibilities designates the use of several independent tasks in these areas. The subsystem control and summary message functions each operate under one independent task.

Distinct advantages are realized in this particular subsystem's structure. First, Telemetry's usage of the Central Processing Unit (CPU) is significantly reduced because less demands are required of the system's control program (RTOS). Maintenance of independent tasks, minimum requests for specific control services (i. e., LINK, RTATTACH, RTPUT) and maintenance of storage areas requires less system "overhead". Second, each functional area conforms to certain standard techniques. Unique logic is isolated in remote sections for expedient mission changes. For example, the high-speed task's responsibility is that of directing the execution of the functional elements rather than actually performing the function itself. Third, more emphasis is placed upon data management techniques. Standard procedures are implemented for handling data tables, control tables, and storage areas in which the data resides. These factors, collectively, reflect a more flexible subsystem.

SUBSYSTEM CONTROL

The primary interface with the telemetry users is the "Control" task, referred to as the Telemetry subsystem Control task. This task receives, via data routing, the inputs from the ESOS panels, SMEK panels, telemetry console logic modules, display selection requests, and telemetry related PBI's. It receives from the Mission Control task requests for initialization, phase changes, and lift-off corrections. The Control task manages the subsystem operation through the use of RTOS data routing and queue control, the Telemetry Status Table, and direct requests to the other subsystem functions. The subsystem Control task is illustrated in Figure 2.

Data routing on the various switch panel inputs and on subsystem initialization is accomplished at the receipt of phase initialization. The data routing and queue controls for high-speed network data are established by the Control task.

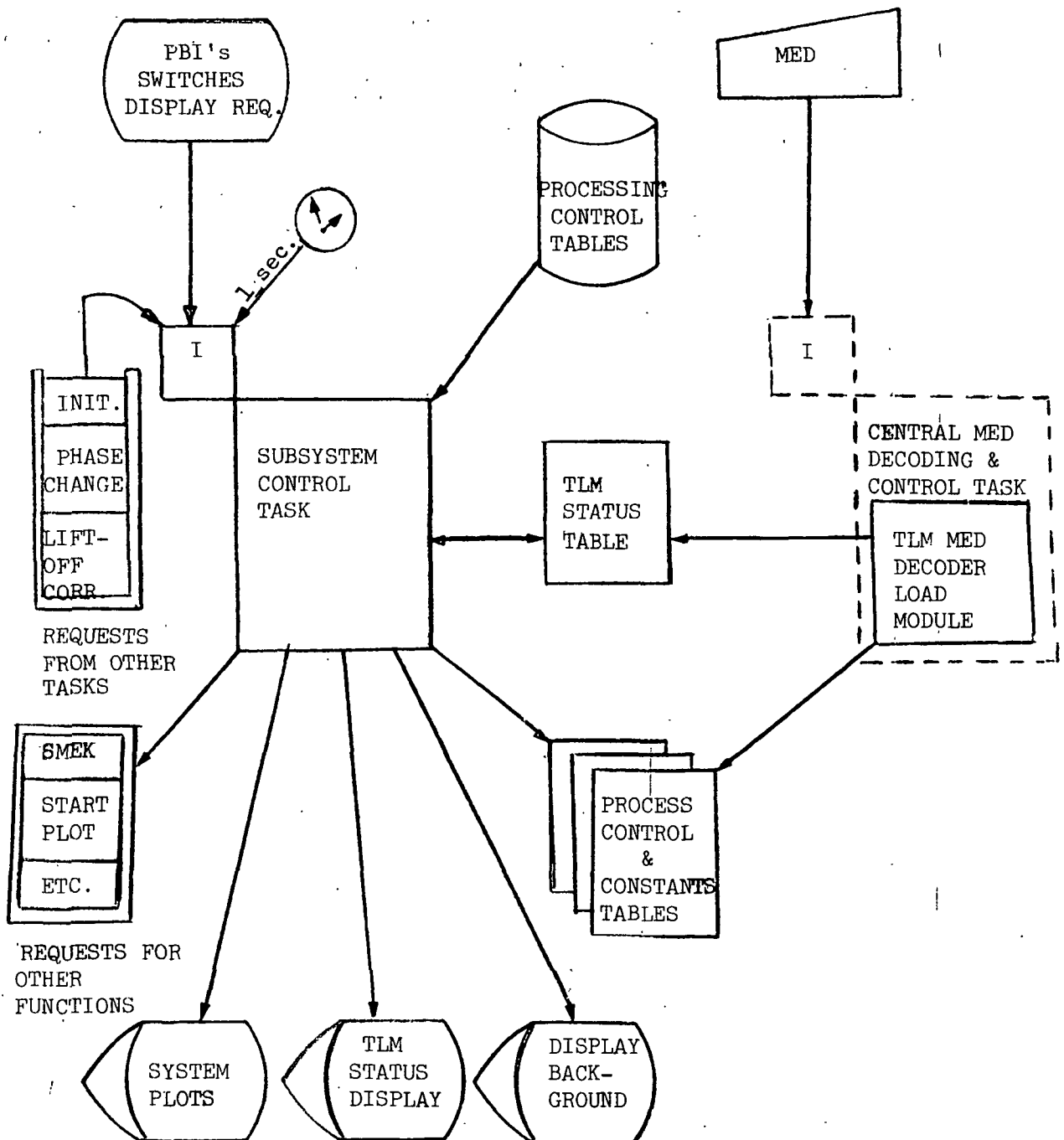


Figure 2. Telemetry Subsystem Control Flowchart

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Inputs that establish a mode of operation, but do not require immediate response, are communicated to the other subsystem tasks via the Telemetry Status Table, which is a data table that provides subsystem control information both by the Control task and other subsystem tasks. Items supplied by the Control task include the ESOS switch positions, logic module controls, limit sense/category controls, D/TV channel and update control, times of certain critical events, and special computations controls.

Other functions and tasks are queued by the Control task when the input requires immediate response. SMEK panel inputs are interrogated, and the results are passed to the summary message task, which operates independently of the Control task. Start plot PBI's cause control to be passed to a dependent function of the Control task, namely the system plots function (TMXSYSPL). Display selection inputs, MSK/DRK, require the services of another dependent function (TMDSPREQ).

An example of processes performed immediately by the Control task's function are the loading of disk-resident tables such as calibration/cross-reference tables, limit tables, and switch selector tables. These tables are generated prior to real time execution and are loaded on to disk at real time preparation.

An auxiliary function of the Control task is the generation and updating of the telemetry status displays, which are D/TV displays of subsystem status driven from the Telemetry Status Table. Only selected items of the status table are presented on these two displays.

A subsystem control function outside of the Control task is the MED Input Decoder. This function operates directly under the Central MED Decoding and Control task, which is a function of the Mission Control subsystem. The following items are types of MED inputs.

1. Computational constants — Constants used by the special computation functions are inserted in their related tables (MED tables).
2. Limit values — Upper and lower limit values are placed in the limit tables for the indicated parameter.
3. Status table controls — The following values and indicators are for processing logic.
 - a. Event times such as GMTLO
 - b. Processing controls - vehicle enable/disable processing, character count overrides, and nuclear particle computation enable/disable
 - c. D/TV processing controls - number of available telemetry channels

The following functions operate under the direction of the Control task (TTSCNTRL)

- TMSUPER1 receives, validates, and interprets ESOS changes, SMEK panel entries, phase changes, program control module entries, and re-broadcast module entries. It updates the Telemetry Status Table and generates requests to associated functions.
- TMSUPER2 initializes routing for network data, and manual controls such as SMEK and ESOS panels.
- TMSTATUS updates the telemetry status displays.
- TMDSPREQ receives display selection inputs, manages the telemetry TVGUIDE and TV dictionary tables, and updates background information on telemetry displays. This function determines telemetry channel availability.
- TMXSYSPL drives all system-plot type of displays. This function retrieves high-speed vehicle data from the necessary intermediate data arrays, maintains this information in data tables, and drives associated PBI indicators.
- TMCLDTAB locates requested tables on the telemetry disk and replaces them in the allocated LCS locations. It generates on-line messages about telemetry table loading.
- TMCDDDLDD writes DDD processing control tables into the DDD data tables at phase initialization. DDD addresses are resolved by the off-line Real Time Link Edit (RTLE) program and thus require a loading procedure.
- TMQTMED decodes, validates, and transmits information entered by the manual entry device (MED) in conjunction with the Control MED Decoder.

HIGH-SPEED TELEMETRY

The Lunar Landing Program design provides several significant improvements in high-speed processing. These improvements are described throughout this discussion, and they fall into four general areas: data routing, data collection, data compression, and standardization.

Fourteen separate input data frames are processed by high-speed telemetry. Live data frames are identified for nine vehicles: CSM, AGC, AMD, LM, LGC, AGS, S-IVB-IU, S-II, and S-IC. The playback mode is applicable for five of these vehicles: CSM, AGC, LM, LGS, and AGS.

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For the Lunar Landing Program, five functional units (tasks) control the processing of these high-speed input frames. Three tasks (TTHSCSML, TTHSLEML, and TTHSSIUL) are responsible for live data, and two tasks (TTSHCSMP and TTHSLEMP) are responsible for playback data. Due to the data similarities, this discussion pertains to live and playback data interchangeably. Concurrent data receipt, display requirements, and system utilization are the determining factors in the generation of this structure. This separation is further illustrated in Figure 3.

Data routing is established for each vehicle/data mode input. At phase initialization, each routing specification is initiated for "data-only" queues. In the data-only type routing, RTOS will create queues to the indicated task when an incoming message satisfies the specified CP LABEL and MESSAGE LABEL codes (message selection criteria). When an incoming message matches the message selection criteria, the input is passed to the delegated task. The routing specification is then changed, by the receiving task, to a "data-or-time" type routing. Data-or-time routing specifies queue generation upon satisfying either of the following conditions:

1. The indicated number of messages (MSGCNT) has been accumulated.
2. The specified time interval has elapsed.

For high-speed vehicle data, MSGCNT is one, and the time interval is 1.1 seconds.

Each active vehicle frame should arrive at one-second intervals; however, high-speed processing allows a .2 receipt "band-width". For the same vehicle/data mode input, normal processing is considered for a delta-time range of 0.9 to 1.1 seconds. "Burst-mode" processing is selected for a delta-time less than 0.9 seconds, and "data-dropout" processing is required for a delta-time greater than 1.1 seconds. Burst-mode processing and data-dropout processing are described under the Subsystem Services section, Message Validation. The time range is computed as:

$$\Delta t = T_2 - T_1$$

where:

T_2 is RTOS message receipt time for the current input frame, and

T_1 is RTOS message receipt time for the previous frame.

When a high-speed task becomes active due to vehicle input, several resources are allocated, which are retained during the active state. The task resource

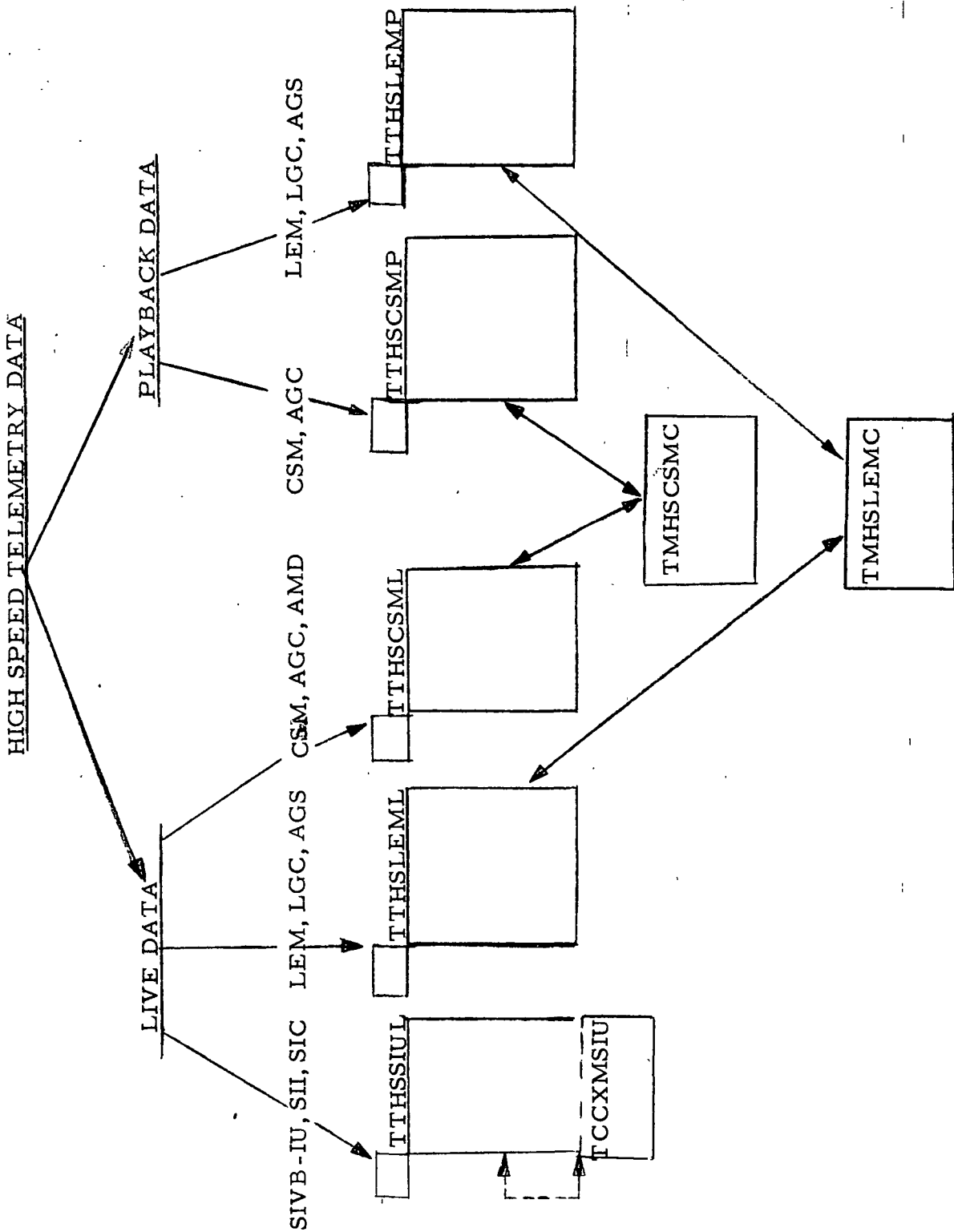


Figure 3. High-Speed Telemetry Task Structure

table is created; the Telemetry Status Table is located; the initial temporary working storage is obtained; the intermediate data array storage is allocated; and the latest vehicle data base is retrieved from LCS. The input frame is validated (Message Validation), and if successful, the frame is converted to engineering units (Data Conversion).

For the initial input frame, processing continues through the intermediate and output phases. The intermediate phase consists of special computations (Computations) and limit sensing (Data Limits Sensing). The output phase consists of digital display updates (Digital Display Drivers), digital television updates (Digital Television), mission event notification, and vehicle data base update on LCS. The processing elements and their interface are illustrated in Figure 4.

Through-put of each succeeding input frame is considered normal processing. During this cycle, the functional processing is identical to the initial cycle except for one important difference. Note that each active task may process a maximum of three vehicle sources. If one "task-assigned" vehicle source is active, processing is uninhibited, input through output. When two or more task-assigned sources are active, the intermediate and output phases are delayed until one of the two following conditions occurs:

1. The input frames for all active task-assigned sources are received and converted, or
2. The 1.1 second time interval elapses for the first active source.

When one of these conditions occurs, control passes to the intermediate and output phases. This collection algorithm expects, but does not require, two assumptions to be valid.

1. All active sources are received in a relatively short time interval within the one-second period.
2. Once the task-assigned sources become active, they will remain in that receipt sequence.

If the assumptions are violated, program logic will rectify the condition.

Data termination is the third type of high-speed processing commonly referred to as LFI logic. This logic is initiated by the detection of an input frame indicator (LFI), and abbreviated processing is performed. The console indicators are updated; the routing is reset to data-only; unlatched DDD's are reset; inactive conditions are reflected on displays; the intermediate data array is flagged; and temporary working storage may be released. If all task assigned sources become inactive, the task and all of its resources are removed from the system.

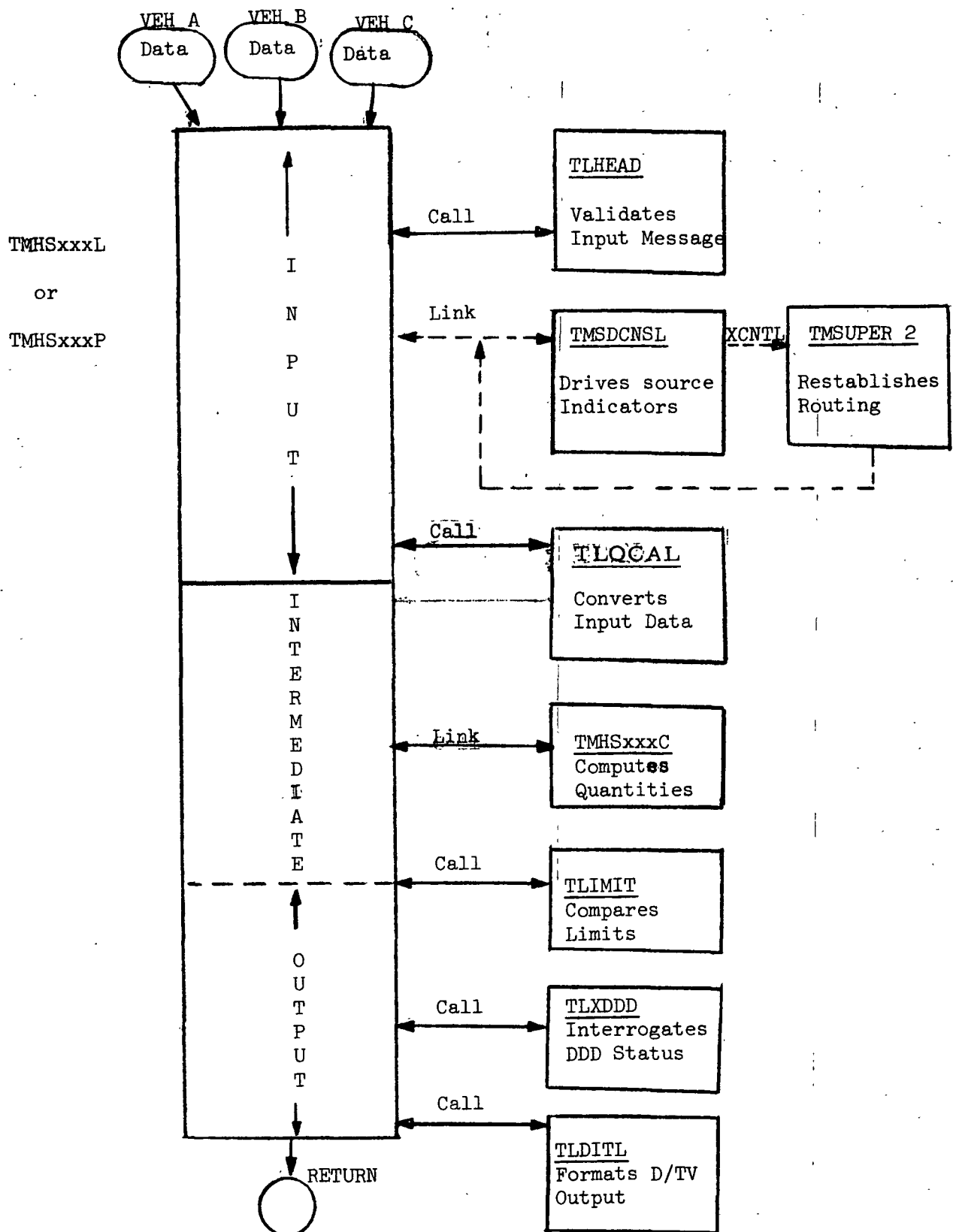


Figure 4. High-Speed Processing Flowchart

Non-redundant processing (data compression or changes-only) is another technique high-speed telemetry uses. This technique is a simple algorithm that states that input value (PCM counts) must change to cause an output quantity change. The following subsystem services utilize this technique: Data Conversion, Computations, Data Limit Sensing, and Digital Display Drivers. Characteristics and exceptions for Data Compression are found in the associated write-ups under Subsystem Services.

Isolated special logic is another characteristic of high-speed processing. Mission critical events, unique DDD interrogation, switch selector processing, and command history processing are typical examples of special logic. Mission critical events and DDD interrogation are highly unstable from mission to mission; therefore, these routines are located in separate routines. Switch selector and command history processing are associated only with the S-IVB-IU function, and this factor makes them desirable as remote functional elements. Inter-system notification is included in the DDD interrogation logic. If an event occurs requiring the attention of the other subsystems, a queue is generated for the Mission Control task (GTPHASE), and the event and its time of occurrence is communicated.

Other subsystems are required to access telemetry parameters, and since high-speed processing is essentially phase-independent, these characteristics make the data table references feasible. The mapping algorithm for the intermediate data arrays is provided to all interested users, and each subsystem may obtain their required parameters at various time intervals. The use of the status indicators is encouraged, and any possible error conditions may be determined at the time of reference.

The following modules service the high-speed processing functions:

1. TMHSCSML - CSM, AGC, AMD live sources
2. TMHSLEML - LM, LGC, AGS live sources
3. TMHSSIUL - S-IVB-IU, S-II, S-IC live sources
4. TMHSCSMP - CSM, AGC playback sources
5. TMHSLEMP - LM, LGC, AGS playback sources
6. TMSDCNSL - drives source light indicators
7. TMSUPER2 - establishes routing, data-only or data or time
8. TMHSCSMC - performs CSM, AGC, AMD computations
9. TMHSLEMC - performs LM, LGC, AGS computations

SUMMARY MESSAGE PROCESSING

The assigned function of the Summary Message task is to control the processing of summary message generation. The inputs to this functional unit are SMEK requests, summary print PBI requests, and rebroadcast switch and PBI controls. The subsystem control function "fields" these requests and queues the necessary function. For SMEK requests, the SMEK processor (TMSMEKIN) receives the decoded inputs and controls the message generation. For summary print PBI input, the control task queues a functional element (TMXPAPER) to release the summary print tape (TSPAP). For rebroadcast inputs, the Control task queues Rebroadcast processor (TMXLSREB), and this function transmits indicated teletype messages to external devices. Figure 5 illustrates the summary message flow.

In SMEK processing, the input function retrieves selected subsets of current high-speed parameter values. Identified by formats, these pre-defined subsets may reflect the status of various on-board systems, or they may reflect an overall status of many systems. Therefore, a particular format may require retrieval of parameter values from several intermediate data arrays. Since several formats may be indicated in one request, the SMEK input processor obtains a copy of the needed high-speed arrays, determines the necessary output indicators, and "calls" the output functions. The calls are created sequentially, one format per call, until the SMEK request is satisfied. Only data from active high-speed sources is processed, and in the case of multi-vehicle formats, inactive parameters will be flagged DEAD if the vehicle source is inactive. For a requested format, at least one high-speed vehicle source must be active to successfully generate a summary message. In the case of AGC and LGC formats, the "downlist" identification from the associated high-speed array determines the requested format. Parameters, not in the current downlist but defined in the requested format, are flagged as DEAD for output generation.

TCQLSDDD drives the input module indicators on the Telemetry console and requires no logging technique. Two sets of input modules are required: one to display AGC, CSM, and AMD formats, and the other to display LM, LGC, AGS, and S-IVB-IU formats. Each module reflects the incoming format number, the external station code, and the class indication.

Requested messages will reside in one or more historical logs. The output functions are selected by an output control processor (TMLSDISP), based upon the SMEK attributes: display and/or rebroadcast. Formats contain pre-defined attributes that take priority over the requested attributes. Both the requested and pre-defined attributes must agree for requested types of processing. (For example, SLV formats cannot be displayed.)

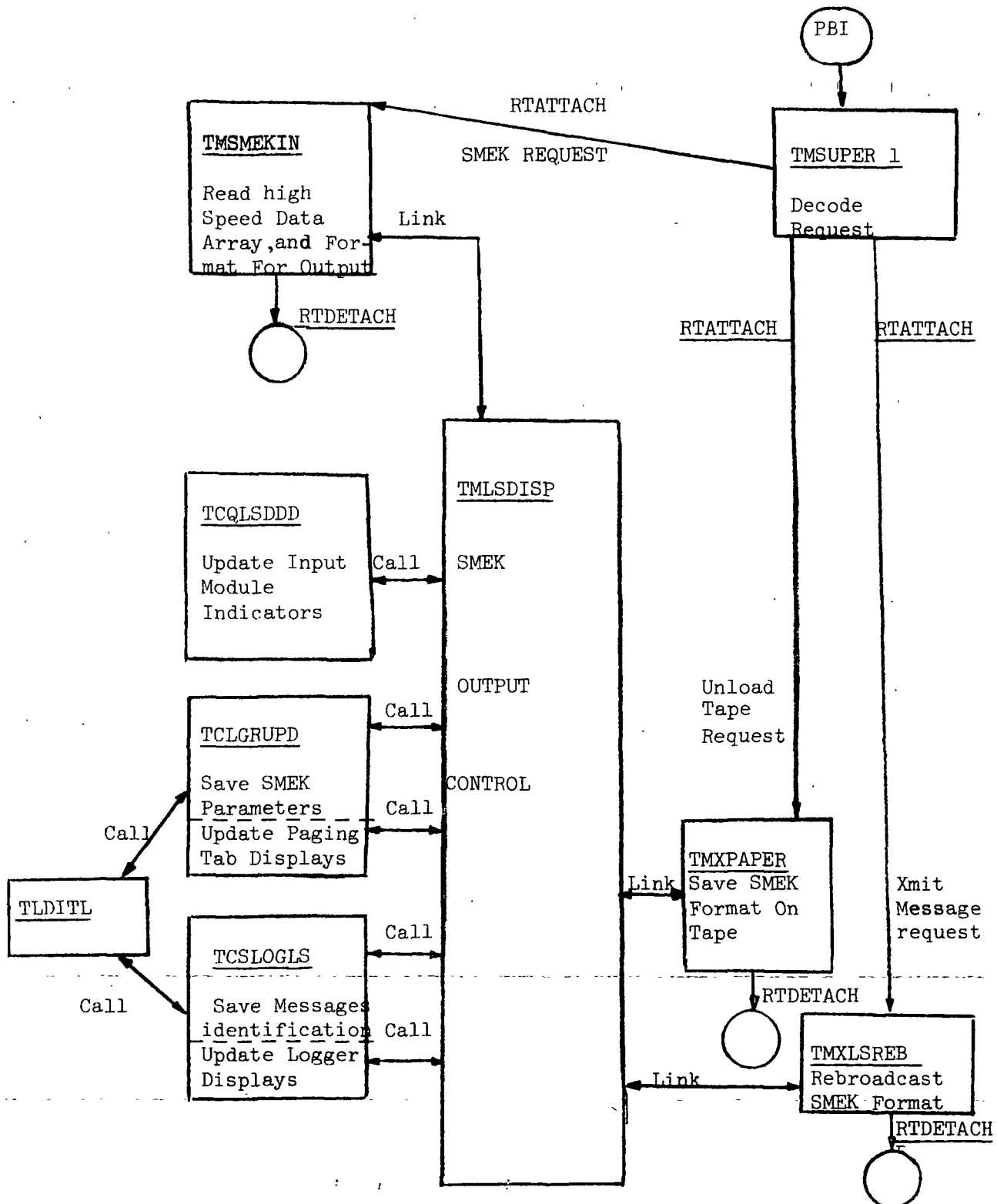


Figure 5. SMEK Task Flowchart

Display output generation consists of paging-tabs type displays, and message-logger type displays. For both types, a dictionary and "save" table (log block) are required. The dictionary reflects the status of the save table, which includes the number of messages held, the latest message logged, and certain control information. The log blocks, one per display-defined format, contain the actual information required for displays.

The method of saving paging tabs data is based on display description. Only those parameters indicated on paging tabs displays are logged. The customer-supplied FDS cards are processed in an off-line environment to generate the log block definitions. When a SMEK format indicates "display", the logging routine (TCLGRUPD) obtains the log block definition, the correct format log block, and the display dictionary. Using the log block definition, the logging routine moves selected high-speed quantities and status indicators to the format's log block, and the display dictionary is updated to reflect the new message. If paging tabs displays are being viewed, each display is checked for format number and updated with the proper format's messages.

Message logger displays require only format-identified information; therefore only the header indicators are saved in a log block. These indicators consist of the external format number, the internal and external station codes, the class indicator, the time of message generation, the GMT, and various flags. A logger dictionary is maintained for display purposes and contains the number of messages and the vehicle code. Twenty messages on each of three pages are currently defined for LLP, and each logger display represents one major vehicle: CSM, LM, or SLV. CSM, AGC, and AMD formats are displayed on the CSM logger; LM, LGC, AGS, and S-IVB-IU formats are placed on the SLV Logger. No formats are defined for S-IC and S-II vehicle sources.

For a display-indicated format, TMLSDISP passes control to the dependent module TMXPAPER. This module writes the associated intermediate data arrays on a magnetic tape (TSPAP) for later off-line processing.

For a rebroadcast-indicated format, TMLSDISP passes control to another dependent module, TMXLSREB. Its function is converting selected parameters into teletype code and saving the converted message for transmission to designated remote stations. The time of transmission depends upon switch-settings on the Telemetry console. The switch positions are "Manual" and "Automatic", and the messages are transmitted as indicated. Up to six messages may be saved, and each message is transmitted in receipt sequence.



SPECIAL DISPLAY PROCESSING

Update methods and the complexity of requirements dictate the use of three independent tasks. Guidance displays, input buffer displays, and the Nuclear Particle Detection System contain requirements that discourage their operation in previously described tasks. The Nuclear Particle Detection System is basically a series of computations; therefore, its characteristics are discussed in the Special Computations section.

Guidance displays contain plots and digital values from the Telemetry, Orbit Trajectory, and Launch/Abort subsystems. These displays are initiated either by PBI control or special events, and are updated on a one-second cycle for a pre-determined time period. The guidance function (TTXGDNCE) retrieves selected parameters from the Telemetry intermediate data arrays, the Orbit Trajectory data tables, and the Launch/Abort data tables. It converts these quantities into digital television formats, updates the associated displays, and saves the formatted data for historical purposes. Certain output quantities require special computations, which are performed by the guidance function. Several digital indicators are also driven by this routine. The stripchart function operates under the Guidance task.

Input buffer displays are driven by an independent task (TTCENTRF). Input high-speed vehicle frames are routed separately to this function. The routing specification indicates a one-second data-and-time type routing with a collection number of nine. Each second, the input buffer function is queued with the collection of messages received in the last second. A MED entry controls the selection of live or playback data, which is viewed on fifteen vehicle-oriented displays. The input values are compared to the displayed values, and if changed, the new value is displayed with a change indicator (diamond). The CP label, CP time, Telemetry message label, and GET are also displayed on each vehicle display. One display contains the header information from all active sources.



SUBSYSTEM SERVICES

Subsystem services are special elements in that they operate under several different tasks and perform unique functions. All subsystem services are re-entrant library subroutines with the exception of Special Computations and Strip-chart Processor, which reside as load modules. Each subsystem service requires a calling sequence, which is generated by a macro.

MESSAGE VALIDATION

Message validation is the high-speed processor's quality control routine. The responsibilities of this function include checking the status of incoming high-speed messages, determining the type of processing, establishing a routing mode, and driving the high-speed input indicators. Three modules are defined for this function: TLHEAD, TMSDCNSL, and TMSUPER2.

The reentrant library subroutine, TLHEAD, determines the current status of input telemetry messages. The high-speed message label is validated for CCATS bit, line format, vehicle identification, and station identification. Other bits interrogated are the last frame indicator, live/playback indicator, and high/low bit rate indicator. Comparison of this information with the "saved" indicators yields one of seven processing flags.

1. Initial flag signifies that the vehicle source was not active before, and special initialization procedures must be performed.
2. Normal flag indicates a periodic update cycle.
3. Station handover flag means the active vehicle source has changed reporting stations.
4. Missing-first flag signifies that a 1.1 second time trap has occurred without receiving the proper message.
5. Missing-nth flag indicates missing data for the "nth" consecutive second.
6. No-process flag indicates that the current message should be rejected.
7. LFI flag denotes that the indicated data should be terminated.

An "output" flag indicates that the intermediate and output processing steps should be performed. This indicator is returned with each initial or station handover flag, and every time the last active acquired vehicle frame occurs, or its time "trap" occurs. A "process-all" flag is returned with the initial or station handover flag. This flag tells TLQCAL (Data Conversion) to ignore data compression logic. If the process-all flag is not set, TLQCAL will execute data compression logic.

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The no-process flag indicates message rejection for one of several conditions: (1) invalid line format, (2) rapid message receipt—"data burst", (3) incorrect message length, or (4) simultaneous receipt of four or more remote sites — "telemetry overload". The associated high-speed processor terminates the related vehicle processing on any of these conditions.

Two manual inputs make use of the LFI flag. Manual LFI simulates an input containing a last frame indicator. Vehicle shutdown uses this flag to initiate "housekeeping" logic in the task.

TMSDCNSL receives control from the high-speed processor when a change of data-type status is determined. Line format change, station change, bit rate change, CCATS validity change, or missing data change constitutes a LINK to TMSDCNSL. The TLHEAD routine is responsible for the normal, missing-nth, and no-process flags, and TMSDCNSL sets the initial, station handover, missing-first, and LFI flags for the appropriate change. Vehicle, station, and data status indicators on the Telemetry console and the MOCR group display are updated by this routine. The erasable memory dump indicators and data-burst indicators are also determined during this processing.

TMSDCNSL prints an on-line message for acquisition and loss of site. This message is generated on initial, station handover, and LFI processing, and the contents of this message are GMT, vehicle source, station and data mode.

TMSUPER2 receives control when initial or LFI processing is detected. The purpose of this routine is to establish a routing mode. A data-or-time² mode is initiated during initial processing, and a data-only² mode is re-established when the last frame indication is sensed. Vehicle shutdown is achieved in this routine by disabling or enabling the appropriate routing specification. TMSUPER2 returns to the calling high-speed processor when its function is complete.

DATA CONVERSION

Library subroutine TLQCAL unpacks high-speed telemetry data, checks for valid input, performs a data conversion and stores the converted data in the intermediate data array. These functions are performed on a parameter basis.

The unpacked data is checked for correct line format and for low bit rate sub-commutation. Analog data is checked for off-scale high and low conditions. A status array is maintained in conjunction with the intermediate data array to indicate error conditions.

²

For definitions, see High-Speed Telemetry under Functional Structure.

Conversion of error-free data is performed under one of four categories:

1. Calibration — A set of single precision coefficients from the calibration table is used in an "nth" degree polynomial curve.
2. Scaling — A double precision scale factor from the calibration table is used to scale the data.
3. No Scaling or Calibration — The data remains in the raw unpacked form.
4. Raw Data Points — A set of single precision X-Y coordinates from the calibration table is used to perform a linear interpolation or extrapolation on the input data.

Each converted parameter is stored in a unique single or double precision slot in the intermediate data array and has an associated error-free status indicator in the status array.

Special handling is performed on the unpacked PCM of a pre-determined set of parameters before calibration or scaling. Special handling before scaling includes:

1. Parity dropped and one's-complementation if negative (AGC, LGC single and double precision data)
2. Two's-complementation if negative (SIU, AGS)
3. Parity dropped and two's-complementation if negative (AGS, LGC/ AGS downlist)
4. Parity dropped (AGC, LGC)
5. Special function sets decommutation (SIU) - An address input with the data word identifies the parameter as an element occupying a position in a particular set. Each set-position address defined for the mission has a unique intermediate data array location for storing the raw unpacked input. Each set-position address may also have pre-defined scaling information and a unique intermediate data array location for the scaled data.

Special handling before calibration include biasing of the parameter using a pre-determined parameter from the input stream. A MED override capability exists to inhibit applying the bias. Special handling such as complementation and bit shifting is also performed on parameters neither calibrated nor scaled. The capability exists to select from multiple scale factors or calibration curves. The selection for a pre-determined set of parameters is controlled by PBI's or bilevel parameters in the input stream.

Two tables, which are generated by the pre-processor, control the unpacking and conversion functions of TLQCAL. The Calibration Table contains all coefficients, scale factors, data points and special information needed to convert the data. The Cross-Reference Table contains one entry for each parameter to be unpacked and converted. The entries are in the order that parameters appear in the high-speed input frame. Each entry contains the number of bits to unpack, the converted parameter's relative displacement into the intermediate data array, a curve code identifying the type of conversion to be performed, a relative displacement in the calibration table, line format binary mask, and a subcommutation binary mask.

Two arrays are updated by the conversion routine. The intermediate data array contains a single or double precision entry for each converted parameter and an associated status indicator. The history array is a work area maintained for data compression logic, and it contains the current unpacked PCM for each parameter. Each parameter's displacement into the history array is equated to the related intermediate data array displacement.

Data compression or changes-only is data conversion of only those input parameters that might effect a change in the intermediate data array. Data compression is accomplished through the use of two modes of operation by TLQCAL: mode 1, process every parameter, and mode 2, process changes-only.

The history array and intermediate data array are intialized under mode 1 and updated under mode 2 for changes in PCM on a parameter basis. PCM comparison is made as each parameter is unpacked under mode 2, and the status bytes are maintained to indicate "change" or "no change". Special consideration is given to the conversion of those parameters that could effect a change in the intermediate data array, regardless of PCM changes. These conversion types include:

1. Multiple scale factors or calibration curves in which the selection (PBI or bilevel bit) of scale factor or calibration curve is subject to change
2. Biased parameters in which the bias parameter or MED override is subject to change
3. Special function sets with multiple scale factors.

These conversion types are flagged in the Cross-Reference Table for special consideration by data compression logic.

The capability exists to perform data conversion on split high-speed input frames of AGC and LGC downlists. A bit in the message label indicates which half of the frame is valid, and TLQCAL unpacks and converts only the valid half. This logic is compatible with data compression.



The following limitations exist for the data conversion routine:

1. Input parameters (PCM count) may not exceed 32 bits in length.
2. Each intermediate data array may not exceed 4095 bytes.
3. The maximum number of curve codes is 255.

SPECIAL COMPUTATIONS

The CSM and LM vehicle tasks each have a load module operating under them which contains the special computations required in Section 6.4 of TR170. The load module consists of a control assembly and at least one assembly containing the computations for each of the three vehicles. (See Table 2.) Because of the number of computations required for the LM, these computations have been divided into three assemblies. The control module determines which of the vehicles is active, then calls the corresponding computation assembly or assemblies. The same computation modules are used for live and playback data.

Since there is no playback data for the SIU, the computations required for this vehicle are in a separate assembly within the high-speed task. There are presently no computations required for the S-I and S-II.



A special task, TTHSNPDS, has been established to perform nuclear particle computations. The computation is initiated by MED, then routed once a minute, and stopped by a MED. The results of the computation are placed in a data table TZMEDNPS. The CSM special computations module reads the table and places the results in the CSM intermediate data array for display via D/TV. These computations are done with high-speed live CSM data.

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Table 2. Special Computations Structure

Task Name	Assembly Name	Veh	Mode
TTHSLEML, TTHSLEMP 	TCHSLEMC	Control Module	L/PB
	TCCMPLEM	LM	L/PB
	TCCMPLM2	LM	L/PB
	TCCMPLM3	LM	L/PB
	TCCMPAGS	AGS	L/PB
	TCCMPLGC	LGC	L/PB
TTHSCSML, TTHSCSMP 	TCHSCSMC	Control Module	L/PB
	TCCXMCSM	CSM	L/PB
	TCCMPAGC	AGC	L/PB
	TCCMPAMD	AMD	L
TTHSSIUL	TCCXMSIU	SIU	L
TTHSNPDS	TCHSNPDS	CSM	L

Data compression techniques are implemented into the LLP computations. If the input parameters or MED's associated with a computation have not changed since the last module entry, the outputs are not recomputed. A flag is set in the MED table to tell when a MED has been entered. Computations involving changed MED values, PBI's, time-based sums, or inter-subsystem parameters are exempt from data compression logic.

Several computations must be implemented for more than one vehicle. Instead of duplicating the code for each vehicle, one reentrant subroutine resides on the System Library. Each of the vehicles needing the routine sets up a parameter list and calls the subroutine. Currently there are subroutines for 5.3.8 DSKY Computations (TLDSKY), 6.4.41 Delta Time (TLDLTM), 6.4.50 (6.4.14.1) Resolver Attitudes (TLRESL), 6.4.51 FDAI Angles (TLFDAI), 6.4.53 Local Horizontal/Local Vertical Attitudes (TLHRVT), 6.4.47 and 6.4.55 Flow Rates (TLFLRT), and 6.4.65 Delta V's Coordinate Transformation (TLTRAN).

The requirements call for the use of the current reference matrix (REFSMMAT) in several computations. It is obtained by reading a data table, EZJGMTX3 (LM) or EZJGMTX1 (CSM), maintained by the Orbit Trajectory Computations group. Requirements indicate that the computations interpolate quantities in the orbit ephemeris table to obtain the LM position and velocity vectors. This is done by using a subroutine ELVCTR also maintained by the Orbit Trajectory Computations group.

Data input to the computation routines can produce questionable results or even computer interrupts. Occasionally, magnitude errors are created from the inputs, and the subsystem has only limited control of the data. No phase checking is done in the special computations routines. Computations using information from other subsystems might also produce questionable results if that information is not properly maintained.

When computations have inputs from other computations, it is possible that they cannot all be done during the same compute cycle. For example, if results of computation A are input to computation B, if results from B are input to computation C, and if the results from C are input to computation A, then it is not possible to do all three computations during the same compute cycle.

DATA LIMITS SENSING

Limit sensing is defined as the procedure involved in comparing engineering values with a pre-defined range of limits. The Telemetry Limit Sensing System Subroutine (TLIMIT) performs this function for selected vehicle-related and computer-derived quantities. This service compares certain vehicle measurements with defined limits, and resulting flags are set to indicate additional high-speed



processing. Each prescribed vehicle source requires a separate limits table; thereby the limit sensing service is performed on a vehicle basis.

The input to TLIMIT is one data table and two data arrays. The Limit Control Table is divided into two sections: (1) the limit control entries, and (2) the sets of upper and lower limits. Entries in the control section consist of a limit bit, and end-of-table bit, and a pointer to the associated limit values. One entry is defined for each parameter in the corresponding intermediate data array, and the limit bit indicates whether that parameter is eligible for limit sensing. If so, a corresponding set of single precision limit values is defined in the limits section. The vehicle's engineering values and status indicators are the two input data arrays that comprise the intermediate data array.

Cyclic examination of the limit control entries is performed by the limit sense routine. If a parameter is not currently eligible for limit sensing, the routine skips to the next control entry. Further tests are required for eligible parameters. First, the parameter's status indication is examined, and if the status reflects a MISSING, DEAD, STATIC or NOCHANGE condition, additional testing is inhibited. The off-scale high/low bits are then interrogated, and if found to be set, result in the limit bit being turned ON and the nochange bit being turned OFF. If the off-scale high/low bits indicate neither of these conditions, the parameter's value is compared to its associated limits. Parameter values within the prescribed range cause the routine to resume its cyclic inspection. Parameter values outside the indicated range necessitate the "out-of-limit" and "change" status indications to be set. Detection of the end-of-table flag causes control to be returned to the high-speed processor.

The capability exists to either dynamically replace the Limit Control Table, to replace a selected upper and/or lower limit, or to change the selection of parameters to be limit sensed. For any of these cases, the limit sense routine disregards the data compression logic.

DIGITAL DISPLAY DRIVER

This Telemetry service consists of three parts: a standard calling sequence, a library routine, and a control and History Table.

In the LLP program, requirements for telemetry data driver DDD's will be extracted from TR155 decks and combined with other telemetry inputs in an off-line procedure to generate two sets of cards. One set is used by Systems Integration to build the appropriate portion of the mission DDD tables, and the other set is assembled to build the tables used by the Telemetry DDD library routine.

A standard calling sequence has been designed for the high-speed task user, so that only the table name need be supplied in a macro call. The calling sequence

generated will read the DDD table, call the library routine, write the updated DDD table, and drive the events the library routine has returned in an output area. The last two functions are performed only if there are some events that have to be changed.

The DDD library routine has three basic functions: first to see if the data is invalid or unchanged, in which case the event is not changed; second to examine the data and the logic for the event to see if it should be on or off; and third to determine if a change in the event is required. If the latter is true, the history in the table must be updated, and appropriate words are moved into the output area to change the event. The location of data, the identity and logic for an event, and the space for its history are all provided in a DDD table entry. When the table is processed, the number of DDD updates and the words to affect them are returned to the caller.

The library routine is designed specifically to drive simple lights with two types of events: a bilevel or logical, represented by a bit in the data base body; or a limit, represented by a bit in the status portion of the data base. There is an extended capability to look at more than one bit with various kinds of logic, but since each bit is examined individually, this becomes impractical if more than two or three bits are involved and would be more efficiently done in a special computation that could present one bit to the routine for examination.

The library routine for LLP has been exclusively designed and tailored for multi-vehicle tasks. The routine will check the status of a vehicle to see if update, LFI, or perhaps no logic need be performed for a vehicle in the table. This structure permits the processing efficiency of up to three vehicles in one pass through the library routine.

Because of the large number of DDD's and the fact that every event in a vehicle portion of a table must be examined, the table and the code that loops through it are constructed in a fashion so as to take the least amount of execution time. Data compression logic is also incorporated in this routine because execution time is cut drastically if data is determined not to have changed. A serious limitation is imposed on multi-bit events in this area. Since detection of one unchanged bit cannot obviate the necessity of examining the other bits in a multi-bit event, the logic is not used on this type of DDD. A large number of multi-bit events would detract from the advantage gained in incorporating data compression logic into the subsystem.

DIGITAL TELEVISION

The RTOS D/TV Management system is based upon the identification of a display by its IFN (internal format number) and DIN (display number) with a certain IFN

range assigned to each mission subsystem. Those IFN's assigned to Telemetry have been further divided into telemetry display types based on similarity of display function and format. Within a type, each display is uniquely identified by its DIN.

Because of the large number of telemetry displays and the volume of data to be presented, a telemetry-oriented display formatting language (TDFL) and an associated real time formatter (TLDITL) are employed to gain execution time efficiency. At assembly time, TDFL statements generate a series of constants and formatting controls, which are presented to the formatter at execution time to be converted into device-dependent instructions and commands necessary for telemetry operation. With the exception of a few special purpose displays, the format control lists (FCL's) generated by TDFL reside in data tables, and are subdivided in such a way that a display may be updated from more than one source.

As a result of TDFL design, the total number of telemetry displays must not exceed 510. Flexibility exists in the assignment of display-type maximums within this range. However, effective limits result from the IFN/DIN range assigned to each type, and exceeding these limits require a reconfiguration of the system. Also, in an effort to maximize telemetry operation efficiency, a ceiling has been placed on the total number of TV channels that may be assigned to telemetry displays. This number may be changed by MED during execution.

When a display is requested, it is the responsibility of the display request function to initiate processing. An area in high-speed core is obtained for the display's FCL (this area will be retained as long as the display is being viewed), and the IFN/DIN is manipulated to determine the appropriate processing. Using the background portion of the FCL, information such as MSK, PCL letter, and registration marks is generated, and the hardware buffer is initialized and prepared for updates to the display.

Whenever new data is needed, the processing routines search the telemetry TVGUIDE for displays within its area of responsibility (the telemetry TVGUIDE contains only currently viewed telemetry displays). After locating such a display, the processor uses the FCL control information to determine whether it updates some or all of the data on that display; and, if so, the appropriate FCL section is located, and the formatter is called to structure the output. The processor then continues its search for other displays requiring updates.

In LLP, all information on a display is collected and reformatted on each update cycle. Exceptions to this procedure are unrelated vehicle sources (CSM with LM or LM with SIU). Separate updates are generated for these conditions.

STRIPCHARTS

A new load module is to be created to operate under the guidance task, TTXGDCTL. The purpose of the module is to drive the two stripchart recorders and update the Guidance Insertion/Injection Digital display.

The stripcharts and the display are updated with parameters from the high-speed AGC intermediate data array, high-speed SIU intermediate data array and a special table, LZSTRIP, maintained by the Launch subsystem. There are fourteen event pens and sixteen analog pens on the two recorders.

The event pens are driven over the DDD subchannel the same as other DDD's. Parameter values are changed from engineering units to count rates between 0 and 255 to drive the analog pens. Maximum engineering units are converted to a count of 255 and minimum engineering units are converted to a count of 0.

There are three data formats defined for the two recorders. The desired format is selected by PBI input and updated once a second until a new request is received. At this time, the old format is deleted, and the new one is started. The digital display is also on a one-second update rate.

UTILITY PROGRAMS

Utility programs are off-line routines that support the development and operation of real time functions. This support is accomplished by the generation of various on-line tables and by the verification of real time routines. Several programs generate post-flight reports further aiding in the overall mission analysis.

TELEMETRY PRE-PROCESSOR SYSTEM

The telemetry pre-processor, which was designed to execute in a non-real time environment, generates data tables for use in a real time environment. Extensive use of these tables has been adopted as a means of reducing the amount of processing. Some of the tables are mainly informational (constants), while others contain various codes that control the logic flow in the routine. This concept of constructing and prestoring data tables is plausible because some processing logic can be rigidly pre-defined. The current areas of concern are as follows:

1. Format control lists for TV display generation
2. Calibration information and control tables
3. Limit sensing information and control tables
4. Switch selector information and control tables
5. TV display directories
6. DDD data processing
7. Source library maintenance for table update convenience.

It is the aim of the pre-processor system to convert user requirements into a set of data tables with the least amount of manual manipulation. These requirements are received as card decks, or transferred to various card decks, which the pre-processor uses to build a data base. The data base is then used to build the desired tables, which are designed for easy use in real time. Finally, the tables are made available to the real time telemetry system by push-button request from a local disk drive.

For format control lists (FCL), the user provides a description of what he desires in a particular display by completing a form with fixed fields for each description entry. The base essentials in describing a display include parameter definition and desired output format. The pre-processor receives the user's definition of a display and builds a formal definition in the form of a source deck. Once the source is assembled³, an object deck that serves as the data (FCL) results.

³The OS/360 Assembler is referred to for source deck assemblies.

Calibration and control table inputs to the pre-processor consist of three types of information. First, each parameter that will be transmitted from a vehicle source via telemetry must be identified, defined, and sequenced. Second, the curve to be used to calibrate any one parameter must be defined by a set of coefficients. Third, the information required to properly scale a parameter must be supplied. These three sets of information form a part of the pre-processing data base. On control card request, the system builds both the information tables (coefficients, scale factors) and the control table (curve codes, relative addresses, etc.,). The control table is more commonly referred to as the cross-reference table. Output of these tables is vehicle-oriented for modular real time processing.

Limit sensing, which serves as a real time data validation and/or warning system, requires a control table to locate and flag parameters and a constants table containing the limiting values for any parameter desired. These tables are generated by the pre-processor from items in the data base. Input to the data base need only be parameter identification, limiting values, and perhaps limit category if applicable. The input is in card form and the output, which is vehicle-oriented, is produced on control card request. As in the case of FCL, an intermediate source deck is generated, and the tables desired are produced by assembling the source deck.

The remaining types of tables are generated in much the same manner, with the exception of DDD's, whose output is a deck of cards rather than a table.

Control cards for the pre-processor system are kept in as simple a format as possible and indicate a system modularity with respect to table type whether it be an input control or an output control. There are currently no manual controls to the system.

Printed output is quite voluminous depending upon the number of inputs made and outputs requested in any one run. As a rule, all input decks are listed to "flush-point" should an error diagnostic interrupt the input process. Some requests produce only printed output without table generation.

Wherever feasible, the generated tables are validated by the pre-processor in a simulated real time environment. This phase of the pre-processor is highly diagnostic and helps to maintain the current integrity of the real time effort.

All data tables with their intermediate source decks are output to a 2314 disk drive. The source decks are retained from one run of the pre-processor to the next to reduce the amount of processing required on a one-item-change type of update to a data table. For purposes of implementation, the IBM utility program IEBUPDAT is used to modify existing source decks, which are re-assembled producing an updated data table.

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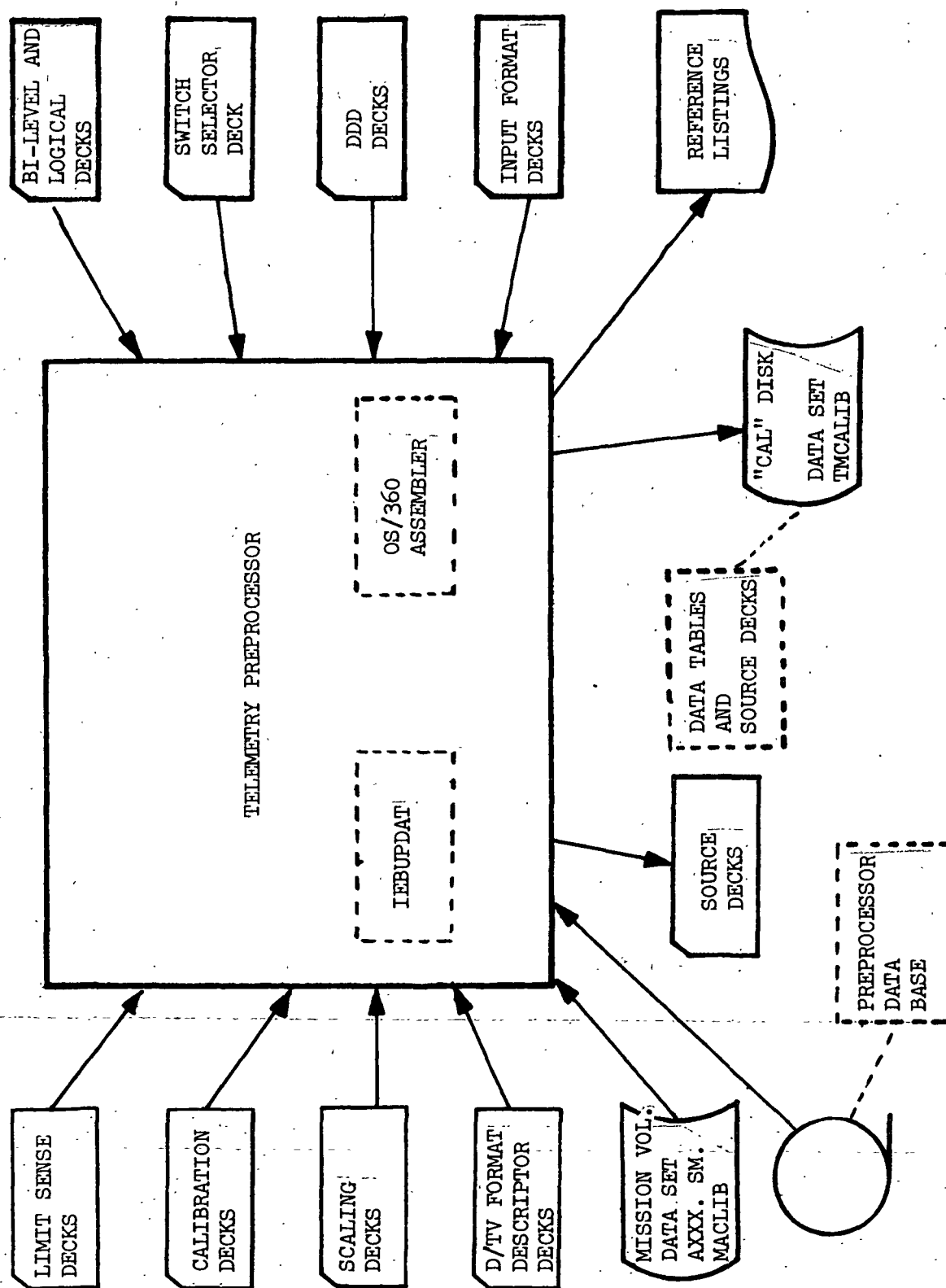


Figure 6. Pre-processor Flowchart

One of the major aims of the pre-processor system is to provide maximum output with a minimum of input; hence the number of utility programs has increased sharply. Currently the two most valuable routines are the OS/360 Assembler and IEBUPDAT. When these programs are used in conjunction with all of the attributes of the telemetry macro library and the systems data base, very little need be specified to request a particular table or set of tables.

REPORT GENERATION

The report processor (QMY PAPER) produces a printed tabulation of parameters appearing on paging tab displays. The input is the TSPAP tape, which is generated by the real time routine (TMX PAPER). Each message is read from the tape and placed on a utility disk. The messages are sorted by GMT and display number (MSK), and the file is then printed. The output processing is controlled by format control tables describing the report format, the background titles, and the parameter's format. Generation of the format control tables is achieved by extracting certain information from paging tabs format description sheet (FDS) cards.

ERASABLE MEMORY OCTAL DUMP

The Erasable Memory Program is used to support erasable memory dump downlist from the Command Module Computer (AGC) and the Lunar Module Computer (LGC).

Inputs are the log tape from either the RTCC mission or standby computer, a table of information specifying the locations to be compared, the name to output with the compared locations, and the constant to be used in the comparison. A card deck of information to be used in making a temporary update to the comparison table may be used if an update is desired.

The output is formatted so the contents of 128 registers (arranged in 3 columns) and associated location numbers are placed on each page. Each register to be compared is also tagged with the name and comparison constant and whether the comparison failed. The GMT of data frame receipt, the EMOD pass number, the downlist identifier, reporting station, and the vehicle identification are output with each page.

A summary of data frames that cannot be processed due to data or request limitations is saved (indicative information only) in a buffer area. At the end of run, these messages are printed. An asterisk (*) placed to the right of a field(s) indicates the reason(s) each message was rejected.



DELOGS

The Telemetry subsystem maintains two delog programs for program and subsystem verification purposes. Both programs are controlled by the mission delog utility (QMDELOG). Each routine is invoked by control card input describing the options desired. The mission log tapes are the data source inputs. The associated log time is printed with each message.

High-Speed Input

The high-speed input delog routine processes selected information from the log tape. This information consist of high-speed telemetry messages, CIM inputs, D/TV outputs, DDD outputs, and other mission-type inputs and outputs. However, this particular program has an output format that is telemetry-oriented for high-speed input messages. The printed output is grouped in eight-bit (1 PCM word) quantities expressed in hexadecimal notation. The CP label, CP time, and message label contents are printed with the vehicle and station indications. Other subchannels are printed in regular dump format.

Teletype Output

The teletype output delog routine formats and prints teletype messages as they would appear on a teletype machine. Each six-bit unit is intrepreted as Baudot code, and the appropriate control function is performed.

**2.2.4 DIGITAL COMMAND SYSTEM SUBSYSTEM FUNCTIONAL
SPECIFICATION FOR THE MISSION SYSTEMS
LUNAR LANDING PROGRAM**

IBM

RTCC APOLLO PROGRAMMING SYSTEMS

BOOK: MISSION SYSTEMS - General

2.2.4
DATE 11/22/68
REV
PAGE 1 of 1DIGITAL COMMAND SYSTEM SUBSYSTEM FUNCTIONAL
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LUNAR LANDING PROGRAM

For the Digital Command System functional specification for LLP, see Section 2.1.4. Data applying to LLP only will be footnoted.

Approval	Approval
<i>F. R. Heath, Jr.</i>	<i>Charles W. Wilkinson</i>

2.2.5 PLOTBOARD SUBSYSTEM FUNCTIONAL SPECIFICATION
FOR THE MISSION SYSTEMS LUNAR
LANDING PROGRAM

2.2.5 PLOTBOARD SUBSYSTEM FUNCTIONAL SPECIFICATION FOR THE MISSION SYSTEMS LUNAR LANDING PROGRAM

PURPOSE

The projection X-Y plotboards provide the flight controllers with a visual representation of various parameters needed to evaluate the mission in real time.

PLOTBOARDS, PLOTS AND PHASES

Four plotboards are used to display various plots during the following phases: Orbit, with its subphase high-speed Orbit; Abort, Trans-Earth/Lunar; Lunar Orbit; Lunar-Ascent/Descent; and Reentry.

The plotboards are the 10 x 20 and 10 x 10 projection plotboards in the Mission Operations Control Room, the 6 x 12 projection plotboard in the Recovery Room, and the X-Y (4) plotboard in the Staff Support Room.

During Condition for Launch, the projection and X-Y plotboards are conditioned for Launch phase processing. The proper background slides are requested and the pens are positioned at 0,0. Control is then passed to LTDATAPF.

During low-speed orbit, the 6 x 12 plotboard displays nominal and present position plots of groundtrack latitude versus longitude superimposed on a world map background. Present position is plotted every twelve seconds. Different sectors of the world map may be viewed by requesting different AMSK's that initiate rescribing of nominals with only a sectorized portion being displayed.

The 10 x 20 plotboard is divided into two areas. The lower area (7 x 20), displays nominal and present position plots of groundtrack latitude versus longitude superimposed on a world map background. The upper area (3 x 20), displays nominal and present position plots of altitude above the oblate Earth versus longitude. Present position is plotted upon receipt of queue every twelve seconds. Every time a queue is received, the station contacts table is checked to see if the point to be plotted is, for the first time, within stations acquisition or loss of acquisition. If either occurs, the color of the spotter for that vehicle is changed.

Two types of nominals may be plotted during the low-speed orbit subphase on the 10 x 20 plotboard. The Standard nominal consists of the present revolution and the next two revolutions. The Special nominal consists of up to six revolutions

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within the bounds of the ephemeris. There are special and standard displays for both the LM and CSM. Scribing of the standard display for the LM begins automatically after an LM ephemeris has been generated during Orbit phase. Scribing for the special display for the CSM or LM may be achieved by an MED request during Orbit phase. The only times the Orbit nominals are redrawn are at Cape Crossing times or upon an MED entry. The SSR X-Y plotboards plot latitude versus longitude of the spacecraft's present position and predicted groundtrack. Nominal and present position scribing are activated upon MED request. Thereafter only present position is updated automatically.

During the high-speed orbit subphase, the 10 x 20 plotboard is divided into two parts. The left half plots height of vacuum perigee above a spherical Earth versus velocity at vacuum perigee. The right half plots the in-plane maneuver monitor (flight-path angle versus velocity). Both nominal and present position data are driven. On the right half, two traces are driven simultaneously. Spacecraft or Instrumentation Unit (IU) telemetry is always the source of one trace, and the second trace is driven by radar, depending on a queue from LTHIGH indicating what data has been processed. The data is picked up from a data table and scribed and spotted. On the left half, the real time values of height of vacuum perigee versus velocity at vacuum perigee are scribed and spotted based on the selected high-speed telemetry trajectory data and high-speed radar data. One spotter is driven for each area of the 10 x 20 plotboard. High-speed radar is assumed at initialization, and an MED can switch to telemetry. The 10 x 10 plotboard monitors out-of-plane maneuvers (inertial velocity versus wedge angle between the current trajectory plane and the target plane) in real time. On both the 10 x 20 and 10 x 10 plotboards, plotting of present position with nominals is activated by either AMSK request or an MED entry (W61). In the case of an AMSK request, either scale 1 or the last scale entered is used. During Trans-Earth/Lunar phase the 10 x 20 projection plotboard displays a background slide with the upper 3 x 20 ft. section scaled for plotting the distance from the center of the Earth along the Earth moon-line defined by the GET axis vs. the projection of the vehicle position in the moon orbit plan (X vs. Z). The lower portion of the background slide is a world map display of latitude vs. longitude (ϕ vs. λ) as displayed in orbit low speed. Present position will be spotted on both the upper and lower portion of the 10 x 20.

During Lunar Ascent/Descent the 10 x 10 is divided into an upper and a lower display. The upper portion is a plot of altitude above a spherical moon vs. range to go to target (h vs. R_{Go}) while the lower portion is a display of wedge angle vs. height of pericyynthion (δ vs. h_p). The nominals are scribed in both phases for h vs. R_{Go} . There is no requirement for nominals in Lunar Descent on the δ vs. h_p plot. During Lunar Ascent the nominal point will be spotted initially with both spotters. When in Lunar Descent an abort to Lunar Ascent does not cause a re-

scribing of the nominals. On both the upper and lower displays one scriber scribes PNGS and the other scribes AGS. Both spotters are used on the lower display, one to spot PNGS and the other to spot AGS. On the 10 x 20 the left half plots altitude above a spherical moon vs. the altitude rate (h vs. \dot{h}) while the right half plots flight-path angle vs. the initial velocity, and vs. the impulsive velocity increment (γ vs. v , γ vs. Δv).¹ Nominals will be scribed for h vs. \dot{h} , γ vs. v , and γ vs. Δv . Present position is scribed for PNGS and AGS on both displays. The AGS and PNGS source is spotted on the left display (h vs. \dot{h}).

During Lunar Orbit the 10 x 20 is used to display height vs. longitude (h vs. λ) on the upper 3 x 20 ft. section and latitude vs. longitude (ϕ vs. λ) on the lower 7 x 20 ft. section. The display, h vs. λ and ϕ vs. λ , is in the moon-referenced system. Present position is both spotted and scribed for both the CSM and LM on the ϕ vs. λ display. The h vs. λ display is scribed only for both the CSM and LM. This display will be automatically updated upon crossing the 180° lunar longitude for each vehicle or upon manual request. Both standard and special capability exist for both the CSM and LM in Lunar Orbit.

During Reentry phase, the 10 x 20 plotboard displays plots of the spacecraft groundtrack against a background of the world map in the lower area, and spacecraft altitude above an oblate Earth versus longitude in the upper area. At initiation of Reentry phase processing, the background slides are displayed nominals are scribed from start of reentry ephemeris to impact point, predicted impact point (actual impact point) is scribed and spotted as a '+', target point (on-board computer impact point) is scribed as a 'T', minimum lift impact point and maximum lift impact point scribed as an 'X', and spotting and scribing of present position begins. Where communications black-out begins (BOI) and ends (BOE), slashes are scribed on the upper area plot of the 10 x 20 section. The 6 x 12 plotboard displays plots of spacecraft groundtrack against a background on the world map. The 6 x 12 plotboard scribes present position, scribes the target point, spots and scribes the nominal impact point, and scribes the minimum and maximum lift impact points. The impact point spotter is updated on each DC. On recycle to orbit phase, the 10 x 20 and 6 x 12 plotboards displays are requested to scribe nominals and resume present position spotting and scribing. Processing then continues as in Orbit phase.

During Abort phase, the 10 x 20 plotboard displays plots of the spacecraft groundtrack superimposed on a partial world map background in the lower area and a spacecraft altitude above an oblate Earth versus longitude in the upper area. Upon initiation of Abort processing, the background slide is displayed, nominals are drawn, the predicted impact point is scribed, scribing and spotting of present

¹ There are two scales of γ vs. v , the third scale is of γ vs. Δv .

position begins, and the predicted impact point is spotted. The impact point spotter is updated on each DC.

DATA DESCRIPTION

A data message for plotting device consists of a control word followed by one or more data words. Several data words will follow a control word in most plotter applications.

The control word for the projection plotters sets the controls and plotting characteristics by specifying character or symbol size, color of the projection, background slide selection, and the "plot or no plot" command. The data word selects the characters and symbols or permits line scribing and provides the X-Y data to position the plot on the plotting surface.

Two methods of plotting curves on the scribing projectors can be used. The normal method positions the scribing stylus automatically at the left screen edge between scribing operations to eliminate the stylus shadow on the screen. The second method is for continuous plotting, and permits the stylus to remain on the slide between operations. It is expected that this method will be used when the data rate is very high or if elimination of the stylus shadow is not required.

The data message for the X-Y plotter controls the action of the plotboard's two channels or plotting arms. The control word for the X-Y plotter provides channel addresses and X-Y positioning data.

MED MESSAGES

Manual entry device messages permit the following functions to be performed by the plotboards.

1. Exchange two devices — The scriber, spotter, or boards may be exchanged on the 10 x 20, 10 x 10 and SSR X-Y plotboards.
2. Delete or restore a device — The scriber, spotter, background or board may be deleted or restored on the 10 x 20, 10 x 10, SSR X-Y, and 6 x 12 plotboards.
3. Initiate world map display — The LM and CSM special and standard nominals may be drawn on the world map. There is a maximum of six revolutions on the special displays.
4. Generate orbit nominals on SSR X-Y plotboards — A maximum of three revolutions of the orbit nominals may be drawn. Present position plotting begins when nominal scribing begins.

5. Recovery world map — A maximum of six revolutions may be drawn on the 6 x 12 plotboard.
6. Set output spotters for 10 x 20 plotboards — This option provides the choice of either radar or telemetry as the source to spot on the 10 x 20 plotboard.
7. Display nominal maneuver quantities — This permits displaying a CSM SIU, or LM maneuver quantity of types analog (D/TV), digital nominals, plotboard nominals, and all nominals. This also provides several different scales to be used when performing high-speed plotting on the 10 x 20 and 10 x 10 plotboards.

PLOTBOARD INPUT TASK (WTPIPTSK)

The Plotboard Input task computes data values to be passed to the Plotboard Output task. The Input task is entered by seven tasks which pass ID's indicating the data calculation to be performed, as described below:

1. GTMSTIME enters either because of a time queue, causing low-speed present position plotting in Orbit phase, or a Cape Crossing, resulting in nominal plotting Orbit phase.
2. LTXHSABT enters because of a time queue, which results in high-speed present position plotting in Abort I or II phase.
3. RTSDEAD enters because of any trajectory update, except for DC-initiated trajectory updates which results in either low-speed nominal plotting in Abort phase or nominal plotting Reentry phase, or because of a time queue which results in either low-speed present position plotting in Abort phase or present position plotting in Reentry phase.
4. GTPHASE enters because of an AMSK request causing nominal plotting, a mission phase change resulting in phase initialization, a recycle from Reentry to Orbit phase resulting in nominal plotting in Orbit phase, or a DTRROUTE causing completion of scribing glass change.
5. LTHIGH enters for one of three reasons. When in high-speed orbit subphase, high-speed initialization takes place. A maneuver nominal queue causes high-speed maneuver nominal plotting to occur Orbit phase. A time queue causes high-speed present position plotting to occur in Orbit phase.
6. GTGMED enters because of an entry on the manual entry device. Any action described under MED Messages may be requested.
7. WTPQPTSK enters to signal completion of glass change.

After processing the data, the Input task passes one of three queues to the Plotboard Output task. The queue with the lowest priority is for a nominal plot. The queue with the next highest priority is for plotting present position, and the queue with the highest priority is for a glass change.

The Input task maintains input queue control by interrogating a communication cell to determine if the Output task is in the process of plotting and if there is a queue backlogged. If there is a backlogged queue, that queue is replaced by the most recent queue received.

The Input task initializes the Plotboard system. The Input task also controls a data edit routine used to delete superfluous points. In addition, the device status table is maintained by this task. The table contains a list of hardware addresses and AMSK's being used, describes the scales available and which one is being used, indicates whether a device is active or inactive, and contains color and scribing glass number. The modules used in the Input task are described below and are functionally illustrated in Figure 1.

Plotboard Supervisor (WMSSUPER)

The Plotboard Supervisor Module maintains the status of the plotting system, decodes all inputs associated with it, and queues the Output task to initiate all plotting action.

All manual and system-generated inputs enter the Plotboard Supervisor Module where validity is checked and all necessary internal indicators are set. AMSK requests are passed to the AMSK Decoder Module for a more detailed validity check, initialization of scribing and spotting projectors, and selection of proper background slide. If the request is for nominal scribing, control is returned to the Plotboard Supervisor Module, which determines if a scribing glass change is required. The supervisor then passes a queue to the Output task to permit the glass to be changed and generates a queue to the Computer Plotboard Nominals Module, which computes the correct raster values for a given plotboard and phase. A queue is then passed to the Output task to scribe the required plot. If the request is for present position plotting, the Supervisor queues the Present Position Computer Module, which obtains and converts the data values to raster values. A queue is then passed to the Output task which outputs the plotboard data words to plot present position.

Present Position Computer Module (WMMCALPP)

The Present Position Computer Module converts data values to rasters and outputs the rasters to a table for use by the Output task.

Upon entry, WMSSUPER obtains, from a table that will reside in subpool zero, an entry code (indicating phase, plotboard, and data to be displayed), an MSK (equivalent of AMSK), and a plotter device address, color, slide number, character to plot, and vehicle code. WMMCALPP determines the phase, plotboards, and data to be displayed. Appropriate data tables are read for real time inputs depending on the mission phase. This data is converted to raster units for the appropriate plotter. Other list inputs consist of the character and plotter address.

When data for the X-Y plotboard is processed, the present rasters are stored in a data area for subsequent referral.

Other data tables used include the following:

1. RNTYIN — This table, which is found by using the macro EKVEH, consists of four data areas: preburn, postburn, tracking, and telemetry. Flags are set indicating if data is available in each area and if that area reflects de-orbit burn data. Current ephemeris data is found by searching for the first available of tracking, postburn, or preburn areas.
2. EZTSCNSI, 2 ... — This table contains present position information relating to the vehicle with which it is associated, plus quantities related to the generation of the current trajectory.
3. LXHSAPLT — This table consists of quantities computed by the high-speed output task and used as input to WMMCALPP.
4. LZDPHS — This table contains present position vectors and display parameters computed from these vectors for high-speed radar and telemetry in the Orbit phase. The table also contains the nominal end of maneuver vector and display parameters.
5. RZDEAD — This table contains present position quantities required to update the X-Y and projection plotboards and the Reentry D/TV displays. It also contains the present position and velocity vectors used to compute these quantities.

Inputs that specify a change of mission phase result in calling the Plotboard Initialization Module, which builds the necessary queues to initialize the projection plotboards and the X-Y boards, and then queues the Plotboard Output task.

Inputs that require nominal scribing and subsequent action include: a change of mission phase, MED inputs that require more than setting of internal indicators, Cape Crossing, and maneuver monitor requests.

Inputs that require plotting special characters, setting internal indicators, and plotting present position include: high-speed abort trajectory updates, low-speed abort trajectory updates, reentry trajectory updates, or a change in orbit tracking speed.

This module uses a table that contains the current status of the device code, color, and slide number. This table resides in subpool zero and is initialized by QZSTATUS.

Control Plotboard Manual Input (WMSMSK)

The AMSK Decoder Module checks the validity of each AMSK input, selects the proper background slide, and builds queues to initialize the scribing and spotting projectors.

This module provides initialization and ensures that the mode, monitor, and AMSK requests are valid for the particular projection plotboard and missions phase. A queue is passed to the Output task, which provides the actual output of data to change backgrounds, slides, open or close scribing shutters, and reposition the spotters when necessary.

In the event that an AMSK request requires rescribing of nominals, a queue is passed back to WMSSUPER to initiate computation of the nominals. WMSMSK is linked to WMSSUPER with inputs of a phase code, MONITOR ID, MODE ID, and an AMSK number.

Initialize Plotboards (WMSINIT)

This program sets up queues to the Output task to initialize the MOCR and X-Y plotboards at mission phase change. The MOCR projection plotboards are initialized by closing all scribing shutters and positioning the spotter at location (0,0). The background slides are then selected according to the mission phase code.

In addition, a queue is generated to the Output task to reset the pens on the plotboards.

Computer Plotboard Nominals (WMMALLNM)

The function of this load module is to compute the correct raster values for a given plotboard.

This module will control the nominal values for the plotboards in Orbit, Reentry, and Abort phases. The control is possible by use of the data in subpool zero, which is initialized by data table WZSTATUS (contains the entry codes) from which the phase and plotboard are determined.

This program also computes the raster values for a plotboard by using the raster specifications placed on the plotboard in a particular phase. The nominal values to be converted are obtained from an appropriate data table. This program then sets up the computed raster values in a useable form to be supplied to the output task in subpool #69.

The data editing routine is then used to remove any points not affecting the shape of the curve.

Data table LZNMFN is used containing the nominals (height at perigee, velocity flight-path angle, wedge angle), for a particular maneuver.

Plotboard Quantities Calculator (WMMILPHV)

WMMILPHV calculates the geodetic latitude and longitude of the subsatellite position, the altitude above the oblate Earth, and the Earth relative velocity. These quantities are calculated for Orbit and Reentry/Abort phases. The results of the calculations are stored in data table GZPCHV, and control is returned to the calling routine.

PLOTBOARD OUTPUT TASK (WTPQPTSK)

The Plotboard Output task plots special displays on the projection and X-Y plotboards. These displays include both nominals and current values. The Output task formats the data received from the Input task to plot present position, draw nominals, and change glass.

This task has the capability to scribe and spot two vehicles on the left and right projection plotboards, but only one vehicle on the 6 x 12 and X-Y plotboards. These displays include both nominals and current values. The Output task formats the data received from the Input task to plot present position, draw nominals, and change glass.

The Output task also interleaves data to various devices to more effectively utilize the sequential data handling the Plotting Displays Subchannel Data Distribution.

The modules used in the Output task are described below and are functionally illustrated in Figure 2.

Output Supervisor Module (WMSSPPGC)

This module keeps track of the subpools passed to it and the work status. WMSSPPGC decodes the queue passed by the Input task to determine if plot present position, plot nominals, or a glass change is called for. If nominal plotting is required, the Plot Nominal Module (WMMPLTMN) is queued. If a glass change is required, this module outputs the control words to change the glass. If plotting present position is required, data is obtained from a parameter list passed by the Input task. Border limits are found that serve as inputs to the Display Formatting Language, which formats the command and data words to drive the plotters. After the data has been formatted, this module scribes, spots, and plots present position and special characters on the projection and X-Y plotboards. When data for the X-Y plotboard is formatted, a vector is traced from the last point (saved from the last input) to the present point.

Plot Nominals (WMMPLTMN)

This module determines the configuration of a nominal by the phase, device and vehicle being observed. WMMPLTMN takes queues from a parameter list passed in a calling sequence and interprets the device and DFL format to be used. The actual data output is found in subpool 101, and the color, slide, spotter, etc. are found in subpool zero of the Input task. The Display Formatting Language then outputs the data to plot the nominals. The plotting consists of a nominal and a revolution number. This module also checks to see if there is more data to be plotted, and if so, the data is obtained and plotting continues.

Print Routine For Plotboard Tasks (WMPRINT)

WMPRINT prints all on-line messages for the plotboard tasks of the Plotboard subsystem. The format number and the list addresses are obtained from the parameter list. GMT, console ID, and the desired message for output are converted, and an RTPUT is issued to the printer.

MED Decoder (WMRMEDIN)

The plotboard MED decoder is called only as the result of a manual entry. This program decodes the manual entry, and through the use of the system MED decoder, passes the manually entered data to the Plotboard Input task, which passes the data to the appropriate load module for subsequent action.

2.2.6 LAUNCH/HIGH-SPEED ABORT-ORBIT SUBSYSTEM
FUNCTIONAL SPECIFICATIONS FOR THE MISSION SYSTEMS
LUNAR LANDING PROGRAM

LAUNCH/HIGH-SPEED ABORT-ORBIT SUBSYSTEM
FUNCTIONAL SPECIFICATIONS FOR THE MISSION SYSTEMS
LUNAR LANDING PROGRAM

INTRODUCTION

The LLP program functional specification for the Launch/High-Speed Abort-Orbit Subsystem requires nine tasks to support a two-vehicle launch mission (Lunar Module and Command and Service Module (LM or CSM)). Figures 1 and 2 and the following paragraphs intend to provide the reader with an overview of the subsystem structure. They include brief descriptions of the tasks and the mission phases under which each operates. Each task discussion includes a detailed description of the functions performed, the load modules operating under each task, and flowcharts of the general logic.

LTDATAPF (HIGH-SPEED INPUT TASK)

LTDATAPF monitors all high-speed trajectory data and manual inputs and computes the launch powered-flight quantities. This task is used during launch, high-speed abort and high-speed orbit phases.

LTRKNI (LAUNCH INTEGRATED IMPACT POINT TASK)

LTRKNI provides the interface between the powered-flight supervisor (High-Speed Input Task) and the Launch Runge-Kutta Impact Predictor, for the purpose of obtaining integrated impact points during powered flight.

LTHLDSPS (LAUNCH HOLD PHASE TASK)

LTHLDSPS calculates the launch hold phase parameters. It is used during launch phase only.

LTXUTPUT (LAUNCH DIGITAL-TO-TELEVISION CONVERTER (D/TV) OUTPUT TASK)

This task formats and outputs the launch D/TV digital and analog displays. It is used during launch phase only.

Approval	Approval
<i>RH Williams</i>	<i>R.O. Soyard</i>

LTXPPBPP (LAUNCH PLOTBOARD TASK)

The Launch Plotboard Task formats and outputs the launch X-Y and projection plotboard analog displays. It is used during launch phase only.

LTXPRNTR (HIGH-SPEED PRINTER TASK)

LTXPRNTR formats and outputs the high-speed events, GO/NO-GO parameters and SPS burn parameters to the mission support on-line printer. This task is used during launch, high-speed abort, and high-speed orbit phases.

LTXHSABT (HIGH-SPEED ABORT OUTPUT TASK)

LTXHSABT calculates and outputs the high-speed abort D/TV digitals and analogs. It is used during high-speed abort phase only.

LTHIGH (HIGH-SPEED ORBIT TASK)

LTHIGH processes high-speed radar and telemetry data during the orbit phase, computing present position-velocity vectors from which related information is displayed.

LTXZSHEL (HIGH-SPEED DELOG TASK)

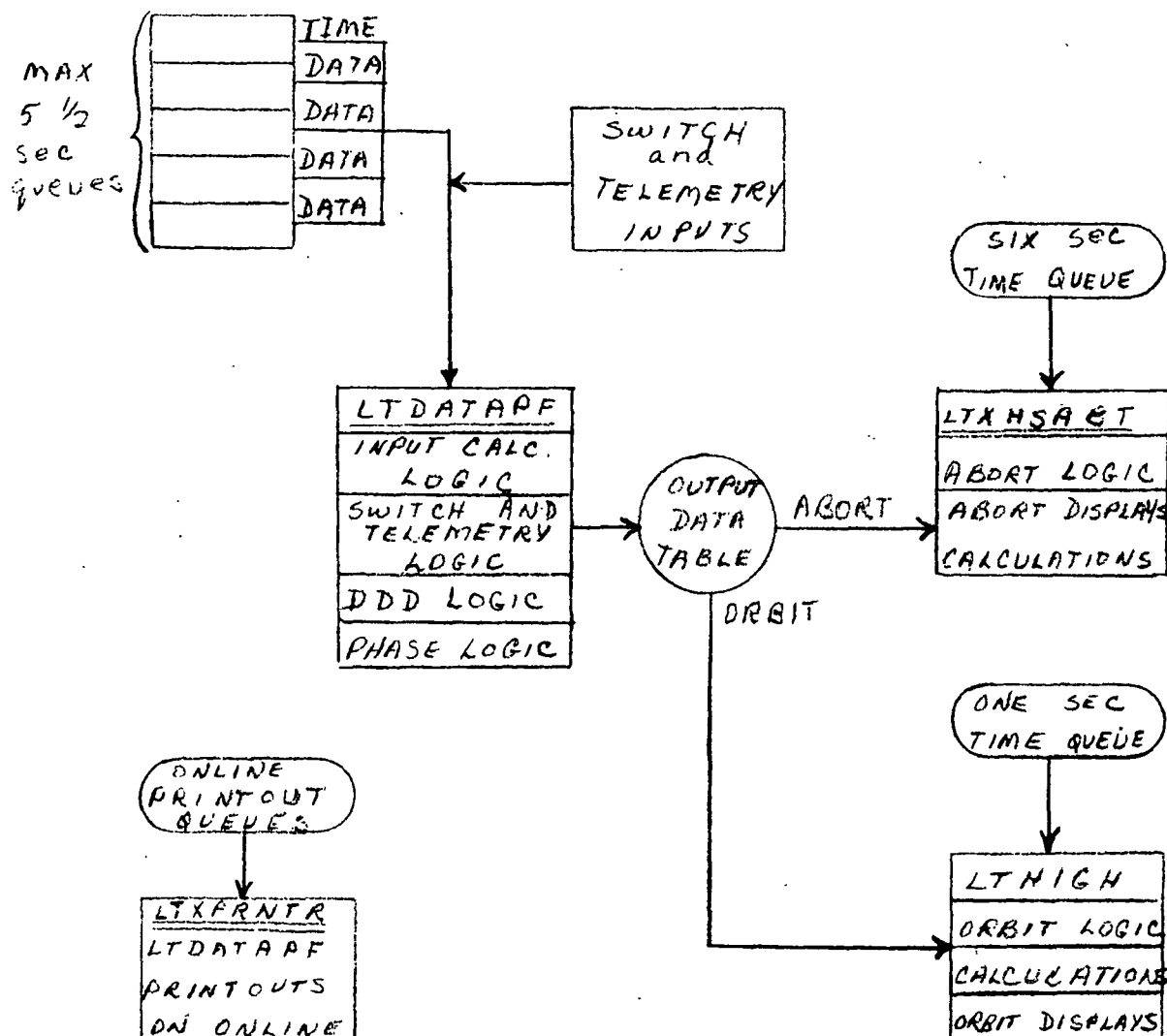
LTXZSHEL provides the post-flight processing required from the Launch/Abort Group in support of the Apollo missions. It is not used during any mission phases, but as a job shop package.

QTMFIT (IMPACT PREDICTOR DATA GENERATION AND CURVE-FIT TASK)

This task calculates the coefficients to be used by the curve-fit Impactor Predictor Program during a CSM launch. It is not used during any mission phases, but as a job shop package. Currently the Launch Integrated Impact Point Task has replaced the Curve Fit Impact Predictor Program.

Figure 1. LM/CSM Launch Subsystem Functional Flow

CSM High-Speed Abort Subsystem
LM/CSM High-Speed Orbit Subsystem
Functional Flow



- 1) LT DATAPF - High-Speed Input Task
- 2) LTXHSABT - High-Speed Abort Output Task
- 3) LTXPRNTR - High-Speed Printer Task
- 4) LTHIGH - High-Speed Orbit Output Task

Figure 2. CSM High-Speed and LM/CSM High-Speed Orbit Subsystem Functional Flow

LTDATAPF (HIGH-SPEED INPUT TASK)

LM/CSM Launch Phases

Tracking Data Input Sources — In the LMSP launch phase, processing will be done for a maximum of six sources from telemetry (2) and radar (4). The telemetry sources will include S-IVB Booster Instrumentation Unit (IU) data for the LM and CSM launches, the Apollo Guidance Computer (AGC) for the CSM launch, and the LM Guidance Computer (LGC) for an LM launch. This data will be received by the telemetry input section via the communications processor (CP) from communications command and telemetry systems (CCATS) in pulse code modulation (PCM) bit counts in three separate modes (downlinks). The data is unpacked and appropriately formatted for output to other tasks (displays, launch, etc.) via telemetry data tables. The IU and AGC/LGC vectors will be processed on a half-second cycle time routing to the input task LTTATAPF. The vectors will be received as hours elapsed since GMTGRR, meters, and meters/second for IU and as hours elapsed since GMTZS, 10^5 feet, and feet/second for AGC, and as hours elapsed since GMTZS, 10^5 feet and feet/second for LGC. The radar sources will include Impact Predictor Smoothed (IPS), Raw Radar (IPR), Unified S-Band (USB), and Ship C-Band. This data will be received via the CP from CCATS and routed by the supervisor routing function to the appropriate load module under the input task on a time and data basis. Each input message must pass a prescribed set of error checks before it is accepted as valid. IPS, Ship C-band, and Ship USB will be received as a vector of the form time, range, and velocity. IPR will be received in the form of a time and radar observations of range, azimuth, and elevation spaced by one-tenth second with a maximum of five observations per message. Land USB will be received as a time, X-angle, Y-angle, range, and range rate (doppler).

After being adjusted for elapsed time and time delay correction by the input processors, the time tag of each vector is adjusted to current GMT. An integral multiple of 24 hours is added to or subtracted from the time-tag as required to give a time tag of current GMT. The vectors are in the RTCC Earth-centered True Inertial Coordinate System. The time is in hours, the position vector components are in Earth radii and the velocity vector components are in Earth radii per hour.

Each of the six input sources will be required, if possible, to output a vector. Each source will provide its vector in the Earth-centered true inertial coordinate system defined at midnight prior to the first launch with the X-axis through Greenwich with RTCC units, whether by smoothing in powered flight or short arc in hold phase for IPR and Land USB, by matrix rotation for IU

and AGC/LGC, or by coordinate conversion for IPS, Ship C-band, and Ship USB. By posting each source, a complete set of data is assured for a half-second time interval. For each vector, the velocity, the flight-path angle, and the height above a spherical Earth will be computed. A current vehicle weight for each vector will be computed using the LM or CSM initial weights and mass flow rates for the SPS. Also the T_{go} parameter from IU is processed and made available to the display programs. After posting of the six input sources is complete, control of the input task is passed on to the launch logic supervisor.

Manual Input Sources — Besides the data inputs described previously, the input task receives manual inputs from (1) Flight Dynamics Officer's Console, (2) Guidance Officer's Console, (3) Retrofire Officer's Console, and (4) Tracking Data Select Console. Other sources of input will be telemetry events (S-IVB cutoff (C/O) only) and MED's (teletype input). The telemetry events and MED inputs to the input task will consist of queues from the appropriate decoding task or interface module. Data Select and other console PBI's are received as one or two words over the MED or CIM channels. These words indicate the present status of the switches that are checked against the history with appropriate changes being made. ESOS events take precedent over the telemetry events except for switches set to normal. Only those switch event words that prove to be valid are accepted. Messages are printed on line (LTXPRTNR) to indicate the changing status of switch and/or telemetry events. There also exists a 30-second time printout to indicate on line the current time and present selected source.

MED's that result in queues to the input task are as follows:

1. P92, SET, CSM or LEM; P92, SET, CSMSIM or LEMSIM; Launch Initialization
2. P10, CSM or LEM, GMTLO; Corrected Liftoff Time
3. P12, CSM or IU1 or IU2, GMTGRR, Launch Azimuth; IU, AGC Guidance Reference Release Time

P92 results in the initialization for a LM or CSM launch phase. P12 causes a change in the telemetry rotation matrix, which will be calculated for the new conditions specified and will be referenced by the input task. P10 results in liftoff being set to the time specified.

Trajectory Computation Control — The storage for this task is set and initialized upon conditioning for launch. All routing is initiated to start processing the appropriate data source inputs and manual inputs depending upon the type launch. The trajectory computation control logic is entered

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on a half-second cycle queue after the six data sources have been posted.

Entry Logic — At entry the hold phase parameters are updated from the hold phase data table, GMT is updated from the present computer time, and the exit switch indication to LMXPHASE reset to not-exit. A vehicle-type check is made to determine which curve-fits for ΔV of separation should be used.

Return Logic — On a standard return and exit the output display table is updated completely, and control is transferred to LMXDDD for driving the input data and event lights. For the other type exit, the hold phase parameters are not updated in the table prior to completion of the NSEC cycle. Before the supervisor returns to the system, the strip chart parameters for a CSM launch are computed and updated into data tables for logging and TLM subsystem.

Logic Prior to Liftoff — When queued prior to liftoff, the display indication is posted to show prelaunch, and the output display table is updated. The standard return logic described in the previous paragraph is followed for the exit.

Liftoff to TWR JETT — After liftoff the selected source is determined and the vector moved. The recycle indicators are set after the S-IVB C/O, and hold phase checks are made. The selected source vector is modified for TWR RKTS to be used in impact prediction, and the Mode I indicator is set. The powered flight quantities to be computed are listed later under "LTDATAPF Selected Source Calculations for Powered Flight." A standard exit is made after these calculations.

The data quality indicator check before powered-flight computations would result in a return when the selected source vector is missing.

Logic for TWR JETT to S-IVB C/O — With TWR JETT to event the logic is the same as above, except for the Mode II indicator setting. Also the selected source vector is modified for spacecraft SEP to be used in the impact prediction.

LES Abort Logic (CSM LAUNCH) — At LES abort the current vectors are saved in the output display table and an indicator set. If TWR JETT is set, the Mode II logic is followed as above. If no TWR JETT has occurred, the exit switch is set for a Mode I abort. The logic followed is the same as in the section entitled "Liftoff to TWR JETT," with the exception that a spacecraft selected source vector must be prior to LES Abort to be modified for TWR RKTS.

Logic for S-IVB C/O to SPS IGN — The logic for S-IVB C/O to SPS IGN includes three possibilities.

1. At a nominal cutoff the Hold Phase Indicators are initialized and checks made for a valid spacecraft SEP. If valid spacecraft SEP occurs, the event is set for the Phase Interface program to assure that the correct weight and cross-sectional area will be passed to orbit phase. The collection cycle is set and started. The raw-radar short-arc processing times are updated based on cutoff. The powered flight selected source vector is stored as the selected vector during the collection cycle with delta V added. The powered-flight computations are executed, and a standard exit made. At completion of the collection cycle, vector averaging is initiated. The following calculations are required for the S-IVB C/O hold phase entry:
 - a. GO/NO-GO Recommendation - IU, USB, AGC, IPR, Ship-C
 - b. Mode II Impact Points - IU, AGC and Selected Source
 - c. Mode III Maneuver - IU, AGC and Selected Source.

Indicators are set for displays, selected source, and Mode II completion. The data table is written and the hold phase task (LTHLDSPS) queued. The standard exit is made after this.

Prior to completion of hold phase calculations and following the S-IVB C/O queue, a return is made moving the new parameters and vector into the selected source table "LTHLDSPS Parameters Moved for Selected Source by LTDATAPF." A check is made for a valid vector prior to making the hold phase selected source calculations. The quantities to be computed are listed under "LTDATAPF Selected Source Calculations for Hold Phase."

2. For a non-nominal S-IVB C/O with CSM SEP during the collection cycle, the time of the valid separation is passed to hold phase. The collection cycle is then reset based on the SEP time. The logic then followed until and after completion is the same as given in Section 1 above.
3. For a non-nominal cutoff with an SPS IGN prior to collection cycle completion, the logic followed is the same as for a nominal cutoff. However, the only calculation required for this S-IVB C/O entry is GO/NO-GO Recommendation - IU.

If thrusting is present prior to hold phase completion, a return is made using the powered-flight selected source vector. The normal powered-flight computations are then executed and a standard exit made. Upon hold phase completion of the S-IVB C/O queue, the preburn results are saved.

4. The exit switch is reset for an orbit or abort at the completion of hold phase computations for the S-IVB C/O queue until a thrust cutoff occurs. The exit switch is then reset for an orbit or abort at the completion of hold phase computations for thrust C/O.

Logic for Running GO/NO-GO's — After a nominal hold phase completion, GO/NO-GO recommendations are updated on an x-second cycle while a booster source is selected (IU, IPS, AGC). The collection time is reset and vector averaging initiated. The following calculations are required for the spacecraft sources: GO/NO-GO recommendation — USB, IPR, Ship-C.

The Hold Phase Table is updated, and LTHLDSPS is queued. A return is made following the same logic described under Section 1 above prior to hold phase completion.

If IU or AGC is selected and a change in Mode III Impact Range Selection has been initiated by the Retrofire Officer, a special queue is made to the hold phase task to compute the Mode III maneuver based on the area selection (a ΔV_{IP} or ΔT_{IP} iteration). The standard exit is made and the running

GO/NO-GO's are not initiated until this special queue is completed.

NSEC Cycle Logic — With a spacecraft source selected (USB, IPR, Ship-C) and hold phase completed, the NSEC cycle logic is entered. The collection time is set and vector averaging initiated. The NSEC cycle time is posted, the hold phase data table updated, and LTHLDSPS queued. Prior to NSEC completion, the return is made as noted above in "Return Logic." At completion, the time is again updated and posted, the table updated, and LTHLDSPS queued. An exit is made following the same logic described in Section 1 prior to completion of hold phase calculations.

Logic for SPS IGN to SPS C/O — At SPS IGN the hold phase and single vector results are saved as preburn information. All indicators are set and SPS C/O checked. If still thrusting, a return is made following the same logic as in Section 3 above. During the thrust period the total thrust time is accumulated for maintaining current CSM weight.

Logic for SPS C/O — Section 1 and 2 below describe the logic for SPS C/O.

1. For a nominal SPS C/O the collection cycle is set and started. The

powered-flight selected source vector is used, and the powered-flight computations executed. At collection cycle completion, vector averaging is initiated. The following calculations are required for the C/O hold phase entry:

- a. GO/NO-GO recommendation — USB, AGC, IPR, Ship-C
- b. Mode II Impact Points — AGC and Selected Source
- c. Mode III Maneuver — AGC and selected Source

The hold phase data table is updated and LTHLDSPS is queued. The standard exit is made after this.

2. For a non-nominal SPS C/O with thrust occurring during the S-IVB collection cycle, the following calculations are required for the SPS C/O hold phase entry:

- a. GO/NO-GO recommendation — IPR, USB, AGC, Ship-C
- b. Mode II Impact Points — IU, AGC and Selected Source
- c. Mode III Maneuver — IU, AGC and Selected Source

The booster SPS burn completion codes are set not-complete, and the LTHLDSPS queue logic followed as normal.

Prior to hold phase completion, a return is made using the same logic described for the nominal S-IVB C/O queue above in Section 1.

After completion of the SPS hold phase queue, the logic is entered for the NSEC or running GO/NO-GO calculations depending upon the source selected. For descriptions, see "Logic for Running GO/NO-GO's" and "NSEC Cycle Logic" given above.

LTDATAPF Selected Source Calculations for Powered Flight — The selected source calculations below are for LTDATAPF powered flight.

V/V_{PS} , d , V , γ , h_o , h_s , GMT300, $(\phi, \lambda)_{pp}$, V_S , V_L , δ ②, ABMODE, R_{IP}

*GMTEI, V_{EI} , γ_{EI} , $(\phi, \lambda)_{MX}$ ①, R_{IP} ①

$V' = V$, $\gamma' = \gamma$, $h'_s = h_s$

LTDATAPF Selected Source Calculations For Hold Phase — LTTDATAPF selected source calculations are given below.

V/V_{PS} , d , V , γ , h_o , h_s , GMT300, $(\phi, \lambda)_{pp}$, V_s , $V_{\perp}^{(2)}$, ABMODE, R_{IP}

For S-IVB C/O⁽³⁾: $V' = V_i = V$, $\gamma' = \gamma_i = \gamma$, $h'_s = h_s$

For SPS C/O: V' , γ' , h'_s are obtained from the preburn table.

LTHLDSPS Parameters Moved for Selected Source by LTTDATAPF — LTHLDSPS parameters are given below.

$(\phi, \lambda)_{IP}$, $(\Delta V_{IP})^{(1)}$, $\Delta V_{IP}^{(1)}$, $\Delta T_{IP}^{(1)}$, GMT_{EI} $(\Delta V_{IP})^{(1)}$, $\gamma_{EI}(\Delta V_{IP})^{(1)}$, $V_{EI}(\Delta V_{IP})^{(1)}$
 GMT_{PI}, GMT_{C/O}, $\Delta T_{EI}^{(1)}$, AREA⁽¹⁾, $P_i(\Delta V_{IP})^{(1)}$, $R_o(\Delta V_{IP})^{(1)}$, $Y_M(\Delta V_{IP})^{(1)}$,
 $(\phi, \lambda)_{MX}$, *GMT_{EI}, GMT_A, $P_i(\Delta V_{INS-C})^{(1)}$

① Not calculated during LM Launch

② If a targeting vector is available from prelaunch, the wedge-angle computation will be done during a LM or CSM launch.

③ The preburn table will save current hold phase information each time IGN is received.

Guidance Insertion/Injection Digitals and Strip Chart Parameters —

1. Input/Output Data Selections for Platform Alignment Parameters

To compute the platform velocity components and differences for the IU and AGC data, the vectors should be time matched. A linear interpolation will be used to time match the two vector sources. The following are the definitions and criteria which will be used in selecting data for the necessary calculations and for outputting the required parameters.

a. Base Vector, Leading Vector

The latest vector received from each source (IU, AGC) will be compared; the one with the smaller time will be called the base vector, and the one with the larger time is the leading vector.

b. Boundary Vectors

From the leading source vector collection table, two vectors will be selected that time bracket the base vector, that is, the vector having the largest time less than the base time, and the vector with the smallest time greater than the base time.

c. Interpolated Vector

The base time will be used to interpolate between the boundary vectors to determine a vector for the leading source which has the same time as the base vector.

d. Static Data

If the base vector or the interpolated is found to be the same for four seconds, then the parameters associated with the repeating source are to be static.

e. Missing Data

- (1) If boundary vectors cannot be found for the base vector, then the parameters associated with the boundary source are said to be missing.
- (2) If the difference between a boundary time and a base time is greater than four seconds, then the parameters associated with the boundary source will again be flagged as missing.
- (3) The base vector source parameters will be missing only if no data has ever been received or only one source has been received.

The terms static and missing should not be confused with the same terms which are used by Data Select in determining the status of vectors. Static in Section I means only that certain data is being used repeatedly in certain computations, while missing implies that no data could be found to obtain a valid vector for computations.

The criteria used in Parts d and e(2) will be defined as system parameters so that they can be updated easily.

2. Output Quantities for Platform Alignment Check

- a. GMTLO_p — predicted lift-off time during pre-launch

- b. AZ_0 — predicted flight path azimuth based on $GMTLO_p$
 - c. ΔAZ — azimuth misalignment
 - d. COUNT — counter for number of PBI inputs for misalignment calculation
 - e. STATIC IU — indicates Saturn IU data is static, missing, or valid
 - f. STATIC SC — indicates CMC data is static, missing, or valid
 - g. V_X, V_Y, V_Z — velocity in platform coordinates of Saturn IU vector
 - h. V_X, V_Y, V_Z — velocity in corrected platform coordinates of CMC vector
 - i. $\Delta V_X, \Delta V_Y, \Delta V_Z$ — differences in respective velocity components of Saturn and CMC vectors
 - j. IU^{V_T}, SC^{V_T} — total velocity for each source
 - k. ΔV_T — difference in total velocities
3. The following quantities are computed from the last valid selected source and AGC vectors without regard to time tags.
- a. MSS, MSC — indicates parameters for selected source or AGC are missing and previous values output are used in computations
 - b. SSIND — selected source ID, i. e., USB, IPR, etc. for data
 - c. $SS^{V_S}, SC^{V_S}, \Delta V_S$ — velocity increments required for a safe perigee for each source and difference in velocities
 - d. TFF_{SS} — time to free fall computed from selected source vector
 - e. $SS^{V_i}, SC^{V_i}, \Delta V_i$ — inertial velocities and difference
 - f. V_{go} — velocity to go = $\Delta V_S - \Delta V_i$
 - g. $SSH, SC^h, \Delta h$ — altitude above earth and difference
 - h. $SS^{\dot{R}}, SC^{\dot{R}}, \Delta \dot{R}$ — radial velocities and difference

The quantities in Items II and III will put output to a data table for reference by users. Note that the AGC vectors used in the computations for Items II and III need not be the same.

Launch Output Resources — The launch input task communicates with other tasks through the use of data tables. These tables are defined as the Hold Phase table, Output Display Table, Preburn Table and the Interface Table. The Hold Phase Table is used by the input task to pass to the hold phase task vectors, calculation codes, and indicators required for calculations of GO/NO-GO, Mode II Impact Points, Mode III Maneuvers, etc. The hold phase task passes back all calculations and necessary completion codes for the required parameters. Also included in this table are vehicle weights and areas from the Mission Plan Table. The Preburn Table is initialized at SPS ignition with the present hold phase vectors plus the latest powered-flight vectors to be used when transferring a preburn vector to orbit or abort phase. At transfer from prelaunch to launch, the Launch Interface Table will contain the directional cosine matrices (REFSMMATS) for the coordinate rotations of telemetry input data and the targeting vector required for the wedge-angle calculation. At transfer of phase, this table will also contain the current (postburn) and maneuver (preburn) vector for transfer to that phase (abort or orbit).

The Launch Output Display Table will contain all Launch output along with the output from the Hold Phase Table for display on D/TV, plotboards, etc. This output is logged for future reference (ZSHEIL tape).

High-Speed Input Task

LTDATAPF

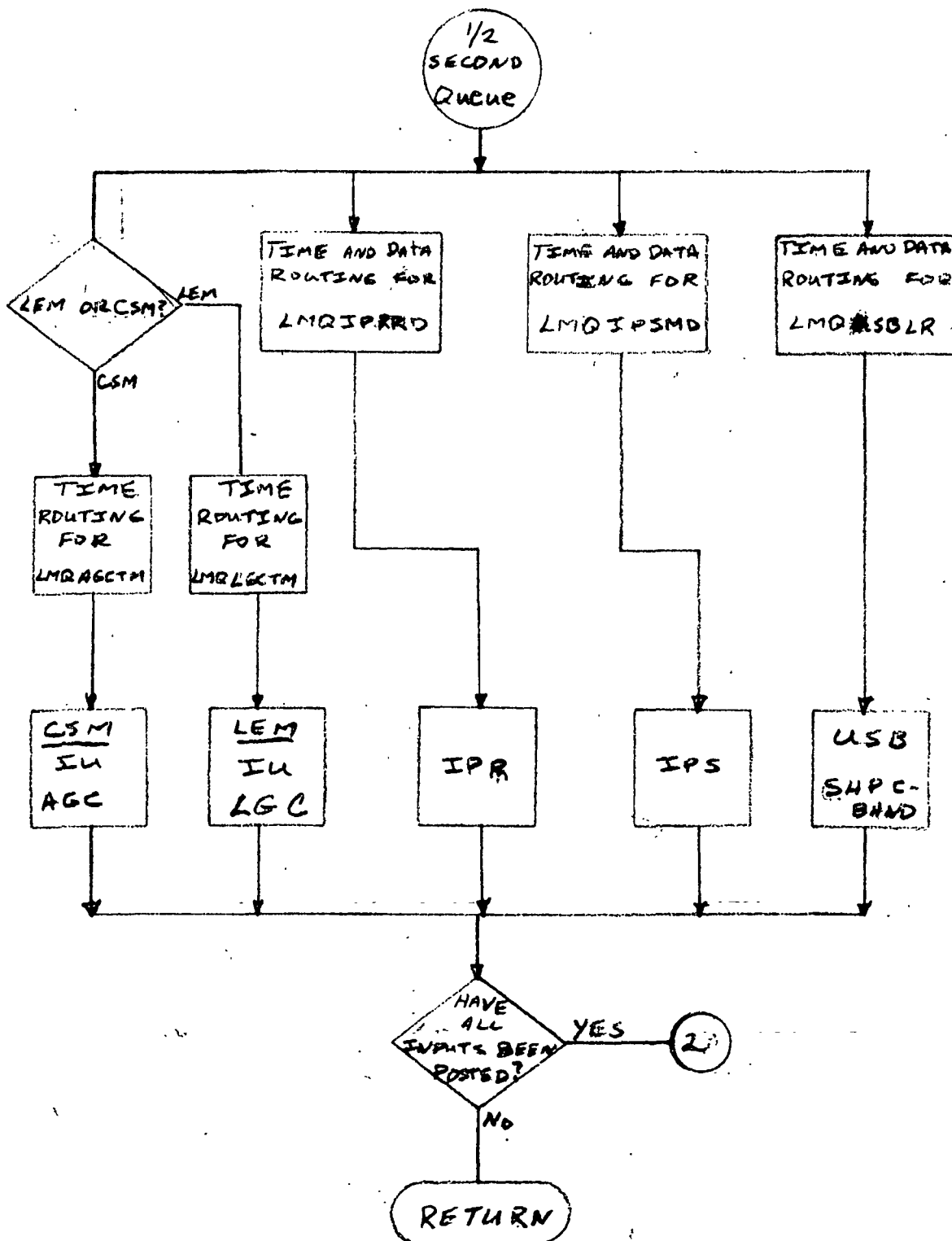


Figure 3. Launch Phase Flowchart

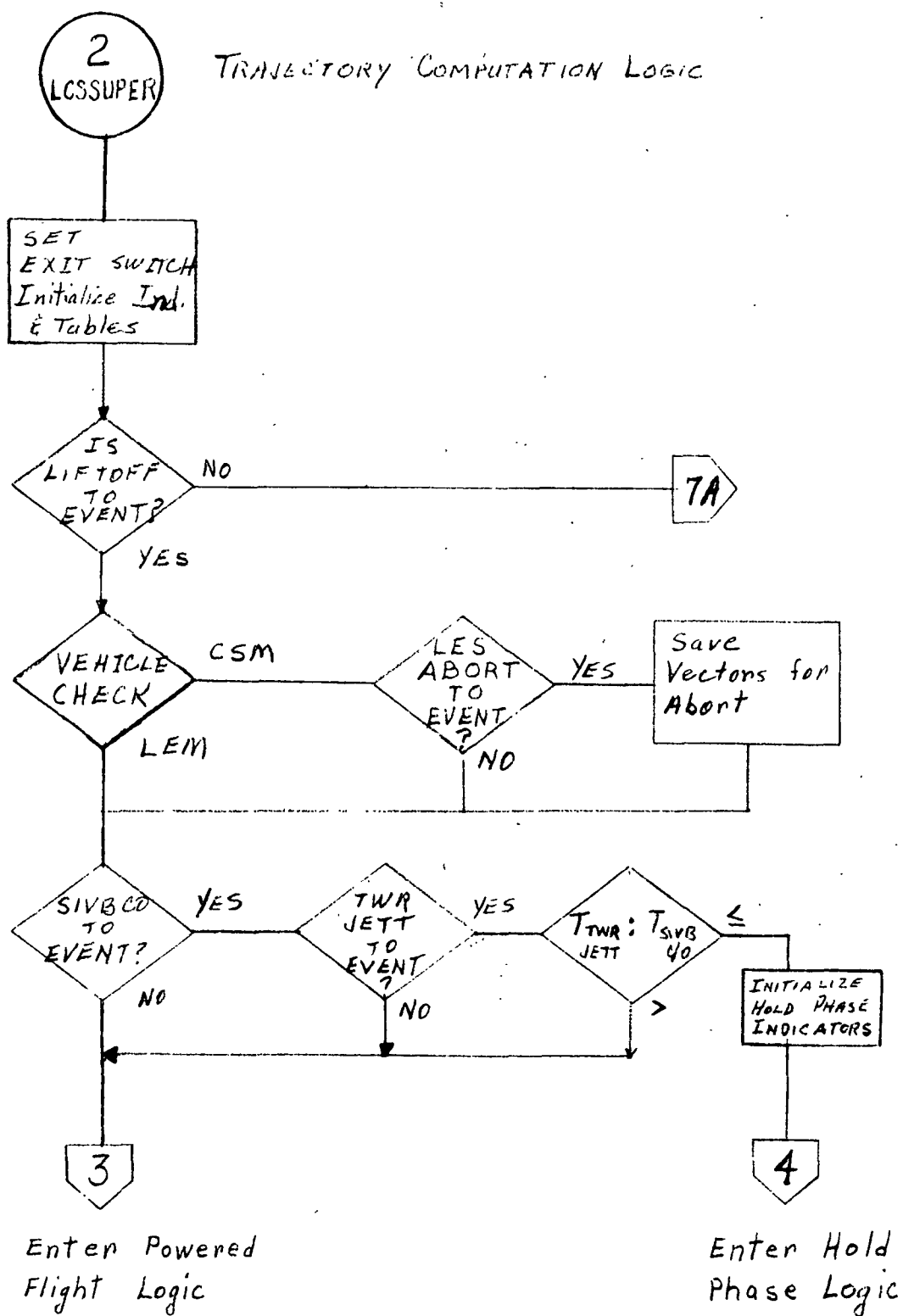


Figure 3. Launch Phase Flowchart

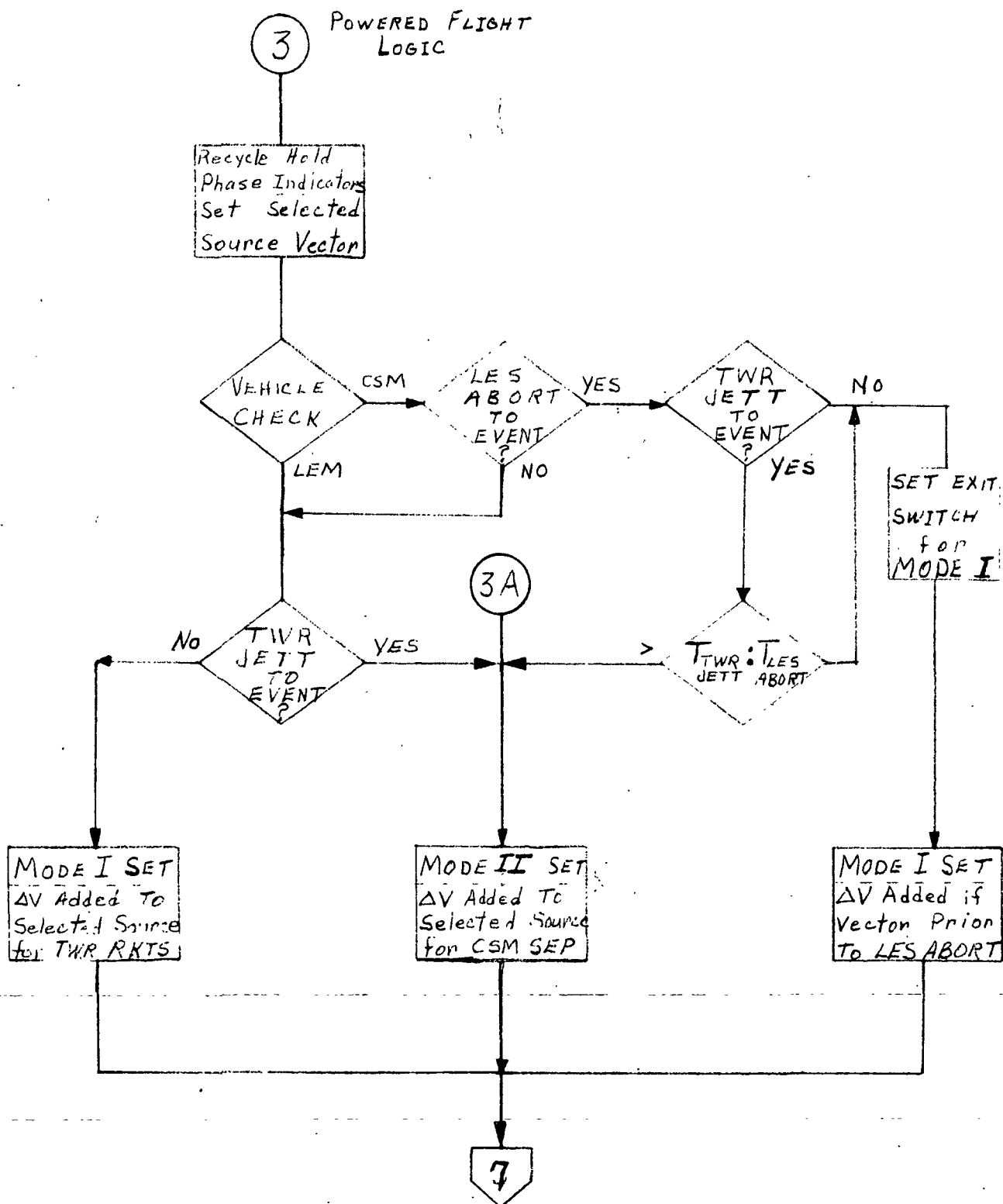


Figure 3. Launch Phase Flowchart

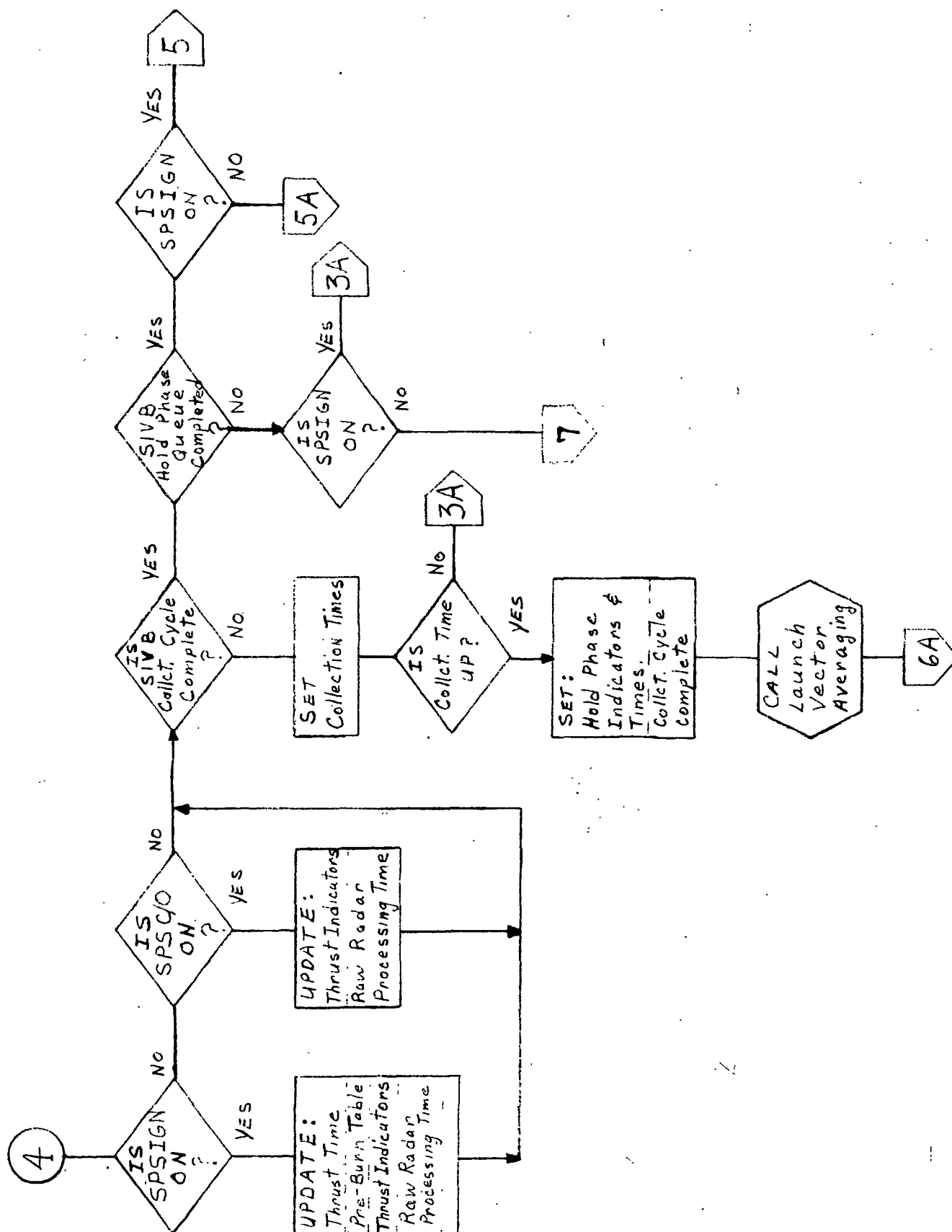
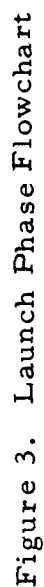


Figure 3. Launch Phase Flowchart

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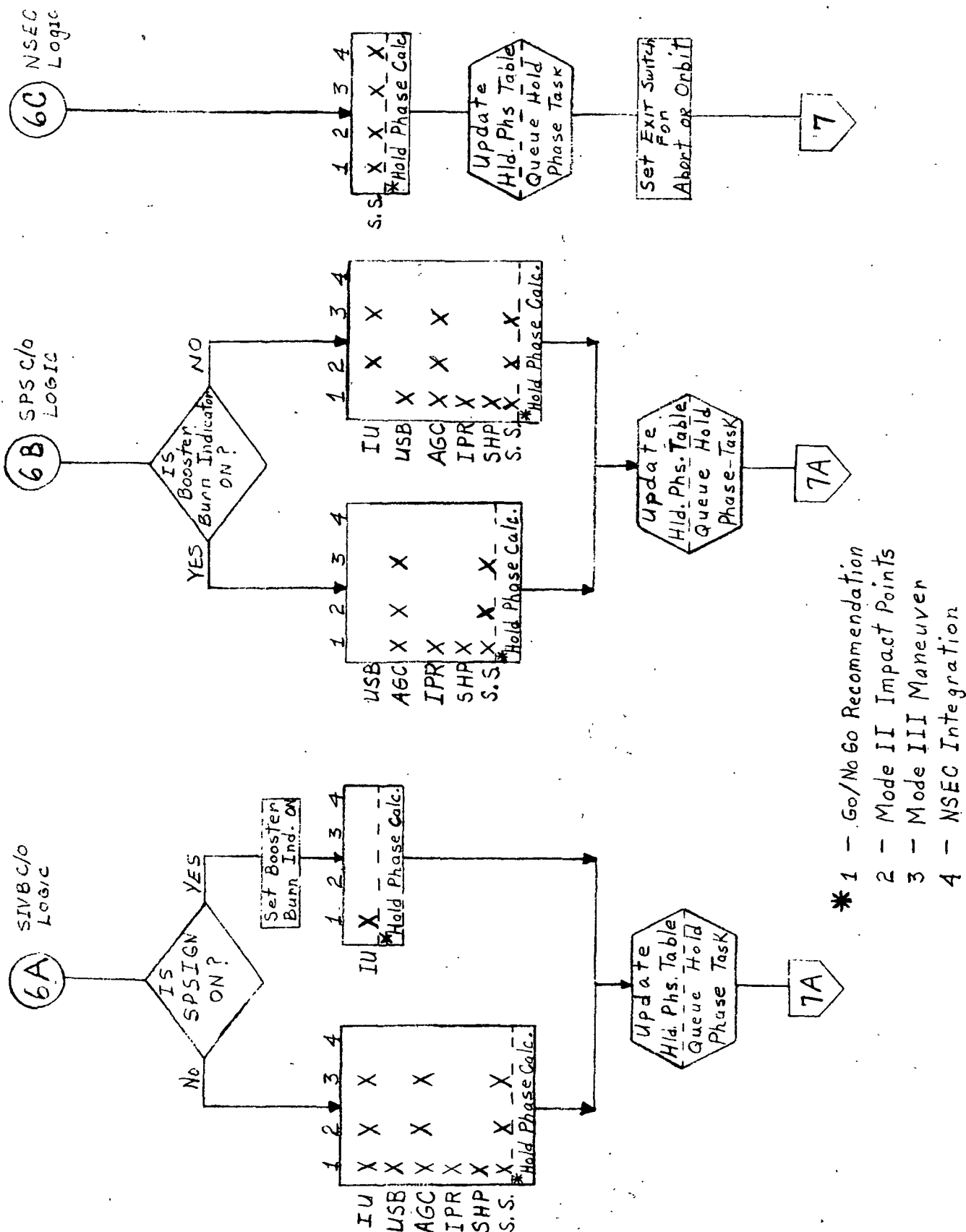


Figure 3. Launch Phase Flowchart

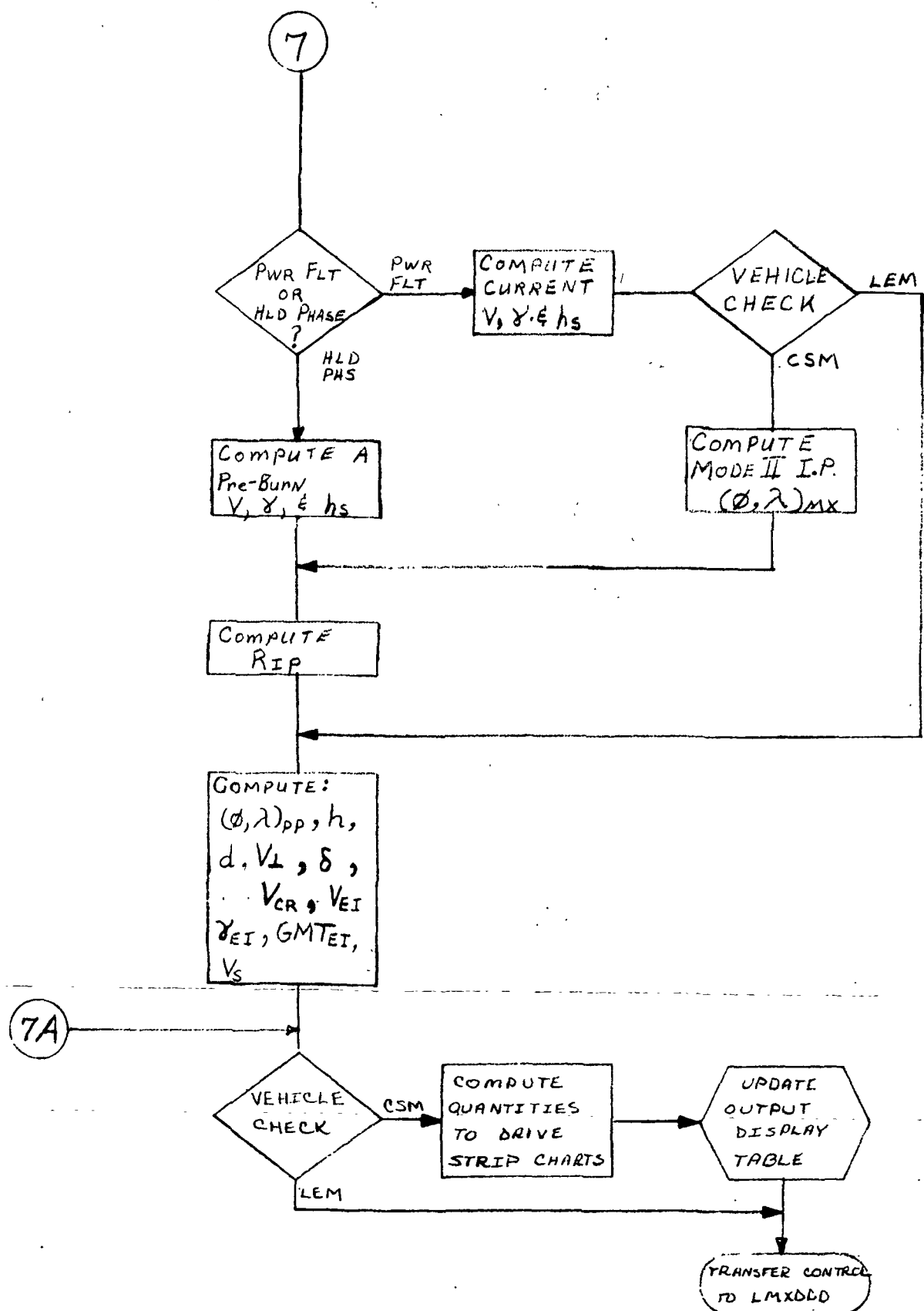


Figure 3. Launch Phase Flowchart

Launch High-Speed Input Task
Manual Entries
(LTDATEPF)

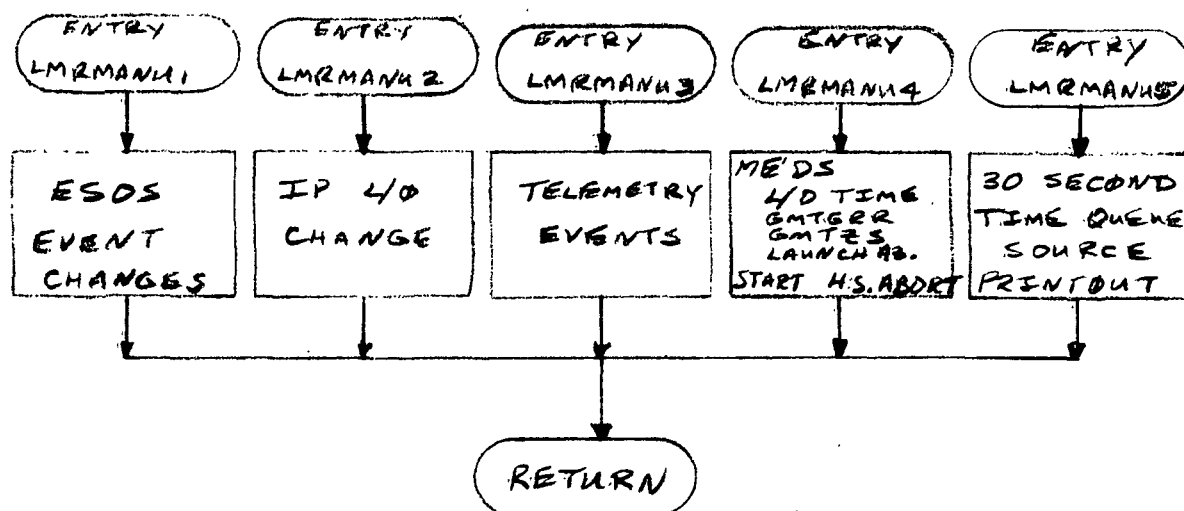


Figure 4. Launch Phase Flowchart



CSM High-Speed Abort Phase

Tracking Data Input Sources — In the high-speed abort phase, processing will be done for a maximum of four sources from spacecraft telemetry (1) and radar (3). The telemetry data will be received by telemetry input section via the CP from CCATS in PCM bit counts in three separate modes (downlinks). The data is unpacked and appropriately formatted for output to other tasks via telemetry data tables. The AGC vectors will be processed on a half-second time routine to the input task LTDATAPF. The radar sources will include IPR, USB (Ship, Land), and Ship C-band. This data will be received via the CP from CCATS and routed to the appropriate load module under the input task on a time and data basis. Each input message must pass a prescribed set of error checks before it is accepted. Ship C-band and Ship USB will be received as a vector of the form time, range, and velocity. IPR will be received in the form of a time and of the radar observations of range, azimuth, and elevation spaced by one-tenth second with a maximum of five observations per message. Land USB will be received as a time, an X-angle, a Y-angle, range, and range rate (doppler).

After being adjusted for elapsed time, and time delay correction by the input processors, the time tag of each vector is adjusted to current GMT. An integral multiple of 24 hours is added to or subtracted from the time tag as required to give a time tag of current GMT. The vectors are in the RTCC Earth-centered True Inertial Coordinate System. The time is in hours, the position vector components are in Earth radii and the velocity vector components are in Earth radii per hour.

Each of the input sources will be required, if possible, to output a vector. Each source will provide its vector in the Earth-centered true inertial coordinate system with RTCC units whether using short arc calculations for IPR and Land USB, a matrix rotation for AGC, or a coordinate conversion for Ship C-band, and Ship USB. By posting each source, a complete set of data is assured for a half-second time interval.

After the completion of all input sources, the input parameters are output via data table and the DDD's will be driven under control of the input task. Output data will be logged for future reference. This output will complete the cycle for the half-second cycle input sources.

Manual Input Sources — Upon entry to abort phase processing, all ESOS entries to the input task are disabled except for the selected and subselected sources from the Tracking Data Select console. The PBI inputs will be received as one-word inputs of the MED channel. These inputs result in

selecting (or subselecting) a new source as the selected source. The new source indication is printed on line with the time. There also exists a 30-second time printout to indicate on line the current time and the present selected source.

MED's that result in queues to the input task are as follows:

1. P10, CSM, GMTLO; Corrected Liftoff Time
2. P12, CSM, IU1 or IU2, GMTGRR, Launch Azimuth; IU, AGC, Guidance Reference Release Time.

P12 causes a change in the telemetry IU rotation matrices, which will be calculated for the new conditions specified and referenced by the input task. P10 results in liftoff being set to the time specified.

Launch Output Resources — In the abort phase, communications with the input task shall be carried out by the Launch Output Display Table and the Launch Phase Interface Table. The Launch Interface Table will contain the directional cosine matrices (REFSMMAT) for the coordinate rotations of telemetry input data to be referenced in case of MED inputs changing the REFSMMAT. The Launch Output Display Table will contain the input vectors necessary for display processing in the abort phase. The launch output display parameters are logged for future reference.

LTDATAPF (High-Speed Input Task)

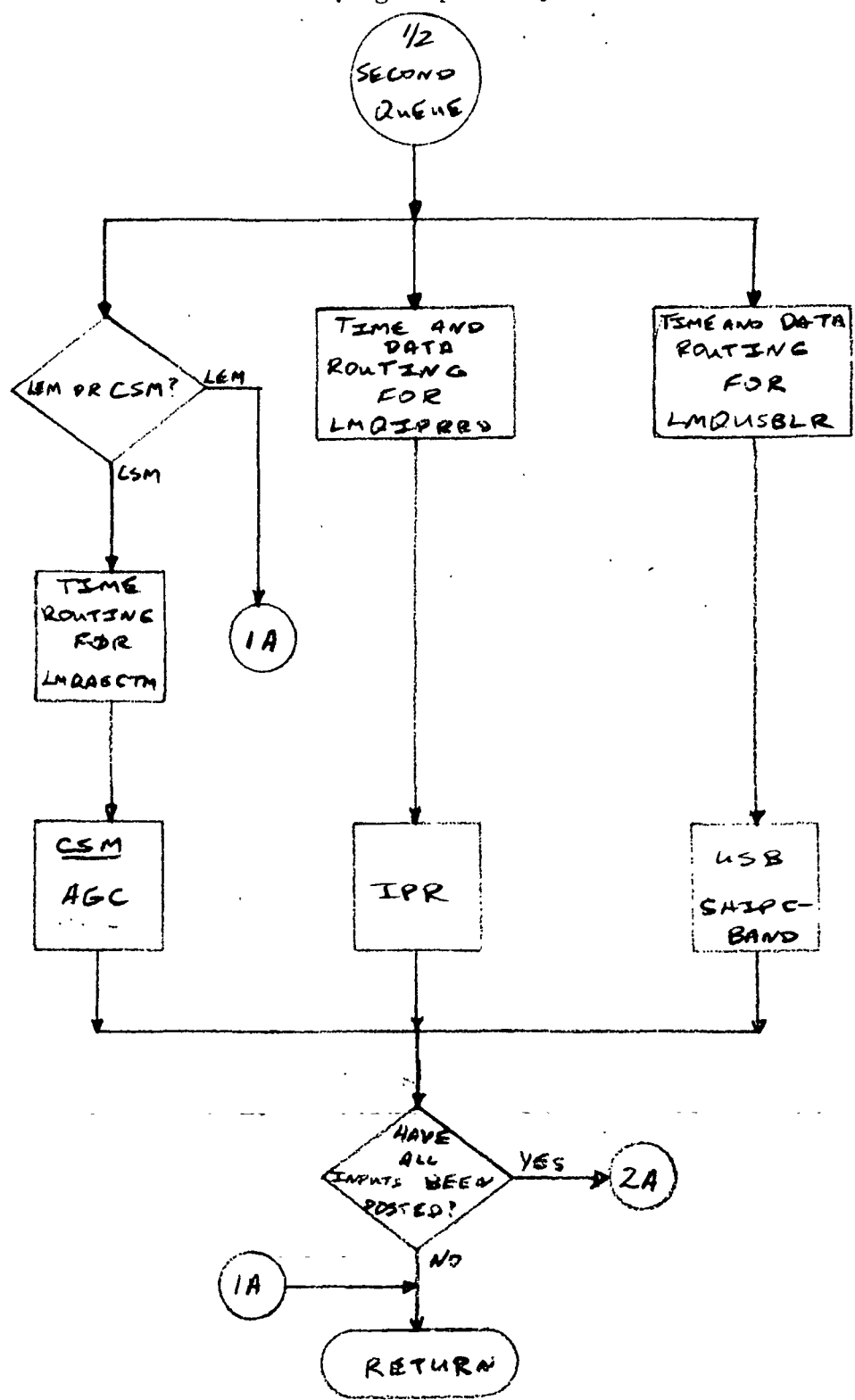


Figure 5. Abort Phase Flowchart

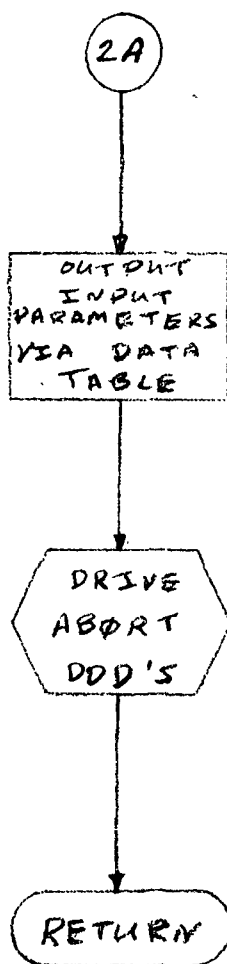


Figure 5. Abort Phase Flowchart

Launch/High-Speed Input Task
Manual Entries
(LTDATAPF)

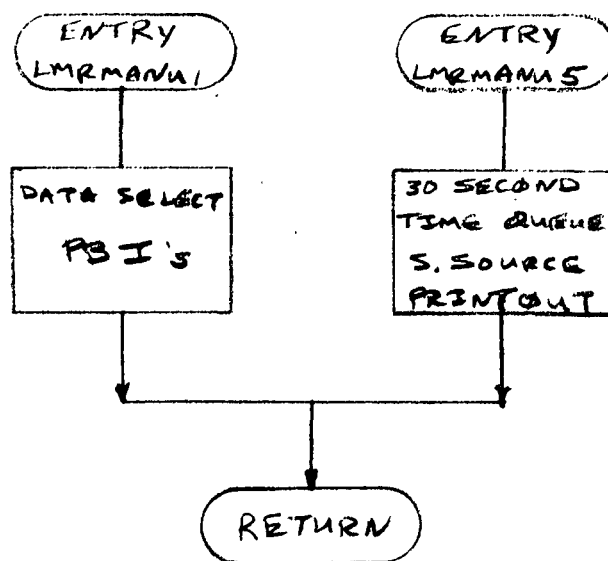


Figure 6. Abort Phase Flowchart

LM/CSM High-Speed Orbit Phase (Earth Reference or Lunar Reference)

Tracking Data Input Sources — In the High-Speed Orbit Earth Referenced Phase, processing will be done for a maximum of six sources from telemetry (2) and radar (4). The telemetry sources will include S-IVB booster IU data and AGC for the CSM or AGS and LGC for the LM, depending upon the vehicle being tracked. This data will be received by the telemetry input section via the CP from CCATS in PCM bit counts and in three separate modes (downlinks). The data is unpacked and appropriately formatted for output to other tasks via telemetry data tables. The vectors output by telemetry via data tables will be processed on a half-second cycle-time routing to the input task LTDATA PF. The vectors will be received as hours elapsed since GMTGRR, meters, and meters/second for IU; as hours elapsed since GMTZS, kilo-feet and feet/second for AGC and LGC; and hours, kilo-feet and feet/second for AGS. The radar sources will include Land C-Band, IPR, USB, and Ship C-band. This data will be received via the CP from CCATS and routed to the appropriate load module under the input task on a time and data basis. Each input message must pass a prescribed set of error checks before it is accepted as valid. Ship C-band and Ship USB will be received as a vector of the form time, range, and velocity. Land C-band and IPR will be received in the form of a time and in the form of radar observations for range, azimuth, and elevation. Land USB will be received as a time, an X-angle, a Y-angle, range and range rate (doppler).

After being adjusted for elapsed time, and time delay correction by the input processors, the time tag of each vector is adjusted to current GMT. An integral multiple of 24 hours is added to or subtracted from the time tag as required to give a time tag of current GMT. The vectors are in the RTCC Earth Centered True Inertial Coordinate System. The time is in hours, the position vector components are in Earth radii and the velocity vector components are in Earth radii per hour.

The actual number of input sources processed is variable and will depend upon a MED input. The telemetry selected source will be controlled by PBI with the radar selected source specified by the MED input. Each of the input sources will be required, if possible, to output a vector on a half-second cycle. Each source will provide its vector in the Earth-centered true inertial coordinate system with RTCC units, whether by smoothing in powered flight or short arc after SPS C/O for Orbit C-band, IPR and Land USB; by matrix rotation for IU, AGC, LGC and AGS; or by coordinate conversion for Ship C-band and Ship USB. Also the V_{gx} , V_{gy} , V_{gz} and telemetry site code parameters from AGC/LGC are made available to the display programs. By posting each source, a complete set of data is assured for a half-second time cycle.

The input parameters will be output via a data table with the DDD's driven under control of the input task after all possible input sources have been posted as complete. During a collection period after SPS cutoff, control is passed to a vector-averaging routine for telemetry and Ship data averaging; otherwise, the input task cycle is complete for half-second inputs. If necessary, logging of the input parameters is done by the Abort Orbit control supervisor.

In the High-Speed Orbit Lunar Referenced Phase, the logic is the same with the following exception:

1. no radar data routed
2. RTCC coordinate system is defined as MCI instead of ECT

Also for both Earth and lunar referenced phases AGC and LGC input coordinate systems are defined in the TLM stream (ECI or MCI) and AGS input referenced body is defined by MED (lunar or Earth).

Manual Input Sources -- The manual inputs received during orbit phase will include the ESOS for SPS thrust and the telemetry selected source PBI. There will also be a 30-second time printout queue. The switch inputs will be received as one or two-word formats and will be checked for validity. Only those switch event words that prove to be valid will be accepted. On-line messages will indicate the results of valid or invalid switch inputs.

Launch Output Resources -- In the orbit phase, communications with the input task will be carried out by the Launch Output Display Table and the Launch Phase Interface Table. The Launch Interface Table will contain the direction cosine matrices (REFSMMAT's) for the coordinate rotations of IU telemetry input data to be referenced. The Launch Output Display Table will contain the input vectors necessary for display processing in the orbit phase. These parameters will be logged for future reference.

High-Speed Input Task - LTDATEPF

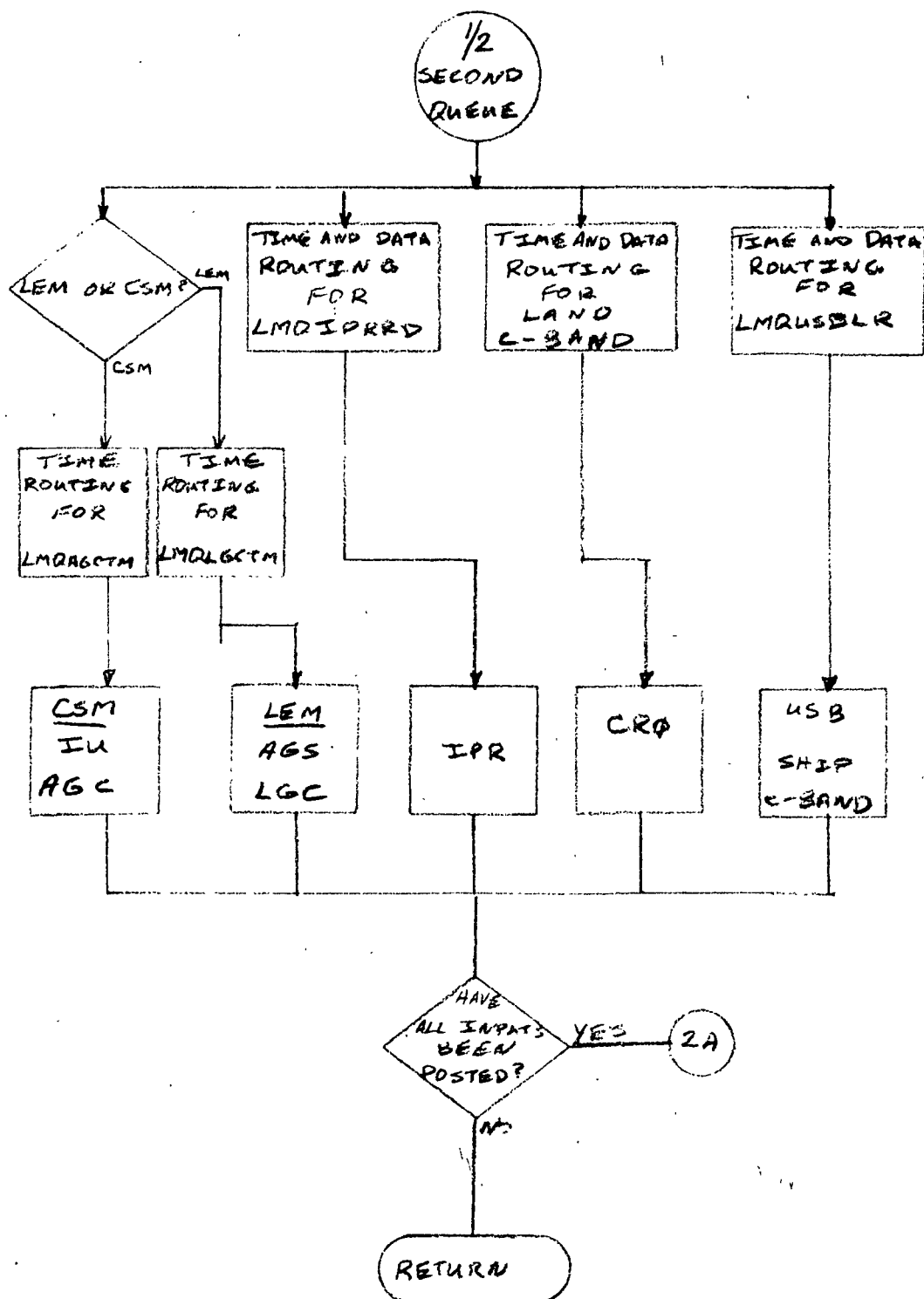


Figure 7. Orbit Phase Flowchart

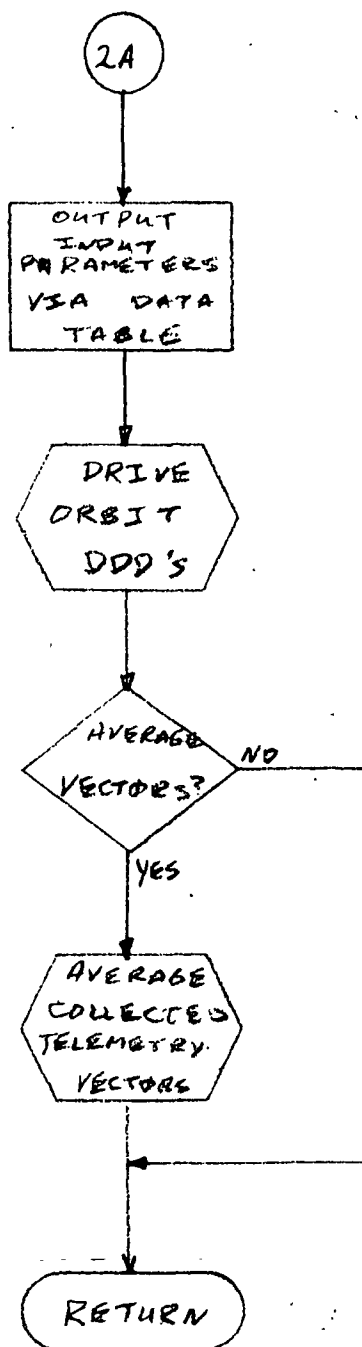


Figure 7. Orbit Phase Flowchart

Launch/High-Speed Input Task
Manual Entries
(LT DATAPF)

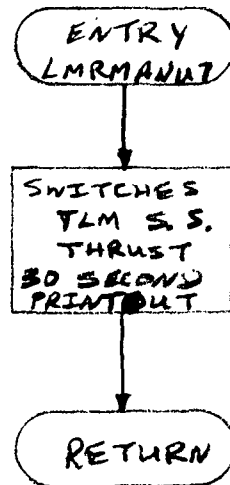


Figure 8. Orbit Phase Flowchart



LMGINITZ (Input Task Initialization Program) — The launch initialization load module is queued in prelaunch by GTPHASE. All necessary storage for LTDATEAPF is obtained. The storage is initialized depending upon the type vehicle launch. The appropriate rotation matrices are saved for use by the tracking data input processors. The mission plan target vector is stored for the wedge-angle (δ) calculation. The applicable vehicle weights are obtained from the mission plan table. All necessary routing is initiated at this time to start processing data sources, manual inputs and entry devices, and output resources.

This load module is also queued for high-speed orbit processing. The initialization of the storage is the same. There is a capability for variable routine and lunar or earth reference in this phase depending upon a manual entry queue. Processing of data sources may either be changed or deleted.

LMQAGCTM - (CSM Telemetry Input Processing) — LMQAGCTM receives a time queue on a half-second cycle and must obtain data via telemetry data tables on a one-second cycle for processing. This data will be accepted as valid data to be processed when the following checks are successful:

1. The message frame is not missing.
2. The message frame is active.

For a valid data frame, the following checks are made on each data parameter:

1. The parameter is not dead.
2. The parameter is not static.

Should any of the vector components (T, R, V) fail the above tests, the vector for that message is rejected, and the correct data is flagged as missing. The other parameters (i.e., VGX, VGY, VGZ, etc.) are checked individually and will be rejected if dead or static.

A check of the data time tag will indicate if the data frame has already been processed and if so the present data will be set as missing. A further check is made of the position and velocity vectors. If all three components of either the position or the velocity vectors are zero, the vector is rejected.

The AGC spacecraft telemetry vector input is defined with respect to the Earth-centered Inertial Coordinate System (ECI), or moon-centered inertial coordinate system (MCI). The general purpose coordinate conversion routine (ELVCNV) is used to convert this vector to the Earth-centered Time (ECT) coordinate system if the Earth reference system is required. The time tag is elapsed time since GMTZS, which is entered by MED. GMTZS is added to the time tag to get the "GMT" vector time tag. Final units for the vector will be hours, Earth radii, and Earth radii per hour.

The Telemetry Instrumentation Unit (TIU) vector defined with respect to the S-IVB platform alignment is converted to the ECT coordinate system by use of a left-hand matrix multiplication of the transpose of the REFSMMAT matrix as defined by the P12 MED for the CSM IU. (See LMMGRP). Using ELVCNV, it is converted to MCI for lunar referenced HS orbit. The time tag is elapsed time since GMTGRR entered via the P12 MED. GMTGRR is added to the time tag to get the "GMT" vector time tag. Final units are the same as AGC above.

Each vector accepted and rotated as above is placed in a collection table for GO/NO-GO vector averaging. In launch, the booster source (IU) discontinues processing at the end of the S-IVB collection period. In Abort, there is no IU processing. If no new vector is output, the data quality indicator will so indicate. For input termination see LIRDAT.

LMQLGCTM - (LM Telemetry Input Processing) - LMQLGCTM receives a time queue on a half-second cycle and must obtain data via telemetry data tables on a one-second cycle for processing. This data will be accepted as valid data to be processed when the following checks are successful:

1. The message frame is not missing.
2. The message frame is active.

For a valid data frame, the following checks are made on each data parameter:

1. The parameter is not dead.
2. The parameter is not static.

Should any of the vector components (T, R, V) fail the above tests, the vector for that message is rejected and the current data flagged as missing. The other parameters (i. e., TGO, etc.) are checked individually and will be rejected if dead or static.

A check of the data time tag will indicate if the data frame had already been processed, and if so, the present data will be set as missing. A further check is made of the position and velocity vectors. If all three components of either the position or the velocity vectors are zero, the vector is rejected.

The LGC spacecraft telemetry vector input is defined with respect to the Earth-centered Inertial Coordinate System or Moon-centered Inertial Coordinate System (MCI). The general purpose coordinate conversion routine (ELVCNV) is used to convert this vector to the Earth-centered TimeCoordinate System when the Earth referenced system is required. The time tag is elapsed time since GMTZS, which is entered by MED. GMTZS is added to the time tag to get the "GMT" vector time tag. Final units for the vector shall be hours, Earth radii and Earth radii per hour.

The Telemetry Instrumentation Unit vector defined with respect to the S-IVB platform alignment is converted to the ECT coordinate system by use of a left-hand matrix multiplication of the transpose of the REF SMMAT matrix as defined by the P12 MED for the LM IU (See LMMGRP). The time tag is elapsed time since GMTGRR entered via the P12 MED. GMTGRR is added to the time tag to get the "GMT" vector time tag. Final units are the same as for LGC above.

In the high-speed orbit phase, the LM IU is replaced by the Abort Guidance System (AGS) vector. This vector is defined with respect to the LM platform. This vector is rotated to the ECT or MCI system by use of the transpose of the AGS matrix defined by GOST. The time tag is elapsed time since GMTZS, which is entered by MED. GMTZS is added to the time tag to get the "GMT" vector time tag. Final units are the same as the LGC above.

Input units for each of the above vectors are as defined by the Telemetry subsystem.

Each vector accepted and rotated as above is placed in a collection table for GO/NO-GO vector averaging. In launch, the booster source discontinues processing at the end of the S-IVB collection period. If no new vector is output, the data quality indicator will so indicate. For input termination, see LIRDAT.

LMQCBAND - (Orbit Land C-Band Input Program) — LMQCBAND processes Land C-band data being received from CCATS via the CP on a half-second cycle rate. Each Land C-band data frame received will contain one T, R, A, E (time, range, azimuth, elevation) data point to be verified for further processing. After assuring that the data is from the currently processed C-band site, the data must pass the following data checks:

1. The data frame has not been previously processed (time check)
2. The frame is valid.
3. The frame consists of real data.
4. The frame has the correct length (character count)
5. The data is "on tract".
6. The data is from the correct vehicle.

A valid data point is converted to RTCC units by use of the granularities defined in the criteria for this site. The time tag is adjusted to current GMT time, and two biases are applied to the range value; one bias a station bias defined in the station characteristics and the other a beacon bias. The T, R, A, E points derived from the Land C-band data are converted to vectors using the Editing-Smoothing-Short Arc Subroutine (See LIMQED) if they are found to pass further editing checks such as data above 3 degrees. If no new vector is output, the data quality indicator will indicate why. For input termination, see LIRDAT.

LMQIPRRD - (IP Raw Input Program) — LMQIPRRD processes IP raw data frames being received from CCATS via the CP on duplex lines at the rate of two frames per half-second with each data frame containing up to five T, R, A, E (time, range, azimuth, elevation) points and up to five sites (usually one site) per data frame. The data frame will be accepted as valid if it passes the following data checks:

1. Duplex line check for message frame that has not been previously processed. (time-tag check).
2. The message frame is valid.
3. The message frame consists of real data.
4. The message frame has the correct length (character count).
5. The message frame contains no transmission errors (checksum).

When the frame has been accepted as valid, each of the five T, R, A, E data points in that frame will be accepted as a valid data point and will be converted to RTCC units, using the granularities defined for the raw radar editing when the following data checks are successful:

1. The data point is from a currently defined site for this mission.
2. The radar is "on track" for the data point.

The time tag for valid data points is corrected to current GMT and adjusted for possible transmission delay. A station range bias is applied to the range component of the T, R, A, E data points. This bias is supplied via the station characteristics. The data points may be further "edited" (see LIMQED) for conditions such as below three degrees or excessive changes in data (data rates, etc.). If no new vector output, the data quality indicator will indicate why. For input termination, see LIRDAT.

LMQIPSMD (IP Smooth Input program) — LMQIPSMD processes IP smooth data frames being received from CCATS via the CP on duplex lines, two frames per half-second and containing one TRV data point per frame. For a data point to be accepted as valid, it must pass the following data checks:

1. The message frame consists of true IP computer words
2. Frame has not been previously processed (time-tag check)
3. The message frame is valid
4. The message frame consists of real data
5. The message frame has the correct length (character count)
6. The message frame has no transmission errors (checksum).

Vectors that pass all data checks are unpacked, the time tag is adjusted for possible transmission delay and corrected to current GMT time, and the vector is rotated through a " Ωt " to account for Earth rotation to the RTCC coordinate system.

Each half-second, this source will output a data quality and, if possible, a vector. If no new vector is output, the data quality indicator will indicate why. For input termination, see LIRDAT.

LMMGRP - (Guidance Reference Platform Initialization) — LMMGRP makes use of a generalized three-dimensioned matrix rotation routine (GLMRTM) to compute the direction cosine values of the CSM platform, the IU (CSM) platform, or the IU (LM) platform when queued as the result of a P12 MED entry. The following rotations are made:

$$\begin{aligned}
 \text{AGC} \quad \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{platform}} &= \underbrace{R_x(A) R_y\left(-\frac{\pi}{2} - \varphi\right) R_z(\Delta\lambda)}_{\substack{\text{(resulting cosine matrix)} \\ \text{(REFSMMAT)}}} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ICS}} \\
 \text{IU (CSM and LM)} \quad \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{platform}} &= \underbrace{R_x(-A) R_y(-\varphi) R_z(\Delta\lambda)}_{\text{(REFSMMAT)}} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ICS}}
 \end{aligned}$$

where: A = launch flight azimuth

φ = geodetic latitude of the CSM or LM pad.

$\Delta\lambda$ = $\lambda_{\text{pad}} + \lambda_0 + \Omega t$ = longitude of the CSM or LM pad + longitude of Greenwich + (angular velocity of the Earth) (GMTGRR)
 = the inertial longitude of the pad.

Use is also made of the generalized coordinate conversion routine (ELVCNV) to convert the REFSMMAT above to the following:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{platform}} = \begin{bmatrix} \text{REFSMMAT} \end{bmatrix} \begin{bmatrix} P05^T \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECT}} = \begin{bmatrix} \text{ECT to platform} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECT}}$$

Both the REFSMMAT and the ECT to platform matrices above are output to the on-line prints. All REFSMMAT's are output via data table. The ECT to platform matrix is also output via data table.

LIMQED High-Speed Raw Radar Editing, Smoothing, and Short Arc — The raw radar editing table is initialized for each radar source. Initialization of the table requires two consecutive radar observations with elevation above three degrees having time tags differing by the applicable data rate as defined in the station characteristics of the radar. Once the editing table is initialized, subsequent observations will be buffered for editing. Each buffered radar point is corrected for refraction and local vertical deflection.

Once the editing table has been established, the time tag of the next expected point is the time tag of the last buffered point plus the data rate of the radar plus or minus a small epsilon. If the next point received has a time tag behind the expected time, it is ignored. If the time tag of the next point is ahead of the expected time, the number of missing points is computed, and bad data points are extrapolated to fill the gap. If the editing table would overflow by extrapolating all of the missing points, the extrapolation is terminated when the table is filled, and any unbuffered points are ignored.

When the raw-radar editing table becomes filled, it will be re-organized after all the new points have been buffered, and the old points that are no longer needed will be removed.

If the raw-radar data is powered-flight data, the radar observations are converted to the RTCC Earth-centered True inertial coordinate system using the station characteristics of the radar. If $2N+1$ points have been edited, the Smoothing routine is used.

If LIMQED is entered with a good data quality indicator and is unable to obtain a solution vector because of bad data or not enough data, the data quality indicator will be set to restart.

If the data is free-flight data, that is, after the S-IVB cut-off event when the thrust switch is not set to EVENT, or after LES ABORT EVENT, the short arc routine will be used. Short arc will be initialized each time the time of free flight changes.

Local to ECT coordinate system conversions

$$M = R_Z(-\lambda) R_Z(-\frac{\pi}{2}) R_X(\varphi - \frac{\pi}{2})$$

AZ - El conversion

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M \left\{ R_Z (A) R_X (-E) \begin{bmatrix} 0 \\ \rho \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ -R_E \sin (\varphi - \varphi^1) \\ R_E \cos (\varphi - \varphi^1) + H \end{bmatrix} \right\}$$

XY - 30 conversion

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M \left\{ R_Y (-X_{30}) R_X (Y_{30}) \begin{bmatrix} 0 \\ 0 \\ \rho \end{bmatrix} + \begin{bmatrix} 0 \\ -R_E \sin (\varphi - \varphi^1) \\ R_E \cos (\varphi - \varphi^1) + H \end{bmatrix} \right\}$$

XY - 85 conversion

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = M \left\{ R_X (-X_{85}) R_Y (-Y_{85}) \begin{bmatrix} 0 \\ 0 \\ \rho \end{bmatrix} + \begin{bmatrix} 0 \\ -R_E \sin (\varphi - \varphi^1) \\ R_E \cos (\varphi - \varphi^1) + H \end{bmatrix} \right\}$$

Polar conversion

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = R_Z \left(\frac{\pi}{2} - \lambda \right) \left\{ R_Z (HA) R_X (-\delta) \begin{bmatrix} 0 \\ \rho \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ R_E \cos \varphi^1 + H \cos \varphi \\ R_E \sin \varphi^1 + H \sin \varphi \end{bmatrix} \right\}$$

$R_A (\theta)$ = clockwise rotation through an angle θ about axis A

$$\lambda = \lambda_g + \lambda_s + \omega t$$

where λ_g = geodetic longitude of Greenwich, England (radians)

λ_s = geodetic longitude of radar site (radians)

ω = rotational velocity of Earth (rad./hr.)

t = elapsed time since coordinate system definition (hour)

R_E	=	radius of Earth	(Er)
φ	=	geodetic latitude	(radians)
φ^1	=	geocentric latitude	(radians)
H	=	altitude above ellipsoid	(Er)
ρ	=	local range observation	(Er)
A	=	C-band azimuth observation	(radians)
E	=	C-band elevation observation	(radians)
X_{30}	=	S-band X_{30} angle observation	(radians)
Y_{30}	=	S-band Y_{30} angle observation	(radians)
X_{85}	=	S-band X_{85} angle observation	(radians)
Y_{85}	=	S-band Y_{85} angle observation	(radians)
HA	=	S-band hour angle observation	(radians)
δ	=	S-band declination angle observation	(radians)

Upon entering the high-speed orbit phase, the raw-radar data processing is initialized for 2N+1 smoothing. After receiving indication of THRUST 'OFF', Short Arc is initialized. The raw-radar processing program (LIMQED) is available in the RTCC Apollo Programming Systems documentation.

USB/Ship Data Routing — All mission high-speed radar data frames accumulated since the last routing in the range 500 octal to 577 octal received from the CPIN will be routed to the USB/Ship processor on a half-second queue with the restriction that a maximum of 60 frames will be routed on any queue. If more than 60 of the above type frames is received between routings of the queue, the oldest frame will be discarded.

Data frames received by the USB/Ship processor with source code ID's in the range 500 octal to 507 octal will be discarded (IP data). Those frames having source code ID in the CCATS label 560, 561, 562, 563 octal will be processed as Ship data. Those frames having CCATS source ID's defined in the tracking data formats document as C-band sites will be discarded. Those frames having CCATS source ID's defined in the tracking data formats document as C-band or USB sites which contain a C-band site ID within the message frame will be discarded. The site ID within the message frame will be examined to determine if it is a USB site that can be processed, and if not, the message frame will be discarded. If all message frames are discarded because of this check, the

illegal source code DDD will be illuminated. The source code ID's for the Ship data and the site ID's for the Land USB data are defined in the Tracking Data Formats Document.

Land USB Input Processing

Land USB data frames being received from CCATS, one frame per 1/10 second or per 2/10 second and containing one USB data point per frame, will be accepted as valid data frames to be processed when the following data checks are successful:

1. The message frame is valid.
[Bit 1 of CCATS label = 1]
2. The message frame has the correct length.
[Character count bits 25-36 of CCATS label - 40_{10}]
3. The message frame consists of real data.
[Bit 88 of the message frame = 1]
4. The message frame contains non-destruct doppler.
[Bit 85 of the message frame = 0]
5. The angle data quality is good.
[Bit 93 of the message frame = 1]
6. The tracking mode is in auto track.
[Bit 92 of the message frame = 1]
7. The range rate data quality is good.
[Bit 202 of the message frame = 1]
8. The manual range-range rate data quality is good.
[Bit 201 of the message frame = 1]
9. The doppler mode is two way; This site is active.
[Bits 94, 95 of message frame = 01]
10. The message is from a currently defined radar site for this mission.
[The source being received has been defined as a valid site by the high-speed input processing programs and it does exist on the station characteristics. Bits 80-84 of the message frame contains the source code.]

11.

- a. For Launch/High-Speed Abort processing, no vehicle checks will be made. If the vehicle ID being received in the message frame does not correspond to either the LM, CSM or S-IVB vehicles, to determine whether f_1 or f_2 frequency values are to be used off the station characteristics, the data will be edited out.
- b. For high-speed orbit processing, vehicle checks will be made. During LM pass, only data with LM vehicle ID will be processed, and during CSM pass, only data with S-IVB or CSM vehicle ID will be processed.

[Bits 89-91 of the message frame contains the vehicle ID of the data.]

When the frame has been accepted as valid, the following data checks are made to identify a range message:

1. The data time tag is an exact six-second multiple.
[Bits 98-126 of the message frame contain the time tag of the data.]
2. The message frame consists of a range reading instead of frequency.
[Bit 97 of the message frame = 1]
3. The range data quality is good.
[Bit 163 of the message frame = 1]
4. The range is not a range message acquisition frame.
[Bit 164 of the message frame = 0]

If the range message test fails, the message frame will be considered a range rate message; but the range rate message will be rejected if no range message has been received from the same site as the current range rate message.

When the above checks are valid to give a range reading or range rate reading, the USB data point is computed and stored for editing processing by applying the following logic.

A land USB data point consists of a time, range, and two angles. The time bits 98-126 are unpacked and converted to hours. (This time is elapsed time from midnight, January 1.) A transmission delay value (currently zero) is added to this time, and a value that is nominally zero but that may be changed by the S24 MED is also added. The time is then adjusted to RTCC GMT. The angles (bits 127-144 and bits 145-162, respectively) are unpacked and converted using the angular granularity found in the station characteristics.

If the message is a range message, the range value (bits 165-194) is unpacked and converted using the range granularity value found in the station characteristics. The range value, time and range rate value (bits 203-237) are saved for use in computing the range value from a range rate message.

The range value from a range rate message is computed using the following formula:

$$R_1 = R_0 + \left(\frac{MC}{F} \right) \left[\frac{(D_1 - D_0)}{16} - (T_1 - T_0) B \right]$$

where

- R_1 = Range to be computed in feet
- R_0 = Range from last range message in feet
- D_1 = Doppler count from update message
- D_0 = Doppler count from range message
- T_1 = Time in seconds of update message
- T_0 = Time in seconds of range message
- B = Bias factor of 10^6 cycles/second (MCLBIS)
- 16 = Doppler counts/range count
- C = Feet/Earth radii = 20925738.18897635 (MCCFCU)
- F = Transmitter frequency in megacycles/second
- M = Factor which divided by frequency in megacycles/second converts range counts to Earth radii = $346.254983 \times 10^{-6}$ (MCLURC)

The transmitter frequency value is obtained from the station characteristics. The frequency used will be the ones corresponding to the vehicle ID of the message.

The range observation is corrected for site and beacon bias. The site bias is obtained from the station characteristics. The beacon bias is obtained from the array system parameter MDSRAB. The used bias within this array is that for the beacon corresponding to the vehicle ID of the data.

A maximum of 20 points may be stored for editing processing during a processing cycle. If more than 20 points are received from the active Land USB site during a half second, the last 20 points received will be retained, and the older ones will be discarded. After receiving a vector from Editing, LIMGED, the vector is made available to the USB site determination logic (Ship or Land).

Ship-C/Ship-USB Input Processing

The Ship data frames containing one C-band and one USB T, R, V data point will be expected at a rate of one frame per half-second. This data for both Ship USB and Ship C-band processing will be accepted as valid data frames to be processed when the following data checks are successful:

1. The message frame is valid.
[Bit 1 of CCATS Label = 1]
2. The message frame has the correct length.
[Character count bits 25-36 of CCATS Label = 92_{10}]
3. The message status is good.
[Bits 589-591 of the message frame = 000]

The following checks will be made of the valid message frame for accepting Ship-C data to be available as a selected source vector:

1. During Launch/High-Speed Abort phase, the program is initialized to accept only the ship specified as the insertion ship in the NASA document 'Station Characteristics for Apollo Mission Support'; while during the high-speed orbit pass, the P60 MED defines the ship to be processed VANGUARD, REDSTONE, MERCURY, or WATERTOWN.
[Bits 4-12 of the CCATS label define the Ship source code.]
2. C-band radar is in the auto track mode.
[Bit 324 of the message frame = 1]
3. Duplex data check for Ship C-band data that has been previously processed successfully.
[Current C-band time word \neq last valid C-band time word]
4.
 - a. For Launch/High-Speed Abort processing, no vehicle checks will be made; but if the vehicle ID being received in the message frame does not correspond to either the LM, CSM or S-IVB, the data will be edited out.
 - b. For high-speed orbit processing, vehicle checks will be made. During LM pass, only data with LM vehicle ID will be processed, and during CSM pass, only data with S-IVB or CSM vehicle ID will be processed.
[Bits 321-323 of the message frame contains the vehicle ID of the C-band data.]

If the C-band tracking indicates skin track (bit 320 of the message frame = 1), the data will not be edited out, but the beacon track DD will be turned off.

The following checks will be made of the valid message frame for accepting Ship-USB data to be available as a selected source vector.

1. The message frame contains Ship-USB active two-way lock data.
[Bit 84 of the message frame = 1]
2. The Ship-USB data is real.
[Bit 73 of the message frame = 1]
3. Duplex data check for Ship-USB data that has not been previously processed successfully.
[Current USB time word \neq last valid USB time word]
4. Same as Ship C-band 4a or 4b.
[Bits 81-83 of the message frame contains the vehicle ID of the USB]
data.

The coordinate system for Ship C-band and Ship USB vectors is assumed to be the RTCC Earth-centered true inertial coordinate system defined at midnight preceding the first launch with the X-axis through Greenwich, the Z-axis through the poles and the Y-axis at right angles to the X- and Z-axes completing a right-handed coordinate system.

The time tags associated with the Ship C-band and Ship USB vectors are elapsed time from midnight, January 1. Transmission delay values (currently zero) will be added to the time tags.

A second value, which is nominally zero but that may be changed by the S24 MED, is also added to the time tags, and the time tags are then adjusted to GMT. The vectors are rotated about the Z-axis to account for the rotation of the Earth during a time period equal to the S24 MED value. The time is then adjusted to RTCC-GMT.

The Ship C-band vector is made available for selected source processing after posting the data quality computations (V , γ) while the Ship USB vector is made available to the USB site determination logic (Ship or Land).

Ship C-Band Site Determination — The Ship C-band site to be processed is determined by an indicator set by the high-speed initialization program. The indicator is used by the Ship C-band processor to determine the CCATS station ID code corresponding to the appropriate Ship. Currently the ship's VANGUARD, MERCURY, REDSTONE, and WATERTOWN with octal CCATS station ID's of 560, 561, 562, and 563, respectively, can be processed.

USB Site Determination — The following criteria are used to determine, (1) which USB site will be used to provide the USB selected source vector when two or more USB sites are transmitting active data and, (2) when to change sites.

1. No ship site will be processed as the USB selected source vector unless a time period of five seconds has elapsed since the last active Land USB message was received. This time period is determined by counting the processing cycles having no active Land messages. The count is reset whenever an active Land message is received. The count, currently 10, required before using Ship to provide the USB selected source vector is defined by a system parameter.
2. When no previous range messages have been received, the first Land USB site to provide a range message will be used to provide the USB selected source vector.
3. A switch in Land sites will occur during a half-second processing cycle if a range message is received from a new site, and no valid six-second multiple message is received from the old site.
4. If two or more new sites provide a range message during a half-second processing period and no valid six-second multiple message is received from the old site, the switch will be made to that new site whose range message is last found in the input buffer.
5. No distinction is made between Ship USB sites. If ships are providing overlapping coverage, the Ship USB vector to be made available as the USB selected source vector will be that last vector accepted by the input processor. The USB site DD indicator will be set to reflect the Ship from which the vector was taken and could possibly alternate every half-second. The on-line print made for each site change could also be made every half-second.
6. No site tracking a vehicle illegal in the current phase will be made available to the site selection logic.



If Land sites are providing overlapping coverage and the range message of the various sites are received during different processing cycles, the program will switch sites for each range message. If Land sites are providing overlapping coverage, if the range messages of the various sites are received in the same processing cycle, and if the current site remains active but becomes faulted, then the program will switch sites. If the above condition occurs when a Land and a Ship site are providing the overlapping coverage, the program will not switch to the Ship site so long as the Land site is active.

The USB site DDD indicator will reflect either of the following.

1. The Land site from which the last USB data point has been derived
2. The Land site from which the last active message was received
3. The Ship site if the last USB selected source vector was provided by the Ship and no active Land site messages have been received since the Ship site provided the USB selected source vector

If during a half-second processing period, some Land USB messages are received, all of which pass the data quality checks and all of which are range rate messages from a site or sites other than that site which provided the last range message, the no message data quality DD indicator will be illuminated.

LMRMANU1 (Launch Switch Module) — This module processes switch inputs that control launch phase trajectory processing from the following consoles: Tracking Data Select Engineer, Guidance Officer, Flight Dynamics Officer, and Retrofire Officer. Each switch input is tested for validity with error messages printed for wrong length, illogical pairs of words, and improper bit patterns. Two new switches will be implemented in the 500 series for this mission; they are the Impact Range Indicator for Retrofire Officer's console and the Wedge Angle Monitor for Guidance Officer's console. Also V_{LO} must be calculated when L/O is received

from the switch without IP L/O time being used.

LMRMANU2 (Launch IP Liftoff Module) — This module processes IP liftoff and sets the event for use by other launch modules depending on the setting of EOS. V_{LO} will be an added calculation for the LMSP.

LMRMANU3 (Launch Telemetry Events Module) — This module processes queues from the mission supervisor for telemetry events. On-line prints and settings of events for use by other launch modules are the outputs. For the LMSP, S-IVB C/O is the only telemetry event that will be processed.

LMRMANU4 (Launch MED Update Module) — This module processes the queues from the mission supervisor for the following: (1) changes to the IU/AGC or IU/LGC platform alignments, and (2) a change to lift-off time as input from MED. The queue to start processing during a high-speed abort is also interfaced through this module. The calculation of V_{LO} on change of lift-off time or launch azimuth is a new requirement for the LMSP

LMRMANU5 (Launch Thirty-Second Printout Module) — This module controls the 30-second printout during launch and high-speed abort.

LMRMANU6 (Delete High-Speed Processing Module) — Operating under Task GTPHASE, this module clears launch, high-speed abort, or high-speed orbit.

LMRMANU7 (High-Speed Orbit Switch Module) — This module is used during high-speed orbit processing to control the 30-second print, process selected telemetry source PBI from Tracking Data Select Engineer's console, and the thrust switch from Flight Dynamics Officer's console.

LMXDDD (Launch DDD Load Module) — The function of this load module is to provide the necessary interface between the Launch Input Task and RTOS DDD Task to drive the DDD's associated with launch, high-speed abort or high-speed orbit.

The indicators that are set by launch, high-speed abort or high-speed orbit are examined, and any changes are output to the RTOS DDD Task. This task then outputs the hardware commands necessary to change the DDD lite settings.

The DDD's driven during launch are as follows:

1. Data faulting and station source (if applicable) for six high-speed data types (IU, USB, IPS, IPR, Ship C, AGC or LGC)
2. Event DDD's, selected source PBI's, AHO, MSS and lift switch indicators, recommended abort mode indicators
3. Group display.

The DDD driven during high-speed abort are as follows:

1. Data faulting and station source (if applicable) for four high-speed data types (USB, IPR, Ship C, AGC)
2. Event DDD's, selected source PBI's, A/H/O, MSS and lift switch indicators, recommended abort mode indicator
3. Selected source portion of group display.

The DDD's driven during high-speed orbit are as follows:

1. Data faulting and station source (if applicable) for five high-speed data types (IU or AGS, USB, IPR, C-Band, AGC or LGC)
2. Selected source portion of group display.

An indicator is passed to the load module upon entry to indicate the entry type (launch, high-speed abort or orbit).

LMXDDD5 (High-Speed DDD Reset Load Module) — The function of this load module is to provide DDD reset capability of the high-speed phase DDD's at phase changeover time. The load module is entered at changeover between launch and abort/orbit/prelaunch, high-speed abort and low-speed abort, high-speed orbit and low-speed orbit.

The load module is entered with a different indicator for each type changeover. The commands necessary to reset the DDD's associated with a given type entry are output to the RTOS DDD Task, which then outputs the necessary hardware commands.

The following is a list of DDD's reset at each entry.

1. Launch/Orbit - All "set" DDD's
2. Launch/High-Speed Abort - All "set" IU faulting indicators, IPS faulting and station indicators, group display indicators
3. Launch/Low-Speed Abort - All "set" group display indicators
4. Launch/Prelaunch - All "set" DDD's
5. Completion of High-Speed Orbit Processing - All "set" DDD's

LMSSUPER (Launch Trajectory Computation Control Program) — The Launch Supervisor Load Module contains the controlling logic to determine the computations to be made throughout the powered flight and hold phase portions of Launch phase. It also sets collection time intervals, phase and logic indications and recommended abort mode.

The trajectory computation control logic written up under the LTDATAPF Task contains a more detailed description of the logic in this load module.

LTRKNI (LAUNCH POWERED FLIGHT INTEGRATOR TASK)

The purpose of this task is to compute the Mode III impact points during the CSM launch powered-flight phase. The task is queued on a two-second cycle from the launch trajectory computation control program (LMSSUPER). Upon the hold phase task being queued after S-IVB C/O, the task is terminated.

Load Module Description

LMRKNI (Impact Predictor Control) — This load module is used during powered flight for the purpose of obtaining impact points. Its function is to provide the interface between the powered-flight supervisor and the launch Runge-Kutta impact predictor. Impact points are requested for a new vector when the answer for the previous vector is complete and at least two seconds have elapsed since the last queue.

LMMRKNI (Launch Runge-Kutta Impact Predictor) — The function of this load module is to integrate an input position and velocity vector until the trajectory impacts the Earth. If the trajectory fails to impact after some reasonable time, processing is terminated, and an appropriate condition code is set (see Figure 9).

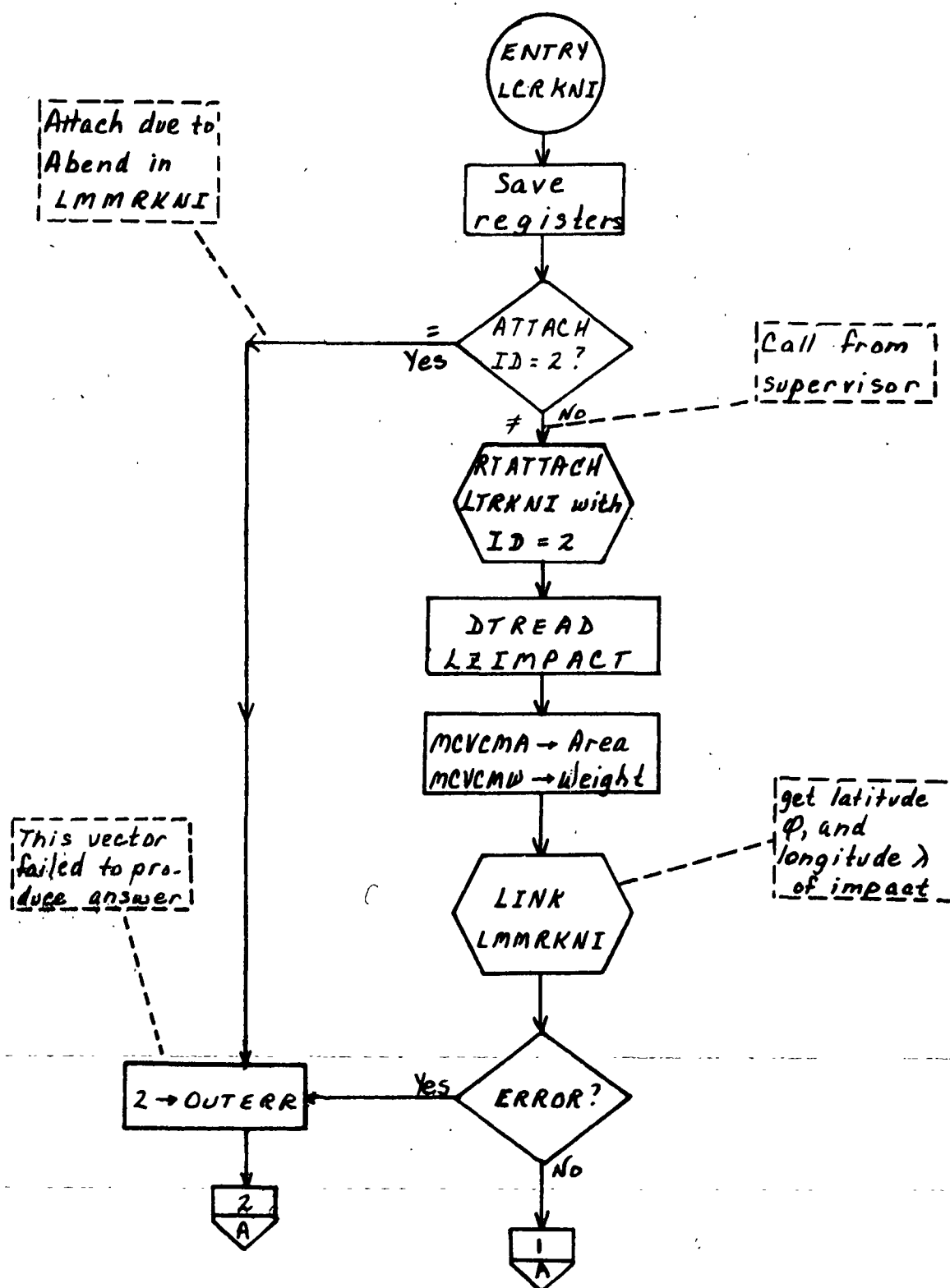


Figure 9. LCRKNI Flowchart

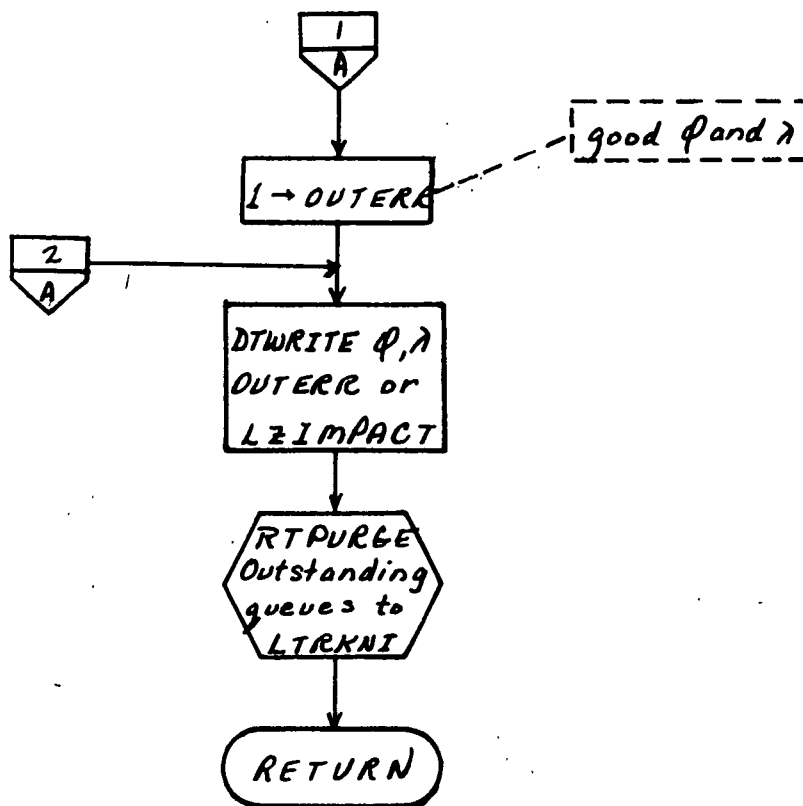


Figure 9. LCRKNI Flowchart

LTHLDSPS (LAUNCH HOLD PHASE TASK)

This task is used during the launch phase after S-IVB C/O and prior to the setting of the ABORT/HOLD/ORBIT (A/H/O) switch. Its purpose is to compute GO/NO-GO recommendation, ΔV_{INS-C} , Mode II Impact Point, Mode III Impact Point, and $(\Delta V_{IP-C}, \Delta t_{IP})$ for one of two target areas. These computations will be performed on request from the High-Speed Input Task, for all high-speed data sources that are valid during hold phase.

Inputs are supplied by the High-Speed Input Task via the Hold Phase Data Table (LZHLDPHS). Outputs are stored in the Hold Phase Data Table. Refer to Table 1 for specific quantities. Calculation codes for each data source are provided as input to be used in determining what computations are required. Separate calculation codes are provided for the following computations:

1. GO/NO-GO Recommendation, ΔV_{INS} , GMT_A
2. Mode II Impact Point
3. Mode III Impact Point, ΔV_{IP-C}
4. NSEC Cycle Integration.

Four types of queues are processed by hold phase and are recognized by use of an ID furnished in the queue.

ID = 1 (S-IVB C/O queue) The Hold Phase Data Table is read into a core work area. The calculation codes are tested for each data source (beginning with the selected source) to determine the required computations. All required values are computed and stored in the core work area.

ID = 2 (SPS C/O queue) Same as S-IVB C/O queue.

ID = 3 (NSEC cycle queue) The Hold Phase Data Table is read into the core work area. The calculation codes are tested for each data source, and if the NSEC indicator is on, the vector for computations required for that source will utilize the NSEC vector in place of the input vector. Computed values are stored in the core work area.

ID = 4 (Running GO/NO-GO queue) The Hold Phase Data Table is read into the core work area. The calculation code for GO/NO-GO recommendation is tested for each source, and the required computed values are stored in the core work area. The other calculation codes are not tested.

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Table 1. Data Source Calculations

<u>Source/Calculation</u>		<u>Queue Type</u>			
		S-IVB C/O	SPS C/O	NSEC	Running GO/NO-GO
IU	GO/NO-GO	X			
	Mode II	X			
	Mode III**	X			
USB	GO/NO-GO	X	X		X
	Mode II				
	Mode III				
AGC	GO/NO-GO	X	X		
	Mode II	X	X		
	Mode III**	X	X		
IPS	GO/NO-GO				
	Mode II				
	Mode III				
IPR	GO/NO-GO	X	X		X
	Mode II				
	Mode III				
SHP	GO/NO-GO	X	X		X
	Mode II				
	Mode III				
SELECTED SOURCE*					
	GO/NO-GO	X	X	X	
	Mode II	X	X	X	
	Mode III	X	X	X	

**If IU or AGC is the selected source after the normal S-IVB C/O queue has been completed, and a Mode III target change is recognized (PBI on RFO console), a special S-IVB C/O queue will be given to hold phase to compute a Mode III on the new target. No other calculations will be done on this queue.

*SELECTED SOURCE may be any one of the six names sources. However, if IPS is selected, no calculations will be performed on the SELECTED SOURCE.

Table 2. Hold Phase Task Output Quantities

<u>GO/NO GO Calculations</u>		
GO/NO GO Recommendation		
V_S	\dot{h}	V'
V_i	ΔV_{INS-C}	γ'
γ_i	Δt_{INS}	h_s'
h_s	GETI Data Points	
GET_A	$P_i(\Delta V_{INS-C})$	
<u>Mode II Calculations</u>		
$(\phi, \lambda)_{MX}$	(Max. Lift Impact Point)	
$(V, \gamma)_{EI}$	GMTEI	
<u>Mode III Calculations</u>		
ΔT_{EI}	V_{EI} (zero burn)	
ΔT_{IP}	γ_{EI} (zero burn)	
ΔV_{IP-C}	GMTEI (zero burn)	
$P_i(\Delta V_{IP})$		
$Y_m(\Delta V_{IP})$		
$R_o(\Delta V_{IP})$		
GETPI		
GETCO		
$V_{EI}(\Delta V_{IP})$		
$\gamma_{EI}(\Delta V_{IP})$		
$GETEI(\Delta V_{IP})$		
$(\phi, \lambda)_{IP}(\Delta V_{IP})$		

At the conclusion of each of the above queues a "completion code" is set in the core work area, and the entire core work area is written into the Hold Phase Data Table.

The following is a description of the computations that are performed on one data source to produce the required output quantities.

Assuming the NSEC queue, the input vector from the High-Speed Input Task is integrated forward to NSEC time and the resultant NSEC vector is stored.

The NSEC vector is used to compute V_S if S-IVB/CSM separation has not occurred.

If separation has occurred, a delta velocity for separation is added to the NSEC vector if necessary. V_S is computed from the resultant vector. The GO/NO-GO recommendation is derived by examining V_S ; $V_S \leq 0$, recommend GO; $V_S > 0$ or $> V_{PSMAX}$ recommend NO-GO. V_i , γ_i , h_s , h , and GMT_A are computed from this "recommendation vector." The vector is saved for later use by the High-Speed Input Task.

A maneuver vector is derived by adding a delta velocity for separation to the NSEC vector, then moving the resultant vector to S-IVB C/O + x seconds (by use of the Launch Runge-Kutta integrator (LMMRKNII)). The velocity change ($V_{INS}-C$) to reach a minimum acceptable orbit and the associated time (T_{INS}) are calculated from the maneuver vector using an analytic method. Also computed from the maneuver vector are V' , γ' , h'_s .

The Mode II Impact Point $(\phi, \lambda)_{MX}$ is computed using the maneuver vector.

The launch Runge-Kutta Impact Predictor (LMMRKNI) is used to obtain the full lift reentry impact point.

Mode III maneuver calculations are performed using the maneuver vector.

There are two types of maneuvers that may be used, depending on the setting of the Range Indicator PBI located on the Retrofire Officer console: (1) variable - ΔV (Atlantic target) and (2) fixed - V (Indian Ocean target).

For the variable ΔV maneuver, the maneuver vector is integrated down to impact using the Launch Runge-Kutta Integrator. The GMTPI vector is obtained from this integration. The angle between the launch pad and the launch pad to determine if the maneuver will be posigrade or retrograde. If the maneuver is prosigrade, the

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output values and completion codes are set for "no maneuver" and stored in the core work area. (Posigrade burn is not required for the variable ΔV maneuver.) If the maneuver is retrograde, the difference between the two angles is used with a table lookup to obtain a first guess Δt of maneuver. (If the Launch Runge-Kutta Integrator cannot compute an impact, a retrograde maneuver is assumed, and the first guess Δt is set to 40 seconds). The velocity components of the GMTPI vector (vector at last C/O + 125 seconds) are modified in proportion to the amount of t , and the resultant vector is moved to 300K feet using Keplerian equations. An MIT curvefit routine is employed to find the impact point from the 300K vector. A test is made to determine if the impact point is within X miles of the target; if not, the Δt is adjusted by an amount proportional to the miss distance. This starts an iterative process that continues until a maximum iteration count is reached, or until impact point is within X miles of the target. In either case, the Maneuver Integrator is then used to move the GMTPI vector through a (Δt) second maneuver and to obtain a burnout vector. The burnout vector is integrated to impact, using the Launch Runge-Kutta Impact Predictor. A test is made to determine if the impact point is within Y miles of the target; if not, the Δt is adjusted by an amount proportional to the miss distance. This starts an iterative process that continues until a maximum iteration count is reached, or until the impact point is within Y miles of the target. If the maximum iteration count is reached first, or if an integration error (such as exceeding available fuel) occurs, the appropriate output error codes are set and stored in the core work area. All trajectories are integrated using half-lift reentry.

The fixed ΔV maneuver uses the maneuver vector as input to the Launch Runge-Kutta Integrator to obtain an impact point. If the impact point is short of the Indian Ocean target, the output values and completion codes are set for "no maneuver" and stored in the core work area (posigrade burn is not required for the fixed ΔV maneuver). If the impact point is beyond the Indian Ocean target, GMTPI is used as the time to start maneuver. (The maneuver used is a fixed ΔV burn in a retrograde direction). The maneuver is simulated by the Maneuver Integrator and the resultant vector is integrated to impact using the Launch Runge-Kutta Impact Predictor. The newly computed impact point is then compared with the target. If they are within Z miles of each other, the current maneuver start time is stored. If not, the maneuver start time is adjusted by an amount proportional to the miss distance, and an iteration process begins. The iteration continues until the maximum iteration count is reached, or convergence on the target has been achieved. The time to start maneuver will always be greater than or equal to last C/O + 125 seconds. If the maximum iteration count is reached before convergence is achieved or if an integration error occurs, the appropriate error codes are set and stored in the core work area. If convergence is achieved without errors, the Mode III output values and completion codes are stored in the core work area. If convergence is achieved without errors, the Mode III output values and completion codes are stored in the core work area. All trajectories are integrated using half-lift reentry.

The Mode III impact point is integrated as follows:

After S-IVB C/O - Use vector reflecting ΔV_{IP-C} maneuver and lift indicated by lift switch.

After Thrusting - Use vector without ΔV_{IP-C} maneuver and lift indicated by lift switch.

The load modules used by this task are:

Hold Phase Initialization (LMGHINIT)

Hold Phase Control (LMSHLDPH)

Maneuver Integrator (PMMRKJ)

Launch Runge-Kutta Impact Predictor (LMMRKN I)

Launch Runge-Kutta Integrator (LMMRKN II)

For a LM launch, the following differences are noted:

1. No ΔV_{IP} maneuver will be computed; ΔV_{IP} and ΔT_{IP} are set to zero.
2. The Mode III impact point will be obtained by applying a ΔV (abort maneuver) to the maneuver vector and integrating the resultant vector to impact using a zero-lift reentry.
3. The Mode II impact point will be obtained using a zero-lift reentry.
4. No ΔV_{INS-C} maneuver will be computed; ΔV_{INS-C} and ΔT_{INS} are set to zero.

NOTE: The data sources to be used in computing the output quantities are determined by the High-Speed Input Task. However, the normal calculations performed on specific data sources are shown in Table 2.

Hold Phase Vectors

Average Vector — Averaged vector from IU, AGC, and Ship-C sources, and short-arc vector from IPR and USB sources. This vector is input to hold phase (see Figure 11).

NSEC Vector — This is the average vector integrated forward to NSEC time (by LMMRKN II) during NSEC cycle. It will reflect ΔV_{SEP} only if separation has occurred.

Separation Vector — This vector is computed by GO/NO-GO using as input, the NSEC vector (during NSEC cycle) or the average vector (not during NSEC cycle). Separation logic is applied by LIMHPS (uses LMMRKN II), to ensure that ΔV_{SEP} is always reflected in the separation vector, even if separation has not occurred (see Figure 12).

Recommendation Vector — If separation has occurred, this vector will be the same as the separation vector. If separation has not occurred, this vector will be:

1. Same as NSEC vector during NSEC cycle.
2. Same as average vector if not NSEC cycle.

Maneuver Vector — This vector is computed by GO/NO-GO by integrating (LMMRKNII) the separation vector backwards to latest cutoff + X seconds (see Figure 13).

SPS On Vector — This vector is obtained in GO/NO-GO by integrating (LMMRKNII) the maneuver vector forward to latest cutoff + Y seconds (GMTIG). It is used in ΔV_{INS} calculations (see Figure 14).

ΔV_{INS} Vector — Same as maneuver vector. The ΔV_{INS} maneuver and Mode II impact point (LMMRKNI) is computed from this vector.

ΔV_{IP} Vector — Whenever Mode III calculations are required, the latest ΔV_{INS} vector (maneuver vector) is stored in the ΔV_{IP} vector position in the Hold Phase Data Table, LZHLDPHS. The Mode III ΔV_{IP} maneuver or LM abort maneuver is computed from this vector. The Mode III impact point is integrated (LMMRKNI) using the ΔV_{IP} burnout vector (S-IVB C/O) or the ΔV_{IP} vector (SPS C/O), and lift switch on RFO console.

Phase Vector — This vector is commonly referred to as the 'current vector.' Whenever GO/NO-GO calculations are requested, the average vector is stored in the phase vector position in the Hold Phase Data Table, LZHLDPHS.

LM Abort Vector — This vector is computed for LM launches only. It is obtained by integrating (LMMRKNII) the ΔV_{IP} vector forward to current time, then applying $\Delta V, \Delta \gamma, \Delta h$ for LM abort maneuver. The LM Mode III impact point is computed from the LM abort vector, using LMMRKNI.



The following vectors are printed on line during hold phase except during running GO/NO-GO's.

<u>Vector Name</u>	<u>On-Line Name</u>
Average vector	AVGVEC
NSEC vector	NS VEC
Recommendation vector	RECVEC
SPS On vector	SPSVEC
Phase vector	PHSVEC
Maneuver vector	MVRVEC

The following vectors are stored in the Hold Phase Data Table, LZHLDPHS.

Average vector
 Recommendation vector
 ΔV_{INS} vector.
 ΔV_{IP} vector
 Phase vector

NOTE: The ΔV_{IP} vector is not printed on line with the Mode III maneuver. However, the last ΔV_{IP} vector used in the Mode III maneuver calculations. The printout of the ΔV_{INS} vector precedes the printout of the Mode III maneuver. During running GO/NO-GO's, the ΔV_{INS} vector is being updated, but the ΔV_{IP} vector is not (Mode III maneuvers are not computed during running GO/NO-GO's).

Load Module Descriptions

Described below are the load modules included in the Launch Hold Phase Task.

LMSHLDPH — This load module makes up the major portion of the Hold Phase Task (LTHLDSPS). It consists of five control sections:

1. Hold Phase Control
2. GO/NO-GO Calculation
3. SPS Burn (Mode III) Calculation
4. SPS Burn (Mode IIIA) Calculation
5. LM Abort Maneuver Calculation



Hold Phase Control accomplishes the necessary testing of calculation codes and queue ID to cause proper sequencing of the required calculations on each data source. In addition, it supplies the necessary interface for integrating the Mode II impact point, and NSEC integration when required.

GO/NO-GO Calculation is called to compute a recommendation vector and a ΔV_{INS} vector. The recommendation vector is then used to compute V_S , GO/NO-GO recommendation, GET_A , etc. The quantities ΔV_{INS-C} and ΔT_{INS} are obtained by an analytic method, using the maneuver vector.

SPS Burn (Mode III) Calculation is used to compute a Mode III maneuver (ΔV_{IP-C}) for one of two possible target areas (the target area requested is supplied with the input data). After the maneuver has been computed, the Mode III impact point is integrated using the ΔV_{IP-C} vector and the lift indicated by the lift switch. (If SPS C/O has occurred, the input vector is used in place of the ΔV_{IP-C} vector). Two control sections are used, one for each target area. LM abort maneuver calculation is used to compute the abort maneuver on the LM vehicle. The Mode III impact point is then computed using the burnout vector from the abort maneuver and zero lift.

LMMRKNI — This load module is used to integrate the maneuver vector to impact (Mode II impact point), or integrate a burnout vector to impact (Mode III impact point). Its only output is $(V, \gamma, GMT)_{EI}$ and (ϕ, λ) of impact.

LMMRKNII — This load module is used to integrate vectors through various time spans, and to obtain an impact point if desired. It is used in the NSEC integration, ΔV_{INS-C} calculation and Mode III ΔV_{IP-C} calculation.

PMMRKJ — This load module is used to integrate the maneuver vector through a predicted maneuver to obtain a burnout vector. The maneuver is fixed inertial using the CSM SPS thrusters. Either ΔV or Δt of maneuver may be input. It is used in the Mode III ΔV_{IP-C} calculation.

LMGHINIT — This load module is a part of the Hold Phase Task. Its purpose is to provide the initialization to the core working area (subpool) and to the Resource Table used by hold phase. It will normally be entered only once during a mission.

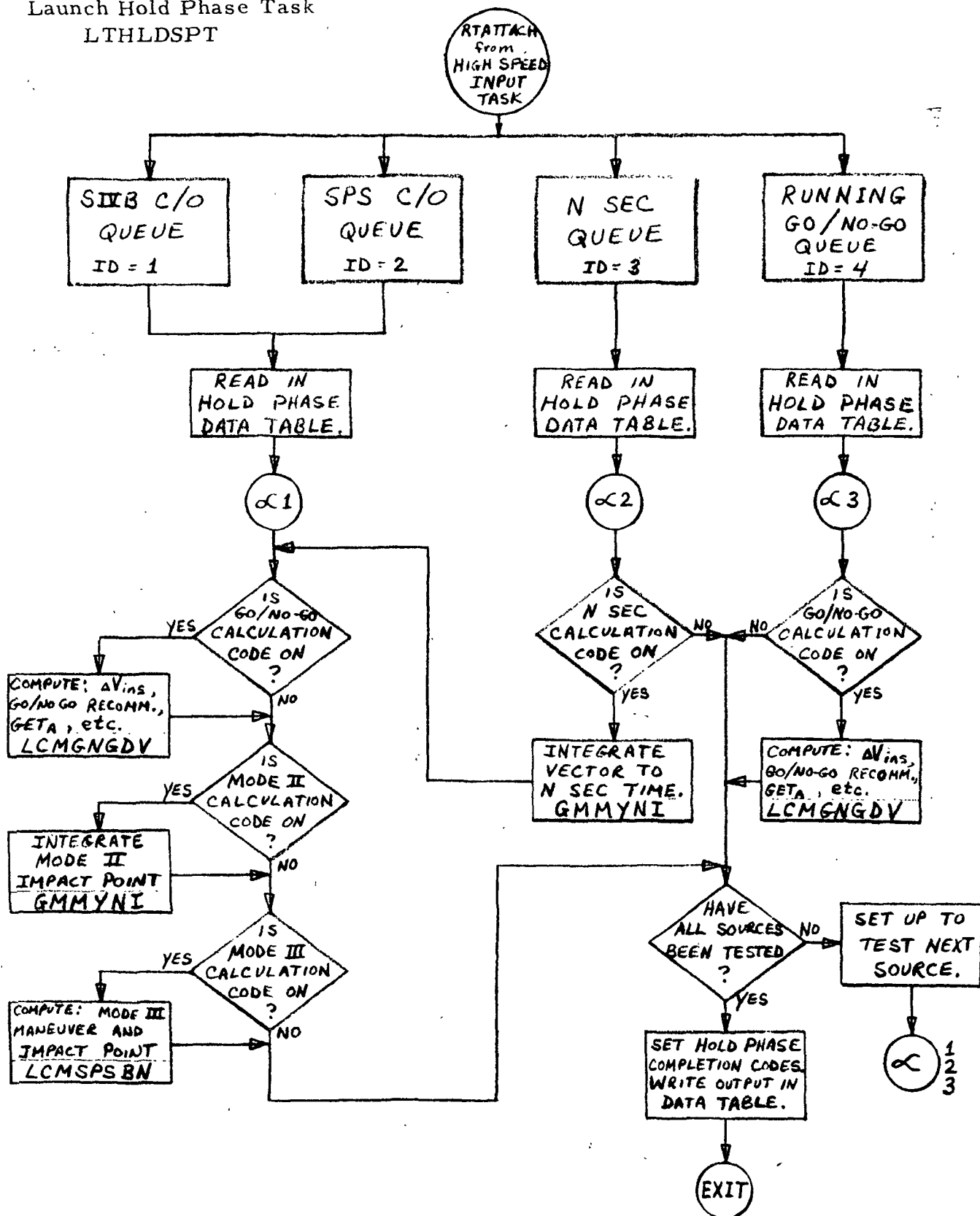
Launch Hold Phase Task
 LTHLDSPT


Figure 10. Hold Phase Flowchart

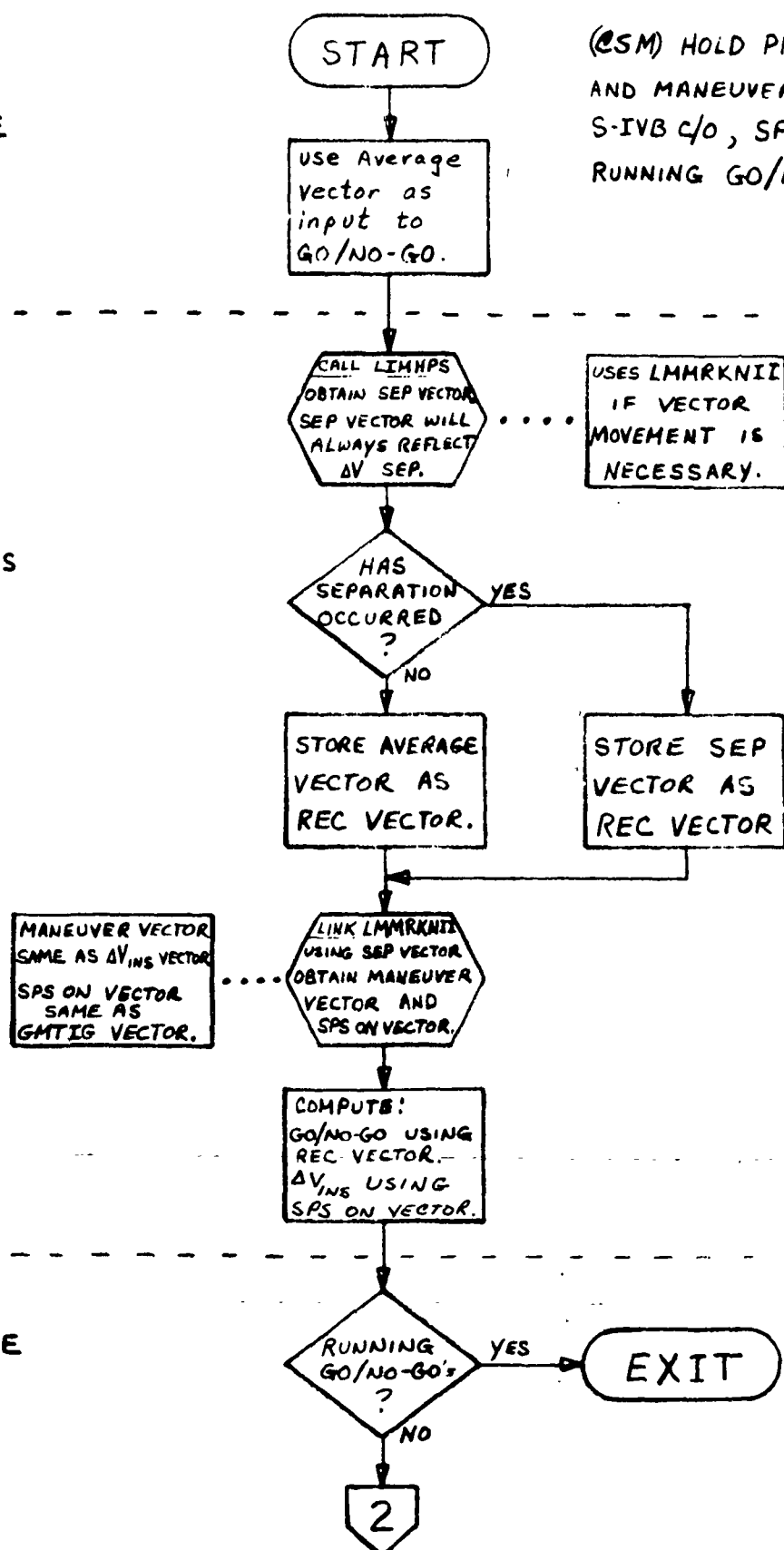
HOLD PHASE
CONTROL(CSM) HOLD PHASE VECTORS
AND MANEUVERS FOR:
S-IVB C/O, SPS C/O AND
RUNNING GO/NO-GO's.GO/NO-GO
CALCULATIONSHOLD PHASE
CONTROL

Figure 11. CSM Hold Phase Flowchart (Sheet 1 of 2)

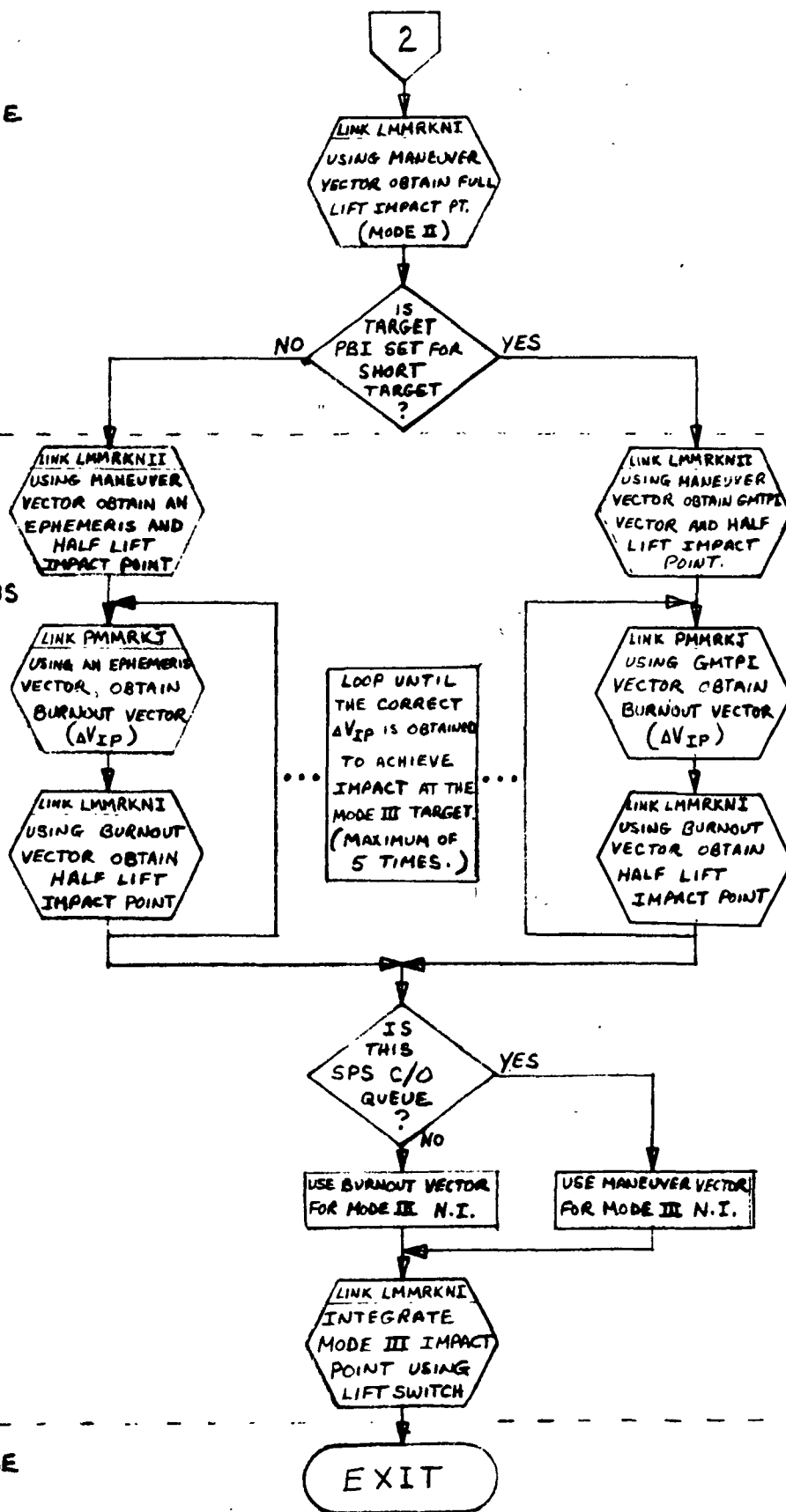
HOLD PHASE
CONTROLMODE III
MANEUVER
CALCULATIONS

Figure 11. CSM Hold Phase Flowchart (Sheet 2 of 2)

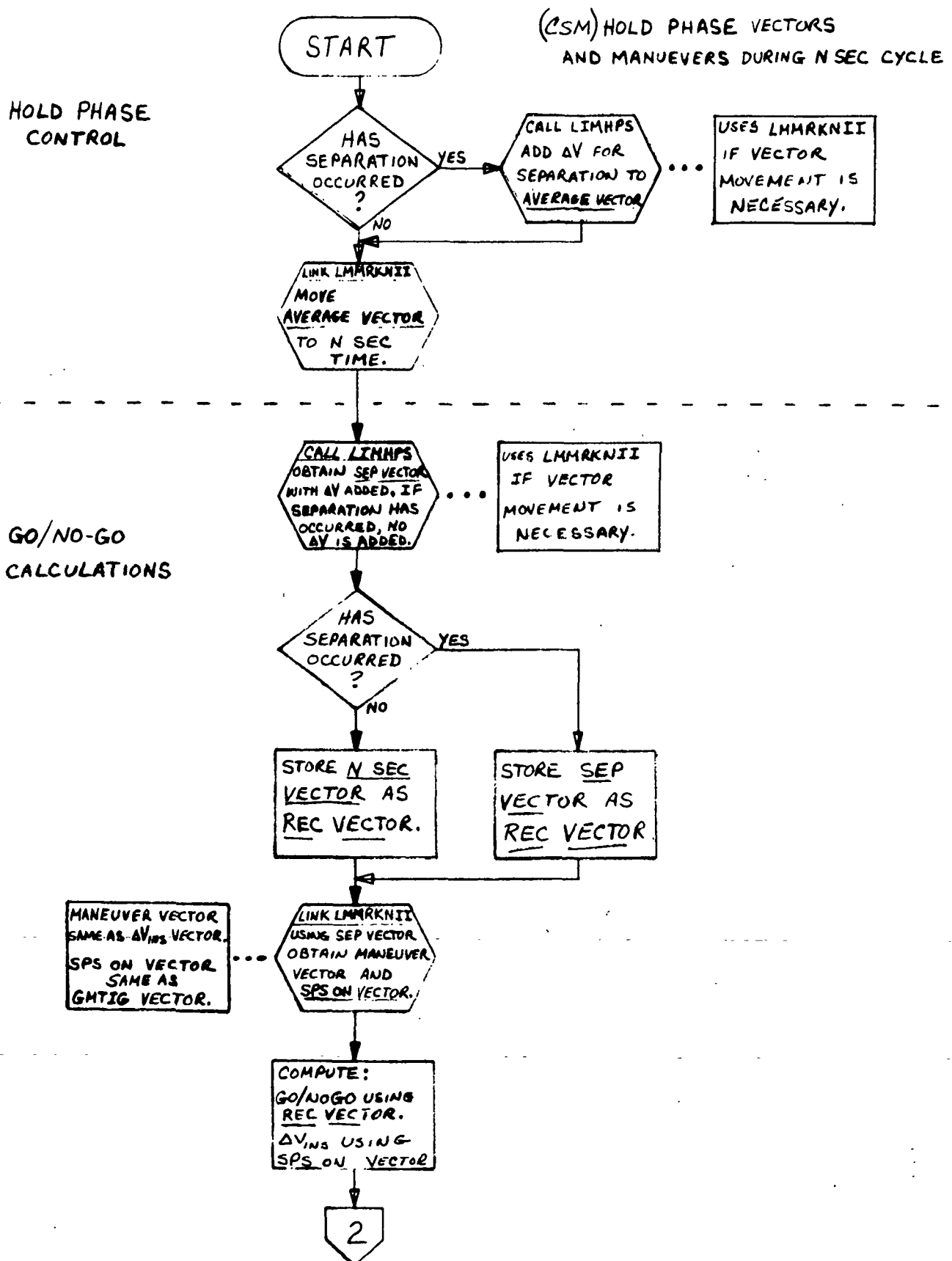


Figure 12. CSM Hold Phase (N. Sec. Cycle) Flowchart

HOLD PHASE
CONTROL

MODE III
MANEUVER
CALCULATIONS

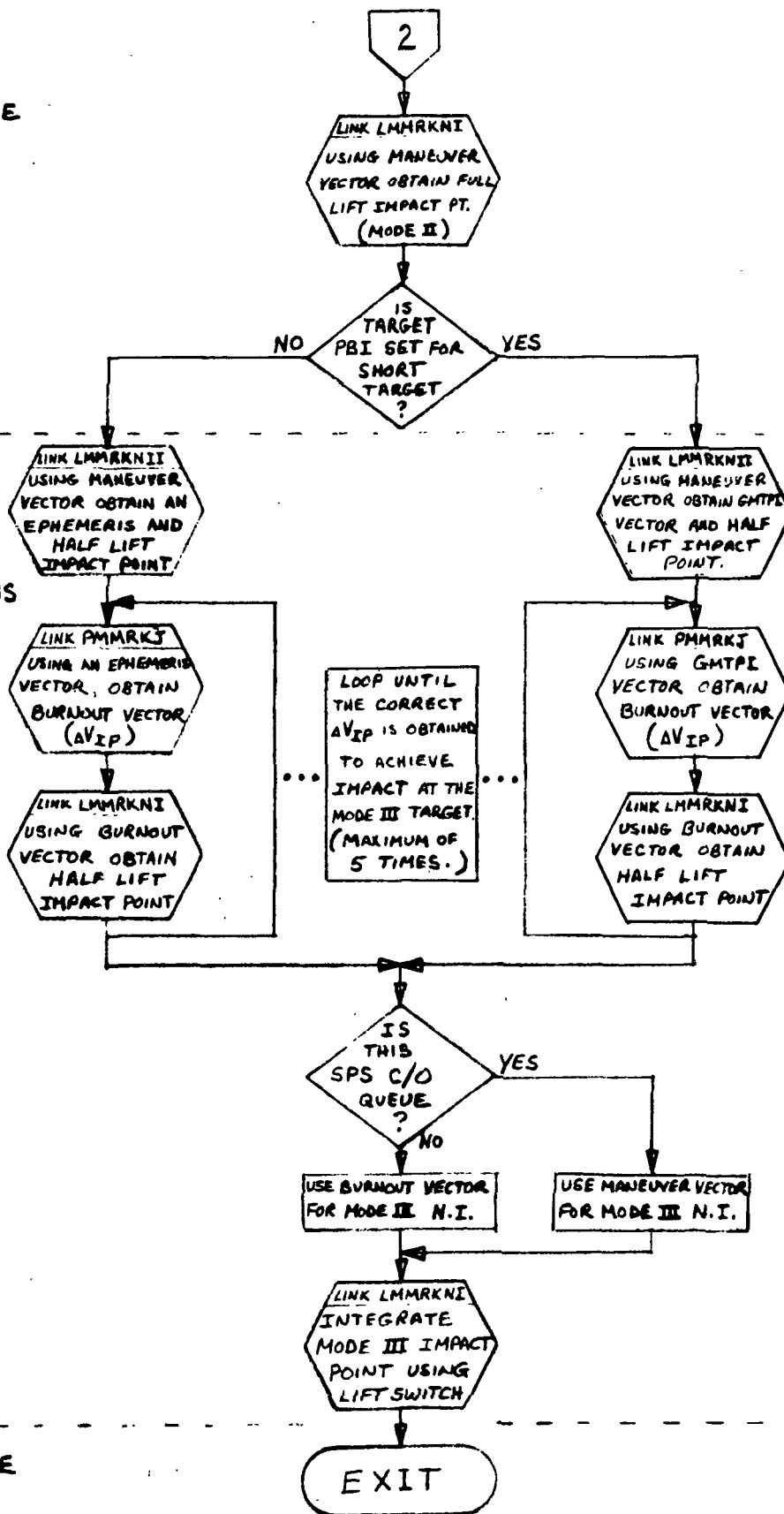


Figure 12. CSM Hold Phase (N. Sec. Cycle) Flowchart

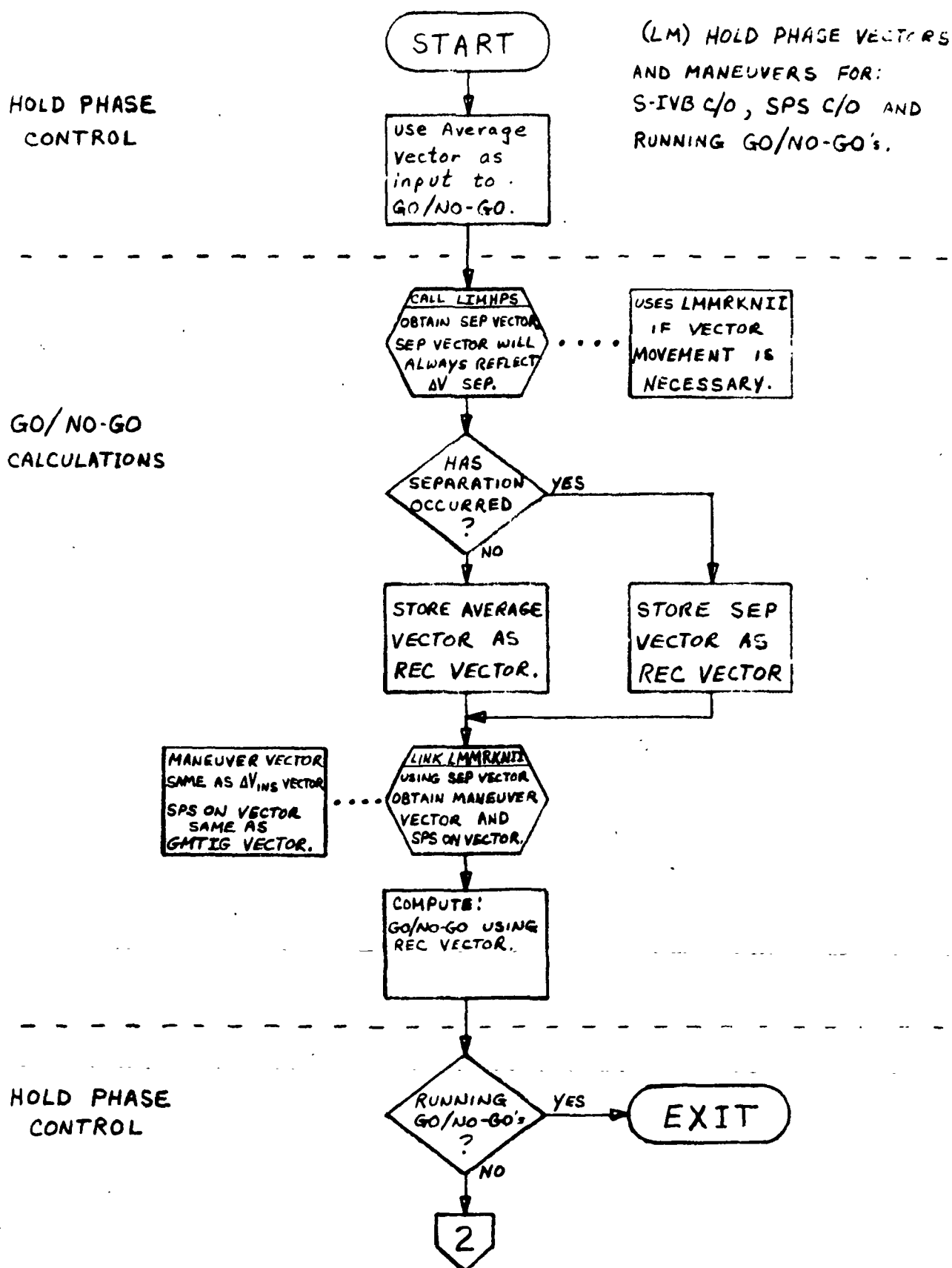


Figure 13. LM Hold Phase Flowchart

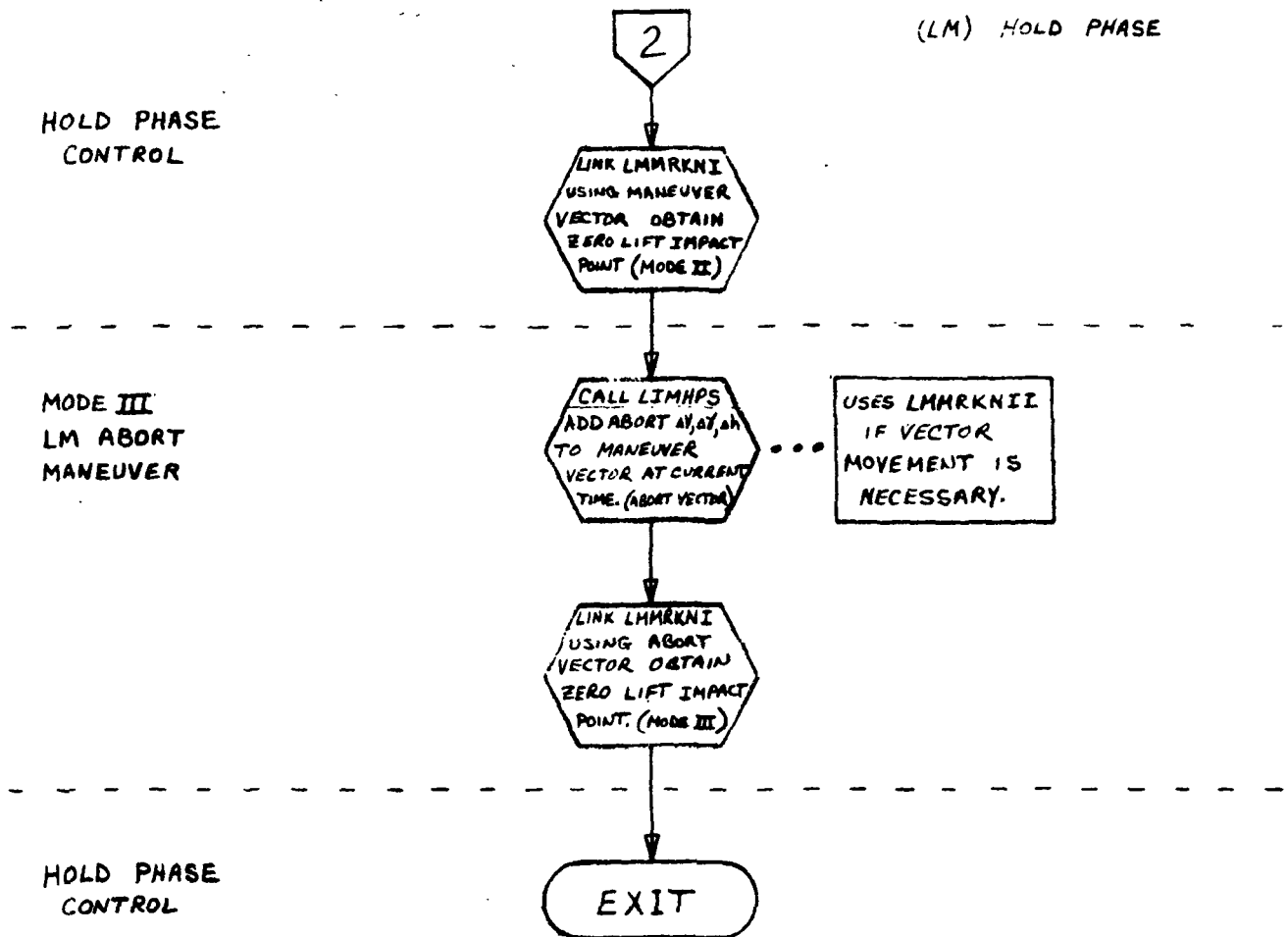


Figure 13. LM Hold Phase Flowchart

(Sheet 2 of 2)

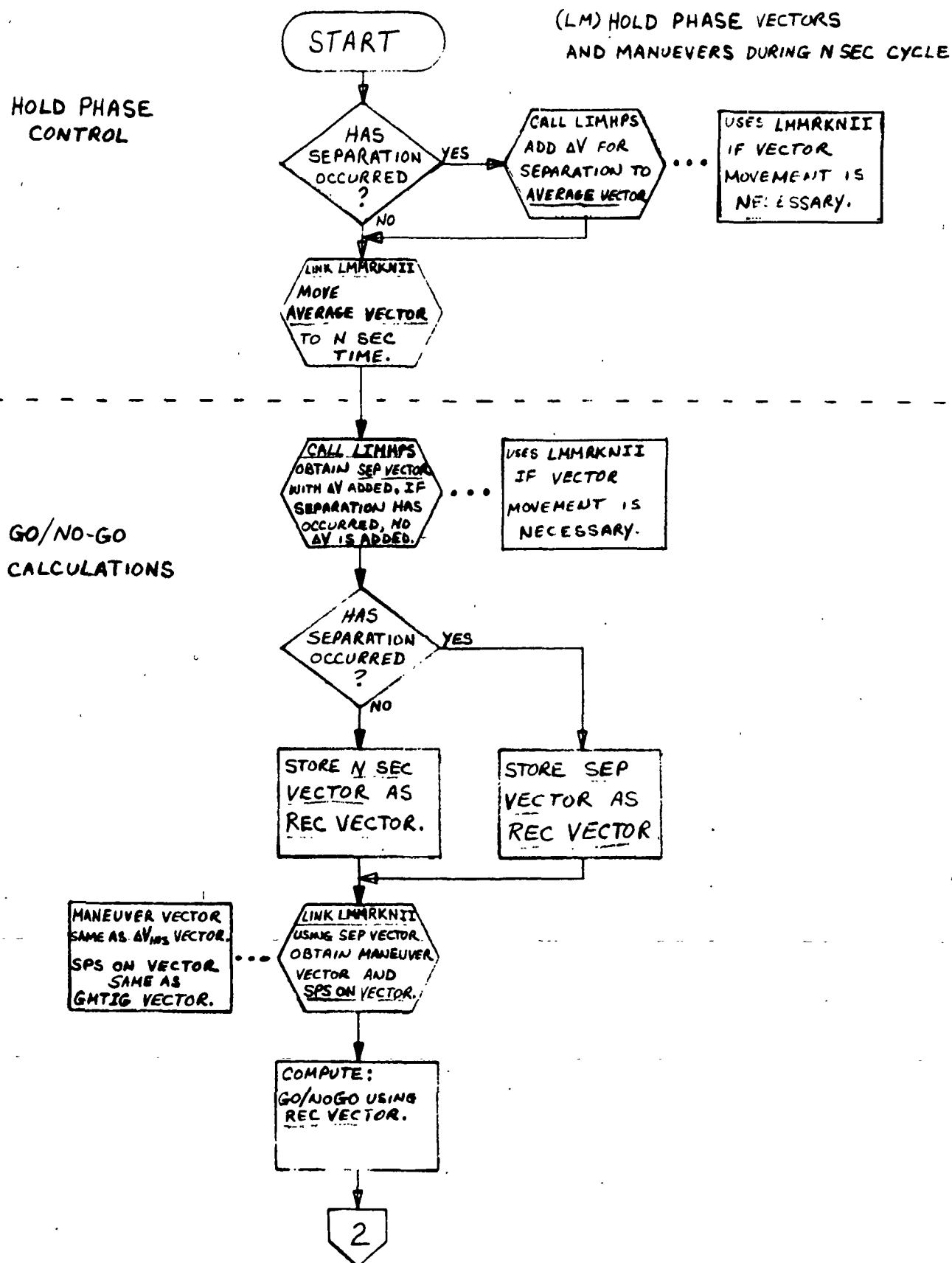


Figure 14. LM Hold Phase (N Sec. Cycle) Flowchart

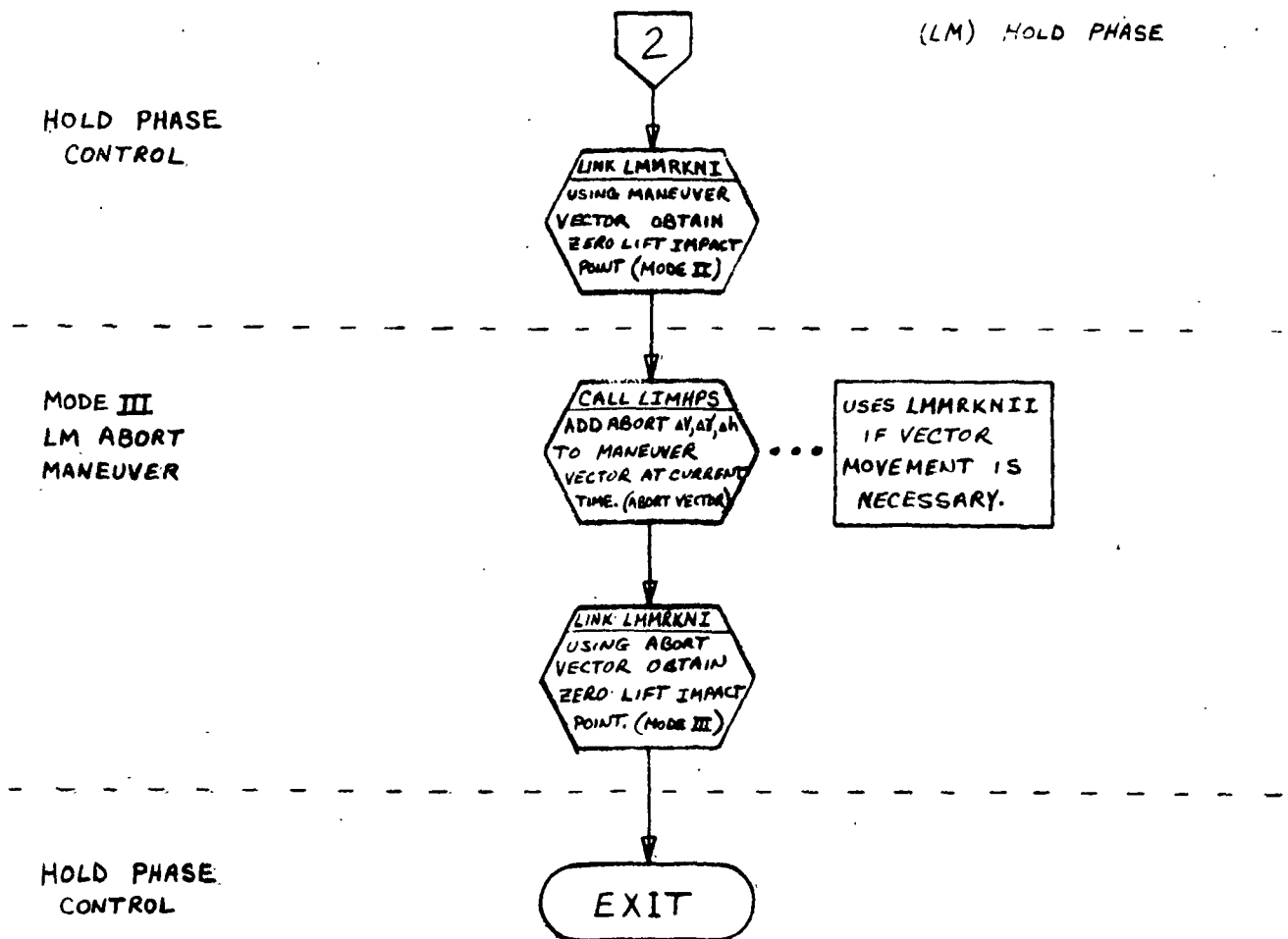


Figure 14. LM Hold Phase (N Sec. Cycle) Flowchart

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LTXUTPUT (LAUNCH D/TV OUTPUT TASK)

Launch Output Task Queues

The Launch Output Task receives three types of queues during the mission; initialization, generate, and update. The initialization queue is issued, and the update queues are routed to the Launch Output Task by the launch initialization load module. The TV generate queues are issued to the output task by the mission display supervisor.

When the initialization queue is received, the following events occur for each launch: (1) the task storage area is obtained, (2) the proper launch display constants (LM or CSM) are obtained, (3) the task resource table is built, and (4) the initialization queue to the launch plotboard task is issued.

When the TV-generate queues are received, the requested launch or high-speed abort displays are generated.

When the update queues are received, the current events and parameters to be displayed are obtained and written, if requested, on the log tape. After liftoff has occurred, the following events occur: (1) time to free fall is computed ($TFF = GMT300 - GMT$), (2) the update queue to the launch plotboard task is issued, and (3) the launch TV displays are updated. If a phase change is indicated, the following events occur: (1) the next phase is determined, (2) the proper vectors are stored into the transfer vector table, and (3) the launch printer task is queued to print the transferred vector.

Launch Displays

The launch displays are as follows:

1. FDO Launch Digital No. 1
2. RFO Launch Digitals
3. FDO Launch Analog No. 1
4. FDO Launch Analog No. 2
5. Tracking and Telemetry Trajectory Data Select (B/S)
6. Tracking and Telemetry Trajectory Data Select (Raw)
7. RFO TFF vs RIP
8. Contingency Insertion Capability (γ vs V_S)
9. Wedge Angle Monitor.

FDO Launch Digital No. 1 — The purpose of the FDO Launch Digital No. 1 is to display the quantities required to monitor launch phase and to make necessary decisions. The following quantities will be displayed through the launch phase: (1) GET, (2) GMTLO, and (3) Selected Source. The following quantities (except

GET_A and P_i) will be computed and displayed during powered flight and until the average selected source vector is available. This occurs if SAT or APL is the selected source at cutoff. If C- or S-Band is selected, these quantities will be computed and displayed until cutoff plus 3 seconds, and updated when a vector is available.

1. V/V_{PS}
 2. V_G (not required)
 3. d
 4. $V, V=V'$
 5. $\gamma, \gamma=\gamma'$
 6. $h_s, h_s=h_s'$
 7. GET_A
 8. T_{FF}
 9. T_{GO}
 10. P_i
- } after SPS C/O

The following quantities will be computed and displayed after S-IVB C/O (after LES jettison) or SPS C/O on the average or short-arc vectors:

1. SOURCE
2. RECOMMEND
3. V_S
4. V_i
5. γ_i
6. h_s
7. h
8. ΔV_{INS-C}
9. Δt_{INS}
10. GET_I
11. DATA POINTS.

An * will be displayed for parameters that cannot be computed for any reason other than no data. If data is unavailable for a quantity, NO SOLUTION will be displayed. Refer to background slide for display format.

RFO Launch Digitals — The purpose of the RFO Launch Digitals is to provide digital information for evaluation of abort conditions. The following quantities will be displayed through the launch phase:

1. h_o
2. SEL SOURCE
3. AB mode
4. GMTLO
5. Spacecraft GMTGRR
6. GET

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7. T_{FF}
8. ϕ_{MX}
9. λ_{MX}
10. *GETEI

The following quantities will be displayed after S-IVB or SPS C/O (after LES jettison):

1. ΔV_{IP-C}
2. ΔT_{IP}
3. $P_i (\Delta V_{IP})$
4. $Y_m (\Delta V_{IP})$
5. $R_o (\Delta V_{IP})$
6. GETPI
7. GETCO
8. $V_{EI} (\Delta V_{IP})$
9. $\gamma_{EI} (\Delta V_{IP})$
10. $\phi_{IP} (\Delta V_{IP})$
11. $\lambda_{IP} (\Delta V_{IP})$
12. GETEI (ΔV_{IP})
- 13.. SOURCE
- 14.. ΔT_{EI}
15. AREA .

An * displayed for parameters that cannot be computed for any reason other than no data. If data is unavailable for a quantity, NO SOLUTION is displayed. Refer to background slide for display format.

FDO Launch Analog No. 1 — The purpose of the FDO Launch Analog No. 1 is to serve as the primary display for trajectory evaluation. The selected source inertial flight-path angle (γ) in degrees versus the inertial velocity (V) in feet per second is plotted on a half-second cycle. The plot is initialized on computer receipt of liftoff and terminated at launch abort or orbit.

FDO Launch Analog No. 2 — The purpose of the FDO Launch Analog No. 2 is to display conditions of $(\gamma, V)_{EI}$. The selected source flight-path angle versus inertial velocity at entry interface (γ vs V)_{EI} is plotted. The plot is initialized when apogee altitude is equal to or above entry interface; it is then updated and terminated at abort or orbit. The plot is terminated after S-IVB C/O or SPS C/O and frozen until the zero and maximum ΔV_{IP} burn point data are to be displayed. At that time the old plot is cleared, and the new ΔV_{IP} burn data is displayed. If SPS thrusting starts after the ΔV_{IP} burn points are displayed, the burn points remain on the display, and the predicted $(\gamma, V)_{EI}$ points are plotted.



Tracking and Telemetry Trajectory Data Select (B/S) — The Tracking and Telemetry Data Select plots (B/S and Raw) purposes are to provide a primary method for evaluating trajectory data so the data sources can be selected during launch. The displays are available before liftoff and until the A/H/O switch is set to either abort or orbit. The inertial flight-path angle (deg) versus inertial velocity (fps) are plotted from the following sources: IPS, Booster TLM, Spacecraft TLM, Ship C-Band, Unified S-Band, and IPR. The updates of the plots are based on a distance check from the previous point. No extrapolation is made for missing data. IPS is not plotted after S-IVB cutoff.

RFO T_{FF} vs R_{IP} — The purpose of the RFO T_{FF} vs R_{IP} plot is to aid in predicting abort mode capability during launch phase. The selected source freefall time to entry interface (T_{FF}) versus range to the predicted impact point (R_{IP}) is plotted on a two-second cycle (same as $(\phi, \lambda)_{MX}$ digital and analog) to the end of launch phase.

Contingency Insertion Capability (γ vs V_S) — The purpose of the Contingency Insertion Capability plot is to monitor and evaluate the contingency insertion capability and GO/NO-GO status at the end of powered flight. The selected source inertial flight-path angle versus the impulsive inertial velocity required to achieve a specified vacuum perigee is plotted on a half-second cycle after V_S is equal to the mission-dependent scale limit during powered flight. The plot is terminated at the end of Launch Phase.

Wedge Angle Monitor — The purpose of the Wedge Angle Monitor plot is to evaluate the Saturn yaw steering. The selected source velocity normal to the plane defined by the launch azimuth (V_I) versus ground elapsed time (T_E), and wedge angle (δ) versus inertial velocity (V) are plotted on a half-second cycle. V_I versus T_E is terminated when a PBI on the Guidance Officer's Console is depressed. Delta versus V_i is terminated when the abort or orbit switch is depressed.

Priority of Vector Types

1. Mode I

- a. LES Abort vector with time tag in time period of 10 seconds prior to LES abort time.
- b. Any LES abort vector.
- c. Predefined nominal vector.

2. Mode II, Mode III and Orbit

- a. Hold phase maneuver vector for the maneuver vector slot.
Hold phase current interface vector for the current vector slot.
- b. Powered-flight vector for both maneuver and current vector slots.
- c. Predefined nominal vector for maneuver vector slot; no vector for current vector slot.

Interface Vector Selection

The interface vectors are selected on a priority basis. The detail logic used for this selection is explained in the following paragraphs.

Mode I Abort Interface — For Mode I Abort, priority is given to vectors with time tags in a ten-second time period prior to LES abort. If no such vector is available, any vector stored in the LES Abort Vector Table with a valid time tag is transferred. If no vector is available from the LES Abort Vector Table, a nominal vector is computed based on GMT of liftoff. The resulting vector is stored in the blocks called maneuver vector.

Mode II/III, Orbit Interface — For other than Mode I and when searching for a vector to store into the blocks called maneuver (preburn) vector, priority is given to the hold phase preburn maneuver vectors. If no such vector is available, the single preburn vectors are searched for a valid time tag. If no data is available, a computed nominal vector is used. When searching for a current (postburn) vector, priority is given to the hold phase current interface vectors. These are the last input vectors on which computations have been completed and displayed. The single current vectors are scanned for a valid time tag if no hold phase vector is found. If both hold phase and the single vectors are not available, the current vector type is set to FF, and the time tag of the current vector is left zero. This indicates to the print program to print NO CURRENT VECTOR TRANSFERRED.

If SPS ignition occurs prior to the completion of the S-IVB cutoff collection cycle, there would be no IU vector in the Preburn Save Table. However, after SPS cutoff, the IU maneuver vector is computed and stored in the Launch Input Table. For this reason, the IU source maneuver vector is moved from the Input Table to the Preburn Save Table after cutoff.

If SPS ignition or cutoff has occurred, the maneuver vector is selected from the preburn save table, and only spacecraft sources are considered when searching for the current vector. If neither SPS ignition nor cutoff has occurred,



the maneuver vector is selected from the input table. The current vector is always taken from the input table.

The logic used by the launch interface program when going to Mode III or Orbit plan is supported by these terms.

1. By priority
 - This term means that if a spacecraft source is the selected source, then the order of sources to be searched is SELECTED SOURCE, IPR, AGC, USB, SHP, IPS, IU. If a booster source is the selected source then the order of sources to be searched is SELECTED SOURCE, IPS, IU, IPR, AGC, USB, SHP.
2. Hold phase vectors
 - These vectors are freeflight vectors, which have been averaged, in the case of SHP and TLM, over a 10-second time period and in the case of RAW data from short-arc processing.
 - a. Current interface vectors
 - these are the last hold phase averaged input vectors that do not reflect Δ Velocity of separation
 - b. Δ VIP vectors
 - These vectors are the Mode III maneuver vectors; current interface vectors moved to latest cutoff time and reflect Δ Velocity of separation. IU is always at S-IVB C/O + Δt .
 - c. Δ VINS vectors
 - These vectors are the orbit maneuver vectors; current interface vectors moved to latest cutoff time and reflect Δ Velocity of separation. IU is always at S-IVB C/O + Δt .
3. Single vectors
 - These vectors are obtained from high-speed input processing and they are single vector direct inputs in the case of TLM and SHP; they are the results of smoothing and short arc for the RAW data sources.
4. Input Vector table
 - This table contains the last half-second of data available including hold phase vectors and single vectors. This table is reinitialized at each SPS IGN.

5. Preburn vector table
 - This table contains the last data available for hold phase and single vectors at the last SPS IGN.
6. Latest cut-off time
 - This time will be S-IVB C/O + Δt if no SPS IGN has occurred. Otherwise, it will be the last cutoff + Δt prior to the last ignition.
7. Zero maneuver
 - This maneuver will have zeroes for the maneuver quantities and a time of one-second later than the time tag of the corresponding vector.
8. Vector type
 - The vector type for all hold phase vectors will indicate freeflight. The vector type for all single vectors will indicate powered flight.
9. Force the vector to reflect Velocity
 - The Δ Velocity for CSM separation will be added to the vector at the time of the vector unless the vector is after separation time.
10. Velocity logic
 - The following logic is used:
 - a. If CSM separation has not occurred, add Δ Velocity;
 - b. If CSM separation has occurred and:
 - if the time of the vector is less than or equal to the time of separation, then the vector is moved to the time of separation and Δ Velocity is added;
 - if the time of the vector is greater than the time of separation and if the source is a booster source, then the vector is moved back to the time of separation and Δ Velocity is added and finally the vector is moved ahead to the original time of the vector. Nothing is done if the source is a spacecraft source.
11. t
 - Maneuver vector time from cutoff controlled by system parameter MCLGNG.

Maneuver Vector

1. Search through the hold phase maneuver ($\Delta VINS/\Delta VIP$) vectors by priority.
 - a. Do nothing to this vector;
 - b. Use the maneuver with the vector if good. Otherwise, pass a zero maneuver.
2. Search through the single vectors by priority only if no hold phase vector is found.
 - *a. Force this vector to reflect $\Delta Velocity$. If the vector time is after the latest cutoff time, move the vector to this latest cutoff time and printout 'powered-flight post cutoff vector is'. If the vector is not after the latest cutoff time, do not move the vector and printout 'powered-flight pre-cutoff vector is'.
 - b. Use a zero maneuver.
 - c. If an error occurs in moving the vector to the latest cutoff time, resume the priority search.
3. If no single vector is found, compute a nominal vector and use the zero maneuver.
4. Use the weight with the vector (CSM weight-fuel depletion) or CSM weight in the case of the nominal.
5. Use the CSM area.
6. As a rule for searching for the maneuver vector:
 - a. If phase change is between liftoff and the first SPS IGN, search through vectors in the input vector table
 - b. If phase change is after the first SPS IGN, search for vectors in the preburn vector table.

Current Vector

1. If phase change does not occur during an SPS burn, search through the hold phase current interface vectors by priority:
 - a. Apply $\Delta Velocity$ logic unless going to orbit without separation;
 - b. Time tag of the vector will depend on the ΔV logic;
 - c. If an error occurs in applying $\Delta Velocity$ logic, resume the priority search.

*These functions are not contained in the existing code but will be implemented in AS-205, AS-206, and AS-501.

2. If no hold phase vector is found or if phase change occurs during a burn, search through the single vectors by priority. Force this vector to reflect Δ Velocity unless going to orbit without separation.
3. If no single vector is found, pass 'no current vector indication'.
4. Use weight with the vector (CSM weight-fuel depletion) unless going to orbit without adapter separation, then use the combined weight.
5. Use the CSM area unless going to orbit without adapter separation, then use the combined area.
6. Always search for the current vector in the input vector table.

Priority of Vector Sources

1. When a booster source is selected, the priority is as follows:
 - a. The selected source
 - b. IPS
 - c. Booster TLM
 - d. IPR
 - e. Spacecraft TLM
 - f. USB
 - g. SHP.
2. When a spacecraft source is selected the priority is as follows:
 - a. The selected source
 - b. IPR
 - c. Spacecraft TLM
 - d. USB
 - e. SHP
 - f. IPS
 - g. SAT

The following is a detailed flowchart of the above logic.

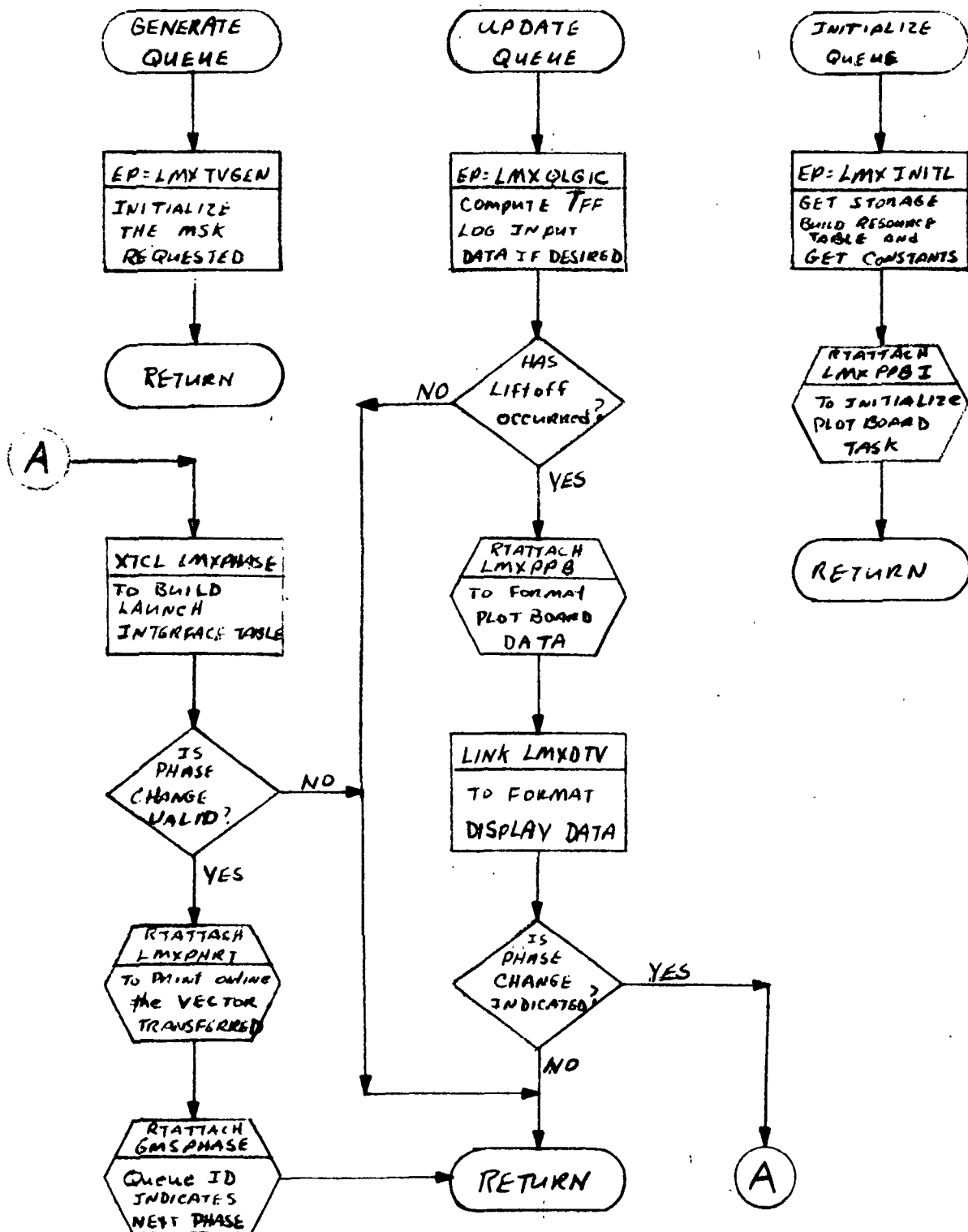


Figure 15. Launch D/TV Output Task Flowchart



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LM0275 B FDO LAUNCH DIGITALS NO.1

GET SELECTED SOURCE GMTLO

V/V_{PS} V γ h P_i
 V_G T_{ff} T_{90}
 d

SOURCE	SAT	APL	C RDR	S RDR	C SHIP
RECOMMEND					
V_s					
V_i					
γ_i					
h					
\dot{h}					
ΔV_{INS-C}					
ΔT_{INS}					
GETI					
DATA PTS					

Figure 16. FDO Launch Digital No. 1

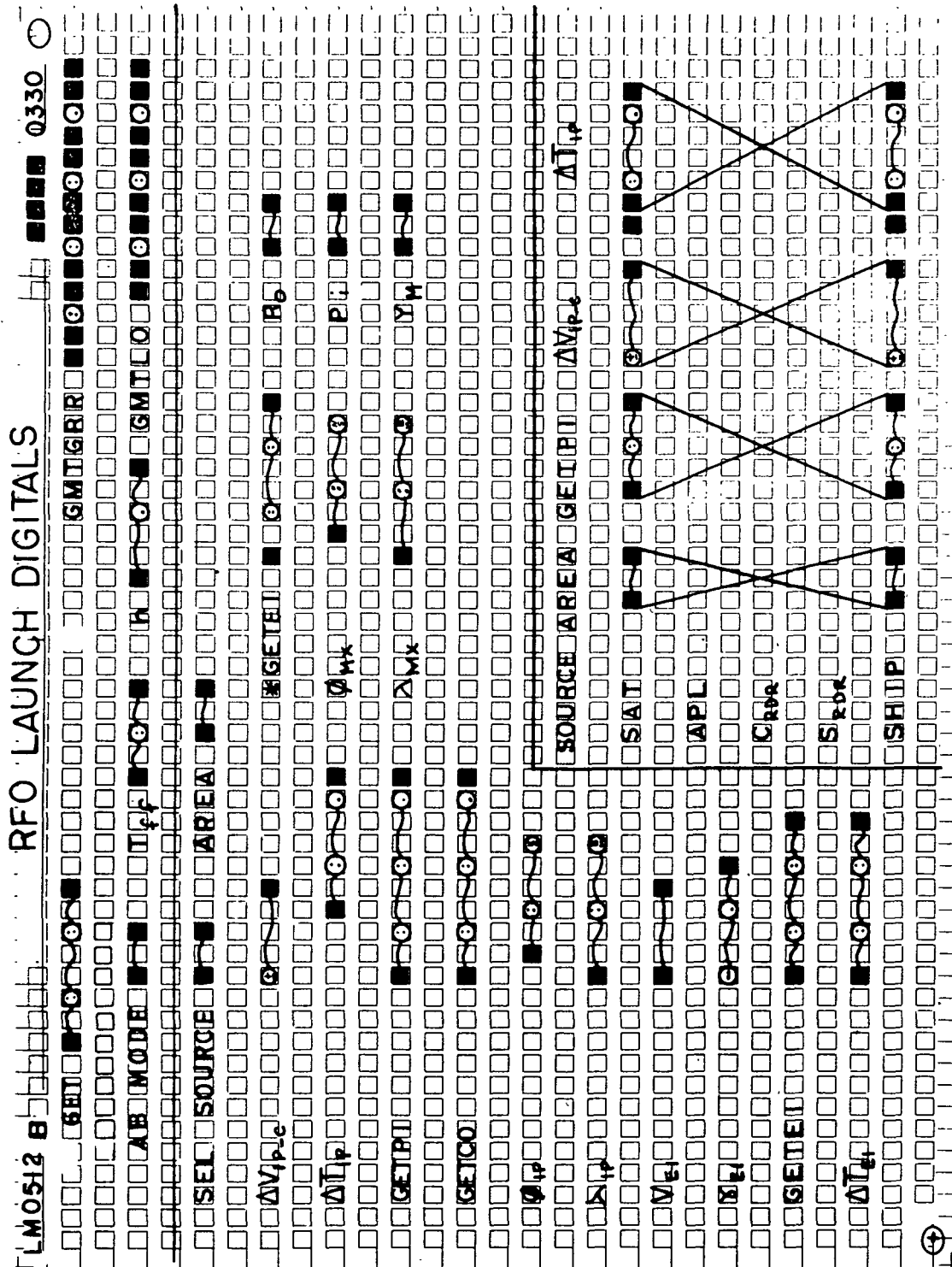


Figure 17. RFO Launch Digitals

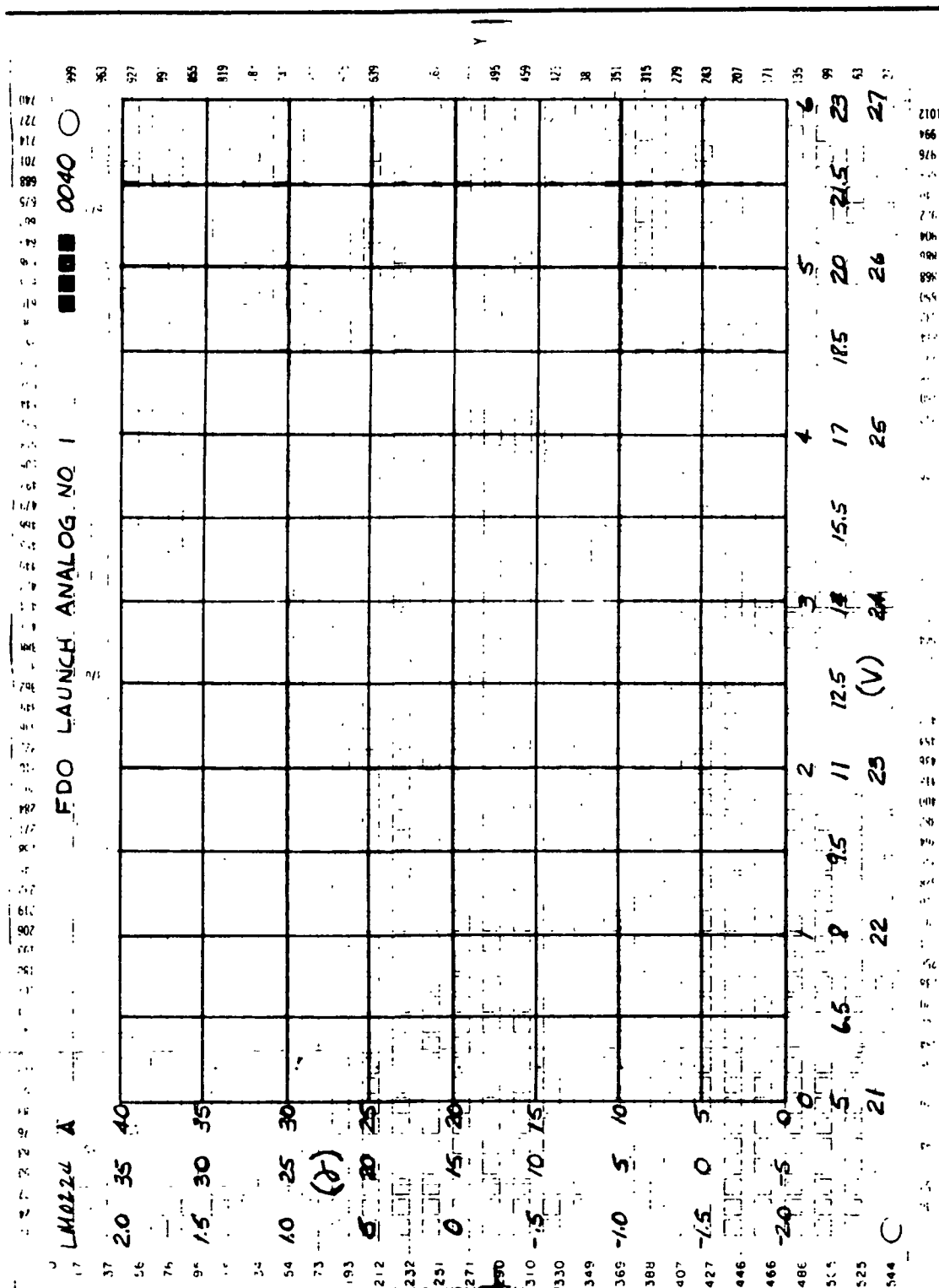
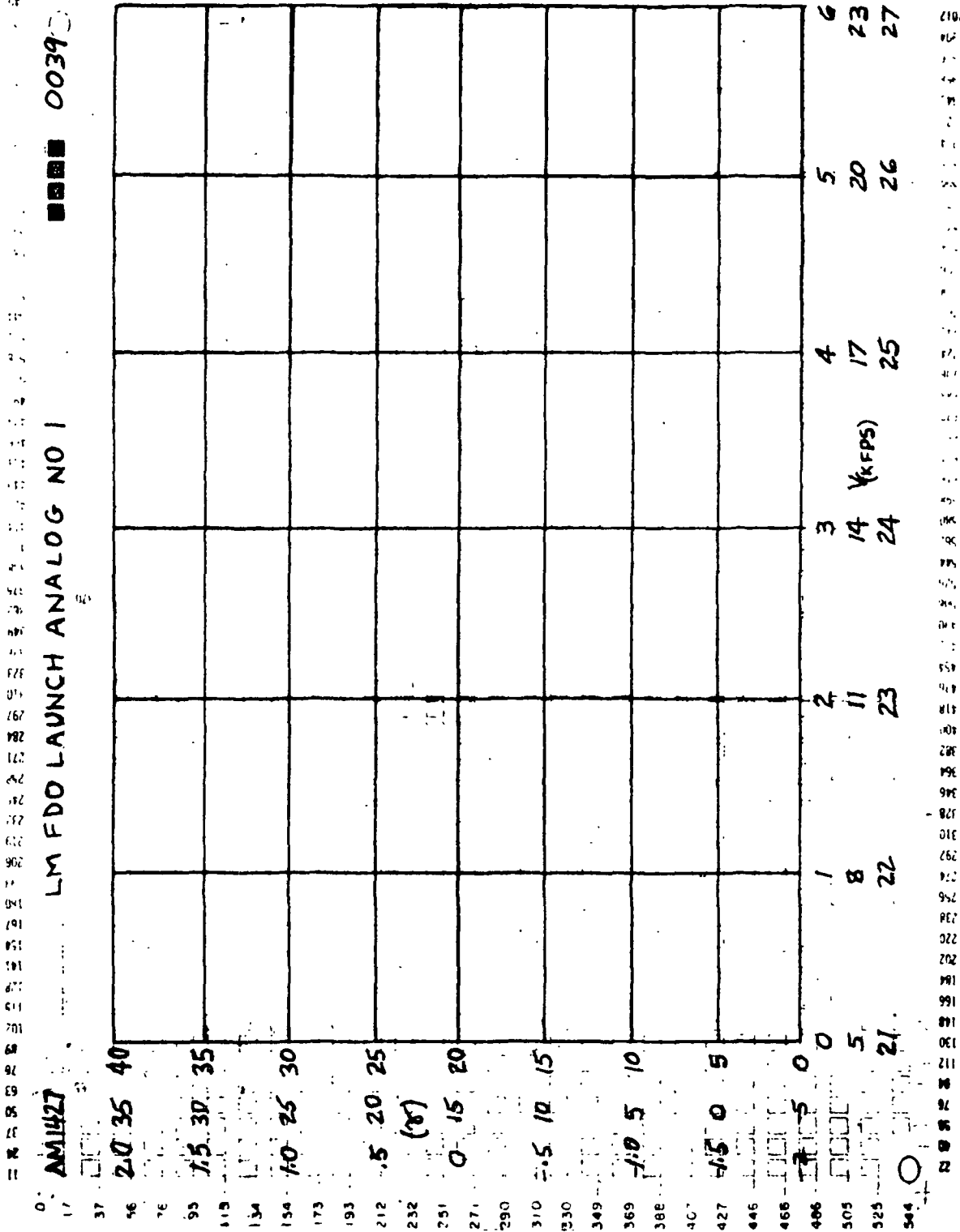


Figure 18. FDO Launch Analog No. 1



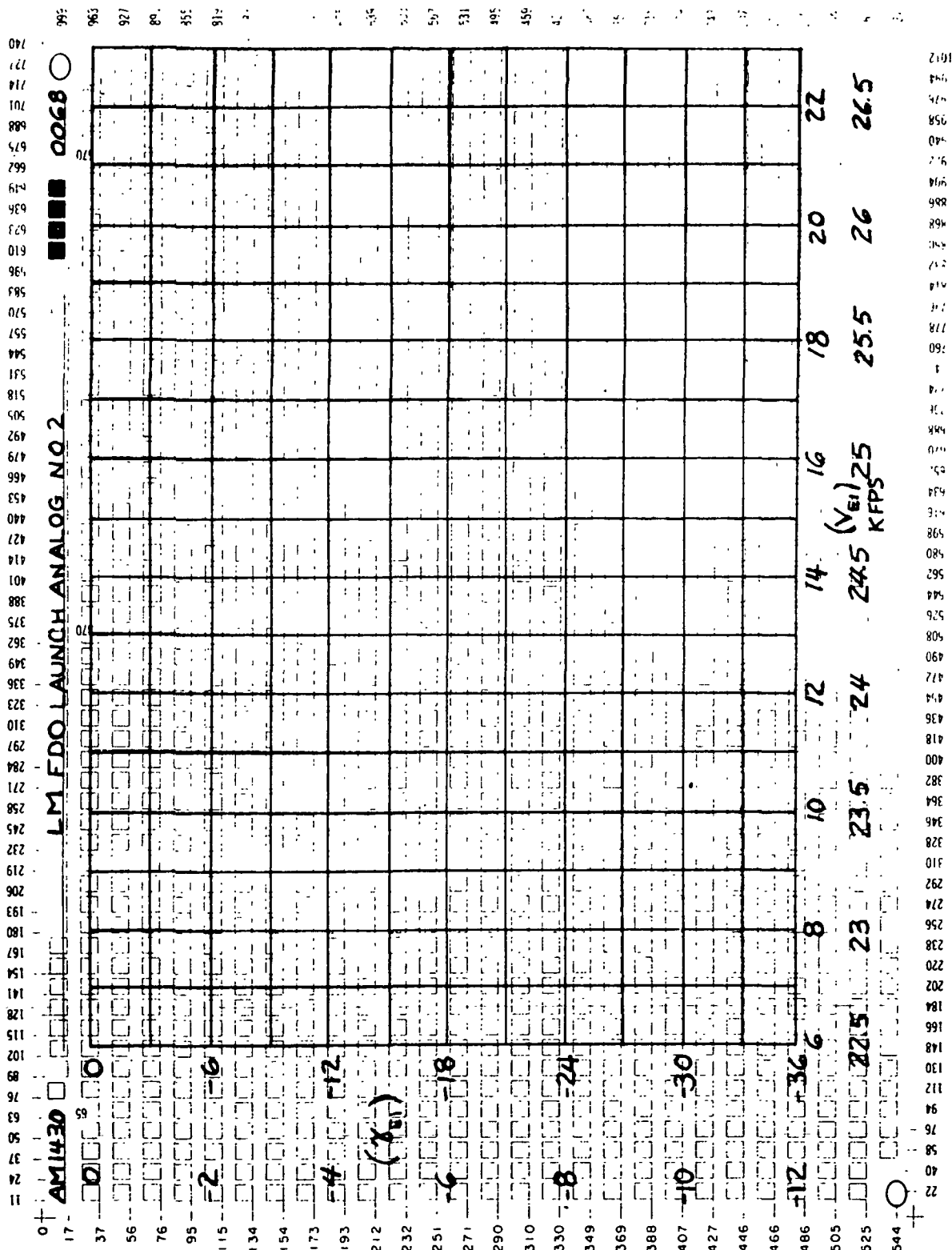
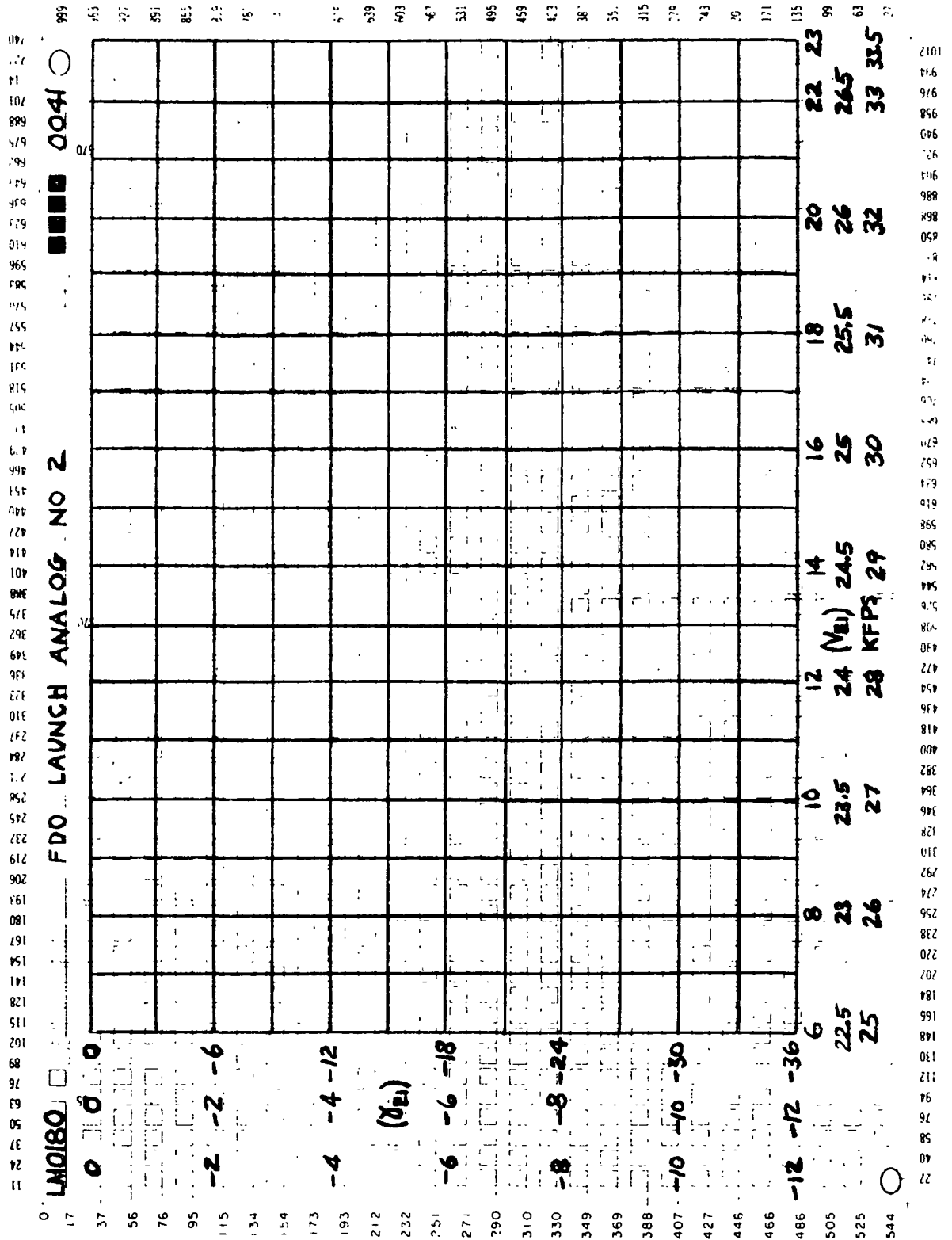


Figure 20. LM FDO Launch Analog No. 2



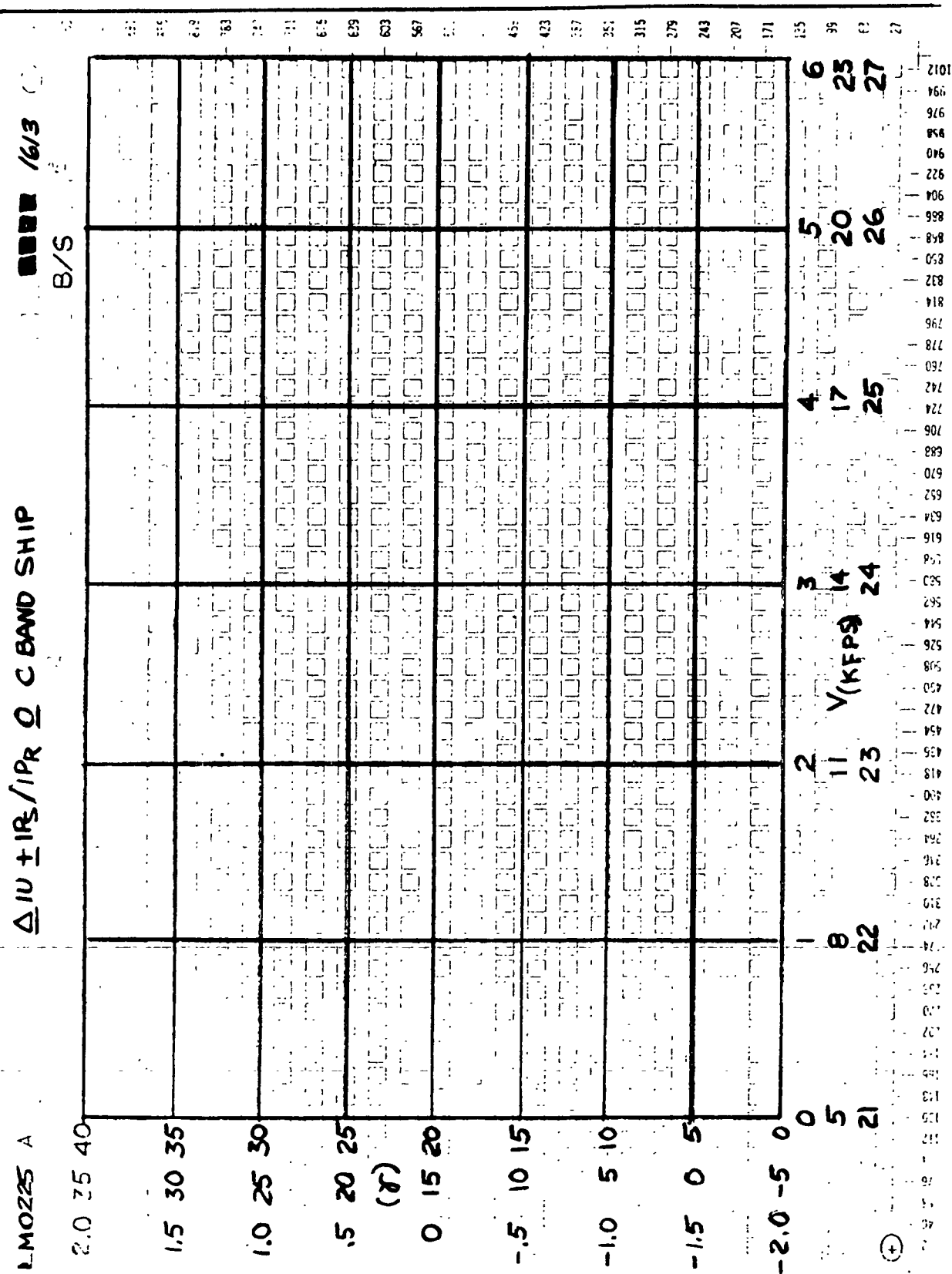


Figure 22. Tracking, Telemetry Trajectory Data Select

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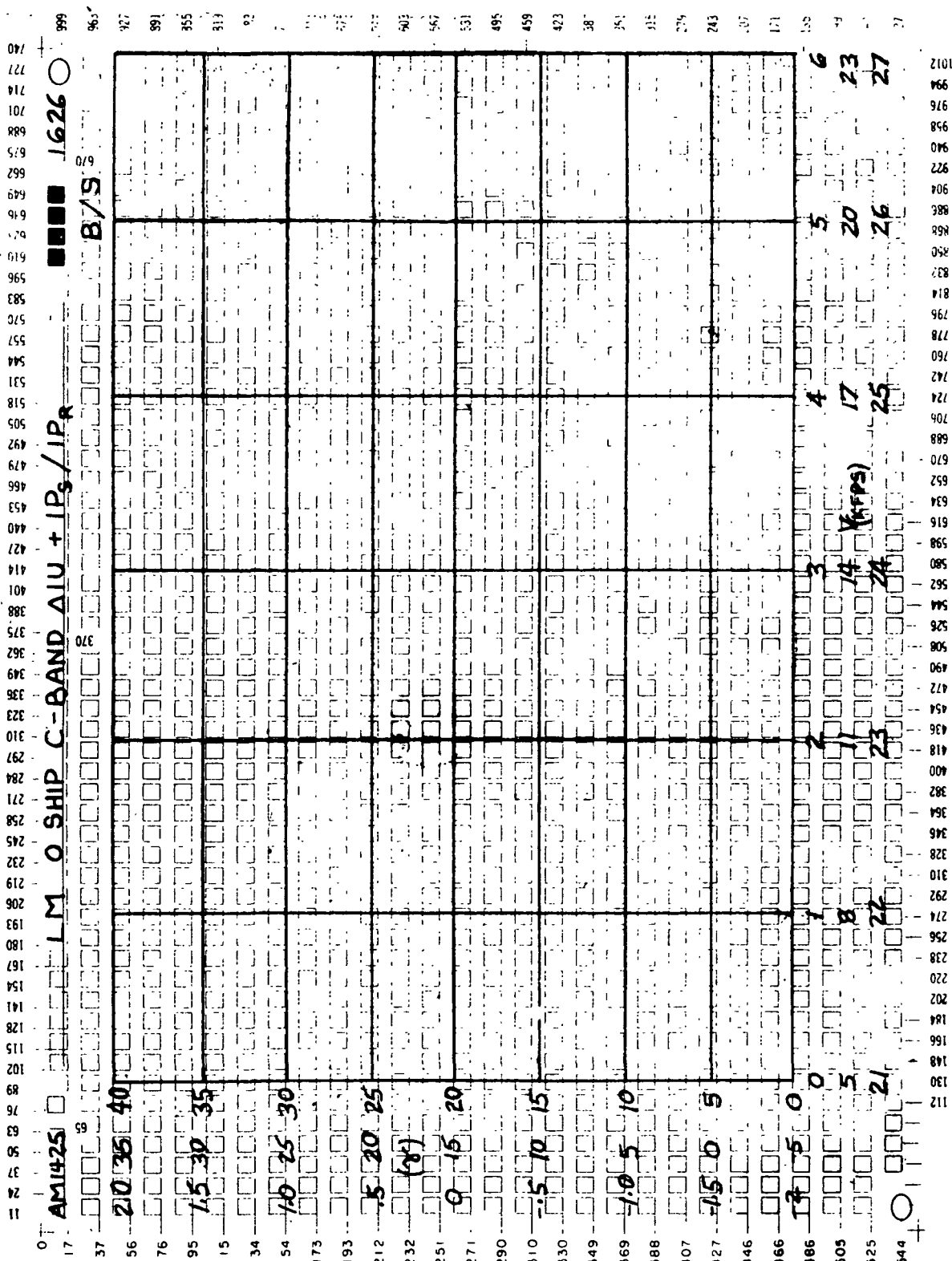


Figure 23. LM GAMMA VS VEL B/S

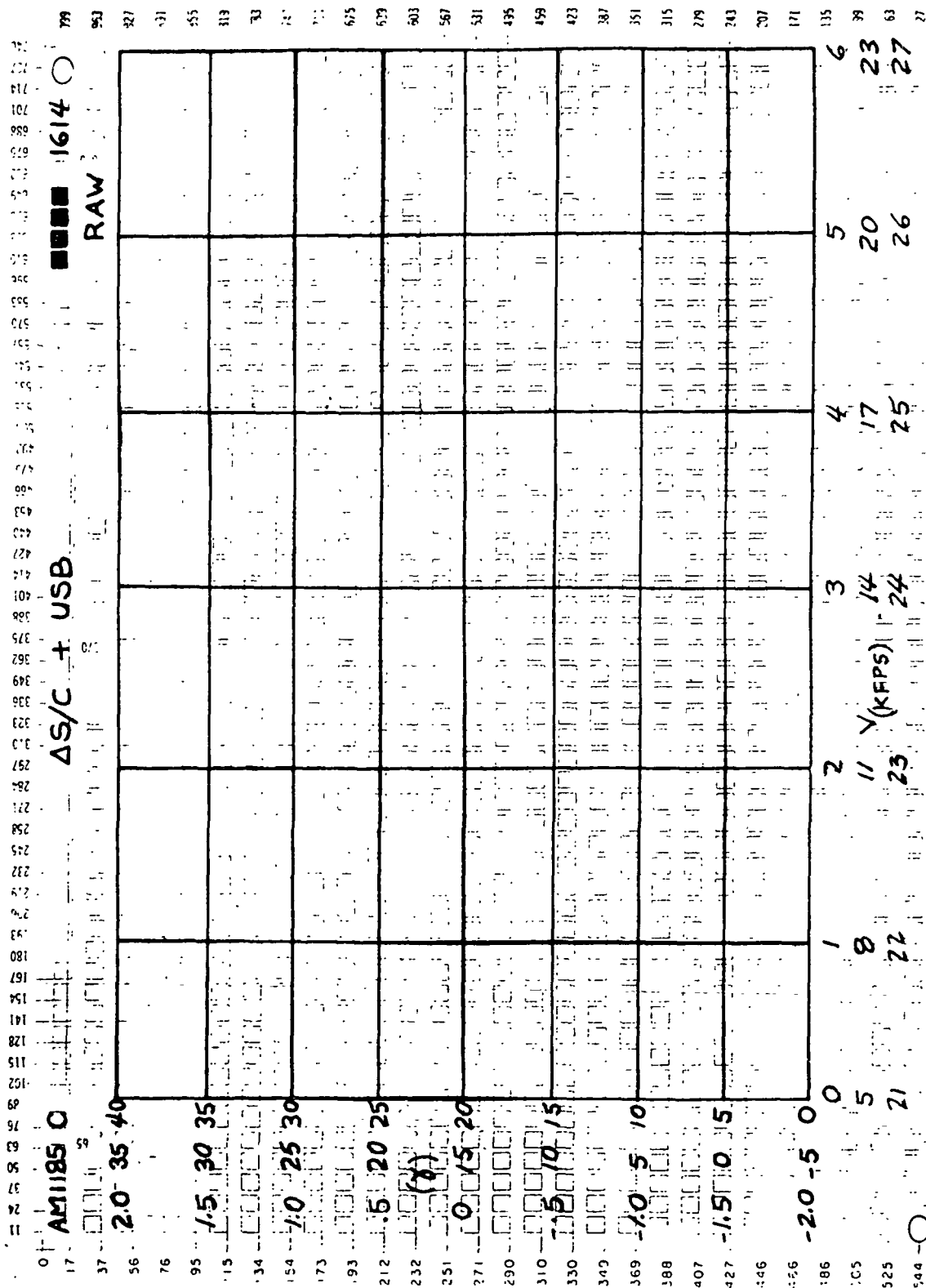


Figure 24. Tracking, Telemetry, Trajectory Data Select (RAW)'

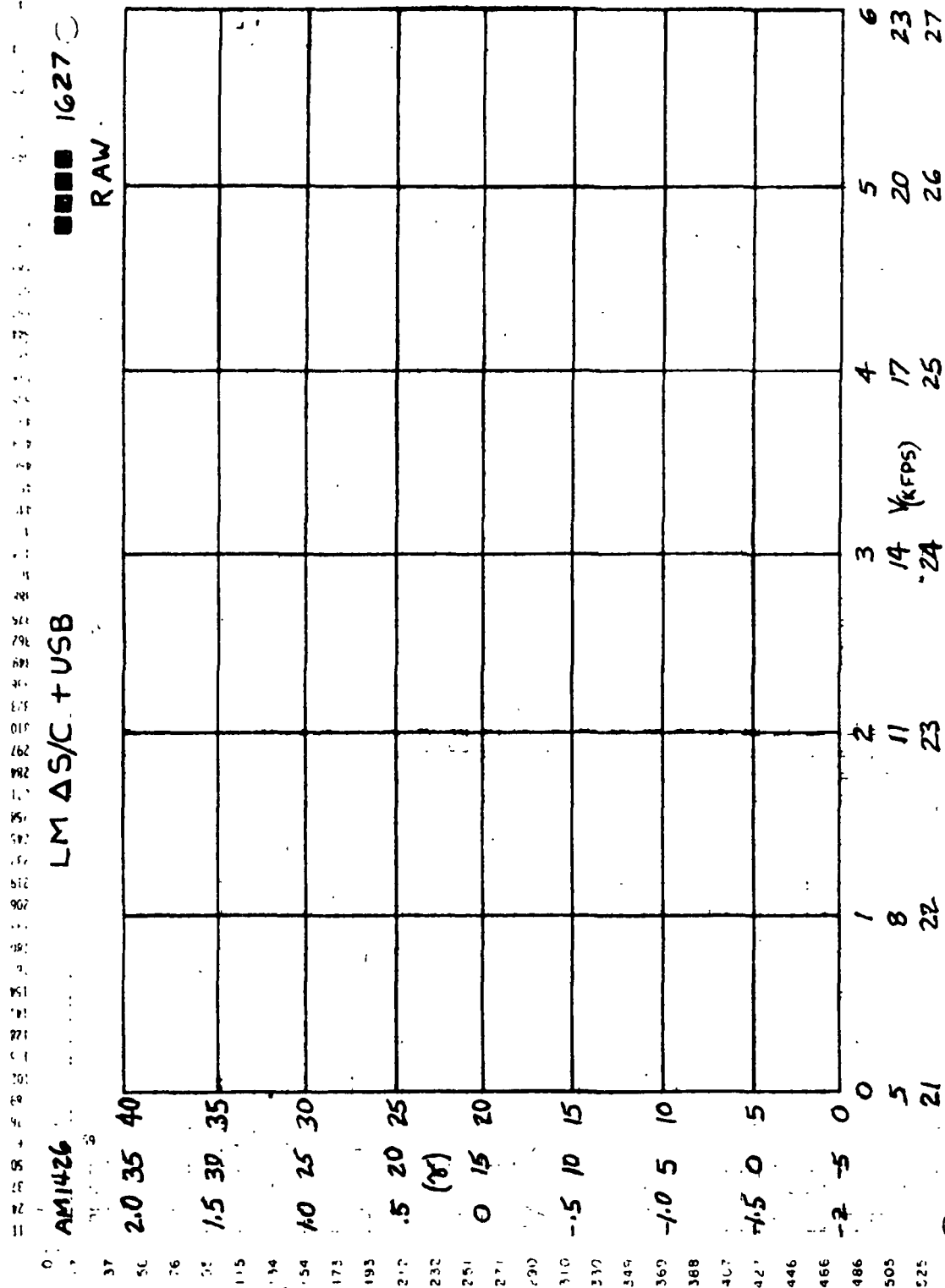


Figure 25. LM GAMMA VS VEL RAW



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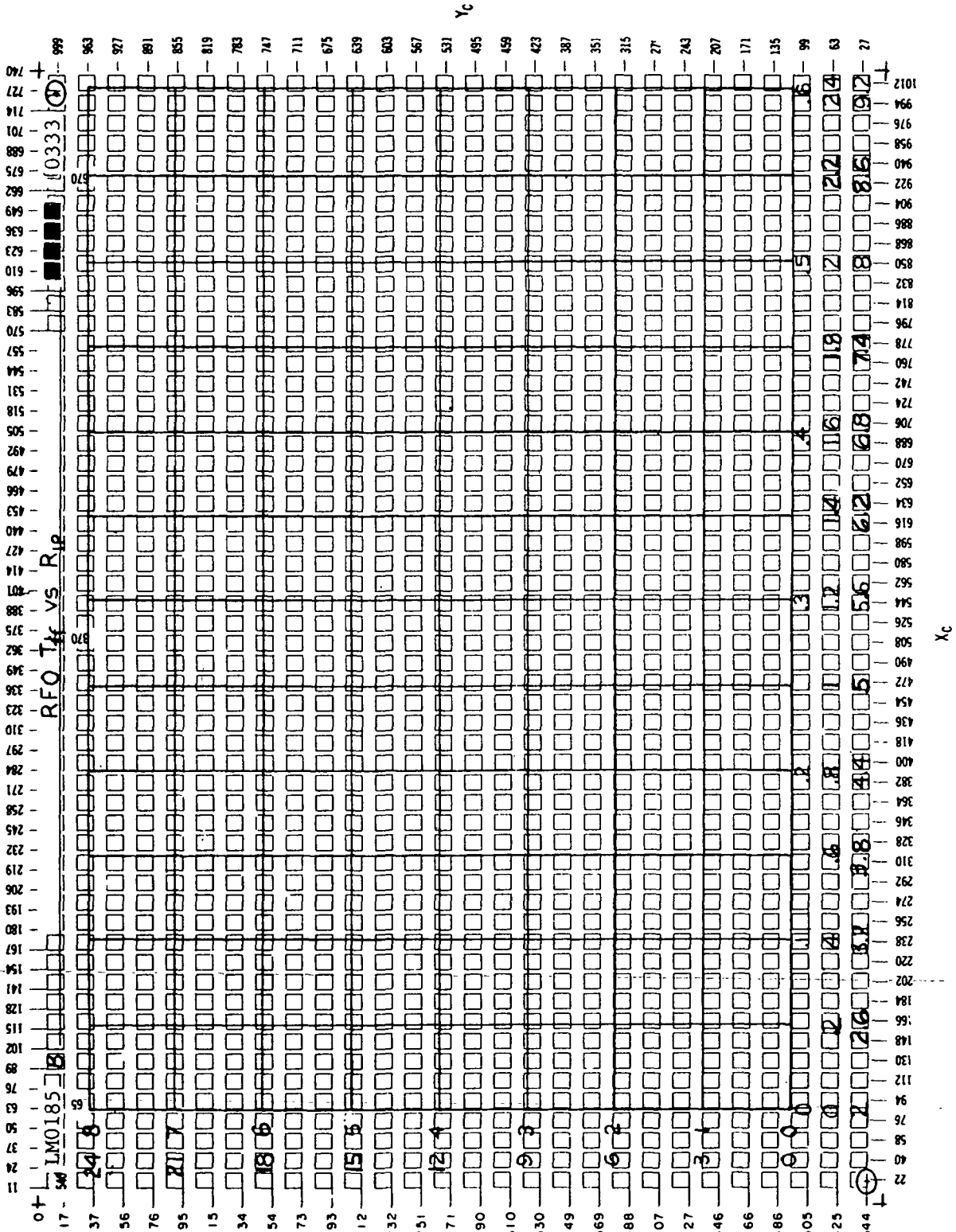


Figure 26. RFOT_{ff} vs R_{IP}

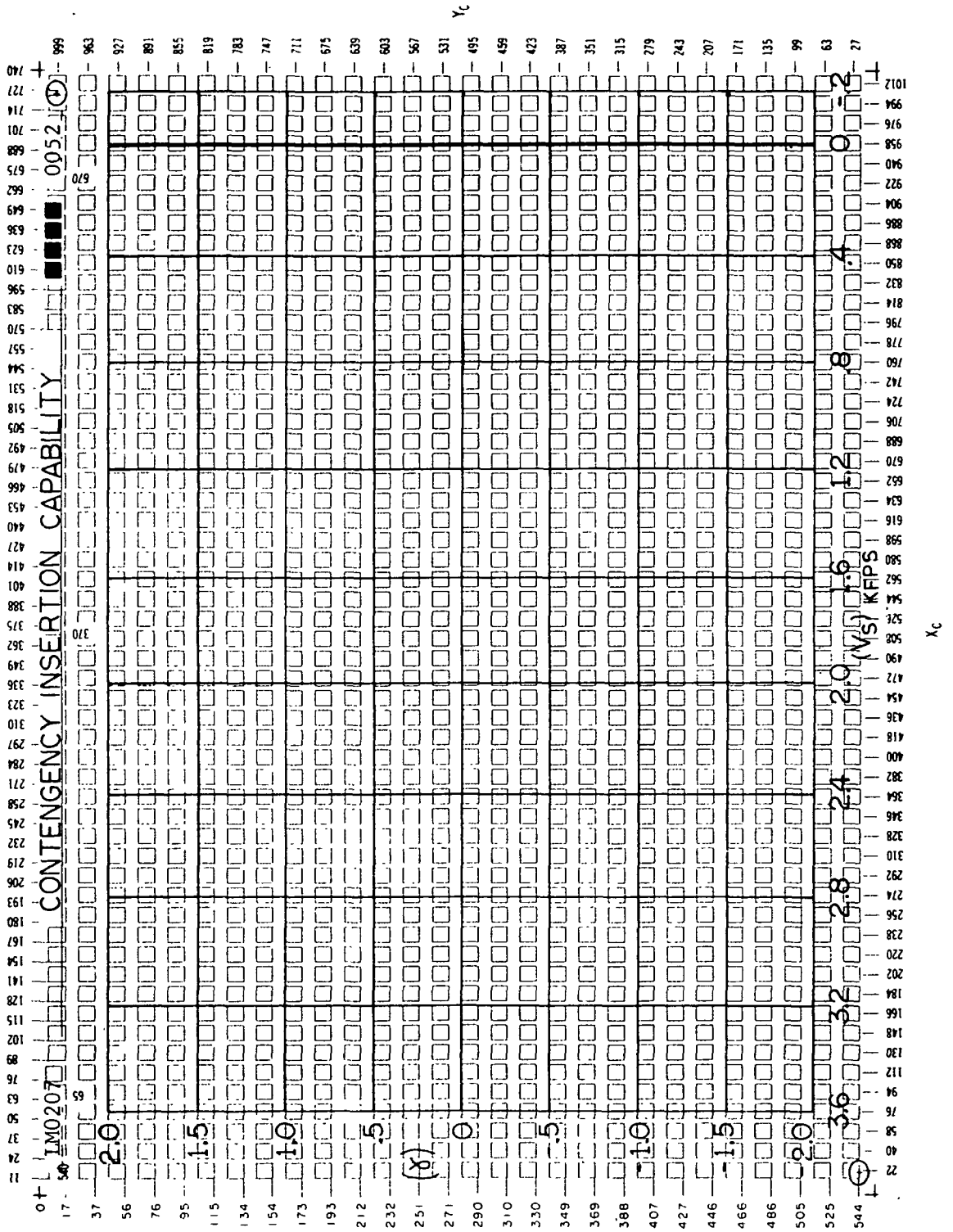


Figure 27. Contingency Insertion Capability

Figure 28. LM Contingency Insertion Capability

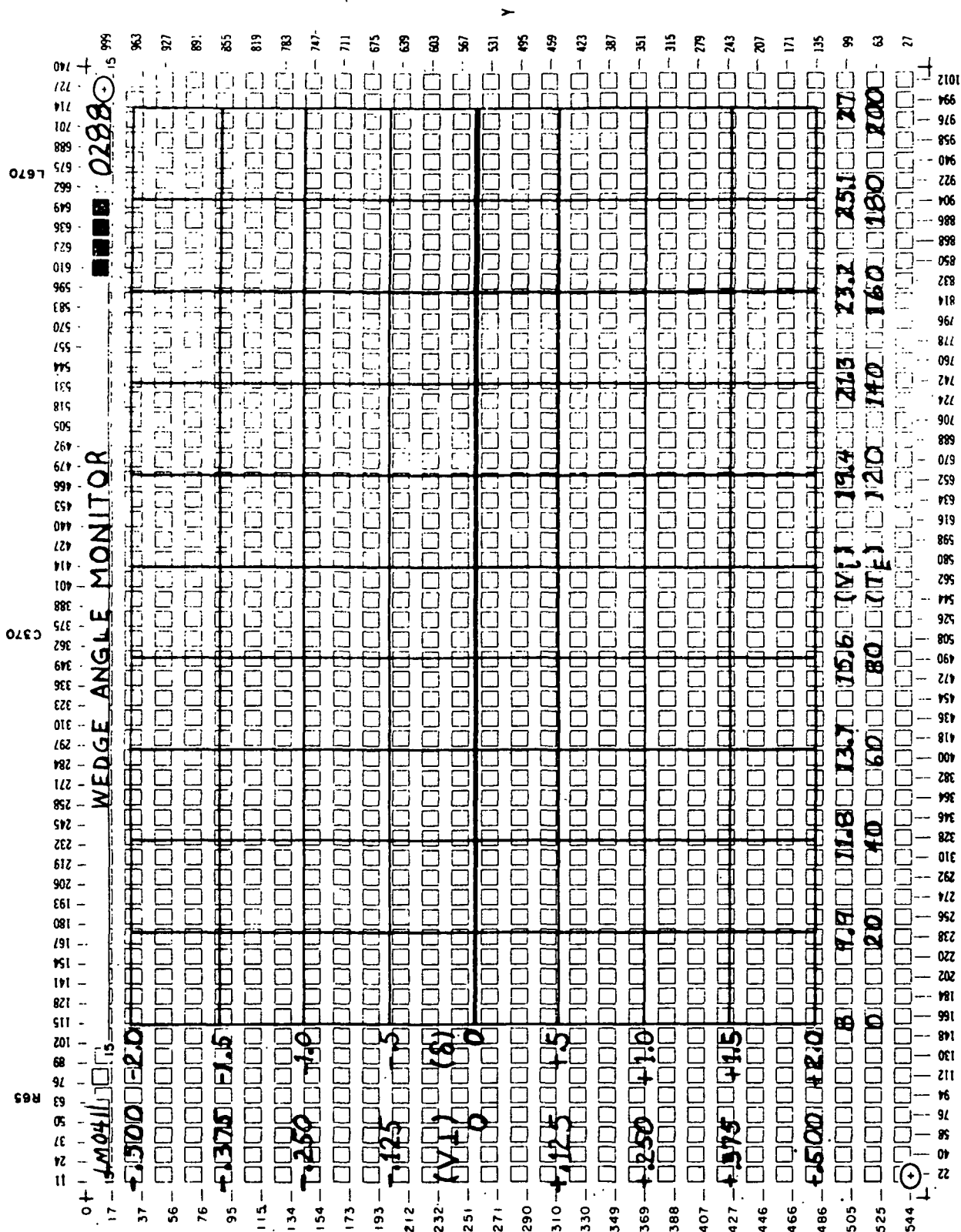


Figure 29. Wedge Angle Monitor

LTXPPBPP (LAUNCH PLOTBOARD TASK)

The Launch Plotboard Task receives an initialization and update queue from the Launch Output Task.

When the initialization queue is received, the following events occur: (1) the task storage area is obtained, (2) the Task Resource Table is built, (3) the plotboard projector addresses are obtained, and (4) the initial plotboard commands are output.

When an update queue is received, the X-Y and projection plotboard commands are generated and output.

Projection Plotboards

The following plotboards are driven by the Launch Plotboard task:

1. MOCR Left Projection Plotboard 3
2. MOCR Right Projection Plotboard 4
3. Recovery World Map Display
4. SSR X-Y Plotboard 1
5. SSR X-Y Plotboard 2
6. SSR X-Y Plotboard 3
7. SSR X-Y Plotboard 4.

MOCR Left Projection Plotboard 3 — The purpose of the MOCR Left Projection Plotboard 3 is to display plots of Apollo trajectory quantities. On the left 10 by 10 foot area, the vehicle altitude (h_0) versus the downrange distance (d) is spotted and scribed; on the right 10 by 10 foot area the inertial flight-path angle (γ) versus the inertial velocity (V) is spotted and scribed. The scribing commands are output to the device at half-second intervals beginning at liftoff.

MOCR Right Projection Plotboard 4 — The purpose of the MOCR Right Projection Plotboard 4 is to display launch phase spacecraft inertial subsystem/AGC interface validation dynamic check and spacecraft capability cues during booster thrusting. The inertial flight-path angle (γ) versus inertial velocity (V) from the selected source and the AGC (telemetry) state vectors are spotted and scribed. Data points are output to the spotting and scribing projectors at half-second intervals starting at liftoff. The plot is terminated at the end of Launch phase.

Recovery World Map Display — The purpose of the Recovery World Map Display is to provide controllers with predicted groundtrack information; dynamic values of $(\phi \text{ vs } \lambda)_{PP}$ and $(\phi, \lambda)_{IP}$ are then scribed and spotted. The quantities are plotted at half-second intervals from liftoff through abort or orbit initiate.

SSR X-Y Plotboard 1 — The SSR X-Y Plotboard 1 serves as the primary display for trajectory evaluation. The selected source inertial flight-path angle (γ) in degrees vs. the inertial velocity (V) in feet per second quantities are scribed at half-second intervals. The plot is initialized on computer receipt of liftoff and terminated at launch abort or orbit.

SSR X-Y Plotboard 2 — The SSR X-Y Plotboard 2 aids in predicting abort mode capability during Launch phase. The selected source freefall time to entry interface (T_{FF}) vs. range to the predicted impact point (R_{IP}) is plotted on a two-second cycle (same as $(\phi, \lambda)_{MX}$ digital and analog). The plot is terminated at the end of Launch phase.

SSR X-Y Plotboard 3 — The purpose of the SSR X-Y Plotboard 3 is to display conditions of $(\gamma, V)_{EI}$. The selected source flight-path angle vs. inertial velocity at entry interface $(\gamma \text{ vs. } V)_{EI}$ is plotted. The plot is initialized when apogee altitude is equal to or above entry interface, and it is updated on a half-second cycle. The plot is terminated after S-IVB maximum ΔV_{IP} burn data is displayed. If SPS thrusting starts, predicted $(\gamma, V)_{EI}$ points are plotted.

SSR X-Y Plotboard 4 — The purpose of the SSR X-Y Plotboard 4 is to display the Apollo trajectory quantities of latitude versus longitude of predicted impact points $(\phi \text{ vs } \lambda)_{IP}$ and present position $(\phi \text{ vs } \lambda)_{PP}$. The display is updated on a half-second cycle after liftoff. The plot is terminated at the end of Launch phase. The $(\phi, \lambda)_{IP}$ is computed on a two-second cycle during powered flight and on a NSEC cycle during hold phase.

Load Modules

The load modules described below are part of the Launch Plotboard Task.

LMXPPBI — The Initialization for Launch Plotboard Task gets storage needed for the plotboard task, builds the tasks resource table, and initializes X-Y projection plotboards, pens, scribes, and spotters.

LMXPPB — The Plotboard Display Output Formatter formats and outputs launch parameters for X-Y and projection plotboards.

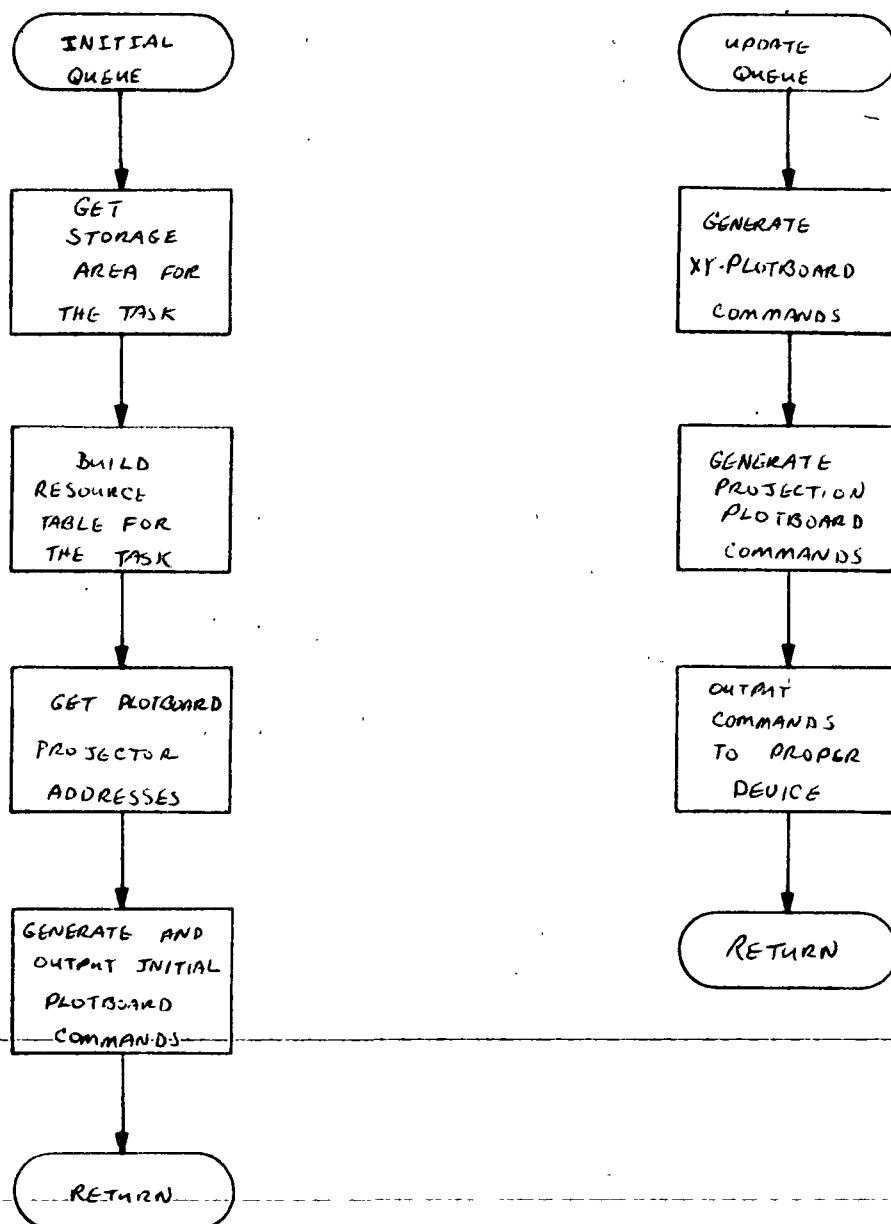
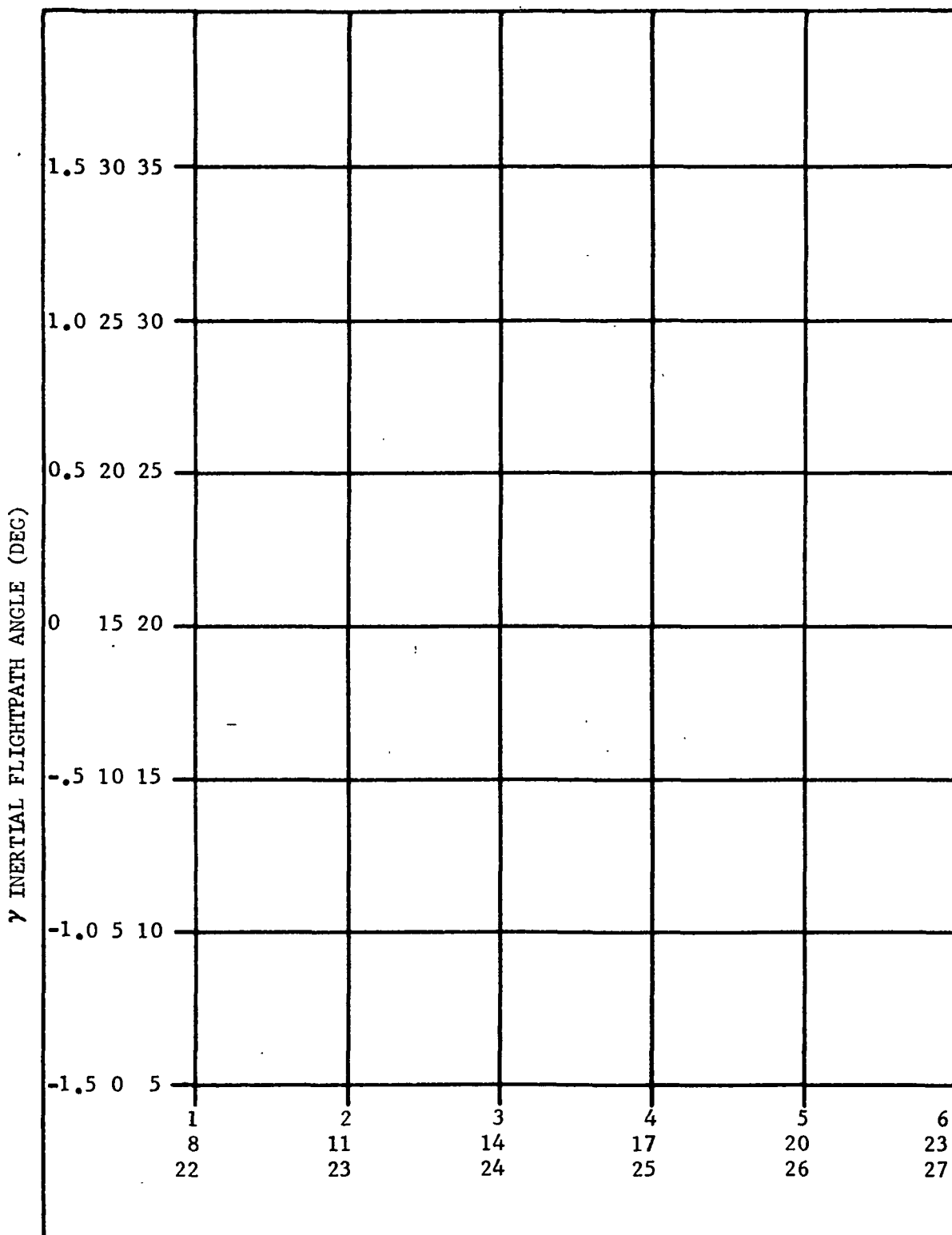
Launch Plotboard Task
LTXPPBPP

Figure 30. Launch Phase Flowchart



PLOTBOARD I
LAUNCH

V INERTIAL VELOCITY (KFPS)

APOLLO
FORMAT 0036

Figure 31. SSR X-Y Plotboard (1)

Figure 32. SSR X-Y Plotboard (2)



X-Y PLOTBOARD DFW

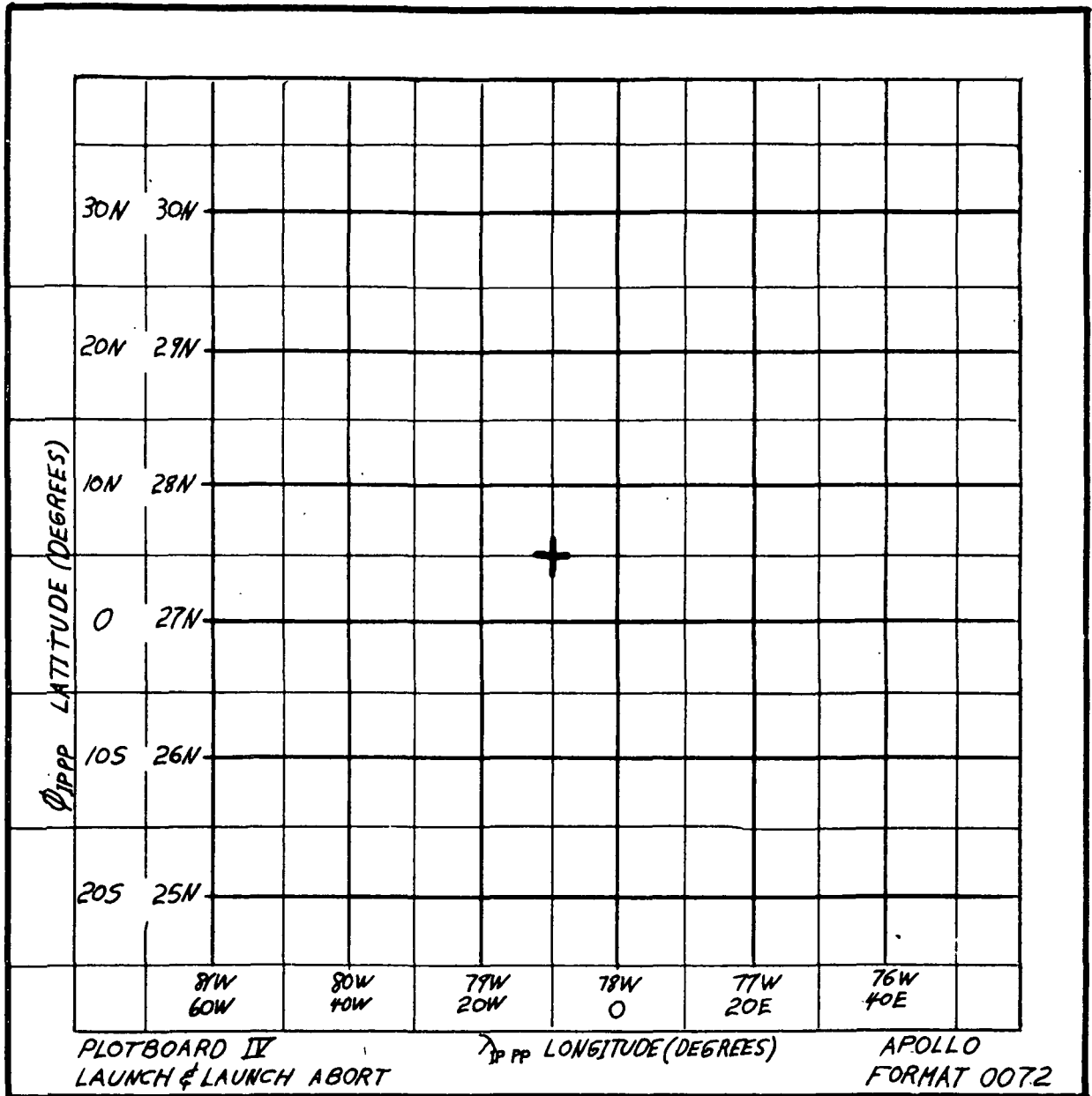


Figure 33. SSR X-Y Plotboard (4)

LP0002

ACC DYNAMIC STATUS

0046

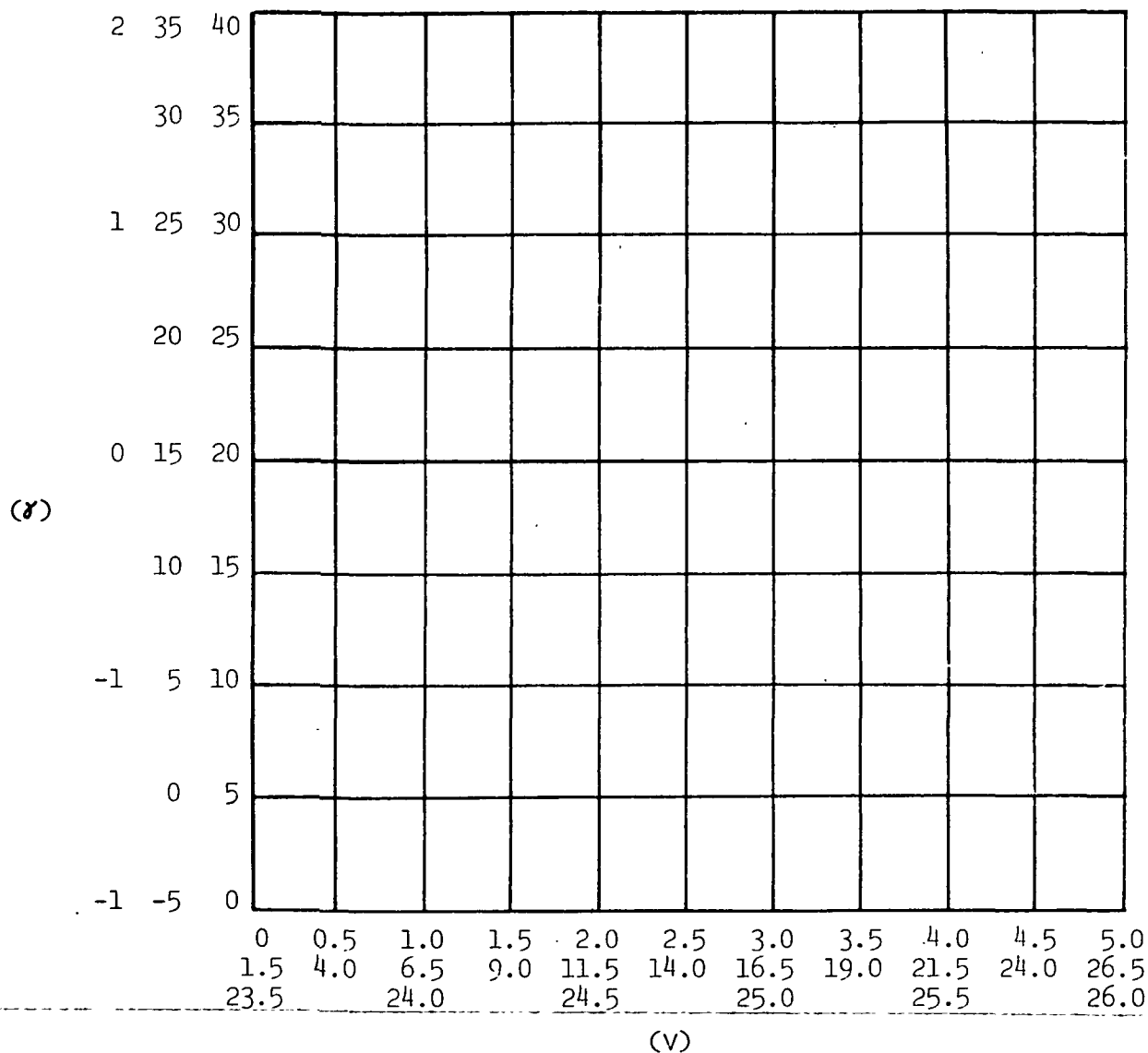


Figure 34. MOCR Right Projection Plotboard No. 4

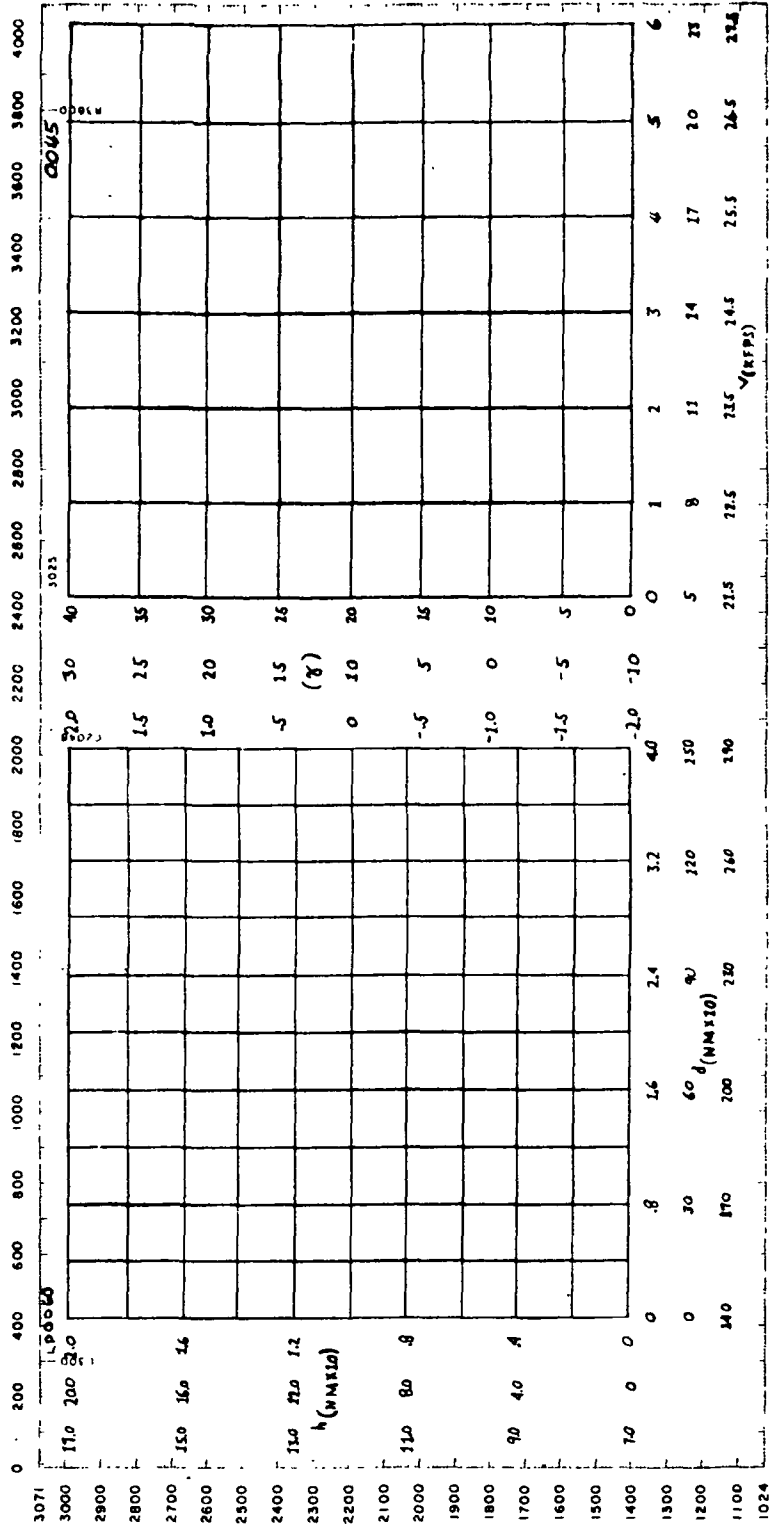


Figure 35. MOCR Left Projection Plotboard No. 3

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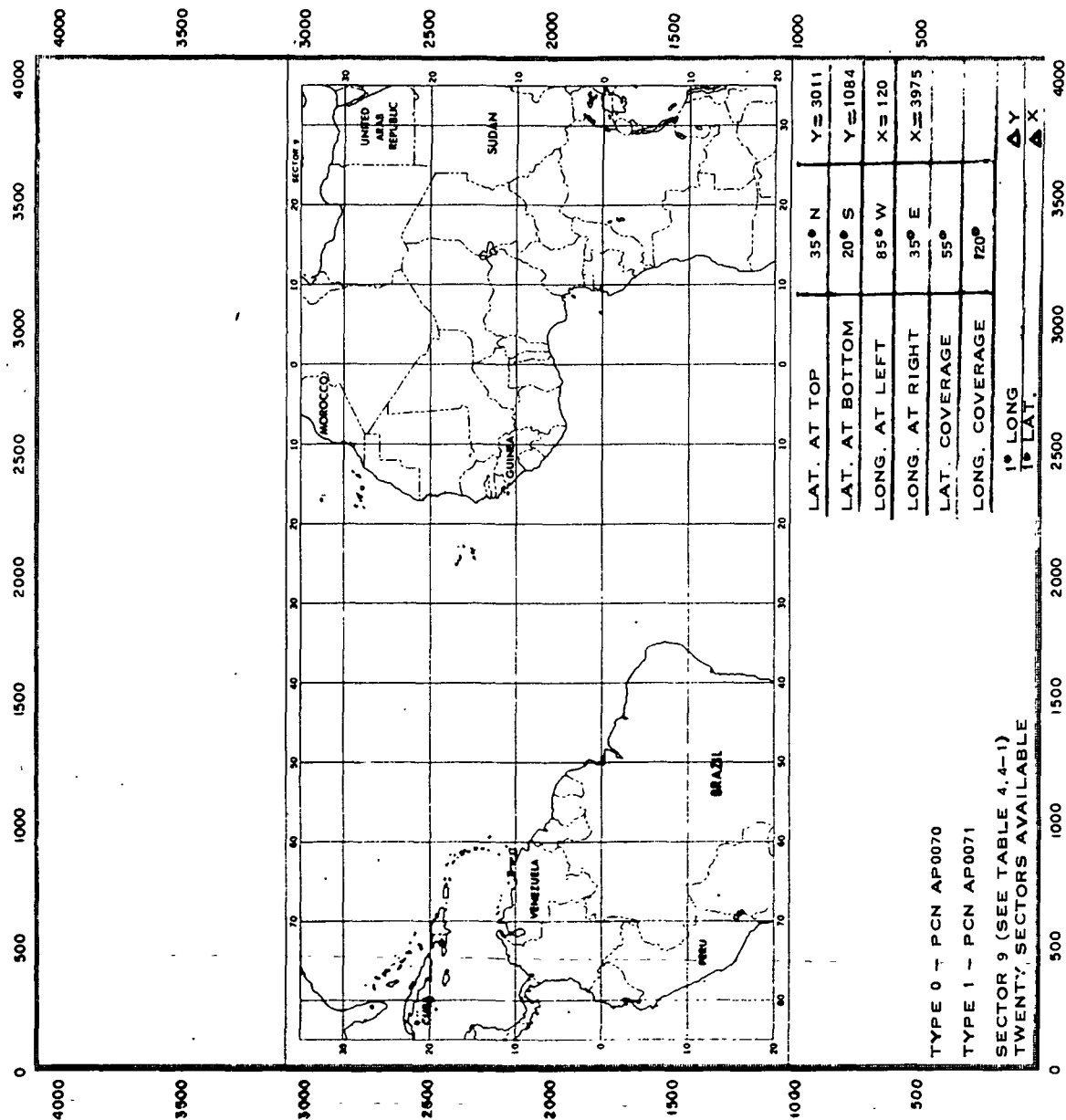


Figure 36. Recovery World Map Display

LTXPRNTR (HIGH-SPEED PRINTER TASK)

This task receives all launch/high-speed queues to the on-line printer (1443). Queues to this task will prevent the stoppage of other user tasks if the printer is out of ready.

Load Module Descriptions

Included in the Printer Task are the modules described below.

LMXPRNTR — The Event Print Load Module is the mission on-line printout routine for launch. It receives an EBCDIC message and one or two times in floating-point hours. Its output is (1) GMT formatting time, (2) GMT queue time, (3) input EBCDIC message, and (4) the second input time if there is one. The entire output is formatted to a maximum length of one line, thus limiting the length of the EBCDIC message accordingly. This load module is also used during the High-Speed Orbit Phase for printing error messages.

LMXPHRT — The Launch Interface Print Load Module prints out the launch interface data on-line. This includes the maneuver vector ($t, x, y, z, \dot{x}, \dot{y}, \dot{z}$, area, weight), the maneuver (GMTPI, DTIP, DVIP, ROLL, PITCH, YAW, TARGET, or GMTI, DTINS, DVINS) with the vector if Mode III or Orbit, the time of CSM separation (if it occurred), and low-speed collection time. Excluding Mode I Abort, the current vector ($t, x, y, z, \dot{x}, \dot{y}, \dot{z}$, area, weight) is printed out also, if one is available.

LMXHSPTR — The High-Speed Orbit Print Load Module prints out high-speed radar and telemetry vectors during high-speed orbit phase. High-speed radar vectors are printed every 10 seconds. The average telemetry cutoff vector is printed when first computed. If the P60, STOP MED is entered, the final radar and telemetry vectors are printed.

LMXGNGPR — The GO/NO-GO Print Load Module formats and outputs to the on-line printer (1443) the computed quantities and some intermediate values generated in the GO/NO-GO CSECT (LCMGNGDC) of the Hold Phase Task (LTHLDSPS). The formatting and output is accomplished via RTOS display formatting language (DFL). The on-line output is used both as a program checkout tool and as a permanent record for test verification.

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The following quantities are formatted for on-line presentation:

Source. . . . High-speed data source on which calculations were performed

STA. Station code if source is USB, IPR or Ship-C

Decision. . . . GO/NO-GO recommendation for the above source

Points. Number of points in vector used in calculation

DVINS. (ΔV_{INS-C}) Delta velocity change required for insertion into minimum acceptable orbit

DTINS. (ΔT_{INS}) Time associated with ΔV_{INS-C}

V_i Current inertial velocity

γ_i Current inertial flight-path angle

h_s Current spherical altitude

\dot{h} Current radial velocity

V_S V_{PS} minus current inertial velocity

V/V_{PS} Ratio of current inertial velocity to velocity necessary to achieve minimum vacuum perigee

GMT_A. GMT of upcoming apogee

AVGVEC or NSVEC. . . . Input vector to GO/NO-GO Csect

MVRVEC Vector at SPS or S-IVB cutoff + x seconds including separation delta velocity (maneuver vector)

RECVEC. Vector on which GO/NO-GO recommendation was calculated

PHSVEC. Current interface vector (vector associated with current displayed quantities)

LMXSPSPR — The SPS Mode III Print Load Module formats and outputs to the on-line printer (1443) the computed quantities generated in the SPS Burn Mode III Calculations Control Section referenced in LMSHLDPH Load Module. The formatting and output is accomplished via RTOS display formatting language (DFL). The on-line output is used both as a program checkout tool and as a permanent record for test verification.

The following quantities are formatted for on-line presentation:

Source. High-speed data source on which calculations were performed

Maneuver type. . . . CSM or LEM

DVIP ΔV of maneuver (ΔV_{IP-C})

DTIP ΔT of maneuver (ΔT_{IP})

GMTPI Time-to-begin maneuver (SPS on)

P Pitch

Y Yaw

R Roll

} Maneuver attitudes

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Target Distance (nm) to target
Lift Lift switch setting
 $(\phi, \lambda)_{IP}$ Mode III impact point
DTEI Fall time to entry interface after maneuver (ΔT_{EI})
WT Weight of vehicle at start of maneuver
 $(\phi, \lambda)_{MX}$ Mode II impact point
Reentry area and weight of vehicle

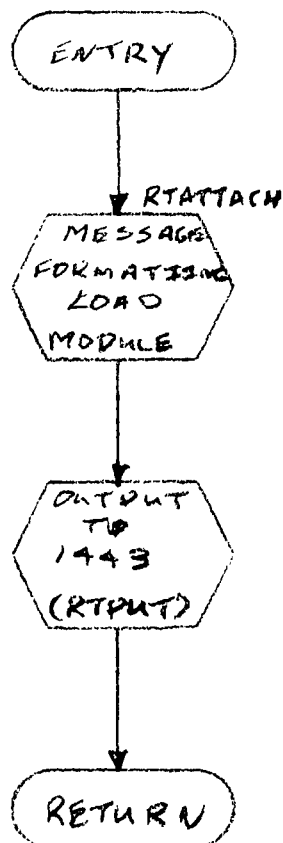
Launch/High-Speed Printer Task
LTXP RNTR

Figure 37. Launch/High-Speed Abort-Orbit Phase Flowchart

LTXHSABT (HIGH-SPEED ABORT OUTPUT TASK)

The High-Speed Abort Output Task, LTXHSABT, is queued at phase change to Abort I or II by the Launch Input Task, LTDATAPF. Storage area for the task is obtained; the resource table is built; and the transferred vector, selected source code, and the abort mode indicator are read in from the Launch Interface Table. An ephemeris is computed by integrating the vector transferred from the launch phase down to drogue chute deploy. A table of nominal h_0 and V_E are computed from the ephemeris, and this table is used as input for the plotboards and high-speed abort displays. The Plotboard Task is issued a queue for initialization, and the h_0 and V_E computed from the ephemeris are formatted for MSK 1615. Routing is set up to the high-speed abort six-second control load module on a six-second cycle.

Every sixth second the selected source code and input vectors are read in from the Launch Data Table. A valid selected source vector is integrated to present GMT. If the selected source vector is not valid, the last six-second output vector is integrated to present GMT.

Present position latitude and longitude, h_0 and V_E , are computed using the integrated vector. $(\phi, \lambda)_{PP}$ is updated on the plotboard and MSK 331, and h_0 is updated on MSK 0331. However, if the vector input to the integrator was below drogue chute deploy, the input vector is used for these computations. The displayed quantities, V_E and h_0 , for MSK 1615 are computed on each available source using the input vectors and not the vectors integrated to present GMT.

If the input vector to the integrator is above drogue chute deploy and data is not missing, the integrator is called. The integrator uses the last integrated vector to compute $(\phi, \lambda)_{IP}$, V_{EI} , γ_{EI} , $GMTEI$, $GMTBOI$, $GMTBOE$, and $GMTDD$. (These quantities are displayed on MSK 0331 and MSK 0338). If impact was achieved, range to impact is computed. (RIP is plotted on MSK 0333). If impact was not achieved, range to impact and impact points are set to a maximum value. (RIP is input to the plotboards and MSK 0333; $(\phi, \lambda)_{IP}$ is input to plotboards).

If the vector input to the integrator is below drogue chute deploy, the impact points are set to present position latitude and longitude, and the reentry values are zeroed out. The integrator is not called to compute impact points, and range to impact is not computed. If data is missing, the computation of impact points and range to impact is bypassed.

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Time to free fall is computed by subtracting GMT from present GMTEI. A queue to the plotboard task is issued to update the plotboards with high-speed abort data. High-speed abort quantities are written on the log tape and in the table used as input to low-speed abort. The high-speed abort displays are then updated, and control is returned to the System.

High-Speed Abort D/TV Digitals and Analogs

Following is a list of displays and the quantities updated on a six-second cycle during high-speed abort.

MSK 0331 RFO Mode I and II Abort Digitals — The purpose of the RFO Mode I and II Abort Digitals is to provide digital data to monitor Mode I and II Aborts. The initial computations are based on the vector transferred from launch, and subsequent updates reflect the current ephemeris. The following quantities are computed by the integrator using zero lift for Mode I Abort and maximum lift for Mode II Abort:

$(\varphi, \lambda)_{IP}$

V_{EI}

γ_{EI}

GETEI

GETBOI

GETBOE

GETDD.

GETLC and GETMD are computed by adding specified constants to GETDD. The following quantities are also displayed: (1) MODE, (2) SELECTED SOURCE, (3) GET, (4) $(\varphi, \lambda)_{PP}$, and (5) h_0 .

MSK 0338 FDO Entry/Abort Interface Analog — The purpose of the FDO Entry/Abort Interface Analog is to display conditions of $(V, \gamma)_{EI}$ utilizing ΔV_{IP} . The computations will be initialized using the transferred vector. Updates will be on a six-second cycle reflecting the current high-speed ephemeris. The quantities plotted are $(\gamma \text{ vs } V)_{EI}$.

MSK 0333 T_{FF} vs R_{IP} Analog — The purpose of the T_{FF} vs R_{IP} Analog is to aid in the monitoring of the abort trajectory in Abort Mode II. This plot will be updated on a six-second cycle using the current ephemeris and will be frozen when $T_{FF} \leq 0$. The quantities plotted are T_{FF} vs R_{IP} .

MSK 1615 Mode I/Mode II Abort Phase/DS — The purpose of the Mode I/Mode II Abort Phase/DS is to provide the Tracking Data Select Controller with analog (h_0 vs V_E) and digital (h_0 , selected source) information concerning Abort Mode I and II trajectories. A nominal based on the transferred vector will be scribed at initialization, and updates will be on a six-second cycle. The digital update will reflect the current ephemeris, and the analog updates will be computed from the current short arc vectors, the APL vectors, and the current ship vector. There will be no extrapolation for mission data on the analog portion of the display. Refer to Figure 42 for display format.

Load Module Descriptions

The High-Speed Abort Output Task includes the following load modules.

LMXAINIT — The High-Speed Abort Output Initialization Load Module obtains the storage area and sets up the resource table for LTXHSABT, reads constants into the storage area, transfers control to the High-Speed Abort Nominal Control Load Module, LMSNCTRL, and sets up routing to the High-Speed Six Second Control Load Module, LMSACTRL.

LMSNCTRL — The High-Speed Abort Nominal Control Load Module controls the computation of high-speed abort nominal data at high-speed abort initialization.

LMSACTRL — The High-Speed Abort Six Second Control Load Module controls the computation and output of high-speed abort display parameters during the six-second cycle.

LMMAPPDS — The Present Position and Data Select Computations Load Module computes the latitude and longitude of present position, Earth relative velocity, the altitude above an oblate Earth for the last integrated vector, and the Earth relative velocity and height above an oblate Earth for each source.

LMXHSDTV — The High-Speed Abort D/TV Output Load Module displays nominals, transferred vector computations, and high-speed abort vector computations on a six-second cycle during high-speed abort.

LMXANDTV — The High-Speed Abort D/TV Format Load Module formats commands for D/TV from a nominal ephemeris.



RMMYNI — The Reentry Runge-Kutta Numerical Integrator Load Module integrates a vector up to present GMT and computes entry interface and impact parameters.

WMMILPHV — The Nominal Trajectory Calculations Load Module calculates the altitude above an oblate Earth and the Earth relative velocity for an ephemeris generated from the transferred vector.

WMSSUPER — The Plotboard Supervisor Load Module initializes the plotboards with nominal data and updates the plotboards on a six-second cycle during high-speed abort.

Six Second Control

Section of LTXHSABT

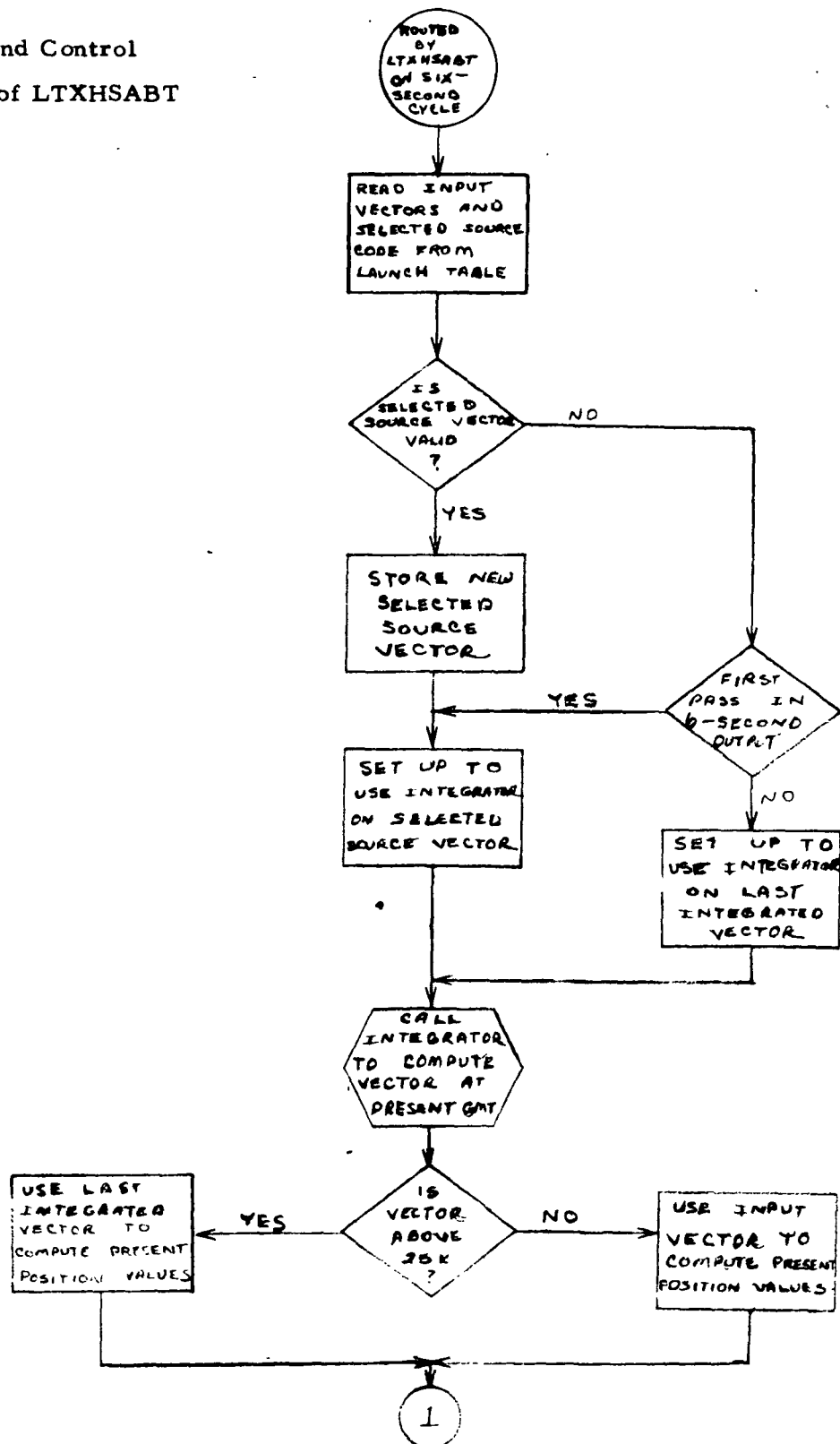


Figure 38. High-Speed Abort Phase Flowchart

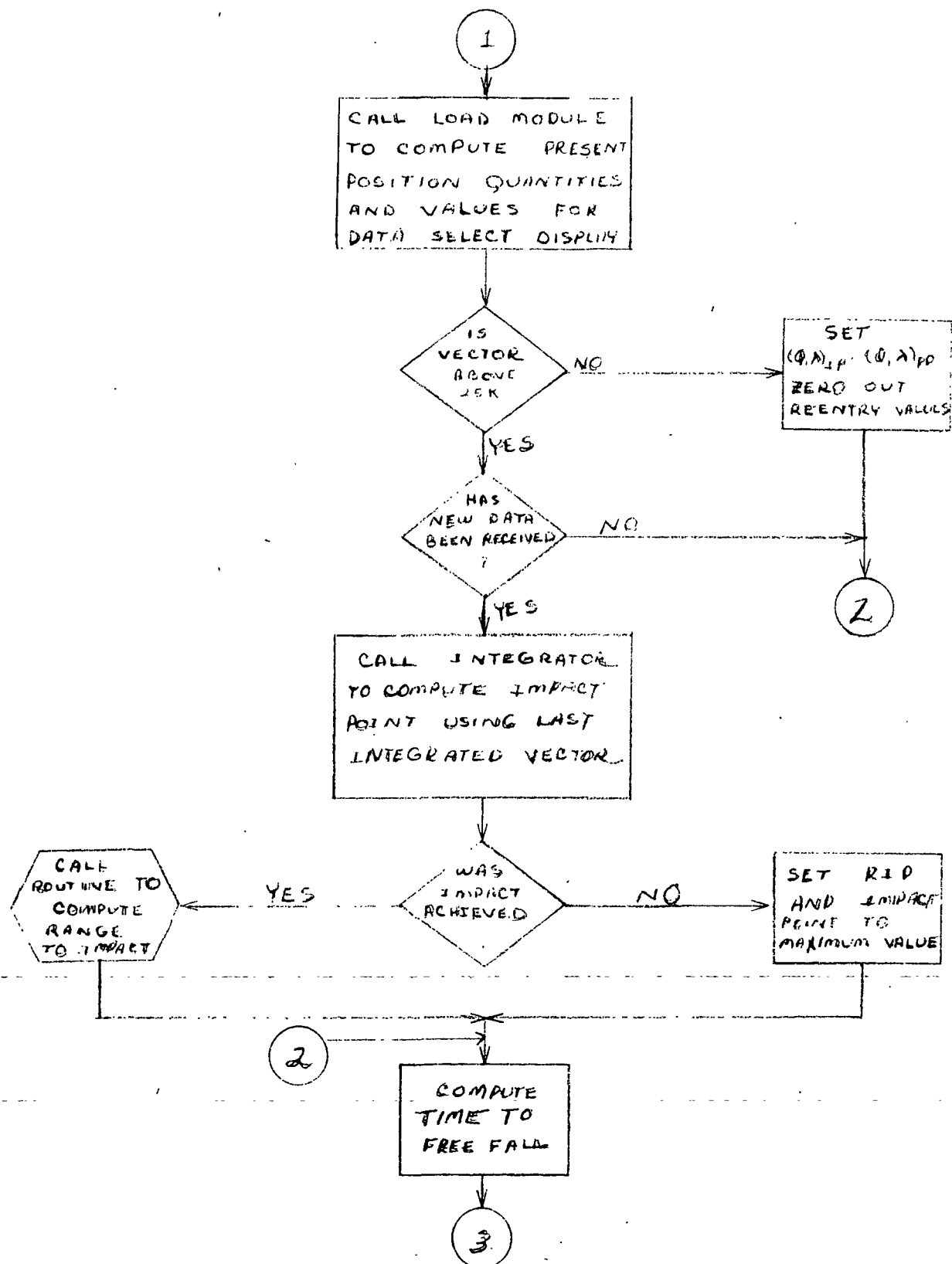


Figure 38. High-Speed Abort Phase Flowchart

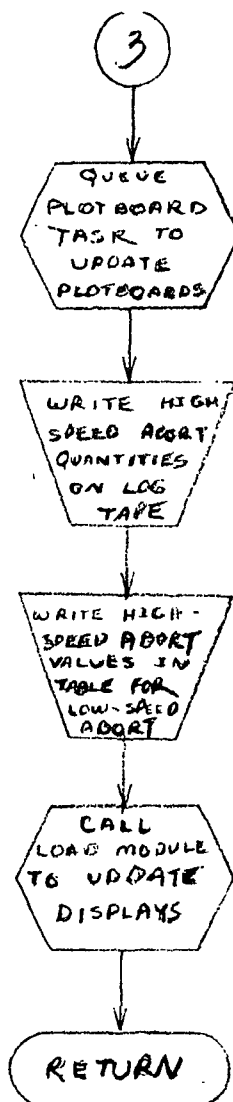


Figure 38. High-Speed Abort Phase Flowchart

```

LM039 A bbbbbb RFO MODE V/I ABORT DIGITALS ■■■■ 0331 ⊕
MODE ■■■■ GET ■■■■ NO NO
TRANSFERRED HIGH LOW
VECTOR SPEED SPEED
TYPE ■■■■ ■■■■ ■■■■
φW ■■■■ ■■■■ ■■■■
λW ■■■■ ■■■■ ■■■■
hW ■■■■ ■■■■ ■■■■
θW ■■■■ ■■■■ ■■■■
λW ■■■■ ■■■■ ■■■■
GETE ■■■■ ■■■■ ■■■■
GETRO ■■■■ ■■■■ ■■■■
GETBO ■■■■ ■■■■ ■■■■
GETDO ■■■■ ■■■■ ■■■■
GETMD ■■■■ ■■■■ ■■■■
GETLC ■■■■ ■■■■ ■■■■
VF ■■■■ ■■■■ ■■■■
YF ■■■■ ■■■■ ■■■■
⊕

```

Figure 39. RFO Mode I/II Abort Digitals



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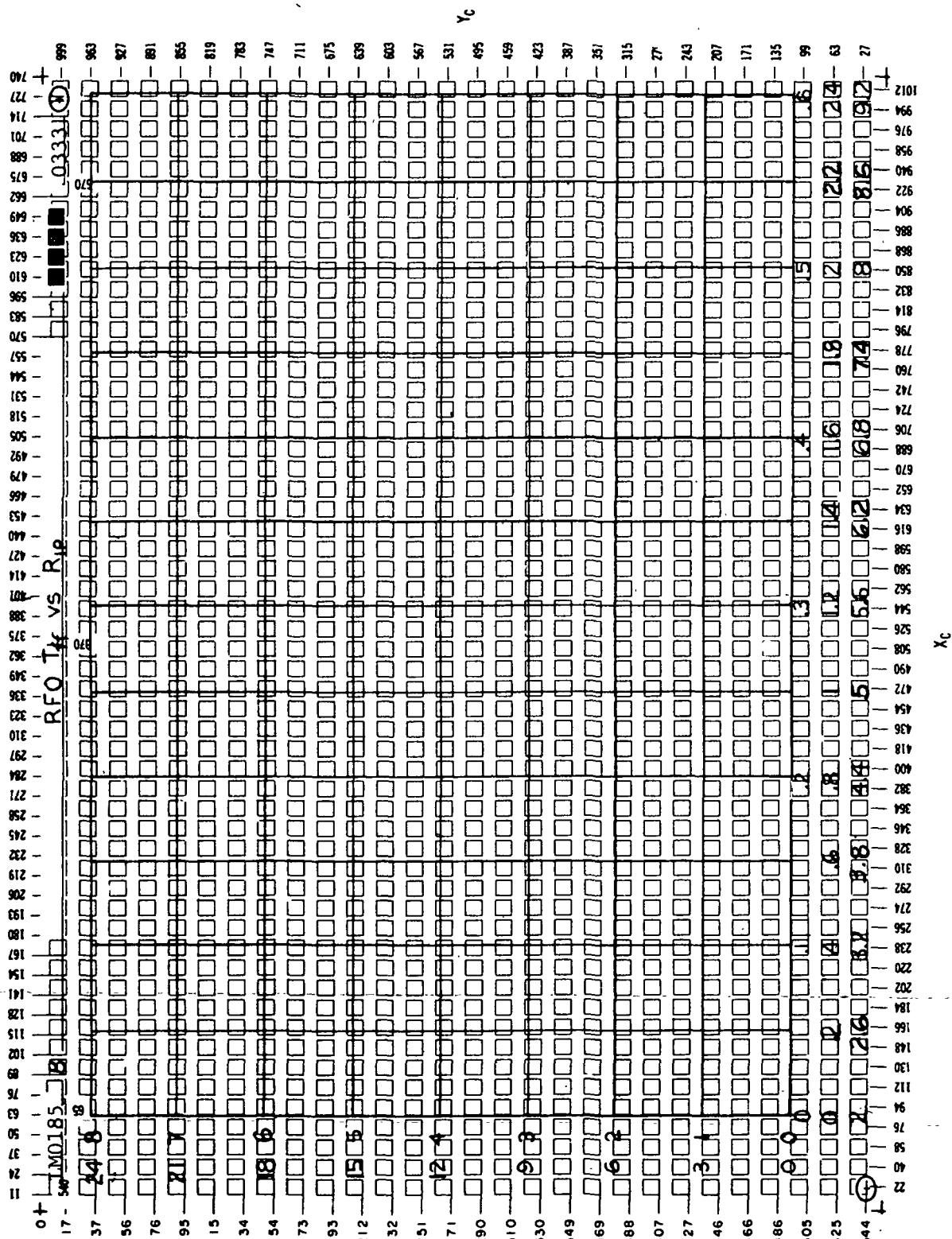


Figure 41. RFO T_{ff} vs. R_{IP}



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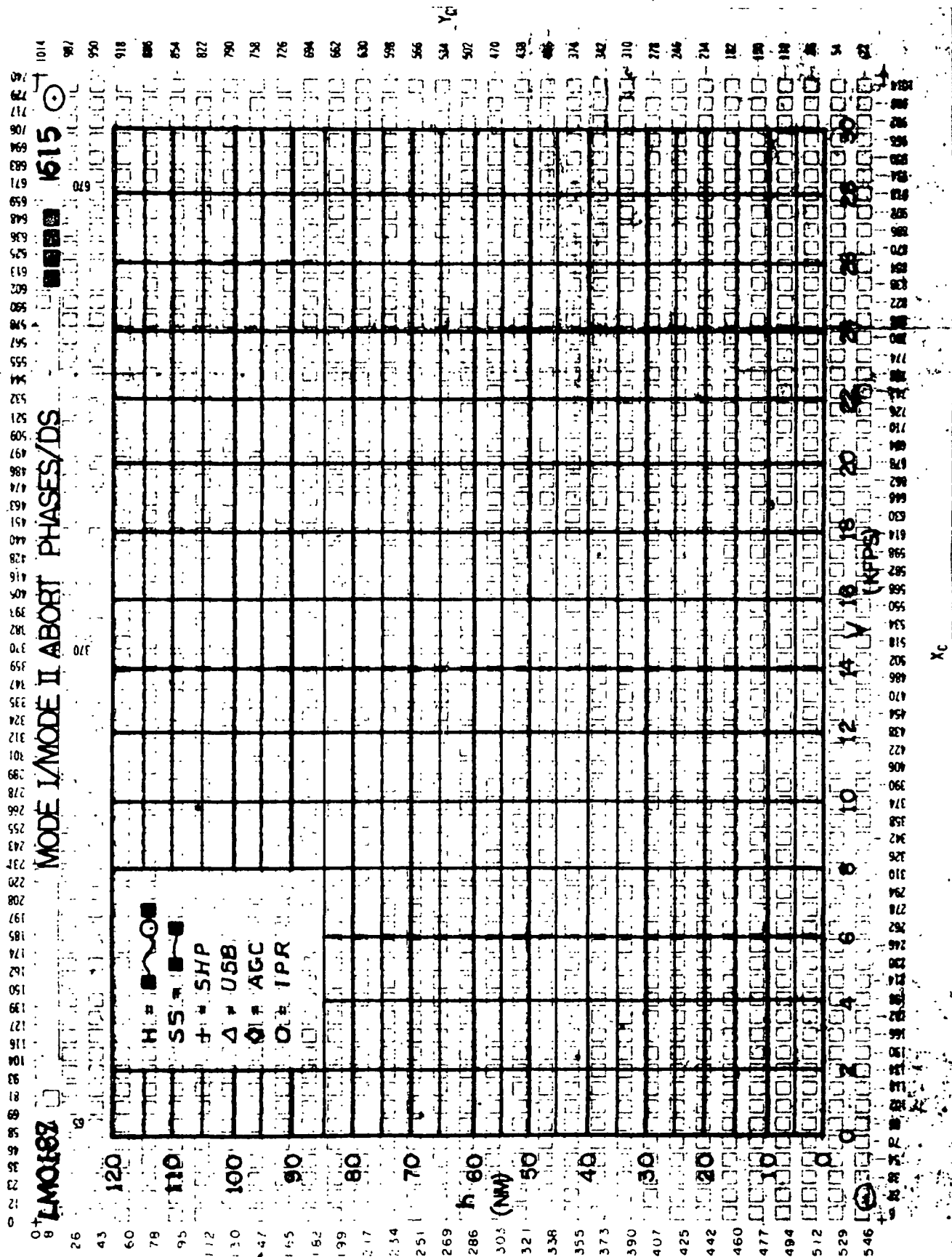


Figure 42. Tracking Data Select

LTHIGH (HIGH-SPEED ORBIT TASK)

The purpose of this task is to process high-speed radar and telemetry data during the orbit phase. Using this data, it calculates present position-velocity vectors from which related information is displayed.

Prior to receipt of high-speed data, high-speed nominals are drawn by request from an S61 MED input with lunar or Earth reference indication. This input requests nominals to be drawn for one, two, or three maneuvers for a particular device (digital, analog, and/or plotting device). The logic for the request is handled by the High-Speed Display Controller Module. Nominal values themselves are calculated by the Maneuver Nominal Generator and the High-Speed Output Calculator Modules using the required and spherical values, which place tables of values in the corefile and return. The High-Speed Display Controller Module then queues the module which is to update displays per controller request. This module is the High-Speed Orbit D/TV Display Module. If plots are required, a queue is also made to that task.

When it is desirable to monitor high-speed data, a P60 START MED for lunar or Earth reference is entered by the controller to initiate the handling of data on a one-second cycle for a particular vehicle and for a particular set of stations. This MED is processed by the Orbit High-Speed Control Module which then initiates high-speed parameters and sets up the proper routing queue. Subsequently, high-speed messages are sent to one of several input modules, each of which checks the data for validity, unpacks it, converts it to proper RTCC units, and presents it to the Edit Module for processing. All input modules are identical with those used in launch phase except for the High-Speed Orbit Input Module which handles land-based C-Band data. Also, the Edit, Smoothing, and Short-Arc Modules are identical to the ones used in launch for the same functions.

Once vectors have been computed by Smoothing or Short Arc, the Orbit High-Speed Vector Input Module is queued on the one-second time cycle. This module tests indicators, (both radar and telemetry), to determine which data sources are to be used. The radar vector is printed at ten-second intervals. In addition, both telemetry and radar vectors are converted to display units by the High-Speed Output Calculator Module using the required and spherical radius. Control is then passed to the High-Speed Display Controller Module, which performs essentially the same work for present position updates of digital-TV's and plotboards that it performs for nominal updates (queuing the High-Speed Orbit D/TV Display Module and the plotboard task).

Other entries of the P60 MED (e.g., those that change the radar data to be viewed or stop the viewing of high-speed data) are processed by the Orbit High-Speed Control Module which changes routing queues accordingly. When in the lunar reference system, only TLM data will be processed and a P60 change MED is not valid.

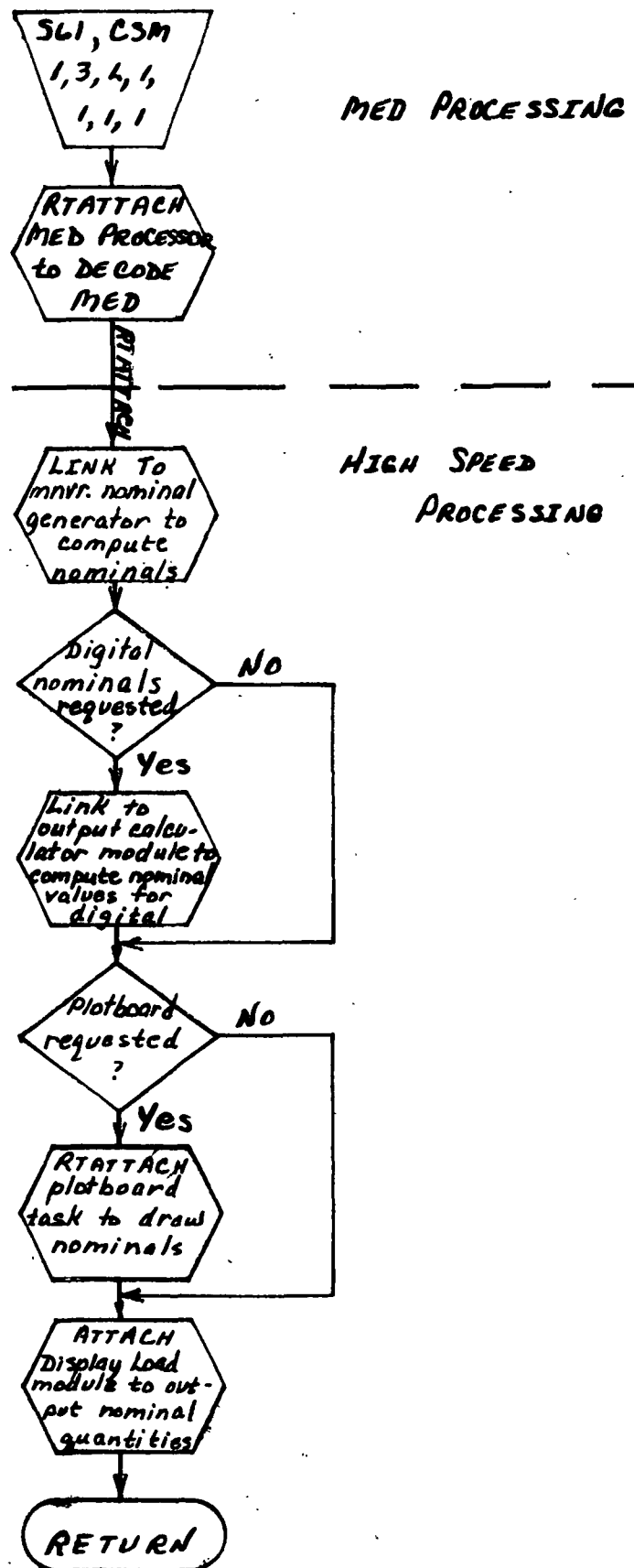


Figure 43. High-Speed Orbit Task Flowchart

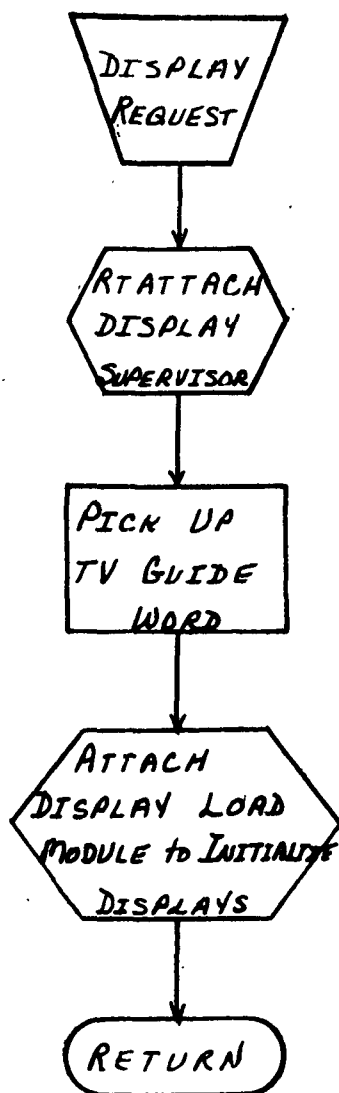
HIGH SPEED ORBIT

Figure 43. High-Speed Orbit Task Flowchart

(Sheet 2 of 5)

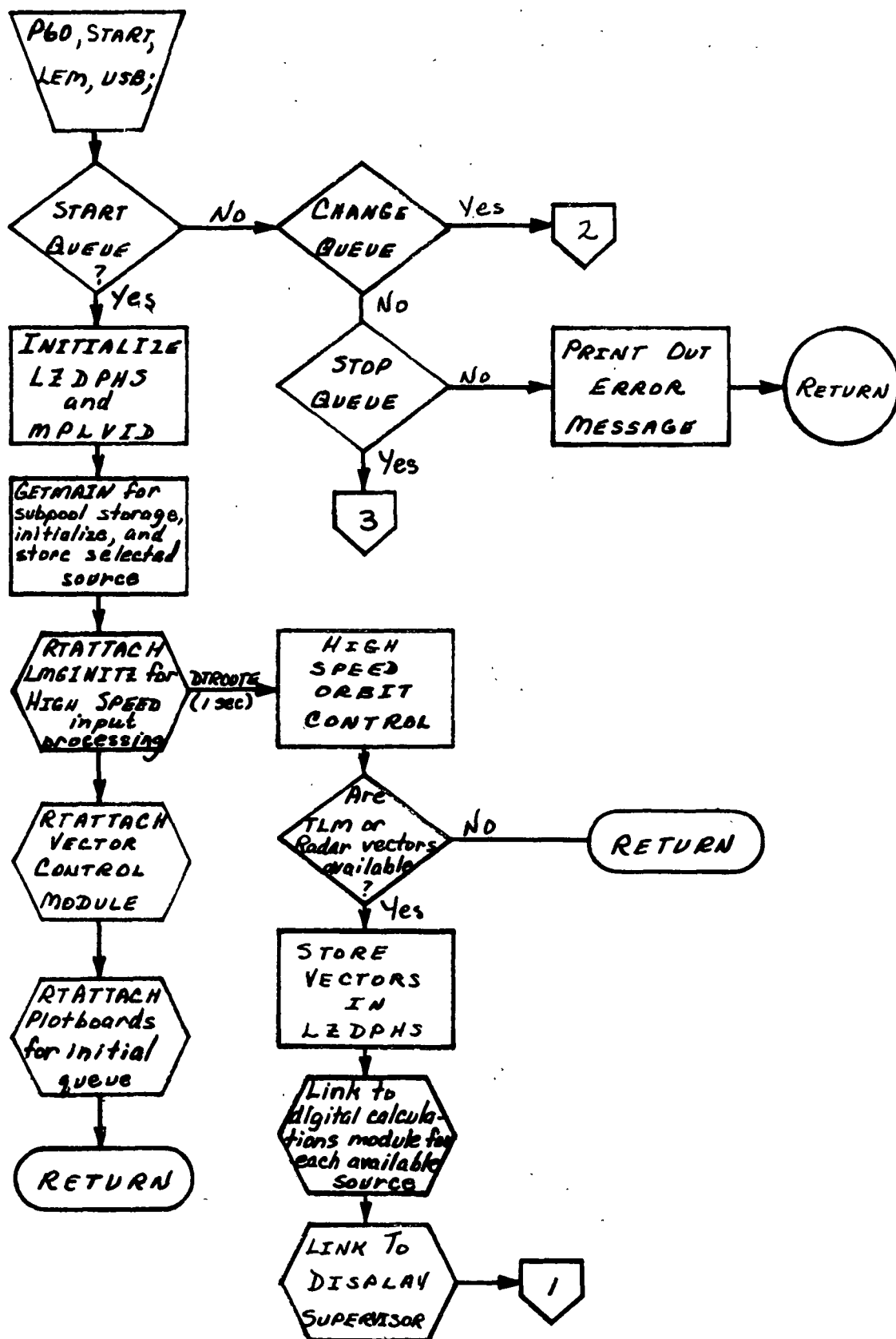


Figure 43. High-Speed Orbit Task Flowchart

(Sheet 3 of 5)

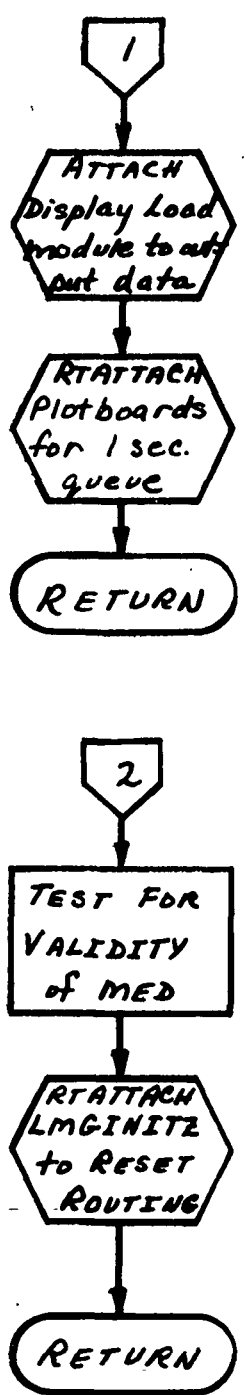


Figure 43. High-Speed Orbit Task Flowchart

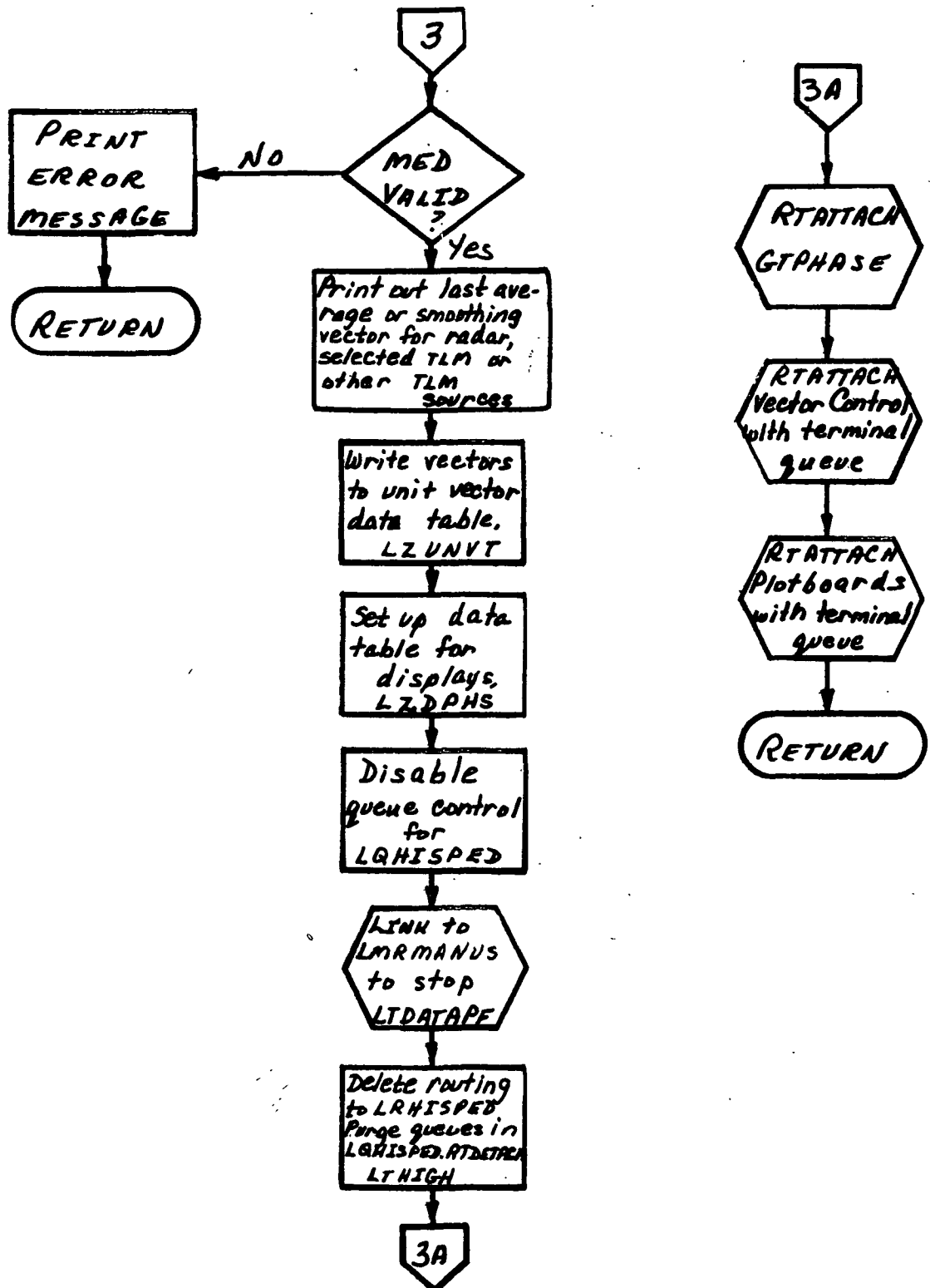


Figure 43. High-Speed Orbit Task Flowchart

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Table 3. Interfaces Between High-Speed Task and Other Tasks

<u>FROM</u>		<u>TO</u>		<u>PURPOSE</u>
<u>TASK</u>	<u>MODULE</u>	<u>TASK</u>	<u>MODULE</u>	
GTGMED	GMGMED	LTHIGH	LMSHSDS	MED to generate man- euver nominal
	RFFDPHTV	LTHIGH	LMSHSDS	MSK to generate dis- play
GTPHASE	GMSMED	LTHIGH	LMQHIGHS	Set up high-speed routing
GTPHASE	GMSMED	LTHIGH	LMQHIGHS	Change telemetry ref- erence times
LTHIGH	LMQHIGHS	LTDATAPH	LMRMANU4	Change telemetry ref- erence times
LTHIGH	LMQHIGHS	WTPIPTSK	WMSSUPER	Condition plotboards for high-speed plots
LTDATAPH	LMGINITZ	LTHIGH	LMQHIGHI	One-second time only queue
LTHIGH	LMSHSDS	WTPIPTSK	WMSSUPER	Generate plots
LTHIGH	LMQHIGHS	LTXPRNTR	LMXPRNTR	Print error messages
LTHIGH	LMQHIGHI	LTXPRNTR	LMXPRNTR	Print error messages
LTHIGH	LMQHIGHS	LTXPRNTR	LMXHSPTR	Print vectors on-line
LTHIGH	LMQHIGHI	LTXPRNTR	LMXHSPTR	Print vectors on-line

Load Modules Functionally Related to High-Speed Task

LMXQDTV - The High-Speed Orbit D/TV Display Module formats nominal and present position data for the following displays: (1) FDO Maneuver Monitor Table, (2) In-Plane Maneuver Monitor, (3) Out-of-Plane Maneuver Monitor, (4) Maneuver Safety Monitor.

LMMMMDP- High-Speed Output Calculator Module receives a position-velocity vector and from this calculates such quantities as velocity, flight-path angle, heights of apogee and perigee, time and longitude or perigee, and latitude and longitude of entry interface. Either the μ or spherical radius for the lunar or Earth reference system will be used.

LMMNFM - Maneuver Nominal Generator Module computes nominal values for as many as three maneuvers. Tables of values are calculated for height of apogee, height of perigee, velocity, flight-path angle, velocity normal to the target plane, elapsed time from maneuver initiate, velocity at perigee, and wedge angle.

LMQHIGHI - Orbit High-Speed Vector Input Module receives vectors from ZLNPUT and determines which vectors are to be displayed. It calls BMMMMDP for the calculation of desired parameters, prints on-line quantities, and passes control to BMSHSDS.

LMQHIGHS - Orbit High-Speed Control Module receives the P60 MED and determines what course of action is to follow. The module then sets indicators that will control functions performed by BMQHIGHI.

LMSHSDS - Orbit High-Speed Display Controller Module contains the logic to control the calculation of high-speed nominals and the display of high-speed nominals and present position radar and telemetry values.

LTXZSHEL (HIGH-SPEED DELOG TASK)

The purpose of the High-Speed Delog Task is to provide the post-flight processing required from the Launch/Abort Group and to provide information helpful in the checkout of the Launch/Abort programs. The task gets its inputs from a log tape. It may provide the following outputs from a log tape.

1. Input vectors and selected source calculations can be listed for the Launch and High-Speed Abort Phases.
2. Input vectors can be listed for the High-Speed Orbit Phase.
3. A NASA trajectory tape can be generated from the input vectors in the Launch, High-Speed Abort, and High-Speed Orbit Phases.
4. Input vectors can be punched in cards for the Launch, High-Speed Abort and High-Speed Orbit Phases.
5. A listing of the Hold Phase calculations can be generated.
6. A listing of High-Speed Raw Radar points can be generated.
7. A listing of IU and AGC input data may be generated (input data as received by the High-Speed Input Program).

The Delog Task may operate as a job shop program or provide background delogging during a checkout run. As a job shop program, the Delog Task receives its delog options through input cards or the typewriter. For background delogging, the options are entered via MED's. The task may also provide vector tapes and punched vectors from a simulation trajectory tape and a GSSC tape.

Load Module LMXZSHEL

This load module consists of the following control section.

LCXZSHEL — This control section is the task supervisor. It interprets the input options, does error checking, obtains input records from a LOG tape for the processing programs, calls the processing programs and terminates the job.

LCXZINPT — This control section provides the input vector listings, the selected source calculations listing for the launch phase and the NASA trajectory tape.

LCXZHLDS — This control section provides the listing of hold phase calculations.



LCXZEDIT — This control section provides the listing of raw radar data and IU, AGC input data.

LCXALIST — This control section provides the listing of the high-speed abort phase selected source calculations.

LCPUNCH — This control section punches vectors in cards.

LCXZPN — This control section opens output data sets for listings.

LCXZPR — This control section is used to write all listings.

LCXZCL — This control section closes output data sets for listings.

LCTRAJTY — This control section reads a simulation trajectory tape; it may write a vector tape or punch vectors in cards.

LCPUTT — This control section reads a GSSC tape and writes a vector tape.

LCGSSC — This control section rotates and converts the units of the GSSC of USB input messages.

LCXZIDFL, LCXZHDFL, LCXZEDFL — These control sections contain DFL language format statements for the listings generated by LCXZINPT, LCXZHLDS, and LCXZEDIT.

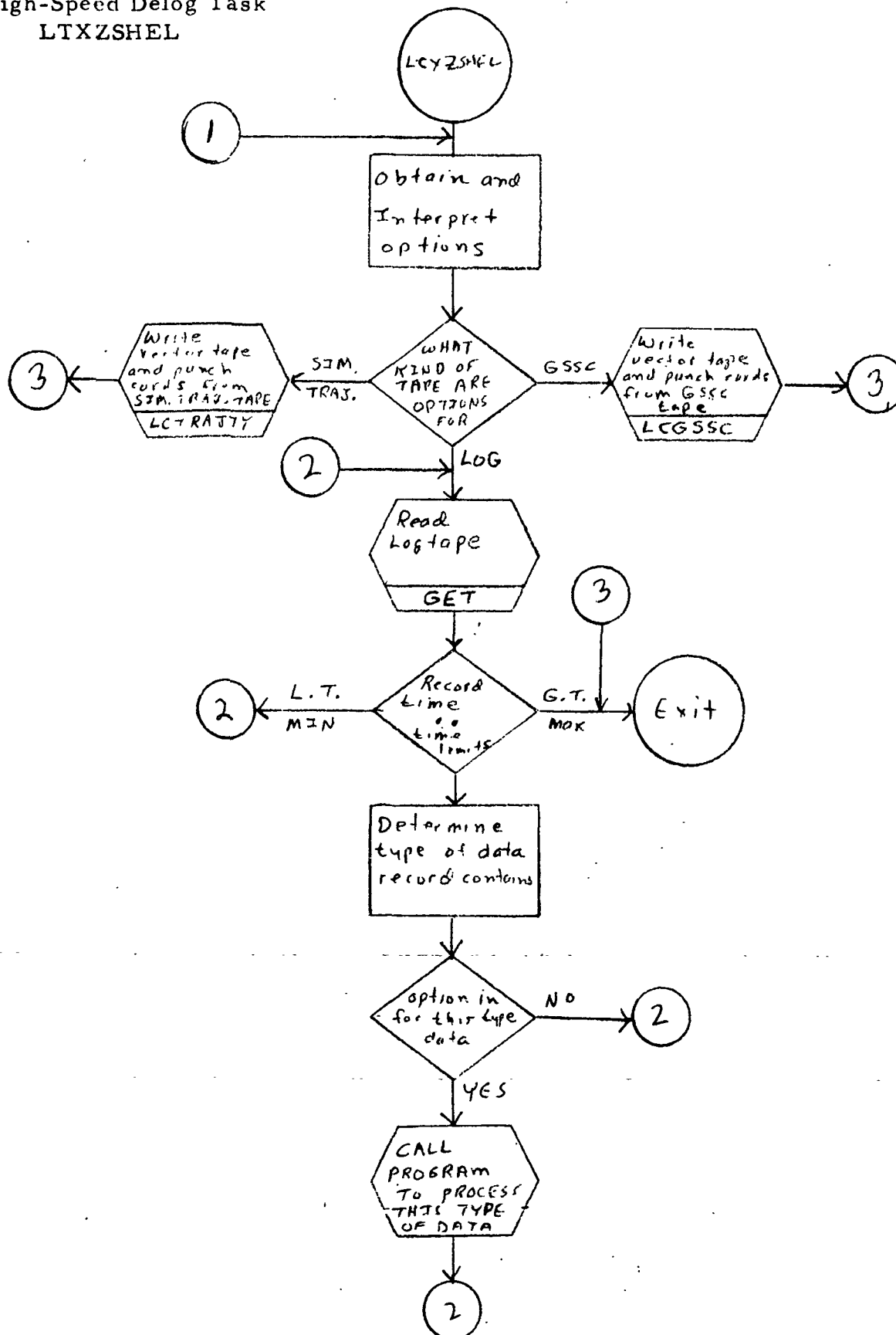
High-Speed Delog Task
LTXZSHEL

Figure 44. Job Shop Package LTXZSHEL Flowchart

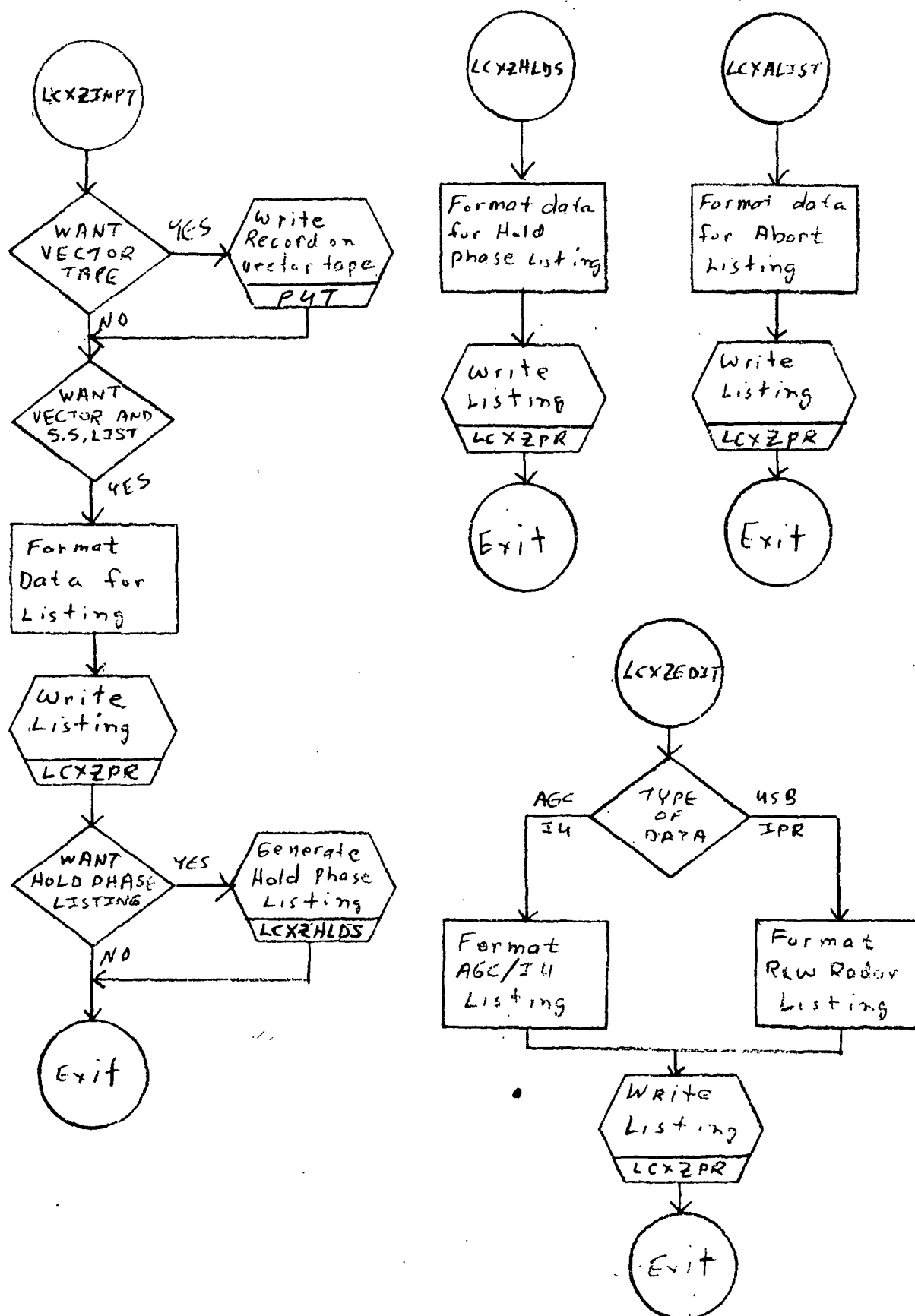


Figure 44. Job Shop Package LTXZSHEL Flowchart

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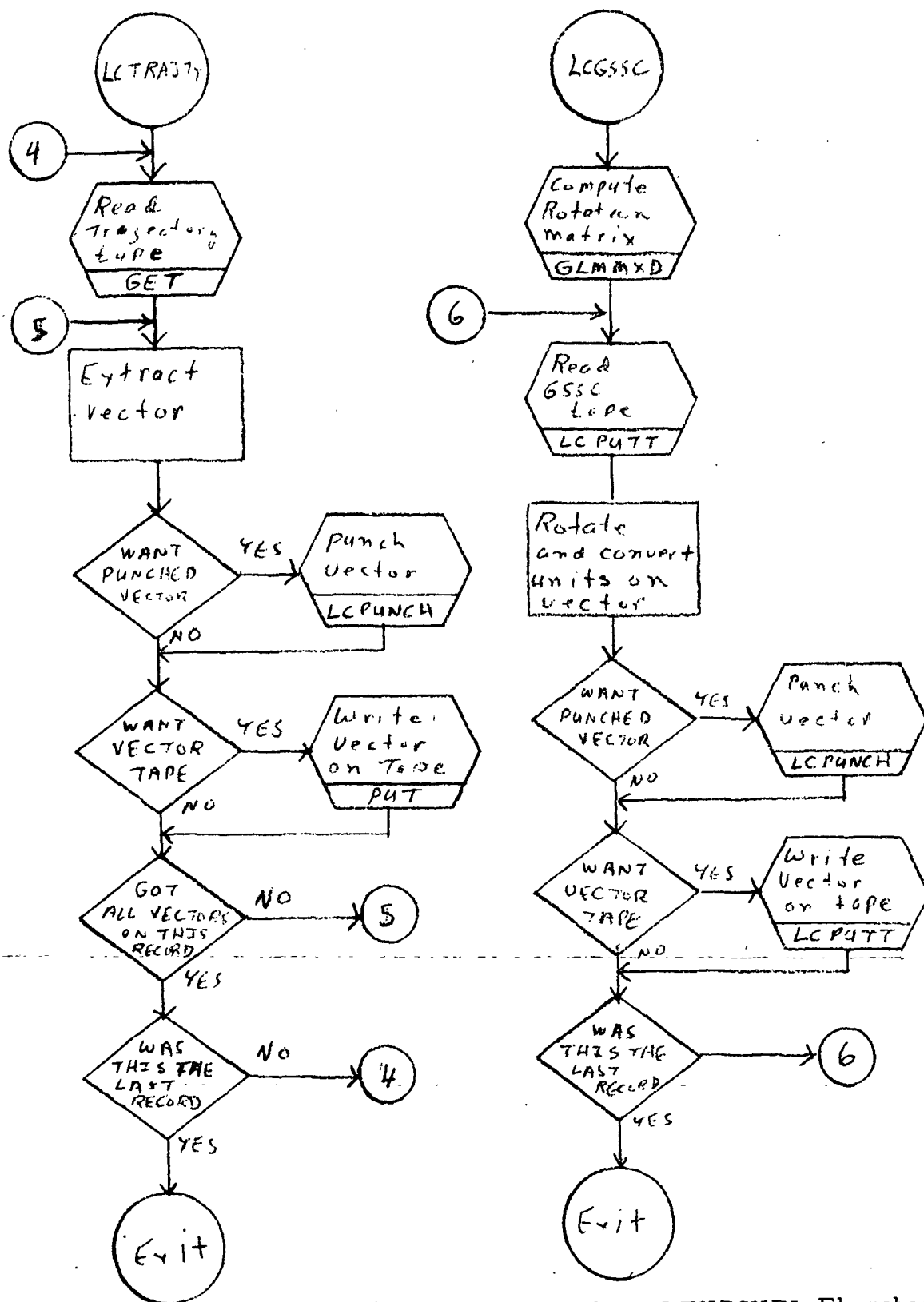


Figure 44. Job Shop Package LTXZSHEL Flowchart

QTMFIT (IMPACT PREDICTOR DATA GENERATION AND CURVEFIT TASK)

The data generation and curvefit load module does not execute as a part of the real time system. Its purpose is to generate basic correction, weight correction, argument of latitude correction, inclination correction, and fictitious altitude (with an associated time correction) correction data. The generated data is used to derive the polynomial coefficients that are used in the real time system for the curvefit impact point prediction during CSM powered flight.

Load Module QMMFIT

The Load Module, QMMFIT, consists of the control sections described below.

QCMFIT — This module determines the job type, calls control section to perform the job, and terminates the job.

QCSKIP — QCSKIP generates a data tape containing the variables necessary to do skip-out velocity and V_{g0} curvefits.

QCDGBW — This module generates a data tape containing the variables necessary to do basic and weight correction curvefits.

QCDGUI — QCDGUI generates a data tape containing the variables necessary to do inclination and argument of latitude correction curvefits.

QCDGFA — This module generates a data tape containing the variables necessary to do a fictitious altitude curvefit.

QCSFIT — QCSFIT is a single variable curvefit section which generates coefficients using the variables from the data tapes generated by other control sections of this load module. This control section also punches and tests the adequacy and reliability of the coefficients.

QCDFIT — This module is a double variable curvefit section which generates coefficients using the variables from the data tapes generated by other control sections of this load module. This control section also punches and tests the adequacy and reliability of the coefficients.

QCINTL — This module generates a family of position vectors at entry interface.



QCINGR — QCINGR sets up input parameters to the numerical integrator, calls it and uses its output to compute the down-range angle, cross-range angle, and time of fall.

QCNIGR — QCNIGR sets up input parameters to the numerical integrator and calls it to compute the geodetic latitude of impact, geodetic longitude of impact, GMT of impact, and the position vector at impact.

QCREAD — QCREAD obtains an impact vector from a NASA trajectory tape.

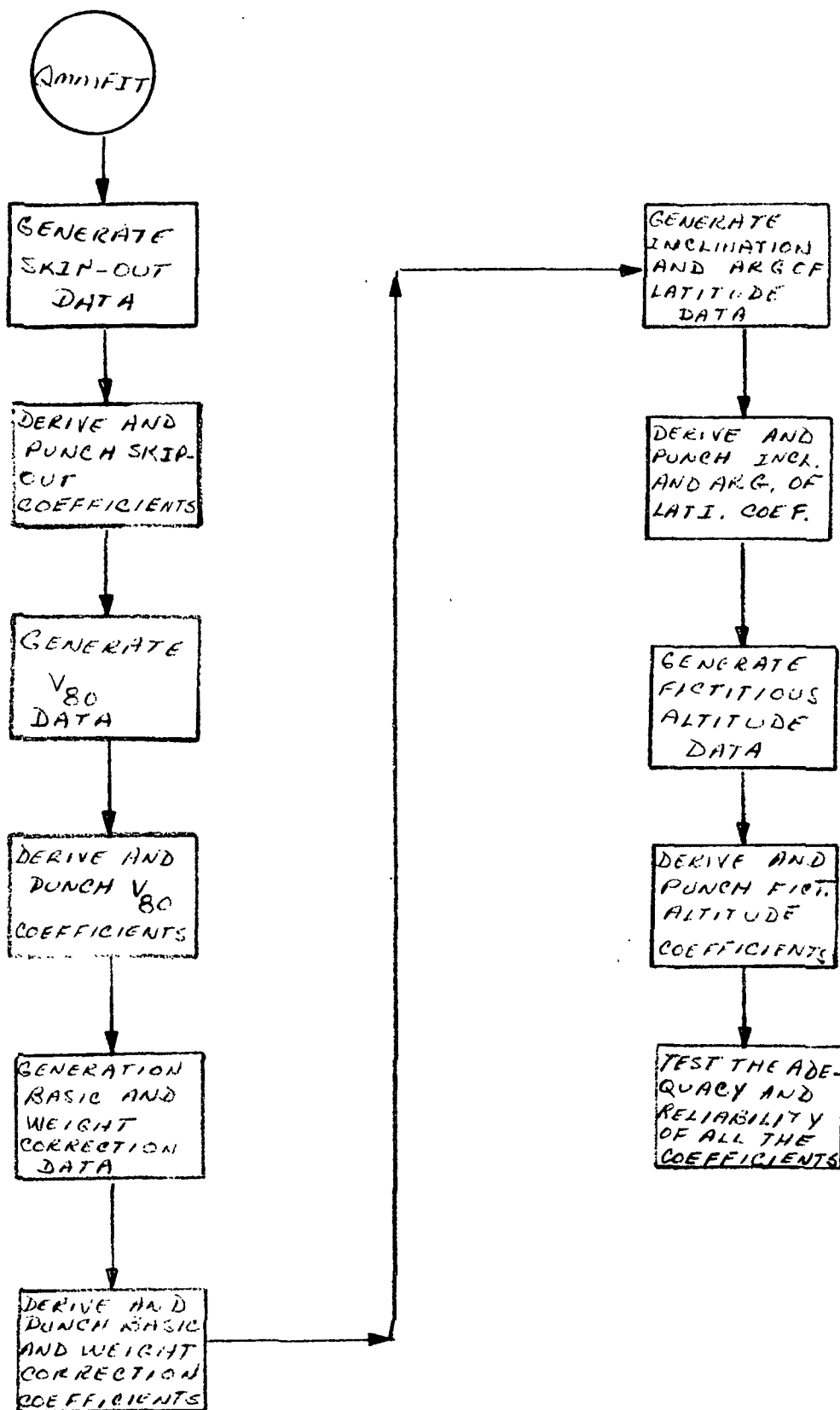


Figure 45. Impact Predictor Data Generation and Curefit Task Flowchart

GLOSSARY OF TERMS

<u>Term</u>	<u>Definition</u>
1. AB Mode	Computer-recommended abort mode
2. *	An * will be output for any parameters that cannot be computed for any reason other than no data.
3. d	Downrange distance (nm) arc length
4. DATA POINTS	Actual number of points used in average solution or effective number of data points considering the relative weighting of the radar sources for short-arc solutions.
5. δ	Wedge angle ($\cos \delta = \hat{i}_c \cdot \hat{i}_d$)
6. ΔT_{EI}	Freefall time (hr:min:sec) to entry interface from GETCO (GETEI-GETCO)
7. Δt_{ins}	Burn duration (min:sec) associated with ΔV_{ins-c} ; time is from SPS ON to SPS OFF.
8. ΔV_{INS-C}	The total velocity increment (fps) including ullage along the spacecraft X-axis
9. ΔT_{IP}	Duration (min:sec:sec/tenth) of SPS burn associated with ΔV_{IP} displayed for the same data as ΔV_{IP}
10. ΔV_{IP-C}	Velocity increment (fps) required from the SPS burn for Mode III Abort; will be either a posigrade (+) or a retrograde (-) burn, and will include ullage, SPS burn, and no tailoff; velocity increment is along the spacecraft X-body axis.
11. γ	Inertial flight-path angle (deg) preburn vector
12. γ_{EI}	Inertial flight-path angle (deg) of spacecraft at entry interface (Mode II only)
13. $\gamma_{EI}(\Delta V_{IP})$	Inertial flight-path angle (\pm deg) at EI based on selected source trajectory data and ΔV_{IP}

GLOSSARY OF TERMS, (Cont.)

<u>Term</u>	<u>Definition</u>
14. γ_i	Current inertial flight path angle (deg)
15. GET	Ground elapsed time (min:sec) from liftoff
16. GET_A (GMT_A)	Elapsed time (min:sec) from liftoff to apogee
17. GETBOE	GET (hr:min:sec) of blackout exit
18. GETBOI	GET (hr:min:sec) of blackout initiate (Mode II only)
19. GETCO ($GMTCO$)	GET (hr:min:sec:sec/tenth) of SPS landing area control burn cutoff ($GETPI$ plus ΔT_{IP})
20. GETDD	GET (hr:min:sec) of drogue chute deploy
21. $GETEI$ (ΔV_{IP})	GET of entry interface based on selected source trajectory data and V_{IP}
22. * $GETEI$ (* $GMTEI$)	GET of entry interface based on selected source trajectory data and no SPS burn
23. GETI	GET (min:sec) of the initiation of the insertion burn. S-IVB or SPS cutoff plus fixed Δt
24. GETMD	GET (hr:min:sec) of main chute deploy
25. $GETPI$ ($GMTPI$)	GET (hr:min:sec:sec/tenth) of SPS landing area control burn ignition (S-IVB or SPS cutoff plus a fixed Δt)
26. GMT	Greenwich Mean Time as maintained in the computer
27. GMTGRR	Greenwich Mean Time (hr:min:sec:sec/hundredth) of guidance reference release
28. GMTLO	GMT (hr:min:sec) of liftoff as maintained in the computer
29. GMTZS	Greenwich Mean Time of zero setting of the spacecraft clock

GLOSSARY OF TERMS, (Cont.)

<u>Term</u>	<u>Definition</u>
30. GO/NO-GO Recommendation	GO or NO-GO based on V_s . If $V_s \leq 0$, GO is recommended; if $V_s > 0$, NO-GO is recommended.
31. h	Current radial velocity (fps) ($V \sin \gamma$)
32. h_o	Height (nm) above an oblate Earth
33. h_s	Current spherical altitude (nm)
34. h'_s	Altitude (nm) above spherical Earth (Cape pad 34 radius) preburn vector
35. \hat{i}_C	Unit vector of (T, R, V) _C (current)
36. \hat{i}_O	Unit vector of (T, R, V) _D (desired insertion vector)
37. $P_i(\Delta V_{INS-C})$	IMU inner gimbal angle relative to the nav base for V_{INS-C} maneuver
38. $P_i(\Delta V_{IP})$	Euler spacecraft attitude pitch (deg)
39. $(\varphi, \lambda)_{IP}(\Delta V_{IP})$	Latitude and longitude (deg and min) of the predicted impact point based on selected source trajectory data and ΔV_{IP}
40. $(\varphi, \lambda)_{MX}$	Latitude and longitude (deg and min) of the predicted impact point during powered flight and the integrated IP following S-IVB cutoff
41. $(\varphi, \lambda)_{PP}$	Latitude and longitude (deg and min) of present position impact point
42. R_{IP}	Range to the predicted impact point (nm)
43. $R_o(\Delta V_{IP})$	Euler spacecraft attitude roll (deg)



GLOSSARY OF TERMS (Cont.)

<u>Term</u>	<u>Definition</u>
44. Selected Source	Trajectory data source as selected by data select (SAT, APL, IPS, IPR, USB, SHP)
45. T_E	Ground elapsed time
46. T_{ff}	Freefall time (min:sec) to go to entry cutoff
47. T_{go}	IU time (min:sec) to go to S-IVB cutoff
48. TYPE	Type of radar; may be C or S for the ship, but will not be displayed for CRDR and SRDR
49. V'	Inertial velocity (fps)
50. V_1	V_{CR} minus the velocity perpendicular to the pitch plane of the S-IVB due to the Earth's rotation
51. V_{CR}	Vehicle velocity component (fps) perpendicular to the pitch plane of the S-IVB
52. V_E	Earth relative velocity (Tfps)
53. V_{EI}	Inertial velocity (fps) of spacecraft at entry interface (Mode II only)
54. $V_{EI} (\Delta V_{IP})$	Inertial velocity (fps) at EI based on selected source trajectory and ΔV_{IP}
55. V_G	SPS velocity (fps) to be gained for orbital insertion maneuver
56. V_s	Current inertial velocity (fps)
57. \overline{V}_{LO}	Inertial velocity of pad at liftoff
58. V_s	V_{ps} minus current inertial velocity (fps)

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GLOSSARY OF TERMS (Cont.)

59. V/V_{PS} The ratio of inertial velocity to the inertial velocity required to achieve minimum vacuum perigee
60. $Y_m (\Delta V_{IP})$ Euler spacecraft attitude yaw (deg)
61. GMT300 GMT time to 300K
62. AREA Target for Mode III Abort computations:
III - Atlantic Ocean
IB - Indian Ocean
63. V_i Current velocity computed from hold phase GO/NO GO recommendation vector (ft/sec)
64. γ_i Current flight path angle computed from hold phase GO/NO GO recommendation vector (deg)
65. $(\gamma, V)_{EI}$ (zero burn) Zero burn points of velocity and flight-path angle obtained from hold phase (deg, ft/sec)

2.2.7 ORBIT TRAJECTORY COMPUTATIONS FUNCTIONAL
SPECIFICATIONS FOR THE MISSION SYSTEMS
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ORBIT TRAJECTORY COMPUTATIONS FUNCTIONAL
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INTRODUCTION

The Orbit Trajectory Computations Subsystem consists of four functional units: ephemeris generation and control, station contacts, evaluation displays, and guidance optics and sighting.

An ephemeris is maintained for two vehicles to be used in all calculations requiring an integrated prediction of vehicle position and velocity. The vector used in generating the ephemeris may be obtained from the Trajectory Determination Subsystem, Telemetry Subsystem, Launch Subsystem, and/or may be manually entered by the controller.

Information relevant to radar stations time and duration of track will be computed and formatted for teletype transmission to the tracking network.

Parameters required for in-flight evaluation and decision making during orbital and lunar stay phases will be computed and displayed. Data of this nature will be presented on the TV system in digital formats and will be updated on a cyclic or demand basis.

The various representations of vehicle platform alignments will be provided for astronaut assistance in the use of platform alignment checks, vehicle body alignment checks, and celestial and Earth sighting experiments. These various representations of platforms will be mathematically simulated, retrieved via telemetry from the on-board system or manually entered by a controller.

For the purpose of providing a meaningful presentation of each functional unit within the subsystem as well as providing a meaningful test base, each unit has been divided into logical elements (a collection of programs that performs a specific function). The respective functional units will provide a statement regarding the scope of the unit and will define the logical elements contained within it. The following sections will be discussed in each logical element.

- Function of the Element
- Load Module/Subroutine Descriptions

Approval	Approval
<i>P. J. Pollack</i>	<i>J. M. Kelly</i>

- Requirement Interpretations

Included within this section are reproductions of requirement sources with the corresponding interpretation. Where necessary, specific deletions and deviations from published requirements are cited as well as program design limitations.

- Functional Diagrams

In this section, diagrams are provided that illustrate interfaces with other subsystems and units, data flow, frequency of calculations, time queues, data queues, etc. (Refer to the Glossary for the key to logical element diagrams.)

- Input/Output Specifications

Included in this section are MED formats, on-line prints, display formats, teletype formats, etc. The on-line prints and error messages presented on the respective displays represent the best information available.



ORBIT TRAJECTORY COMPUTATIONS FUNCTIONAL
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EPHEMERIS GENERATION AND CONTROL UNIT

SCOPE

The Ephemeris Generation and Control (EGC) Unit mainly predicts the vehicle trajectory, maintains a table of vectors representing the predicted trajectory, and informs other units and subsystems when the predicted trajectory has been updated. It provides control logic to ensure that other units do not reference inconsistent data when the trajectory is being updated and maintains a table of history anchor vectors. In addition, the EGC unit maintains a table of present position information that is updated every twelve seconds and transmits trajectory related data via teletype to offsite locations as well as the Real Time Auxiliary Computing Facility (RTACF).

The EGC unit is composed of the following logical elements.

1. Queue Control and Anchor Vector Maintenance
2. Time Queue Control
3. Trajectory Update Control
4. Numerical Integration Control
5. Teletype Transmissions and Special On-Line Prints

QUEUE CONTROL AND ANCHOR VECTOR MAINTENANCE ELEMENT

Function

This element is composed of two programs, the Queue Control Processor, EMSCTRL, and the Anchor Vector Maintenance program, EMGVECST. These programs provide the necessary control logic to prevent simultaneous processing of certain functions that can adversely affect each other and provide a table of history anchor vectors to be used for maneuver confirmation. In general it can be said that EMSCTRL contains the control logic, and EMGVECST maintains the table of history vectors. However both programs are required for performing certain functions, and there is a two-way communication between them. The two functions mentioned above and other special functions will be discussed separately.

Load Modules/Routines Description

Queue Control Logic - EMSCTRL

The control technique exercised by EMSCTRL is basically one of enabling and disabling queue control blocks. Since EMSCTRL was designed to handle a large number of queue control requests, it is not feasible to discuss each queue separately. Instead, the queue requests have been broken into four groups. The first two groups cause a trajectory update or modify the Mission Plan Table (MPT). The third group is composed of "permission-to-process" queues that cannot operate when queues from either of the first two groups are active. The fourth group suspends most of the activity under EMSCTRL during special phases.

Following is a discussion of the four groups of queue requests.

1. Queues that modify the MPT

This group of queues consists mainly of "M" code MED entries, which are used to add or delete maneuvers, modify weights, etc. Normally, a trajectory update is initiated if any changes to the MPT are made.

2. Queues that cause trajectory updates

This group is composed of insertion vectors, restart vectors, launch overrides, vectors from the usable vector table, etc. There are almost as many vector sources as there are vector types. The insertion vector is extracted from the launch to orbit transfer table, the restart vector is passed from an MED decoder, and the DC vector is passed from the usable vector table supervisor.



3. Queues that initiate permission-to-process requests

This group is composed of those queues that cannot be active if any queues in groups 1 and 2 are active. There can be any number of queues in this group active at the same time, however. Presently, there are 35 queue control blocks through which queues in this group are issued. The design is open-ended, and many more queue control blocks can be added without modifying the program. Examples of queues in this group are station contact generation, time-to-fire computations and the RTACF vector transfer on MED input.

4. Queues that suppress processing during special phases

Queues in this group are received from the phase supervisor, GMSPHASE. These queues suppress a major portion of routing program activity when special events are taking place. In particular, when a phase change is made to process high-speed radar, all activities in groups 1, 2, and 3 are suppressed. Suppression is achieved by disabling various queue control blocks. When the high-speed phase ends, the queue control blocks are enabled, and any queues previously stacked are released.

A complete understanding of "how" the queue control technique works would require a rather comprehensive study not only of the design of EMSCTRL, but also of how the Real Time Operating System handles queue control blocks. It is believed that such a study would be of little benefit here. Instead, attention will be given to "what" is done, and "when".

When a trajectory update forcing queue or a mission plan table modifying queue is received by EMSCTRL, it disables all queue control blocks for incoming requests and then reroutes the queue to itself through a special queue control block, EQ3CTL. Thus incoming queues are shut down, but there can be active queues in the permission-to-process group. If this is the case, EQ3CTL will be in a disabled status and will remain so until all of the outstanding queues in the permission-to-process group have completed processing. EQ3CTL will then be enabled, and the queue it contains will be activated. Thus, when a trajectory update or mission planning queue is received and rerouted through EQ3CTL, no other queues of this type can be received until processing of the first queue is complete. After the task receiving the queue from EQ3CTL has completed processing, EMSCTRL is informed, and the incoming queue control blocks are enabled. Processing then continues on a priority basis.

A similar, but more straightforward technique is used when permission-to-process queues are received. At this time it is only necessary to disable EQ3CTL

to lock out both trajectory update and mission planning activities. Any number of queues of this type may be received and issued until a trajectory update or mission planning queue is received. The permission-to-process incoming queues are then suppressed as described above. A record is kept of the outstanding queues in this group, and EQ3CTL is not enabled until all have returned.

Some of the permission to process queues have been found to adversely effect each other, and so special logic has been implemented to serialized these queues. A system parameter has been initialized that identifies the queues which must be serialized. When such a queue is received by EMSCTRL, an indicator is set stating that the serial processing stream is busy, and the queue is issued. If any additional serial queues are received while the serial stream is busy, they are rerouted to EMSCTRL through a disabled queue control block. When the return queue from the outstanding serial queue is received by EMSCTRL, the busy indicator is turned off, and the rerouting queue control block is enabled.

All incoming queues that cause a trajectory update (P13, P14, P16, M codes, etc.) are routed to EMSCTRL through a single queue control block, EQ1CTL, which has a queue length of 10. Thus a maximum of 10 trajectory update queues can be accumulated for all vehicles. The queue control block for incoming permission-to-process queues, EQ2CTL, has a queue length of 50. In all cases, if too many queues are generated, it is because of negligent manual intervention or hardware problems and is generally desirable to discard queues.

Anchor Vector Maintenance - EMGVECST

The anchor vector maintenance program, EMGVECST, maintains a table of up to ten anchor vectors for each active vehicle. The vectors are arranged in ascending order with the current anchor vector always the last entry. As each new trajectory update is performed, the anchor vector is added to the bottom of the table until the table is filled; then on subsequent updates, the oldest vector is purged, and the other vectors are moved up one slot.

When a vector is received by EMGVECST that is identified as an insertion vector or as a restart vector, it is stored at the top of the anchor vector table, and all other vectors are purged. When a vector from the usable vector table is received by EMGVECST, it is entered in time sequence into the anchor vector table, and any vectors with a later time tag are purged. The new anchor vector is then routed to EMSCTRL to initiate the trajectory update. The end result for maneuver confirmations, as far as anchor vector maintenance is concerned, is the same as that for the usable vector type updates. The process, however, is quite different. A request is received from mission planning activities to provide the nearest anchor vector prior to a given time. After some internal processing, Mission Planning decides whether or not a trajectory update should be initiated, and if so, EMGVECST is instructed to purge all vectors with a later time tag. If Mission Planning decides for some reason that the confirmation cannot be done, the anchor vector table remains intact.

Requirements Interpretation

Exhibits 1 through 3 represent TR170 requirements applicable to this element as of the date of this specification. Our interpretation of these requirements are provided in the pages that follow each exhibit.

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Exhibit 1

PHO-TR170A
Volume 2, Change 58
19 April 1968

TABLE OT 1.1.2-1

MANUAL ENTRIES

Item

MANUAL ENTRY	EFFECT
<p>1</p> <p>GMT, Inertial flight path angle γ, Inertial Velocity V, Geocentric Latitude ϕ, Height above a spherical Earth h, Inertial Azimuth ψ, Longitude λ, REV. S, VEH;</p> <p>REV, GMT, X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}, S, VEH;</p> <p>Code, $\begin{cases} S \\ M \\ L \\ PN \end{cases}$, GMT</p> <p>Where S = Sun, M = Moon, L = Liberation Matrix, PN = P&N Matrix and λg</p> <p>Density Factor - K</p> <p>Weight, Cross-Sectional Area</p>	<p>Cause the initialization of the real-time program. This vector will be in Earth or Moon Centered True Coordinates. The "S" indicates that a static ephemeris is desired.</p> <p>Cause the initialization of the real-time program. This vector will be in Mean or True earth and moon centered coordinates. The "S" indicates that a static ephemeris is desired.</p> <p>Cause either the sun vector, moon vector, liberation matrix, or P&N matrix and λg to be printed on-line at the specified GMT. (Note: The liberation matrix must be interpolated; however, the P&N matrix associated with the nearest 6 hour increment to GMT will be printed.</p> <p>Modifies the earth orbit coefficient of drag.</p> <p>Cause the trajectory update</p> <ul style="list-style-type: none"> • CSM • LM
<p>2</p> <p>Code, GMT, MNV, EPH, S</p> <p>Where EPH = C for CSM = L for LM</p> <p>GMT = Time of vector MNV = Cutoff vector after the specified Maneuver.</p>	<p>Cause a vector to be transferred for the specified GMT or maneuver number from one ephemeris to another. The "S" indicates that the ephemeris that the vector is to be transferred to is static.</p>

Approved: 2 3

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Exhibit 2

PHO-TR170A
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17.5 TERMINATION AND INTERFACE

The Ascent Phase will be terminated when the A/H/O switch is set to Orbit after the Thrust switch has been set to NO EVENT at least once following liftoff.

- A. If the thrust switch is not set to EVENT following the first NO EVENT (NOMINAL CASE), the following data will be transferred when the A/H/O is set to Orbit.
 1. Both the PNGS and/or AGS averaged vectors following the first setting of the thrust switch to NO EVENT, or the last powered flight vector if no averaged vector is available on that source, will be placed in the Evaluation Table of the Vector Panel Summary (VPS) display.
 2. The same vectors will be placed in the Usable Vector table of the VPS display.
 3. A weight will be transferred. This weight is computed at interface using $WEIGHT = TOTAL\ WEIGHT\ OF\ LM\ AT\ LIFTOFF - (\Delta t)(APS\ \dot{W})$ where first GETCUTOFF after liftoff - GETLIFTOFF = Δt and \dot{W} = weight loss rate of the APS. Manual inputs for GETCUTOFF and LIFTOFF can be used to change the original times assumed from the Thrust and liftoff switches, respectively. If the MEDS are not made, switch times will be used. This weight will be made available to the MPT.
 4. In the case of abort from descent the weight will be computed as follows:
 - a. Following GETDESCENT, but prior to thrust to NOEVENT in descent phase, the weight will be computed as follows:
 - (1) If no GETSTAGE manual entry has been made the weight will be $WEIGHT = TOTAL\ WEIGHT\ OF\ UNSTAGED\ LM - \Delta t (DPS\ \dot{W})$ where $\Delta t = GETCUTOFF - GETDESCENT$
 - (2) If the GETSTAGE input has been made the $WEIGHT = TOTAL\ WEIGHT\ OF\ STAGED\ LM - \Delta t (APS\ \dot{W})$ where $\Delta t = GETCUTOFF - GETSTAGE$.
 - b. If the Thrust switch has been set to NO EVENT in descent phase the weight will be computed as follows:
 - (1) If the GETSTAGE has not been made $WEIGHT = TOTAL\ WEIGHT\ OF\ UNSTAGED\ LM - [\Delta t_1 (DPS\ \dot{W}) + \Delta t_2 (DPS\ \dot{W})]$ where $\Delta t_1 = GET\ THRUST\ SWITCH\ TO\ NO\ EVENT - GETDESCENT$ and $\Delta t_2 = GETCUTOFF - GETABORT$

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- (2) If the GETSTAGE manual entry has been made $WEIGHT = TOTAL\ WEIGHT\ OF\ STAGED\ LM - \Delta t (APS\ \dot{W})$ where $\Delta t = GETCUTOFF - GETSTAGE$.
5. The weight will normally reflect the estimated weight at the GETCUTOFF. If a powered flight vector is transferred and is before GETCUTOFF, the weight will only be computed at vector time.
 6. There is no requirement to move vectors back to last cutoff time.
- B. If the thrust switch is recycled to EVENT following the first NO EVENT (CONTINGENCY CASE) the following data will be transferred when the A/H/O is set to Orbit.
1. Both the PNGS and/or AGS averaged vectors following the first setting of the thrust switch to NO EVENT, or the last powered flight vector if no averaged vector is available on that source, will be placed in the Evaluation Table of the Vector Panel Summary (VPS) display.
 2. The last PNGS and/or AGS averaged vectors, or the last powered flight vectors, if no averaged vector is available for that source, will be placed in the Usable Vector table of the VPS display provided the time-tags of these vectors are greater than the time that the thrust switch was recycled to EVENT. If no such vectors exist, no vectors will be placed in the Usable Vector Table.
 3. The APS weight described above will be transferred. In addition another weight will be transferred to reflect the contingency maneuver. This weight is arrived at by $WEIGHT = APS\ WEIGHT\ computed - (\Delta t) (RCS\ \dot{W})$ where $\Delta t = Time\ thrust\ switch\ recycled\ to\ NO\ EVENT\ after\ first\ cutoff - Time\ thrust\ switch\ set\ to\ EVENT\ after\ first\ cutoff$ and $\dot{W} = weight\ loss\ rate\ of\ the\ LM\ RCS$. These weights will be made available to the MPT. If the A/H/O is set to Orbit before the thrust is set to NO EVENT, i.e., during a maneuver, the RCS weight will be computed at vector time.
 4. One zero maneuver will also be transferred, i.e., a GMTPI will be made available to the MPT. The GMTPI will be one second later in time than the latest vector time in the Evaluation Table.

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- C. For subsequent maneuvers the vectors that are given to the evaluation table will always be the averaged or last powered flight vectors prior to the last thrust to Event. The vectors for the Usable Vector Table will always be the last averaged or powered flight vectors after the last thrust to Event.
- D. The time of GETCUTOFF and the status of the data select PNGS/AGS PBI panel will be made available to the Differential Correction program at interface.

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Exhibit 3

PHO-TR170A
Volume 2, Change 58
19 April 1968OT 1.1.4 Earth Orbit Phase

The Earth Orbit Phase of the mission is defined as that logic pertaining to the processing of Apollo spacecraft data for the period which begins at the time the computer recognizes the Orbit setting of the Abort/Hold/Orbit switch on the Flight Dynamics Officer's console (following Launch) and upon receipt of data transferred from hold phase processing to Orbit Phase processing.

The initialization of trajectory processing is based on the following information transferred from Launch Phase.

- A. A maneuver (preburn) vector will always be transferred.
 - 1. This vector can be time-tagged before or after SIVB cutoff.
 - a. The vector will normally be time-tagged at SIVB cutoff time.
 - b. If a priority vector is transferred, because of missing data after SIVB cutoff, the maneuver vector will be time-tagged prior to SIVB cutoff.
 - c. In the event of a contingency insertion maneuver(s) the maneuver vector will always be time-tagged before the maneuver that is performed.
 - 2. The maneuver vector will always have CSM/SIVB (LM/SIVB) separation included in the data.
 - 3. A weight and area will always be available with the maneuver vector.
 - 4. A maneuver will always be transferred with the maneuver vector. In the case of a priority vector this will be a zero maneuver.
- B. A current (postburn) vector will always be transferred provided there is available data after the SIVB cutoff. In the event of a contingency maneuver a current vector will always be transferred unless there is no data following SPS ignition.

The current vector will always be tagged as free-flight or powered flight.

A weight and area will always be transferred with the current vector.
- C. If a current vector is indicated as free-flight, this vector will be used to generate the ephemeris at launch/orbit interface. If the vector is tagged powered flight, the maneuver vector will be automatically used to generate the ephemeris.

Approved: T. J. J. NASA/FSB PHO/PARS

Item1 Static Ephemeris Constraints

A static ephemeris may be generated for any vehicle until such time that a live ephemeris is generated for that vehicle. Once a live ephemeris has been generated, there will be no provision to ever generate a static ephemeris again for that vehicle. Any attempt to route a static vector for a vehicle that is already live will result in a warning message on line and the vector will be routed as a live vector.

Static vectors used for trajectory updates will be stored in the appropriate anchor vector table even though in most cases they will not be history vectors. The vector ID associated with static vectors will be STAT, and this ID will be used internally to determine if the current ephemeris for a particular vehicle is live or static.

2 The MED will require the name of the vehicle for which the ephemeris is to be generated as well as the name of the vehicle from which the vector is to be retrieved. In addition a time (GMT) or a maneuver number, but not both, and a static or live indicator will be required.

EMSCTRL, using EMSFFV, will fetch the appropriate vector and route it for a trajectory update with the same action code as a re-start vector. This means that the vector will be stored in the appropriate anchor vector table, and all other vectors in the table will be purged. If the requested vector is not available, a message will be printed, and the update will be terminated.

Static ephemeris requests will be subject to the constraints outlined in Item 1.

There will be no provision to input a revolution number on the MED. The rev. number will be determined by the rev. processor, making use of the old rev. table. The rev. number may be adjusted, if desired, using the P17 MED.

Lunar Ascent to Lunar Orbit Transfer

At the end of lunar ascent, Lunar Orbit phase is entered, but a trajectory update is not automatically queued. Instead, a "hold"



period occurs until a manual decision is made as to which vector should be used to transfer to Lunar Orbit. The selected vector and appropriate indicators are passed from usable vector table processor to the anchor vector maintenance program to initiate the trajectory update.

The anchor vector program stores the vector in the anchor vector table and then queues the Mission Planning Transfer program, passing along the necessary indicators, to determine the type of transfer to be performed. The Mission Planning Transfer program retrieves from the launch transfer table the weight associated with the transfer vector and the maneuver, if any, that must be transferred to the Mission Plan Table. The transfer vector is then routed for a trajectory update.

Normal Launch Transfer Logic

When a phase change to Orbit occurs, program GMSPHASE issues a queue to EMSCTRL to initiate the launch transfer. EMSCTRL issues a LINK to EMGVECST instructing it to go to the launch transfer table and extract the transfer vector on which the initial ephemeris will be based. Since the phase change switch can be thrown at any time, there is not a unique slot in the launch transfer table from which a vector can be selected. EMGVECST interrogates the table to determine what the status was at the time the phase change was made. A discussion of the possible situations and the action taken is given below.

1. Tagging the transfer vector as a thrust vector

An attempt is made to transfer a preburn vector and a maneuver. If the preburn vector is not available, or if the maneuver is not available, or if the time of the preburn vector is greater than the time of the maneuver, an appropriate message is printed on line; no further action is taken. If the preburn vector and maneuver are both available and if the time of the vector is prior to the maneuver, a queue is generated that simulates a launch override MED with the preburn option. Thus, if the transfer vector is tagged as thrust, the preburn vector and maneuver are automatically transferred if they are consistent.

2. Non-available transfer vector

This situation is regarded as an error condition since, if the transfer vector is not available, the phase change to Orbit probably should not be made. A message is printed, and no attempt is made to determine if a preburn vector or maneuver is available.

3. Free-flight transfer vector

This is the normal launch transfer situation. In this case, EMGVECST generates a queue that is exactly like a launch override MED with the postburn option. It then returns to EMSCTRL informing it that the transfer has been initiated.

When a launch to Mode III occurs, EMSCTRL receives a queue from GMSPHASE exactly like the launch to orbit queue. However, program EMGVECST checks the mission phase word, and, when it recognizes the Mode III abort phase, it simulates a launch override MED with the preburn option.

Manual Override of Launch Transfer Logic

The capability exists to manually override the normal launch transfer logic with a MED entry specifying either the PRE or TRA option. If the TRA option is used, the normal transfer vector will be selected although it may be a thrust vector.

1. Requested preburn vector

If the preburn vector is not available, or if the maneuver is not available, or if the time of the preburn vector is greater than the time of the maneuver, an appropriate message is printed; no further action is taken. If the preburn vector and maneuver are both available and if the time of the vector is prior to the maneuver, the transfer is accomplished as follows:

- a. The preburn vector, area, and weight are stored in the caller's area.
- b. Indicators are set to identify the type of transfer performed.
- c. The vector is stored in the anchor vector table.
- d. EMGVECST returns to PMMXFR.

2. Requested postburn vector

If the postburn vector is not available, a message is printed, and no further action is taken. If the transfer vector is a thrust vector, the transfer is accomplished as follows:

- a. The postburn vector, area, and weight are stored in the caller's area.
- b. A message is printed indicating that a thrust vector was transferred.
- c. Indicators are set to identify the type of transfer performed.
- d. The vector is stored in the anchor vector table.
- e. EMGVECST returns to PMMXFR, which then queues EMSCTRL to initiate the trajectory update.

If the transfer vector is free-flight, which is the case for the normal transfer, the transfer is accomplished as follows:

- a. A message is printed to indicate whether the vector is prior to or after separation time.
- b. The postburn vector, area, and weight are stored in the caller's area.
- c. The vector is stored in the anchor vector table.
- d. EMGVECST returns to PMMXFR, which then queues EMSCTRL to initiate the trajectory update.

Reentry Queue Control Logic

The basic queue control logic provided by EMSCTRL is the same for reentry as for orbit, including the capability to handle "permission-to-process" requests. However it should be noted that in Reentry phase, EMSCTRL provides protection against Mission Plan Table changes, but does not provide protection against re-entry trajectory updates unless reentry is XCTRLed under PTMANC. Also, special logic has been included to allow a restart in Reentry phase with the ability to input a maneuver and transfer it to the Mission Plan Table.

Functional Diagrams

Figures 1 through 5 illustrate the interface between the programs in the Queue Control and Anchor Vector Maintenance Element and other elements, units, or subsystems. They also show data table usage, task structure, and input/output data flow. The key to the symbols used in the diagrams may be found in the Glossary of this document. These diagrams appear in the following pages.

1. Queue Control and Anchor Vector Maintenance
2. Restart
3. Normal Insertion and Launch Override
4. Permission-to-Process Queue and Completion Queue
5. Lunar Ascent to Lunar Orbit Interface

Input/Output Specifications - On-Line Prints

The following is a listing and description of the on-line printouts that will be provided by the Queue Control and Anchor Vector Maintenance Element.

1. INVALID REQUEST

An unrecognizable action code was passed to EMGVECST. This should happen only in program checkout.

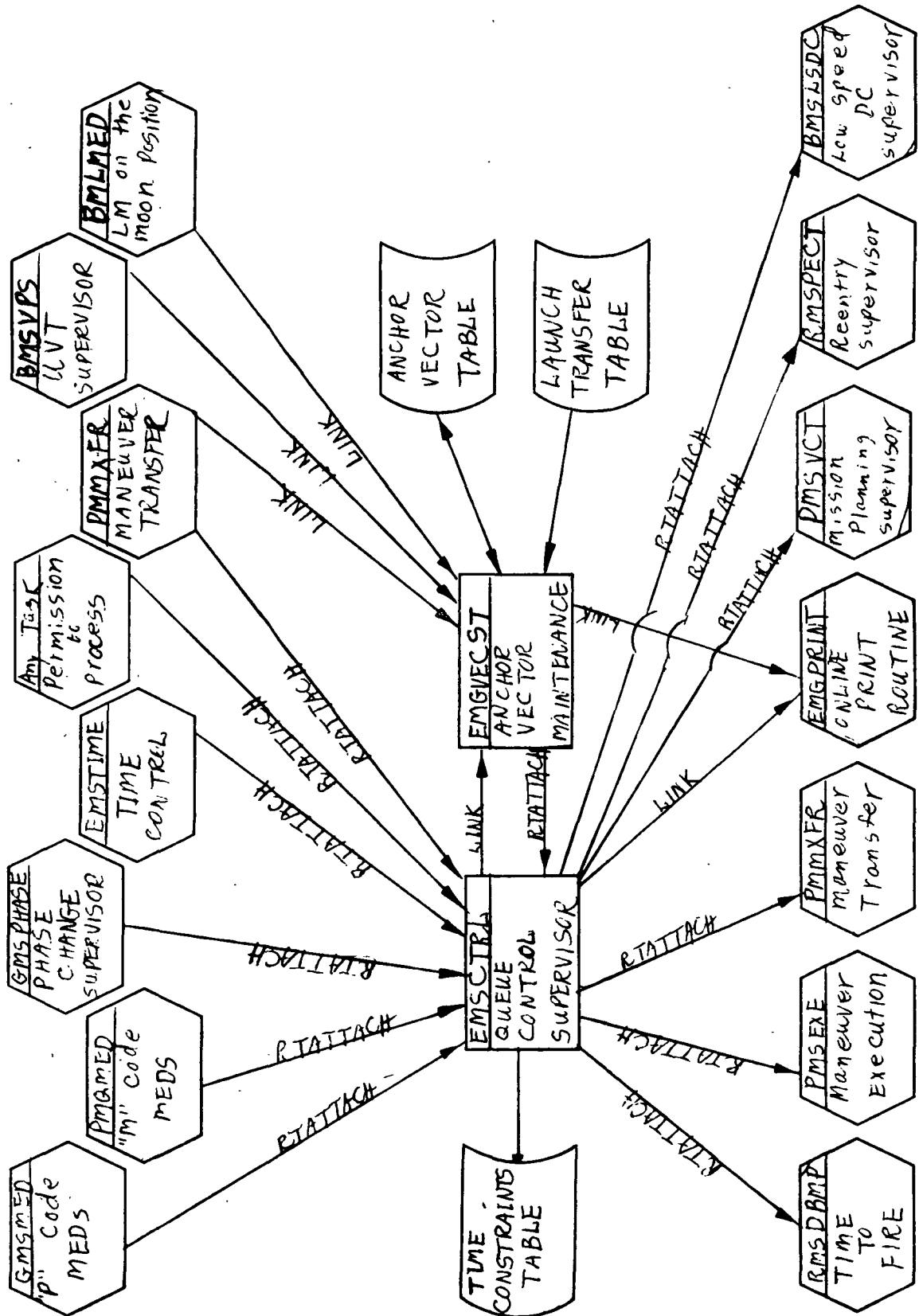


Figure 1. Queue Control and Anchor Vector Maintenance

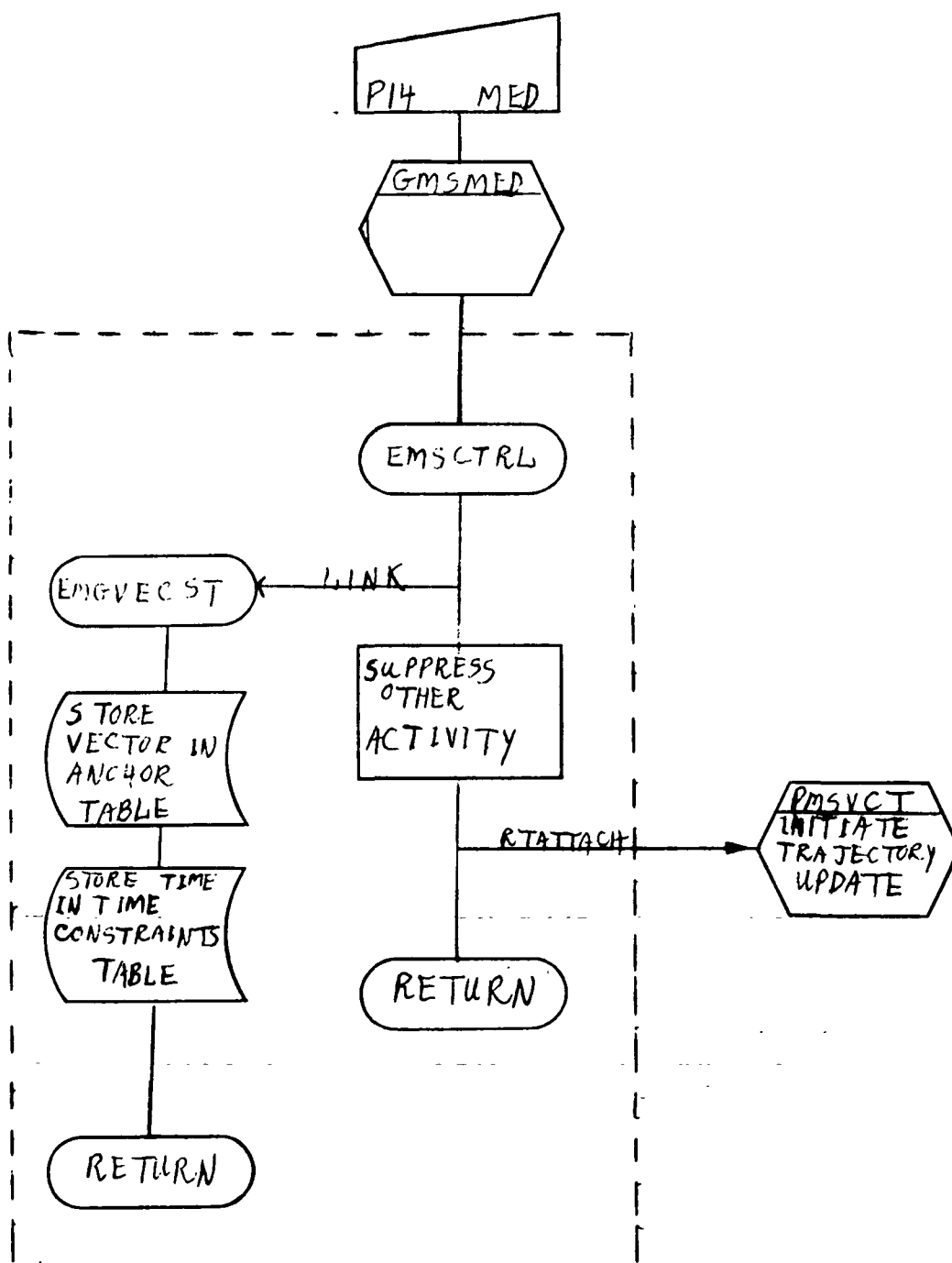


Figure 2. Restart

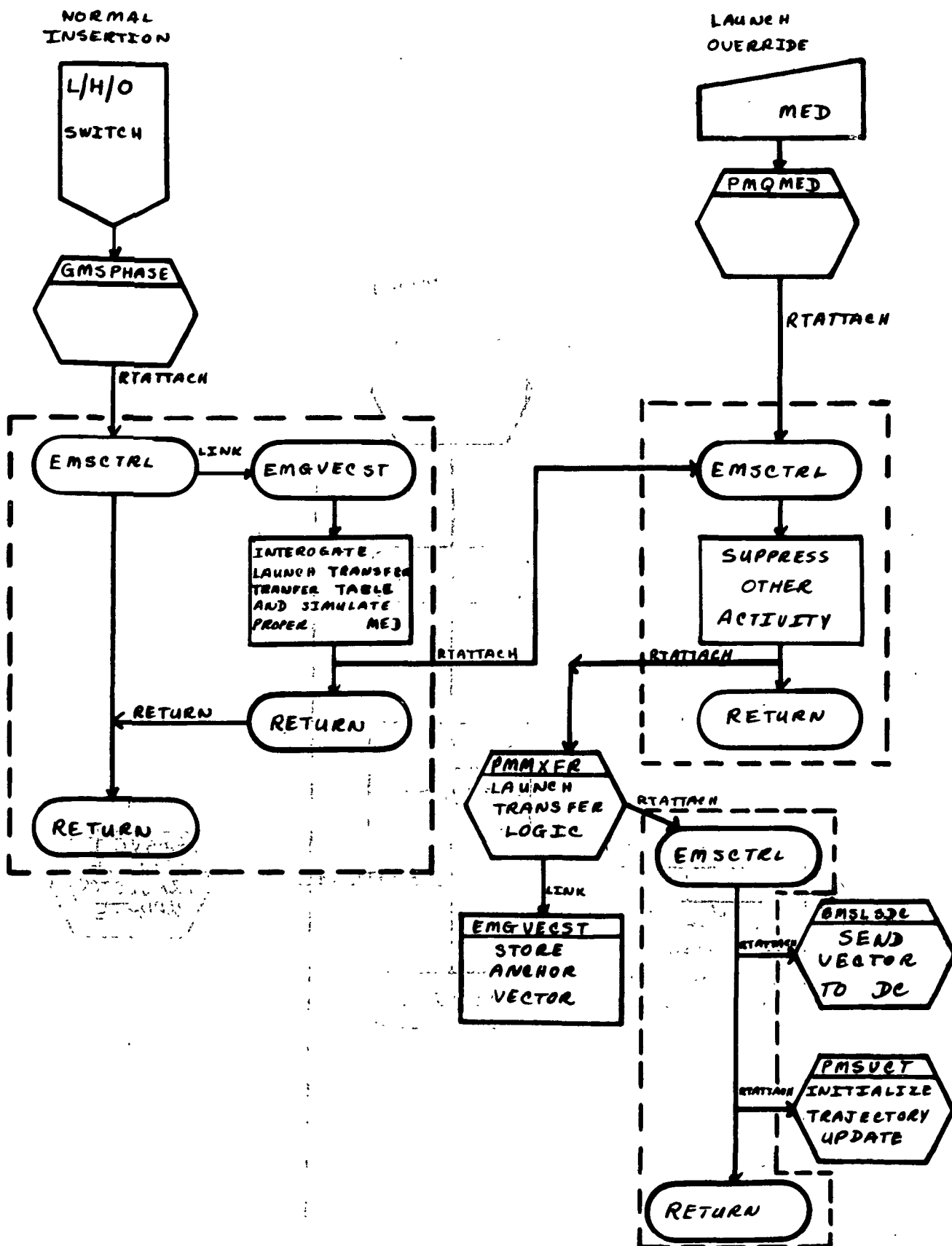


Figure 3. Normal Insertion and Launch Override

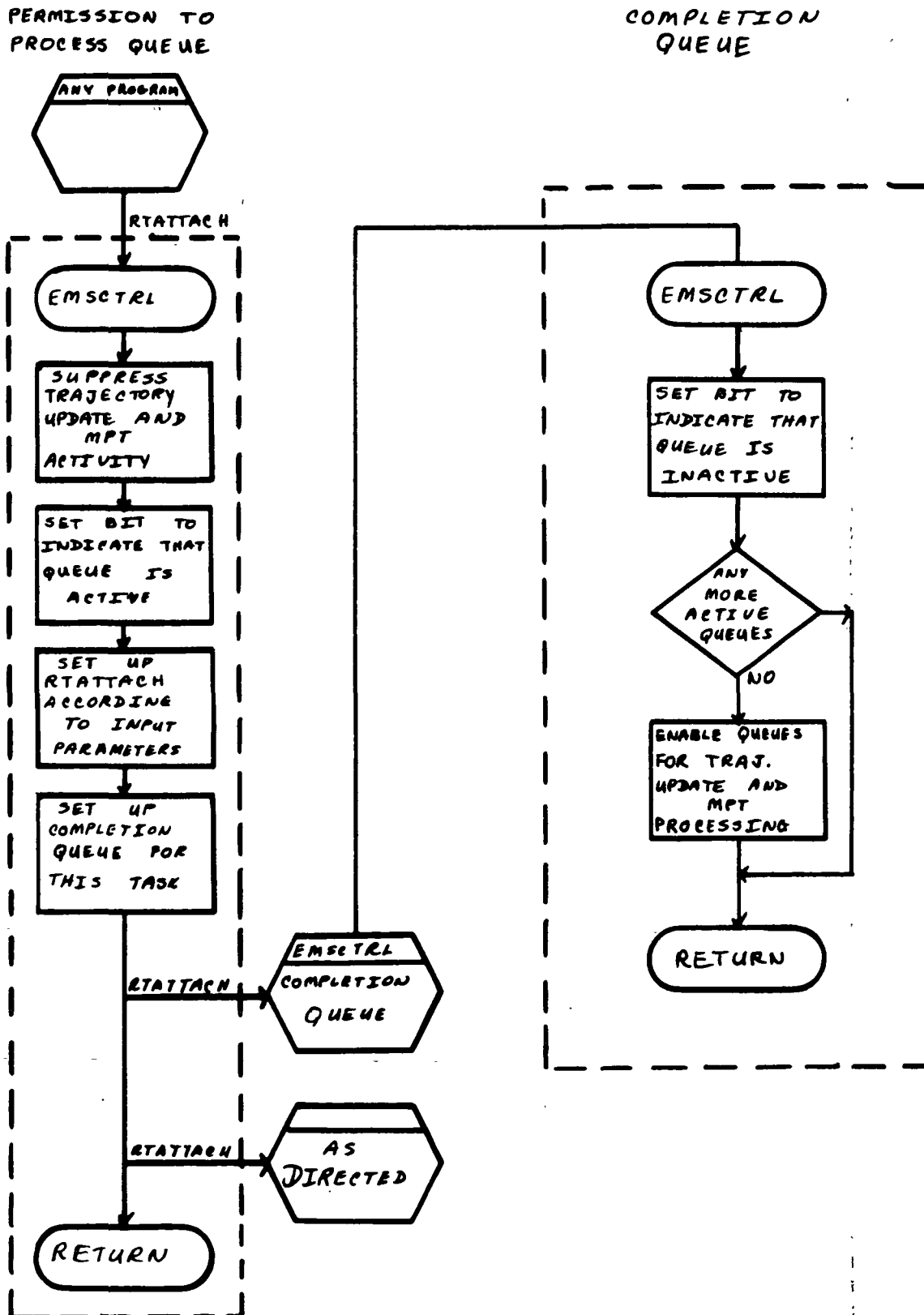


Figure 4. Permission-to-Process and Completion Queues

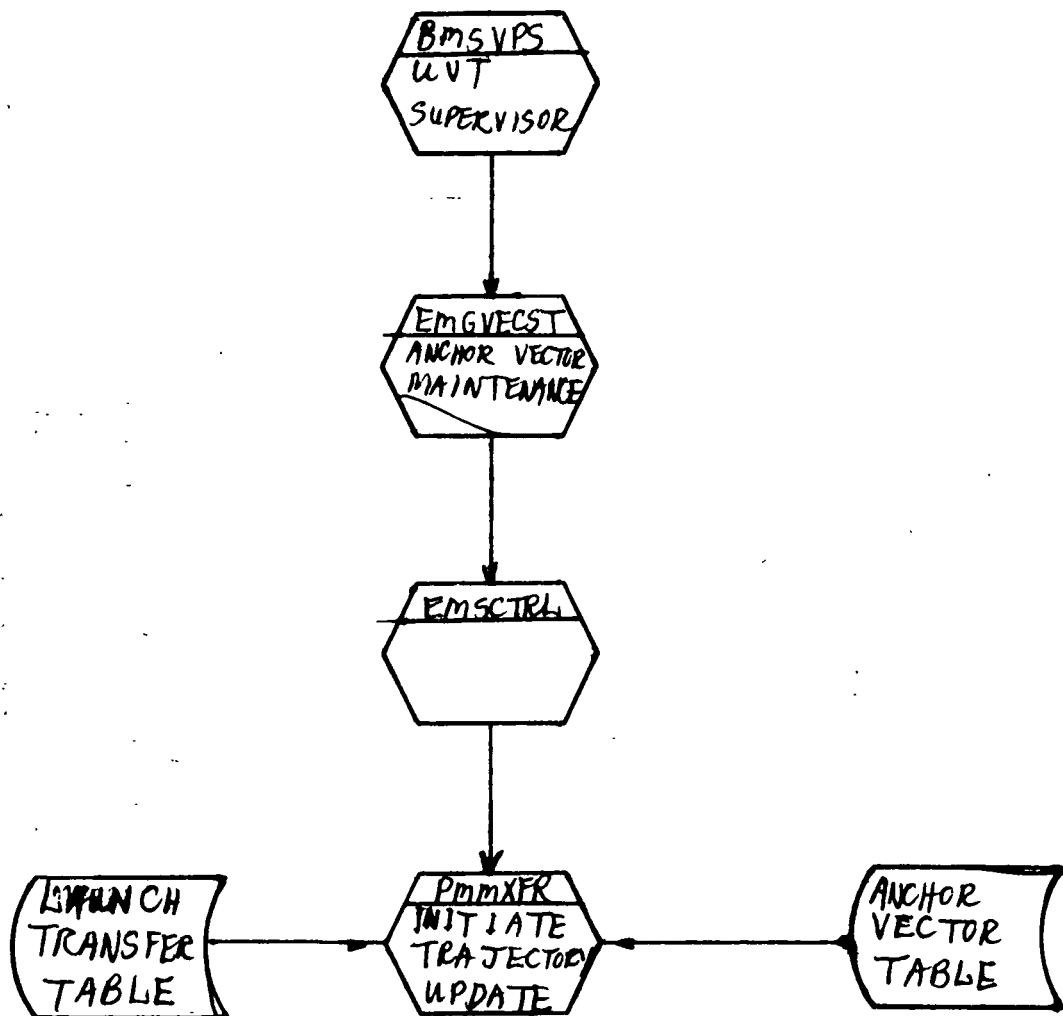


Figure 5. Lunar Ascent to Lunar Orbit

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2. INSERTION VECTOR IS POSTBURN

The transfer vector passed to Orbit or Mode III Abort is free-flight and is after the separation time supplied in the launch transfer table.

3. INSERTION VECTOR IS PREBURN TRANSFER

The time of the transfer vector is less than the separation time, or no separation time was found in the launch transfer table.

4. INSERTION VECTOR IS PREBURN CUTOFF

The Launch/Hold/Orbit (L/H/O) switch was set to Orbit or Mode III Abort during a thrust period, or a MED was entered specifying the PRE option. In both cases, the preburn vector is selected, and a maneuver is transferred to the Mission Plan Table.

5. INSERTION VECTOR IS THRUST

A MED was entered specifying the TRA option even though the transfer vector existed during a thrust period. The transfer vector is selected even though it is a thrust vector; no maneuver is transferred to the Mission Plan Table.

6. INSERTION VECTOR IS INVALID

The desired vector is unavailable in the launch transfer table. In the normal launch to orbit transfer, or when a MED with the TRA option is entered, if vector 2 is desired and is void, no automatic attempt is made to select vector 1. Only a MED with the PRE option will force the selection of vector 1.

If vector 1 is desired, then the GMT of vector 1 must not exceed the GMT of the maneuver in the launch transfer table, nor can the GMT of the maneuver be void.

This print represents a definite problem in the launch transfer attempt. If the transfer to orbit is still desired, the nominal orbit insertion vector should be entered via P13 or P14.

7. HISTORY VECTOR IS UNAVAILABLE

The anchor vector maintenance program, EMGVECST, received a request for a history vector, and the requested time was prior to the oldest entry in the table. This occurs most frequently in maneuver confirmation attempts because the controller tries to confirm a maneuver to a time prior to the oldest history vector.

8. $\left\{ \begin{array}{l} \text{CSM} \\ \text{LEM} \end{array} \right\}$ VECTOR CANNOT BE ROTATED TO ECI — UPDATE
TERMINATED

An error return was received from the vector rotation routine, ELVCNV. Probably, the time of the anchor vector does not lie within the time span of the sun/moon ephemeris and/or the PN matrices. The trajectory update is terminated, and all tables are unchanged.

9. REQUESTED VECTOR UNAVAILABLE — UPDATE TERMINATED

An MED was entered requesting that an ephemeris be generated for one vehicle using a vector from the other vehicle, and the requested vector was unavailable.

10. STATIC VECTOR ROUTED FOR $\left\{ \begin{array}{l} \text{CSM} \\ \text{LEM} \end{array} \right\}$ — VEHICLE IS ALREADY LIVE

The static indicator is ignored, and the vector is routed as a live vector.

TIME QUEUE CONTROL ELEMENT

Function

The Time Queue Control Element is composed of a single program, EMSTIME. Its functions are to maintain a table of present position information for each active vehicle and to issue periodic queues to other tasks so that displays, plotboards, etc. are kept up to date. In addition, EMSTIME monitors the main ephemeris for each vehicle and forces an ephemeris extension if less than the required amount of ephemeris remains.

Time Queue Control Load Module Description - EMSTIME

EMSTIME receives six distinct queues that are identified by queue ID's. Each queue is discussed below.

Twelve-Second Time Trap

On each 12-second time queue, EMSTIME uses program ELVCTR to interpolate for a vector at present time. The vector is immediately rotated to MCI, and its magnitude is checked to see if it is within the lunar sphere of influence. If it is, moon reference is assumed; otherwise, Earth reference is assumed. The vector is then rotated to the appropriate true-of-data coordinate system, and EMMDYNEL is called to compute the necessary orbital elements. The vehicle weight and the current revolution number are monitored on each 12-second time queue, and updated when a maneuver is encountered or if the revolution number changes. The Time Constraints Table is then updated with all present position information.

If the current revolution number has changed, program EMSTIME issues an RTATTACH to the plotboard supervisor to update plotboards. This queue is issued only on a rev. change and is not to be confused with the regular 12-second queue to be mentioned later.

A check is then made to see if present time is within a predetermined (system parameter) delta time of the reentry threshold time. If this is the case, a queue is stacked through EMSCTRL to queue the reentry supervisor. An indicator is set in the task resource table for ETMSTIME indicating that reentry has been queued and should not be queued again on a time update.

The current main ephemeris is then checked to see how much future ephemeris remains. If less than the required amount remains (20 hours is currently being used), and the ephemeris header does not indicate an abnormal or premature termination, an ephemeris extension is queued through EMSCTRL. Premature terminations may be the result of impacting trajectories, maneuver errors, or not enough space being available to store the minimum ephemeris.

Finally, 12-second time queues are issued to the orbit display supervisor, the reentry display supervisor, and the plotboard supervisor.

Nominal Insertion or Static Vector

The purpose of the nominal insertion or static vector is to generate a static target ephemeris for a vehicle that has not yet been launched. Thus, the static ephemeris is not directly related to present time. When EMSTIME receives a nominal insertion queue, it queues program EMMDYNEL to compute the orbital elements, extracts the current weight from the Mission Plan Table, extracts the revolution number from the Cape Crossing table, and then updates the Time Constraints Table. If the time of the vector is within a predetermined (system parameter) delta time of the reentry threshold time, a queue to reentry is issued.

A nominal insertion does not cause the vehicle to be added to the active list, and time updates are not initialized for that vehicle. However, once a vehicle has been added to the active list, a nominal insertion will not delete it.

Activate and Non-Nominal Vector Queues

Activate queues are received from program GMSPHASE and are issued on a recycle from reentry to orbit. Actually, it is used to reactivate a vehicle that was previously suppressed. Non-nominal vector queues are received from EMSTRAJ each time a trajectory update is generated.

When one of the above queues is received, EMSTIME checks to see if the vehicle is already active, and if it is not, it is added to the active list.

Thus, the activate and non-nominal vector queues initialize or reinitialize all parameters in ETMSTIME so that on the next time queue, present position information will reflect the current ephemeris. After initialization is complete on non-nominal trajectory update queues, EMSTIME simulates a 12-second queue so that displays will be updated immediately.

P17 MED Entry

After the necessary revolution table changes have been made as a result of a P17 MED, EMSTIME is queued to update the current rev number if necessary. If no ephemeris has yet been generated, EMSTIME exits with no changes. If an ephemeris does exist, EMSTIME checks to see if a rev change has occurred, and if so, prints a message on line and queues the plotboard supervisor.

Suppression of a Vehicle

When the phase change is made from orbit to reentry, program GMSPHASE queues EMSTIME instructing it to remove the reentering vehicle from the active list.

Functional Diagrams

Figures 6 and 7, show the interfaces of the programs in the Time Queue Control Element with other elements, units, or subsystems. Data table usage, task structure, and input/output data flow also are illustrated. The symbols used in the diagrams are defined in the Glossary of this document.

Input/Output Specifications - On-Line Prints

The following listing describes the on-line printouts that will be provided by Time Queue Control Element.

1. LESS THAN FIVE DAYS NP MATRICES/SUN-MOON EPHEMERIS REMAINING

EMSTIME monitors the amount of future nutation and precession data and Sun/Moon ephemeris data remaining. The first time that it detects less than five days of either remaining, the above message is printed.

2. $\left\{ \begin{matrix} \text{LUNAR} \\ \text{EARTH} \end{matrix} \right\}$ REV. NOS. FOR $\left\{ \begin{matrix} \text{CSM} \\ \text{LEM} \end{matrix} \right\}$ ARE NO LONGER VALID

Present time is beyond the range of rev. numbers in the Cape Crossing Table. Therefore, displays should not be called up with the rev. option.

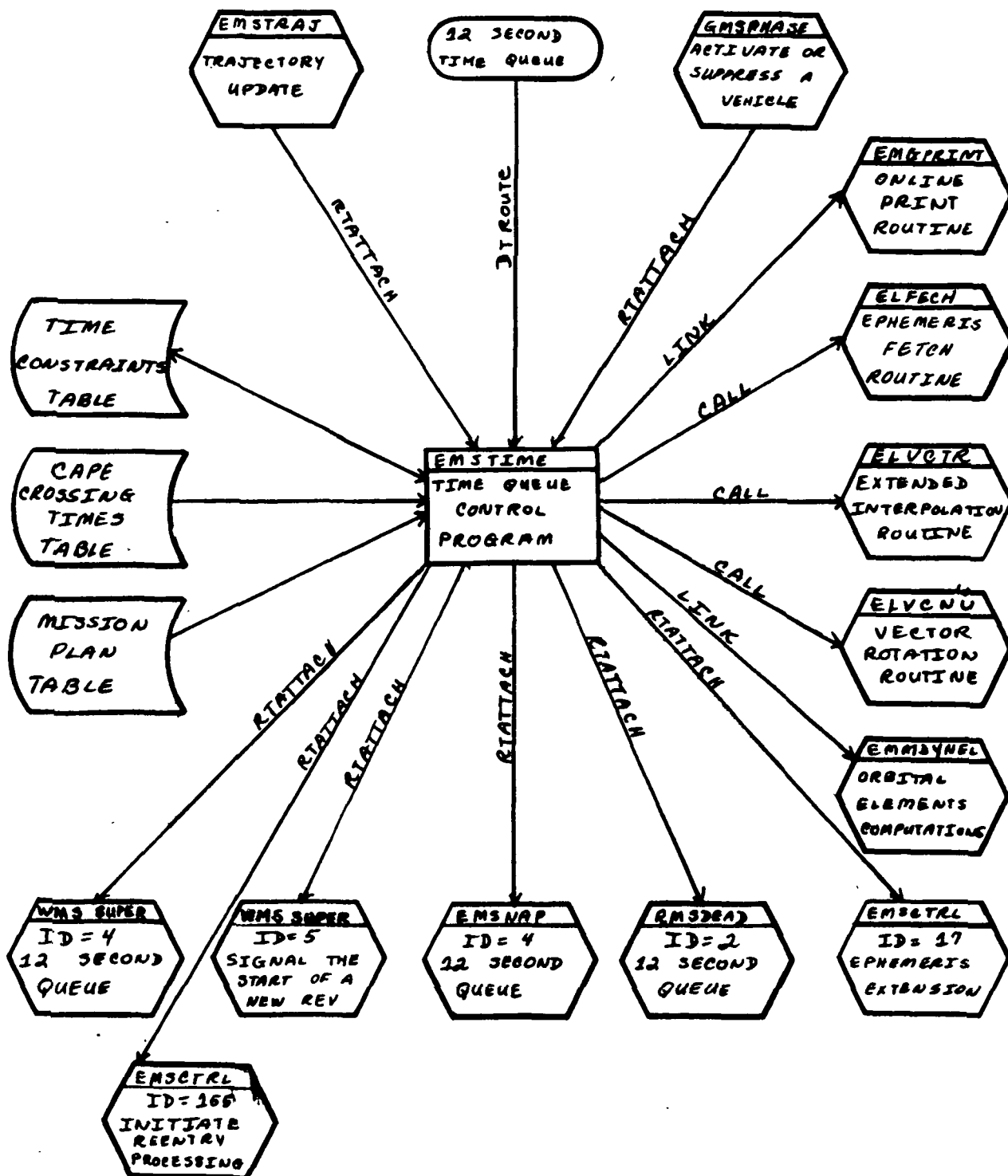


Figure 6. Time Queue Control Level 1

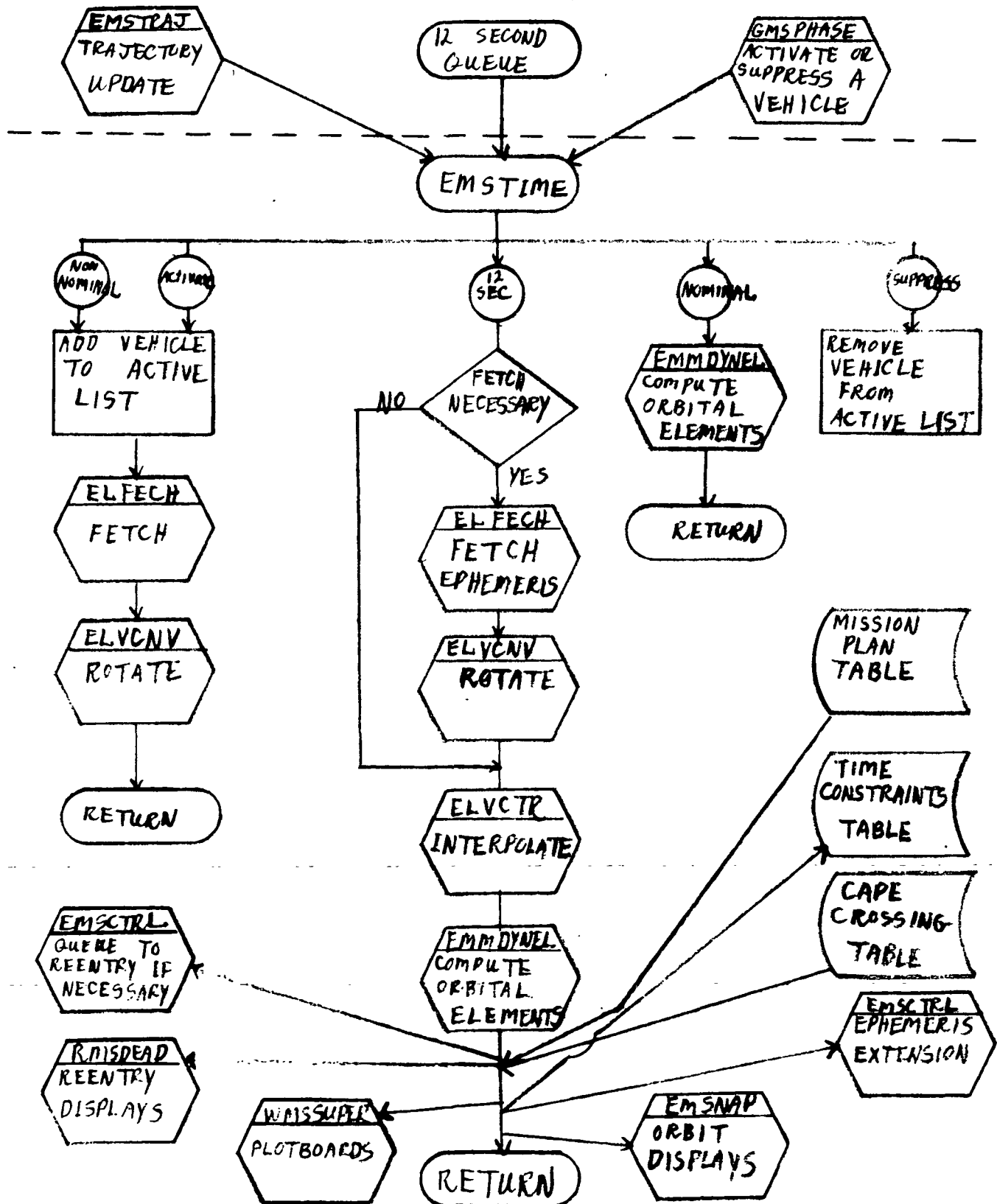


Figure 7. Time Queue Control Level 2

3. ERROR RETURN FROM ELVCNV. $\left\{ \begin{matrix} \text{CSM} \\ \text{LEM} \end{matrix} \right\}$ PRESENT POSITION NOT
UPDATED.

An error occurred while attempting to rotate the present position vector to the appropriate true-of-date system.

TRAJECTORY UPDATE CONTROL ELEMENT

Function

This element is composed of two programs, EMSTRAJ and EMSEPH. The purpose of the element is to provide the necessary logic to generate an orbit ephemeris and to issue queues to programs that need to be informed of the trajectory update.

Load Modules/Routines Description

Trajectory Update Control Module - EMSTRAJ

Program EMSTRAJ is the main control program during trajectory updates and controls a serial process that prevents conflicting actions. It first LINKs to program EMSEPH to generate the orbit ephemeris; then LINKs to Cape table generation program to generate the table of Cape crossing times, and finally LINKs to program EMGXVTRA to transmit the current anchor vector to the RTACF. The vector ID is then stored in the Time Constraints Table.

Once this serial processing is complete, RTATTACH's are issued to several independent tasks to inform them of the trajectory update. Some of these queues are passed through program EMSCTRL for further protective control. In particular, queues for station contact processing and time-to-fire processing are passed through EMSCTRL while queues for display and present position updates are routed directly to the concerned program. Time-to-fire queues are only issued if the vehicle is a CSM.

After issuing the necessary queues, EMSTRAJ will check the position magnitude of the anchor vector relative to the moon. If the check indicates that the vector is within the lunar sphere of influence, moon reference will be assumed; otherwise, Earth reference is assumed. EMSTRAJ then LINKs to EMMDYNEL to compute the orbital elements in the proper reference frame. The elements are then printed on line. If the anchor vector is a lunar surface vector, no elements will be printed or computed.

EMSTRAJ performs multiple trajectory updates on a single queue (i. e., while the "update in process" condition exists) by repeating the steps outlined above using a second input table. The purpose of this capability is to transfer DKI plans with both vehicles thrusting and to update both trajectories simultaneously.

Ephemeris Storage and Control Module - EMSEPH

Program EMSEPH contains the logic to integrate a history vector up to present time and to generate an orbit ephemeris. These two functions are performed by two distinct queues. The Detail Maneuver Table (DMT) processor is queued at the end of each maneuver for post-maneuver processing.

For the most part, EMSEPH uses the numerical intergration control routine, EMSMISS, to interface with the mission plan tables and the various integrators. It goes directly to the Mission Plan Table to get the trajectory update number and begin times of future maneuvers.

The storage of ephemeris is accomplished with either two or three DTWRITE's. With the first DTWRITE, the header is updated, and the table is locked. If a maneuver was encountered, the second DTWRITE is used to update the maneuver times while the table remains locked. The last DTWRITE is used to transmit the vectors to the ephemeris and to unlock the table. Thus, the ephemeris table is always locked when in a state of change.

On each call to EMSMISS, whether or not the ephemeris is requested, cutoff is requested at the end of the first encountered maneuver. Thus, if a maneuver occurs within the requested integration span, EMSMISS will cut off at the end of the maneuver and return the Runge-Kutta auxiliary output table. When a return from EMSMISS indicates cutoff at the end of a maneuver, EMSEPH stores the ephemeris or burnout vector, as the case may be, updates the maneuver times in the ephemeris table, and updates the ephemeris header. It then queues the DMT mathematics processor for post-maneuver processing, passing along the Runge-Kutta Auxiliary Output Table. The DMT processor is also queued at the end of the trajectory update.

EMSEPH first requests EMSMISS to terminate integration at EI altitude, and then if EI occurs, it recalls EMSMISS to cut off at kickout altitude. If EI and/or kickout occur during freeflight integration, the exact time is determined. However, if EI or kickout occur during a maneuver, EMSMISS will back off to the beginning of the maneuver and flag the maneuver initiate vector as the EI or kickout vector.

A complete description of the ephemeris generation logic may be found in the Requirements Interpretation section for this element.

Requirements Interpretation

Lunar surface vectors will be generated by assigning the desired times to the LM position vector in the MCT system, and then rotating the vectors to the ECI system via the MCI system. When rotating from MCT to MCI, the rotational rate of the moon will be considered. The storage interval of the lunar surface ephemeris will be three minutes. (See Exhibit 4)

Exhibit 4

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ITEM

1 OT 1.1.1 General

An ephemeris will be generated and stored in earth centered mean coordinate system (ECI) for each active vehicle, reflecting the maneuvers in the Mission Plan Table for a minimum of 30 hours ahead and a maximum of approximately 48 hours ahead for low orbits or approximately 10 days ahead for high orbits or until the vehicle reaches a kickout altitude of 50K above the earth. Kickout altitude above the moon will be zero K provided there is no descent maneuver in the Mission Plan Table.

Each trajectory update is completely independent of any previous trajectory updates. Future maneuvers defined in the Mission Plan Table are processed sequentially, and the maximum integration span is based on the type of orbit as a result of the last processed maneuver. The maximum integration span is used as a guide, and is not interpreted as an absolute maximum. The maximum integration time will be applied as follows:

- A. No ephemeris or maneuver processing will extend beyond ten days from the original anchor time.
- B. If the orbit is determined to be "low," integration will be terminated if the next maneuver is more than 48 hours away from the last integrated vector time.
- C. If the orbit is determined to be "high" and if the next maneuver is less than 10 days away from the time of the last integrated vector, it will be processed unless it has already failed the test described in (A).

The criteria for determining the maximum integration span will be the eccentricity and semimajor axis of the orbit. The eccentricity will be checked first. If it is greater than the criterion value, then a high orbit is assumed. If the eccentricity is less than the criterion value, then the orbit type is determined by the semimajor axis. The amount of ephemeris to be generated for the low and high orbits will be determined from system parameters. Currently, these values are 48 hours and 10 days respectively. (See Figure OT 1.1.1-1.) There will be a manual input to change the values of eccentricity and semimajor axis.

The ephemeris will be stored at a variable step size that is a function of the Encke integration step. The stored ephemeris will be stored at intervals which are consistent with accurate interpolation from the ephemeris.

Approved: NASA/FSB PHO/PARS

(OT) 1.1.1-1

Exhibit 4 (Cont'd.)

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Maneuvers will be represented in the ephemeris by vectors at ullage on, burnout, and vectors at a fixed interval (\underline{x} seconds) from each phase boundary within the maneuver. The fixed interval will be chosen to provide acceptable linear interpolation between any two consecutive points in the maneuver.

A table of maneuver times will be provided in the ephemeris data table, but will be logically separate from the ephemeris. The ullage on and burnout times of each maneuver encountered during the trajectory update will be stored. The interpolator makes use of these times to prevent interpolation from a mixture of free flight and thrust data.

If and when the minimum amount of ephemeris has been stored, space is reserved (at the end of the ephemeris) to store burn out vectors for the remaining maneuvers, and then integration continues until the table is full. Integration then continues through any remaining maneuvers, and the vectors at the end of each maneuver are stored in the reserved space. These burnout vectors are intended to provide free-flight vectors to be used for integrations in the future. That is, if ephemeris is desired beyond the range of the stored ephemeris, a burnout vector can be acquired from the nearest previous maneuver, and be used to integrate the desired ephemeris. However, there will exist the restriction that integration will not go beyond the anchor vector time plus maximum Δt hours that the main ephemeris would be generated.

At mission initialization a subset of precession-nutation matrices, sun and moon ephemeris data and libration matrices will be selected. The Encke NI will neglect precession-nutation. However, there are some computations that require precession-nutation. Therefore, when vectors are selected from the ephemeris and P&N is required, the vector must be rotated through P&N.

The vectors in the ephemeris will be in mean earth centered Inertial (ECI) Coordinate System, but the capability will exist to convert a vector to any one of the following coordinate systems:

ECT - Earth centered true

MCI - Moon centered inertial

MCT - Moon centered true

EMP - Moon centered Earth Moon plane.

The standard moon reference model to the assumed is a spherical moon having a radius of the landing site.

x To be provided by IBM

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Exhibit 4 (Cont'd.)

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The ephemeris will be generated the same way as outlined above for the following phases:

- Earth Orbit
- Translunar
- Lunar Orbit
- Transearth

If a descent maneuver is in the Mission Plan Table (MPT), a LM on the moon ephemeris will be generated provided no other criteria are violated. This ephemeris will be computed using a predetermined Δt which will be added to descent burnout time to establish the begin time of lunar stay. The Δt will be sufficiently small to prevent interpolation problems. There will be no free-flight integration between descent ignition and ascent burnout time.

The "lunar surface ephemeris" will be stored at three minute intervals.

The best $\phi\lambda R$ will be available from the LM Position Vector table and will be used to generate the lunar surface ephemeris.

The lunar surface ephemeris will be generated until the ascent maneuver is encountered or until normal ephemeris termination criteria are met. If an ascent maneuver is encountered, integration will be performed through the maneuver and then normal free flight integration will be resumed.

If the Ephemeris table is filled during lunar surface ephemeris generation any maneuvers remaining in the MPT will be processed as they normally are.

A kickout altitude of zero feet will be assumed for non-nominal impacting trajectories around the moon; that is, if the trajectory impacts without encountering the descent burn. The update will then be terminated and the T, ϕ , λ , of impact will be printed on-line.

The time, latitude and longitude will be printed on-line if the predicted trajectory reaches an Entry Interface altitude above an oblate earth or above the standard lunar reference model. The same information will be printed on-line for an altitude of 50K feet above an oblate earth and zero K above the standard lunar reference.

The SIVB ullage sequence will be included in the SIVB maneuvers computation, and the SPS ullage sequence will be included in the SPS maneuvers computation. SIVB venting maneuvers can be manually inserted in the Mission Plan Table.

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(OT) 1.1.1-5

Exhibit 4 (Cont'd.)

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A manual input of K-factor for modifying the earth orbit coefficient of drag is to be provided. The coefficient of drag will be multiplied by the manually inserted value. A trajectory update will be performed after each manual input of K-factor. Once a K-factor is manually inserted, it will be used until overridden by another manually inserted value.

A manual input of vehicle weight, cross-sectional area, is to be provided. This input will cause a trajectory update.

The capability will exist to generate a static ephemeris in any phase of the mission provided that ephemeris had not previously been active. Once an active ephemeris is generated there is no requirement to turn it off.

Approved: *[Signature]* NASA/FSB PHO/PARS

(OT) 1.1.1-6

ITEM

1

Lunar Surface Ephemeris Capabilities

While in lunar reference, the LM ephemeris will be maintained just as it is in Earth reference except additional information will be provided. A continuous Earth-centered mean inertial (ECI) ephemeris will be provided during Lunar Orbit, Lunar Descent, Lunar Stay, Lunar Ascent, and finally back to Lunar Orbit unless some cut-off criterion is met. The cut-off criteria will be basically the same as for a normal ephemeris. The following conditions will cause the LM ephemeris to be terminated:

1. Ephemeris table is filled.
2. Maximum time span is reached.
3. There is an error return from a maneuver integrator.
4. Lunar impact is not a result of the descent maneuver.

When the descent burn is encountered, it will be processed with an integrator provided by the Maneuver Control Department. Ephemeris will be stored through the descent burn just as it is for all other maneuvers. However, the descent burn will be recognized as such, and immediately after burnout (.1 of a second), the lunar surface ephemeris will start. There will be no free-flight integration between the descent and ascent maneuvers.

It is assumed that a position vector for the LM, representing the "BEST" landing site, will be available, and it will be used to generate the lunar surface ephemeris. It is understood that this same "BEST" LM vector will be used as a target by the descent integrator, and the descent burnout vector should be reasonably close to the target.

Since the lunar surface portion of the ephemeris starts immediately after the descent maneuver, there should be no interpolation problems involving free flight, thrust, and lunar surface vectors. However, the lunar surface vectors are limited in use and must be clearly identified. Since they do not have two-body motion relative to the moon, any attempt to integrate or make any calculations that assume two-body motion will provide erroneous results. It is not feasible to flag each lunar surface vector in the ephemeris, but the beginning and ending times of lunar stay will be stored for each trajectory update and will be provided upon request by ELFECH. Each user will then have the responsibility of identifying any lunar surface vectors that are passed to other programs.

Exhibit 5 is an excerpt from MSC Internal Note 68-FM-98, which provides formulation for the velocity transformation from selenographic to mean nearest Besselian year.

Functional Diagrams

Figure 8, the Trajectory Update Control diagram, shows the interfaces of EMSTRAJ and EMSEPH with other elements, unit, or subsystems. It also illustrates data table usage, task structure, and input/output data flow, as well as the general logic to be followed in providing the processing previously described. The symbols used in the diagrams are defined in the Glossary of this document.

Input/Output Specifications - On-Line Prints

This section is comprised of an excerpt from TR170A (see Exhibit 6), which outlines the required on-line prints, and the formats of these and other on-line prints that will be used for the trajectory update logic.

1. {LEM} {CSM} EPHEMERIS UPDATE COMPLETED

This message is printed each time EMSEPH completes the ephemeris storage. It does not necessarily indicate that a successful update was accomplished. Ensuing messages should be checked to see how much ephemeris was generated.

2. MINIMUM EPHEMERIS WAS NOT GENERATED

This message is only printed when an error condition exists. The error could originate with one of the integrators, or it could be that the ephemeris table was filled before minimum number of hours had been reached. Due to this error condition, the minimum number of hours could not be generated.

3. EPHEMERIS LIMITS ARE XXX:XX:XX.XX TO XXX:XX:XX.XX GMT

This message indicates the actual time range of the current ephemeris.

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Exhibit 5

RTCC REQUIREMENTS FOR MISSIONS F AND G:

SELENOGRAPHIC-MNEY VELOCITY TRANSFORMATION FORMULATION

By Paul F. Flanagan

SUMMARY

This document presents the formulation and implementation procedures for use in the RTCC for transforming velocity vectors from the selenographic coordinate system to the mean nearest Besselian year (MNEY) system. The formulation includes equations for computing the lunar angular velocity vector.

INTRODUCTION

The selenocentric MNEY system is moon centered and has its axes parallel to the following: the X-axis is in the mean earth equatorial plane and through the mean vernal equinox at the beginning of the nearest Besselian year; the Z-axis is north through the mean earth spin axis; and the Y-axis is on the mean earth equatorial plane and forms a right-handed orthogonal system.

The moon fixed selenographic system is defined as follows. The X-axis is fixed in the moon's equatorial plane and points approximately toward the center of the earth; the Z-axis is fixed in the moon through the moon spin axis; and the Y-axis is in the equatorial plane and completes the right-handed orthogonal system.

The interpolated precession-libration matrix (L) used to transform the velocity is also used to transform position vectors. If R_M is a position vector in the selenocentric MNEY system and R_G is a position vector in the selenographic system, then

$$R_M = L^T R_G$$

and

$$R_G = L R_M$$

Exhibit 5 (Cont'd.)

2

VELOCITY VECTOR TRANSFORMATION

The inertial MNBV velocity, \dot{R}_M , of a vehicle with a fixed selenographic position, R_G , is computed using the following equation

$$\dot{R}_M = L^T(\dot{W} \times R_G)$$

where W is the moon's angular velocity expressed in the selenographic system.

The following general equations can be used to compute the inertial velocity for a vehicle moving relative to the selenographic system at velocity \dot{R}_G or for the reverse computation.

$$\dot{R}_M = L^T(\dot{R}_G + W \times R_G)$$

$$\dot{R}_G = L\dot{R}_M - W \times R_G$$

COMPUTATION OF W

The following equations are used to compute the angular velocity vector, W . These equations account for the rate of change of Ω , the longitude of the mean ascending node of the lunar orbit measured in the ecliptic plane from the mean equinox of date, and M , the geocentric mean longitude of the moon measured in the ecliptic plane from the mean equinox of date to the mean ascending node of the lunar orbit, and then along the orbit.

The computations neglect the small effect of the rates of precession, obliquity of the ecliptic, and physical libration. The inclination (i) of the lunar orbit to the ecliptic is constant and is $1^\circ 32' 39''$ (ref. 1).

Prelaunch initialization:

1. Input year of launch, YOL, and day of launch, DOL.
2. Compute Julian centuries from January 0.5, 1900 to midnight prior to launch:

$$TIL = \text{integral part } [(YOL - 1901)/4]$$

$$TB = (YOL - 1900)365 + TIL + DOL$$

$$TM = TB/36525$$

3. Compute time rates of angles, $\dot{\Omega}$ and \dot{M} in rad/hr:

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Exhibit 5 (Cont'd.)

3

$$\dot{\Omega} = [-1934.1420083 + 0.004155556TM + (0.6666667 \times 10^{-5})TM^2]RATE$$

$$\dot{M} = [481267.8831417 - 0.002266667TM + (0.5666667 \times 10^{-5})TM^2]RATE$$

where $RATE = \pi / (180 \cdot 36525 \cdot 24) = 1.9110212776572292 \times 10^{-8}$ and converts $\dot{\Omega}$ and \dot{M} from deg/Julian century to rad/hr.

4. Compute constant terms:

$$K1 = \dot{\Omega} \cos i$$

$$K2 = \dot{\Omega} \sin i$$

5. Compute W_Z in rad/hr:

$$W_Z = \dot{M} - \dot{\Omega} + K1$$

Computation of W_X and W_Y at any time t during mission:

1. Input hours from midnight prior launch, H .
2. Compute Julian centuries from January 0.5, 1900 to anytime t :

$$T = (TB + H/24)/36525$$

3. Compute $M - \Omega$ in deg:

$$M - \Omega = 11.2508889 + 483202.02515T$$

$$- 0.003211111T^2 - (0.0333333 \times 10^{-5})T^3$$

4. Compute W_X and W_Y in rad/hr:

$$W_X = K2 \sin (M - \Omega)$$

$$W_Y = K2 \cos (M - \Omega)$$

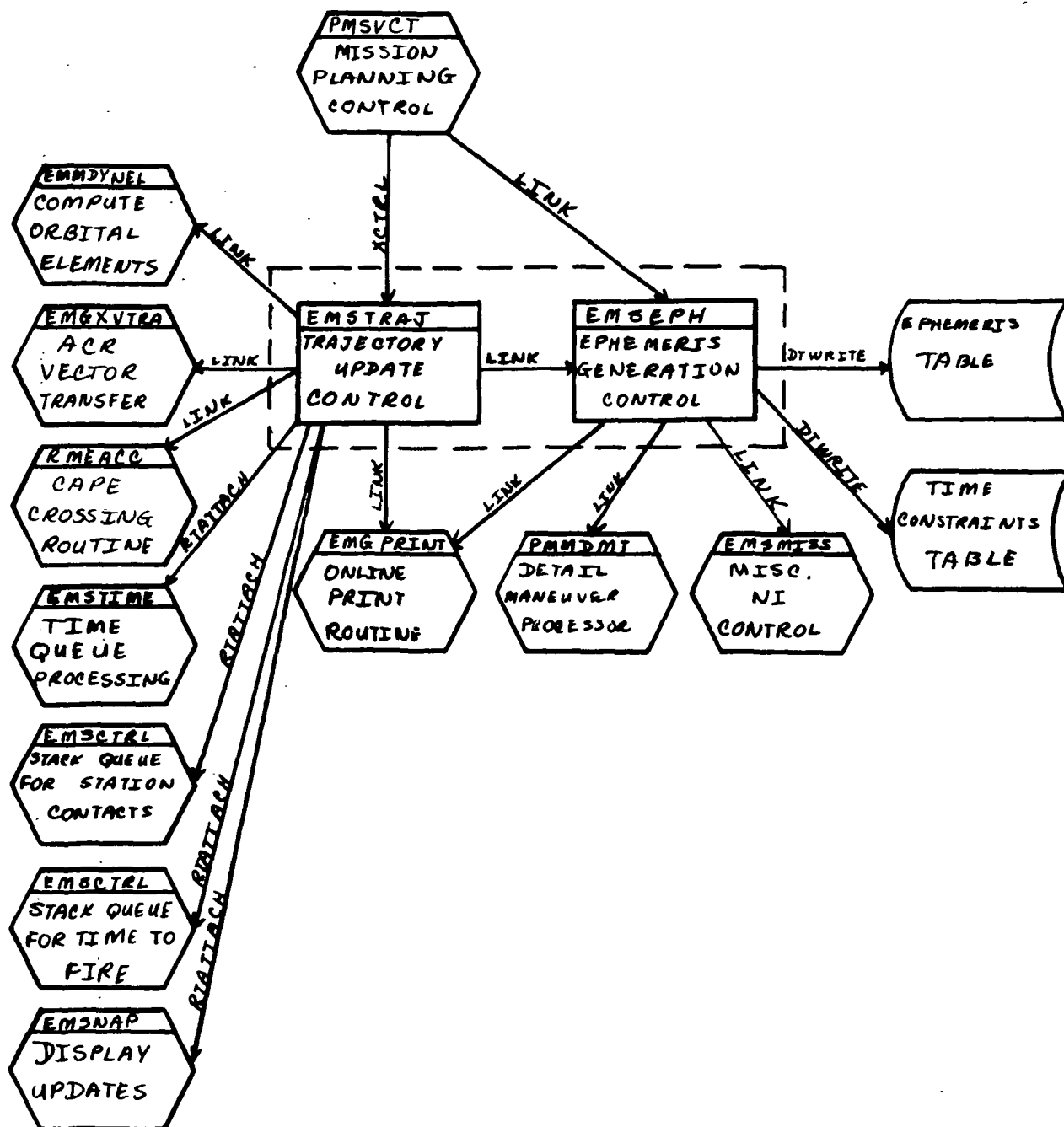


Figure 8. Trajectory Update Control

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Exhibit 6

PHO-TR170A
Volume 2, Change 53
11 March 1968

OT 1.2.1 On-Line Prints(EMSTRAJ) - $\left\{ \begin{smallmatrix} \text{CSM} \\ \text{LEM} \end{smallmatrix} \right\}$ Orbital Elements for Update No. XXX

A = XXXXXX.X NM Mean Anomaly = XXX.XX DEG $\mu(\text{AP})$ XXXXXX
I = XXX.XX DEG Arg. Perigee = XXX.XX DEG $\mu(\text{PER})$ = XX/XXX.
E = XXX.XXX Arg. Ascend. Node = XXX.XX DEG

Cause - Trajectory Update
Action - None

Cause - Trajectory update. This is the same vector that is
sent to the ACR on each trajectory update.

(EMSEPH) - $\left\{ \begin{smallmatrix} \text{CSM} \\ \text{LEM} \end{smallmatrix} \right\}$ below $\left\{ \begin{smallmatrix} \text{KO} \\ \text{EI} \end{smallmatrix} \right\}$ altitude at GET - XXX:XX:XX.

LAT = XX.XX (N or S) LON = XX.XX (E or W)

BURNOUT VECTOR FOR MANEUVER NO. XX CS XXX

X = +XX.XXXXXXXXXX Y = +XX.XXXXXXXXXX Z = +XX.XXXXXXXXXX

XV = +XX.XXXXXXXXXX YV = +XX.XXXXXXXXXX ZV = +XX.XXXXXXXXXX

GMT = HHH/MM/SS.SS WEIGHT = XXXXXX.X GMT = DDD/HH/MM/SS.SS

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4. $\left\{ \begin{matrix} \text{CSM} \\ \text{LEM} \end{matrix} \right\}$ BELOW $\begin{matrix} \text{KO} \\ \text{EI} \end{matrix}$ ALTITUDE AT GET = XXX:XX:XX.XX

$$\text{LAT} = \text{XX.XX} \left\{ \begin{matrix} \text{N} \\ \text{S} \end{matrix} \right\} \quad \text{LON} = \text{XX.XX} \left\{ \begin{matrix} \text{E} \\ \text{W} \end{matrix} \right\}$$

This message is printed if entry interface or kickout altitude is reached. If EI is reached, integration continues; but if kickout altitude is reached, the update is terminated.

5. $\left\{ \begin{matrix} \text{CSM} \\ \text{LEM} \end{matrix} \right\}$ ORBITAL ELEMENTS FOR UPDATE NO. XXX

A = XXXXXX.X NM MEAN ANOMALY = XXX.XX DEG

H (AP) = XXXXXX.NM

I = XXX.XX DEG ARG. PERIGEE = XXX.XX DEG

H(PER) = XXXXXX.NM

E = XXX.XXX ARG. ASCEND. NODE = XXX.XX DEG

The above values are calculated using Keplerian equations. They are printed at the end of each trajectory update and are based on the vector at or near current time that was used for the trajectory update.

6. BURNOUT VECTOR FOR MANEUVER NO. XX CS XXX

X = \pm XX.XXXXXXXXXX Y = \pm XX.XXXXXXXXXX Z = \pm XX.XXXXXXXXXX

XV = \pm XX.XXXXXXXXXX YV = \pm XX.XXXXXXXXXX ZV = \pm XX.XXXXXXXXXX

GMT = HHH/MM/SS.SS WEIGHT = XXXXXX.X GMT = DDD/HH/MM/SS.SS

7. ANCHOR VECTOR IS LUNAR SURFACE - NO ELEMENTS CALCULATED

DDD Lights

There are two Digital Display Driver (DDD) lights per vehicle controlled by the trajectory update logic. One of these indicates when a trajectory update is in process, and the other indicates that an error has occurred during the trajectory update processing. Exhibit 7 explains exactly when the lights are turned ON or OFF.

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Exhibit 7

PHO-Tri/oa
Volume 2, Change 42
18 Dec. 1967OT 1.2.2 DDD Lights

- A. Trajectory Update in Process. This light will be controlled by program EMSTRAJ. It will be turned on when a vector at or near current time is routed for a trajectory update and will be turned off when all trajectory processing under task PTMANC is complete. This includes ephemeris generation, cape table generation, ACR vector transfer, etc.
- B. Abnormal Ephemeris Conditions. This light is controlled by program EMSEPH. It will be turned on when an abnormal ephemeris condition is detected and will be turned off when a normal ephemeris update is completed. Conditions recognized as abnormal are as follows:
1. Any error occurs while attempting to integrate a vector up to present time to initiate a trajectory update.
 2. An error return other than kickout altitude is returned by an integrator.
 3. Ephemeris table was filled before the minimum time span was met.

Approved: Ly

NASA/FSB

PHO/PARS

(OT) 1.2.2-1

NUMERICAL INTEGRATION CONTROL ELEMENT

Function

The numerical integration element is composed of the two programs, EMSMISS and EMMENI. The purpose of the element is to predict the trajectory of the spacecraft, considering two-body motion and all significant perturbations, and to provide this information to the user according to his needs as conveniently as possible.

Program EMSMISS is a generalized numerical integration control program, which was designed to satisfy the integration needs of most users including the trajectory update logic. Program EMMENI is the Encke Numerical Integrator, which is used for all of the free-flight integration.

Load Module/Routines Description

Miscellaneous Numerical Integration (NI) Control Module - EMSMISS

Program EMSMISS provides the numerical integration capabilities that are required by most NI users. It was designed to operate within the framework of the real time mission system making use of various data tables and interfacing with other mission programs.

In particular, EMSMISS uses the Mission Plan Table to determine if and when maneuvers are scheduled. The area and weight that are passed to the Encke Integrator are normally the area and weight at the end of the last maneuver. However, the area and weight that are passed to the maneuver integrators are the area and weight of the configuration at maneuver initiation. For a separation maneuver, the configuration change is made prior to maneuver initiation. EMSMISS contains special logic to account for venting and expendables from the time of the last stored weight up to the time of the input vector.

EMSMISS contains the logic to interface with all necessary integrators. These integrators will be selected according to the type of maneuver being performed. The Runge-Kutta integrators will be used only for maneuvers, never for free-flight integration.

EMSMISS will contain the capability to generate a continuous ephemeris including lunar orbit and lunar surface vectors. Indicators will be provided in the input table to identify lunar surface vectors that are passed to EMSMISS and to specify

whether or not the ephemeris should be terminated at the end of the descent maneuver. The lunar stay portion of the ephemeris will be identified by begin and end times that will be stored in the auxiliary output table. If ephemeris generation continues beyond the descent maneuver, the "BEST" LM position vector will be used for lunar surface ephemeris generation. However, if the input vector is identified as a lunar surface vector, it will be used to generate the lunar surface ephemeris. Lunar surface ephemeris is always assumed to start .1 of a second after the end of the descent maneuver.

EMSMISS will operate in two modes: ephemeris and cut-off condition. When operating in the cut-off condition mode, the user does not desire an ephemeris but only a single vector that represents some desired condition on the trajectory. When operating in the ephemeris mode, the prime consideration is an ephemeris over a given interval, but certain cut-off conditions may also be requested.

In both modes of operation, the user will have the option of specifying whether or not maneuvers are to be considered. However, maneuvers will never be considered during backward integration or when the input anchor vector is within a maneuver. Since Runge-Kutta does not recognize all of the cut-off conditions, some conditions will not be found if they occur within a maneuver.

Cut-off conditions have been broken into three groups, and only one condition in each group may be requested.

- Group I: A radial distance from the Earth or moon
 The first reference switch encountered
 An altitude above the oblate Earth or spherical moon
 An inertial flight-path angle relative to the Earth or moon
 The first ascending node relative to the Earth
- Group II: The begin time of the first maneuver encountered
 The end time of the first maneuver encountered
- Group III: An elapsed time from the input anchor time
 (i. e. , a single vector at a particular time is desired.)

EMSMISS will handle ephemeris requests where the anchor time lies within or on either side of the ephemeris interval. If backward integration is required, it will be performed first without considering maneuvers. Forward integration will then be performed, if required, considering or not considering maneuver, depending upon the user's option. In all cases, the total requested ephemeris will be stored contiguously and forward in time. Ephemeris may be requested and returned in any of the following coordinate systems, which will be provided for trajectory-related processing.

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1. Earth-centered Inertial (ECI) (mean) - geocentric

The mean Besselian Coordinate System is an inertial system having the basic X-Y plane defined as the mean equatorial plane with the X-axis through the mean vernal equinox and the Z-axis through the mean North Pole at some epoch. The epochs for defining mean Besselian Coordinate Systems are on January 1 each year, and for our purposes, the nearest January 1 to launch date.

2. Earth-centered True (ECT) - geographic

This pseudo-inertial system has the basic X-Y plane defined as the true equatorial plane, with the Z-axis through the true North Pole. Now the X-axis is through Greenwich at midnight, preceding launch, and the orientation epoch is the nearest six-hour interval to current time.

3. Moon-centered Inertial (MCI) (mean) - selenocentric

This system is the same coordinate system as ECI, but with the origin at the center of the moon instead of the Earth.

4. Moon-centered True (MCT) - selenographic

This is a non-inertial coordinate system with the basic X-Y plane in the moon's true equatorial plane and the Z-axis through the true lunar rotational axis. The X-axis here is fixed in the moon's prime meridian and therefore rotates with the moon.

Because of the variable time steps, the user will not know how much space to allow for each table. Therefore, EMSMISS will use the GETMAIN facility to provide the maximum space and will then free the portion that is not used. The user will be left with the responsibility of freeing the ephemeris space after processing the data. For convenience of the user, all ephemeris space will be provided from subpool 101. This space may then be relinquished by a single FREEMAIN on the entire subpool.

The following is a listing of the input table for EMSMISS along with a brief description of each item. These items present the program's capabilities, but should not be assumed as a program standard.

1. Anchor time (time associated with the input vector)
2. Anchor vector (input vector)
3. Desired value of stopping parameter relative to the Earth
4. Desired value of stopping parameter relative to the moon

5. Maximum time of integration

This item is used to determine the integration termination time if no other cut-off criterion is met.

6. Storage interval for maneuver ephemeris

The maneuver integrator will be requested to store vectors at each maneuver phase boundary and at this interval from each phase boundary.

7. Storage interval for lunar surface ephemeris

Lunar surface vectors will be stored at this fixed interval except when an odd step is required to reach a particular time.

8. Density multiplier value

This item is required only if the user desires to perturb atmospheric density. The value supplied here will be used to multiply the system K-factor used in the integration.

9. Left limit of ephemeris (time to begin ephemeris)

10. Right limit of ephemeris (time to end ephemeris)

11. Minimum time between ephemeris points

This item is used in the calculations to determine the maximum amount of space required to contain the requested ephemeris. However, due to the special smoothing algorithm that is used by the Encke integrator, it is sometimes necessary to store points slightly closer together than the requested interval.

12. Reference frame of desired stopping parameter

This item may be used to specify that the cut-off condition be monitored in only Earth Orbit, only Lunar Orbit, or both. However, the Encke integrator can only monitor a cut-off condition relative to the central body in the integration scheme. The values of the Earth and moon stopping parameters must be supplied in items 3 and 4 above.

13. Minimum number of points desired in ephemeris

This item is used to guarantee the user enough points for a given order of interpolation. Integration will first be performed over the requested interval in the normal fashion. If the minimum number of points is not provided, the requested interval will be integrated in the time mode using a time step sufficiently small to guarantee the minimum number of points. If a maneuver is encountered in the requested interval, no attempt will be made to satisfy a minimum number of points.

- | | | |
|-----------------------------|---|--|
| 14. ECI ephemeris indicator |) | Any or all of the ephemerides may be requested in a single entry to EMSMISS. |
| 15. ECT ephemeris indicator | | |
| 16. MCI ephemeris indicator | | |
| 17. MCT ephemeris indicator | | |

18. Ephemeris build indicator

This item is used to specify whether or not any ephemeris is desired.

19. Maneuver cut-off indicator

The item is used to specify whether integration should be terminated at the beginning of the first encountered maneuver, the end of the first encountered maneuver, or neither.

20. Descent burn indicator

This item is used to specify whether or not to terminate ephemeris at the end of the LM descent maneuver.

21. Cut-off indicator (type of cut-off condition (e.g. T, R, h, γ))

22. Integration direction indicator (forward or backward)

23. Coordinate system indicator (PRF standards)

24. Maneuver indicator

This item is used to specify whether or not to consider maneuvers encountered during forward integration.

25. Vehicle code

26. Density multiplication override indicator.

This item is used to specify whether or not a density perturbing factor has been provided (item 8).

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27. Table of ephemeris addresses indicator
28. Reference switch table indicator
29. Maneuver times table indicator
30. Runge-Kutta auxiliary output table indicator
31. Runge-Kutta dense ephemeris table indicator
32. Update in process override indicator
33. Maneuver number of last maneuver to be ignored

The ephemeris is stored in T, R, V format at a variable step size. The regular ephemeris format contains the following output items:

1. Update number
2. Vehicle code
3. Coordinate system ID
4. Number of bytes in ephemeris
5. Number of vectors in ephemeris
6. Error return
7. Time of first vector in ephemeris
8. Time of last vector in ephemeris.

The miscellaneous NI auxiliary output table contains the error code, termination code, and other miscellaneous data related to the integration request. The following are output items in the table:

1. GMT of cut-off vector
 2. Cut-off vector
 3. Area corresponding to input vector
 4. Weight corresponding to input vector
 5. Area corresponding to cut-off vector
 6. Weight corresponding to cut-off vector
 7. Coordinate system of cut-off vector
 8. Error code
 9. Termination code
 10. Maneuver number of last processed maneuver.
 11. Lunar stay begin time
 12. Lunar stay end time
- } as reflected in ephemeris span

A table of ephemeris addresses is required only when the user has indicated that he wants an ephemeris built. It is the user's responsibility to FREEMAIN from subpool 101 the ephemeris storage area returned to him once his processing of that data is complete. The output items in this table are the addresses of the ECI, ECT, MCI, and MCT tables.

Since more than one vector is returned when cutoff occurs at a reference switch, a special table is required. The items listed below are found in this table.

1. GMT of input vector
2. Input vector
3. Coordinate system ID of input vector
4. GMT of vector at reference switch
5. Vector prior to switch
6. Coordinate system ID prior to switch
7. GMT of vector at reference switch
8. Vector after reference switch
9. Coordinate system ID after switch
10. GMT of last vector (TR)
11. Last vector in proper reference
12. Coordinate system ID of last vector

Additional output tables may be provided, but the number would be dependent upon the user's request. The following tables are not discussed in this document, but may be among those required.

- Table of Maneuver Times

The table of maneuver times is optional in both the ephemeris and cut-off modes. However, unless the user does not wish to consider maneuvers, or he is sure that no maneuvers occur in his ephemeris span, it is strongly recommended that this table be requested in the ephemeris mode.

- Runge-Kutta Auxiliary Output

This table is exactly the same as that returned by Runge-Kutta. It may be requested for the last processed maneuver in either mode. Although it is not required to cut off at the end of the maneuver, it is recommended because other maneuvers may occur in the integration span.

- Runge-Kutta Dense Ephemeris

When operating in the cut-off mode, a dense ephemeris through the first encountered maneuver may be requested. The user need only supply a step size for the Runge-Kutta ephemeris and set the proper indicators.



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Vehicle Weight Specifications for EMSMISS

Past philosophy has dictated that the stored weights in the Mission Plan Table were correct, except possibly for venting weight losses, and should be used throughout the system. However, cases have been identified where the user starts with a vector that is different from the current trajectory, and as a result, the weights after maneuvers are different. Since it is sometimes necessary for the user to make repeated calls to EMSMISS, maintaining his updated weights, it is almost imperative that EMSMISS allow the user to supply the initial weights.

To maintain consistency and to implement the above capabilities with the least amount of impact, the following assumptions are made.

1. During a trajectory update, the DMT processor will store the weights returned by the maneuver integrator intact.
2. The vehicle weight library routine will provide an option to allow the user to provide the initial weights, and to request updated weights at a given time.
3. The vehicle weight library routine will provide an option to include or exclude venting in the weight loss considerations.

Below is an outline of the steps to be taken by EMSMISS to determine the vehicle weight at any given time.

1. An option will be provided so the user can specify whether he is providing the initial weights or whether the weights should be determined from the Mission Plan Table. If weights are supplied, they are assumed to be absolutely correct for the application. If weights are not provided, the vehicle weight routine will be called to provide the weights, considering all weight losses including venting. In both cases, the initial weights will then be stored in an internal table in EMSMISS.
2. The total weight passed to the Encke integrator will be determined by adding the component weights in the internal table according to the current configuration.
3. On each return from the Encke integrator, the S-IVB weight will be adjusted, if necessary, to account for venting.
4. If a maneuver is encountered, EMSMISS will determine if it is a separation maneuver; if it is, EMSMISS will adjust the configuration code and zero the weight of the vehicle being discarded. The weight routine will then be provided with the table of weights and will be requested to adjust the weights, considering all weight losses except venting.
5. On each return from a maneuver integrator, the weights in the internal table will be updated, using the weights returned by the maneuver integrator. EMSMISS will then determine if the maneuver was a docking maneuver; if it was, EMSMISS will get the weight of the new component(s) from the Mission Plan Table.

6. The above process will be repeated until the termination time of integration is reached. The weight routine will be called again to adjust the weights, if necessary, to account for all weight losses except venting. The user's input weight table will then be overlayed with the weights from the EMSMISS internal table.

Encke Numerical Integrator - EMMENI

This program has the function of trajectory computation or orbit prediction of a spacecraft at any time from a given initial state vector and time. The equations of motion, which have no analytical solution, are numerically integrated and are restricted to the general vicinity of the Earth or moon. This restriction is imposed because the potential function contains only the terms related to the Earth, moon and sun. Gravitational accelerations acting on the spacecraft due to the Earth, moon and sun are considered as point masses with the central body potential function being modified to include the effect of oblateness. The acceleration contributions due to atmospheric drag and thrusting are also included when appropriate. The central body is defined as the body (Earth or moon) at which the center of origin of the inertial reference system is located. The direction of the X-axis of the inertial reference frame is dictated by the line of ascending node of the mean equator of the Earth and the equinox based on the nearest beginning of a year. The Z-axis is directed northward along the spin axis of the Earth, and the Y-axis completes the right-handed coordinate system.

There are two basic perturbation schemes available to the program user, namely the Cowell and Encke schemes. The Encke scheme has the additional option of using the universal conic parameter " β ", usually attributed to Herrick, as the independent variable, as well as the commonly used independent variable, time. The methods available for performing the stepwise numerical integration of the three second-order differential equations of motion are a sixth-order backward difference multistep predictor-corrector procedure and a onestep Runge-Kutta method, as modified by Nystrom, equivalent to a fourth-order Taylor series expansion. The predictor-corrector method uses the Runge-Kutta method as a starting procedure in all cases to build the needed difference tables. The first seven integration steps of any restart caused by rectification, step size change and/or reference body switch are taken using the Runge-Kutta method. The step size used by the Runge-Kutta method is calculated as one-fourth the predictor-corrector method's step size. The step sizes for the predictor-corrector are obtained as a function of the radial distance of the spacecraft from the central body or as they are commonly called, concentric rings, and their values have been chosen sufficiently conservative to enable the predictor-corrector formulas to be applied only once per step.

The equations of a spacecraft relative to a central body are generally written in vector notation shown in equation (1). The first term on the right-hand side of the equation represents the acceleration due to the attraction of the central

body with the second term, often called the perturbation term, accounting for all other accelerations such as central body oblateness, atmospheric drag, thrusting and sun and/or secondary body attractions.

$$\ddot{\vec{r}} = -\frac{\mu}{|\vec{r}|^3} \vec{r} + \ddot{\vec{P}} \quad (1)$$

In the Cowell scheme, the above vector equation is integrated twice in a straightforward manner by a stepwise numerical integration procedure to obtain \vec{r} and $\dot{\vec{r}}$ at time $(t + h)$, using the given initial \vec{r} and $\dot{\vec{r}}$ at time (t) as a base. Simplicity and the relative lack of concern about the dominate term in equation (1) are the biggest assets of the Cowell scheme.

The Encke scheme requires rearrangement of equation (1) into a different but equally valid form shown as equation (2).

$$\ddot{\vec{r}} = \ddot{\vec{r}}_{2\text{-body}} + \ddot{\vec{\zeta}} \quad (2)$$

The term $\ddot{\vec{r}}_{2\text{-body}}$ in equation (2) yields the classical two-body problem that treats the central body as a point mass, neglecting all perturbations, and can be written in the vector notation form shown in equation (3).

$$\ddot{\vec{r}}_{2\text{-body}} = -\frac{\mu}{|\vec{r}_{2\text{-body}}|^3} \vec{r}_{2\text{-body}} \quad (3)$$

The solutions of equation (3) for the position and velocity vectors at any time (t) relative to a reference point resulting from the unperturbed orbit associated with the two-body problem can be found to a high degree of accuracy without the use of a numerical integration procedure. Taking advantage of the closed form two-body solution leaves only the term $\ddot{\vec{\zeta}}$ of equation (2) to be accounted for by numerical integration. Substitution of equations (1) and (3) into equation (2) results in equation (4) accounting for the deviation of the two-body solution vectors associated with equation (3) from the true position and velocity vectors and the perturbation term previously defined in (1).

$$\ddot{\vec{\zeta}} = -\mu \left(\frac{\vec{r}}{|\vec{r}|^3} - \frac{\vec{r}_{2\text{-body}}}{|\vec{r}_{2\text{-body}}|^3} \right) + \ddot{\vec{P}} \quad (4)$$

The time mode of the Encke scheme requires integration of equation (4) twice, using the same stepwise numerical integration procedure employed in the Cowell scheme to obtain the $\vec{\zeta}$ and $\dot{\vec{\zeta}}$ vectors at time $(t + h)$.

The solution for the true position and velocity vectors, \vec{r} and $\dot{\vec{r}}$ at time $(t + h)$, may then be completed by adding on the two-body vectors, $\vec{r}_{2\text{-body}}$ and

$\dot{\vec{r}}_{2\text{-body}}$ at time $(t + h)$ obtained from the closed-form solution. Numerical accuracy control of the above procedure is accomplished by a process called rectification, which redescribes the reference point for the two-body problem whenever the contribution of the integrated portion to the true solution reaches any significant amount, say 2% for either the position or velocity vectors. The need for a slightly more sophisticated logic and accuracy control has been shown to be far outweighed by the reduction in running time on typical Earth-moon free-flight trajectories due to the ability of the Encke scheme to use larger computational step sizes in the numerical integration procedure to achieve the same degree of accuracy as the Cowell scheme.

The β mode of the Encke integration scheme is analogous to the previously defined time mode except that equation (4) is now relative to β instead of time. This program makes use of exactly the same code for the acceleration calculations and then converts the time relative quantities to β units. This conversion is made possible by use of some basic relationship between β and time. The definition of β shown as equation (5) provides one such relationship *

$$\beta = \sqrt{a} \theta$$

where

$$\theta = E - E_0 \quad (5)$$

a = semimajor axis of the conic described
at the last point of rectification.

Another relationship is Kepler's equation concerning two-body motion.

$$\eta(t - \tau) = E - e \sin E \quad (6)$$

Differentiating equations (5) and (6) in various manners results in several useful relationships between time, β , and eccentric anomaly that can be applied to arrive at the desired conversion constants.

* All relationships in terms of β are shown for the elliptic case, but equivalent expressions are available for all conics.

$$\beta = \sqrt{a} (E - E_0)$$

$$\eta(t - \tau) = E - e \sin E$$

$$\frac{d\beta}{dE} = \sqrt{a} \quad (7)$$

$$\frac{dE}{dt} = \frac{\eta}{1 - e \cos E} \quad (10)$$

$$\frac{dE}{d\beta} = \frac{1}{\sqrt{a}} \quad (8)$$

$$\frac{dt}{dE} = \frac{1 - e \cos E}{\eta} \quad (11)$$

$$\frac{d^2 E}{d\beta^2} = 0 \quad (9)$$

$$\frac{d^2 t}{dE^2} = \frac{e \sin E}{\eta} \quad (12)$$

By use of the above identities and the chain rule of differentiation, it is possible to establish conversion factors that will convert any velocity term between time and β units. These conversion constants are given as equations (13) and (14).

$$\frac{d\beta}{dt} = \left(\frac{d\beta}{dE} \right) \left(\frac{dE}{dt} \right) = (\sqrt{a}) \left(\frac{\eta}{1 - e \cos E} \right) \quad (13)$$

$$\frac{dt}{d\beta} = \left(\frac{dt}{dE} \right) \left(\frac{dE}{d\beta} \right) = \left(\frac{1 - e \cos E}{\eta} \right) \left(\frac{1}{\sqrt{a}} \right) \quad (14)$$

Equations (15) and (16) show the use of the above conversion factors after substitution for the following two quantities.

$$\eta = \sqrt{\frac{\mu}{a^3}}$$

$$1 - e \cos E = \frac{|\vec{r}_{2\text{-body}}|}{a}$$

$$\frac{d\vec{r}}{d\beta} = \left(\frac{d\vec{r}}{d\beta} \right) \left(\frac{d\beta}{dt} \right) = \left(\frac{d\vec{r}}{dt} \right) \left(\frac{|\vec{r}_{2\text{-body}}|}{\sqrt{\mu}} \right) \quad (15)$$

$$\frac{d\vec{r}}{dt} = \left(\frac{d\vec{r}}{d\beta} \right) \left(\frac{d\beta}{dt} \right) = \left(\frac{d\vec{r}}{d\beta} \right) \left(\frac{\sqrt{\mu}}{|\vec{r}_{2\text{-body}}|} \right) \quad (16)$$

It is now desired that a conversion procedure be found for converting acceleration with respect to time to β units. Differentiating equation (15) again with respect to β and using the chain rule results in equation (17).

$$\begin{aligned}
 \frac{d^2 \vec{r}}{d\beta^2} &= \left\{ \frac{d \left(\frac{d\vec{r}}{dt} \right)}{d\beta} \right\} \left(\frac{dt}{d\beta} \right) + \left(\frac{d\vec{r}}{dt} \right) \left\{ \frac{d \left(\frac{dt}{d\beta} \right)}{d\beta} \right\} \\
 &= \left\{ \frac{d \left(\frac{d\vec{r}}{dt} \right)}{dt} \right\} \left(\frac{dt}{d\beta} \right) \left(\frac{dt}{d\beta} \right) + \left(\frac{d\vec{r}}{dt} \right) \left(\frac{d^2 t}{d\beta^2} \right) \\
 &= \left(\frac{d^2 \vec{r}}{dt^2} \right) \left(\frac{dt}{d\beta} \right)^2 + \left(\frac{d\vec{r}}{dt} \right) \left(\frac{d^2 t}{d\beta^2} \right) \quad (17)
 \end{aligned}$$

The term $\frac{d^2 t}{d\beta^2}$ is now developed in the following manner using equation (14) as a foundation.

$$\begin{aligned}
 \left(\frac{d^2 t}{d\beta^2} \right) &= \left\{ \frac{d \left(\frac{dt}{dE} \right)}{d\beta} \right\} \left(\frac{dE}{d\beta} \right) + \left(\frac{dt}{dE} \right) \left\{ \frac{d \left(\frac{dE}{d\beta} \right)}{d\beta} \right\} \\
 &= \left\{ \frac{d \left(\frac{dt}{dE} \right)}{dE} \right\} \left(\frac{dE}{d\beta} \right) \left(\frac{dE}{d\beta} \right) + \left(\frac{dt}{dE} \right) \left(\frac{d^2 E}{d\beta^2} \right) \\
 &= \left(\frac{d^2 t}{dE^2} \right) \left(\frac{dE}{d\beta} \right)^2 + \left(\frac{dt}{dE} \right) \left(\frac{d^2 E}{d\beta^2} \right)
 \end{aligned}$$

Substitution of equations (8), (9), (11) and (12) into the above equation gives us the desired constant, (18)

$$\begin{aligned}\frac{d^2 t}{d\beta^2} &= \left(\frac{e \sin E}{\eta} \right) \left(\frac{1}{\sqrt{a}} \right)^2 + \left(\frac{1 - e \cos E}{\eta} \right) (0) \\ &= \frac{e \sin E}{a\eta}\end{aligned}$$

where

$$e \sin E = \frac{\vec{r}_{2\text{-body}} \cdot \dot{\vec{r}}_{2\text{-body}}}{\mu a}$$

Therefore,

$$\frac{d^2 t}{d\beta^2} = \frac{\vec{r}_{2\text{-body}} \cdot \dot{\vec{r}}_{2\text{-body}}}{\mu} \quad (18)$$

Equation (17) now gives us the capability of expressing the β -related acceleration by use of two conversion factors pertaining to the two-body problem, the time related velocity and the time related acceleration. We now write (19), an equivalent of equation (4) expressed with respect to β . The nomenclature used below has prime quantities designating β -related terms, and the dotted quantities are relative to time.

$$\begin{aligned}\ddot{\xi} &= \ddot{\xi} \left(\frac{dt}{d\beta} \right)^2 + \dot{\xi} \left(\frac{d^2 t}{d\beta^2} \right) \\ &= \ddot{\xi} \left(\frac{|\vec{r}_{2\text{-body}}|^2}{\mu} \right) + \dot{\xi} \left(\frac{\vec{r}_{2\text{-body}} \cdot \dot{\vec{r}}_{2\text{-body}}}{\mu} \right) \quad (19)\end{aligned}$$

The necessity of evaluating the velocity relative to time for both the $\dot{\xi}$ and $\dot{\vec{r}}_{2\text{-body}}$ terms in equation (19) was found to be wasteful for this particular application. Equation (20) is used in place of (19) to take advantage of the existing programming units.

$$\ddot{\xi} = \ddot{\xi} \left(\frac{|\vec{r}_{2\text{-body}}|^2}{\mu} \right) + \dot{\xi}' \left(\frac{\vec{r}_{2\text{-body}} \cdot \dot{\vec{r}}_{2\text{-body}}}{\sqrt{\mu} |\vec{r}_{2\text{-body}}|} \right) \quad (20)$$

Equation (20) is the final form of the equation for evaluating the acceleration in β units. The same numerical integration procedure as previously described is used to obtain $\vec{\xi}$ and $\vec{\xi}'$ at a time point that is a function of β .

The β mode of the Encke integration scheme was introduced for a variety of reasons. The use of a consistent set of two-body motion modules by all phases of the mission planning program has been convenient. Reasons more specific to the integration procedure require examination of some of the definitions. The first such examination reveals that the behavior of β enables us to use a more nearly uniform integration step size for the entire Earth-moon trajectory without sacrificing accuracy. This results in a time savings from not needing to rebuild the difference tables associated with the predictor-corrector procedure as often. An even more important factor is the elimination of the need for solving Kepler's equation by an iterative procedure. Since the two-body position and velocity vectors are the foundation of the Encke scheme, any reduction in the complexity of their solution is normally worthwhile. This savings can be shown by looking at equation (21), which is Kepler's equation written in universal form with β and time as the free variables.

$$\mu (t - t_0) = \beta^3 f_1(\beta) + \frac{\vec{r}_0 \cdot \vec{f}_0}{\mu} \beta^2 f_2(\beta) + |\vec{r}_0| \beta f_3(\beta) \quad (21)$$

Since this equation contains both β and transcendental functions of β ($f_1(\beta)$, $f_2(\beta)$, $f_3(\beta)$), the ease of solution of equation (21) is immeasurably simpler when β is known instead of $(t - t_0)$. The Encke β mode requires only a direct substitution of β into a set of series approximations for values of the transcendental functions (described in detail in the β -related routines writeup) in order to determine the corresponding value of $(t - t_0)$. The Encke time mode requires an iterative procedure involving the selection of a value of β that results in the known $(t - t_0)$. Each pass through the iteration requires evaluation of the transcendental functions.

Examination of the conversion factor applied to the $\vec{\xi}'$ term in equation (20) led to another worthwhile idea. Replacement of the dot product quantity by an equivalent expression in terms of the base point on the reference trajectory eliminates the need of always dotting the two vectors to find the dot product. Equation (22) is this replacement taking advantage of the already formed transcendental function, and it can be validated by referring to the β -related routines writeup.

$$\frac{\vec{r}_{2\text{-body}} \cdot \vec{r}'_{2\text{-body}}}{|\vec{r}_{2\text{-body}}|} = \left(1 - \frac{|\vec{r}_o|}{\alpha}\right) f_3(\beta) + \left(\frac{\vec{r}_o \cdot \vec{r}'_o}{|\vec{r}_o|}\right) f_4(\beta) \quad (22)$$

Program EMMENI stores ephemeris at a variable time step in the format T, R, V. Each integration step is stored unless the user specifies a minimum output step. In this case, a special algorithm is used, which was developed for storing a variable step ephemeris at a multiple of the natural variable step size subject to a desired minimum interval.

This algorithm, developed by H. L. Norman of IBM, states that when the time required to reach the next minimum output point is less than one-half of the time span of the last integration step, the vector at the end of the last integration step should be stored. The minimum step size specified by the user is not regarded as an absolute minimum, but is used as a guide in determining the output step. The algorithm prevents excessive use of space by not storing at too small an interval, guards against too large an interval with resulting interpolation errors, and gives an almost constant step size within the time domain, where a certain multiple "n" is used. The discontinuity points where "n" changes are given by

$$\Delta t = n \Delta t_i = \frac{2 \Delta t_{\min}}{2n + 1}$$

where $n = 1, 2, \dots$. For $\Delta t_{\min} = 3^m$, the ephemeris would be stored as follows:

$$2^m \leq \Delta t_i < \infty \quad \Delta t = \Delta t_i$$

$$1.2^m \leq \Delta t_i < 2^m \quad \Delta t = 2 \Delta t_i$$

$$51^s \leq \Delta t_i < 1.2 \quad \Delta t = 3 \Delta t_i$$

The potential model for the Lunar Landing Program (LLP) will contain both Earth and Lunar Orbit consideration, using harmonic coefficients J2, J3, J4 and J22 in each case. When in Earth reference, the moon is treated as a point mass and when in moon reference, the Earth is treated as a point mass. The sun is considered as a point mass in either reference. The atmospheric drag perturbation will be considered up to 700 kilometers above the surface of the Earth. In addition, a venting model will be included to consider thrust due to the venting of

hydrogen vapors when the S-IVB is a part of the vehicle configuration. The venting model will make use of a table of thrust values that is measured from approximately orbit insertion. On each integration step, a linear interpolation will be performed to determine the thrust level to be used for that step. Also, making use of the computed thrust level and a specific impulse constant, a weight loss rate will be calculated and applied over each integration step. The Encke integrator will not consider precession or nutation of the Earth.

The Encke integrator will terminate integration on an absolute maximum time span that is determined by the type of orbit unless it encounters some other cut-off condition first. The type of orbit is determined by the eccentricity and semimajor axis.

Limitations and Constraints of EMMENI

During the program development and testing activities, it became apparent that a special protective code should be implemented to avoid prolonged periods of integration as well as irrecoverable loop conditions. Below is a list of current "fail soft" procedures and known program constraints:

- Some cut-off conditions are only detected if they occur in the reference frame in which the integrator is integrating. For example, a request to terminate at an altitude of 50 Earth radii from the moon will not be successful since the integrator will not be integrating in moon reference when the spacecraft is 50 Earth radii from the moon. (Radial distance is exception.)
- Cut-off conditions can not be detected unless they can be bounded on an integration step. For example, a request to terminate at a radial distance that occurred at apogee probably would not be successful since points to either side of apogee would be less than apogee. A similar problem occurs at perigee.
- When EMMENI detects that the trajectory passes below the surface of the central body, all perturbations are zeroed.
- If the drag perturbation is zero when the trajectory enters the central body, integration will continue. If the drag perturbation is non-zero, integration will be terminated.
- When integrating in the atmosphere, if the altitude/relative velocity ratio reaches a certain minimum value, the drag perturbation will not be recomputed; but the last computed drag perturbation will be used.

- On each integration step, EMMENI will monitor a system parameter setting. If the system parameter is zero, integration continues. Otherwise, integration is terminated, and an error code is returned to the user. A MED capability has been added to set the system parameter as desired.

Functional Diagrams

The Numerical Integration Control, Figure 9, shows the interface between EMSMISS and other elements, units, or subsystems. Included also are data table usage, task structure, and input/output data flow. A key to the symbols used in this diagram may be found in the Glossary of the document.

Input/Output Specifications - On-Line Prints

The following error message is printed on line for additional information.

ERROR RETURN FROM MANEUVER INTEGRATOR
ERROR CODE=XX MANEUVER NO.=XX

An error occurred while trying to process a maneuver. The error code is the same as is returned by the integrator. An explanation of the error codes should be available at the Dynamics console.

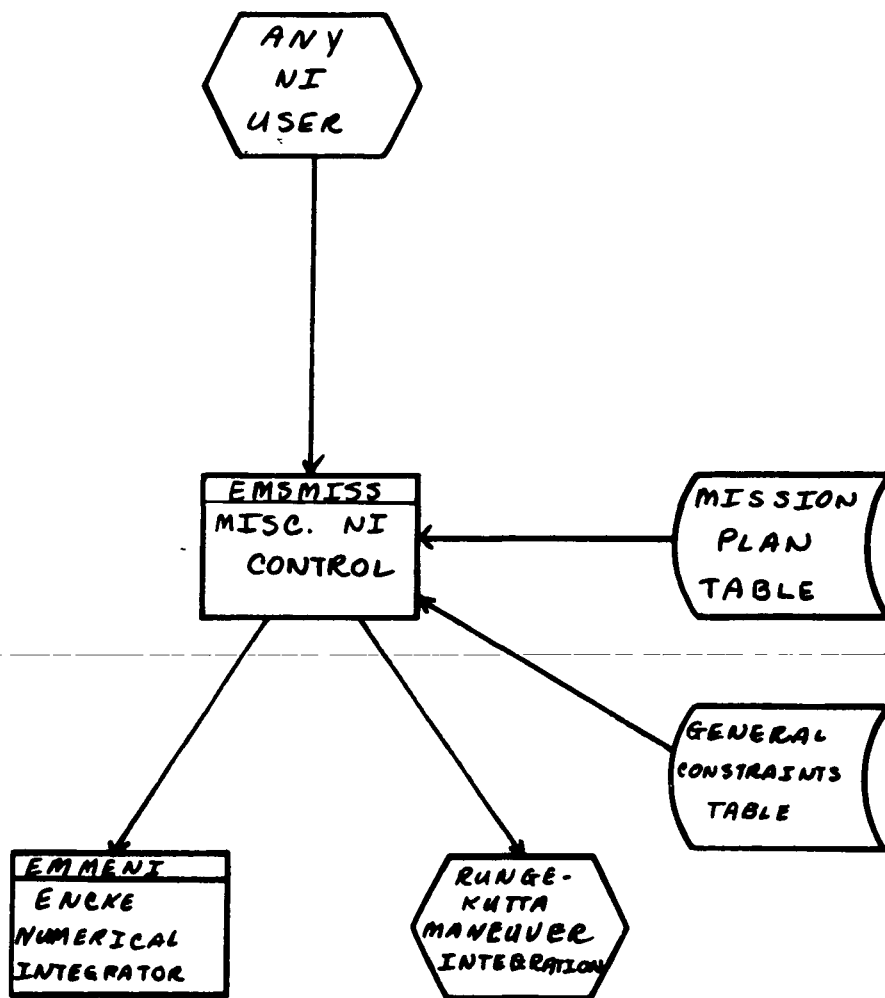


Figure 9. Numerical Integration Control

TELETYPE TRANSMISSIONS AND SPECIAL ON-LINE PRINTS

Function

This element is composed of three programs, EMGXVTRA, EMMVRTTY, and EMMLINUS. The purpose of the element is to transmit trajectory-related data to offsite locations for off-line processing and to print special trajectory-related information on line when requested by MED. In addition, each teletype transmission will have a corresponding on-line print.

Load Modules/Routines Description

RTACF Vector Transfer Module - EMGXVTRA

Program EMGXVTRA is queued on each trajectory update and upon manual request. It transmits the specified vector, revolution number, vehicle weight, lift-off time, and coordinate system ID to the Real Time Auxiliary Computing Facility (RTACF). An option exists on the MED to transmit the same data to the Marshall Space Flight Center (MSFC) instead of the RTACF.

When EMGXVTRA is queued on a trajectory update, it transmits the vector at or near present time that was used to generate the new ephemeris. When it is queued by MED, a vector ID is supplied, and EMGXVTRA retrieves the specified vector from the usable vector table using program BMSVPS.

GSFC Maneuver Definition Transfer Module - EMMVRTTY

Program EMMVRTTY is queued only by manual request and is used to transmit maneuver information to Goddard Space Flight Center (GSFC). Only maneuvers that are completely defined in the Mission Plan Table may be transmitted, and only one maneuver may be transmitted on each queue. The following information will be transmitted for each request:

1. Vehicle ID corresponding to the Mission Plan Table from which the maneuver was taken
2. The duration of the burn in seconds excluding ullage
3. GMT of main engine ignition
4. Vehicle weight (configuration weight) at main engine ignition
5. Vector at main engine ignition
6. GMT at the end of tailoff
7. Vehicle weight (configuration weight) at the end of tailoff
8. Vector at the end of tailoff.

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The vector coordinate systems will always be Earth-centered True of Date (ECT).

Special On-line Print Module - EMMLINUS

Program EMMLINUS is queued only by manual request and is used to print special trajectory-related information on line. In particular, the position of the sun relative to the Earth, the position and velocity of the moon relative to the Earth, an interpolated libration matrix or the nearest precession and nutation matrix, and the longitude of Greenwich will be printed for the time specified on the MED. If no time is entered, present time is assumed.

Requirements Interpretation

Exhibits 8 through 12 show the requirements presented in the TR-170A and the Apollo Tracking Data Format Control Book that relate to the processing of this element. The significant items have been assigned a number, and our interpretation has been given for each.

ITEMS

- 1 On each trajectory update, the vector at or near present time will be sent to the RTACF. In addition, any vector in the usable vector table will be sent to the RTACF upon manual request. The format of the message will be as set forth in the excerpt from the Apollo Tracking Data Format Control.
- 2 The vector ID will be the same as the one provided in the usable vector table when applicable. If the vector is an insertion vector or a restart vector, the ID will be INSE. If it is a nominal insertion vector, such that a static ephemeris is generated, the ID will be STAT.
- 3 Revolution numbers are obtained from the table of Cape Crossing times. Thus, EMGXVTRA is subject to the constraints imposed by the Cape Crossing processor.
- 4 When program EMGXVTRA is queued on the trajectory update cycle, the vector that is sent to the RTACF has been integrated to some multiple of a centisecond. However, when EMGXVTRA is queued by MED to transmit a vector from the Usable Vector Table, the time of the vector may not be on a centisecond boundary and, thus, is rounded.

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Exhibit 8

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ITEM

OT 5.2.7 Real-Time Auxiliary Computer Facility (RTACF) Vector

- 1 Certain data for both the CSM, S4B and LM will be computed by the RTCC and transmitted (via teletype) to the RTACF. These data will be used as the basis for off-line computations made during mission periods for study purposes. These computations will be made for a particular vehicle for the initial phase vector, for each trajectory update, and upon manual request.

A. The format of the RTACF vector message is contained in the Apollo Tracking Data Format Control Book, Section 2.4.2.

B. Requirements for the transmitted data are as follows:

	<u>QUANTITY</u>	<u>DEFINITION</u>
2	Vector ID	Indicates the data source used to compute the vector
3	Revolution Number	Revolution number in which data was gathered if it can be determined. If the revolution number cannot be determined, zeroes are placed in the revolution number slot.
4	GMT	GMT (HHMMSS.SS) of the vector
5	GMTLO	GMT (HHMMSS.SS) of liftoff
6	X,Y,Z, \dot{X} , \dot{Y} , \dot{Z}	Inertial position and velocity of the vector (ER and ER/HR in floating octal)
7	Vehicle Name	S4B, CSM, <u>LM</u>
8	W	Weight of the vehicle
	E or M	Reference body indicator (E = Earth reference, M = Moon reference)

The inertial position and velocity anchor vector may be sent via MED from the usable vector slot. The vector will be transmitted to the RTACF in either the ECI or MCI depending upon which reference is associated with the stored vector.

When a vector is sent to the RTACF using the automatic mode, the vector will be transmitted to the RTACF in either the ECI or MCI depending upon which system the integrator is currently using.

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Exhibit 8 (Cont'd.)

PHO-TR170A
Volume 2, Change 41
11 Dec. 1967ITEM C. RTACF Retransmission MEDCODE, VECTOR ID, VEHICLE ID, M;

9

VECTOR ID

- CMC - Command Module Computer (AGC)
- LGC - LM Guidance Computer
- AGS - Abort Guidance System Computer
- IU - Instrumentation Unit on S-IVB
- HSR - High-Speed Radar
- DC

VEHICLE ID

- LM
- CSM

M. The use of this option causes a vector to be sent only to the Marshall Space Flight Center, HOSC.

Approved: 

NASA/FSB

PHO/PARS

(OT) 5.2.7-2

Exhibit 9

PHO-TR170A
Volume 2, Change 53
11 March 1968ITEM OT 5.2.2 On-Line Print RequirementsA. Transmission of Acquisition Messages. Should indicate:

- Station ID
- VEHICLE (CSM, LM)
- Indication if a DOD vector was transmitted

B. Transmission of the Real-Time Auxiliary Computer Facility (RTACF) Vector. Should indicate:

- GMT of vector: $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$
- WEIGHT
- STATION ID
- VEHICLE (CSM, LM)
- Earth or Moon Reference Indicator

C. Transmission of Vector to Marshall Space Flight Center (MSFC). Should indicate:

- GMT of vector; $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$
- WEIGHT
- STATION ID
- VEHICLE (CSM, LM, S4B)
- Earth or Moon Reference Indicator

10 D. Transmission of Real-Time Auxiliary Computer Facility (RTACF) Reference Matrix. Should include:

- REFSMMAT ID
- VEHICLE ID (CSM, LM)

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(OT) 5.2.2-1

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Exhibit 9 (Cont'd.)

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E. Transmission of Ephemeris Data/Targeting Parameters. Should indicate that the vector was transmitted to Marshall Space Flight Center (MSFC).

F. Goddard Space Flight Center Maneuver Information. Should include:

- Maneuver number
- VEHICLE (CSM, LM, S4B)
- Vectors at GMTPI and GMTCO

G. Suppress/Unsuppress all C-band Station Contacts.

Code, Stop, All C-band Station Contacts
Start

Approved: _____

BMC

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Exhibit 10

 PHO-TR170A
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TABLE OT 1.1.2-1

MANUAL ENTRIES

ITEM

MANUAL ENTRY	EFFECT
GMT, Inertial flight path angle γ , Inertial Velocity V , Geocentric Latitude ϕ , Height above a spherical Earth h , Inertial Azimuth ψ , Longitude λ , REV. S, VEH;	Cause the initialization of the real-time program. This vector will be in Earth or Moon Centered True Coordinates. The "S" indicates that a static ephemeris is desired.
REV, GMT, X, Y, Z, \dot{X} , \dot{Y} , \dot{Z} , S, VEH;	Cause the initialization of the real-time program. This vector will be in Mean or True earth and moon centered coordinates. The "S" indicates that a static ephemeris is desired.
Code, $\begin{Bmatrix} S \\ M \\ L \\ PN \end{Bmatrix}$, GMT Where S = Sun, M = Moon, L = Liberation Matrix, PN = P&N Matrix and λg	Cause either the sun vector, moon vector, liberation matrix, or P&N matrix and λg to be printed on-line at the specified GMT. (Note: The liberation matrix must be interpolated; however, the P&N matrix associated with the nearest 6 hour increment to GMT will be printed.
Density Factor - K	Modifies the earth orbit coefficient of drag.
Weight, Cross-Sectional Area	Cause the trajectory update <ul style="list-style-type: none"> • CSM • LM
Code, GMT, MNV, EPH, S Where EPH = C for CSM = L for LM	Cause a vector to be transferred for the specified GMT or maneuver number from one ephemeris to another. The "S" indicates that the ephemeris that the vector is to be transferred to is static.
GMT = Time of vector MNV = Cutoff vector after the specified Maneuver.	

Approved: *[Signature]*

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(OT) 1.1.2-2

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Exhibit 11

PHO-TR170A
Volume 2, Change 58
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OT 5.2 Teletype OutputOT 5.2.1 MED EntriesA. RetransmissionCODE, VEHICLE, SITE, GET;

VEHICLE: CSM or LM

SITE: Three letter site code plus band type (zero for voice sites).

GET: Either the Pseudo AOS time for that site if it is in acquisition at this GET or the time to begin searching for the next contact if the site is not in acquisition. The GET should be in HRS:MIN:SEC.

Applies to the following phases: 3, 4, 5, 6, 7, 9.*

B. Suppress and Unsuppress Acquisition DataCODE, FUNCTION, VEH;

FUNCTION: Start or stop

VEH: Vehicle ID (CSM, LM)

This MED allows the computer controller to start or stop all acquisition data.

Applies to the following phases: 1, 3, 4, 5, 6, 7, and 9.

C. Suppress and Unsuppress C-Band Station ContactsCODE, FUNCTION, VEH;

FUNCTION: Start or stop

VEH: Vehicle ID (CSM, LM)

This MED allows the computer controller to start or stop C-band station contacts and, thus, stop or start all C-band acquisition.

Applies to the following phases: 1, 4, 6, 7, and 9.

* Prelaunch = 1; Launch = 2; Abort = 3; Earth Orbit = 4; Reentry = 5;
Translunar/Transearth = 6; Lunar Orbit = 7; Descent = 8; LM Prelaunch = 9; LM Ascent = 10.

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THG

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(OT) 5.2.1-1

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Exhibit 11 (Cont'd.)

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12

D. Transmit GSFC Maneuver InformationCODE, MANEUVER NO., VEH;

MANEUVER NO.: The maneuver number in the MPT

VEH: CSM, LM, SIVB

This MED allows the computer controller to transmit maneuver information to Goddard Spaceflight Center (GSFC).

Applies to the following phases: 4, 6, 7, and 9.

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(OT) 5.2.1-2



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Exhibit 12

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OT 5.2.11 Goddard Spaceflight Center (GSFC)

- A. Format. The format of the GSFC maneuver information is contained in the Apollo Tracking Data Format Control Book, Section 2.4.2.
- B. Maneuver Information. Upon MED request the following maneuver information will be transmitted for a specified maneuver and vehicle to GSFC.
- Time of ignition - GMT of main engine ignition in HHH:MM:SS.S
 - Ignition vector - Vector at main engine ignition
TIME - GMT in HHH:MM:SS.S
X, Y, Z in Earth Radii (+XX.XXXXXXXXXX)
 \dot{X} , \dot{Y} , \dot{Z} in ER/HR (+X.XXXXXXXXXX)
 - Burn duration - Time from main engine ignition to tailoff in seconds (SSSS.S)
 - Ignition weight - Weight at main engine ignition in pounds (XXXXXX.X)
 - Burnout weight - Weight at tailoff in pounds (XXXXXX.X)
 - Burnout vector - Vector at tailoff
TIME - GMT in HHH:MM:SS.S
X, Y, Z in Earth Radii (+XX.XXXXXXXXXX)
 \dot{X} , \dot{Y} , \dot{Z} in ER/HR (+X.XXXXXXXXXX)
- C. Coordinate System. The vectors at GMTPI and GMTCO should be in Greenwich Midnight Prior to Launch ECT coordinate system.

Approved: _____

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- 5 The GMT of liftoff is interpreted to mean the lift-off time of the first vehicle.
- 6 When the RTACF vector is transmitted as a result of a trajectory update, the coordinate system will be the same as the one used by the integrator. That is, it will be in the mean system referenced to the nearest Besselian year. The reference frame will be relative to the Earth unless the position radius is less than nine Earth radii from the center of the moon.

 When the RTACF vector is selected from the Usable Vector Table (UVT), it will be transmitted in the same reference frame as it was stored in the UVT. However, if the vector was stored in the true-of-date system, it will be rotated to the corresponding mean system prior to transmission.
- 7 Vehicle names will as set forth in message description in the Apollo Tracking Data Format Control.
- 8 The weight of the vehicle is assumed to be the weight at the end of the last maneuver prior to the time of the vector.
- 9 An MED format is attached. If the M option is present, the vector is sent only to MSFC. If it is omitted, the vector is sent only to RTACF.
10. The on-line message provided as a result of transmitting a REFSMMAT to the RTACF will contain only the REFSMMAT ID and the vehicle ID (CSM, LEM, S4B). The exact format of this message is found in the Guidance Optics and Sighting Unit section of this document.
11. The sun and/or moon vectors will be interpolated from the sun/moon ephemeris. If a sun vector is requested, only the position vector is printed. If a moon vector is requested, both position and velocity vectors are printed. In all cases, the sun and moon vectors will be relative to the Earth.
12. Vectors and/or maneuver information may be transmitted to RTACF, GSFC, or MSFC in any phase except Condition for Launch, Abort I, Abort II, Lunar Descent, and Lunar Ascent. In valid phases the vector must be in the usable vector table, and the maneuver, in the Mission Plan Table.

Functional Diagrams

Figures 10, 11, and 12 illustrate the interfaces of the programs in this element with other elements, units, or subsystems. Also included are data table usage, task structure, and input/output data flow. The symbols used here are defined in the Glossary of this document. The diagrams listed below are included.

1. RTACF Vector Transmission via Teletype
2. Vector and/or Maneuver Transmission via Teletype
3. Special On-Line Prints

Input/Output Specifications

This section may be divided into three main groups. These groups represent the input/output specifications for the processing of this element.

Teletype Formats: Requirements for teletype formats are defined in Annex D of the Apollo Tracking Data Format Control. Exhibits 13 and 14 have been provided to show the exact format in which data will be transmitted.

Manual Inputs: MED Format Tables, A06, A09 and A12 will be found in the following pages.

On-line Prints: The on-line prints that follow are provided by the Teletype Transmissions and Special On-Line Prints Element.

1.

{	CSM-CMC
	CSM-LGC
	CSM-AGS
	CSM-IU
	CSM-HSR
	CSM-DC
	LEM-CMC
	LEM-LGC
	LEM-AGS
	LEM-IU
	LEM-HSR
	LEM-DC

Not in usable vector table

When A06 MED is input and the requested vector is not available, this message is output.

2.

{	LEM
	CSM

MANEUVER NUMBER XX NOT IN MISSION PLAN TABLE

When A09 MED is input and the requested maneuver is not available, this message is output.

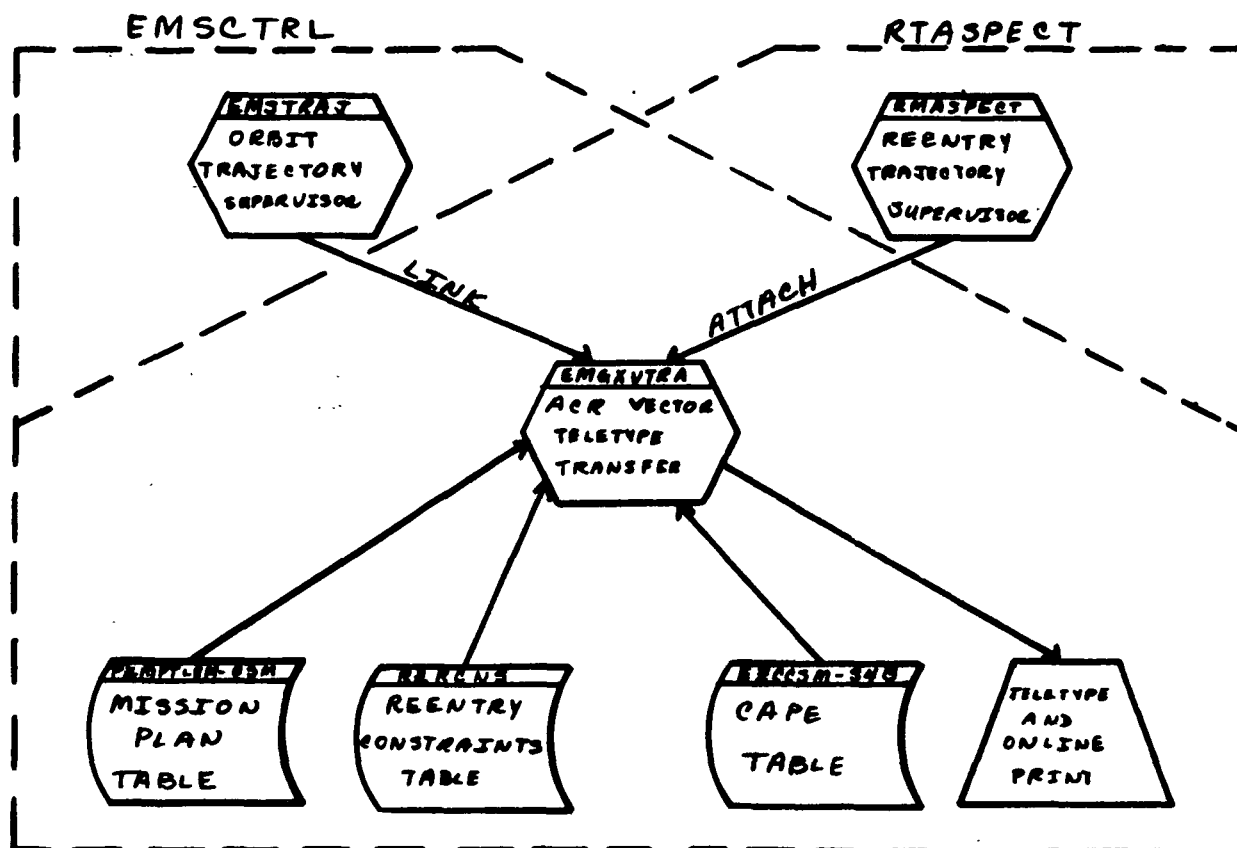


Figure 10. RTACF Vector Transmissions Via Teletype

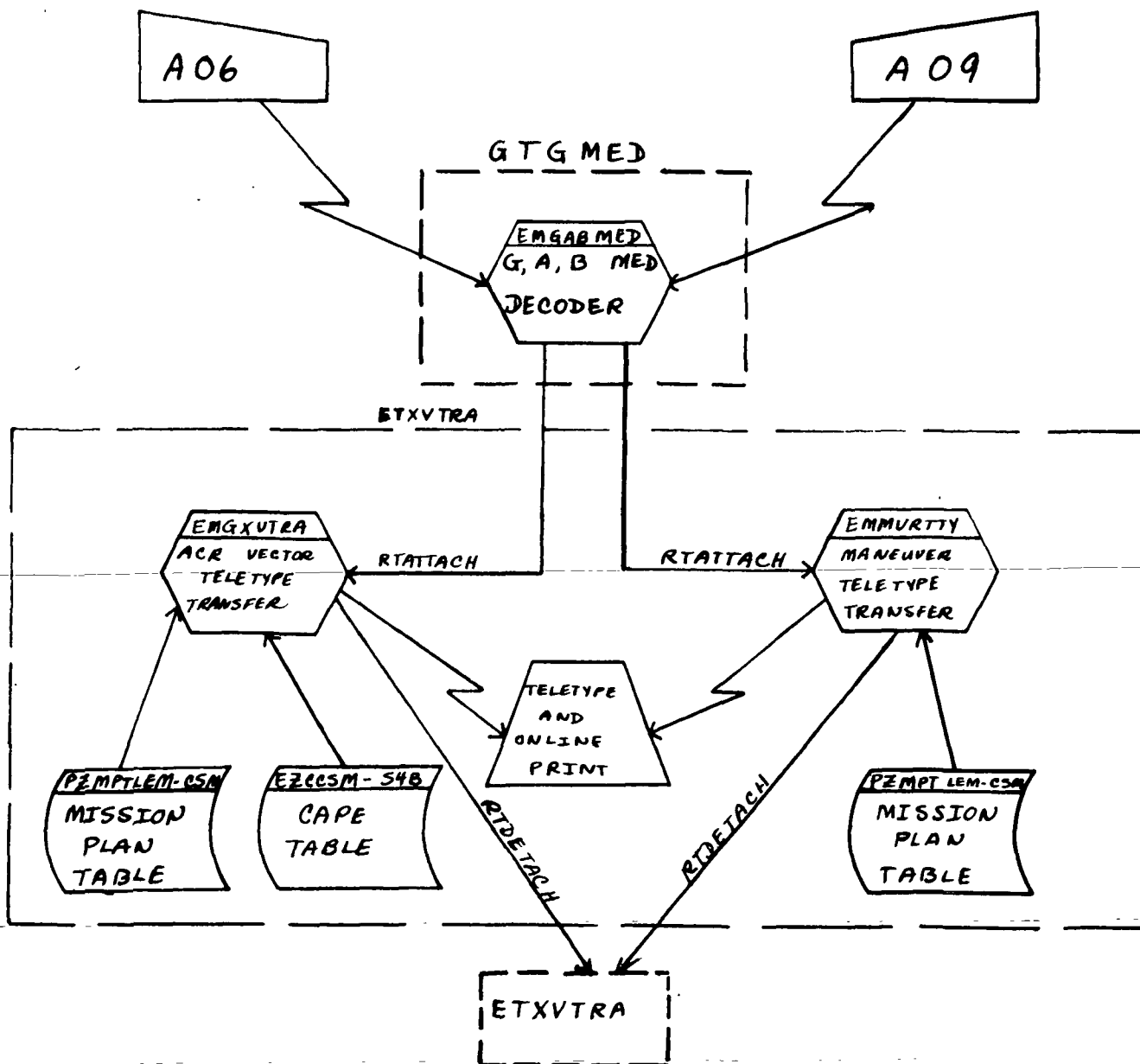


Figure 11. Vector and/or Maneuver Transmission Via Teletype

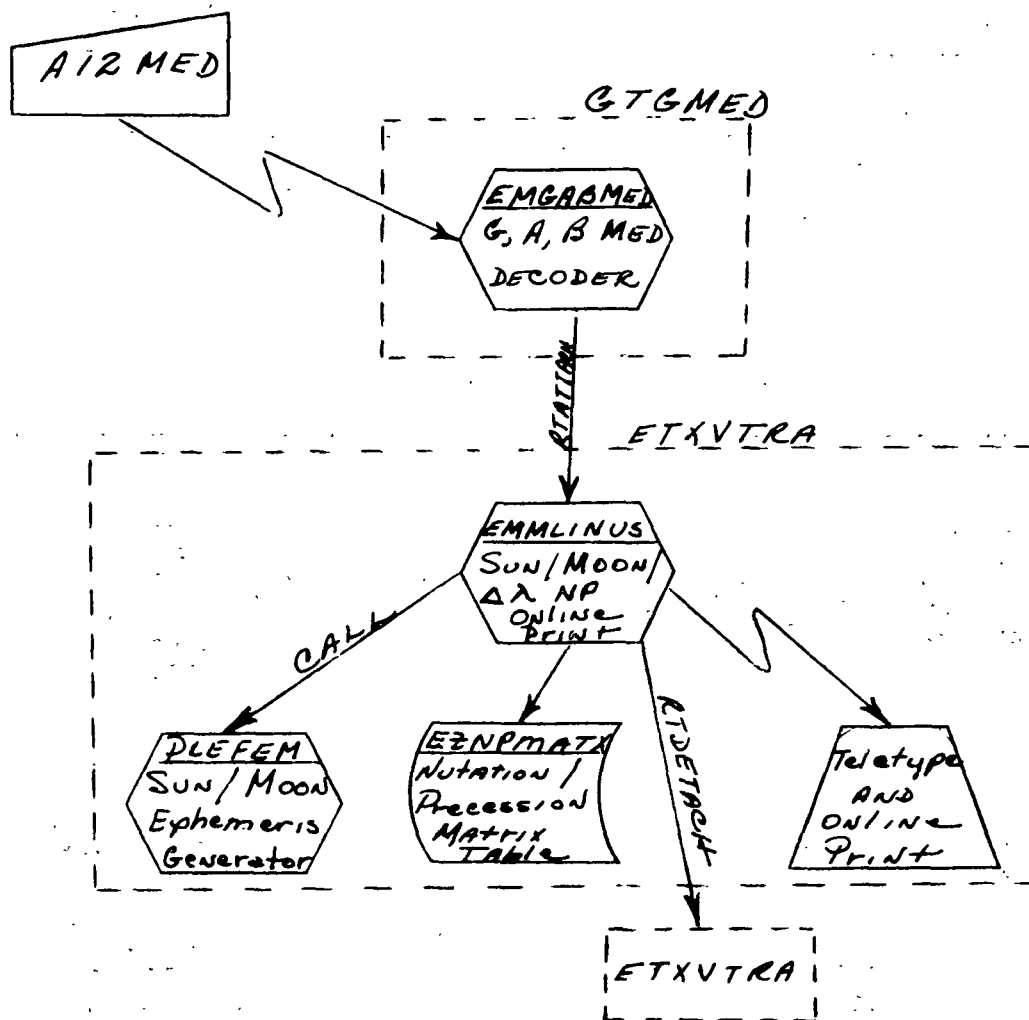


Figure 12. Special On-Line Prints

Exhibit 13

REVISION 2
2/29/68GSFC Maneuver Information Format

Line No.

1 ++++++<<≡+
 2 ***+\$\$\$+*+++++<<≡+
 3 **Δ***<<≡+
 4 **Δ***Δ+\$\$\$<<≡+
 5 \$\$/\$\$\$\$+Z<<≡+

Header Provided
by CP

1 APOLLOΔMANEUVERΔINFORMATION<<≡+

— Veh. ID —
 2 ***ΔΔ\$\$\$\$. \$<<≡+

|Hr| |Mn| |Sec| |Weight|
 3 \$\$\$\$ΔΔ\$\$\$\$. \$ΔΔ\$\$\$\$. \$<<≡+

4 SXX.XXXXXXXXXΔASY.YYYYYYYYΔΔSZ.ZZZZZZZZ<<≡+

5 ΔSX.XXXXXXXXXΔΔSY.YYYYYYYYΔΔSZ.ZZZZZZZZ<<≡+

|Hr| |Mn| |Sec| |Weight|
 6 \$\$\$\$ΔΔ\$\$\$\$. \$ΔΔ\$\$\$\$. \$<<≡+

SXX.XXXXXXXXXΔASY.YYYYYYYYΔΔSZ.ZZZZZZZZ<<≡+

8 ΔSX.XXXXXXXXXΔΔSY.YYYYYYYYΔΔSZ.ZZZZZZZZ

1 <<≡+

2 \$\$/\$\$\$\$+ZΔ***Δ***

3 <<≡=====

4 +\$+++++

Ending Provided
by CP

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Exhibit 14

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ACR Vector Message Format:

Line No.

```

1.  ++++++<<≡+
2.  ***+$$$+*+++++<<≡+
3.  **Δ*****<<≡+
4.  **Δ*****Δ+$$$<<≡+
5.  $$/$$$+Z<<≡≡+

|Vector ID| |Veh.ID|
1.  ****Δ+$$$Δ+*****<<≡+
2.  |Hr| |Mn| |Sec| |Hr| |Mn| |Sec|
   |$$$$$. $Δ$$$$$. $$<<≡
3.  /Rev. No.
   $$$<<≡
4.  XXXXXXXXXXXX<<≡
5.  YYYYYYYYYYYY<<≡
6.  ZZZZZZZZZZZZ<<≡
   .....
7.  XXXXXXXXXXXX<<≡
   .....
8.  YYYYYYYYYYYY<<≡
   .....
9.  ZZZZZZZZZZZZ<<≡
10. WWWWWW.

1.  <<≡≡+
2.  $$/$$$+ZΔ***Δ****
3.  <<≡≡≡≡≡≡≡≡≡
4.  †#+++++†++++†

```

Heading Provided
by CP

Ending Provided
by CP

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Exhibit 14 (Cont'd.)

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ACR Vector Format Notes:

1. Line 1 of text contains a vector designator and vehicle ID. The vector designator indicates data source used to compute the vector. The first three letters are a standard NASA 3-letter station abbreviation, the fourth letter is a C for C-band system data or an S for USB system data, and the three numerals indicate segment of station pass. Vehicle ID-CSMAAA = Command Service Module
LEMAAA = Lunar Module
S-IVAB = Saturn - IVB
2. Line 2 contains GMT of vector and GMTLO in that order.
3. Line 3 contains revolution number in decimal integers. When this value cannot be computed it will contain zeros.
4. Lines 4, 5, and 6 contain X, Y, and Z position components, respectively. Lines 7, 8, and 9 contain X, Y, and Z velocity components, respectively. All components are in floating octal.
5. Line 10 contains the weight of vehicle in pounds. Weight is in decimal numbering with decimal point indicated.



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MED Format Table

MED Code: A06

Purpose: Transmit vector from usable vector table to ACR or MSFC

Load Module: EMGABMED

Task: ETMSCTRL

EP: EMSCTRL

QNAME: EQ2CTL

QUEID: 10 QCRANK: 10

DPRIOR: MKDGLM

Desc.	Item	1	2	3	4	5	6
Item Name		CSM or LEM Vehicle	Vector Name	Marshall Indicator			
Input Format		XXX	XXX	X(M)			
Input Units		EBCDIC	EBCDIC	EBCDIC			
Program Units		Numeric code	Numeric code				
Scale Factor							
Checking Option		Exact	Exact	Exact			
Missing Item Option		Error	Error	= 0			
Item Destination							

Programmer: J. Emrick

Initial Logic:

Final Logic: Output passed in subpool 1

Illegal Phases: Prelaunch, Condition for Launch, Launch, Abort I, Abort II, Lunar Descent, Launch Ascent

Notes:

- Item 2 vector names can be CMC, LGC, AGS, IU, HSR, or DC
- At a displacement of 208, the following shall be passed: ETXVTRA, EMGXVTRA, EQ2CTL16, and QUEID. The QUEID shall be 2561 - 2572 depending upon the input. (CSM, CMC) - (LEM, AGS)

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MED Format Table

MED Code: A09
 Purpose: Transmit maneuver information to
 Goddard Space Flight Center
 Load Module: EMGABMED

Task: ETMSCTRL
 EP: EMSCTRL
 QNAME: EQ2CTL
 QUEID: 10 QRANK: 10
 DPRIOR: MKDGLM

Desc.	Item	1	2	3	4	5	6
Item Name		Vehicle	Maneuver Number				
Input Format		XXX	XX				
Input Units		EBCDIC	FXP				
Program Units		Numeric code	FXP				
Scale Factor							
Checking Option		Exact	$\geq 1, \leq 15$				
Missing Item Option		Error	Error				
Item Destination							

Programmer: J. Emrick

Initial Logic:

Final Logic:

Illegal Phases: Prelaunch, Condition for Launch, Launch, Abort I, Abort II, Lunar Descent,
 Lunar Ascent

Notes:
 1. At a displacement of 208, the following shall be passed: ETXXVTRA, EMGXVTRA,
 EQ2CTL16, and QUEID. (1-15 for CSM and 41-55 for LEM)

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MED Format Table

MED Code: A12

Purpose:

Cause either the sun or moon vector, libration matrix, or P & N and λ to be printed on lineTask: ETXVTRA
EP: EMMMLINUS

QNAME:

QUEID: 0

DPRIOR: MKDGMF

Load Module: EMGABMED

Desc.	Item	1	2	3	4	5	6
Item Name		Code	GMT				
Input Format		xx	xxx:xx:xx.xx				
Input Units		EBCDIC	hrs:min:sec				
Program Units		Numeric code	hours				
Scale Factor							
Checking Option		Exact					
Missing Item Option		Error	= current time				
Item Destination		Disp. 10 H	Disp. 16 D				

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: Condition for launch, launch, Abort I, Abort II, Lunar Descent, Lunar Ascent

Notes: 1. Valid codes for item 1 are:

S = Sun vector

M = Moon vector

L = Libration matrix

PN = P & N matrix and λ G Subsystem

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3. $\left\{ \begin{matrix} \text{CSM} \\ \text{LM} \end{matrix} \right\} \left\{ \begin{matrix} \text{OBT} \\ \text{REN} \\ \text{ABT} \end{matrix} \right\} \left\{ \begin{matrix} \text{STATION} \\ \text{ID} \end{matrix} \right\} \quad W = \text{XXXXXXX.X} \quad \begin{matrix} \text{GMT} = \text{XXX:XX:XX.XX} \\ \text{GMT} = \text{XXX:XX:XX:XX:XX} \\ \text{GMT} = \text{XXX:XX:XX:XX:XX} \end{matrix}$

GMTLO = XXX:XX:XX.XX

$X = \pm \text{XX.XXXXXXXXXX} \quad Y = \pm \text{XX.XXXXXXXXXX} \quad Z = \pm \text{XX.XXXXXXXXXX}$

R = XXX

$XV = \pm \text{XX.XXXXXXXXXX} \quad YV = \pm \text{XX.XXXXXXXXXX}$

$ZV = \pm \text{XX.XXXXXXXXXX} \quad CS = \left\{ \begin{matrix} \text{ECI} \\ \text{MCI} \end{matrix} \right\}$

This message is output upon a queue from EMSTRAJ, RMASPECT, or an A06 MED input.

4. LM MVR # GMTI = XXX:XX:XX.XX WT = XXXXXX.X

GMTCO = XXX:XX:XX.XX WT = XXXXXX.X

BRN = XXXX.X SEC

IGN VEC = $\pm \text{XX.XXXXXXXXXX} \pm \text{XX.XXXXXXXXXX} \pm \text{XX.XXXXXXXXXX}$

$\pm \text{X.XXXXXXXXXX} \pm \text{X.XXXXXXXXXX} \pm \text{X.XXXXXXXXXX}$

CO VEC = $\pm \text{XX.XXXXXXXXXX} \pm \text{XX.XXXXXXXXXX} \pm \text{XX.XXXXXXXXXX}$

$\pm \text{X.XXXXXXXXXX} \pm \text{X.XXXXXXXXXX} \pm \text{X.XXXXXXXXXX}$

This message is output upon an A09 MED input.

5. $\left\{ \begin{matrix} \text{P AND N MATRIX} \\ \text{LIBRATION MATRIX} \\ \text{SUN VECTOR} \\ \text{MOON VECTOR} \end{matrix} \right\} \quad \text{NOT AVAILABLE AT REQUESTED GMT.}$

An A12 MED was input, and the requested information is not available.

6. {SUN VECTOR
MOON VECTOR} AT GMT = XXX:XX:XX.XX

$$\left\{ \begin{array}{l} R (SE) = \pm XXXXX.XXXXXXXXXX \quad \pm XXXXX.XXXXXXXXXX \\ \quad \pm XXXXX.XXXXXXXXXX \\ \left[\begin{array}{l} R (ME) = \pm XX.XXXXXXXXXX \quad \pm XX.XXXXXXXXXX \quad \pm XX.XXXXXXXXXX \\ V (ME) = \pm X.XXXXXXXXXX \quad \pm X.XXXXXXXXXX \quad \pm X.XXXXXXXXXX \end{array} \right] \end{array} \right.$$

If the sun vector is selected only the position is printed. If the moon vector is selected, then both position and velocity are printed. SE indicates sun with respect to Earth, and ME, moon with respect to Earth.

7. {LIBRATION MATRIX
P AND N MATRIX} AT GMT = XXX:XX:XX.XX { [BLANK]
LAMBDA G =
XXX.XXXXXXXXXX } }

±.XXXXXXXXXXXXXXXX	±.XXXXXXXXXXXXXXXX	±.XXXXXXXXXXXXXXXX
±.XXXXXXXXXXXXXXXX	±.XXXXXXXXXXXXXXXX	±.XXXXXXXXXXXXXXXX
±.XXXXXXXXXXXXXXXX	±.XXXXXXXXXXXXXXXX	±.XXXXXXXXXXXXXXXX

STATION CONTACT UNIT

SCOPE

The Station Contact Unit is comprised of programs that are divided into three logical elements. The Contact Generation and Control Element consists of programs that control the generation of Orbit phase station contact data and provide a generalized contact generation capability, which may be used by other programs in other elements, units, or subsystems. The Station Contact Displays Element contains programs that display times of contact of radar stations or experimental sites and other associated tracking information. The Remote Site Acquisition Element contains programs that format and transmit acquisition messages to the remote tracking stations. These elements and the programs that comprise them are discussed in the sections that follow.

THE CONTACT GENERATION AND CONTROL ELEMENT

Function

The generation of orbit station contact information is performed by load modules operating under the task name ETSTAGEN. The load module that provides supervisory control over the task is EMSTAGEN. EMXING performs computations necessary to determine when the various radar sites will acquire the vehicle. This information is combined with data gathered from the station characteristics table by EMGENGEN (which controls EMXING) and returned to EMSTAGEN (which invoked EMGENGEN). The data is assigned revolution numbers (when the revolution numbers are available) and is stored in one of the station contacts tables by EMSTAGEN. A maximum of 45 station contacts will be generated.

Load Module/Routine Description

Orbit Station Contact Generation Control - EMSTAGEN

This program controls the generation of orbit station contact information. The current orbit ephemeris, a table of maneuver times, and the station characteristics table are given to EMGENGEN to perform the actual contact generation. A maximum of 45 contacts is generated. The contacts returned by EMGENGEN are assigned revolution numbers (if the orbit is such that revolution numbers can be computed) and then are stored in the station contacts table. If the acquisition data processing is not suppressed, or if it has not been queued previously, a queue is given to EMSSACQ.

Generalized Contact Generator - EMGENGEN

This load module interfaces with the horizon crossing program, EMXING, to generate a table of contact information during any phase. An ephemeris, a table of maneuver times, and a table of station or site characteristics are used to generate the number of contacts requested. A table of contact information, which is time-sorted according to acquisition of site times, is returned to the calling program.

Horizon Crossing Subprogram - EMXING

Program EMXING determines the number of times a radar site will acquire the vehicle during a given time span. The quantities computed for each detected contact are the horizon ascent and descent times

and the time and value of the maximum elevation obtained. The formulation must be adequate for all phases of a full Apollo Mission starting with Earth orbit where satellite motion is the dominate factor, and then going through a transition phase on the translunar leg until the Earth's rotation rate is the dominate parameter, and finally reversing the transition as the satellite returns from trans-Earth to Earth Orbital phase with subsequent reentry.

All the parameters that wholly define an observation station will be referred to as the station characteristics of the station. The formulation that follows will have need for some but not all these parameters. Figure 13 below depicts these station parameters that we will use. All representations are in the ECT Coordinate System. The formulation was developed by F. M. Riddle of IBM.

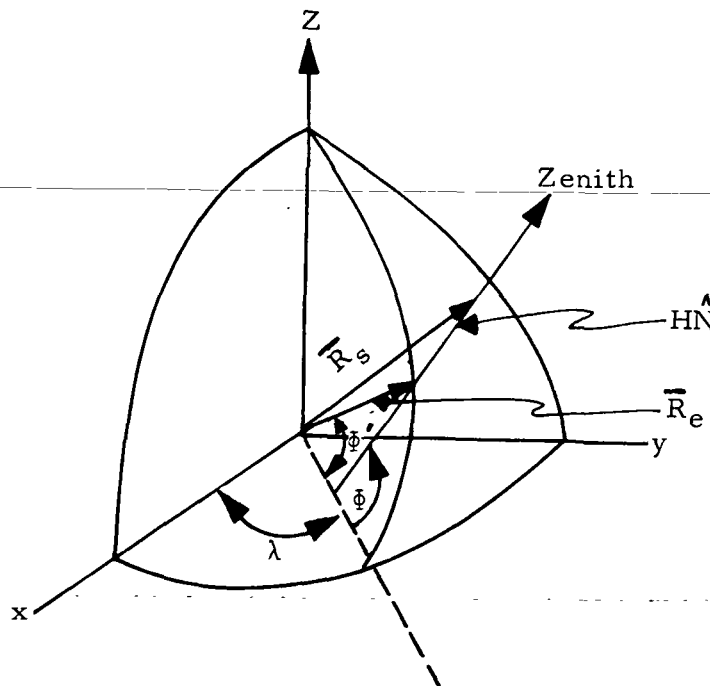


Figure 13

From Figure 13 we note that

$$\bar{R}_s = \bar{R}_e + \hat{H}\hat{N} \quad (1)$$

$$\hat{N} = (\cos \phi \cos \lambda, \cos \phi \sin \lambda, \sin \phi) \quad (2)$$

$$\bar{R}_e = (R_e \cos \Phi' \cos \lambda, R_e \cos \Phi' \sin \lambda, R_e \sin \Phi') \quad (3)$$

$$\bar{R}_s = [(R_e \cos \Phi' + H \cos \Phi) \cos \lambda, (R_e \cos \Phi' + H \cos \Phi) \sin \lambda, (R_e \sin \Phi' + H \sin \Phi)] \quad (4)$$

where:

Φ = Geodetic latitude of station

Φ' = Geocentric latitude of station

λ = Inertial longitude of the station = $\lambda_s + \omega_e t$

\bar{R}_e = Distance from center of the Earth to the reference ellipsoid at the station

\bar{R}_s = Distance from center of the Earth to top of the station

H = Geodetic height of the station above the reference ellipsoid

\hat{N} = Unit normal to the reference ellipsoid at the station

The mathematical computations proceed as follows:

The ascending horizon crossing time (AOS) is determined by interrogating vectors in the ephemeris of the vehicle. By inspecting the product $\hat{\rho} \cdot \hat{N}$,

where $\bar{\rho} = \bar{r} - \bar{R}_s$

$$\hat{\rho} = \frac{\bar{\rho}}{\sqrt{\bar{\rho} \cdot \bar{\rho}}}$$

the program detects when the vehicle crosses the ascending horizon plane of the station. (When $\hat{\rho} \cdot \hat{N}$ is negative, the vehicle is below the station's horizon plane; when it is positive, the vehicle is above the station's horizon plane.) Once the program detects that the vehicle has crossed above the horizon plane, it iterates, using a linear interpolation scheme, for the time at which $\hat{\rho} \cdot \hat{N} = 0$. This time is AOS.

As the program searches for AOS, it also determines the slope of the elevation curve by evaluating the function

$$f(t) = \rho^2 [\dot{\hat{\rho}} \cdot \hat{N} + \bar{\rho} \cdot \dot{\hat{N}} - \dot{\rho} \sin E].$$

The sign of $f(t)$ is the sign of the slope of the curve. If a change in sign is detected while searching for AOS, the maximum elevation is computed and tested to see if the vehicle passed above the horizon plane between the last two vectors interrogated. If so, AOS is computed; if not, the ephemeris search is continued.

Once an AOS time has been found, the maximum elevation above the horizon plane and the time of the maximum elevation are computed. The maximum elevation is a point where the above function $f(t) = 0$. As when computing AOS, vectors in the ephemeris of the vehicle are used to compute $f(t)$. When $f(t)$ changes sign from positive to negative, a linear interpolation scheme is used to iterate for the time at which $f(t) = 0$. This time is the time of maximum elevation and the product $\hat{\rho} \cdot \hat{N}$ is the maximum elevation of the pass. In some types of orbits it is possible to have more than one point in the elevation curve where $f(t) = 0$. In these cases, the point with the greatest elevation is used as the point of maximum elevation.

Once AOS, E_{\max} , and time of E_{\max} have been computed, the program searches for the descending horizon crossing time (LOS). The procedure for computing LOS is the same as that for computing AOS, except that LOS is interpolated for when the product $\hat{\rho} \cdot \hat{N}$ changes sign from positive to negative.

Special situations arise when a station is in contact with the vehicle at either the beginning or the ending of the ephemeris. If a station is in contact at the beginning time of the ephemeris, the first time in the ephemeris is stored as the AOS time and an indicator is set showing that AOS is the "best available" time rather than the true AOS time. If the maximum elevation occurs prior to the beginning of the ephemeris, the first time in the ephemeris is stored as the time of E_{\max} and the elevation at that point is E_{\max} ; likewise, if the maximum elevation for a pass occurs after the end of the ephemeris, the last time in the ephemeris is stored as the time of E_{\max} , and the elevation at that point is E_{\max} . In either case, indicators are set showing that E_{\max} and time of E_{\max} are "best available" values rather than the true values. If a station is in contact at the ending time of the ephemeris, the last

time in the ephemeris is stored as the LOS time, and an indicator is set showing that LOS is the "best available" time rather than the true LOS time.

Once a contact is computed, a check is made to determine if the spacecraft is occulted by the moon any time during the pass. If so, the pass will be adjusted in one or more of the following ways:

1. If the vehicle is occulted by the moon at AOS, the time when the vehicle comes into view of the station (i. e., the time at which it comes out from behind the moon) will be computed and stored as the AOS time.
2. If the station has contact with the vehicle when it disappears behind the moon, the pass will be divided into two segments. The AOS time of the first segment will be the true AOS, and the LOS time will be the time at which the spacecraft is occulted by the moon. The time when the spacecraft reappears from behind the moon will be the AOS time of the second segment, and the LOS time will be the true LOS.
3. If the vehicle is occulted by the moon at LOS, the time when the vehicle is occulted by the moon will be computed and stored as LOS.

If any one of the above conditions arises, each segment of the total pass over a station will be treated as a complete pass, each having AOS, LOS, and E_{\max} times and an elevation. (Special indicators for times and elevation will be set when any of these quantities are "best available" times due to the occultation of the moon.) The E_{\max} time will be the time between AOS and LOS that is closest to the maximum elevation time calculated before occultation times were considered; the elevation at that time will be computed and stored as the "maximum" elevation.

The convergence criteria for all times computed is three seconds.

Requirements Interpretation

Source: The requirements for the Contact Generation and Control element are outlined on page (OT) 2. 1-1 of PHO-TR170, Volume 2, Change 39, 22 November 1967, (Exhibit 15).

Amendments to Source: The following items are amendments to the requirements stated in the referenced source.



Exhibit 15

PHO-TR170A
Volume 2, Page 39
22 Nov. 1967

OT 2.1 Processing

A. Initiation. The generation of orbit station contacts will be initiated in Prelaunch beginning at the nominal insertion time. After insertion into orbit station contacts will be re-generated beginning at present time.

B. Quantities To Be Computed. The following quantities will be computed for each station contact.

1. Greenwich Mean Time of ascending horizon crossing.
2. Greenwich Mean Time of descending horizon crossing.
3. Greenwich Mean Time of maximum elevation over a station.
4. Maximum elevation angle.

C. Additional Information

1. Station contacts will only be generated out of the main ephemeris. A maximum of 200 vectors (a minimum of approximately ten hours) will be used to determine station contact information and a maximum of 25 contacts will be stored in the station contact tables.
2. After each trajectory update or manual request station contacts will be generated. The generation of C-Band radar sites station contacts can be suppressed or unsuppressed by manual input.
3. If the Cape Crossing Table is available, revolution numbers will be assigned to each contact. If revolution numbers could not be generated, a number zero will be assigned to each contact.
4. Horizon crossing ascending and horizon crossing descending times will be based on zero degree elevation. If the vehicle's maximum elevation is equal to or less than zero degrees station contacts will not be generated.
5. The manual inputs associated with station contacts generation are as follows:
 - a. To regenerate station contacts: Code, VEH;
 - b. To suppress generation for C-Band radar sites: Code, S;
 - c. To unsuppress generation for C-Band radar sites: Code, U;

Approved: TP NASA/FSB

1. The on-line messages printed by programs in this element are given in the On-Line Prints segment of the Input/Output Specifications section.
2. The formats of the manual inputs are given in the Manual Input segment of the Input/Output Specifications section.
3. The block of the Cape Crossing Table to be accessed will be determined by the present position reference body at time of contact generation.

Additions to Source: The following items are extensions of the requirements stated in the reference source:

1. The convergence criteria of all of the computed times is ± 3 seconds. The maximum elevation angle is defined to be the angle above the horizon at the computed time of maximum elevation.
2. Eight-order interpolation will be used whenever possible. If conditions are such that less than nine vectors are stored in the ephemeris, the order of interpolation will be determined by the number of vectors available.
3. If a station is in contact with the vehicle at the time the station contacts are generated, the time of generation will be stored as the ascending horizon crossing time. If the maximum elevation of the pass is prior to the station contact generation time, the time of maximum elevation will be the same as the time of ascending horizon crossing, and the maximum elevation angle will be the angle at that time. If the maximum elevation of the pass is after the end of the ephemeris, the time of maximum elevation will be the time of the last vector in the ephemeris, and the maximum elevation angle will be the angle at that time. If a station is in contact with the vehicle at the time the ephemeris ends, the time of the last vector in the ephemeris will be stored as the time of descending horizon crossing. Indicators will be set if and when any of the above conditions are present.
4. The on-line print messages are given in the On-Line Prints segment of the Input/Output Specifications section.

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Exhibit 15

DDO-TR170A
Volume 2, Change 39
22 Nov. 1967

OT 2.1 Processing

- A. Initiation. The generation of orbit station contacts will be initiated in Prelaunch beginning at the nominal insertion time. After insertion into orbit station contacts will be re-generated beginning at present time.
- B. Quantities To Be Computed. The following quantities will be computed for each station contact.
1. Greenwich Mean Time of ascending horizon crossing.
 2. Greenwich Mean Time of descending horizon crossing.
 3. Greenwich Mean Time of maximum elevation over a station.
 4. Maximum elevation angle.
- C. Additional Information
1. Station contacts will only be generated out of the main ephemeris. A maximum of 200 vectors (a minimum of approximately ten hours) will be used to determine station contact information and a maximum of 25 contacts will be stored in the station contact tables.
 2. After each trajectory update or manual request station contacts will be generated. The generation of C-Band radar sites station contacts can be suppressed or unsuppressed by manual input.
 3. If the Cape Crossing Table is available, revolution numbers will be assigned to each contact. If revolution numbers could not be generated, a number zero will be assigned to each contact.
 4. Horizon crossing ascending and horizon crossing descending times will be based on zero degree elevation. If the vehicle's maximum elevation is equal to or less than zero degrees station contacts will not be generated.
 5. The manual inputs associated with station contacts generation are as follows:
 - a. To regenerate station contacts: Code, VEH;
 - b. To suppress generation for C-Band radar sites: Code, S;
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Approved: TP NASA/FSB

DDO/170A

(OT) 2.1-1

1. The on-line messages printed by programs in this element are given in the On-Line Prints segment of the Input/Output Specifications section.
2. The formats of the manual inputs are given in the Manual Input segment of the Input/Output Specifications section.
3. The block of the Cape Crossing Table to be accessed will be determined by the present position reference body at time of contact generation.

Additions to Source: The following items are extensions of the requirements stated in the reference source:

1. The convergence criteria of all of the computed times is ± 3 seconds. The maximum elevation angle is defined to be the angle above the horizon at the computed time of maximum elevation.
2. Eight-order interpolation will be used whenever possible. If conditions are such that less than nine vectors are stored in the ephemeris, the order of interpolation will be determined by the number of vectors available.
3. If a station is in contact with the vehicle at the time the station contacts are generated, the time of generation will be stored as the ascending horizon crossing time. If the maximum elevation of the pass is prior to the station contact generation time, the time of maximum elevation will be the same as the time of ascending horizon crossing, and the maximum elevation angle will be the angle at that time. If the maximum elevation of the pass is after the end of the ephemeris, the time of maximum elevation will be the time of the last vector in the ephemeris, and the maximum elevation angle will be the angle at that time. If a station is in contact with the vehicle at the time the ephemeris ends, the time of the last vector in the ephemeris will be stored as the time of descending horizon crossing. Indicators will be set if and when any of the above conditions are present.
4. The on-line print messages are given in the On-Line Prints segment of the Input/Output Specifications section.

Functional Diagrams

Figures 14 and 15 show the interfaces of the programs in the Contact Generation and Control Element with other programs in the element and with other elements, units, or subsystems. They also show the general logic to be followed in providing the processing described in the previous paragraphs. The key to the symbols used in the diagrams may be found in the Glossary of this document. The functional diagrams enclosed are EMSTAGEN and EMGENGEN/EMXING.

Input/Output Specifications

The Input/Output Specifications for this element may be divided into two groups, manual inputs and on-line prints.

Manual Inputs: The programs in the Contact Generation and Control Element receive inputs from the following manual inputs.

1. B03 (Generate Station Contacts Table)
2. B04 (Suppress/Unsuppress C-Band Station Contact Generation)

Copies of these MED formats will be found in the following pages.

On-Line Prints: The following on-line prints are issued by programs in the Contact Generation and Control Element.

1. EMGENGEN

If the horizon crossing subprogram (EMXING) detects an error condition such that it can not compute acquisition times for a station, EMGENGEN will cause the following message to be printed on line.

"ERROR nn FROM EMXING For veh, sta"

where nn is the error number, veh is the vehicle ID, and sta is the radar station ID. A list of the error numbers and detailed descriptions of each will be provided at a later date in the Orbit Trajectory Computations Subsystem User's Guide.

2. EMSTAGEN

At the completion of the generation of station contacts, the following message will be printed on line:

"nn veh STATION CONTACTS GENERATED"

where nn is the number of contacts stored in the station contacts table, and veh is the vehicle for which contacts were generated.

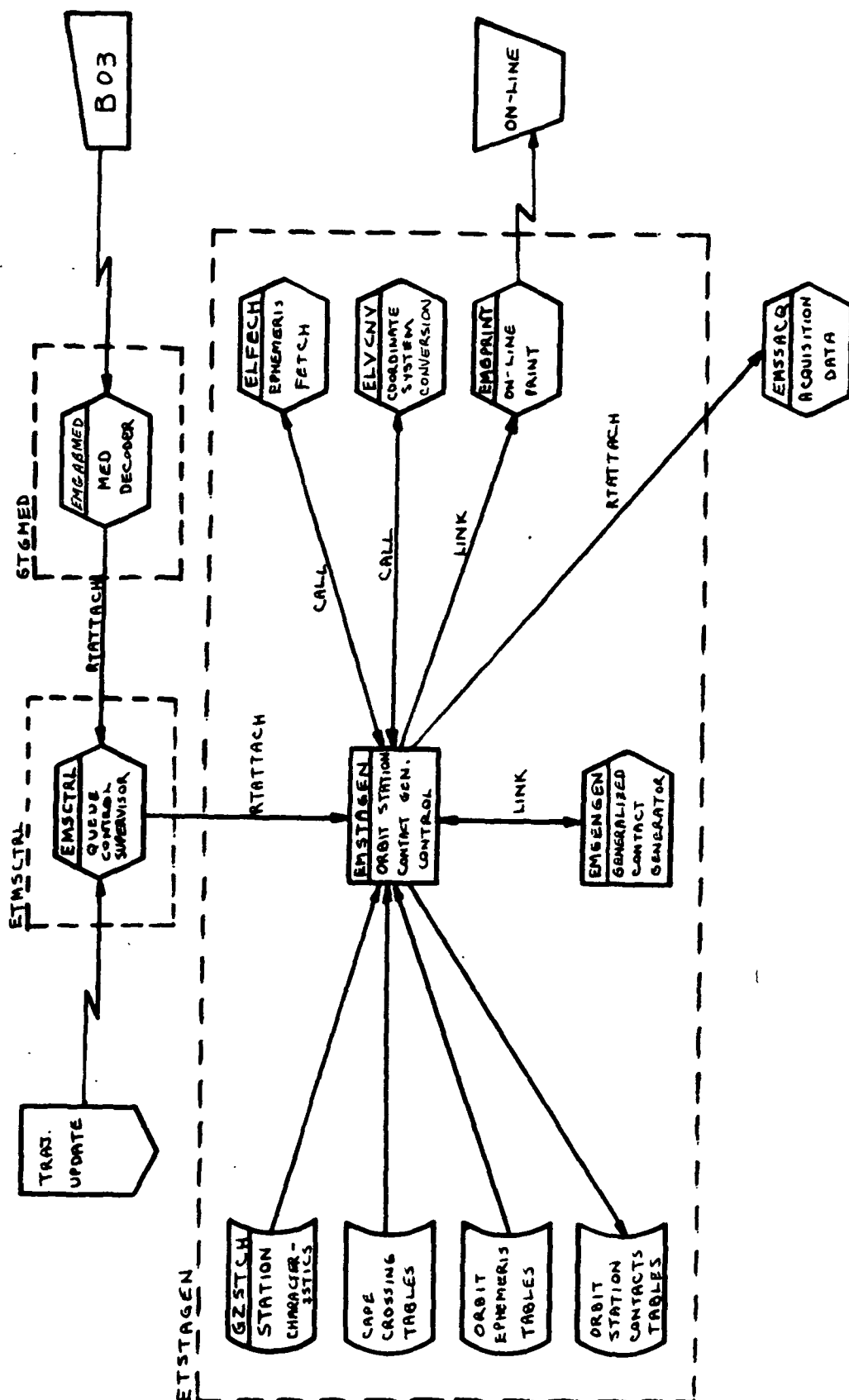


Figure 14. EMSTAGEN

Functional Diagrams

Figures 14 and 15 show the interfaces of the programs in the Contact Generation and Control Element with other programs in the element and with other elements, units, or subsystems. They also show the general logic to be followed in providing the processing described in the previous paragraphs. The key to the symbols used in the diagrams may be found in the Glossary of this document. The functional diagrams enclosed are EMSTAGEN and EMGENGEN/EMXING.

Input/Output Specifications

The Input/Output Specifications for this element may be divided into two groups, manual inputs and on-line prints.

Manual Inputs: The programs in the Contact Generation and Control Element receive inputs from the following manual inputs.

1. B03 (Generate Station Contacts Table)
2. B04 (Suppress/Unsuppress C-Band Station Contact Generation)

Copies of these MED formats will be found in the following pages.

On-Line Prints: The following on-line prints are issued by programs in the Contact Generation and Control Element.

1. EMGENGEN

If the horizon crossing subprogram (EMXING) detects an error condition such that it can not compute acquisition times for a station, EMGENGEN will cause the following message to be printed on line.

"ERROR nn FROM EMXING For veh, sta"

where nn is the error number, veh is the vehicle ID, and sta is the radar station ID. A list of the error numbers and detailed descriptions of each will be provided at a later date in the Orbit Trajectory Computations Sybsystem User's Guide.

2. EMSTAGEN

At the completion of the generation of station contacts, the following message will be printed on line:

"nn veh STATION CONTACTS GENERATED"

where nn is the number of contacts stored in the station contacts table, and veh is the vehicle for which contacts were generated.

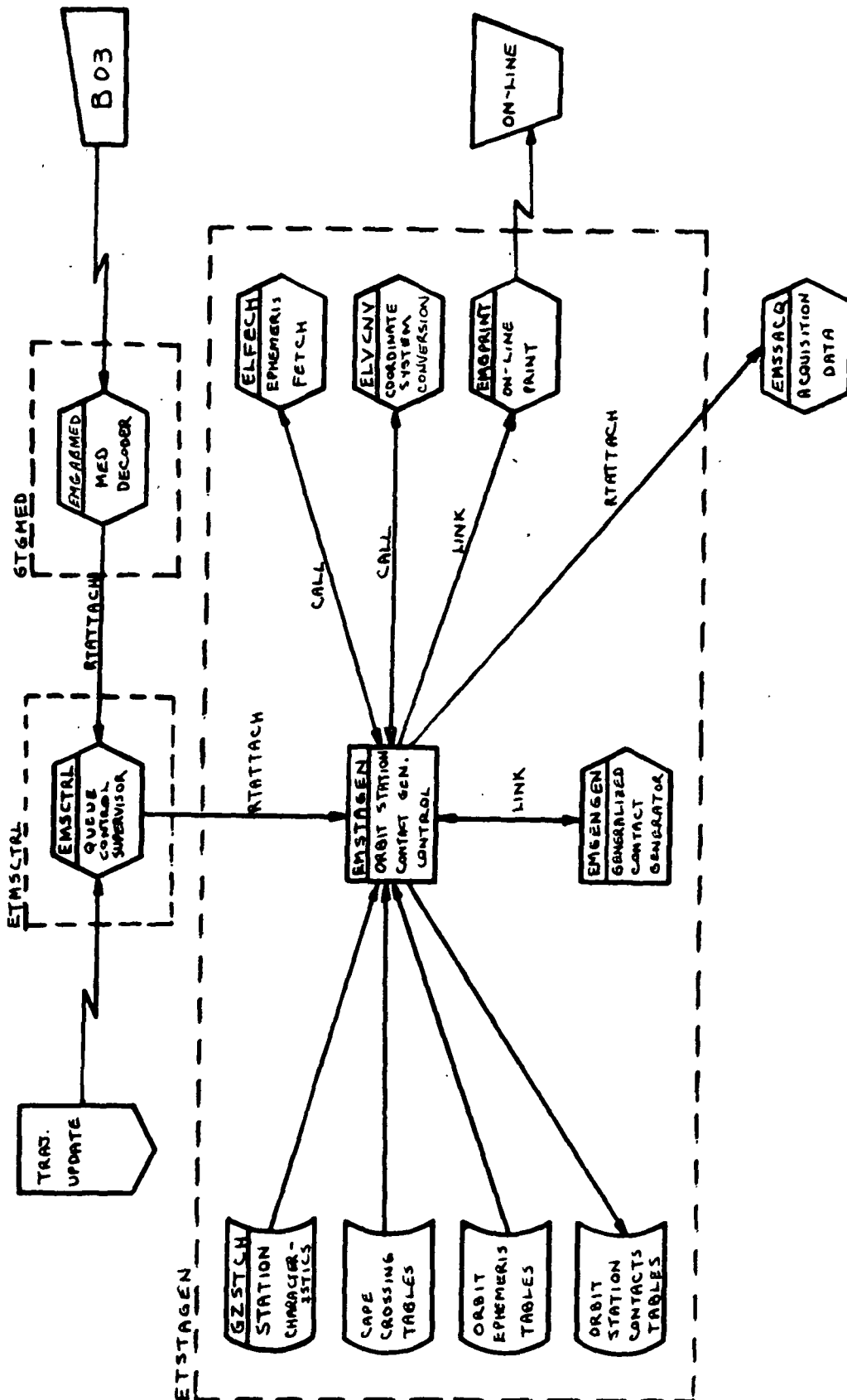


Figure 14. EMSTAGEN

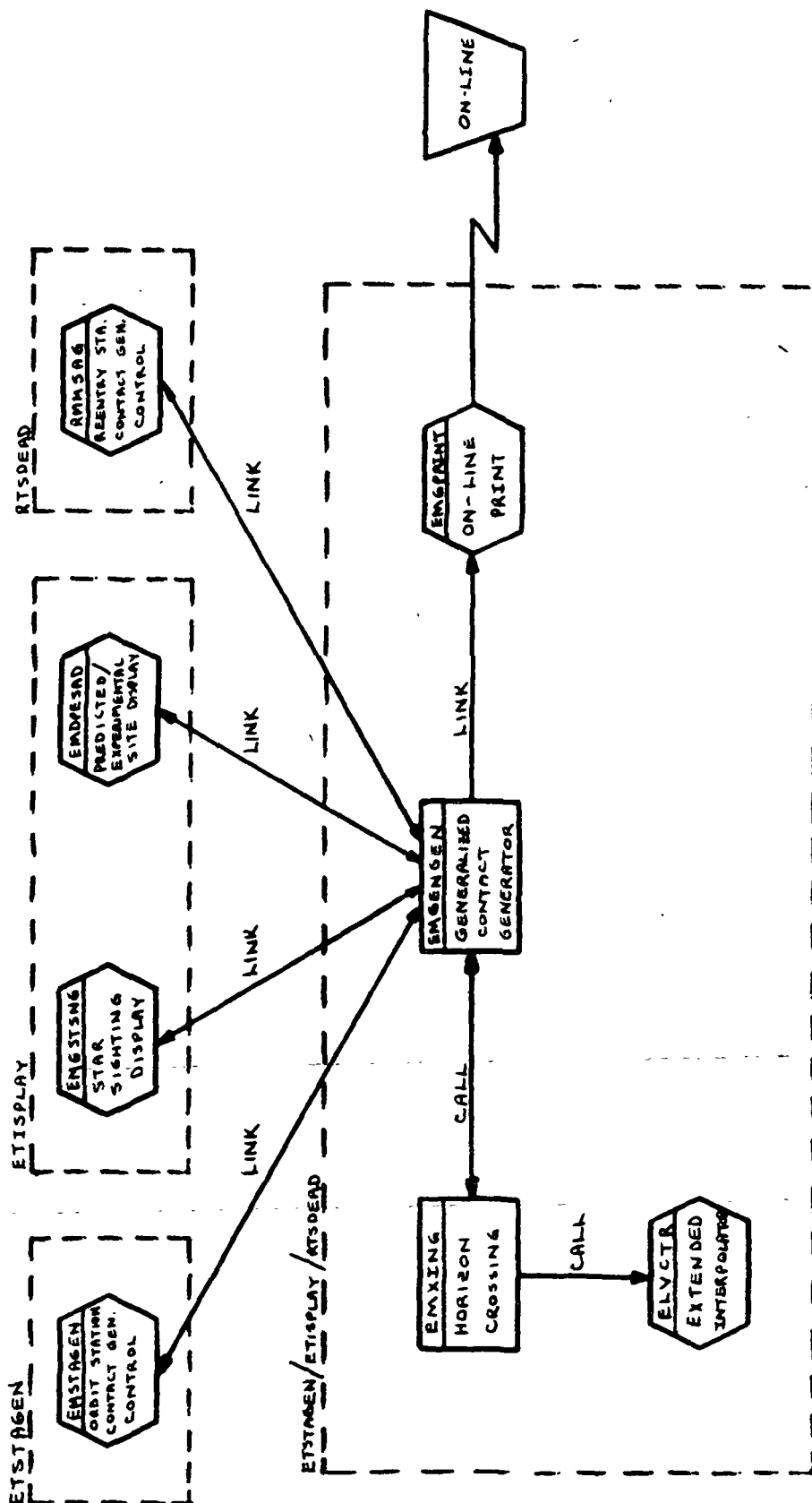


Figure 15. EMGEN/EMXING



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MED Format Table

MED Code: B03
 Purpose: Generate Station Contact Table
 Load Module: EMGABMED
 Task: ETMSCTRL
 EP: EMSCTRL QRANK: 10
 QNAME: EQ2CTL
 QUEID: 10
 DPRIOR: MKDGLM

Desc.	Item	1	2	3	4	5	6
Item Name		CSM or LEM Vehicle					
Input Format		XXX					
Input Units		EBCDIC					
Program Units		Numeric Code					
Scale Factor							
Checking Option		Exact					
Missing Item Option		Error					
Item Destination		Disp. 232 F					

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low)

Notes: At a displacement of 208, the following shall be passed:

ETSTAGEN

EMSTAGEN

GQ2CTLn, where n is 9 or 11 depending on the vehicle

QUEID = Vehicle ID



MED Format Table

MED Code: B04
 Purpose: Suppress/unsuppress C-band station contacts generation
 Load Module: EMGABMED
 Task: NA
 EP: NA
 QNAME:
 QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name	Function						
Input Format	START STOP						
Input Units	EBCDIC						
Program Units	Numeric code						
Scale Factor							
Checking Option	Exact						
Missing Item Option	Error						
Item Destination							

Programmer: J. Emrick

Initial Logic:

Final Logic:

Illegal Phases:

Notes:

- All except orbit (low)
1. If START/STOP is input, the system parameter will be set to zero/one.
 2. A message will be printed on line that C-band contact generation has been suppressed or unsuppressed.



3. EMSTAGEN

If conditions are such that station contact information cannot be generated (no ephemeris, unable to converge on any contacts, etc.), the following message will be printed on line:

"ERROR nn UNABLE TO GENERATE veh STATION CONTACTS"

where veh is the vehicle for which the request to generate contacts was made, and nn is a message number. A list of error numbers and detailed descriptions of each will be provided at a later date in the Orbit Trajectory Computations Subsystem User's Guide.

4. EMGABMED

When a B04 MED is input to suppress or unsuppress C-band station contact generation, the MED decoding program, EMGABMED, will cause one of the following messages to be printed on line:

"C-BAND CONTACT GENERATION SUPPRESSED", or

"C-BAND CONTACT GENERATION UNSUPPRESSED".

5. EMSTAGEN

If the time to generate contacts is prior to the beginning of the ephemeris, the anchor time will be adjusted to the first time in the ephemeris and the following message will be printed:

"ANCHOR TIME ADJUSTED FOR veh STATION CONTACTS"

where veh is the vehicle for which the request to generate contacts was made.



STATION CONTACT DISPLAYS ELEMENT

Function

The data in the station contacts tables is displayed on the Next Station Contacts Display (EMDSTAC). The data displayed on the Predicted Site Acquisition Display and the Experimental Site Acquisition Display (EMDPESAD) is generated using the generalized contact generation capability provided by EMGENGEN. The limits of the data generated are specified via MED. These displays operate under the task ETISPLAY and are queued by the load module EMSNAP.

Load Module/Routine Descriptions

Next Station Contact Display - EMDSTAC

This load module displays detailed station contact information for the next six stations to acquire the vehicle(s). Acquisition times are taken from the orbit station contacts tables; keyhole times are computed using the subprogram ECKEYH. The MSK for this display is 1503.

Keyhole Computations Subprogram - ECKEYH

ECKEYH computes the times (if any) that a vehicle enters into and exits from the keyholes of a S-band radar station. These computations are based on data in the current orbit ephemerides and in the orbit station contacts tables. This program is used only by EMDSTAC and therefore is included as a part of that load module.

Predicted and Experimental Site Acquisition Displays - EMDPESAD

EMDPESAD displays data for both the Predicted Site Acquisition Display (PSAD) and the Experimental Site Acquisition Display (ESAD). The station characteristics table and the current orbit ephemeris tables are used to generate a maximum of 42 station contacts for display on PSAD. The limit of the number of contacts requested for display is implied by the bounds specified on the U15 MED, but in no instance will more than 42 contacts be generated.

The ground point table and the current orbit ephemeris tables are used to generate a maximum of 40 experimental site contacts for display on ESAD. The limit of the number of contacts requested for display is implied by the bounds specified on the U16 MED, but in no instance will more than 40 contacts be generated. Ground range and altitude quantities are computed using the subprogram ECMEXP.

The MSK's for these displays are 55, 56 (PSAD), and 1506 (ESAD). EMGENGEN is used to perform the actual generation for both PSAD and ESAD.

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Ground Range and Altitude Subprogram - ECMEXP

Given a ground point and the subsatellite position of the vehicle at its maximum elevation over the ground point, ECMEXP will compute ground range and altitude of the vehicle at its maximum elevation over the ground point. The program is used only by EMDPESAD and therefore is included as a part of that load module.

Requirement Interpretation

Source: The requirements for the Station Contact Display element are outlined in Volume 2 of PHO-TR170 on the following pages:

Pages	Change	Date
(OT)2. 2. 1-1 to (OT)2. 2. 1-2	39	22 November 1967
(OT)2. 2. 1-3 to (OT)2. 2. 1-4	58	19 April 1968
(OT)2. 2. 2-1	39	22 November 1967
(OT)2. 2. 2-2	53	11 March 1968
(OT)2. 2. 2-3	58	19 April 1968
(OT)2. 2. 2-4	39	22 November 1967
(OT)2. 2. 3-1	53	11 March 1968
(OT)2. 2. 3-2	39	22 November 1967
(OT)2. 2. 3-3 to (OT)2. 2. 3-4	58	19 April 1968
(OT)2. 2. 3-5	39	22 November 1967

(See Exhibits 16 through 18)

Amendments to Source: The following items are amendments to the requirements stated in the referenced source.

1. The formats of the manual inputs are given in the Manual Input segment of the Input/Output Specification section. See Section C in Exhibits 17 and 18.
2. Since there is a maximum of two pages for the PSAD display and since a message will be displayed indicating the end of the data requested, "PAGE nn OF nn" will not be displayed. Instead, the actual page number (1 or 2) will be displayed. See Section D in Exhibit 17.
3. If no acquisition message has been sent to a station displayed on PSAD, the quantity "ACQLOS" for that station will be displayed as a zero time.

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Exhibit 16

PHO-TR170A
Volume 2, Change 49
22 Nov. 1967OT 2.2 OutputOT 2.2.1 Next Station Contact DisplayA. Purpose

1. To indicate quality of next station contacts for each vehicle (CSM and LM).
2. To enable vehicle systems controllers to obtain critical telemetry information while the vehicle is still in contact.
3. To indicate blind spot (keyhole) constraints for the 30 and 85 foot unified S-band antennas.

B. Data Sources. The following sources will be used:

- Station Characteristics Table
- Orbit Station Contacts Tables
- Current Ephemeris
- Keyhole Constraints Table.

C. Initialization of Display. This display is initialized upon entry into Orbit Phase utilizing the current ephemeris.D. Parameters to be Computed and Displayed. The following quantities will be computed and displayed:

<u>QUANTITY</u>	<u>DEFINITION</u>
GETHCA	GET (hr:min:sec) of horizon ascent
E _{MAX}	Maximum elevation angle (deg) above station
Δt Pass	Duration of contact (hr:min:sec)
Δt Keyhole LOS	Duration from GETHCA to entrance into keyhole (hr:min:sec) GETK _{LOS} - GETHCA
Δt Keyhole	Duration of time in keyhole (min:sec) GETK _{AOS} - GETK _{LOS}
GET	Current GET (hr:min:sec)
XXX	Trajectory update number

Approved:  NASA/FSB PHO/PARS

(OT) 2.2.1-1

Exhibit 16 (Cont'd.)

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E. Updates. Display quantities will be updated on the completion of the computer time cycle (12 sec). Δt will count down every update while a station is in contact with the vehicle.

F. Additional Information

1. The next six stations, having E_{MAX} equal to or greater than 0 degrees, will be displayed. E_{MAX} will be counted down on the computer time cycle during station contact.
2. If a station is in contact with the vehicle at the time the station contacts are generated, the time of generation will be displayed as GETHC_A. Asterisks will be displayed immediately preceding GETHC_A. If the maximum elevation of the pass is prior to the station contact generation time, E_{MAX} will be the elevation above the station at GETHC_A and will be preceded by an asterisk on the display. If the maximum elevation of the pass is after the end of the ephemeris, E_{MAX} will be the elevation above the station at the time the ephemeris ends and will be preceded by an asterisk on the display.
3. If less than six contacts exist in the station contact table, a message will be displayed following the last contact.
4. If a keyhole exists for a contact, an "kH" will be displayed under the station name and the Δt keyhole LOS and Δt keyhole quantities will be displayed. When there is no keyhole or when the vehicle has exited from the last keyhole of a pass the above mentioned items will not be displayed.
5. Δt keyhole LOS will be counted down to entrance into keyhole starting at AOS (GETHC_A). At keyhole LOS, this should equal zero if there is no other keyhole for this pass. If there is another keyhole for the station pass, this time will be displayed and will immediately be counted down to the second keyhole LOS. If there are two keyholes for a station in one pass, an asterisk will be displayed immediately preceding Δt keyhole LOS of the first keyhole.
6. Δt keyhole counts down to zero on entrance into keyhole. If there is a second keyhole for this pass, this time will be displayed and will remain static until the second keyhole is reached.
7. Keyhole information will only be displayed for stations that have unified S-band antennas.
8. For lunar orbits, moon occultation effects must be included.

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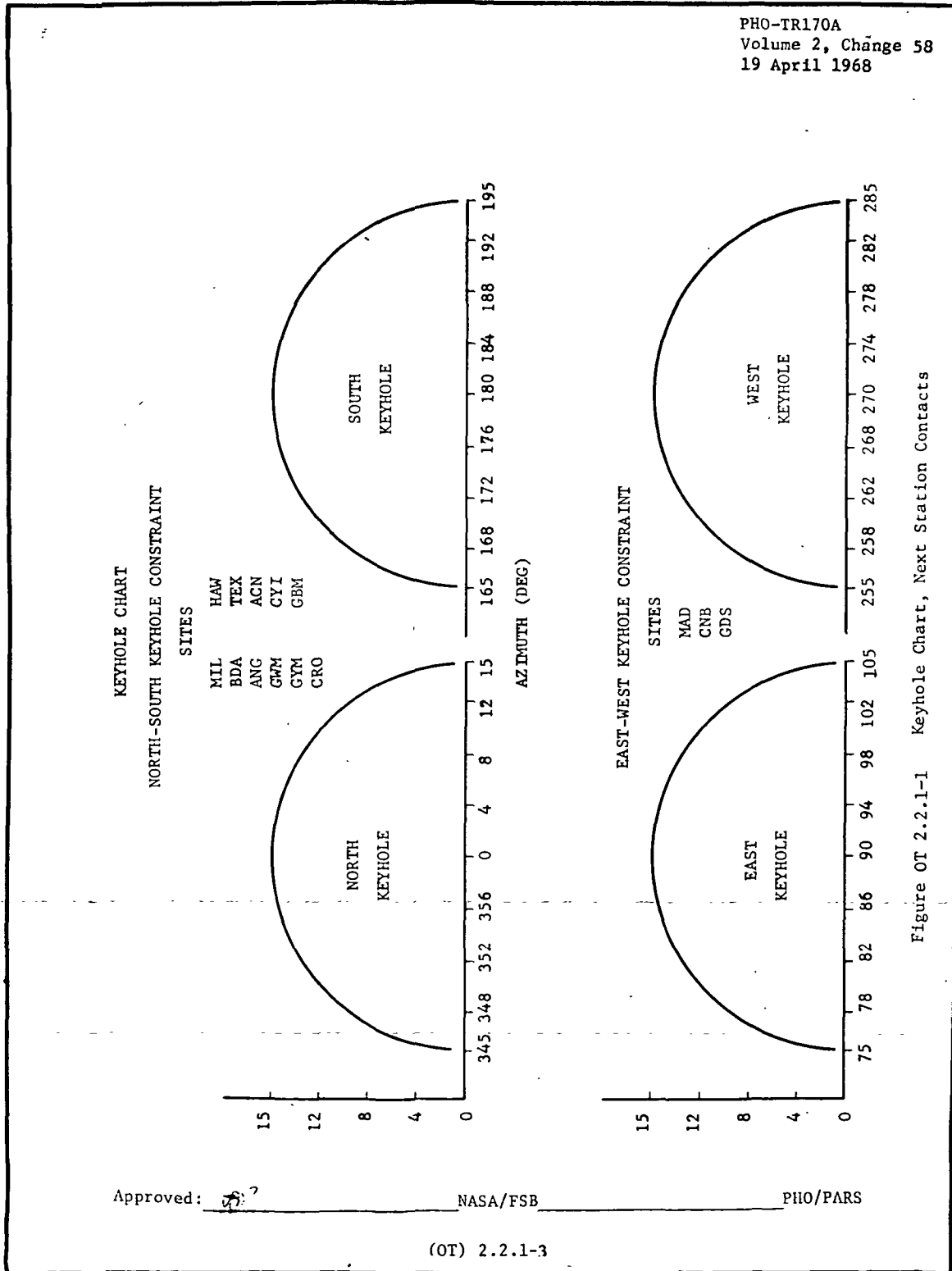


Exhibit 17

PHO-TR170A
Volume 2, Change 39
22 Nov. 1967

NT 2.2.2 Predicted Site Acquisition Display (CSM/LM)

- A. Purpose. To plan CSM/LM commands; and to determine periods during which a station may be removed from operational status.
- B. Data Source. The following sources will be utilized:
- Station Characteristics Table
 - Current Ephemerides
 - Manually entered GET and Δt
 - Manually entered begin rev (N_1) and end rev (N_2).
- C. Initialization of Display. This display is initialized upon manual entry of the following:

Code, Vehicle, GET, Δt , Begin Rev, End Rev;

where	
Vehicle	CSM or LM
GET	Ground elapsed time from liftoff
Δt	The interval from the specified GET that contacts are to be generated
Begin Rev	The beginning revolution that contacts are to be generated
End Rev	The ending revolution number that contacts are to be generated

The display may be requested either by time or by revolution number.

- D. Parameters to be Computed and Displayed. The following quantities will be computed and displayed.

<u>QUANTITY</u>	<u>DEFINITION</u>
VEHICLE	Alphabetical
Vector ID	The identification code for the last vector used to update the trajectory on which these computations are based (station, data source, Rev.)

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Exhibit 17 (Cont'd.)

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11 March 1968

XXX Trajectory update number

PAGE NUMBER In some cases the monitor may not be able to display all of the information requested. In these cases, a maximum of 2 pages may be required to display all of the information. This will indicate which page is being viewed.

The following information is displayed for each predicted station contact and is available for both CSM and LM:

REV. NO.	Revolution number in which contact is made (If no revolution numbers are available, zero will be displayed)
STATION	Name
GETHC _A	GET (hr:min:sec) of Horizon Crossing Ascending from liftoff
GETHC _D	GET (hr:min:sec) of Horizon Crossing Descending from liftoff
E _{MAX}	Maximum elevation (deg) of S/C from station
Capability	Station Equipment
RDR	Radar
T/M	Telemetry
CMD	Command
VOICE	Voice
ACQLOS	The time-tag of the last data point in an acquisition message that the station received.

- E. Updates. No provision for automatic updates (with trajectory, etc.) exists. If a display request is made, and the station contact table is being updated while the display is being formatted, an asterisk and a message will appear on the screen. In this event the flight controller must request the display again. If a trajectory update occurs, the next display request will cause the display to return to Page 1.

F. Additional Information

1. Starting at the greater of present GET and requested GET (or Rev), contacts will be generated and displayed for up to two full pages (42 contacts), the end of the ephemeris, or the depletion of the Δt (or REVS) whichever comes first. In all cases, no more than 24 hours of data will be processed.

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Exhibit 17 (Cont'd.)

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2. If request is made by revolution number, data will be displayed for those revolutions that an ending time is available (i.e., request is made for revolution 1-6, and ending times are available for only revolutions 1-2, then data will only be displayed for revolutions 1-2)
3. If the display currently being viewed contains all information requested, an appropriate message will appear on the format. If the message does not appear, it may be assumed that the information requested required more than one page. The flight controller must rerequest the display to get the rest of the requested information. Data will not be displayed for those stations for which the vehicle's maximum elevation is equal to or less than zero degrees.
4. If a station is in contact with the vehicle at the time of station contact generation, the time of generation will be displayed as GETHC_A. An asterisk will be displayed immediately preceding GETHC_A when this occurs. If the maximum elevation of the pass is prior to the generation time, an asterisk will precede the displayed value of E_{MAX} (which will be the elevation at GETHC_A).
5. If a station is in contact with the vehicle at current time + Δt (or the end of the ephemeris table), GETHC_D will be the last time in the ephemeris table and will be preceded by an asterisk. If the maximum elevation of the pass is after GETHC_D, an asterisk will precede E_{MAX}. The value of E_{MAX} will be the elevation at GETHC_D. For lunar orbits, moon occultation effects must be included.

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Exhibit 18

PHO-TR170A
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2.2.3 Experimental Site Acquisition Display

- A. Purpose. To determine availability of groundtrack sites for employment in vehicle-ground experiments.
- B. Data Source
- Ground point table
 - Current ephemeris
 - Manually entered GET and Δt
 - Manually entered Begin rev and End rev.
- C. Initialization of Display. This display will be initialized upon manual entry of the following.


Code, Vehicle, GET, Δt , Begin rev, End rev;

where:	
Vehicle	CSM or LM
GET	GET time to start generating contact information
Δt	the interval from GET over which contacts will be generated
Begin Rev	The beginning revolution to start generating contacts
End Rev	The ending revolution in which contacts will stop being generated.

The display may be requested either by time or by revolution number.

- D. Parameters To Be Computed and Displayed. The following quantities will be computed and displayed:

<u>QUANTITY</u>	<u>DEFINITION</u>
Vector ID	The identification code for the last vector used to update the trajectory on which these computations are based (station, data source, Rev.)
XXX	Trajectory update number
PAGE NO.	In some cases, the monitor may not be able to display all of the information requested. In these instances, 2 "pages" may be required to display all of the information. This will indicate which "page" is being viewed.

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NASA/FSB

PHO/PARS

(OT) 2.2.3-1

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For each groundtrack experimental site which is to be in contact with the spacecraft, information is displayed as follows:

<u>QUANTITY</u>	<u>DEFINITION</u>
REV	The revolution number in which the contact is made (If no revolution numbers are available, zero will be displayed)
STA ID	A 4-digit code indicating the ground station which will be in contact with the S/C
GETAOS	Ground Elapsed Time of Acquisition (0 deg elevation angle from the station) (hr:min:sec)
GETLOS	Ground Elapsed Time of Loss of Acquisition (0 deg elevation angle from the station) (hr:min:sec)
GET	Time of closest approach to Ground Point or star (hr:min:sec) (Time of E_{MAX})
RNG	Ground range of closest approach of Ground Point (nm) (E_{MAX})
h_o	S/C altitude at closest approach of Ground Point or star. (E_{MAX})
E_{MAX}	Maximum elevation angle (deg) from the station

- E. Updates. There is no provision for automatic updates (with trajectory, etc.). If a display request is made while a trajectory update is in process, the request will not be satisfied until the update is completed. Should a trajectory update occur while the display is being formatted, the request being processed will be satisfied, and all outstanding requests (prior to trajectory update) will be released. In this event the flight controller must re-request the display. If a trajectory update completes while the display is being viewed, upon the next MSK entry the data will be regenerated for page 1 based on the most recent ephemeris.

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F. Additional Information

1. Starting at the greater of present GET of requested GET, the display shall generate and display contacts for up to two full pages of contacts (40), the end of the ephemeris, or the depletion of the Δt or REV input via MED--whichever comes first. In all cases, no more than 24 hours of data will be processed.

If request is made by revolution number, data will be displayed for those revolutions for which an ending time is available (i.e., request is made for revolutions 1-6 and ending times are available for revolutions 1-2, then data will only be displayed for revolution 1-2).

2. If the display currently being viewed contains all information requested, an appropriate message will appear on the format. If the message does not appear, it may be assumed that the information requested required more than one "page." The flight controller then must request the display again in order to obtain the remainder of the information desired. Data will not be displayed for those stations for which the vehicle's maximum elevation is less than 0 degrees.
3. Revolution numbers are based on ascending horizon-crossing times of the stations.
4. If a vehicle can see a site at the time of contact generation, the time of generation will be displayed as GETAOS. An asterisk will be displayed immediately preceding GETAOS when this occurs. If the maximum elevation of the pass is prior to generation time, an asterisk will precede the displayed value of E_{MAX} . The value of E_{MAX} will be the elevation at GETAOS.
5. If a vehicle can see a site at the time of generation $+\Delta t$ (or the end of the ephemeris table), GETLOS will be the time of generation $+\Delta t$ (or the last time in the ephemeris table) and will be preceded by an asterisk. If the maximum elevation of the pass is after GETLOS, an asterisk will precede E_{MAX} . The value of E_{MAX} will be the elevation at GETLOS.
6. This display is only required for the primary vehicle.
7. Earth or moon sites can be loaded into the Ground Point Table but cannot be mixed.

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8. Earth site contact information will be available in earth orbit, translunar and transearth coast, lunar orbit phase and during lunar stay.
9. Moon site contact data can only be requested if the primary vehicle is X earth radii from the moon. The X E.R. will be a system parameter.

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(OT) 2.2.3-4

4. The standard seven-character vector ID will be displayed on ESAD. See Section D in Exhibit 18.
5. Revolution number processing will be for either Earth or Moon revs as specified on the U15 MED for PSAD. See Sections C and D in Exhibit 17.

Additions to Source: The following items are extensions of the requirements stated in the referenced source.

1. When interpolation is required, eighth order will be used whenever possible. If conditions are such that less than nine vectors are stored in the ephemeris table, the order of interpolation will be determined by the number of vectors available.
2. The convergence criteria of all of the computed times is ± 3 seconds. The maximum elevation angle is defined to be the angle above the horizon at the computed time of maximum elevation.

Functional Diagrams

Figure 16 and 17 illustrate the interfaces between the programs in this element and other elements, units, or subsystem, as well as data table usage, task structure and input/output data flow. The systems used here are defined in the Glossary of this document.

Input/Output Specifications

The Input/Output Specifications for the Station Contact Displays Element may be divided into two main groups, manual inputs and display formats. The programs in this element receive data limits from the following inputs: U15 (Predicted Site Acquisition Display) and U16 (Experimental Site Acquisition Display). Copies of these MED formats and the formats of the Next Station Contacts Display, the Predicted Site Acquisition Display, and the Experimental Site Acquisition Display are included in the next pages.

On-Line Prints

The following on-line print is issued by EMDSTAC if an error condition is encountered by the keyhole routine:

KEYHOLE ERROR nn FOR veh, sta

where nn is the error number, veh is the vehicle ID, and sta is the radar station ID. A list of error numbers and detailed descriptions of each will be provided at a later date in the Orbit Trajectory Computations Subsystem User's Guide.

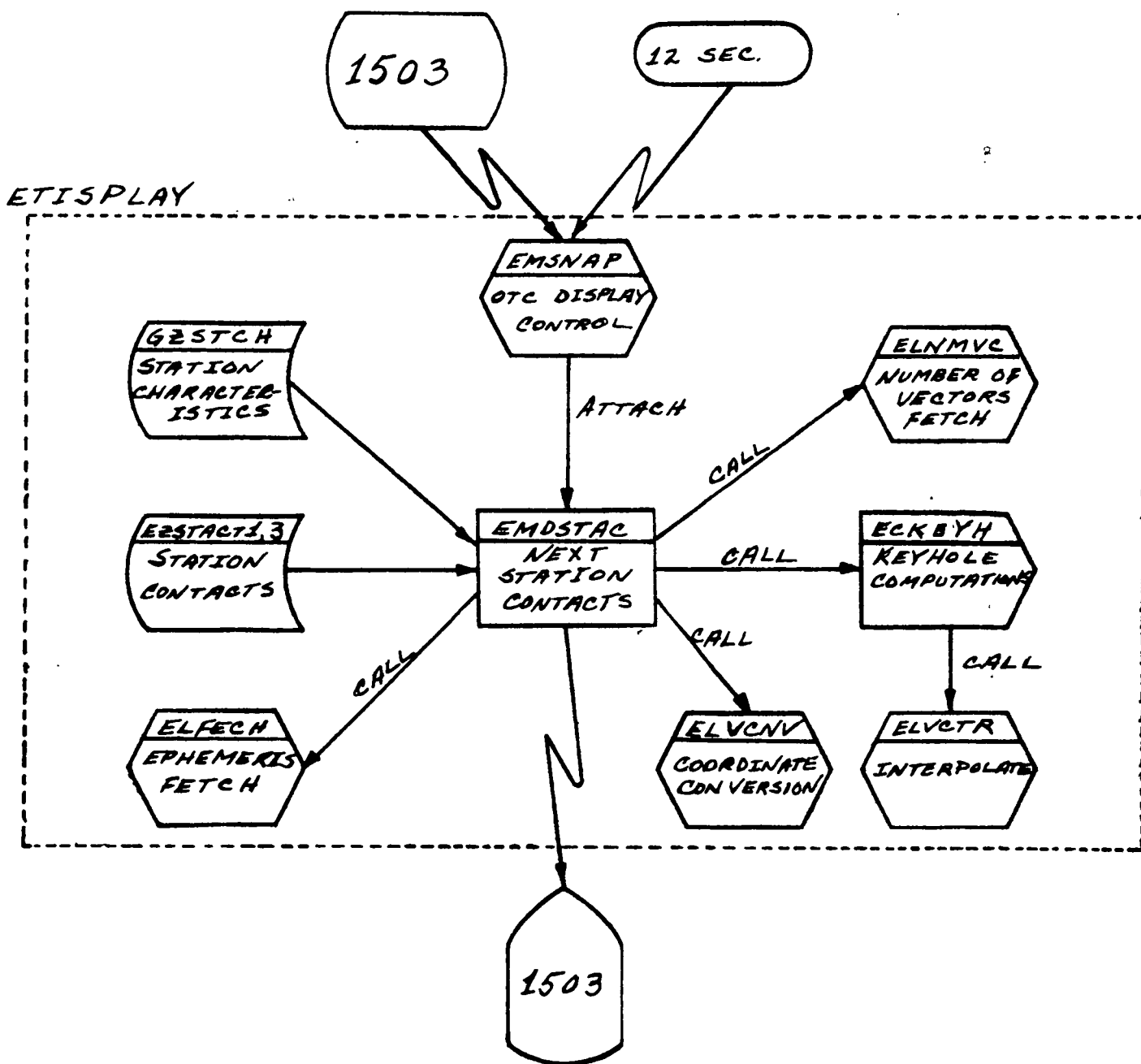


Figure 16. EMDSTAC

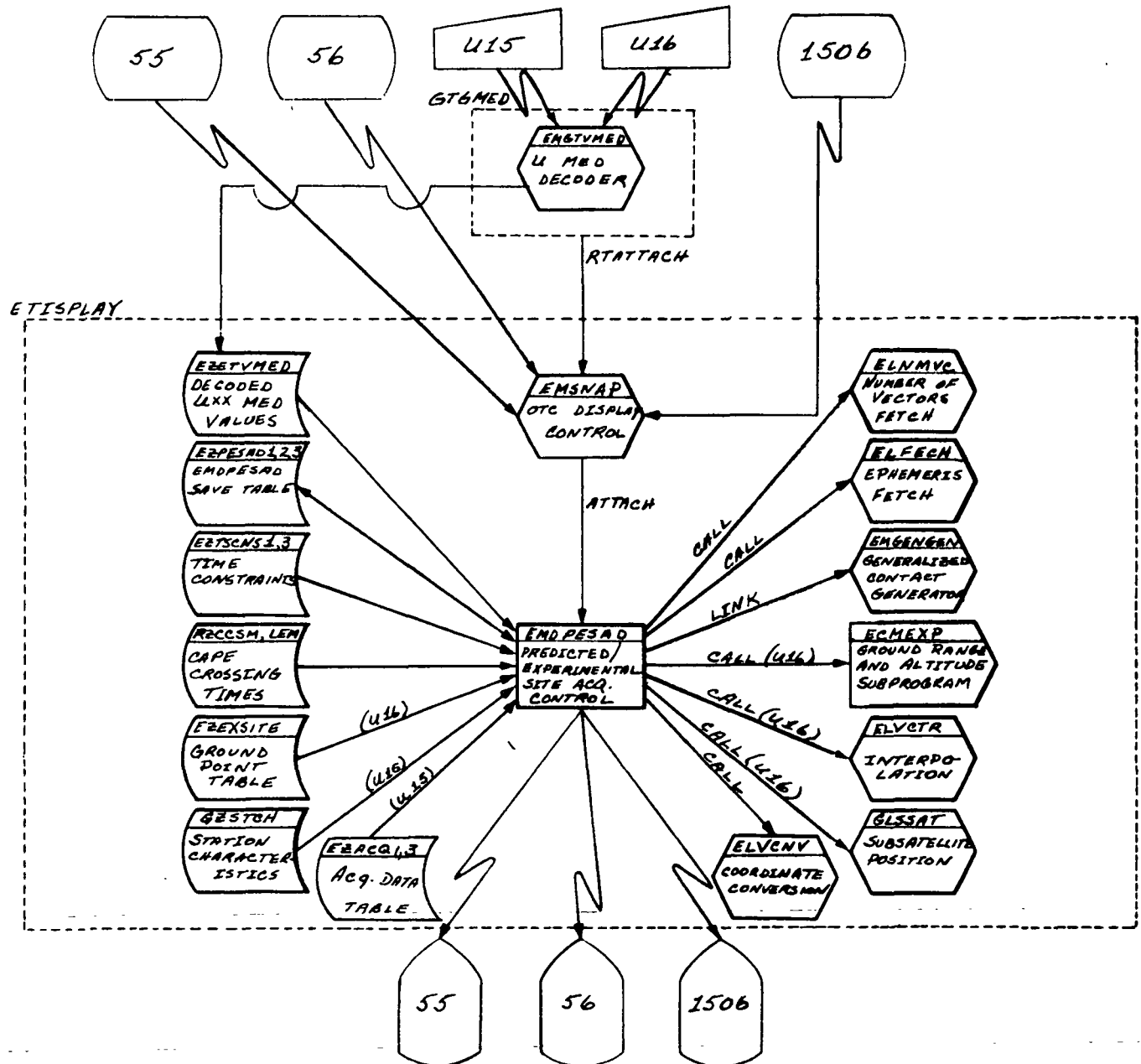


Figure 17. EMDPESAD



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MED Format Table

MED Code: U15
 Purpose: Predicted site acquisition
 Load Module: EMGTVMED

Task:
 EP:
 QNAME:
 QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name		VEH ID	IND	Time RevB	Δ -Time RevF	Ref Body	
Input Format		VEH	AAA	HHH:MM:SS.SS NN	HHH:MM:SS.SS NN	A	
Input Units		EBCDIC	EBCDIC	GET FXP	GET FXP	EBCDIC	
Program Units		Note 1		hours FXP	hours FXP	FXP(6)	
Scale Factor							
Checking Option		Note 2 Exact	Note 3 Exact	None MIN	Minmax(5) Min	EXACT(6)	
Missing Item Option		Error	Error	Error	Error	Insert "E"	
Item Destination							

Programmer:

Initial Logic:

Final Logic: Store in block 14 (CSM) or 15 (LEM) of EZETVMED

Illegal Phases: All but low speed orbit

Notes: 1. EBCDIC name and numeric code

2. CSM or LEM

3. Rev if rev numbers are to be input for parameters 3 and 4

GET if time and delta time option is to be used.

4. NN > 0

5. $0 \leq \Delta t \leq 24$ hrs.

6. E for Earth (=0), M for Moon (=2)



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MED Format Table

 Task:
 EP:
 QNAME:
 QUEID:

 MED Code: U16
 Purpose: Experimental site acquisition

Load Module: EMGTVMED

Desc.	Item	1	2	3	4	5	6
Item Name		VEH ID	IND	Time Rev E	Δ - Time Rev E	Central Body	
Input Format		VEH	AAA	HHH:MM:SS.SS NN	HHH:MM:SS.SS NN	A	
Input Units		EBCDIC	EBCDIC	GET FXP	GET FXP	EBCDIC	
Program Units		Note 5		hours FXP	hours FXP	FXP(6)	
Scale Factor							
Checking Option		Exact (4)	Exact (1)	None (3) Min	Minmax(2) Min	Exact (6)	
Missing Item Option		Error	Error	Error	Error	Insert "E"	
Item Destination							

Programmer:

Initial Logic:

Final Logic: Store in block 16 of EZETVMED

Illegal Phases: All but low speed orbit

Notes: 1. IND = REV if rev numbers are to be input for parameters 3 and 4

= GET if time and delta time option is to be used

2. $0 \leq \Delta t \leq 24$ hrs.

3. NN > 0

4. CSM

5. EBCDIC name and numeric code

6. E for Earth (=0); M for moon (=2)

Exhibit 19

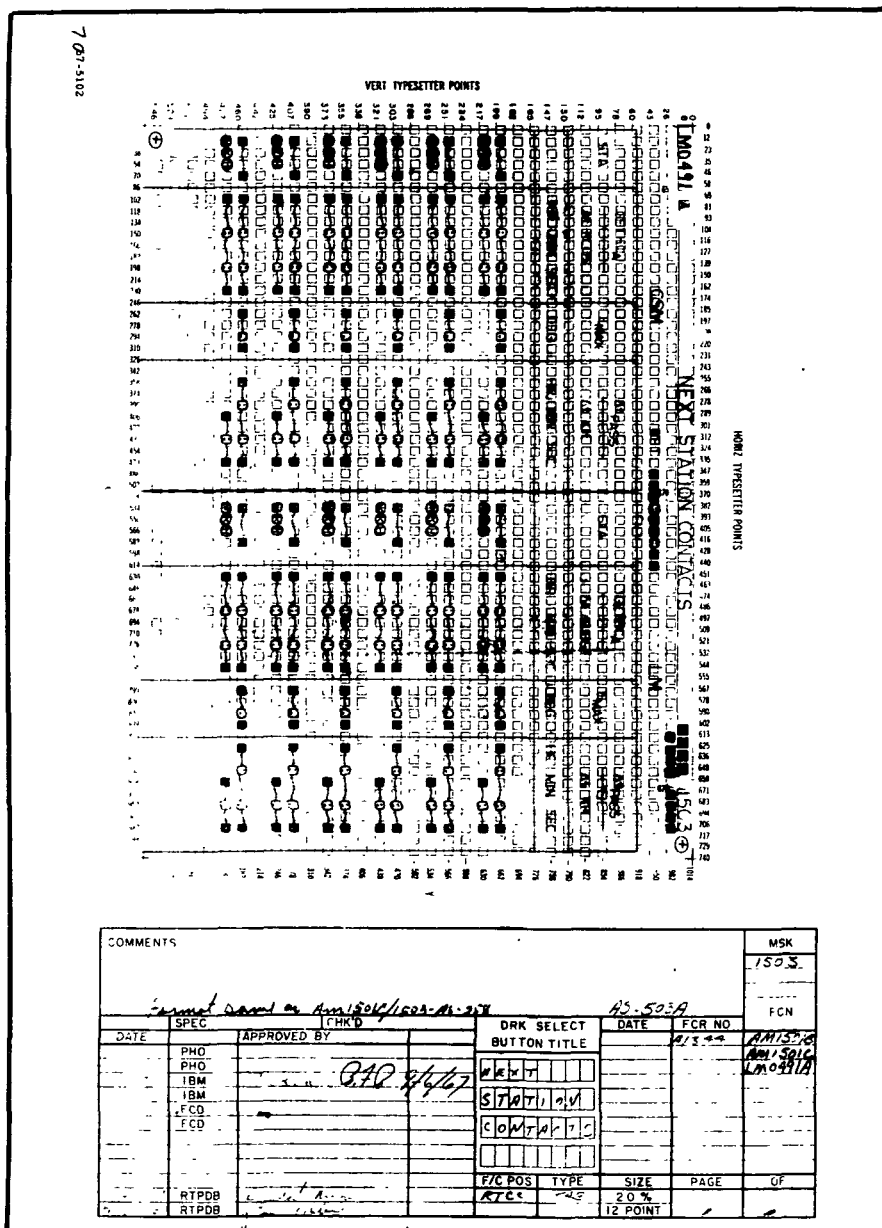
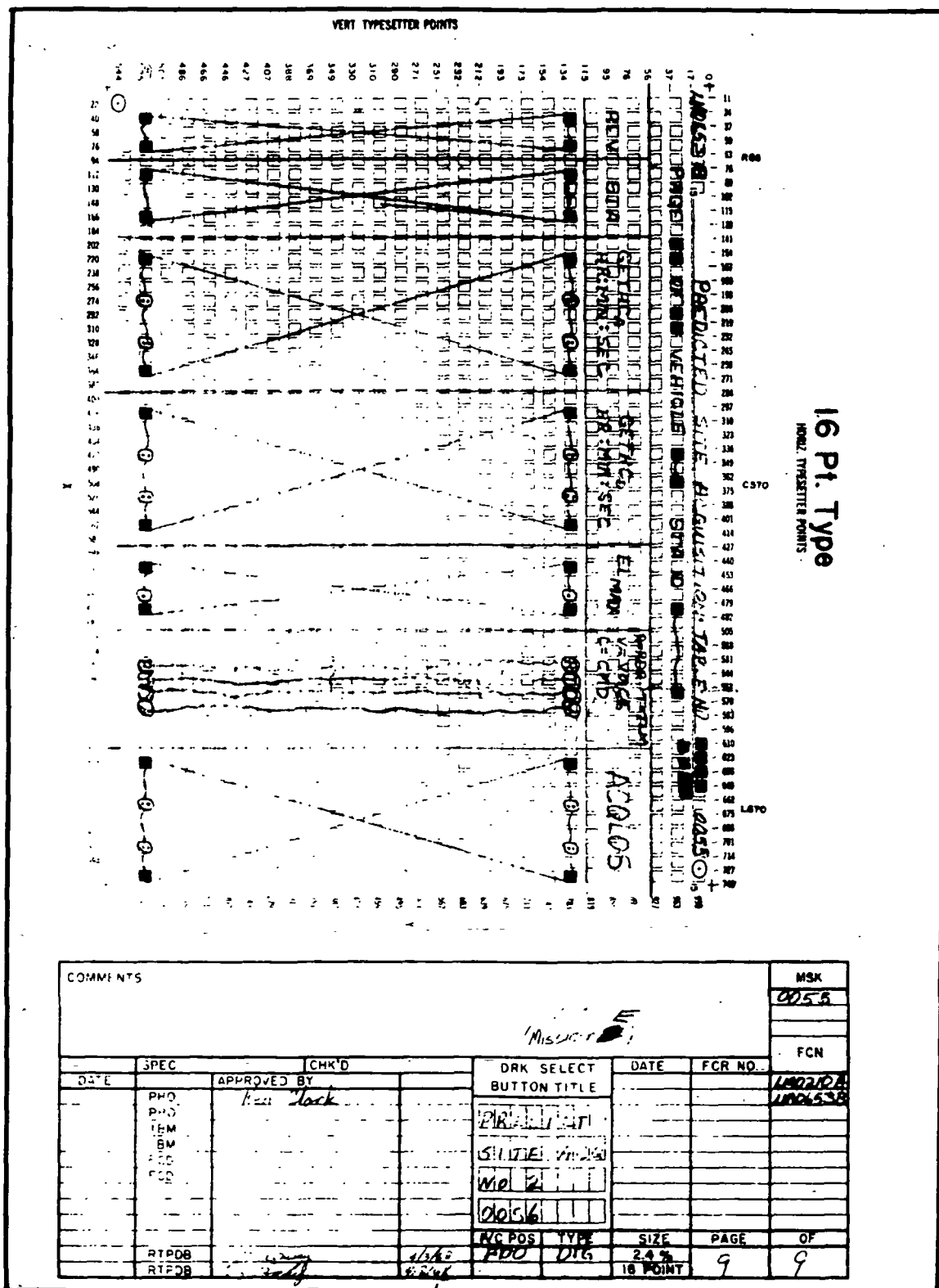


Exhibit 20



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Exhibit 21

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REV	STA	GETHCA HR:MIN:SEC	GETHCD HR:MIN:SEC	EL MAX	VEHICLE CE CHD	ACQ LOS
X	X	X	X	X	X	X

PREDICTED SITE ACQUISITION TABLE NO. 0056

PAGE 0056

LHSP
(Mission E)

DATE	SPEC	CHND	DRW SELECT	DATE	FCR N.
		Ken Clark			
		Dr. Gallina			
		Ed. B. 10/17/68	PREDICT		
			SITE ACQ		
			MAP 2		
			0056		
			EDD		
			013		

9
9

COMMENTS						MSK	
						FCN	
<i>to mail name as Am 107-29/100 - A1-208</i>							
<i>21 Oct 66</i>	SPEC <i>2</i>	CHECKED <i>LL</i>	ORR SELECT BUTTON TITLE	DATE	FCR NO.		
DATE	PHO	APPROVED BY				36	
	PHO		[Y] [] [] []			LMQ990	
	IBM		[] [I] [E]				
	IBM		[] [] [] []				
	FCD		[] [] [] []				
	FCD						
			F/C POS TYPE	SIZE	PAGE	OF	
	RTPOB		(S-P-D)	2.0 %			
	RTPOB			12 POINT	?	?	

REMOTE SITE ACQUISITION ELEMENT

Function

The transmission of acquisition messages to the remote tracking sites is performed by load modules operating under the task name ETXSACQ. EMSSACQ is the controlling load module of the acquisition data task. It contains the logic necessary to determine when messages are to be transmitted to the remote sites. The actual formatting and transmitting of the messages is performed by the load modules, EMMCBND (C-band messages), EMMSBND (S-band messages), and EMDUD (DOD messages).

The queue to initialize the acquisition data task is given by EMSTAGEN (in Orbit phase) or RMSDEAD (in Abort III or Reentry phase). After initialization, periodic queues on even thirty-minute multiples (when acquisition data is not suppressed) and queues resulting from manual inputs will be processed by ETXSACQ; no more queues from EMSTAGEN or RMSDEAD are given.

Load Module/Routine Description

Remote Site Acquisition Control - EMSSACQ

EMSSACQ determines when orbit and reentry acquisition messages should be transmitted based on the data stored in the orbit or reentry station contacts tables. When messages are to be sent, EMMCBND, EMMSBND, and EMDUD are invoked to perform the actual formatting and transmission of the messages.

C-Band Acquisition Data Messages - EMMCBND

EMMCBND formats and transmits acquisition data to all C-band radar sites that acquire the vehicle. It performs all conversions necessary to ensure that data is transmitted in the proper units.

S-Band Acquisition Data Messages - EMMSBND

EMMSBND formats and transmits acquisition data to all S-band radar sites that acquire the vehicle. In addition to performing necessary conversions to ensure that data is transmitted in the proper units, EMMSBND computes slant range, receiver VCO frequency, transmitter VCO frequency, bias doppler, and one-way doppler quantities for inclusion in the message. The equations used in computing the above quantities are given below.

f_o = Frequency for the particular vehicle (found in the station characteristics table)

c = Speed of light = 983571200.0 (system parameter MCMLFS)

K_1 = 5812.705055 (system parameter MCCVCU)

c_1 = 6378165. (system parameter MCCMCU)

c_2 = 1.049694624 (system parameter MCCMRU)

K_2 = 1.08597285 (system parameter MCZRVD)

K_3 = $7.7824 * 10^6$ (system parameter MCZCBD)

\dot{R} = Range rate, which is computed

$$\lambda_1 = \lambda_{\text{site}} + \omega * t_{\text{aos}}$$

where $\omega = 0.2625161418$ (system parameter MCERTS).

$$\bar{R}_{\text{site}} = \begin{bmatrix} X_{\text{site}} = (r_e \cos \Psi' + h \cos \Psi) \cos \lambda_1 \\ Y_{\text{site}} = (r_e \cos \Psi' + h \cos \Psi) \sin \lambda_1 \\ Z_{\text{site}} = R_e \sin \Psi_R \end{bmatrix}$$

$$\bar{V}_{\text{site}} = \begin{bmatrix} \dot{X}_{\text{site}} = -\omega Y_{\text{site}} \\ \dot{Y}_{\text{site}} = \omega X_{\text{site}} \\ \dot{Z}_{\text{site}} = 0.0 \end{bmatrix}$$

where $(r_e \cos \Psi' + h \cos \Psi)$ and $(R_e \sin \Psi_R)$ are in the station characteristics table.

Now

$$\bar{R}_a = \bar{R}_s/c - \bar{R}_{\text{site}}$$

and

$$\bar{V}_a = \bar{V}_s/c - \bar{V}_{\text{site}}$$

then

$$\dot{R} = \frac{\bar{R}_a \cdot \bar{V}_a}{|R_a| * K1}$$

With these definitions in mind, the following equations may be stated.

To compute slant range in octal units:

$$R_{RU} = R_{er} \left(\frac{C_1}{C_2} \right), \quad (1)$$

where R_{er} is obtained from the inertial-to-local routine, and C_1 and C_2 are system parameters (meters/er and meters/RU, respectively).

To compute receiver VCO frequency:

$$RVCO = \frac{(K2) f_o \left(1 - \frac{\dot{R}}{C} \right) - 50}{96} \quad (2)$$

To compute transmitter VCO frequency:

$$TVCO = \frac{f_o}{96 \left(1 - \frac{\dot{R}}{C} \right)} \quad (3)$$

To compute bias doppler:

$$D_B = \frac{K3}{1+2 (K2) f_o \left(\frac{\dot{R}}{C} \right)}$$

To compute one-way doppler:

$$D = f_o \left(\frac{\dot{R}}{C} \right) * 10^3$$

DOD Vector Messages - EMMDUD

EMMDUD formats and transmits the DOD vector acquisition messages to the specified sites and performs all conversions necessary to ensure that data is transmitted in the proper units.

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Requirement Interpretation

Source: The processing requirements for the Remote Site Acquisition Element are outlined in Volume 2 of PHO-TR170 on the following pages:

Pages	Change	Date
(OT)5.2.1-1	58	19 April 1968
(OT)5.2.1-2 to (OT)5.2.3-3	53	11 March 1968
(OT)5.2.4-1	41	11 December 1967
(OT)5.2.5-1 to (OT)5.2.6-1	58	19 April 1968
(OT)5.2.6-2	53	11 March 1968

Some of the requirements outlined in the referenced pages are amended by requirements outlined in RTCC Transmittal 9147. A copy of these pages is included in this section (see Exhibits 23 through 29).

The teletype formats of the messages are described in Annex D of the Apollo Tracking Data Format Control Book (for the AS-205 and all subsequent Apollo missions), Sections 2.4 and 4.2 of the original release, Revision 1 (14 December 1967), Revision 2 (29 February 1968), and Revision 3 (29 May 1968). A copy of these pages is included in the Teletype Formats segment of the Input/Output Specification section.

Amendments to Source: The following items are amendments to the requirements stated in the referenced source.

1. The formats of the manual inputs are given in the Manual Input segment of the Input/Output Specifications section (see Exhibit 23).
2. The on-line print messages are given in the On-line Prints segment of the Input/Output Specifications section (see Exhibit 24).
3. Each message will be transmitted at least twenty minutes prior to the time-arc it represents, except on the initial queue (see Section A in Exhibit 25).
4. Upon sending an acquisition message to a particular site, the time corresponding to the station name in the ACQLOS table will be LOS if the Δt of the pass ≤ 30 minutes or either pseudo or actual AOS + 30 minutes if the Δt of the pass is > 30 minutes (see Section A in Exhibit 25).

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Exhibit 23

PHO-TR170A
Volume 2, Change 58
19 April 1968OT 5.2 Teletype OutputOT 5.2.1 MED EntriesA. RetransmissionCODE, VEHICLE, SITE, GET;

VEHICLE: CSM or LM

SITE: Three letter site code plus band type (zero for voice sites).

GET: Either the Pseudo AOS time for that site if it is in acquisition at this GET or the time to begin searching for the next contact if the site is not in acquisition. The GET should be in HRS:MIN:SEC.

Applies to the following phases: 3, 4, 5, 6, 7, 9.*

B. Suppress and Unsuppress Acquisition DataCODE, FUNCTION, VEH;

FUNCTION: Start or stop

VEH: Vehicle ID (CSM, LM)

This MED allows the computer controller to start or stop all acquisition data.

Applies to the following phases: 1, 3, 4, 5, 6, 7, and 9.

C. Suppress and Unsuppress C-Band Station ContactsCODE, FUNCTION, VEH;

FUNCTION: Start or stop

VEH: Vehicle ID (CSM, LM)

This MED allows the computer controller to start or stop C-band station contacts and, thus, stop or start all C-band acquisition.

Applies to the following phases: 1, 4, 6, 7, and 9.

* Prelaunch = 1; Launch = 2; Abort = 3; Earth Orbit = 4; Reentry = 5;
Translunar/Transearth = 6; Lunar Orbit = 7; Descent = 8; LM Prelaunch =
9; LM Ascent = 10.

Approved: _____

Big

NASA/FSB

PHO/PARS

(OT) 5.2.1-1

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Exhibit 23 (Cont'd.)

PHO-TR170A
Volume 2, Change 03
11 March 1968D. Transmit GSFC Maneuver InformationCODE, MANEUVER NO., VEH;

MANEUVER NO.: The maneuver number in the MPT

VEH: CSM, LM, SIVB

This MED allows the computer controller to transmit maneuver information to Goddard Spaceflight Center (GSFC).

Applies to the following phases: 4, 6, 7, and 9.

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(OT) 5.2.1-2

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Exhibit 24

PHO-TR170A
Volume 2, Change 53
11 March 1968OT 5.2.2 On-Line Print Requirements

- A. Transmission of Acquisition Messages. Should indicate:
- Station ID
 - VEHICLE (CSM, LM)
 - Indication if a DOD vector was transmitted
- B. Transmission of the Real-Time Auxiliary Computer Facility (RTACF) Vector. Should indicate:
- GMT of vector: $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$
 - WEIGHT
 - STATION ID
 - VEHICLE (CSM, LM)
 - Earth or Moon Reference Indicator
- C. Transmission of Vector to Marshall Space Flight Center (MSFC). Should indicate:
- GMT of vector: $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$
 - WEIGHT
 - STATION ID
 - VEHICLE (CSM, LM, S4B)
 - Earth or Moon Reference Indicator
- D. Transmission of Real-Time Auxiliary Computer Facility (RTACF) Reference Matrix. Should include:
- REFSMMAT ID
 - VEHICLE ID (CSM, LM)

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Exhibit 24 (Cont'd.)

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- E. Transmission of Ephemeris Data/Targeting Parameters. Should indicate that the vector was transmitted to Marshall Space Flight Center (MSFC).
- F. Goddard Space Flight Center Maneuver Information. Should include:
- Maneuver number
 - VEHICLE (CSM, LM, S4B)
 - Vectors at GMTPI and GMTCO
- G. Suppress/Unsuppress all C-band Station Contacts.

Code, Stop, All C-band Station Contacts
Code, Start

Approved: _____

TMC

NASA/FSB

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(OT) 5.2.2-2

Exhibit 25

PHO-TR170A
Volume 2, Change 3
11 March 1968

OT 5.2.3 Acquisition Generation Logic

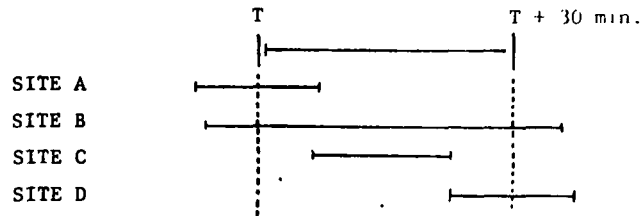
An acquisition message will represent an arc of not more than 30 minutes and each message will be transmitted 30 minutes prior to the time-arc it represents.

A. Normal Acquisition.

- A table, ACQLOS, will be constructed, consisting of at most, 50 entries; each entry will contain a site and a time.
- Upon sending an acquisition message to a particular site, the time-tag of the last point of the message will be entered beside the name of the site in the ACQLOS Table.
- The automatic generation logic will use even multiples of 30 minutes (expressed in GMT) as the queue to send data to sites which have contact from 30 minutes to 60 minutes in advance of current time. An example would, perhaps, clear the meaning of this:

When current time reaches 3^H 30^M GMT, acquisition data will be sent to all sites viewing in the time interval from 4^H to 4^H 30^M.

- The checks necessary to determine that a site has contact in a given 30-minute segment should include checks for both AOS and LOS. The types of contact must fall into one of the following categories:



This picture, of course, represents the period of track by a site with respect to the time interval in question. Thus, the checks must include the following:

Case 1 Is $AOS \leq T < LOS$? (Sites A and B fall into this category.)

Case 2 Is $T < AOS < T + 30 \text{ min.}$? (Sites C and D fall into this category.)

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Exhibit 25 (Cont'd.)

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Volume 2, Change 5
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Using the above checks, those sites which have contact in the proper 30-minute segment can be determined.

- For each site determined to have contact for the time interval in question, a check will be made to determine the time-tag of the latest point sent for that site; i.e., a check of the ACQLOS Table. For the site in question the following logic would apply and should be checked in the order indicated:

Case 1. Is $ACQLOS \leq T$?

A "yes" answer implies that acquisition should be sent to that site such that pseudo AOS time for the site is either true AOS if $ACQLOS \leq AOS$ of pseudo AOS time is ACQLOS.

Case 2. Is $ACQLOS < LOS$?

This implies that acquisition should be sent to that site, and the pseudo AOS time is ACQLOS.

If the answer to Case 1 is "no," then Case 2 must still be examined. If the answer to Case 2 is "no," then no message should be sent to that site (a message has already been sent to that site).

- When a new message is sent to a site, its ACQLOS is recorded in the ACQLOS Table. This Table is unaffected by the retransmit MED.
- Without exception, an acquisition message will cover either a 30-minute arc or will include actual LOS for the site.
- It should be emphasized that the above logic is designed to determine if a site should receive a message and, if so, to determine the time arc which a message should cover. No change in the computation or format for individual messages is desired.

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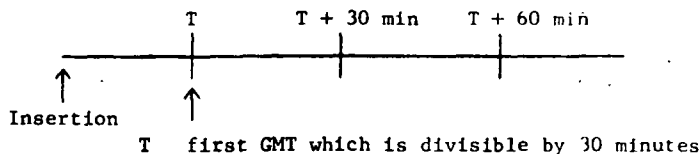
(OT) 5.2.3-2

Exhibit 25 (Cont'd.)

PHO-TRI 70A
Volume 2, Change 53
11 March 1968

B. Initialization.

- Upon initial insertion into orbit (or P14 MED) acquisition data will be generated for all sites which have contact between current time and 30 minutes following the first even multiple of 30 minutes (expressed in GMT). A diagram will clear the meaning of this:



Referring to the diagram, acquisition data will be sent to all sites which have contact between insertion and T + 30 minutes.

- C. Type of Acquisition Messages. Three indicators on the station characteristics are set to indicate which type or types (IRV/DOD, C-band, or S-band) of acquisition messages are to be sent to each site.
- D. Mode III Abort Phase. Upon entry into Mode III abort phase acquisition data will be generated for all sites which have contact between current time and 30 minutes following the first even multiple of 30 minutes (expressed in GMT). See Paragraph OT 5.2.3 B. Recycles and trajectory updates will not cause acquisition data to be regenerated.
- E. Entry Phase. Prior to reentry, a station will receive a normal acquisition message with a true AOS and a true LOS if LOS occurs at or above 300K feet. When a Reentry Threshold Time (RTT), a GMT time of an even multiple of 30 minutes, is entered via MED into the computer, a reentry ephemeris will be generated. The time arc of the reentry ephemeris will cover the period from one hour prior to RTT to impact. When current time is within ninety minutes of RTT, acquisition data will be computed and transmitted for all stations which are in view in the interval from one hour prior to RTT to one-half hour prior to RTT.

But, if the RTT has not been entered, a station will receive acquisition data from true AOS to true LOS if true LOS occurs at or above the time of 300K feet; however, if true LOS occurs below 300K feet, acquisition data will be generated from true AOS to time of 300K feet. Recycles and trajectory updates will not cause acquisition data to be regenerated.

Approved: PMG NASA/FSB PHO/PARS

Exhibit 26

PHO-TA170A
Volume 2, Change 41
11 Dec. 1967

OT 5.2.4 IRV/DOD Vector

- A. Purpose. To provide acquisition information to selected sites. (Selected sites are those with a special indicator in the station characteristics table.)
- B. Data Source. The current ephemeris stored in the RTCC.
- C. Coordinate System. The coordinate system is defined as earth-centered equatorial with the positive X-axis through Greenwich, the positive Z-axis through the North Pole, and the Y-axis completing the right-handed system. Velocity components are relative rather than inertial.
- D. Output Timing. Vector messages will be computed and output by the RTCC 30-36 minutes before the time-tag of the vector.
- E. Time Tags of the Vectors. Vectors destined for a particular site will be time-tagged 2 minutes before horizon crossing (ascending). If a maneuver is scheduled to end between AOS and LOS, the time tag will be the end of the maneuver. However, if the maneuver is scheduled to begin before and end after LOS, the vector approximately 2 minutes before AOS will be sent.
- F. Revolution Numbers. Revolution numbers will be transmitted in the vector message when they can be determined. When the revolution numbers cannot be determined, zeroes will be transmitted in the revolution number slot in the vector message format.
- G. Format. The format of the IRV/DOD vector message is contained in the Apollo Tracking Data Format Control Book, Section 2.4.2.

Approved: 12 NASA/FSB PHO/PARS

Exhibit 27

PHO-TR170A
Volume 2, Change 58
19 April 1968

OT 5.2.5 C-Band Acquisition Message

- A. Format. The format of the C-band message is contained in the Apollo Tracking Data Format Control Book, Section 2.4.2.
- B. 6 Point C-band Message. This message will contain time, range, azimuth, and elevation for 6 points or multiple 6 points throughout the pass.

The 6 points in the message will be at the following times:

- T_1 = psuedo AOS: for the first message of a pass, psuedo AOS equals AOS
- T_2 = AOS + $1/6 \Delta T$
- T_3 = AOS + $1/3 \Delta T$
- T_4 = AOS + $1/2 \Delta T$
- T_5 = AOS + $2/3 \Delta T$
- T_6 = AOS + $5/6 \Delta T$

Where

The ΔT is the time arc of the acquisition message. The ΔT should not exceed 30 minutes.

- C. Marginal Pass. When the maximum elevation of a pass is between 0 and +1 degrees, a one-point message at the time of maximum elevation will be transmitted.
- D. Tags. Tags will be supplied for each point of the C-band messages in the following manner:
1. If a particular point occurs on or between maneuver begin or end times, the point will have a tag of "T." This tag is not used in reentry of Mode III Abort phases.
 2. If a particular point is on or between blackout begin and end time in reentry, the point will have a tag of "X."
 3. If the pass is a marginal one (i.e., E_{MAX} is less than or equal to 1 degree but greater than zero degrees) the point will have a tag of "M."
 4. Normal orbital message points will have a tag of "O."
 5. Normal reentry message points will have a tag of "R."

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Exhibit 28

PHO-TR170A
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19 April 1968

OT 5.2.6 Unified S-Band Acquisition Message

- A. Format. The format of S-band message is contained in the Apollo Tracking Data Format Control Book, Section 2.4.2.
- B. Header Portion. The header portion of the message is composed of ten lines. The first five header lines refer to the CM. The second five header lines should refer either to the LM or SIVB. Both sets of header lines should be computed from the same vector. Only the first line for each vehicle will contain the one-way doppler frequency. Each line will contain a time-tag, slant range (in octal range units), receiver VCO frequency, transmitter VCO frequency, and the bias doppler (in octal). The times of the five points for each vehicle are as follows:
- $$t_1 = \text{psuedo AOS; for the first message of a pass, psuedo AOS equals AOS}$$
- $$t_2 = \text{AOS} + 1/4 \Delta T \text{ of the pass}$$
- $$t_3 = \text{AOS} + 1/2 \Delta T$$
- $$t_4 = \text{AOS} + 3/4 \Delta T$$
- $$t_5 = \text{LOS}$$
- C. Pointing Information. The pointing information will contain a variable number of points with a minimum of 6 points and a maximum of 29 points. These points are X-Y angles.
1. If the ΔT of the pass is less than 6 seconds, no message will be transmitted.
 2. If the ΔT of the pass is between 6 and 29 seconds, the message length will vary and the interval between points will be one second.
 3. If the ΔT of the pass is greater than 29 seconds, there will be 29 points. The time interval between points is $1/29$ (LOS-AOS) as follows:

$$t_1 = \text{AOS}$$

$$t_2 = \text{AOS} + 1/29 \Delta T$$

$$t_3 = \text{AOS} + 2/29 \Delta T$$

$$t_{29} = \text{AOS} + 28/29 \Delta T$$

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PM

NASA/FSB

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Exhibit 28 (Cont'd.)

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- D. Hour Angle/Declination Radars. Hour angle and declination radar sites should receive a 29 point USB acquisition message using a USB 85 foot X/Y radar orientation.

Approved: CLV/14 NASA/FSB PHO/PAL

(OT) 5.2.6-2

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Exhibit 29

REPLY**RTCC TRANSMITTAL****Nº 9147**

FILE NO. _____

DATE March 20, 1968TO: Records Control DepartmentFROM: Flight Software Branch
 SUBJECT: Acquisition Messages for Mission D (IMSP) and subsequent missions
 ORIGINATOR: James C. Stokes, Jr.

PURPOSE:

1. The items in enclosure I should be implemented for mission D and subsequent missions.
2. The logic for the transmission of acquisition messages should follow the flowchart in enclosure II. This flowchart is the basic flowchart developed by IBM in response to PCR 173R but modified by NASA to include logic that requires each acquisition message to be sent at least 20 minutes prior to the time arc that it represents.
3. The new definition of ACQLOS is given in item 2.b of enclosure I.
4. Reentry Station Contacts should be used when current GMT reaches the first GMT divisible by 30 minutes following RTT (Reentry Threshold Time) -1.5 hours.
5. The requirement should be deleted for special logic to handle Station Contacts during the period when the spacecraft becomes stationary relative to the Earth. The requirement for splitting acquisition messages during this period should also be deleted.

cc:

IBM(Houston)/G. N. Kelly

REPLY:

SENDER

RECEIVER

Date		Date		Date		Date
<u>3/21</u>	<u>5</u>	<u>1</u>		<u>5</u>		
<u>3/21</u>	<u>6</u>	<u>2</u>		<u>6</u>		
<u>3/21</u>	<u>7</u>	<u>3</u>		<u>7</u>		
<u>3/21</u>	<u>8</u>	<u>4</u>		<u>8</u>		

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Exhibit 29 (Cont'd.)

Enclosure I

1. A change in the acquisition generation logic is desired which will insure that no acquisition message represents more than a 30-minute arc and, further, that each message is sent at least 20 minutes prior to the time-arc that it represents.

2. The following logic is a desirable change which will meet these objectives.

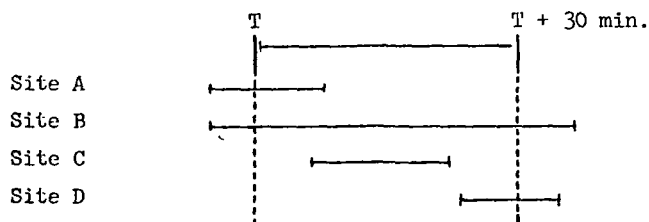
a. A table, ACQLOS, will be constructed, consisting of at most, 50 entries; each entry will contain a site and a time.

b. Upon sending an acquisition message to a particular site, the time-tag that will be entered beside the name of the site in the ACQLOS Table will be Pseudo AOS + 30 minutes or LOS of the site, whichever is less. For a station whose pass is greater than 30 minutes, Pseudo AOS + 30 minutes equals AOS + 30 minutes for the first message.

c. The automatic generation logic will use even multiples of 30 minutes (expressed in GMT) as the queue to send data to sites which have contact from 30 minutes to 60 minutes in advance of current time. An example would, perhaps, clear the meaning of this:

When current time reaches $3^H 30^M$ GMT, acquisition data will be sent to all sites viewing in the time interval from 4^H to $4^H 30^M$.

d. The checks necessary to determine that a site has contact in a given 30-minute segment should include checks for both AOS and LOS. The types of contact must fall into one of the following categories:



This picture, of course, represents the period of track by a site with respect to the time interval in question. Thus, the checks must include the following:

Case 1 Is $AOS \leq T < LOS$? (Sites A and B fall into this category.)

Case 2 Is $T < AOS < T + 30 \text{ min.}$? (Sites C and D fall into this category.)

Using the above checks, those sites which have contact in the proper 30-minute segment can be determined.

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Exhibit 29 (Cont'd.)

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e. For each site determined to have contact for the time interval in question, a check of the ACQLOS Table will be made to determine the time that represents the last message that was sent. The time of the last message is defined in item 2.b. For the site in question, the following logic would apply and should be checked in the order indicated:

Case 1. Is $ACQLOS \leq T$?

A "yes" answer implies that acquisition should be sent to that site such that pseudo AOS time for the site is either true AOS if ACQLOS AOS or pseudo AOS time is ACQLOS.

Case 2. Is $ACQLOS < LOS$?

This implies that acquisition should be sent to that site, and the pseudo ACS time is ACQLOS.

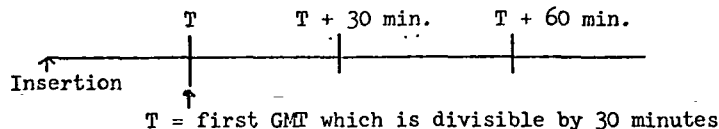
If the answer to Case 1 is "no," then Case 2 must still be examined. If the answer to Case 2 is "no," then no message should be sent to that site (a message has already been sent to that site).

f. When a new message is sent to a site, its ACQLOS is recorded in the ACQLOS Table. This Table is unaffected by the retransmit MED.

g. Without exception, an acquisition message will cover either a 30-minute arc or will include actual LOS for the site.

h. It should be emphasized that the above logic is designed to determine if a site should receive a message and, if so, to determine the time arc which a message should cover. No change in the computation or format for individual messages is desired.

i. Upon initial insertion into orbit (or P14 MED) acquisition data will be generated for all sites which have contact between current time and 30 minutes following the first even multiple of 30 minutes (expressed in GMT). A diagram will clear the meaning of this:



Referring to the diagram, acquisition data will be sent to all sites which have contact between insertion and T + 30 minutes.

j. The MED to retransmit a particular message should function like this:

CODE, VEHICLE, SITE, GET;

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Exhibit 29 (Cont'd.)

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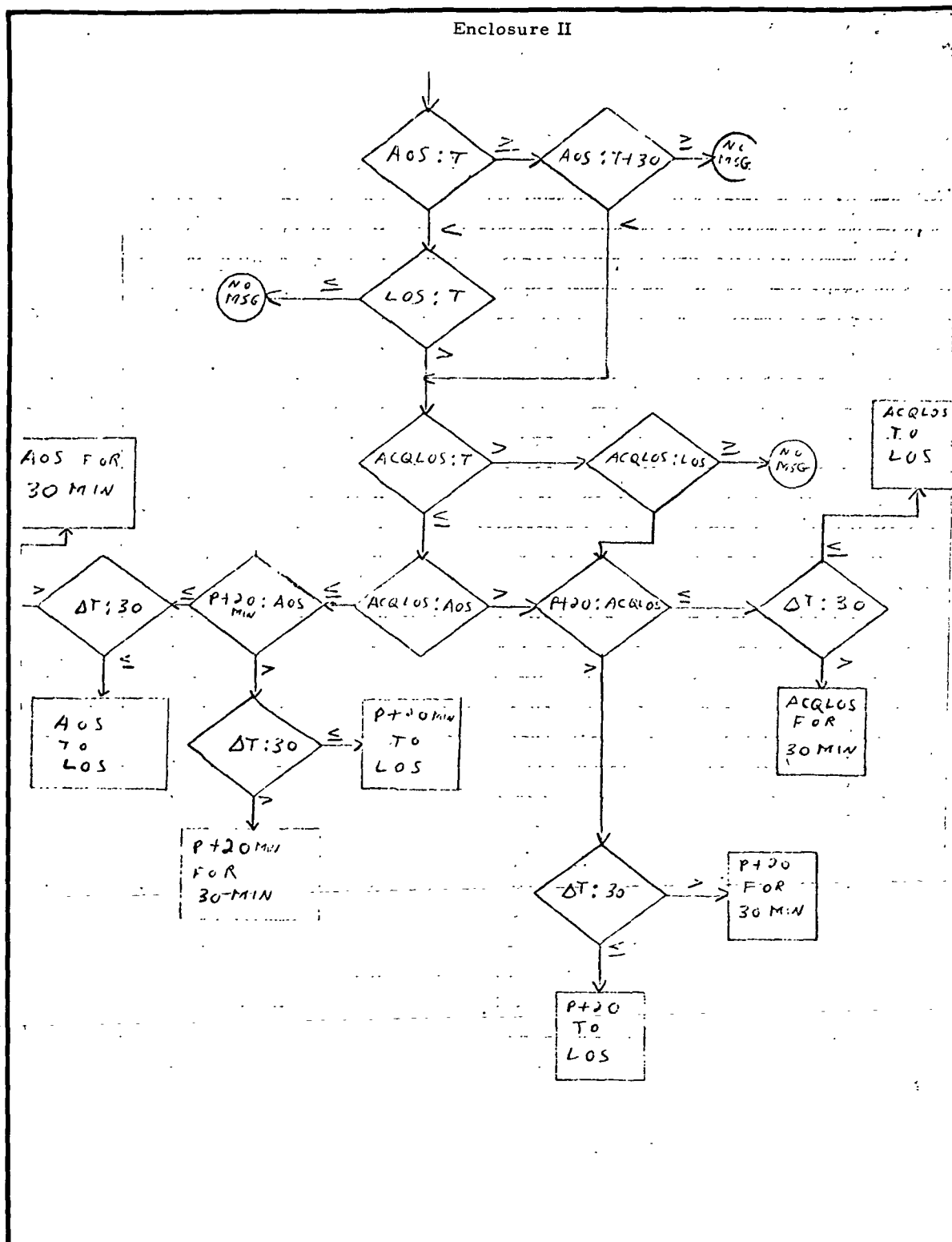
VEHICLE = CSM or LEM

SITE = Three letter site code plus band type (zero for voice sites).

GET = Either the Pseudo AOS time for that site if it is in acquisition at this GET or the time to begin searching for the next contact if the site is not in acquisition.

3. It is further desired that the ACQLOS for each site be displayed on the Predicted Site Acquisition Display (PSAD). The space is available by moving the "R, T, V, C" indicators into a much smaller space.

Exhibit 29 (Cont'd.)



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5. Upon initial insertion into orbit, acquisition data will be generated for all sites which have contact between one minute prior to current time and 30 minutes following the first even multiple of 30 minutes beyond current time (see Section B in Exhibit 25).
6. Upon entry into Mode III abort phase, acquisition data will be generated for all sites which have contact between one minute prior to current time and 30 minutes following the first even multiple of 30 minutes beyond current time (see Section D in Exhibit 25).
7. RTT is not necessarily an even multiple of 30 minutes (see Section E of Exhibit 25).
8. When current time is within 90 minutes of the reentry threshold time, acquisition data will be computed and transmitted for contacts in the reentry station contacts table. No orbit acquisition messages for the reentering vehicle will be sent after that time (see Section E of Exhibit 25).
9. References to 300K feet are interpreted to mean the end of the orbit ephemeris (see Section E of Exhibit 25).
10. DOD vector messages will be computed and output by the RTCC at even multiples of 30 minutes (i. e., at the same time that C-band and S-band messages are sent) (see Section D of Exhibit 26).
11. All references to horizon crossing times (AOS and LOS) imply either true or pseudo horizon crossing times (see Section E of Exhibit 26).
12. All references to AOS and LOS imply either true or pseudo horizon crossing times (see Section B of Exhibit 27 and B and C of Exhibit 28).
13. The month and day values on the DOD message will be valid only for the month of liftoff and for the month following the month of liftoff. (see Exhibits 33 and 36).
14. If acquisition data is suppressed prior to the first trajectory update and unsuppressed after the first trajectory update, it will not begin to process data until after the next update of station contacts. If acquisition is both suppressed and then unsuppressed after the first trajectory update, the next queue to acquisition data will be on the first 30 minute GMT multiple after the unsuppress MED.
15. The range quantities on the C-band messages are five characters rather than four (see Exhibits 31 and 34).
16. The revolution number on the DOD vector message will be referenced to the present position central body at the time the station contact table was generated (see Section F in Exhibit 26).

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Additions to Source: The following items are extensions of the requirements stated in the referenced source:

1. The station acquisition times are acquired from the orbit or reentry station contacts tables.
2. When interpolation is required, sixth-order will be used whenever possible. If conditions are such that less than seven vectors are available for interpolation, the order of interpolation will be adjusted to the maximum order possible for the number of vectors available.
3. Those sites having AZ/EL radar mounts that also get an S-band message will get a 30' X/Y angle message.
4. The type of message that a site receives is determined by a bit in the station characteristics table.

Functional Diagrams

These functional diagrams show the interfaces of the programs in the Remote Site Acquisition Element with other programs in the element and with other elements, units, or subsystems. They illustrate the general logic to be followed in providing the processing described in the previous sections. The symbols used in the diagrams are defined in the Glossary of this document. The diagrams in this section are EMSSACQ, EMMCBND, EMMSBND, and EMMDUD.

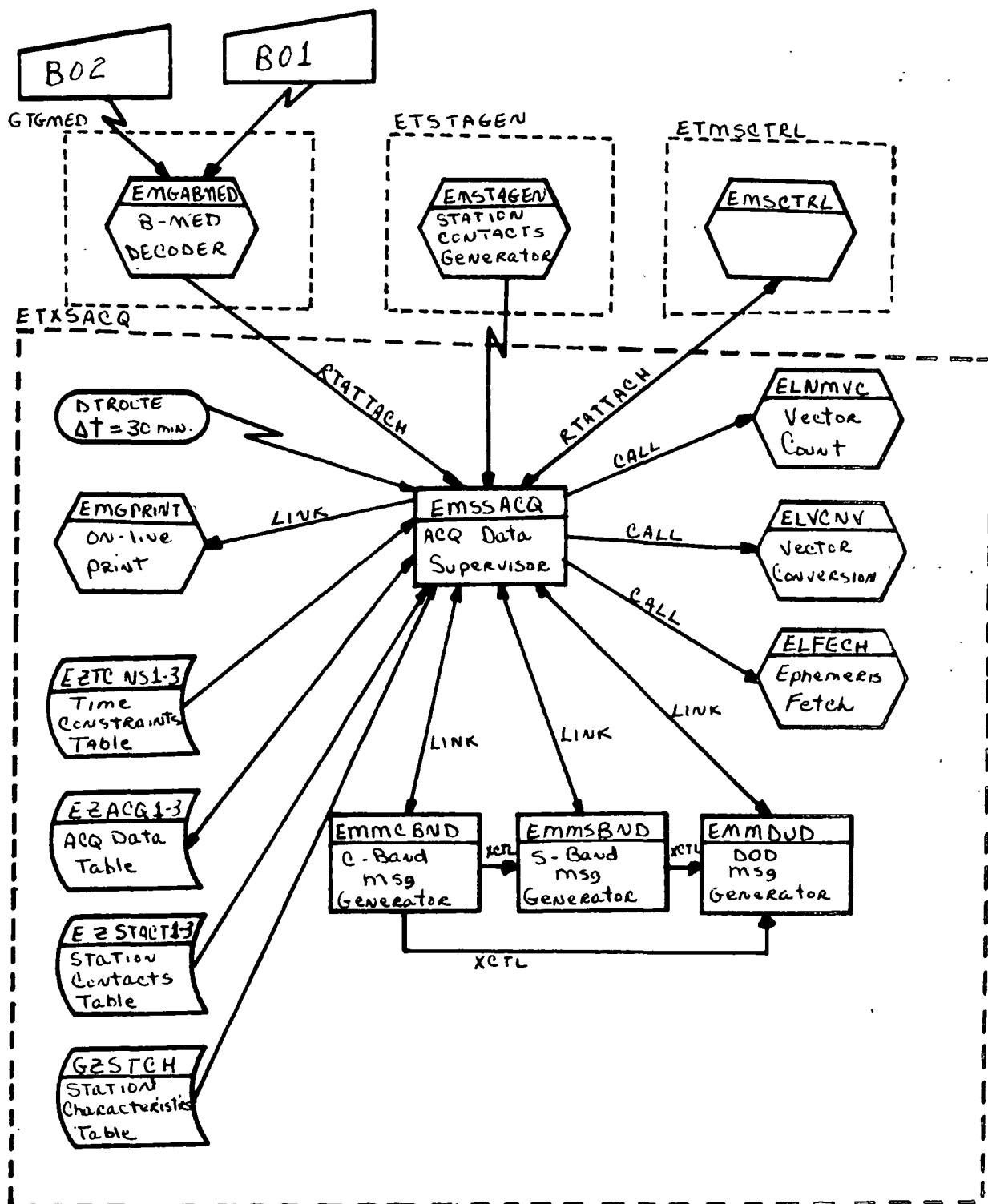


Figure 18. EMSSACQ

ETXSACQ

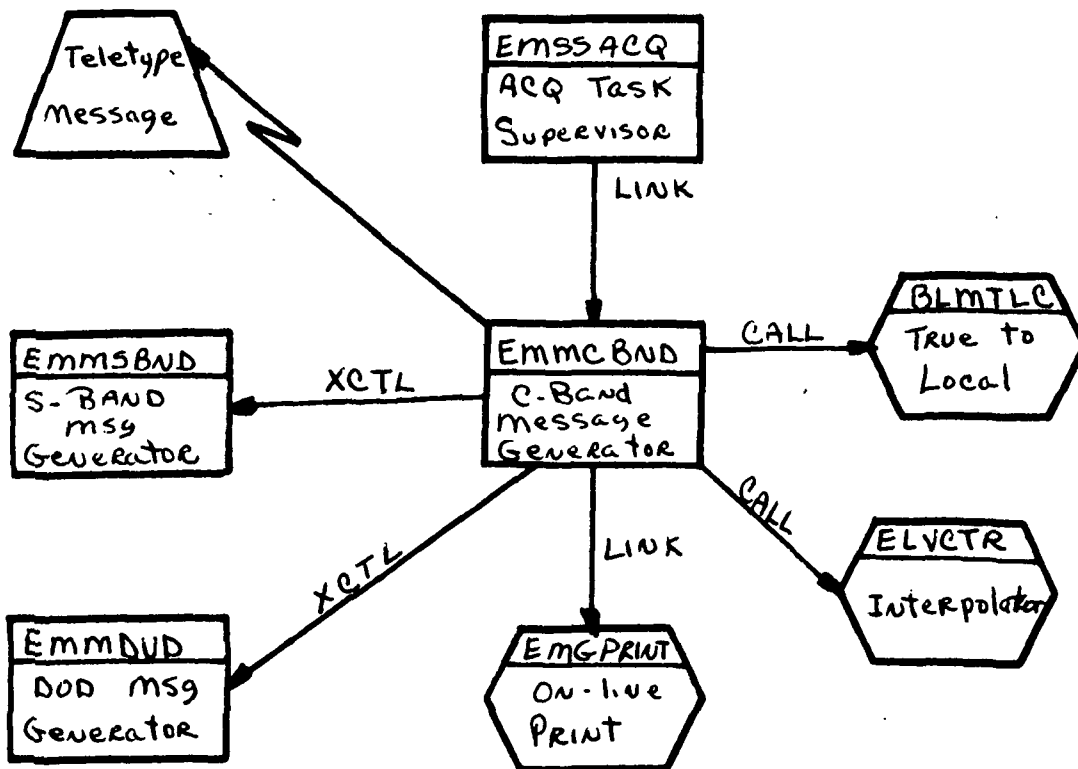


Figure 19. EMMCBND

ETXSACQ

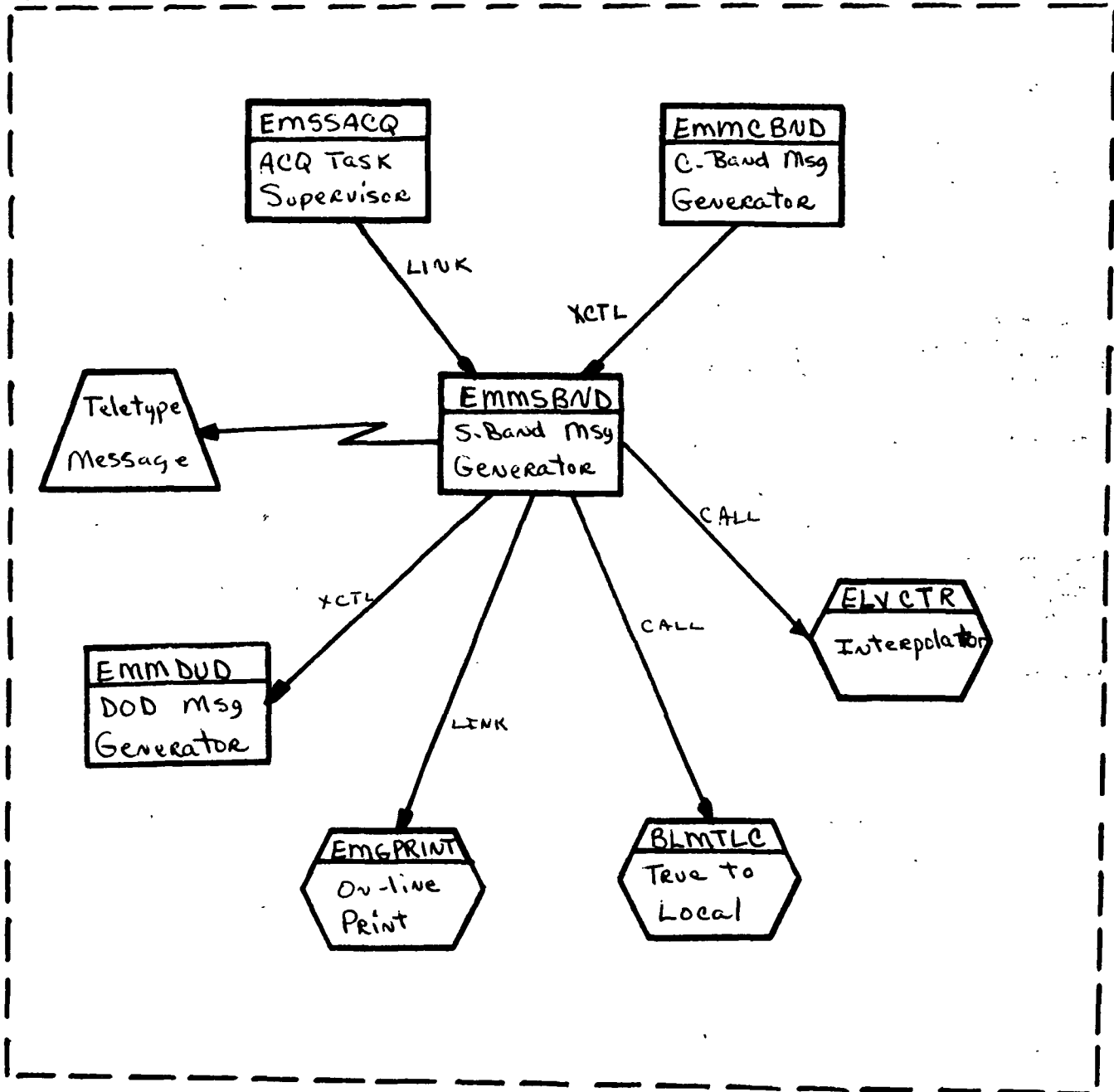


Figure 20. EMMSBND

ETXSACQ

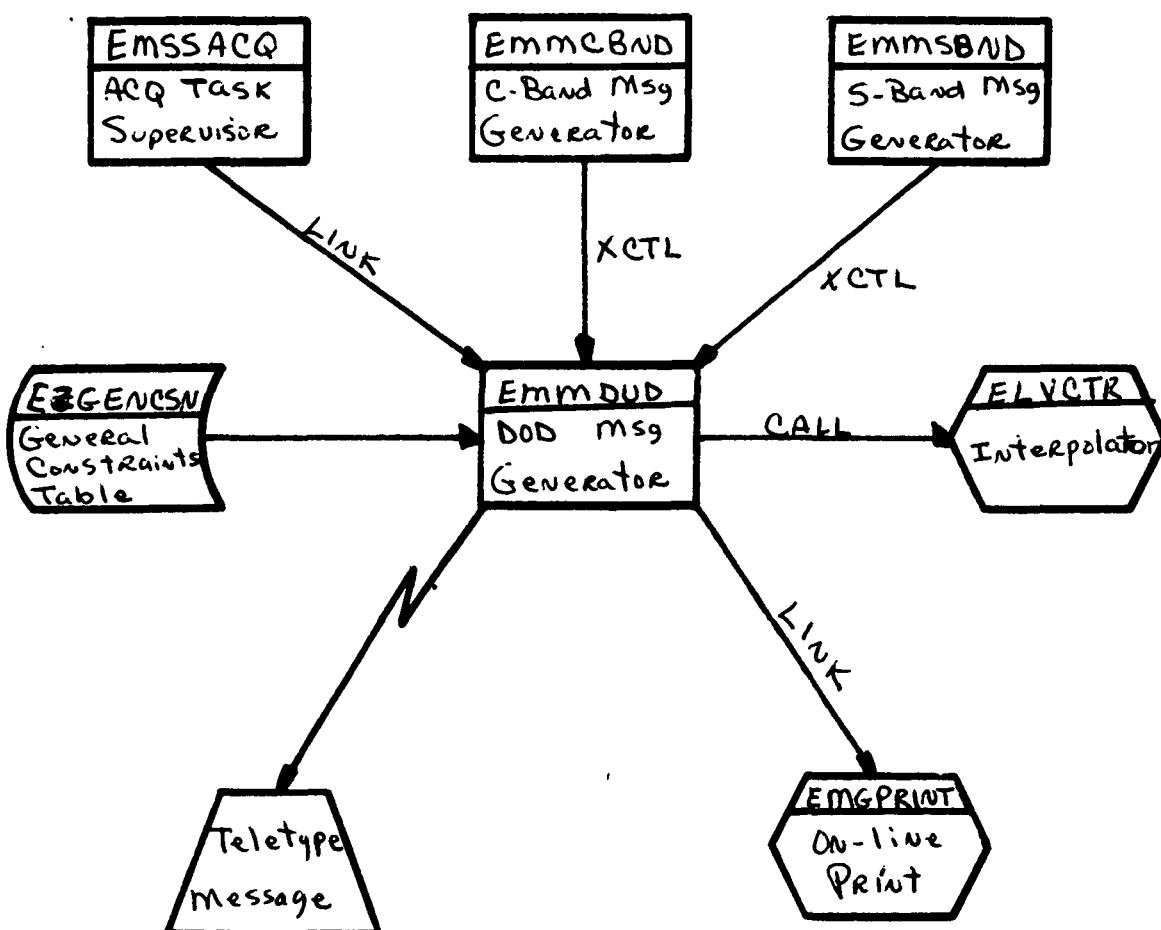


Figure 21. EMMDUD



Input/Output Specifications

The Input/Output Specifications for the Remote Site Acquisition Element may be divided into three groups: manual inputs, teletype formats and on-line prints.

Manual Inputs: The programs in the Remote Site Acquisition Element receive data from B01 (Suppress/Unsuppress Acquisition Messages) and B02 (Retransmit Acquisition Messages). Copies of these MED formats will be found in the following pages.

Teletype Formats: The formats of the various acquisition messages transmitted by programs in the Remote Site Acquisition Element are described in Annex D of the Apollo Tracking Data Format Control Book. Copies of these pages are enclosed (see Exhibits 30 through 36).

On-Line Prints: The following on-line prints are issued by programs in the Remote Site Acquisition Element.

1. EMSSACQ

If a B02 MED is input and no contacts for the requested station exist after the threshold time, the following message will be printed on line:

"NO CONTACTS FOR sta - veh AFTER TIME REQUESTED"

where veh is the vehicle for which the request was made, and sta is the requested radar station.

2. EMSSACQ

If no ephemeris is available over the time span requested by the acquisition data program, the following message is printed on line:

"ERROR FLAG RECEIVED FROM EPHEM FETCH ROUTINE FOR veh"

where veh is the vehicle for which ephemeris was requested.

3. EMMCBND, EMMSBND, EMMDUD

If no vector is returned by the extended interpolation routine, the following message is printed on line:

"ERROR FLAG RECEIVED FROM INTERPOLATOR FOR sta - veh"



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MED Format Table

MED Code: B01 Task: ETXSACQ
 Purpose: Suppress/unsuppress acquisition data EP: EMSSACQ

QNAME:

Load Module: EMGABMED QUEID: 6

QRANK: 3 DPRIOR: MKDGMF

Desc.	Item	1	2	3	4	5	6
Item Name		CSM or LEM Vehicle	Function				
Input Format		XXX	START STOP				
Input Units		EBCDIC	EBCDIC				
Program Units		Numeric code	Numeric code				
Scale Factor							
Checking Option		Exact	Exact				
Missing Item Option		Error	Error				
Item Destination		Disp. 0 H	Disp. 2 H				

Programmer: J. Emrick

Initial Logic:

Final Logic: All output passed in subpool 1

Illegal Phases: All except orbit (low), reentry, and abort III

Notes: For Item 2, 0 shall denote START and -1 shall denote STOP

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MED Format Table

MED Code: B02

Task: ETXSACQ

Purpose: Request retransmission of acquisition data

EP:

EMSSACQ

Load Module: EMGABMED

QNAME:

QUEID: 5

QRANK: 2 DPRIOR: MKDGMF

Desc.	Item	1	2	3	4	5	6
Item Name		CSM or LEM Vehicle	Radar	Threshold Time (GET)			
Input Format		XXX	XXXX	XXX:XX:XX.XX			
Input Units		EBCDIC	Radar code Band code	HHH:MM:SS.SS			
Program Units		Numeric code	EBCDIC	Fixed-point centiseconds			
Scale Factor							
Checking Option		Exact	Band codes =C/S/ZERO				
Missing Item Option		Error	Error	Error			
Item Destination		Disp. 0 _H	Disp. 4 _F	Disp. 8 _F			

Programmer: J. Emrick

Initial Logic:

Final Logic: All output passed in subpool 1

Illegal Phases: All except orbit (low), reentry, and abort III

Notes: Item 3 output will be GMT.

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Exhibit 30

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Outgoing (Text) TTY Messages

The RTCC generates ephemeris data which is sent to appropriate destinations as messages on NASCOM TTY lines. This section defines the formats for messages as they are received at remote sites (or final destinations). The following formats are included:

- o Acquisition Message received by C-band sites.
- o Acquisition Message received by USB Sites.
- o Acquisition Message received by Apollo ships and DOD sites.
- o Targeting Message received by MSFC.
- o Ephemeris Messages received by ACR.
- o GSFC Maneuver Information Message.

All messages will consist of a standard NASCOM message header, the message text, and a standard NASCOM message ending:

Line No.

```

1  +++++<<=+
2  *** $$$+*****<<=+
3  **Δ*****<<=+
4  **Δ*****Δ+$$$<<=+
5  $$/$$$Z<<=+

```



Message Header

TEXT

Line No.

```

1  <<=+
2  $$/$$$ZΔ*****
3  <<=====
4  +#+*****

```



Message Ending

Message Header:

Line 1 contains machine control characters.

Line 2 contains a 3-letter channel designator, a 3-character channel number, and a 1-letter line designator.

Line 3 contains a 2-letter priority classification (SS=Special, NN=Normal, PP=Priority, RR=Routine, UU=Urgent), and one or more 4-letter routing indicators. These must be in alphabetical order with a space between each. A list of NASCOM routing indicators is shown on page 4-24.

Line 4 contains a 2-letter routing code (DE), a 4-letter routing indicator designating the source of the message, and a 3-character message number.

Line 5 contains Zulu time (day of month/Zulu hours) that transmission is initiated.

Exhibit 30 (Cont'd.)

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Message Ending:

Line 1 contains machine control characters.

Line 2 contains Zulu time (day of month/Zulu hours) that transmission is completed, a 3-letter abbreviation of month, and a 4-letter routing indicator designating the source of the message.

Lines 3 and 4 contain machine control characters.

During TTY message transmission, the information contained in the message will be in Baudot Code. A Baudot code conversion chart is shown on page 2-48.

Teletype symbols used in acquisition message formats:

- \$ = numeral
- * = alphabetic character
- + = letter shift
- † = figure shift
- < = carriage return
- = = line feed
- Δ = space
- S = sign of parameter

Exhibit 31

C-Band Sites' Acquisition Message Format:

Line No.

```

1      ↓↓↑↑↓↓↑↑<<≡↓
2      ****$$$$↑↑↓↑↓↑↓↑↓↑<<≡↑
3      **Δ****<<≡↓
4      **Δ****Δ↑$$$$<<↑↑
5      $$/$$$$$Z<<≡↓

                                     Heading Provided
                                     by CP

1      Sta. ID
   AQA***<<:
   Veh. ID
2      ***<<↑
Day|Hr|Min|Sec|Range|Az|El|Tag
3  $$ Δ $$$^$$ Δ $$$ Δ $$$$ Δ $$$.$Δ$$$.$Δ↑* <<≡↑
.
.
.
.
.
8  $$$ Δ $$$Δ$$$ Δ $$$ Δ $$$$ Δ $$$.$Δ$$$.$Δ↑*

                                     Ending Provided
                                     by CP
1      <<≡↑
2      $$/$$$$$ZΔ***Δ*****
3      <<≡↑
4      ↑#↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑

```

NOTES:

1. Station ID - Standard NASA 3-letter station abbreviation.
2. Vehicle ID - CM = Command Module
LM = Lunar Module
SB = Saturn - IVB
3. Day of mission, Hours, Minutes, Seconds - GMT
4. Range - Thousands of yards
5. Azimuth and Elevation - degrees
6. Tag - T = Orbital Maneuver point
M = Marginal pass acquisition point
X = Communications Blackout point
O = Orbital (Free Flight)
R = Reentry (Not Blackout)

Exhibit 32

[illegible]

Exhibit 32 (Cont'd.)

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USB Acquisition Message Notes:

1. Station ID - Standard NASA 3-letter station abbreviation.
2. Vehicle ID - CM = Command Module
LM = Lunar Module
SB = Saturn - IVB
3. Characters in line 3 of the text are headings for respective columns containing:

Day of mission, Hours, Minutes, Seconds, GMT.
Range - Slant range in octal range units.
RVCO - receiver VCO frequency in megacycles/sec.
TVCO - transmitter VCO frequency in megacycles/sec.
Bias - bias doppler in octal cycles/sec.
Doppler - one-way doppler in kilocycles (the first character is a sign indicator).

The data on line 4 is computed at AOS, line 5 at $\frac{1}{4}$ station pass duration, line 6 at $\frac{1}{2}$ station pass duration, line 7 at $\frac{3}{4}$ station pass duration, and line 8 at LOS for CM.

The data on line 9 is computed at AOS, line 10 at $\frac{1}{4}$ station pass duration, line 11 at $\frac{1}{2}$ station pass duration, line 12 at $\frac{3}{4}$ station pass duration, and line 13 at LOS for LM or SIVB.

Note: The CM and LM/SIVB header information is calculated from one vector and both sets will be correct as long as the vehicles are attached. When the vehicles are not attached, the data is only good for the one given in the Vehicle ID.

4. Frame Interval - Time in seconds between each X-Y angle pointing set.
5. Lines 10 and 11 contain GMT time of AOS and LOS, respectively. First two characters indicate day of mission followed by two characters indicating hours, minutes, and seconds GMT.
6. USB acquisition messages will contain 6 to 29 X-Y angle pointing sets. Nominal message length is 29 points. Each X and Y angle is preceded by a sign indicator and the decimal point is not shown but is placed XX.XX. Spaces are used instead of leading zeros where needed.
7. Check sum - decimal addition of all characters on indicated line (plus sign = 10; minus sign = 11).
8. Sign convention: Δ (space) = plus; - = minus.

Exhibit 33

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DOD Sites' and AIS' Acquisition Message Format:

```

1  ++++++<=>+
2  ***+$$$+*+++++<=>+
3  **Δ***<=>+
4  **Δ***Δ+$$$<=>+
5  $$/$$$$+Z<=>+

Header Provided
by CP

1  Sta. ID
   IRST***ΔΔ<=>+
2  MdDayOrbit Body No.
   200000Δ$$$Δ$$$Δ<=>+
3  SXXXXXXXXXΔ$$SYYYYYYYYΔ$$SZZZZZZZZΔ$$<=>+
4  SXXXXXXΔ$$SYYYYYYYΔ$$SZZZZZZΔ$$Δ$$$$$Δ$$<=>+
   | Time |
5  IRED

1  <=>+
2  $$/$$$$+ZΔ***Δ***
3  <=>=====
4  ++++++

Ending Provided
by CP

```

NOTES:

1. Station ID - Standard NASA 3-Letter station abbreviation
2. First six characters of line 2 of text are fixed for messages from MSC RTCC.
3. Orbit - right justified with leading zeros and orbit # 0001 begins at launch. When this value cannot be computed it will contain zeros.
4. Body No. - 1 = CSM; 2 = S-IVB; 3 = LM.
5. Line 3 of text contains X,Y, Z position components and line 4 contains X, Y, Z velocity components. The coordinate

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Exhibit 33 (Cont'd.)

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DOD Site's and AIS' Acquisition Message Format: (con't)

system is cartesian equatorial with the positive X-axis through Greenwich, the positive Z-axis through the North Pole, and the Y-axis completes the right hand system. X, Y, and Z components of position and velocity are decimal feet and feet/second, respectively. Position components are right justified with leading zeros and decimal point for velocity components is placed XXXX.XX. The velocity components are relative to the motion of the Earth. Each parameter is preceded by a sign character (& = plus; - = minus). Each parameter is also followed by a 2-character check sum which is a decimal addition of the characters in each parameter (add 1 for minus sign).

6. Time - GMT with the first two characters indicating hours, followed by two characters indication minutes and three characters indicating seconds with the decimal placed XX.X. Time data is also followed by a 2 character check sum.

Exhibit 34

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RTCC to CCATS Data Formats

C-band Acquisition Message Format:

Word No.	S	35
1	CCATS/RTCC Label	
2	S 6 RTCC Time Word	35
3	S 3 12 PRI Rtg. Ind. No. Routing Indicator No. 1	35
4	S 12 35 0 0 0 0 0 0 0 0 0 0 Routing Indicator No. 2	
5	S 12 35 0 0 0 0 0 0 0 0 0 0 Routing Indicator No. 3	
6	S 6 12 18 24 30 35 A Q Space Sta. ID Sta. ID Sta. ID	
7	S 35 CR CR LF Veh. ID Veh. ID CR	
8	S 35 CR LF Figs Day ₁ Day ₁ Space	
9	S 35 Hrs ₁ Hrs ₁ Space Min ₁ Min ₁ Space	
10	S 35 Sec ₁ Sec ₁ Space Range ₁ Range ₁ Range ₁	
11	S 35 Range ₁ Space Az ₁ Az ₁ Az ₁ Point	
12	S 35 Az ₁ Space El ₁ El ₁ El ₁ Point	
13	S 35 El ₁ Space Ltrs Tag ₁ CR CR	
14	S 35 LF Figs Day ₂ Day ₂ Space Hr ₂	

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Exhibit 34 (Cont'd.)

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Band Acquisition Message Format (con't):

Word No.	6	12	18	24	30	36
16	Hr ₂	Space	Min ₂	Min ₂	Space	Sec ₂
17	Sec ₂	Space	Range ₂	Range ₂	Range ₂	Range ₂
18	Space	Az ₂	Az ₂	Az ₂	Point	Az ₂
19	Space	El ₂	El ₂	El ₂	Point	El ₂
20	Space	Ltrs	Tag ₂	CR	CP	LP
21	Figs	Day ₃	Day ₃	Space	Hr ₃	Hr ₃
22	Space	Min ₃	Min ₃	Space	Sec ₃	Sec ₃
23	Space	Range ₃	Range ₃	Range ₃	Range ₃	Range ₃
24	Az ₃	Az ₃	Az ₃	Point	Az ₃	Space
25	El ₃	El ₃	El ₃	Point	El ₃	Space
26	Ltrs	Tag ₃	CR	CR	LP	Figs
27	Day ₄	Day ₄	Space	Hr ₄	Hr ₄	Space
28	Min ₄	Min ₄	Space	Sec ₄	Sec ₄	Space
29	Range ₄	Range ₄	Range ₄	Range ₄	Range ₄	Range ₄

(con't on following page)

Exhibit 34 (Cont'd.)

4-29

C-band Acquisition Message Format (cont):

Word No.	1	6	12	18	24	30	36
20	Az ₄	Az ₄	Point	Az ₄	Space	El ₄	
	S						
30	El ₄	El ₄	Point	El ₄	Space	Ltrs	
	S						
31	Tag ₄	CR	CR	LF	Figs	Day ₅	
	S						
32	Day ₅	Space	Hr ₅	Hr ₅	Space	Min ₅	
	S						
33	Min ₅	Space	Sec ₅	Sec ₅	Space	Range ₅	
	S						
34	Range ₅	Range ₅	Range ₅	Space	Az ₅	Az ₅	
	S						
35	Az ₅	Point	Az ₅	Space	El ₅	El ₅	
	S						
36	El ₅	Point	El ₅	Space	Ltrs	Tag ₆	
	S						
37	CR	CR	LF	Figs	Day ₆	Day ₆	
	S						
38	Space	Hr ₆	Hr ₆	Space	Min ₆	Min ₆	
	S						
39	Space	Sec ₆	Sec ₆	Space	Range ₆	Range ₆	
	S						
40	Range ₆	Range ₆	Space	Az ₆	Az ₆	Az ₆	
	S						
41	Point	Az ₆	Space	El ₆	El ₆	El ₆	
	S						
42	Point	El ₆	Space	Ltrs	Tag ₆	000000	

(See notes on following page)

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Exhibit 34 (Cont'd.)

A-6

RTCC to CCATS C-band Acquisition Message Notes:

1. This six-point acquisition message will be transmitted to ground sites for nominal passes, maneuvers, retrofire, communications blackout, and reentry. When a marginal pass acquisition message is being sent, lines 1 through 13 will be sent with the last two characters (last 12 bits) of line 13 being filled with zeros.
2. When the duration of the pass is less than or equal to 30 minutes, the six-point acquisition message which is shown will be transmitted with:

T_1, R_1, A_1, E_1 at 0 degrees elevation (AOE)
 T_2, R_2, A_2, E_2 at 1/6 station pass duration
 T_3, R_3, A_3, E_3 at 1/3 station pass duration
 T_4, R_4, A_4, E_4 at 1/2 station pass duration
 T_5, R_5, A_5, E_5 at 2/3 station pass duration
 T_6, R_6, A_6, E_6 at 5/6 station pass duration

3. When the duration of the pass is greater than 30 minutes, the six-point acquisition message which is shown will be transmitted with:

T_1, R_1, A_1, E_1 at 0 degrees elevation (AOE)
 T_2, R_2, A_2, E_2 at 0 degrees elevation plus 5 minutes
 T_3, R_3, A_3, E_3 at 0 degrees elevation plus 10 minutes
 T_4, R_4, A_4, E_4 at 0 degrees elevation plus 15 minutes
 T_5, R_5, A_5, E_5 at 0 degrees elevation plus 20 minutes
 T_6, R_6, A_6, E_6 at 0 degrees elevation plus 25 minutes

All following messages will be in 25-minute blocks providing an acquisition data point at each 5-minute interval until the remainder of the station pass to be covered is less than 30 minutes.

The last segment will be formatted with six T, R, A, E points spaced evenly as defined in Note 2.

Exhibit 34 (Cont'd.)

4-3

Notes (con't):

4. Each six-bit group contains a leading zero and the five-bit Baudot Code for the TTY data indicated. When a single character is shown in any six-bit group, that group contains a leading zero and the Baudot Code for the indicated TTY character.
5. Station ID - Standard NASA 3-letter station abbreviation.
6. Vehicle ID - CM = Command Module
IM = Lunar Module
SR = Saturn IVB
7. Time - Day of mission, hours, minutes, and seconds, GMT.
8. Range is right justified and in thousands of yards.
9. Azimuth and elevation angles are in degrees.
10. The following tags will be used within the format:
T = Point anticipated to be within an orbital maneuver.
X = Point anticipated to be within communications blackout.
M = Point is for a marginal pass acquisition message.
O = Orbital (Free Flight)
R = Reentry (Not Blackout)
11. Bits 30-35 of line 42 are zeros added to maintain modulo 36.

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Exhibit 35

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RTCC to CCATS Data Formats

USB Acquisition Message Format:

Word No.	S	35
1	CCATS/RTCC Message Label	
2	S 6 RTCC Time Word	35
3	S 3 PRI Rtg. Ind. No. 12 Routing Indicator No. 1	35
4	S 12 Routing Indicator No. 2	35
5	S 12 Routing Indicator No. 3	35
6	S 6 Q Space 12 Sta. ID 18 Sta. ID 24 Sta. ID 30	35
7	S CR CR LF Ltrs. Veh. ID Veh. ID	35
8	S CR CR LF Ltrs. D D	35
9	S Space H H Space M M	35
10	S Space S S Space Space Space	35
11	S Space Space R A N G	35
12	S E Space Space Space Space Space	35
13	S Space Space R V C O	35
14	S Space Space Space Space Space Space	35

(con't on following page)

Exhibit 35 (Cont'd.)

RTCC to CCATS USB Acquisition Message Format (con't):

Word No.	S	6	12	18	24	30
15	Space	T	V	C	O	Space
16	Space	Space	Space	Space	Space	Space
17	I	A	S	Space	Space	Space
18	D	O	P	P	L	E
19	R	CR	CR	LF	Figs	Day
20	Day ₁	Space	Hr ₁	Hr ₁	Space	Min ₁
21	Min ₁	Space	Sec ₁	Sec ₁	Space	Space
22	Range ₁	Range ₁	Range ₁	Range ₁	Range ₁	Range ₁
23	Range ₁	Range ₁	Range ₁	Range ₁	Space	Space
24	R Freq ₁	R Freq ₁	Point	R Freq ₁	R Freq ₁	R Freq ₁
25	R Freq ₁	R Freq ₁	R Freq ₁	Space	Space	T Freq ₁
26	T Freq ₁	Point	T Freq ₁	T Freq ₁	T Freq ₁	T Freq ₁
27	T Freq ₁	T Freq ₁	Space	Space	Bias ₁	Bias ₁
28	Bias ₁	Bias ₁	Bias ₁	Bias ₁	Bias ₁	Bias ₁

(con't on following page)

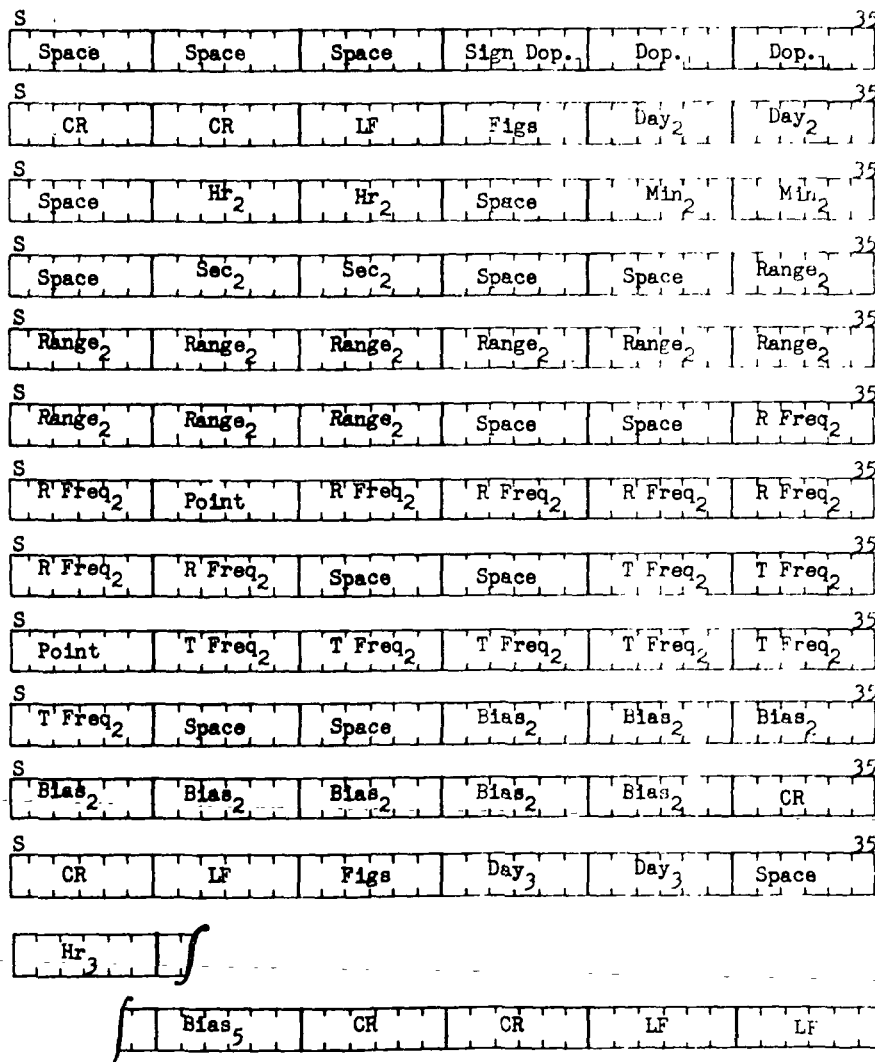
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RTCC to CCATS USB Acquisition Message Format (cont'd.)

S	Figs	Day ₆	Day ₆	Space	Min ₆	Hr ₆	35
S	Space	Min ₆	Min ₆	Space	Sec ₆	Sec ₆	35
S	Space	Space	Range ₆	Range ₆	Range ₆	Range ₆	25
S	Range ₆	Range ₆	Range ₆	Range ₆	Range ₆	Range ₆	35
S	Space	Space	R Freq ₆	R Freq ₆	Point	R Freq ₆	35
S	R Freq ₆	R Freq ₆	R Freq ₆	R Freq ₆	P Freq ₆	Space	35
S	Space	T Freq ₆	T Freq ₆	Point	T Freq ₆	T Freq ₆	35
S	T Freq ₆	T Freq ₆	T Freq ₆	T Freq ₆	Space	Space	35
S	Bias ₆	Bias ₆	Bias ₆	Bias ₆	Bias ₆	Bias ₆	35
S	Bias ₆	Bias ₆	Space	Space	Space	Sign Dop. ₂	35
S	Dop. ₂	Dop. ₂	CR	CR	CR	Figs	35
S	Day ₇	Day ₇	Space	Hr ₇	Hr ₇	Space	25

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RTCC to CCATS USB Acquisition Message Format (cont'd.)

S	Min ₇	Min ₇	Space	Sec ₇	Sec ₇	Space	35
S	Space	Range ₇	Range ₇	Range ₇	Range ₇	Range ₇	35
S	Range ₇	Range ₇	Range ₇	Range ₇	Range ₇	Space	35
S	Space	R Freq ₇	R Freq ₇	Point	R Freq ₇	R Freq ₇	35
S	R Freq ₇	R Freq ₇	R Freq ₇	R Freq ₇	Space	Space	35
S	T Freq ₇	T Freq ₇	Point	T Freq ₇	T Freq ₇	T Freq ₇	35
S	T Freq ₇	T Freq ₇	T Freq ₇	Space	Space	Bias ₇	35
S	Bias ₇	Bias ₇	Bias ₇	Bias ₇	Bias ₇	Bias ₇	35
S	Bias ₇	CR	CR	LF	LF	Day ₈	35
S	Day ₈						

	Bias ₁₀	CR	CR
--	--------------------	----	----

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RTCC to CCATS USB Acquisition Message Format (con't):

S						35
	LF	Ltrs.	Figs	Figs	Fr. Int.	Fr. Int.

S						35
	Fr. Int.	Fr. Int.	CR	CR	LF	Figs

S						35
	Day _A	Day _A	Hr _A	Hr _A	Min _A	Min _A

S						35
	Sec _A	Sec _A	CR	CR	LF	Figs

S						35
	Day _L	Day _L	Hr _L	Hr _L	Min _L	Min _L

S						35
	Sec _L	Sec _L	CR	CR	LF	Figs

S						35
	Sign X ₁	X ₁	X ₁	X ₁	X ₁	Sign Y ₁

S						35
	Y ₁	Y ₁	Y ₁	Y ₁	Space	C. Sum

S						35
	C. Sum	CR	CR	LF	Figs	Sign X ₂

S						
	X ₂	X ₂				

						35
	Y _N	Y _N	Y _N			

S						35
	Y _N	Space	C. Sum	C. Sum	CR	Figs

S						35
	CR	Figs	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0	0 0 0 0 0 0

(See notes on following page)

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RTCC to CCATS USB Acquisition Message Notes:

1. USB acquisition messages will contain 6-29 evenly-spaced points (X-Y angle sets). For normal USB acquisition messages, $Y_N = Y_{29}$. All messages are formatted as shown with X_1 and Y_1 computed at AOS, X_N and Y_N computed at LOS, and the appropriate number of zeros following the last character to maintain modulo 36.
2. Each six-bit group contains a leading zero and the 5-bit Baudot Code for the TTY character indicated.
3. When a single character is shown in any six-bit group, that group contains a leading zero and the Baudot Code for the indicated TTY character.
4. Station ID - Standard NASA 3-letter station abbreviation.
5. Vehicle ID - CM = Command Module
LM = Lunar Module
SB = Saturn IVB
6. Day_N = Day of mission (Launch day = 0)
 Hr_N = GMT Hours
 Min_N = GMT Minutes
 Sec_N = GMT Seconds
 $Range_N$ = Slant Range in octal range units
 $R\ Freq_N$ = Receiver VCO frequency in megacycles
 $T\ Freq_N$ = Transmitter VCO frequency in megacycles
 $Bias_N$ = Bias Doppler in octal cycles per second
 $Sign\ Dop$ = Sign of one-way Doppler (Δ (space) = plus; - = minus)
 Dop = One-way Doppler in kilocycles

$Day_1, Hr_1, Min_1, Sec_1, Range_1, R\ Freq_1, T\ Freq_1, Bias_1, Sign\ Dop_1$, and Dop_1 are computed at AOS for CM.

$Day_2, Hr_2, Min_2, Sec_2, Range_2, R\ Freq_2, T\ Freq_2$, and $Bias_2$ are computed at 1/4 station pass duration for CM.

$Day_3, Hr_3, Min_3, Sec_3, Range_3, R\ Freq_3, T\ Freq_3$, and $Bias_3$ are computed at 1/2 station pass duration for CM.

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NOTES (con't):

Day₄, Hr₄, Min₄, Sec₄, Range₄, R Freq₄, T Freq₄, and Bias₄
 are computed at 3/4 station pass duration for CM.

Day₅, Hr₅, Min₅, Sec₅, Range₅, R Freq₅, T Freq₅, and Bias₅
 are computed at LOS for CM.

Day₆, Hr₆, Min₆, Sec₆, Range₆, R Freq₆, T Freq₆, Bias₆, Sign
 Dop₂, and Dop₂ are computed at AOS for LM or SIVB.

Day₇, Hr₇, Min₇, Sec₇, Range₇, R Freq₇, T Freq₇, and Bias₇
 are computed at 1/4 station pass duration for LM or SIVB.

Day₈, Hr₈, Min₈, Sec₈, Range₈, R Freq₈, T Freq₈, and Bias₈
 are computed at 1/2 station pass duration for LM or SIVB.

Day₉, Hr₉, Min₉, Sec₉, Range₉, R Freq₉, T Freq₉, and Bias₉
 are computed at 3/4 station pass duration for LM or SIVB.

Day₁₀, Hr₁₀, Min₁₀, Sec₁₀, Range₁₀, R Freq₁₀, T Freq₁₀, and Bias₁₀
 are computed at LOS for LM or SIVB.

Note: The CM and LM/SIVB header information is calculated from
 one vector and both sets will be correct as long as the
 vehicles are attached. When the vehicles are not attached,
 the data is only good for the one given in the Vehicle ID.

7. Fr. Int = Frame Interval - Time between each X-Y angle set in seconds.
8. Day_A = Day of mission (Launch day = 0) at AOS
 Hr_A = GMT hours at AOS
 Min_A = GMT minutes at AOS
 Sec_A = GMT seconds at AOS
 Day_L = Day of mission (Launch day = 0) at LOS
 Hr_L = GMT hours at LOS
 Min_L = GMT minutes at LOS
 Sec_L = GMT seconds at LOS
9. X and Y angles are in degrees with the decimal point placed XX.XX. Each X and Y angle field is preceded by a sign character, (Δ(space) = plus; - = minus).
10. C. Sum = Check Sum - decimal addition of characters on each line (plus sign = 10; minus sign = 11).

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Exhibit 36

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RTCC to CCATS Data Formats

Apollo Ships' and DOD Sites Acquisition Message Format:

Word No.	S	35
1	CCATS/RTCC Label	
2	S 6 RTCC Time Word	35
3	S 3 PRI Rtg. Ind. No. 12 Routing Indicator No. 1	35
4	S 12 Routing Indicator No. 2	35
5	S 12 Routing Indicator No. 3	35
6	S 6 I R 12 S 18 T 24 Sta. ID 30 Sta. ID	35
7	S Sta. ID Space Space CR CR LF	35
8	S LF Figs Data Type Test No. Test No. Test No.	35
9	S Test No. Test No. Space Month Month Space	35
10	S Day Day Space Orbit x 10 ³ Orbit x 10 ² Orbit x 10 ¹	35
11	S Orbit x 10 ⁰ Space Body No. CR CR LF	35
12	S LF Figs Sign X X x 10 ⁹ X x 10 ⁸ X x 10 ⁷	35
13	S X x 10 ⁶ X x 10 ⁵ X x 10 ⁴ X x 10 ³ X x 10 ² X x 10 ¹	35
14	S X x 10 ⁰ Space C. Sum X C. Sum X Space Sign Y	35
15	S Y x 10 ⁹ Y x 10 ⁸ Y x 10 ⁷ Y x 10 ⁶ Y x 10 ⁵ Y x 10 ⁴	35

(con't on following page)

Exhibit 36 (Cont'd.)

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RTCC to CCATS Apollo Ships' and DOD Sites Acquisition Message Format (cont.):

Word No.	S	6	12	18	24	30	35
16	Y x 10 ³	Y x 10 ²	Y x 10 ¹	Y x 10 ⁰	Space	C. Sum Y	
17	S	C. Sum Y	Space	Sign Z	Z x 10 ⁹	Z x 10 ⁸	Z x 10 ⁷
18	S	Z x 10 ⁶	Z x 10 ⁵	Z x 10 ⁴	Z x 10 ³	Z x 10 ²	Z x 10 ¹
19	S	Z x 10 ⁰	Space	C. Sum Z	C. Sum Z	CR	CR
20	S	LF	LF	Figs	Sign X	X x 10 ⁴	X x 10 ³
21	S	X x 10 ²	X x 10 ¹	X x 10 ⁰	X x 10 ⁻¹	X x 10 ⁻²	Space
22	S	C. Sum X	C. Sum X	Space	Sign Y	Y x 10 ⁴	Y x 10 ³
23	S	Y x 10 ²	Y x 10 ¹	Y x 10 ⁰	Y x 10 ⁻¹	Y x 10 ⁻²	Space
24	S	C. Sum Y	C. Sum Y	Space	Sign Z	Z x 10 ⁴	Z x 10 ³
25	S	Z x 10 ²	Z x 10 ¹	Z x 10 ⁰	Z x 10 ⁻¹	Z x 10 ⁻²	Space
26	S	C. Sum Z	C. Sum Z	Space	Hrs x 10 ¹	Hrs x 10 ⁰	Min x 10 ¹
27	S	Min x 10 ⁰	Sec x 10 ¹	Sec x 10 ⁰	Sec x 10 ⁻¹	Space	C. Sum T
28	S	C. Sum T	CR	CR	LF	LF	Ltrs
29	S	I	R	E	D	00000000000000	0

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RTCC to CCATS Apollo Ships, DOD Sites Acquisition Notes:

1. This vector message will be transmitted to all Apollo Ships and DOD Sites. Other sites may receive the IRV acquisition message upon request. Routing indicators will be as follows:
 - a) ETR DOD/IRV vectors - GCNV
 - b) Non ETR DOD/IRV vectors - normal routing indicators of the particular site.Note: ETR acquisition messages other than DOD/IRV's will use the normal routing indicators of the particular ETR site and NOT GCNV.
2. Each six-bit group contains a leading zero and the 5-bit Baudot Code for the TTY data indicated. When a single character is shown in any six-bit group, that group contains a leading zero and the Baudot Code for the indicated TTY character.
3. Station ID - Standard NASA 3-letter station abbreviation.
4. Data Type - Set = 2 (In Flight) for all messages generated by the MSC RTCC.
5. Text Number - These five characters are fixed as "00000" for all messages generated by the MSC RTCC.
6. Orbit Number - Right justified with leading zeros and orbit number one begins at launch. When this value cannot be computed it will contain zeros.
7. Body Number - 1 = CSM
2 = SIVB
3 = LM
8. The coordinate system is defined as cartesian equatorial with the positive X axis through Greenwich, and the positive Z axis through the North Pole. The Y axis completes the right hand system. X, Y, Z and \dot{X} , \dot{Y} , \dot{Z} are position and velocity components in feet and feet/sec, respectively. All components are preceded by a sign indicator: & = plus; - = minus.
9. Check Sum - Decimal addition of characters in parameters indicated (plus sign = 0; minus sign = 1).
10. All time data (month, day, hours, minutes, seconds) GMT.

where veh is the vehicle for which a vector was requested, and sta is the radar station for which a message was being computed.

4. EMSSACQ

If a station characteristics block cannot be found for a given station, the following message will be printed on line:

"STATION CHARACTERISTICS BLOCK NOT FOUND FOR sta - veh"

where veh is the vehicle for which acquisition data was processing, and sta is the station name which could not be found in the station characteristics table.

5. EMMCBND, EMMSBND, EMMDUD

When a teletype acquisition message is sent for a radar site, the following message is printed on line:

"band ACQ MESSAGE SENT FOR sta - veh phase"

where veh is the vehicle for which acquisition data was processed, sta is the station name for which the message was sent, phase is the phase name, band is the type of message sent.

6. EMSSACQ

When an acquisition message has been sent for the last station in the contact table, the following message will be printed on line:

"ACQ DATA HAS BEEN SENT TO THE LAST CONTACT IN THE (veh) STATION CONTACT TABLE. "

where veh is the vehicle for which acquisition data was processed.

EVALUATION DISPLAY UNIT

SCOPE

This unit is comprised of eight evaluation displays, four mathematical subroutines, a display control program, and a manual entry device decoding program. The subroutines provide many of the mathematical quantities needed by the displays of this unit. They are also used to some extent by programs within other units. The displays included in this unit have been chosen as the basis for defining logical elements.

The functions of these displays are broad in scope providing a wide variety of data to aid in evaluations and decisions by flight controllers, computer controllers, and astronauts. The individual function of each display is described under the appropriate heading.

The MED decoding program provides the manual inputs to the unit's displays while the Display Control program transmits this information by providing the necessary linkage between the Philco hardware and the programmed displays for both MSK requests and MED requests. Listed below are the logical elements comprising this unit.

1. FDO Digitals Display
2. Checkout Monitor Display
3. AGS Navigation Update Display
4. Relative Motion Digitals Display
5. Sunrise/Sunset Display
6. Moonrise/Moonset Display
7. Space Digitals Display
8. Landmark Acquisition Display

FLIGHT DYNAMICS OFFICER ORBIT DIGITALS DISPLAY

Function

The function of the Flight Dynamics Officer (FDO) Orbit Digital Display is to compute present position information and predicted data concerning apogee/perigee and longitude crossings as manually requested.

Load Module/Subroutine Description - EMMDYNMC

EMMDYNMC contains the overall logic and display features to drive the FDO Orbit Digital Display. In order that this program satisfy the requirements imposed upon it, other load modules are used. The first of these is the Ascending Node program, RMMASCND, which provides the geographic longitude of the upcoming ascending node subsequently displayed. A second load module, PMMAPD, provides all of the apogee/perigee related quantities displayed. RLMTLC is used to compute the time-of-crossing of a geographic or selenographic longitude specified via the MED. Utility programs used by EMMDYNMC are ELFECH (the ephemeris fetch program), ELVCTR (the extended interpolation subroutine), and ELVCNV (vector conversion subroutine). The controlling program, EMMDYNMC, obtains most of the present position quantities from the Time Constraints Table and then scales them to displayable dimensions. This source table is updated every 12 seconds with values computed from the present position vector.

Requirements Interpretation

In this section, an attempt has been made to include all known requirements as of the publication date of this document. In addition to the interpretation of these requirements, a copy of the TR170 requirements has been included and annotated for direct reference to appropriate paragraphs in the interpretation section. These references have been provided where clarification or qualification was felt necessary. If any item or capability described in the TR170 document has not been provided, specific mention of this has been made in the margin adjacent to the appropriate paragraph. Parameters computed and/or displayed or capabilities afforded but not included in the NASA requirements, have been mentioned in the margin of the TR170 and appropriately indexed to the interpretation. The abbreviation I/O refers to the Input/Output Specifications section.

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1. Requirements source

The requirements for the processing of the FDO Orbit Digitals Display originate from two sources: TR170, Section OT, par 3.2.1, Change #58 (see Exhibit 37) and the Philco Formats FCN #LM0546C and FCN #LM0578D. The latter will be discussed further in the Inputs/Outputs section (Exhibits 39 and 40).

2. Initialization of display

This display will be initialized by MSK request. All quantities except MED parameters will be regenerated upon MSK request.

3. Updates

The explicit updates associated with this display are as follows: (1) time cycle (12 sec.), (2) trajectory update, and (3) MED (U12, U13, and U14).

Various event occurrences are sensed following the 12-sec. update rather than requiring special external queues upon their occurrence. The update cycle for each parameter is shown in the following paragraph.

4. Parameters to be computed and/or displayed

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
Trajectory update number	Update number associated with subject vehicle ephemeris		(2)
Rev	Current revolution number associated with subject vehicle and central body		(1)
Vector ID	ID of anchor vector		(2)
GET	Ground elapsed time associated with pres- ent position data	hr:min:sec	(1)
Weight	Total current weight	lbs.	(2)
VEH ID	Vehicle name		(1)

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
NV_1^*	Number of vectors used in interpolating for vector from which present position parameters were computed		(1)
K-Factor	Atmospheric density multiplier considered in generating the ephemeris		(1), (2)
λ_{PP}	Present position, longitude	deg.	(1), (2)
ϕ_{PP}	Present position, latitude	deg.	(1), (2)
GET_{CC}	GET of arrival at next rev crossing	hr:min:sec	(1), (2)
N_{PP}	True anomaly	deg.	(1), (2)
λ_{AN}	Longitude of ascending node (Earth-fixed or moon-fixed)	deg.	Node crossing, (2)
h_o	Current height	N. M.	(1), (2)
V_i	Current inertial velocity	F. P. S.	(1), (2)
α_i	Current inertial flight-path angle	deg.	(1), (2)
a	Semimajor axis of orbital ellipse	NM	(1), (2)
e	Eccentricity of orbital ellipse		(1), (2)
i	Orbital inclination to Earth or lunar equator	deg.	(1), (2)

*Subscripts will not appear on background but will be indicated by their background positions.

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
GET _{EI}	GET of arrival at unsafe altitude	hr:min:sec	(2)
ϕ_{EI}	Latitude of entry interface	deg.	(2)
λ_{EI}	Longitude of entry interface	deg.	(2)
REF ₁ *	Central body for present position data		(1)
PET	Phase elapsed time		(1)
GET _{λ}	Time spacecraft will pass over λ_M	hr:min:sec	(Computed-U13, manually entered-U14)
λ_M^*	The longitude associated with GET _{λ}	deg.	(manually entered-U13 or computed-U14)
h_a^{**}	Height of next apogee at GET _a	NM	Crossing of apogee, (2), maneuver initiated
ϕ_a^{**}	Latitude of next apogee at GET _a	deg.	Crossing of apogee, (2), maneuver initiated
λ_a^{**}	Longitude of next apogee at GET _a	deg.	Crossing of apogee, (2), maneuver initiated
GET _R	Event Reference Time	hr:min:sec	(1), (2)

**These parameters are also displayed manually for future time periods; however, they are updated only when manually requested.

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
GET_a^{**}	Time of arrival at next apogee	hr:min:sec	Crossing of apogee, (2), maneuver initiated
h_p^{**}	Height of next perigee at GET_P	NM	Crossing of perigee, (2), maneuver initiated
ϕ_p^{**}	Latitude of next perigee at GET_P	deg.	Crossing of perigee, (2), maneuver initiated
λ_p^{**}	Longitude of next perigee at GET_P	deg.	Crossing of perigee, (2), maneuver initiated
GET_P^{**}	Time of arrival at next perigee	hr:min:sec	Crossing of perigee, (2), maneuver initiated
GET_{BV}	Time tag of vector from which predicted A/P values were computed	hr:min:sec	Computed or manually entered-U12
REV_{BV}^*	Revolution of GET_{BV}		Computed or manually entered-U12
REF_2^*	Central body for predicted apogee/perigee data		Computed or manually entered-U12
NV_2^*	Number of vectors used in interpolating for base vector for predicted apogee/perigee data		(Computed-U12)

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TIME

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
REV_{λ}	Revolution associated with GET_{λ}		(Computed U14-or manually entered-U13)
REF_3^*	Central body of λ_M		(Computed U14 or manually entered-U13)
T_o	Orbital period	hhh:mm:ss	(1)
GETID	GET of Vector ID	hhh:mm:ss	(1), (2)
GMTID	GMT of Vector ID	hhh:mm:ss	(1), (2)

5. General

- a. There will be one MSK for each vehicle required to be processed by the FDO Orbit Digitals Display. MSK 46 applies to the CSM while MSK 45 applies to the LM. Each MSK will be required to drive data relative to the Earth and also the moon. Present position and next apogee/perigee data will be processed for the Earth when in Earth orbit and the moon when in lunar orbit.
- b. When interpolating for a vector or displaying data computed from an interpolated vector, the interpolation must have been performed so as not to mix free-flight and thrust vectors.
- c. Entry interface conditions will apply to the first central body for which they are encountered. This data will be displayed during any phase.

6. Manually-driven data

These special processing requirements for manually entered data are applicable to longitude crossing and predicted apogee/perigee information.

a. Longitude crossing information

- (1) This display will respond to a manually entered time and will compute the geo/selenographic longitude associated with that time. The longitude will be referenced to the central body determined by the sphere of influence associated with the input time.



- (2) It will also respond to a longitude, revolution number, and central body indicator from which the first time of crossing of this longitude within the specified revolution for the indicated central body will be computed. This option cannot be exercised for time periods where revolution numbers are not defined.

Predicted longitudinal information will be limited to the current ephemeris.

b. Predicted apogee/perigee information

- (1) The display will respond to a manually entered time from which apogee/perigee information will be computed.
- (2) It also generates apogee/perigee data based on the burnout vector of the maneuver corresponding to a manually input maneuver code.
- (3) It further responds to an entered revolution number and central body indicator from which apogee/perigee data will be computed based on a vector interpolated from the main ephemeris. The revolution number displayed will apply to the central body into whose sphere of influence the base vector time falls.

The base vector secured for predicted apogee/perigee information will be limited to and interpolated from the time frame of the current ephemeris, except for the maneuver code option. The central body considered will be determined by the sphere of influence associated with the base vector.

7. Computation requirements

- a. The following computation requirements have been set for logical processing limits.

- (1) Immediately following a trajectory update or MSK, all manually driven data will be blanked and next apogee/perigee information will be computed from a base vector interpolated from the main ephemeris at current time. Should, however, this time fall within a maneuver the burnout vector will be selected as the base vector.
- (2) Should the time on the MED (time option) for computing predicted apogee/perigee data fall within a maneuver, the base vector selected will be the burnout vector of the subject maneuver.
- (3) For both next apogee/perigee and predicted apogee/perigee, all maneuvers and venting subsequent to the base vector will be ignored and a free-flight ephemeris assumed. Should a perigee fail to exist beyond the base vector, only the apogee data will be displayed. This data will relate to the apogee following the base vector unless there is none. In this case, the data will relate to the first apogee preceding the base vector.

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- (4) The present position weight displayed will be that at the termination of the previous maneuver.
 - (5) GETCC will be displayed as zero if the next rev crossing for the subject central body does not exist.
 - (6) The entry interface quantities are blanked until they apply. In the event the vehicle enters the entry interface more than once, the EI quantities displayed relate to the first "dip" sensed integrating in a forward direction.
 - (7) Should the next ascending node not exist, it will be displayed as XXXXXX.
 - (8) Revolution numbers will be displayed zeros when they are not valid.
- b. The following constitute the mathematical requirements.
- (1) Cape crossing times must be accurate to within .001 radians.
 - (2) Ascending nodes must be accurate to within 2 seconds.
 - (3) Under hyperbolic conditions, only perigee data will be computed.
 - (4) EI conditions for the Earth are defined at 400,000 ft. and 35,000 ft. for the moon.
 - (5) Precession and nutation must be considered for any Earth-related computations, and libration must be considered for moon-related computations.
 - (6) Eighth-order interpolations will be used whenever possible. End point eighth-order interpolations will be preferred over mid-point, using a lesser order.
 - (7) Current height will be oblate (true subsatellite) for the Earth and spherical for the moon while apogee/perigee heights will be spherical. The Earth radius considered is the radius at Cape Kennedy. Lunar spherical heights are computed using the lunar landing site radius.
 - (8) The true anomaly will be blanked when the instantaneous eccentricity of the vector from which true anomaly is computed is $\leq .0001$.
 - (9) Should the eccentricity corresponding to the apogee and perigee heights determined be $\leq .0001$, only the general height will be displayed (at h_p).
 - (10) All lunar latitudes and longitudes will be selenographic. All Earth longitudes will be geographic. Present position Earth latitudes and Earth EI condition latitudes will be true subsatellite; apogee/perigee latitudes will be geocentric.

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OT 3.2 OutputOT 3.2.1 FDO Orbit Digitals

A. Purpose. To provide present position information, general information, current apogee/perigee information, predicted apogee/perigee information, and predicted longitude information.

B. Data Source. Current ephemeris, burnout vectors.

Item 2 C. Initialization of Display. Present position information and general orbital parameters will be initialized by MSK request, and the predicted information will be initialized with the following MEDS.

- MED formats defined in I/O section
- Code, vehicle, GET, $\begin{smallmatrix} E \\ M \end{smallmatrix}$; \longrightarrow Longitude crossing at specified GET
 - Code, vehicle, REV, longitude (E/W), $\begin{smallmatrix} E \\ M \end{smallmatrix}$; \longrightarrow time of crossing the specified longitude for the specified rev
 - Code, vehicle, OPTION, parameter.

The allowable OPTIONS are:

GET - time option

REV - revolution option

MNV - maneuver code option

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(OT) 3.2.1-1

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D. Parameters To Be Computed and Displayed

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSIONS</u>	<u>UPDATES</u>
	Vehicle	Vehicle name		
Item 7a	Rev	Current revolution number associated with subject vehicle and central body		(1)
	Vector ID	Last vector used for updating the ephemeris		(2)
	GMT ID	GMT Time of anchor vector	Hr:min:sec	(2)
	GET ID	GET Time of anchor vector	Hr:min:sec	(2)
Item 4	GET	Current ground elapsed time	Hr:min:sec	(1)
	Weight	Total current weight of subject vehicle	lbs.	(1)
	K-Factor	Atmospheric density multiplier considered in generating the ephemeris		(1), (2)
	λ_{pp}	Present position, longitude (Selenographic for moon)	deg.	(1), (2)
	ϕ_{pp}	Present position, latitude (geodetic for earth)(selenographic for moon)	deg.	(1), (2)
Item 7a	GET _{CC} *	GET of arrival at next cape crossing	Hr:min:sec	(1), (2)

(1) Output cycle (12 sec.)

(2) Trajectory Update, MSK Request

* For lunar orbit this will be the time of the vehicle crossing of the 180° selenographic longitude.

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(OT) 3.2.1-2

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	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSIONS</u>	<u>UPDATES</u>
Item 7b	Npp	True anomaly	deg.	(1), (2)
Item 7a	λ_{AN}	Longitude of ascending node (earth fixed or moon fixed)	deg.	Node crossing, (2)
Item 7b	h	Current oblate height (Spherical for moon)	N.M.	(1), (2)
	V_i	Current inertial velocity	f.p.s.	(1), (2)
	γ	Current inertial flightpath angle	deg.	(1), (2)
	a	Semimajor axis of orbital ellipse	N.M.	(1), (2)
	e	Eccentricity of orbital ellipse		(1), (2)
	i	Orbital inclination to central body equator	deg.	(1), (2)
Items 7a and 7b	GET _{EI}	GET of arrival at unsafe altitude		(2)
	ϕ_{EI}	Geodetic latitude of entry interface	deg.	(2)
	λ_{EI}	Longitude of entry interface	deg.	(2)
Item 7a	PET	Phase elapsed time (GET of an event minus GETR)	Hr:min:sec	(4)

(1) Output cycle (12 sec.)

(2) Trajectory Update

(4) These times will be updated when a new GETR and a new event is specified.

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(OT) 3.2.1-3

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	QUANTITY	DEFINITION	DIMENSIONS	UPDATES
	GETR	GET of reference (elapsed time of an event)	Hr:min:sec	(4)
Item 6a	GET _λ	Time S/C will pass over λ below	Hr:min:sec	Computed or manually entered
	REV _λ	Revolution associated with GET _λ		Manually entered or computed
Item 7b	λ	The longitude associated above GET	deg.	Manually entered or computed
	h _a **	Spherical height of next apogee at GET _a	N.M	Crossing of Apogee, (2), maneuver executed
	φ _a **	Latitude of next apogee at GET _a . Geocentric in earth reference, selenographic around moon	deg.	Crossing of Apogee, (2), maneuver executed
	λ _a **	Longitude of next apogee at GET _a	deg.	Crossing of Apogee, (2), maneuver executed
Items 4 and 7b	GET _a **	Time of arrival at next apogee	Hr:min:sec	Crossing of Apogee, (2), maneuver executed
	h _p **	Spherical height of next perigee at GET _p	N.M.	Crossing of Perigee, (2), Maneuver executed
	φ _p **	Latitude at next perigee at GET _p . Geocentric relative to the earth and selenographic around moon	deg.	Crossing of Perigee, (2), Maneuver executed
	λ _p **	Longitude of next perigee at GET _p	deg.	Crossing of Perigee, (2), Maneuver executed
	GET _p **	Time of arrival at next perigee	Hr:min:sec	Crossing of Perigee, (2), Maneuver executed
Item 6b	GET _{BV}	Time tag of vector from which apogee/perigee values were computed	Hr:min:sec	Computed or manually entered
	REV _{BV}	Revolution of GET _{BV}		Computed or manually entered

(2) Trajectory Update, MSK Request

(4) These times will be updated when a new GETR and a new event is specified.

** Also displayed manually for future time periods as requested.

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	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSIONS</u>	<u>UPDATES</u>
Item 4	T ₀	Orbital period	Hr:min:sec	(1)
	REF ₁	Indicator of which central body is being referenced for present position data and for manual Apogee/Perigee and longitude		
	REF ₂			
	REF ₃			
	NV ₁	Number of vectors used for interpolation for present position values		
	NV ₂	Number of vectors used in interpolating for base vector for predicted apogee/perigee data		
	Trajectory Update Number	Update number associated with subject vehicle ephemeris		(2)

Updates. See updates column of D.

Additional Information

1. General

- Item 5 a. There will be one MSK for each vehicle required to be processed by the FDO Orbit Digitals Display. Each MSK will be required to drive data (for the appropriate vehicle) relative to the earth and also the moon. Present position, next apogee/perigee and entry interface data will be processed for the earth when in Earth Orbit and the moon when in Lunar Orbit.

- Item 6a, 6b.
(Also see I/O section) b. The predicted apogee/perigee data or the predicted longitudinal information may pertain to either central body and will be determined by a MED indicator. Both the predicted longitudinal data and the base vector for predicted apogee/perigee information will be limited to the current ephemeris except when the latter is requested by maneuver code.

2. Manually Driven Data

- a. Longitude crossing information

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- (1) The display will respond to a manually entered time and compute the geo/selenographic longitude associated with that time.
- (2) The display will respond to a manually entered longitude and revolution number for which the first time of crossing of this longitude within the revolution specified will be computed.

b. Apogee/Perigee Information

- (1) The display will respond to a manually entered time for which apogee/perigee information following that time will be computed.
- (2) The display will respond to a manually entered maneuver code for which apogee/perigee information based on the burnout vector of the respective maneuver will be computed.
- (3) This display will respond to a manually entered revolution for which apogee/perigee information will be computed following that cape crossing time.
- (4) For GET and REV options the base vector will be interpolated from the main ephemeris.

3. Computation Requirements**a. Logical Processing Limits**

- (1) The manually driven longitudinal data will not be required beyond the limits of the main ephemeris.
- (2) Revolution number will be displayed in Earth Orbit and Lunar Orbit only and will apply to the respective central body. In all other phases they will be displayed as zero. For the earth the revolution number will begin at 1 upon insertion and will be incremented by one for each successive crossing of the geographic longitude of Cape Kennedy while in Earth/Orbit. For the moon the revolution number will start at one upon entering Lunar Orbit and be incremented by one for each successive crossing of the selenographic longitude of 180° while in Lunar Orbit.
- (3) Immediately following a trajectory update all manually driven data will be blanked.

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(OT) 3.2.1-6

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Item 7a

- (4) Following a trajectory update or MSK next apogee/perigee information will be computed from a base vector interpolated from the main ephemeris at current time.
- (5) Should the time on the MED (time option) for computing predicted apogee/perigee data fall within a maneuver, the burnout vector will be used.
- (6) For both next apogee/perigee and predicted apogee/perigee all maneuvers subsequent to the base vector will be ignored. A free flight ephemeris is assumed.
- (7) Should a perigee fail to exist beyond the base vector, only the apogee data will be displayed. This data will relate to the apogee following the base vector unless there is none, in which case the data will relate to the first apogee preceding the base vector.
- (8) If the next cape crossing does not exist, GETCC will be displayed as zero.
- (9) The Entry Interface quantities are blanked until they apply. In the event the vehicle enters the entry interface more than once, the EI quantities displayed relate to the first "dip" sensed integrating in a forward direction.

Item 4

- (10) Current apogee/perigee information is automatically updated when current time reaches the time of apogee or perigee, after each trajectory update, and when current time reaches the burnout time of a maneuver.
- (11) Current apogee/perigee and other present position quantities information is manually updated each time the MSK is entered.
- (12) With each MSK or trajectory update, the manual columns are wiped clean. It should be clear that the MSK should be used cautiously and no more frequently than absolutely necessary.
- (13) Should the base vector be taken from the MPT the quantity NV₂ will be zero.

Approved: _____

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(OT) 3.2.1-7

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NOTE: See Input/Output section

[illegible]

Figure OT 3.2.1-1 Display Format, Orbit Digitals No. 1, MSK 0046

Approved: *AS*

NASA/FSB

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(OT) 3.2.1-9

Functional Diagrams

The FDO Digital's Display, Figure 22, shows the interfaces of the programs in this element with other elements, units, or subsystems. Also included are data table usage, task structure, and input/output data flow. The key to the symbols used in the diagram may be found in the Glossary of this document.

Input/Output Specifications

This section is divided into four groupings of data: MED formats, display formats, on-line prints, and cathode-ray tube (CRT) error indications. Each grouping will be discussed separately.

MED Formats: The following MED formats are contained within this section:

1. U12, which predicts apogee/perigee
2. U13, which computes longitude crossing times
3. U14, which computes longitude at a given time.

Display Formats: The following display formats are included in this section:

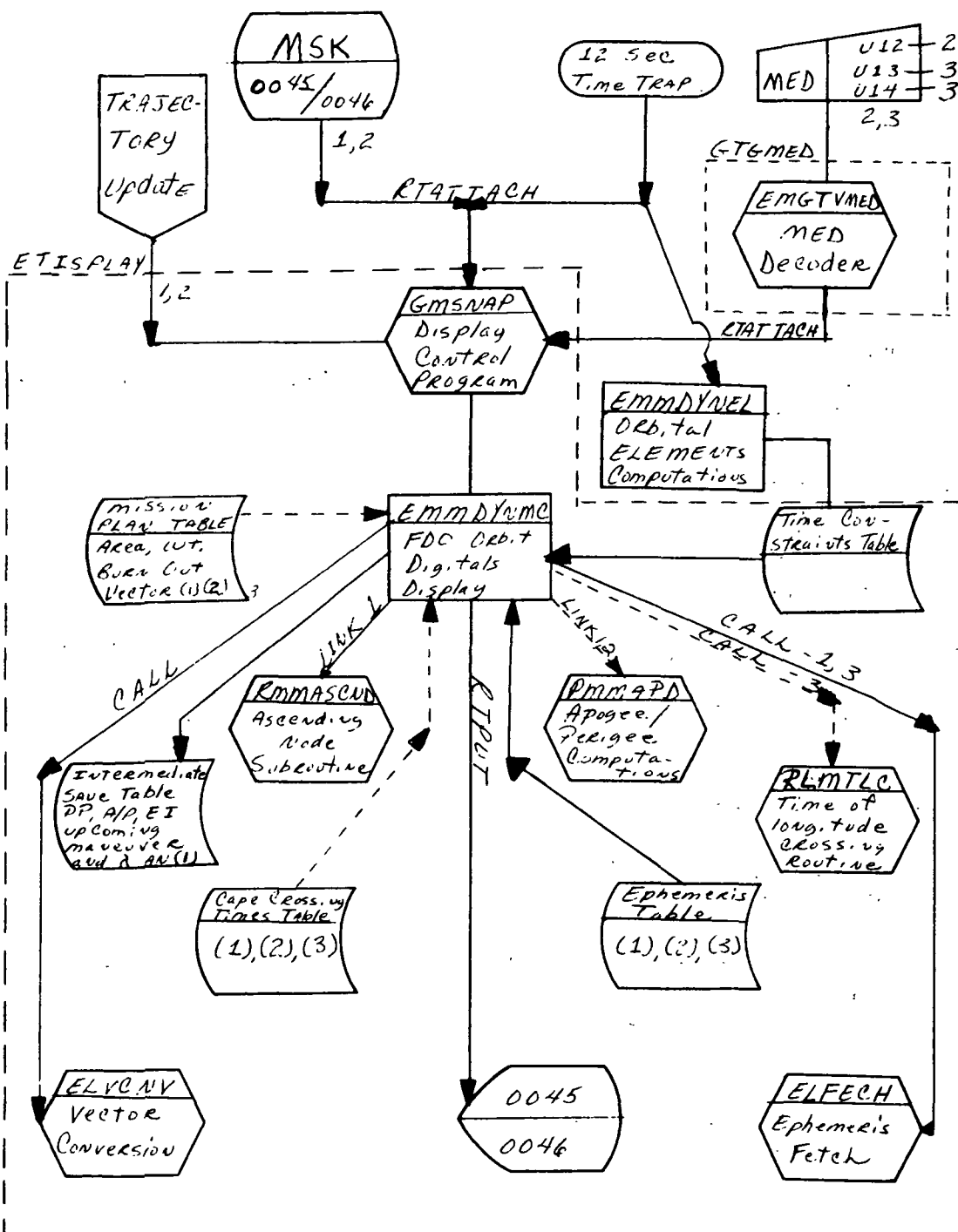
1. FDO Orbit Digitals, No. 1 - Exhibit 16
2. FDO Orbit Digitals, No. 2 - Exhibit 17

On-Line Prints: Two on-line prints are associated with this display.

RMASCND CONVERGENCE LIMIT - (VALUE)

RLMTLC CONVERGENCE LIMIT - (VALUE)

Each of these prints has been implemented to indicate that the corresponding mathematical program, which was calculating on an iterative basis, was unable to converge on the desired orbital parameter within the tolerance required. The best value it could determine will be displayed on the CRT with an asterisk adjacent to the parameter, while the on-line print will state how much deviation exists between the displayed quantity and the actual value. This deviation is expressed in terms of seconds for the ascending node; but for the time of longitude crossing, the deviation is expressed in radians.



Function Codes: 1 - Present Position Information
 2 - Predicted Apogee/Perigee Data
 3 - Predicted Longitudinal Data

Figure 22. FDO Orbit Digitals Display



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MED Format Table

Task:
EP:
QNAME:
QUEID:

MED Code: U12
Purpose: Predict apogee/perigee

Load Module: EMGTVMED

Desc.	Item	1	2	3a	3b	3c	4
Item Name	VEH ID	IND		REV NO	TIME	MNV NO	CENTRAL BODY
Input Format	VEH	AAA		N	HHH:MM:SS. SS	NN	A
Input Units	EBCDIC	EBCDIC		FXP	GMT	FXP	EBCDIC
Program Units	Numeric Code			FXP	hours	FXP	FXP (4)
Scale Factor							
Checking Option	Exact See Note 3	Exact See Note 1		MINIMAX See Note 2	None	None	Exact See Note 4
Missing Item Option	Error	Error		Error	Error	Error	Assume "E" Notes 5
Item Destination							

Programmer:

Initial Logic:

Final Logic: Set up SP2 for special queue to ETISPLAY

Illegal Phases: All but low-speed orbit

Notes: (1) IND = REV, parameter 3a entered
= GET, parameter 3b entered
= MNV, parameter 3c entered

(4) E for EARTH (=0)

66-2656-1 M for MOON (=2)

(2) Current REV ≤ REV ≤ Last REV in Cape table

(3) CSM or LEM

(5) This parameter is valid only when IND=REV.



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MED Format Table

MED Code: U13
 Purpose: Longitude crossing times
 Load Module: EMGTVMED
 Task:
 EP:
 QNAME:
 QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name	VEH ID	REV NO	Longitude	CENTRAL BODY			
Input Format	VEH	NN	DDD:MM:SS E/W or +DDD.XXXX	A			
Input Units	EBCDIC	FXP	LONG	EBCDIC			
Program Units	Numeric Code	FXP	radians	FXP (3)			
Scale Factor							
Checking Option	Exact See Note 2	MINMAX See Note 1	None	Exact See Note 3			
Missing Item Option	Error	Error	Error	Assume "E"			
Item Destination							

Programmer:

Initial Logic:

Final Logic: Set up SP2 for special queue to ETISPLAY

Illegal Phases: All but low-speed orbit

Notes:

(1) Current REV ≤ REV ≤ Last REV in Cape table

(2) CSM or LEM

(3) E for EARTH (=0)

M for MOON (=2)

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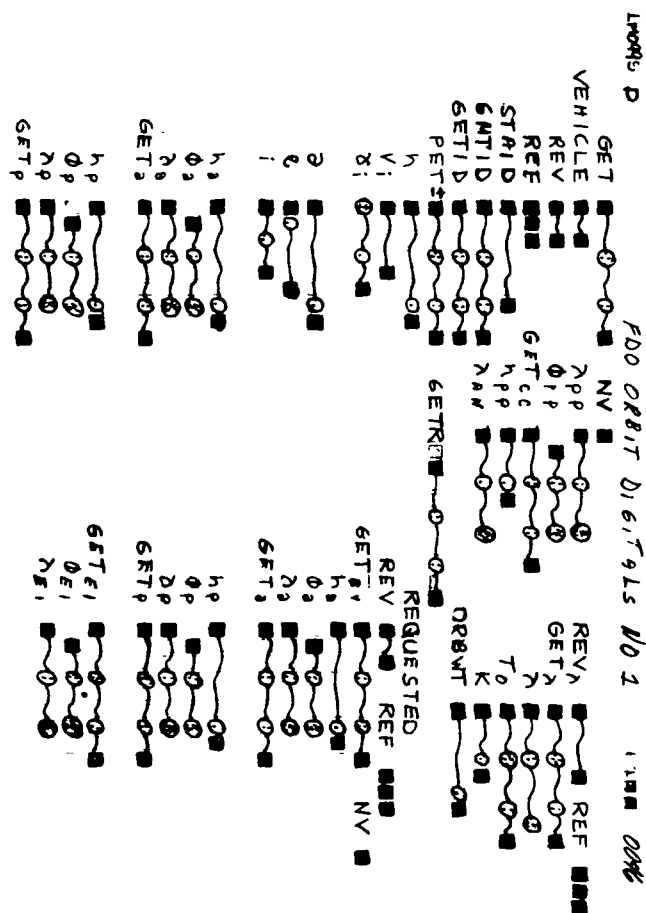
MED Format Table

MED Code: U14 Task:
Purpose: Compute longitude at given time EP:
Load Module: EMGTVMED QNAME:
QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name		VEH ID	TIME				
Input Format		VEH	HHH:MM:SS.S				
Input Units		EBCDIC	GET				
Program Units		Numeric	hours				
Scale Factor		Code					
Checking Option		See Note 1 Exact	None				
Missing Item Option		Error	Error				
Item Destination							

Programmer:
Initial Logic:
Final Logic: Set up SP2 for special queue to ETISPLAY
Illegal Phases: All but low-speed orbit
Notes: (1) CSM or LEM

Exhibit 39



0006

F E G

LM0391A
LM0446B
KM05452
KM0995D

FDO
ORBIT
DIG NO 1
0046

FIO D16

4 4

6/9/58

B. L. Buckley

Exhibit 40

[illegible]

CRT Error Indications: The following error conditions are detected and indicated by an asterisk on the CRT accompanied by the corresponding numerical code.

1. The trajectory for subject vehicle is not generated.
2. The Mission Plan table is either in an update state or inconsistent with trajectory update number.
3. The revolution defining times table is either in an update state or is inconsistent with trajectory update number.
4. The main ephemeris is in update status.
5. The revolution number on the MED U13 is less than the first available revolution defining time.
6. The revolution number on the MED U13 is greater than the last available revolution defining time.
7. The revolution number on the U13 MED is valid; however, the longitude crossing requested is outside the range of the ephemeris.
8. The time on the U14 MED precedes the start of the ephemeris.
9. The time on the U14 MED exceeds the end of the ephemeris.
10. The revolution number on the U12 MED is smaller than the first available revolution defining time.
11. The revolution number on the U12 MED is greater than the last revolution defining time.
12. The time on the U12 MED precedes the start of the ephemeris.
13. The time on the U12 MED exceeds the end of the ephemeris.
14. The maneuver number requested is greater than the number of maneuvers in the Mission Plan Table.
15. The base vector selected for predicted apogee/perigee computation was rejected by the Analytical Ephemeris Generator.
16. The base vector selected for upcoming apogee/perigee computation was rejected by the Analytical Ephemeris Generator.
17. No precession/nutation matrix is available for subject time.
18. Open
19. Present position data not initialized in Time Constraints Table.
20. End of ephemeris reached.

These error codes are based on the best information to date. Final error codes will be published at the time of subsystem delivery.

CHECKOUT MONITOR DISPLAY

Function

The function of the Checkout Monitor Display, EMDCHECK, is to obtain or calculate various orbital parameters, system parameters, and mission planning quantities to aid in the RTCC program checkout.

Load Module/Routine Description - EMDCHECK

EMDCHECK acts as the controlling load module for this logical element and also provides the necessary display formatting. To accomplish this, it requires the assistance of two utility routines, ELVCTR (extended interpolation) and ELVCNV (vector conversion), and also EMMDYNEL, which computes various orbital characteristics from a single position and velocity vector. EMMDYNEL in turn utilizes the sub-satellite position subroutine, GLSSAT, in conjunction with its own on-line formulation to calculate a total of seventeen orbital elements. PMMAPD provides apogee and perigee altitudes. The miscellaneous numerical integration program, EMSMISS, is queued for options requiring integration, while PLAWDT accesses correct areas and weights.

Requirements Interpretation

In this section, an attempt has been made to include all known requirements as of the publication date of this document. In addition to the interpretation of these requirements, a copy of the TR170 requirements has been included and annotated for direct reference to appropriate paragraphs in the interpretation section. These references have been provided where clarification or qualification was felt necessary. If any item or capability described in the TR170 document has not been provided, specific mention of this has been made in the margin adjacent to the appropriate paragraph. Parameters computed and/or displayed or capabilities afforded but not included in the NASA requirements, have been mentioned in the margin of the TR170 and appropriately indexed to the interpretation. The abbreviation I/O refers to the Input/Output Specifications section.

ITEM

1. Requirements source

The requirements for the processing of the Checkout Monitor Display originate from two sources: TR170, OT section, par. 3.2.3, change #58 (see Exhibit 41) and the Philco Format FCN #LM0903B.

ITEM

2. Initialization of display

This display will be initialized by MSK request.

3. Updates

There are no automatic updates associated with this display; however, it will respond to one MED, in which case all parameters are regenerated.

4. Parameters to be computed and displayed

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
VEH	Vehicle associated with parameters	
GET	Ground elapsed time tag of the vector	hhh:mm:ss.ss
GMT	Greenwich mean time tag of the vector	hhh:mm:ss.ss
VID	Identification of the last vector used to update the ephemeris	
X	Position vector	(ft. or Earth rad.)
Y		
Z		
\dot{X}	Velocity vector	FPS or Earth rad./hr.
\dot{Y}		
\dot{Z}		
V_i	Inertial velocity	FPS
γ_i	Inertial flight-path angle	deg.
ψ	Inertial azimuth	deg.
φ_c	Geocentric/selenographic latitude	deg.
λ	Geographic/selenographic longitude	deg.
h_s	Height of vehicle above a spherical Earth or moon	NM
h_a	Height of apogee above a spherical Earth or moon	NM

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
h_p	Height of perigee above a spherical Earth or moon	NM
h_o	Height above an oblate Earth	NM
h_o	Height above an oblate Earth	ft.
φ_D	Geodetic/selenographic latitude	deg.
λ_D	Mean geographic/true inertial longitude	deg.
a	Semi-major axis of orbital ellipse	NM
e	Eccentricity of orbital ellipse	
i	Orbital inclination	deg.
ω_p	Argument of perigee	deg.
Ω	Right ascension of the ascending node (inertial)	deg.
u	True anomaly	deg.
m	Mean anomaly	deg.
R	Vector magnitude radius	nm
R-DAY	Calendar day of liftoff	day:month:year
A	Vehicle area at GET	sq. ft.
K-FAC	Current atmospheric density multiplier	
CFG	Vehicle configuration at GET	
RF	Reference frame the vector is in ECT = true Earth ECI = mean Earth MCT = true moon MCI = mean moon	
WT	Total weight for above configuration	lb.
WC	Total CSM weight	lb.
WL	Total LM weight	lb.
SPS	Total SPS propellant remaining	lb.

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
RCS _C	Total CSM RCS propellant remaining	lb.
APS	Total APS propellant remaining	lb.
DPS	Total DPS propellant remaining	lb.
RCS _L	Total LM RCS propellant remaining	lb.
J2	Total J2 propellant remaining	lb.
LO/C	Lift-off time of the CSM	hhh:mm:ss.ss
GRR/C	Guidance reference release time of the spacecraft	hhh:mm:ss.ss
ZS/C	Time that S/C register was zeroed	hhh:mm:ss.ss
GRR/S	Guidance reference release time of the S-IVB	hhh:mm:ss.ss
LO/L	Lift-off time of the LM	hhh:mm:ss.ss
ZS/L	Time that the LGC register was zeroed	hhh:mm:ss.ss
ZS/A	Time that the AGS register was zeroed	hhh:mm:ss.ss
EPHB	The begin time of the ephemeris	hhh:mm:ss.ss
EPHE	The end time of the ephemeris	hhh:mm:ss.ss
Update No.	To indicate the number of times that the ephemeris was updated	
NV	Number of vectors used to interpolate for vector displayed	
THT	MED threshold time	hhh:mm:ss.ss
RTT	Reentry threshold time	hhh:mm:ss.ss
LSB	Lunar stay begin time	hhh:mm:ss.ss
LLS	Lunar stay termination	hhh:mm:ss.ss
δ L	Lunar declination	deg.
VSF	Venting scale factor	
EB2	Ephemeris begin time (other vehicle)	hhh:hh:ss.s
EE2	Ephemeris end time (other vehicle)	hhh:hh:ss.s

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
X _T	Unit thrust vector associated with the requested maneuver	
Y _T		
Z _T		
Option	MED option to which displayed data corresponds (GET, GMT, MVI, MVE, RAD, ALT, or FPA)	

5. General

There will be one MSK to process all required vehicles.

6. Manually driven data

- a. The following are the special processing requirements for manually entered data.

- (1) There will be only one MED associated with this display, however, there will be seven distinct options on this MED - MVI, MVE, GET, GMT, RAD, ALT, FPA.
- (2) MVI and MVE options result in the vectors displayed being retrieved directly from the Mission Plan Table.
- (3) RAD, ALT, FPA options require integrating (free-flight) from the base vector (determined from the threshold time) to a radial distance, altitude, or flight-path angle cutoff condition respectively.
- (4) GMT and GET options may be used to interpolate for a vector in the main ephemeris, or to integrate from an ephemeris or maneuver burnout vector to some desired time.

- b. The MED format for this display will be:

U02, VEH, INDICATOR, PARAMETER, THRESHOLD TIME,
COORDINATE SYSTEM, DIMENSION;

The indicator will be:

GET - Ground Elapsed Time Option
 GMT - Greenwich Mean Time Option
 MVI - Maneuver Initiation Option
 MVE - Maneuver Burnout Option
 ALT - Altitude Cutoff Option
 RAD - Radial Distance Cutoff Option
 FPA - Flight Path Angle Cutoff Option.

The parameter is either hhh:mm:ss.ss (GMT or GET), a maneuver number (MVI or MVE), nautical miles (RAD or ALT), or degrees (FPA). The allowable coordinate systems will be ECT - True Earth, ECI - Mean Earth, MCT - True Lunar, MCI - Mean Lunar, and EMP - Earth/Moon Plane.

- (1) Precession/nutation will be considered for the ECT options.
For MCT options, libration will be considered.
- (2) All parameters computed are calculated directly using the vector displayed.

The allowable dimension is FT, in which case the position and velocity vectors are displayed in feet and feet per second. Should this item be omitted, the dimensions of Earth radii and Earth radii per hour will be assumed.

The format for these vectors will be:

Position Vector		Velocity Vector	
ft., ft/sec	± XXXXXXXXXXXX. (ft.)	± XXXXX.XXXXXX (ft./sec.)	
Er, Er/hr.	± XX.XXXXXXXXXX (Er)	± XX.XXXXXXXXXX (Er/hr)	

7. Computation requirements

- a. The following computation requirements have been set for logical processing limits.

- (1) All weights will be actual weights at the vector time with the following exceptions:
 - (a) For the MVI option, the individual weights will be those at maneuver initiation (ullage on if applicable).
 - (b) Weight loss owing to disposing of expendables subsequent to the base vector for options requiring integration will not be reflected.
 - (c) GET or GMT request (from the ephemeris) during ullage will reflect pre-ullage weights.
- (2) If the subject vehicle is not docked, the weight of the "other" vehicle will be blanked.
- (3) The unit thrust vector will correspond to the burn initiate of some planned or executed maneuver; therefore, it will be driven only when the display is requested for the MVI option. In all other cases, it will be blanked.
- (4) The number of vectors (NV) will be blanked if interpolation was not performed to obtain the vector displayed.
- (5) The time options (GET or GMT) will not be limited to the time bounds of the main ephemeris. Should the time on the GET or GMT option (when interpolating for an ephemeris vector only) fall within a maneuver (between main engine thrust and tailoff), no processing will occur other than an indication displayed that this condition exists.

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- (6) For MVI or MVE options, the parameter manually entered will be a numerical code corresponding to some maneuver within the Mission Plan Table. The display will process for the appropriate maneuver whether or not it is reflected in the main ephemeris. For the MVI option, the vector selected will be that associated with main engine ignition. For the MVE option, the vector selected will be the tail-off vector of the appropriate maneuver.
- (7) The true anomaly will be blanked if the eccentricity of the associated vector is $\leq .00001$.
- (8) The central body for which the RAD, ALT, and FPA options will be the same as that implied by the coordinate system indicator. These cut-off conditions will be discerned only if the condition occurs within the sphere of influence of the central body specified. For FPA options, the condition must occur later than the first integration time step within the lunar sphere of influence.
- (9) The maximum time to integrate to any desired end condition will be determined by the constraints imposed on the ENCKE Integrator.
- (10) Eighth-order interpolations will be performed for GMT and GET options, which are within the ephemeris and no threshold time is specified.
- (11) Threshold times are optional for GET or GMT options, but are mandatory for ALT, RAD, & FPA options, and threshold times are not permitted for MVI or MVE options.
- (12) Threshold times are not limited to the end time of the main ephemeris. The first non thrusting ephemeris vector (or maneuver burn-out vector if the threshold time is beyond the end of the main ephemeris) prior to the threshold time will be selected as the "base vector" and all maneuvers subsequent to that vector will be ignored in determining the desired cut-off condition. Venting will be considered beyond the base vector if applicable.
- (13) Any specified threshold time for GET or GMT options must precede the GET or GMT. (No backward integration will be performed.)
- (14) If the GET or GMT option is requested for a time beyond the end of the main ephemeris and no threshold time is specified, the time of the vector to be displayed will be assumed the threshold time.
- (15) The time for determining any desired end condition will be the same as that imposed on the Encke Integrator.
- (16) Integration options once serviced by this display will not be honored by subsequent MSK requests. The associated MED must be entered to cause reprocessing.

- (17) The items h_o , ϕ_D , and λ_D are blanked when the data relates to the moon.
- (18) Lunar stay times will be displayed as zeros if they do not exist for the subject vehicle.
- (19) The configuration code will be denote by one or more of the following letters C-CSM, L-LM, A-Ascent stage, D-Decent stage.
- b. The mathematical requirements are as follows:
- (1) Geodetic computations will be true subsatellite positions, as will oblate heights.
- (2) All orbital parameters except apogee/perigee altitudes will be computed by Keplerian methods.
- (3) Eighth-order interpolations will be performed whenever possible for GET and GMT options. End-point interpolation will be preferred over mid-point, using a lesser order. Interpolations must be performed so as not to mix free-flight and thrust vectors.
- (4) Where orbital elements are not defined for the characteristics of the orbit at hand (circular, elliptical, parabolic, hyperbolic, or rectilinear), they will be displayed as "Z's."
- (5) Threshold time will be blanked if not entered on MED.
- (6) The spherical height, h_g , will be computed using the radius at the Cape for the Earth and the lunar landing site radius for the moon.
- (7) The items λ , λ_D , and ϕ will have the following significance depending on the coordinate system requested.

	<u>ECI</u>	<u>MCI</u>	<u>ECT</u>	<u>MCT</u>	<u>EMP</u>
λ	mean inertial	mean inertial	true geographic	true selenographic	Longitude relative to "X" axis of Earth-moon plane
λ_D	mean geographic		true inertial (RTCC)		
ϕ	mean inertial	mean inertial	geocentric	selenocentric	latitude relative to Earth-moon plane (All other body-fixed values will be blanked in this system.)

- '8) The displayable limits for the inclination angle are $0^\circ \leq i < 180^\circ$.

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Exhibit 41

PHO-TR170A
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OT 3.2.3 Checkout Monitor Display

- A. Purpose. To generate and display quantities that will aid in the checkout of the RTCC program.
- B. Data Source. Current Ephemeris.
- C. Initialization of Display. This display will be initialized with the following manual entries.

MED defined
in item 6b.
(See also I/O
section)

Code, VEH, Indicator, Parameter, Coordinate System, GETTH, FT.

where: vehicle = CSM or LM

Reference = ECT - true earth

ECI - mean earth

MCT - true lunar

MCI - mean lunar

IndicatorParameter

GMT

XXX:XX:XX.X

GET

XXX:XX:XX.X

Maneuver Initiate (MVI)

Maneuver number

Maneuver End (MVE)

Maneuver number

Height (ALT) in feet (oblate)

Earth = E, Moon = M

Radius (RAD) in nautical miles

Earth = E, Moon = M

Flightpath angle (FPA)

Earth = E, Moon = M

Item 7a

When (FT) is specified then the following quantities will be displayed as follows.

(X, Y, Z) in feet (\dot{X} , \dot{Y} , \dot{Z}) ft/sec.

When a threshold (GETTH) time is specified then all subsequent maneuvers will be ignored.

Approved:

NASA/FSB

PHO/PARS

Exhibit 41 (Cont'd.)

PHO-TR170A
Volume 2, Change 58
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D. Parameters To Be Computed and Displayed

QUANTITY	DEFINITION	DIMENSION	
VEH	Vehicle that the parameters are associated with	None	
GET	Ground elapsed time tag of the vector.	HHH:MM:SS.SS	
GMT	Greenwich mean time tag of the vector	HHH:MM:SS.SS	
VID	Identification of the last vector used to update the ephemeris	None	
X Y Z	Position Vector	(Ft and earth rad)	
\dot{X} \dot{Y} \dot{Z}			
	Velocity Vector	fps and earth rad/hr	
V_i	Inertial velocity	fps	
γ_i	Inertial flightpath angle	deg	
ψ	Inertial azimuth	deg	
Item 7b ϕ_c	Geocentric latitude	deg	
Item 7b λ	Subsatellite longitude	deg	
Item 7b	h_s	Height above a spherical earth or moon	nm
	h_a	Height of apogee above a spherical earth or moon	nm
	h_p	Height of perigee above a spherical earth or moon	nm
	h_o	Height above an oblate earth or moon	nm and ft.

Approved: 20 NASA/FSB PHO/PARS

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	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSIONS</u>
Item 7a	ϕ_D	Geodetic latitude	deg
Item 7a and 7b	λ_D	Geodetic longitude	deg
	a	Semi-major axis of orbital ellipse	nm
	e	Eccentricity of orbital ellipse	None
	i	Orbital inclination	deg
	ω_p	Argument of perigee	deg
	Ω	Right ascension of the ascending node	deg
Item 7a	v	True anomaly	deg
	m	Mean anomaly	deg
	δL	Lunar declination	deg
	R	Vector Magnitude Radius	nm
	R-DAY	Calendar day of liftoff	day:month:year
	A	Vehicle area at GET	SQ. FT.
	K-FAC	Current atmospheric density multiplier	None
	CFG	Current vehicle configuration	None
	RF	Reference frame the vector is in ECT = true earth ECI = mean earth MCT = true lunar MCI = mean lunar	None
Item 7a	WT	Total weight at vector time	lb
	WC	Total CSM weight at vector time	lb
	NV	Number of vectors used to determine the solution.	
	Option	MED option to which Display data corresponds (GET, GMT, MVI, MVE, ALT, RAD, FPA)	

Approved: *SK*

NASA/FSB

PHO/PARS

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
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Volume 2, Change 39
22 Nov. 1967

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSIONS</u>
Item 6a	WL	Total LM weight at vector time	1b
	SPS	Total SPS propellant remaining at vector time	1b
	RCS _C	Total CSM RCS propellant remaining at vector time	1b
	APS	Total APS propellant remaining at vector time	1b
	DPS	Total DPS propellant remaining at vector time	1b
	RCS _L	Total LM RCS Propellant remaining at vector time	1b
	J2	Total J2 propellant remaining at vector time	1b
	LO/C	Liftoff time of the spacecraft	HHH:MM:SS.SS
	GRR/C	Guidance reference release time of the spacecraft	HHH:MM:SS.SS
	ZS/C	Time that S/C register was zeroed	HHH:MM:SS.SS
	GRR/S	Guidance reference release time of the S-IVB	HHH:MM:SS.SS
	LO/L	Liftoff time of the LM	HHH:MM:SS.SS
	ZS/L	Time that the LGC register was zeroed	HHH:MM:SS.SS
	ZS/A	Time that the AGS register was zeroed	HHH:MM:SS.SS
Item 4	{ EPHB	The begin time of the ephemeris	HHH:MM:SS.SS
	{ EPHE	The end time of the ephemeris	HHH:MM:SS.SS
Items 4, 7a and 7b	THT	The time that the program will start looking for a vector that will give the desired end conditions	HHH:MM:SS.SS
	Update	To indicate the number of times that the ephemeris was updated	None

Approved: 

NASA/FSB

PHO/PARS

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Exhibit 41 (Cont'd.)

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	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSIONS</u>
Item 6a	X _T Y _T Z _T	Unit thrust vector associated with the requested maneuver	None
E. <u>Updates.</u> There are no automatic updates associated with this display.			
F. <u>Additional Information</u>			
Restrictions and/or limits of design:			
		1. If the eccentricity of the orbit is .00001 or less, the true anomaly will be zeroed.	
		2. All values displayed are assured to be consistent in relation to update numbers.	
Item 7a		3. When possible vectors will be selected out of the ephemeris and integrated for the desired end condition. However, when a request is made for end conditions outside the ephemeris then the maneuver burnout vectors stored at the end of the ephemeris will be selected and integrated for the desired end conditions.	
		4. All orbital elements except h_a and h_p will be Keplerian.	
		5. Apogee will be zeroes if it cannot be computed.	
		6. Perigee will be zeroes if it cannot be computed.	
		7. There will be one MSK to process all required vehicles.	
		8. If the subject vehicle is not docked the weight of the "other" vehicle will be blanked.	
		9. The unit thrust vector will correspond to the burn initiate of some planned or executed maneuver; therefore, it will be driven only when the display is requested for the MVI option. In all other cases it will be blanked.	
		10. The number of vectors (NV) will be blanked if the display was requested by either type of maneuver option.	
		11. Precession/nutation will be considered for ECT or MCT options.	

Approved: *Lg* NASA/FSB PHO/PARS

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Exhibit 41 (Cont'd.)

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Items 7a
and 7b

12. All parameters computed will be calculated directly using the vector displayed. Earth-fixed latitudes, longitudes, and oblate heights are meaningful only when the ECT or MCT options are exercised.
13. For the FT dimension option the position and velocity vectors are displayed in feet and feet per second. Should this item be omitted the dimensions of earth radii and earth radii per hour will be assumed. The format for these vectors will be:

	<u>POSITION VECTOR</u>	<u>VELOCITY VECTOR</u>
Ft., ft/sec.	+XXXXXXXXXX. (ft.)	+XXXXX.XXXXXX (ft/sec)
E.R., E.R./hr	+XX.XXXXXXXXXX (E.R.)	+XX.XXXXXXXXXX (E.R./Hr)

14. For MVI or MVE options, the parameter manually entered will be a numerical code corresponding to some maneuver within the Mission Plan Table. The display will process for the appropriate maneuver whether or not it is reflected in the main ephemeris. For the MVI option, the vector selected will be that associated with main engine ignition. For the MVE option, the vector selected will be the tailoff vector of the appropriate maneuver.

Item 7b

15. Geodetic computations will be time subsatellite positions, as will oblate heights.

Item 7a

16. Fifth-order interpolations will be performed for GMT and GET options which are within the ephemeris and no threshold time is specified.
17. Threshold times are not permitted for MVI or MVE options.
18. Threshold times are optional for GET or GMT options.
19. Threshold times are mandatory for ALT, RAD, and FPA options.
20. Threshold times are not limited to the time frame of the main ephemeris. The first ephemeris vector (or maneuver burnout vector if the threshold time is beyond the end of the main ephemeris) prior to the threshold time will be selected as the "base vector" and all maneuvers subsequent to that vector will be ignored in determining the desired cutoff condition.
21. If the GET or GMT option is requested for a time beyond the end of the main ephemeris and no threshold time is specified, the time of the vector to be displayed will be assumed the threshold time.

Approved: _____ NASA/FSB _____ PHO/PARS

(OT) 3.2.3-6

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Exhibit 41 (Cont'd.)

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22. The time limit for determining any desired end condition will be the same as that imposed on the Encke integrator.
23. Where orbital elements are not defined for the characteristics of the orbit at hand (circular, elliptical, parabolic, hyperbolic, rectilinear) they will be blanked.

Approved: 4/1 NASA/FSB PHO/PARS

(OT) 3.2.3-7

Functional Diagrams

Figure 23 illustrates the interfaces of the programs in the Checkout Monitor Display Element with other elements, units, or subsystems. Data table usage, task structure, and input/output data flow are also included. The symbols used in the diagrams are defined in the Glossary of this document.

Input/Output Specifications

This section contains the U12 MED format, the Checkout Monitor display format, and a list of CRT error indications.

The following error conditions are detected and indicated by an asterisk on the CRT accompanied by the corresponding numerical code.

1. MED input is required.
2. The Mission Plan Table is in an update state.
3. Update numbers are inconsistent across trajectory related tables.
4. Input time is outside of ephemeris range.
5. Input time is during a maneuver.
6. Open
7. Requested maneuver is not in MPT.
8. No ephemeris is available for subject vehicle. (Zero update number in MPT.)
9. Precession/nutation matrix is not available for time of concern.
10. End conditions not achieved within integration time limits.
11. Base vector rejected by analytical ephemeris generator.
12. Base vector rejected by ENKE Integrator.

These error codes have been selected based on the best information available to date. Final error codes will be published at time of subsystem delivery.

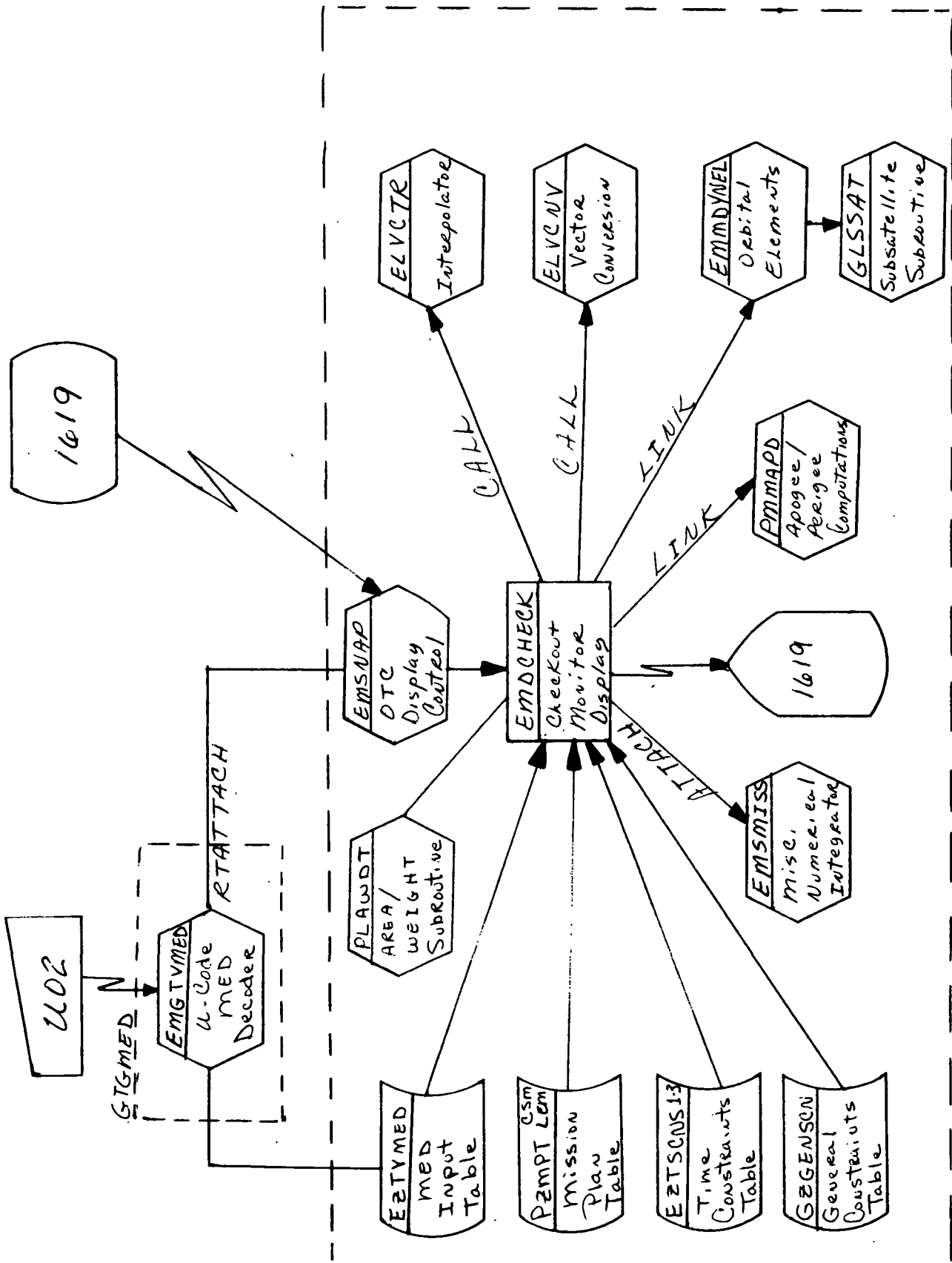


Figure 23. Checkout Monitor Display

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MED Format Table

MED Code: U02
 Purpose: Initiate checkout monitor
 Load Module: EMGTVMED

Task: NA
 EP: NA
 QNAME: NA
 QUEID: NA

Desc.	Item	1	2	3	4	5	6
Item Name	Veh Id	Option Ind	Parameter	Threshold Time	Reference	Feet	
Input Format	Veh	AAA	HHH:MM:SS.SS HHH:MM:NN NNNN	SS.SS	AAA	AA	
Input Units	EBCDIC	EBCDIC	Hours, FXP or FLP	Hours	EBCDIC	EBCDIC	
Program Units	Numeric Code	Ind Code Note 1	Hours, FXP or FLP	Hours	FXP (5)	(8)	
Scale Factor							
Checking Option	Exact (2)	Exact (1)	Special (3)	None	Exact (5)	Exact (7)	
Missing Item Option	Error	Error	Error	Special (4)	Insert (6)	Insert zero	
Item Destination							

Programmer: S. Wright

Initial Logic:

Final Logic:

Illegal Phases:

Notes: (1) IND IND CODE PARAMETER

GMT

GET

MVI

MVE

RAD

ALT

FPA

(2) CSM or LEM

(3) Parameter must be consistent with option ind.

(4) Optional for GET, GMT
 Illegal for MVI, MVE
 Mandatory for RAD, ALT,
 FPA

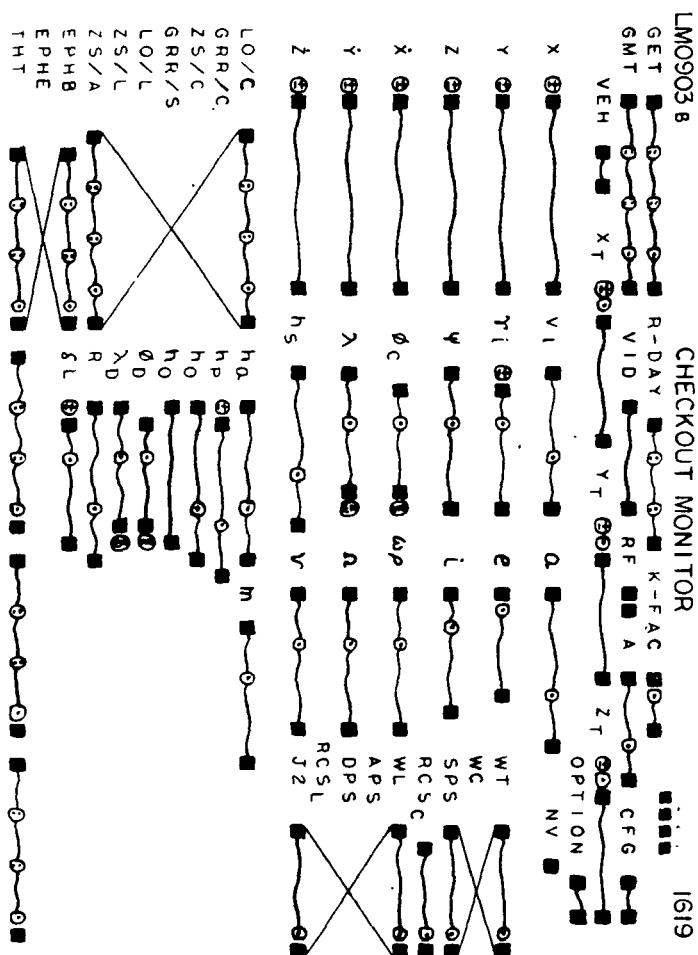
(5) ECI=0, ECT=1, MCI=2,
 MCT=3

(6) Assume ECI (=0)

(7) Ft

(8) Reference indicator set
 negative if ft input.

Exhibit 43



1619

LM0903B

CHECKOUT.
MONITOR :

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ABORT GUIDANCE SYSTEM NAVIGATION UPDATE DISPLAY

Function

The primary function of the Abort Guidance System (AGS) Navigation Update display is to generate and display data for AGS/LM and CSM state vector update in a form suitable for voice uplink and manual insertion into the Abort Guidance System.

Load Module/Routine Description - EMDGAGSN

The principle load module controlling the overall logic and display formatting for this element is EMDGAGSN. In the accomplishment of its objectives, EMDGAGSN requires the services of three other load modules. ELVCTR, the extended interpolation subroutine, is used to obtain inertial vectors from the ephemerides of the LM and CSM. GLMMXD is also queued to express these vectors in terms of some specified platform alignment. The function performed by GLMMXD could also be expressed as:

$$\begin{bmatrix} \text{REFSMMAT} \end{bmatrix} \begin{bmatrix} R_{(ECI, MCI)} \\ V_{(ECI, MCI)} \end{bmatrix} = \begin{bmatrix} R_{(AGS)} \\ V_{(AGS)} \end{bmatrix}$$

Lastly, EMGPRINT is available for printing certain error conditions on line.

Requirements Interpretation

In this section, an attempt has been made to include all known requirements as of the publication date of this document. In addition to the interpretation of these requirements, a copy of the TR170 requirements has been included and annotated for direct reference to appropriate paragraphs in the interpretation section. These references have been provided where clarification or qualification was felt necessary. If any item or capability described in the TR170 document has not been provided, specific mention of this has been made in the margin adjacent to the appropriate paragraph. Parameters computed and/or displayed or capabilities afforded but not included in the NASA requirements have been mentioned in the margin of the TR170 and appropriately indexed to the interpretation. The abbreviation I/O refers to the Input/Output Specifications section.

ITEM

1. Requirements source

The requirements for the processing of the AGS Navigation Update Display are prescribed by the TR170, Section OT, par. 3.2.7, change #56 (see Exhibit 44) and the Philco Format FCN #LM0468. The latter will be discussed in the Input/Output Specifications section.

2. Initialization of display

This display will be initialized by MSK request.

3. Updates

There are no automatic updates associated with this display; however, it will respond to one MED, in which case all parameters are regenerated.

4. Parameters to be computed and/or displayed

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
GEN. NO.	Display regeneration number	
GETGEN	GET of data regeneration	hhh:mm:ss
GMTK	GMT at which AGS clock was zeroed	hhh:mm:ss
AGS MATRIX	LM REFSMMAT Identification Code	
TRAJ. UP.	Trajectory update numbers for both LM and CSM	

The following parameters will apply to both the CSM and LM state vector columns.

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
VID	Identification of last vector used to update subject ephemeris	
GETSV	GET corresponding to vector	hhh:mm:ss
X	X - component of position vector in AGS coordinates	ft.
Y	Y - component of position vector in AGS coordinates	ft.

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
Z	Z - component of position vector in AGS coordinates	ft.
\dot{X}	\dot{X} component of velocity vector in AGS coordinates	ft. /sec.
\dot{Y}	\dot{Y} component of velocity vector in AGS coordinates	ft. /sec.
\dot{Z}	\dot{Z} component of velocity vector in AGS coordinates	ft. /sec.
T	Time tag of vector in AGS clock time	10^{-1} sec.
REF	Central body indicator	

5. General

- a. Only the sign and five most significant digits of the displayed vectors will be voiced up to the LM crew for entry into the AGS. The additional digits displayed are for reference purposes only.
- b. When interpolating for vectors, interpolations must be performed so as not to fix free-flight and thrust vectors.

6. Computation requirements

- a. The following are computation requirements for logical processing limits.
 - (1) Data is not regenerated upon MSK request unless a new MED has been entered since the last MED request was honored by the display.
 - (2) The matrix specified on MED will always refer to the LM REFSMMAT locker.
 - (3) Time on MED will be rounded to the nearest six-second interval - of the equivalent AGS clock time.
 - (4) If the GET on the MED falls outside of the range of either ephemeris, the data for that particular vehicle will be blanked and a meaningful comment displayed in the respective column (s).

- (5) Should the time on the MED correspond to a GMT, which falls within a maneuver, no processing will occur other than an optical indication that such a situation exists.
- (6) The vector components will be displayed as follows according to the requested coordinate system.

<u>ECI</u>		<u>MCI</u>	
X ± XXXXX	XXXdXX	X ± XXXXX	XXdXX
Y ± XXXXX	XXXdXX	Y ± XXXXX	XXdXX
Z ± XXXXX	XXXdXX	Z ± XXXXX	XXdXX
\dot{X} ± XXXXX	dXX	\dot{X} ± XXXXdX	X
\dot{Y} ± XXXXX	dXX	\dot{Y} ± XXXXdX	X
\dot{Z} ± XXXXX	dXX	\dot{Z} ± XXXXdX	X

b. The following are the mathematical requirements for this element.

- (1) Eighth-order interpolation will be used if possible for obtaining vectors from the main ephemeris to be transformed to the AGS coordinate system.
- (2) End-point eighth-order interpolation will be preferred to mid-point interpolation using a lesser order.
- (3) Inertial (ECI, MCI) vectors will be used for rotation via the specified REFSMMAT.

$$\begin{bmatrix} R_{AGS} \\ V_{AGS} \end{bmatrix} = \begin{bmatrix} REFSMMAT \end{bmatrix} \begin{bmatrix} R_{(ECI, MCI)} \\ V_{(ECI, MCI)} \end{bmatrix}$$

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Exhibit 44

PHO-TK17CA
Volume 2, Change 56
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OT 3.2.7 LM AGS Navigation Update

- A. Purpose. To provide the Guidance Officer with data generated for AGS/LM and CSM state vector update in a form suitable for voice uplink and manual insertion into the AGS and to provide associated information.
- B. Data Sources. The following sources will be utilized:
- LM ephemeris
 - CSM ephemeris
 - LM Optics Support Table.
- C. Initialization of Display. This display will be initialized by manual entry only.
- D. Parameters to be Computed and Displayed

<u>QUANTITY</u>	<u>DEFINITION</u>
GEN NO	Display serial number to be incremented each time the display is generated.
GETGEN	GET of data generation.
GMTK	GMT at which AGS clock was zeroed.
AGS MATRIX	Identification code of any REFSMMAT in the LM REFSMMAT locker used to rotate the CSM and LM vectors into AGS coordinates.

Trajectory
update num-
ber also
displayed

The following parameters apply to both the CSM and LM state vector columns.

<u>QUANTITY</u>	<u>DEFINITION</u>
STA ID	Standard vector identification code of ephemeris anchor vector.
GETSV	GET at which vector is valid.

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Exhibit 44 (Cont'd.)

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QUANTITYDEFINITIONX,Y,Z, \dot{X} , \dot{Y} , \dot{Z}

Components of vector in ft and ft/sec in AGS coordinates. Only the sign and five most significant digits will be voiced to the LM crew for entry into the AGS. The additional digits displayed are for reference purposes only.

Central body T
indicator
also driven

Time in tenths of minutes at which vector is valid in AGS clock time. AGC time is equivalent to GMTSV - GMTK.

- E. Updates. The display will be updated only on reinitialization by MED (or MSK request following MED if display is not currently being viewed).

F. Additional Information

Item 6a

1. Manual entry of T Central body indicator and the matrix ID is required to initialize the display. The input time T entered in h:m:s will be rounded to the nearest 6 seconds (tenth minutes) before further processing.
2. The system value for GMTK will be used.
3. The data generated are for voice uplink only.
4. For LLP an indicator on the initialization MED will determine the coordinate system, ECI or MCI, of the displayed data.
5. A variable order interpolation will be used in obtaining vectors from the main ephemerides. If possible eighth order will be used. However, if this results in using powered flight vectors, a lower order will be used. An optical indicator will be displayed any time less than eighth order interpolation has been performed in addition to an on-line comment stating actual order used.
6. If a vector is not available at the requested time, that vehicle's data will be blanked. A comment will be displayed to indicate the error condition.
7. If the requested time is within a maneuver, that vehicle's data will be blanked. A comment will be displayed.
8. If REFSMMAT is omitted from initialization MED, AGS REFSMMAT will be used.
9. Two four digit numbers will be dynamically driven to indicate the trajectory updates of the ephemerides from which the displayed vectors were obtained.

Approved: NASA/FSE PHO/PARS

Functional Diagrams

The AGS Navigation Update Display, Figure 24, shows the interfaces of the programs in this element with other elements, units, or subsystems. Also illustrated are data table usage, task structure, and input/output data flow. The symbols used in the diagrams are defined in the Glossary of this document.

Input/Output Specifications

This section contains copies of the AGS Navigation Update display format (see Exhibit 45) and the U10 MED format, on-line prints and CRT error messages.

This display is capable of causing two on-line prints.

1. CSM VECTOR ORDER OF INTERPOLATION HAS BEEN CHANGED FROM 8 TO {XX}
2. LEM VECTOR ORDER OF INTERPOLATION HAS BEEN CHANGED FROM 8 TO {XX}

Whenever less than nine contiguous free-flight ephemeris vectors exist for a span of time, these prints can be produced by simply requesting the display for that time period.

The following error conditions are displayed on the CRT.

1. U10 MED INPUT REQUIRED
2. AGS MATRIX NOT AVAILABLE
3. CSM VECTOR NOT AVAILABLE
4. LEM VECTOR NOT AVAILABLE
5. CSM INTERPOLATION ORDER WAS CHANGED
6. LEM INTERPOLATION ORDER WAS CHANGED
7. TIME ON MED WITHIN CSM MANEUVER
8. TIME ON MED WITHIN LEM MANEUVER
9. POSITION FORMAT OVERFLOWED

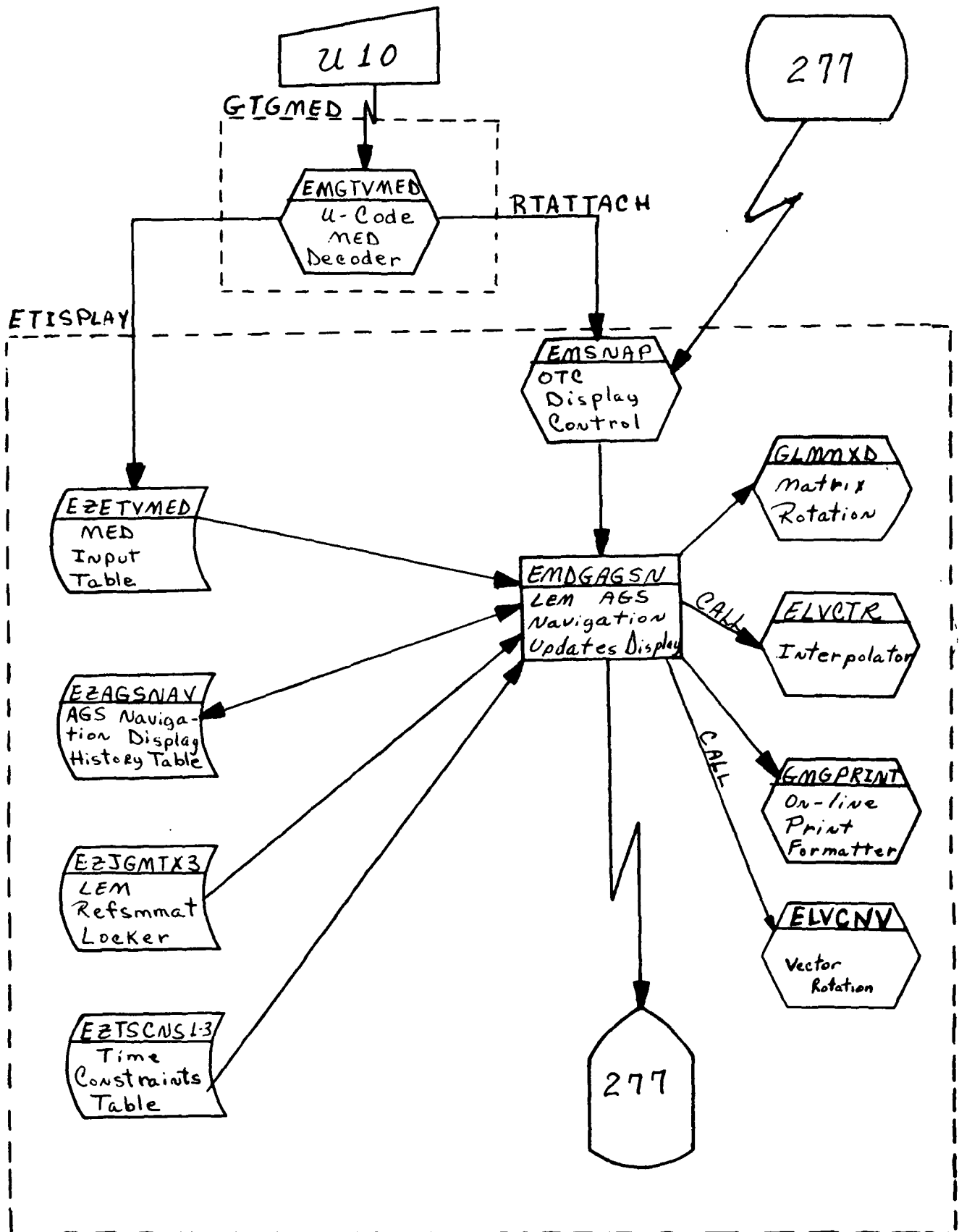


Figure 24. AGS Navigation Update Display



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MED Format Table

MED Code: U10
Purpose: AGS navigation update

Task:
EP:
QNAME:
QUEID:

Load Module: EMGTVMED

Desc.	Item	1	2	3	4	5	6
Item Name		GET	Matrix ID	Central Body			
Input Format		HHH:MM:SS.H	AAA	A			
Input Units		GET	EBCDIC	EBCDIC			
Program Units		hours	FXP	FXP (3)			
Scale Factor							
Checking Option		None	Exact ⁽¹⁾	Exact ⁽³⁾			
Missing Item Option		Error	Insert ⁽²⁾	Assume "E"			
Item Destination							

Programmer:

Initial Logic:

Final Logic: Store in block 1 of EZETVMED

Illegal Phases: All but low speed orbit

Notes: (1) INPUT

CUR

PCR

TLM

OST

MED

(2) Assume 'AGS' (=1)

(3) E for EARTH (=0)

M for MOON (=2)

INPUT

DMT

DOD

LDV

AGS

DOK

PROG UNIT

=6

=7

=8

=9

=10

INPUT

LLD

LLA

PROG UNIT

=11

=12

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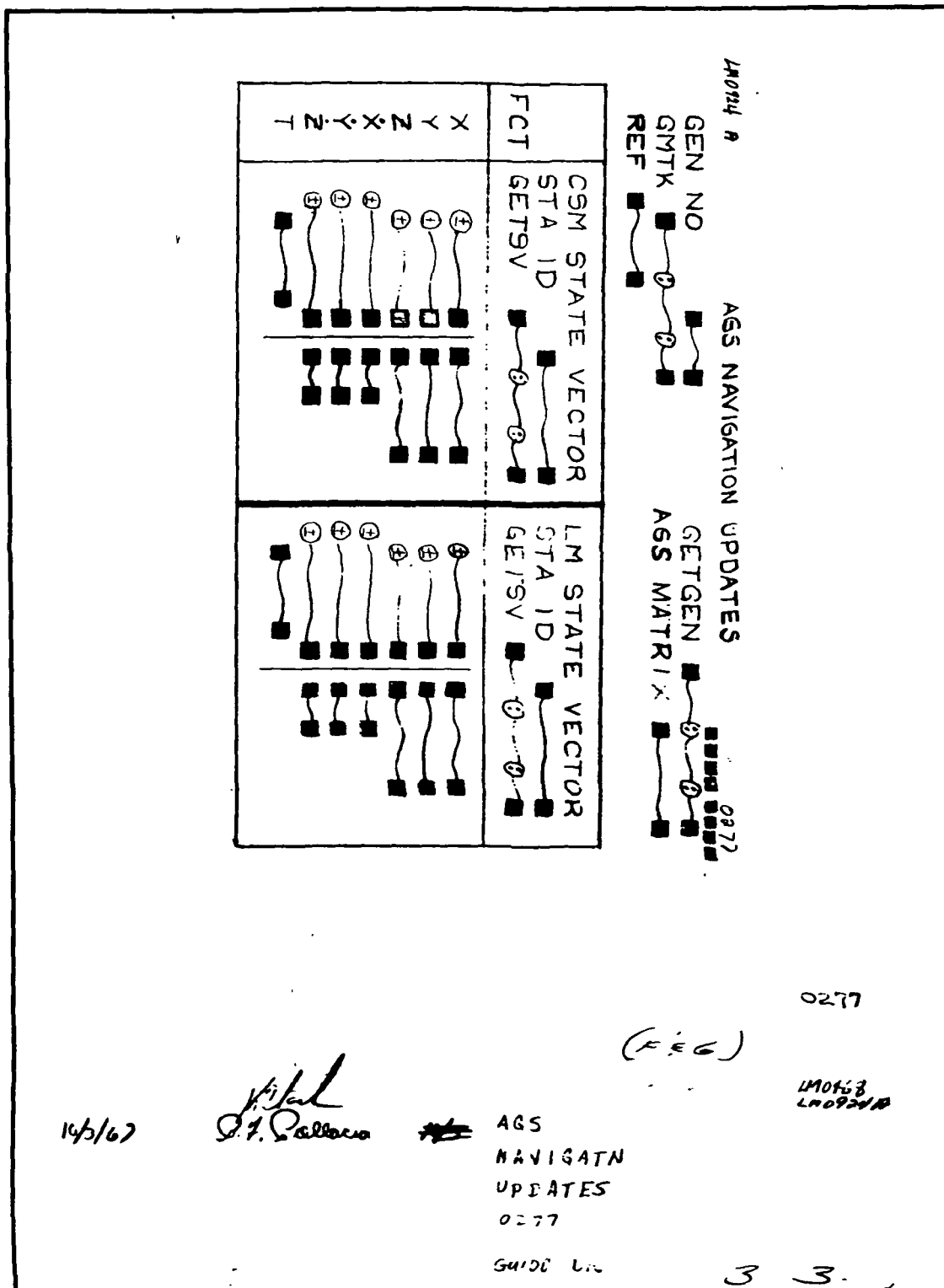
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Exhibit 45



RELATIVE MOTION DIGITALS DISPLAY

Function

The function of this element is to compute and display various parameters describing the relative position and the relative motion of two orbiting vehicles at selected points in time.

Load Module/Routine Descriptions - EMMRMD

The symbolic name of the program that acts as the controlling load module for the Relative Motion Digital Display is EMMRMD. To accomplish its function, the assistance of other load modules is required including ELFECH (ephemeris fetch subroutine), ELVCTR (extended interpolation subroutine), EMGLMRAT (LM gimbal angles and FDAI angles computation routine), and GLMPYR (CSM gimbal angle computation routine). GLMRTV and GLMMXD are required in computing shaft and trunion angles. ELVCNV is called upon to rotate LM body matrices. GLMRTM is used to compute LM body alignment.

Requirements Interpretation

In this section, an attempt has been made to include all known requirements as of the publication date of this document. In addition to the interpretation of these requirements, a copy of the TR170 requirements has been included and annotated for direct reference to appropriate paragraphs in the interpretation section. These references have been provided where clarification or qualification was felt necessary. If any item or capability described in the TR170 document has not been provided, specific mention of this has been made in the margin adjacent to the appropriate paragraph. Parameters computed and/or displayed, or capabilities afforded but not included in the NASA requirements, have been mentioned in the margin of the TR170 and appropriately indexed to the interpretations. The abbreviation I/O refers to the Input/Output Specifications section.

ITEM

1. Requirements sources

The requirements prescribed for the processing of the Relative Motion Digital Display originate from the TR170, Section OT, par. 3.2.9, change 61 (see Exhibit 46) and the Philco Format FCN #LM0517B.

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2. Initialization of display

This display will be initialized by MSK request.

3. Updates

There are no automatic updates associated with this display; however, it will respond to one MED, in which case all parameters are regenerated.

4. Parameters to be computed and displayed

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
CSM STAID	ID of last vector from which CSM ephemeris was generated	
LEM STAID	ID of last vector from which the LM ephemeris was generated	
GMTV	GMT time tag of above vector	hr:min:sec
GETV	GET time tag of above vector	hr:min:sec
MODE	MODE I - Chaser and target trajectories available MODE II - LM on moon, CSM orbiting moon	
VEH	Vehicle designated chaser	
AXIS AT TARGET	Either "X" or "Z" indicating which axis of chaser vehicle is pointed at target vehicle.	
REFSMMAT	Identification code for chaser reference matrix used in computations	
GET	GET corresponding to quantities displayed on given line	hr:min:sec
R	Range from chaser to target	NM
\dot{R}	Range rate from chaser to target	ft. /sec.

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
GET_R	Manually controlled reference time (system parameter)	hr:min:sec
\dot{Y}^*	Velocity component in Y (as defined below) direction	
PET^*	$GET - GET_R$	hr:min:sec
AZ_H	Azimuth of the target vehicle from the chaser vehicle (Limits = 0° to 360°)	deg.
EL_H	Elevation of the target vehicle from the chaser vehicle (Limits 0° to 90° , 270° to 360°)	deg.
X, Y, Z	Relative position of the chaser with respect to the target	NM
ϕ, I, M	Outer, inner, and middle IMU gimbal angles which will exist if the specified axis of the chaser is pointed at the target.	
Y_B, P_B, R_B	FDAI attitude angles which will exist if the specified axis of the chaser is pointed toward the target.	deg.
TUN CSM	Trajectory update number of CSM ephemeris	
TUN LEM	Trajectory update number of LM ephemeris	
SH^{**}	Shaft angle for rendezvous radar pointing angles to the orbiting CSM	deg.
T^{**}	Trunion angle for the rendezvous radar pointing angle to the orbiting CSM	deg.

5. General

Eleven lines of data will be computed commencing at the input GET and incremented by ΔT ten times or until either vehicle ephemeris is terminated. If less than the required number of sets of data (11) can be processed owing to premature termination of either or both ephemerides, all data which can be processed will be displayed.

* Not displayed for Mode II

** Not displayed for Mode I

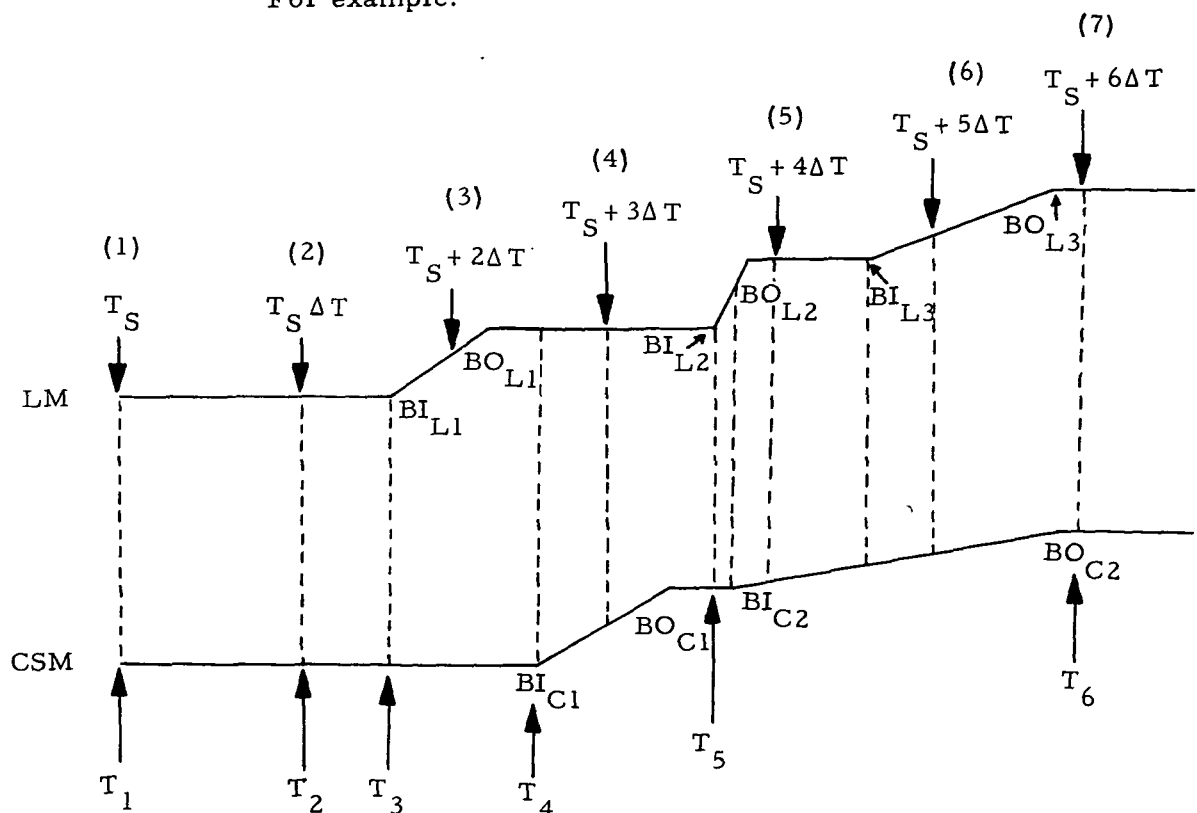
6. Manually driven data

- a. The following special processing requirements have been set for manually entered data.

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- (1) Y_B , P_B , and R_B will be computed only if the LM is the chaser.
If the chaser vehicle is the CSM, P , Y , R will be subscripted I , M , ϕ , respectively, and the FDAI angles will be equal to the gimbal angles. If the LM is the chaser, the subscripts will be I , ϕ , M .
- (2) Should the computations for range or X-coordinate exceed 9999.9 nautical miles, or if the range rate, Z-coordinate, \dot{Y} , or Y coordinate display units exceed 999.9, the excessive parameter will be blanked.
- (3) If the MED input start time or any other normal data display time (as a result of ΔT increments) falls within a maneuver (between maneuver initiation, to include ullage on, and tail-off) for either vehicle, the following special processing is performed.
 - (a) The latest maneuver initiation time for either vehicle (prior to the normal output time), which is maneuver free for the opposite vehicle, is chosen for the displayed data processing time.

For example:



T_S is MED input start time. Points at (1), (2), (3), ... (7) represent times which correspond to "natural" output points. BI and BO signify burn initiation and burnout points with the subscripts designating CSM or LM, and maneuver numbers relative to T_S . $T_1, T_2, T_3 \dots T_6$ indicate points of actual display processing. T_S and $T_S + \Delta T$ are maneuver free for both vehicles and therefore are processed normally. $T_S + 2\Delta T$ falls within a LM maneuver; therefore, the burn initiate time of that maneuver (BI_{L1}) is chosen. Since its time tag corresponds to a free-flight portion of the CSM ephemeris, the point of processing (T_3) has been found. T_4 is determined in a like manner except that this time the "natural" point falls within a CSM maneuver. The fifth natural point ($T_S + 4\Delta T$) is free-flight for the LM but also falls within a CSM maneuver. However, this time the respective CSM burn initiate time (BI_{C2}) corresponds to a LM thrust period. The burn initiate time of this LM maneuver is then chosen. When matched with the CSM, ephemeris is found to be in a free-flight period of that vehicle and, therefore, is chosen as T_5 . $T_S + 5\Delta T$ fall within LM maneuvering. Its burn initiation time falls within CSM maneuvering whose appropriate BI time falls within the period of a different LM maneuver. The BI time of this maneuver is finally free-flight as far as the CSM is concerned and would be chosen as T_6 if it were not that this time is equal to T_5 . Next $T_S + 6\Delta T$ becomes T_6 and so forth.

- (b) The maneuver initiation vector for one vehicle is selected directly, while the time tag of this vector is used to interpolate from the opposite vehicle ephemeris.
- (c) The ΔT for subsequent data processing is always added to the last "would be" (normal) output time.
- (d) If any modified processing time coincides with the previous processing time, it will not be displayed but will be considered as one of the 11 data sets.
- (e) For Mode I, the lunar stay period will be processed as orbital periods assuming a fixed IMU.

(f) For Mode II:

- Both the threshold time and the time associated with P, Y, R on the MED must fall within the lunar stay period.
- The Pitch, Yaw, Roll angles input on MED correspond to the gimbal angles from the specified REFSMMAT to the LM body axis and are valid at the GET specified on the MED.

The gimbal angles displayed for any times other than the input GET must be computed at the subject times assuming no physical realignment of the IMU (powered up), and change in body platform alignment owing only to the motion of the moon.

- The LM is necessarily the chaser.

b. The U03 MED initiates the processing of this Relative Motion Digitals Display Element

U03, chaser veh., target veh., GET_T, ΔT , REFSMMAT, AXIS, Reference Body, MODE, P, Y, R, GET;

ΔT is entered in whole seconds and is limited to a maximum of 30 minutes. If the REFSMMAT is omitted, CUR is assumed. If the chaser vehicle is CSM, "CX" must be input for AXIS. If the chaser vehicle is the LM, either LX or LZ is required. Should the modification of T_g introduce a time prior to current time, no processing will occur. If mode is omitted, Mode I is assumed. Earth and Moon ("E" or "M") are the allowed reference bodies; however, "E" is not permitted for Mode II option.

7. Computation requirements

a. The following computation requirements have been set for logical processing limits.

- (1) Negative PET's will be displayed positive and can be detected by an increasing rather than a decreasing trend.
- (2) The letters L/T, R/L, and A/B are dynamically driven with the position coordinates "X", "Y", and "Z", respectively, to indicate whether the chaser vehicle is leading or trailing, to the right or left of, and above or below the target vehicle.
- (3) Should the display be requested by inputting a GET less than current time, no processing will take place.

- (4) For Mode I, the characters "/PET" will be driven dynamically adjacent to the background letters "GET", and the characters "/Y" will be dynamically driven adjacent to "R" on the background. For Mode II, "/SH" and "/T" will be driven in the same positions respectively.

b. The mathematical requirements for this element are as follows:

- (1) For AZ_H and EL_H computations, a local vertical/local horizontal coordinate system is assumed centered at the chaser vehicle.
- (2) Interpolation will be the means by which vectors are derived from the main ephemerides except as noted in par. 6a.
- (3) If the magnitude of the position vector from the chaser to the target vehicle is less than 1.0×10^{-10} nautical miles, all computations are set to zero for the subject GET.
- (4) Eighth-order interpolations will be performed whenever possible. End-point interpolation will be preferred over mid-point, using a lesser order. Interpolations must be performed so as not to mix free-flight and thrust vectors.
- (5) Mode II of the rendezvous radar operation will be preferred to Mode I for shaft/trunion angle computations.
- (6) The rotational sequence for shaft/trunion angle computations will be that of shaft, trunion.
- (7) ECI vectors will be used for computations if Earth is specified as the desired central body. For moon option MCI vectors are used.

The following diagrams, formulation, and discussion constitute the computational methods utilized in determining range, range rate, azimuth, elevation, and the relative positional components and their associated directional indicators.

The problem can be stated as follows:

Given the position and velocity of a chaser vehicle, $\bar{r}_c = (x_c, y_c, z_c)$ and $\bar{v}_c = (\dot{x}_c, \dot{y}_c, \dot{z}_c)$, the position and velocity of a target vehicle, $\bar{r}_t = (x_t, y_t, z_t)$ and $\bar{v}_t = (\dot{x}_t, \dot{y}_t, \dot{z}_t)$, compute the following quantities:

ρ = the distance between target and chaser vehicles

$\dot{\rho}$ = the time rate of change of this distance (range rate)

X = the great circle distance measured on the surface of a sphere of radius " \bar{r}_t " between the target vehicle and the projection of \bar{r}_c into the orbit plane of the target vehicle

Y = the perpendicular distance between chaser and its projection into the orbit plane of the target vehicle

A = wedge angle between chaser orbit plane and plane formed by vectors \bar{r}_c and \bar{r}_t

E = elevation = the angle that ρ makes with the plane perpendicular to \bar{r}_c

Z = difference in lengths of \bar{r}_t and \bar{r}_c , that is $Z = |r_t - r_c|$.

\dot{Y} = component of velocity along Y above, $\dot{Y} = \bar{V}_c \cdot (\bar{V}_T \text{ X } r_T)$

Great Circle Arc "X" and Distance "Y"

$$r_c = \sqrt{\bar{r}_c \cdot \bar{r}_c}$$

$$r_t = \sqrt{\bar{r}_t \cdot \bar{r}_t}$$

$$\hat{r}_c = \left(\frac{x_c}{r_c}, \frac{y_c}{r_c}, \frac{z_c}{r_c} \right)$$

$$\hat{r}_t = \left(\frac{x_t}{r_t}, \frac{y_t}{r_t}, \frac{z_t}{r_t} \right)$$

$$\hat{h}_c = \frac{\bar{r}_c \times \bar{v}_c}{|\bar{r}_c \times \bar{v}_c|} = (h_{cx}, h_{cy}, h_{cz})$$

$$\hat{h}_t = \frac{\bar{r}_t \times \bar{v}_t}{|\bar{r}_t \times \bar{v}_t|} = (h_{tx}, h_{ty}, h_{tz})$$

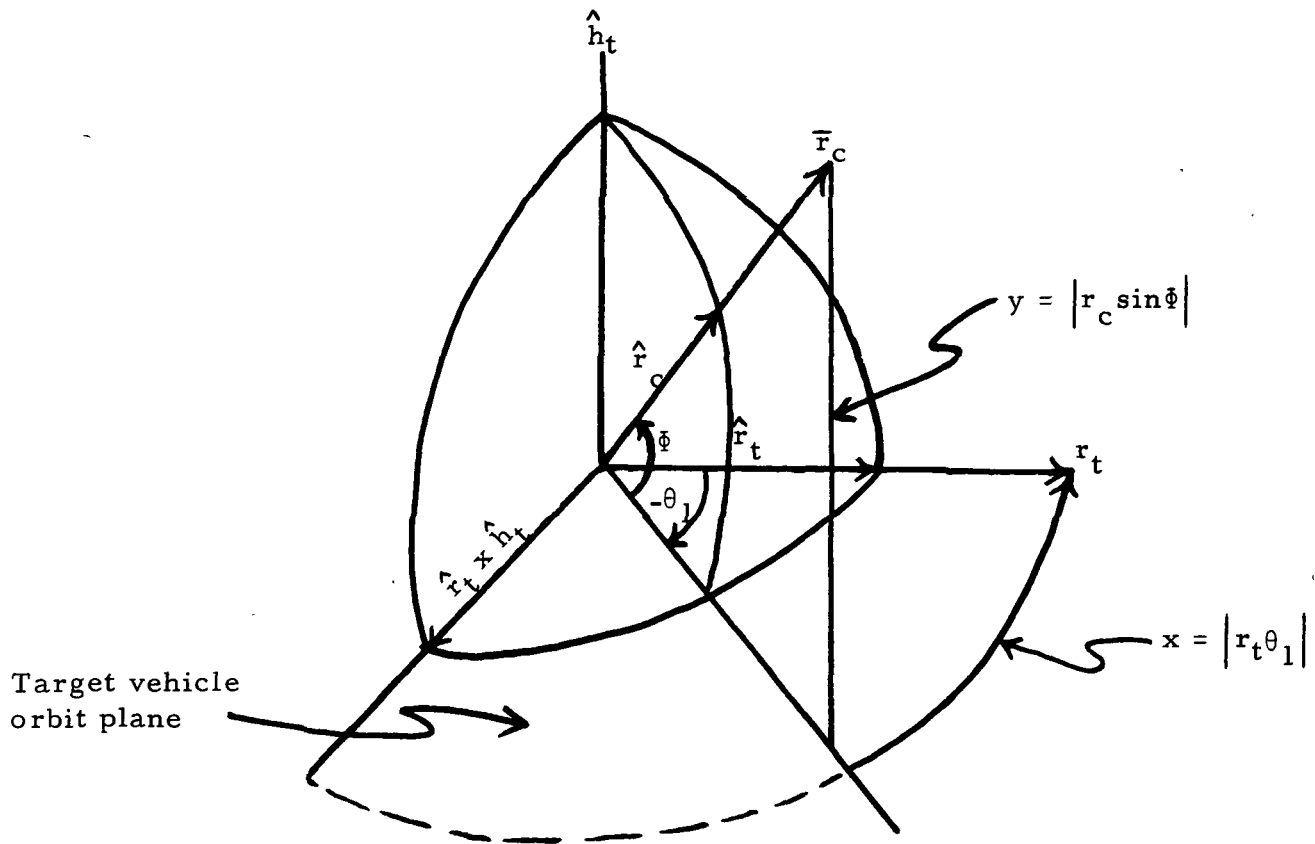


Figure 25.

From Figure 25 we have

$$\hat{r}_c \cdot (\hat{h}_t \times \hat{r}_t) = \cos \phi \sin \theta_1$$

$$\hat{r}_c \cdot \hat{r}_t = \cos \phi \cos \theta_1$$

$$\tan \theta_1 = \frac{(\hat{h}_t \times \hat{r}_t) \cdot \hat{r}_c}{\hat{r}_c \cdot \hat{r}_t} = \frac{\hat{h}_t \cdot (\hat{r}_t \times \hat{r}_c)}{\hat{r}_c \cdot \hat{r}_t}$$

$$(-\pi \leq \theta_1 \leq \pi)$$

$$\sin \phi = \hat{h}_t \cdot \hat{r}_c \quad \left(-\frac{\pi}{2} \leq \phi \leq \frac{\pi}{2}\right)$$

$$x = |r_t \theta_1|$$

$$y = |r_c \sin \phi|$$

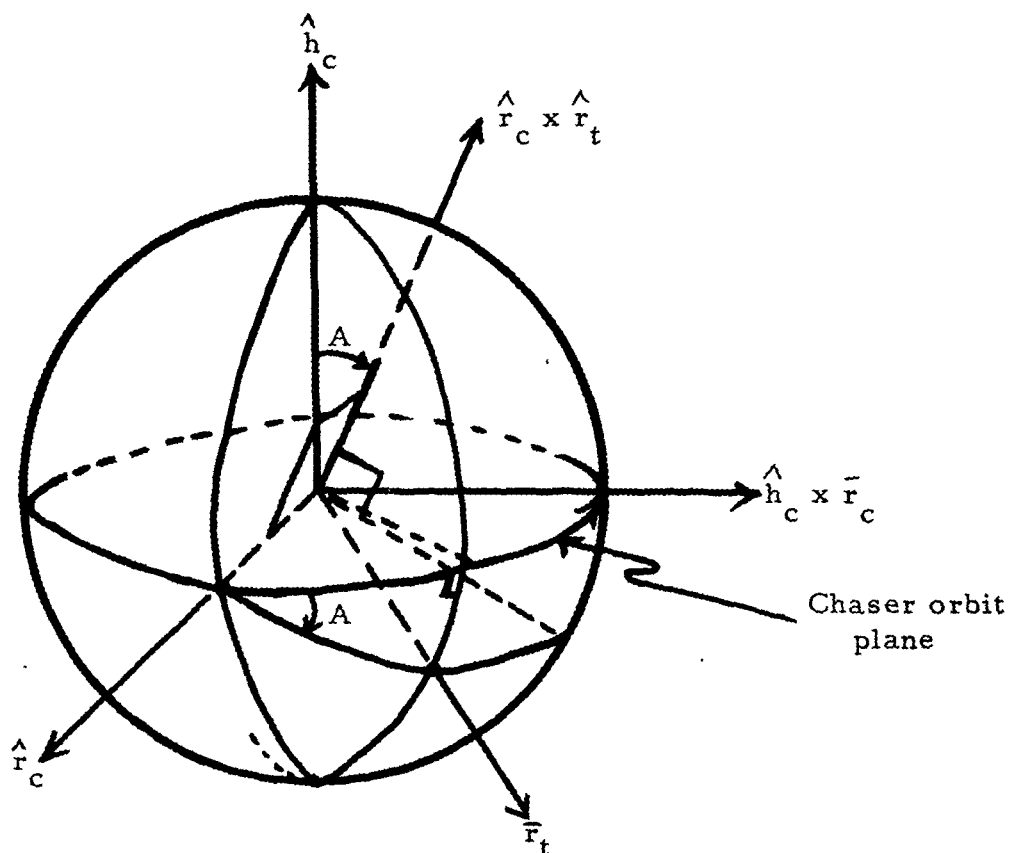


Figure 26. Azimuth Angle "A"

From Figure 26 we have

$$\hat{r}_c \cdot [\hat{h}_c \times (\hat{r}_c \times \hat{r}_t)] = (\hat{r}_c \times \hat{h}_c) \cdot (\hat{r}_c \times \hat{r}_t) = \hat{h}_c \cdot \hat{r}_t = -|\hat{r}_c \times \hat{r}_t| \sin A$$

$$\hat{h}_c \cdot (\hat{r}_c \times \hat{r}_t) = |\hat{r}_c \times \hat{r}_t| \cos A$$

$$\tan A = \frac{-\hat{h}_c \cdot \hat{r}_t}{\hat{h}_c \cdot (\hat{r}_c \times \hat{r}_t)} \quad (0 \leq A \leq 2\pi)$$

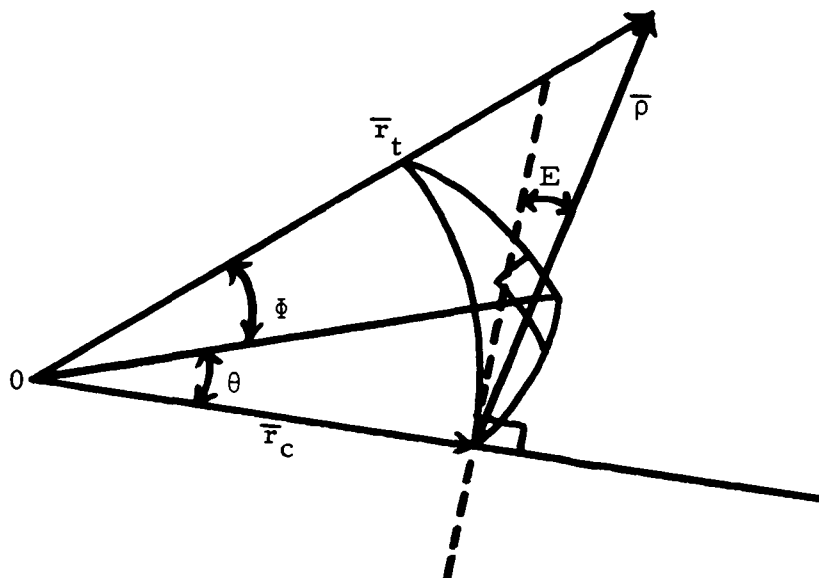


Figure 27. Elevation Angle "E"

From Figure 27 we have

$$\bar{\rho} = \bar{r}_t - \bar{r}_c$$

and

$$\dot{\bar{\rho}} = \dot{\bar{v}}_t - \dot{\bar{v}}_c$$

$$\rho = \sqrt{\bar{\rho} \cdot \bar{\rho}}$$

and

$$\dot{\rho} = \frac{\bar{\rho} \cdot \dot{\bar{\rho}}}{\rho}$$

$$\sin E = \frac{\bar{\rho} \cdot \bar{r}_c}{\rho r_c}$$

$$\left(\begin{array}{l} 0 \leq E \leq \frac{\pi}{2} \\ \text{and} \\ \frac{3}{2}\pi \leq E \leq 2\pi \end{array} \right)$$

Height "Z"

$$Z = |r_t - r_c|$$

Indicators

An appropriate indicator is displayed to indicate whether the chaser is above or below the target.

If $(r_t - r_c) \geq 0$, indicator (A/B) = B. If $(r_t - r_c) < 0$, indicator (A/B) = A.

The second indicator displayed shows whether the chaser is to the left or the right of the target.

If $\sin \phi \geq 0$, indicator (L/R) = L. If $\sin \phi < 0$, indicator (L/R) = R.

The final indicator displayed indicates whether the chaser is leading or trailing the target.

If $\theta \geq 0$, indicator (T/L) = L. If $\theta < 0$, indicator (T/L) = T.

LM Rendezvous Radar

Rendezvous radar data consists of two rotation angles, shaft and trunion. The trunion angle is measured from the X-Z plane positive toward the $-\hat{Y}_b$ axis, and the shaft angle is measured counter-clockwise about the $+\hat{Y}_b$ axis.

Given the shaft and trunion angles for some sighting direction, the line-of-sight vector in the LM body coordinate system is obtained by

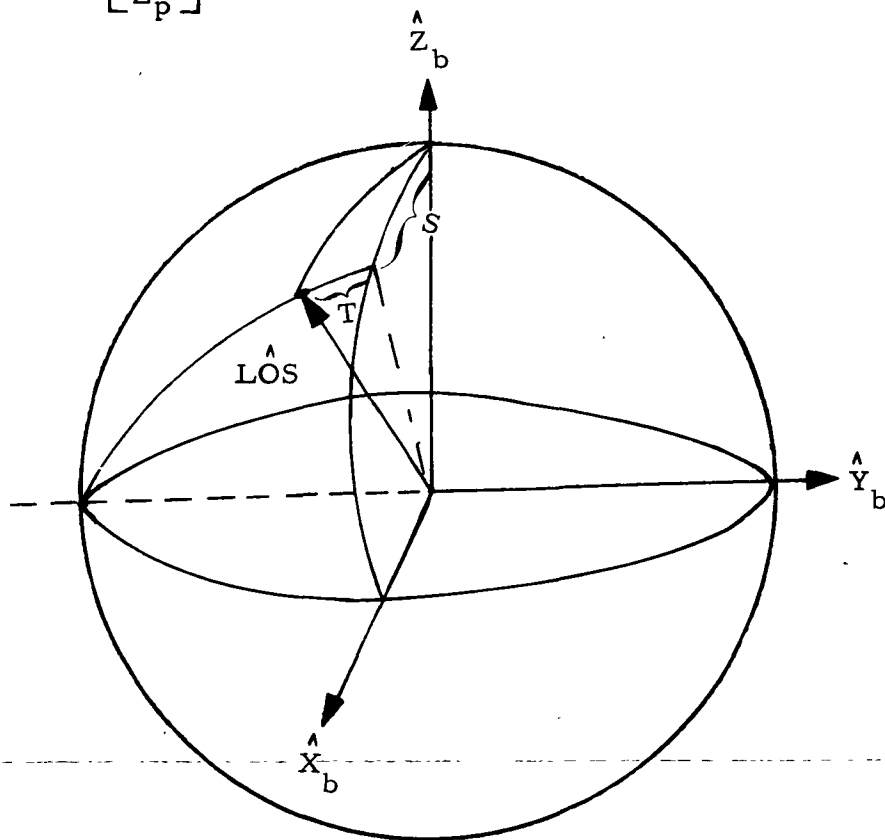
$$\hat{LOS}_b = \begin{pmatrix} \cos T \sin S \\ -\sin T \\ \cos T \cos S \end{pmatrix} \quad \begin{array}{l} T = \text{Trunion angle} \\ S = \text{Shaft angle} \end{array}$$

which can be converted to the platform system by rotating through the gimbal angles using GLMRTV,

$$\hat{L}OS_p = R_y(-P)R_z(-R)R_x(-Y)\hat{L}OS_b$$

and then converted to the inertial reference frame using the REFSMMAT

$$\hat{L}OS_I = \hat{L}OS_p \begin{bmatrix} \hat{X}_p^T \\ \hat{Y}_p^T \\ \hat{Z}_p^T \end{bmatrix}$$



Computing the shaft and trunion angles to point the radar at the CSM,

$$\hat{LOS}_I = \frac{(\vec{r}_{CSM} - \vec{r}_{LM})}{|\vec{r}_{CSM} - \vec{r}_{LM}|} = \hat{\rho}$$

Now

$$\text{Trunion} = \sin^{-1} (-\hat{\rho} \cdot \hat{Y}_b) \quad 3\pi/2 \leq I \leq \pi/2$$

$$\text{Shaft} = \tan^{-1} \left\{ \frac{\hat{\rho} \cdot \hat{X}_b}{\hat{\rho} \cdot \hat{Z}_b} \right\} \quad 0 - 2\pi$$

The radar does not have full coverage however, and operates in two modes. In Mode I the shaft and trunion angles are given directly by the above equations with coverage from $305^\circ \leq T \leq 55^\circ$ and from $290^\circ \leq S \leq 55^\circ$.

In Mode II the shaft and trunion angles are given by

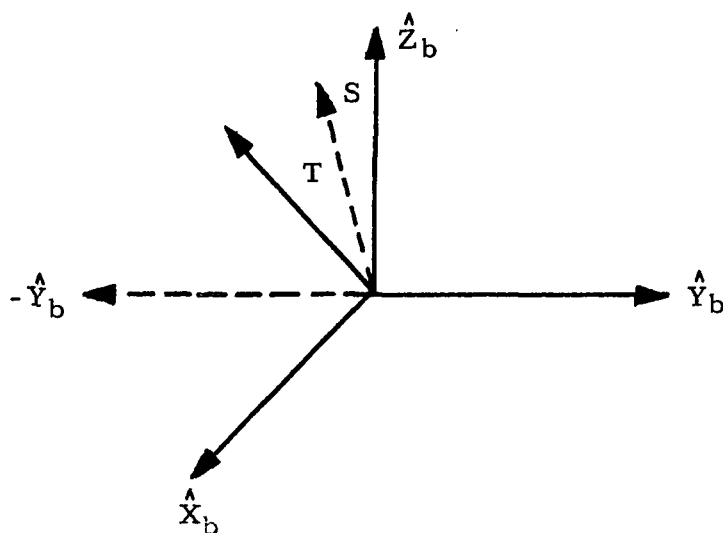
$$\text{Shaft} = \left[\tan^{-1} \left\{ \frac{\hat{\rho} \cdot \hat{X}_b}{\hat{\rho} \cdot \hat{Z}_b} \right\} + 180^\circ \right]$$

$$\text{Trunion} = \left[\sin^{-1} (-\hat{\rho} \cdot \hat{Y}_b) + 180^\circ \right] \pi/2 \leq T \leq 3\pi/2$$

with coverage from $125^\circ \leq T \leq 235^\circ$ and $225^\circ \leq S \leq 335^\circ$.

The LM body axes $(\hat{X}_b, \hat{Y}_b, \hat{Z}_b)$ are obtained from the input REFSMMAT and gimbal angles.

$$\begin{bmatrix} \hat{X}_b^T \\ \hat{Y}_b^T \\ \hat{Z}_b^T \end{bmatrix} = R_x(Y)R_z(R)R_y(P) \begin{bmatrix} \hat{X}_p^T \\ \hat{Y}_p^T \\ \hat{Z}_p^T \end{bmatrix}$$



T - Trunion angle measured out of X-Z plane, positive toward $-\hat{Y}_b$

S - Shaft angle measured about \hat{Y}_b from Y-Z plane counter-clockwise

$$\hat{LOS}_b = \begin{pmatrix} \cos T \sin S \\ -\sin T \\ \cos T \cos S \end{pmatrix}$$

$$\hat{LOS}_p = R_y(-P)R_z(-R)R_x(-Y)\hat{LOS}_b$$

$$\hat{LOS}_I = \hat{LOS}_p \begin{bmatrix} \hat{X}_p^T \\ \hat{Y}_p^T \\ \hat{Z}_p^T \end{bmatrix}$$

P = Pitch (inner gimbal)

Y = Yaw (outer gimbal)

R = Roll (middle gimbal)

IMU Gimbal Angles and FDAI Angle

CSM — The IMU gimbal angles for the CSM are the pitch, yaw and roll angles (in this sequence) measured from the stable-platform-coordinates when the astronaut is in the "heads-up" position and the roll axis, (X-axis) is pointing toward the target vehicle along the line of sight from CSM to target.

$$\hat{X}_B = \left(\frac{\rho_X}{\rho}, \frac{\rho_Y}{\rho}, \frac{\rho_Z}{\rho} \right)$$

$$\hat{Y}_B = \frac{\bar{r}_t \times \bar{r}_c}{|\bar{r}_t \times \bar{r}_c|}$$

$$\hat{Z}_B = \hat{X}_B \times \hat{Y}_B$$



$$\begin{bmatrix} \hat{X}_B^T \\ \hat{Y}_B^T \\ \hat{Z}_B^T \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos R & \sin R \\ 0 & -\sin R & \cos R \end{bmatrix} \begin{bmatrix} \cos Y & \sin Y & 0 \\ -\sin Y & \cos Y & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos P & 0 & -\sin P \\ 0 & 1 & 0 \\ \sin P & 0 & \cos P \end{bmatrix} \begin{bmatrix} \hat{X}_P^T \\ \hat{Y}_P^T \\ \hat{Z}_P^T \end{bmatrix}$$

Performing the matrix multiplication we get

$$\begin{bmatrix} \hat{X}_B^T \\ \hat{Y}_B^T \\ \hat{Z}_B^T \end{bmatrix} = \begin{bmatrix} \cos Y \cos P & \sin Y & -\sin P \cos Y \\ -\sin Y \cos P \cos R + \sin R \sin P & \cos R \cos Y & \cos R \sin Y \sin P + \sin R \cos P \\ \sin Y \cos P \sin R + \cos R \sin P & -\sin R \cos Y & -\sin R \sin Y \sin P + \cos R \cos P \end{bmatrix} \begin{bmatrix} \hat{X}_P^T \\ \hat{Y}_P^T \\ \hat{Z}_P^T \end{bmatrix}$$

Solving for P, Y, R

$$\sin Y = \hat{X}_B \cdot \hat{Y}_P \quad \frac{3\pi}{2} \leq Y \leq 2\pi \text{ or } 0 \leq Y \leq \frac{\pi}{2} .$$

If Y is not within some ϵ of $\frac{3\pi}{2}$ or $\frac{\pi}{2}$,

$$\tan R = \frac{-\hat{Z}_B \cdot \hat{Y}_P}{\hat{Y}_B \cdot \hat{Z}_P} \quad (0 \leq R \leq 2\pi)$$

$$\tan P = \frac{-\hat{X}_B \cdot \hat{Z}_P}{\hat{X}_B \cdot \hat{X}_P} \quad (0 \leq P \leq 2\pi)$$

If Y is within some ϵ of $\frac{3\pi}{2}$ or $\frac{\pi}{2}$, then

$$R = 0$$

$$\tan P = \frac{\hat{Z}_B \cdot \hat{X}_P}{\hat{Z}_B \cdot \hat{Z}_P} \quad (0 \leq P \leq 2\pi)$$

FDAI angles for the CSM are the same as the above IMU gimbal angles.
That is

$$\left. \begin{array}{l} P' = P \\ Y' = Y \\ R' = R \end{array} \right\} \begin{array}{l} \text{where } P', Y', R' \text{ are the} \\ \text{FDAI angles and } P, Y, \text{ and} \\ R \text{ are the IMU gimbal angles} \end{array}$$

LM —

1. Option A — The IMU gimbal angles for this LM option are the pitch, roll and yaw (in this sequence) measured from the stable platform coordinate when the astronaut is in the "heads-up" position with the roll axis (Z-axis) pointing toward the target vehicle along the line of sight from LM to target.

$$\hat{Z}_B = \left(\frac{\rho_X}{\rho}, \frac{\rho_Y}{\rho}, \frac{\rho_Z}{\rho} \right)$$

$$\hat{Y}_B = \frac{\bar{r}_t \times \bar{r}_c}{|\bar{r}_t \times \bar{r}_c|}$$

$$\hat{X}_B = \hat{Y}_B \times \hat{Z}_B$$

2. Option B — The IMU gimbal angles for this LM option are the pitch, roll and yaw (in this sequence) measured from the stable platform coordinates when the astronaut is in the "heads-up" position with the yaw axis (X-axis) pointing toward the target vehicle along the line of sight from LM to target.

$$\hat{X}_B = \left(\frac{\rho_X}{\rho}, \frac{\rho_Y}{\rho}, \frac{\rho_Z}{\rho} \right)$$

$$\hat{Y}_B = \frac{\bar{r}_t \times \bar{r}_c}{|\bar{r}_t \times \bar{r}_c|}$$

$$\hat{Z}_B = \hat{X}_B \times \hat{Y}_B$$

Performing the matrix multiplication in the appropriate order and solving for P, Y and R we get for both options A and B

$$\sin R = \hat{X}_B \cdot \hat{Y}_P \quad \left(\frac{3\pi}{2} \leq R \leq 2\pi \right) \quad \text{or} \quad \left(0 \leq R \leq \frac{\pi}{2} \right)$$

If R is not within some ϵ of $\frac{3\pi}{2}$ or $\frac{\pi}{2}$

$$\tan Y = \frac{-\hat{Z}_B \cdot \hat{Y}_P}{\hat{Y}_B \cdot \hat{Y}_P} \quad (0 \leq Y \leq 2\pi)$$

$$\tan P = \frac{-\hat{X}_B \cdot \hat{Z}_P}{\hat{X}_B \cdot \hat{X}_P} \quad (0 \leq P \leq 2\pi)$$

If R is within some ϵ of $\frac{3\pi}{2}$ or $\frac{\pi}{2}$

$$Y = 0$$

$$\tan P = \frac{\hat{Z}_B \cdot \hat{X}_P}{\hat{Z}_B \cdot \hat{Z}_P} \quad (0 \leq P \leq 2\pi)$$

For the LM the FDAI gimbal arrangement has a different natural sequence from the IMU gimbal arrangement. The FDAI is constructed and driven so a given P', Y', R' may be achieved by first performing a

$$\Delta P' = P' \text{ about the LM } \hat{Y}_B \text{-axis}$$

$$\Delta Y' = -Y' \text{ about the LM } \hat{X}_B \text{-axis}$$

$$\Delta R' = R' \text{ about the LM } \hat{Z}_B \text{-axis}$$

The matrix rotation is

$$M_1 = R_Z(R') R_X(-Y') R_Y(P')$$

$$= \begin{bmatrix} \cos R' \cos P' - \sin R' \sin Y' \sin P' & \sin R' \cos Y' & -\cos R' \sin P' - \sin R' \sin Y' \cos P' \\ -\sin R' \cos P' - \cos R' \sin Y' \sin P' & \cos R' \cos Y' & \sin R' \sin P' - \cos R' \sin Y' \cos P' \\ \cos Y' \sin P' & \sin Y' & \cos Y' \cos P' \end{bmatrix}$$

The same orientation can be had by the IMU gimbal sequence. The matrix is

$$M_2 = R_X(Y) R_Z(R) R_Y(P)$$

where

$$\left. \begin{array}{l} Y = \text{Yaw} \\ R = \text{Roll} \\ P = \text{Pitch} \end{array} \right\} \text{IMU angles}$$

and Y' , R' and P' are the FDAI angles.

$$M_2 = \begin{bmatrix} \cos P \cos R & \sin R & -\cos R \sin P \\ -\sin R \cos P \cos Y + \sin P \sin Y & \cos Y \cos R & \cos P \sin Y + \sin P \cos Y \sin R \\ \cos Y \sin P + \sin Y \cos P \sin R & -\cos R \sin Y & \cos P \cos Y - \sin P \sin Y \sin R \end{bmatrix}$$

Equating elements of M_1 and M_2 and solving for P' , Y' and R' , we get

$$\tan P' = \frac{\sin Y \sin R \cos P + \cos Y \sin P}{-\sin Y \sin R \sin P + \cos Y \cos P} \quad (0 \leq P' \leq 2\pi)$$

$$\sin Y' = -\sin Y \cos R$$

where

$$(0 \leq Y' \leq \frac{\pi}{2} \text{ if } 0 \leq \sin Y \leq 1)$$

and

$$\left(\frac{3\pi}{2} \leq Y' \leq 2\pi \text{ if } -1 \leq \sin Y \leq 0 \right)$$

$$\tan R' = \frac{\tan R}{\cos Y} \quad (0 \leq R' \leq 2\pi)$$

These are the required LM FDAI angles in terms of the IMU gimbal angles.

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OT 3.2.9 Relative Motion Digitals Display

A. Purpose. To provide the flight dynamics staff with a digital representation of the relative positions of two spacecrafts and the pointing angles from one spacecraft to the other.

B. Data Sources. The following data sources will be used.

- CSM and LM ephemerides
- CSM and LM REFSMMAT lockers
- Manual entries.

C. Initialization of Display. The display will be initialized only upon manual entry.

D. Parameters to be Computed and Displayed

<u>QUANTITY</u>	<u>DEFINITION</u>	<u>AVAILABLE IN MODE</u>
CSM STA ID	Standard ID of the CSM anchor vector from which CSM ephemeris was generated	1,2
GMTV, GETV	GMT and GET of CSM anchor vector	1,2
LM STA ID	Standard ID of the LM anchor vector from which LM ephemeris was generated	1,2
GMTV, GETV	GMT and GET of LM anchor vector	1,2
MODE	Requested mode of display. In Mode 1 attitude of chaser required to point a specified axis at the target is displayed. In Mode 2 LM rendezvous radar pointing angles to the CSM will be displayed	1,2
VEH	Identification code of requested chaser vehicle. Only LM can be chaser for Mode 2	1,2
AXIS AT TGT	Axis of chaser vehicle which is pointed at target vehicle. X and Z allowed for LM. Only X allowed for CSM	1

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<u>QUANTITY</u>	<u>DEFINITION</u>	<u>AVAILABLE IN MODE</u>
REFSMAT NO.	Standard 6-character ID of REFSMAT used to define attitudes for chaser vehicle	1,2
GET	Ground elapsed times for displayed pointing and relative motion data	1,2
GET _R	System value for reference time from which phase elapsed time is computed	1,2
PET	Phase elapsed time corresponding to GET's. PET equals GET minus GET _R	1
R	Range from chaser to target in nautical miles	1,2
\dot{R}	Range rate from chaser to target in feet per second	1,2
AZ _H	Azimuth of the target vehicle in a local vertical/horizontal coordinate system centered at the chaser (0 to 360 degrees)	1,2
EL _H	Elevation of the target vehicle in a local vertical/horizontal coordinate system centered at the chaser (270 to 90 degrees)	1,2
X,Y,Z	Relative position of the chaser with respect to the target in nautical miles. Let \bar{r}_c , \bar{v}_c , \bar{r}_t , \bar{v}_t equal position and velocity vectors of chaser and target respectively	1
X	Great circle distance, measured on the surface of a sphere of radius \bar{r}_t , between the target vehicle and the projection of \bar{r}_c into the orbit plane of the target vehicle. Each value of X is followed by either L or T to indicate that the chaser is leading or trailing the target	

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<u>QUANTITY</u>	<u>DEFINITION</u>	<u>AVAILABLE IN MODE</u>
Y	Perpendicular distance between chaser and its projection into the orbit plane of the target vehicle. Each value of Y is followed by either L or R to indicate that the chaser is either to the left or right of the target.	
Z	Difference in magnitude of \bar{r}_t and \bar{r}_c . Each value of Z is followed by either A or B to indicate that the chaser is above or below the target.	
P, Y, R	IMU angles required for chaser to achieve sighting attitude. P, Y, R will be subscripted I, M, O if chaser is CSM. P, Y, R will be subscripted I, O, M if chaser is LM.	1,2
P_B, Y_B, R_B	FDAI attitude angles corresponding to the displayed IMU angles.	1,2
SH, T	Shaft and trunnion angles required to point the LM rendezvous radar at the orbiting CSM. Displayed as positive angles.	2

E. Updates. This display will be updated only upon manual entry.

F. Additional Information.

1. This display is available in two modes.
 - a. In Mode 1 attitude angles are displayed for the chaser vehicle to point a specified body axis at the target vehicle.
 - b. In Mode 2 rendezvous radar angles are displayed for the LM's tracking of the orbiting CSM.

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2. Mode 1 will be available for all nonpowered flight phases.
3. Requested times for Mode 2 must be within the lunar stay period.
4. The manual entry initializing this display will contain the following parameters: 1) mode, 2) chaser vehicle, 3) target vehicle, 4) threshold time, 5) time increment, 6) REFSMMAT, 7) spacecraft axis, 8) IMU Pitch, 9) IMU Yaw, 10) IMU Roll, 11) time gimbal angles valid.
 - a. Parameters 1, 2, 3, 4, 5, 6 and 7 are required for Mode 1.
 - b. Parameters 1, 2, 3, 4, 5, 6, 8, 9, 10, and 11 are required for Mode 2.
 - c. CUR will be assumed if parameter 6 is missing.
 - d. For LM chaser allowable axes (parameter 7) are LX and LZ. For CSM chaser only CX is allowable.
 - e. Time increment will be specified in seconds from 1 to 1800.
5. The trajectory update numbers for the CSM and LM ephemerides corresponding to the time of display generation will be displayed.
6. If possible 11 lines of data will be computed and displayed commencing at the input threshold time and incremented by the specified time increment ten times. If less than 11 lines of data can be computed due to termination of either vehicle's ephemeris or in Mode 2 termination of lunar stay, that data which can be computed will be displayed.
7. Data will be blanked rather than display values with most significant digits truncated.
8. No times which correspond to powered flight for either vehicle will be used for data generation. If the threshold time (TT) or an incremented time (TT + nΔt) corresponds to powered flight for either vehicle, the nearest earlier time which is free-flight for both vehicles will be used unless this time corresponds to a display time already selected. In this case the data will not be duplicated but this one time will count as two (or more as the case might be) of the required 11 display times.
9. Variable order interpolation will be used in obtaining vectors for computation except for display times which correspond to ephemeris vectors in which case the ephemeris vectors will be used.

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10. The first display time must be greater than present time. If an adjusted first time is prior to present time, no processing will occur even though the input threshold time was past present time.
11. If the input threshold time precedes the starting time for one ephemeris, the first display time will be set equal to that ephemeris's starting time.
12. In Mode 1 the characters "/PET" will be driven dynamically beside "GET".
13. For AZ_H and EL_H computations a local vertical/horizontal coordinate system is assumed centered at the chaser vehicle.
14. All outputs will be set to zero for any GET when distance between vehicles is less than 1.0×10^{-10} nautical miles.
15. In Mode 2, the attitude of the LM will be defined at a time by input of IMU gimbal angles, REFSMMAT code and GET. The attitude with respect to the landing site is then determined. The inertial attitude of the LM is determined at each display time by use of the libration matrix. The IMU gimbal angles that would result from LM rotation with the moon will be displayed in addition to the rendezvous radar angles. The system value for position of landing site will be used.
16. Mode II operation of the rendezvous radar (RR) will be preferred over Mode I operation. Zero shaft and trunnion angles of the RR result in a line-of-sight along the LM +Z axis. The rotational sequence from the body to the RR line-of-sight is shaft, trunnion. Limits on RR angles will be established as system parameters. Initial values are as follows:

Mode I operation

$$-70^\circ \leq \text{SHAFT} \leq 55^\circ$$

$$-55^\circ \leq \text{TRUNNION} \leq 55^\circ$$

Mode II operation

$$225^\circ \leq \text{SHAFT} \leq 335^\circ$$

$$125^\circ \leq \text{TRUNNION} \leq 235^\circ$$

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17. The parameters X, Y, Z, AZ_H , EL_H , R and \dot{R} will be computed as follows:

Let: $\bar{r}_c, \bar{v}_c, \bar{h}_c$ = position, velocity, and angular momentum vectors of the chaser vehicle

$\bar{r}_t, \bar{v}_t, \bar{h}_t$ = position, velocity, and angular momentum vectors of the target vehicle

Then:

$$X = | r_t \theta |$$

$$\text{where } \theta = \tan^{-1} \frac{\hat{h}_t \cdot (\hat{r}_t \times \hat{r}_c)}{\hat{r}_c \cdot \hat{r}_t}$$

$$\text{and } -\pi \leq \theta \leq \pi$$

Indicator is L if $\theta \geq 0$

Indicator is T if $\theta < 0$

$$Y = | r_c \sin \phi |$$

$$\text{where } \sin \phi = \hat{h}_t \cdot \hat{r}_c$$

$$\text{and } -\frac{\pi}{2} \leq \phi \leq \frac{\pi}{2}$$

Indicator is L if $\sin \phi \geq 0$

Indicator is R if $\sin \phi < 0$

$$Z = | r_t - r_c |$$

Indicator is B if $(r_t - r_c) \geq 0$

Indicator is A if $(r_t - r_c) < 0$

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$$R = \sqrt{\bar{R} \cdot \bar{R}}$$

$$\text{where } \bar{R} = \bar{r}_t - \bar{r}_c$$

$$\dot{R} = \frac{\bar{R} \cdot \dot{\bar{R}}}{R}$$

$$\text{where } \dot{\bar{R}} = \dot{\bar{r}}_t - \dot{\bar{r}}_c$$

$$AZ_H = \tan^{-1} \frac{-\hat{h}_c \cdot \hat{r}_t}{\hat{h}_c \cdot (\hat{r}_c \times \hat{r}_t)}$$

$$\text{And } 0 \leq AZ_H \leq 2\pi$$

$$EL_H = \sin^{-1} \frac{\bar{R} \cdot \bar{r}_c}{R r_c}$$

$$\text{and } 0 \leq EL_H \leq \frac{\pi}{2}$$

and

$$\frac{3}{2}\pi \leq EL_H \leq 2\pi$$

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Functional Diagrams

The Relative Motion Digitals Display, Figure 28, illustrates the interfaces of the programs in this element with other elements, units, or subsystems. Data table usage, task structure, and input/output data flow is also shown. The key to the symbols used in the diagrams is found in the Glossary of this document.

Input/Output Specifications

The input/output specifications for this element consist of the U03 MED format, Relative Digitals Display format (Exhibit 47) which will be found on succeeding pages, and CRT error messages.

The following error conditions will cause the indicated remark to be displayed.

1. If the input GET is less than the current ground ellapsed (or if no MED has been entered prior to requesting MSK 0060), a message is displayed.

"*MED OUTDATED"

2. If a trajectory update is detected during the processing of data, one of the following two messages is displayed.

"*UPDATE IN PROCESS" or

"*INCONSISTENT TABLES"

3. Should the input time precede the starting time of both ephemerides, the message will be

"*TIME NOT IN EPHEM".

If less than 11 lines of data can be processed, an asterisk will be displayed directly above the GET column.

4. "*TIME NOT WITHIN LUNAR STAY PERIOD" will be displayed if either input time on the MED for Mode II is not within the lunar stay period.

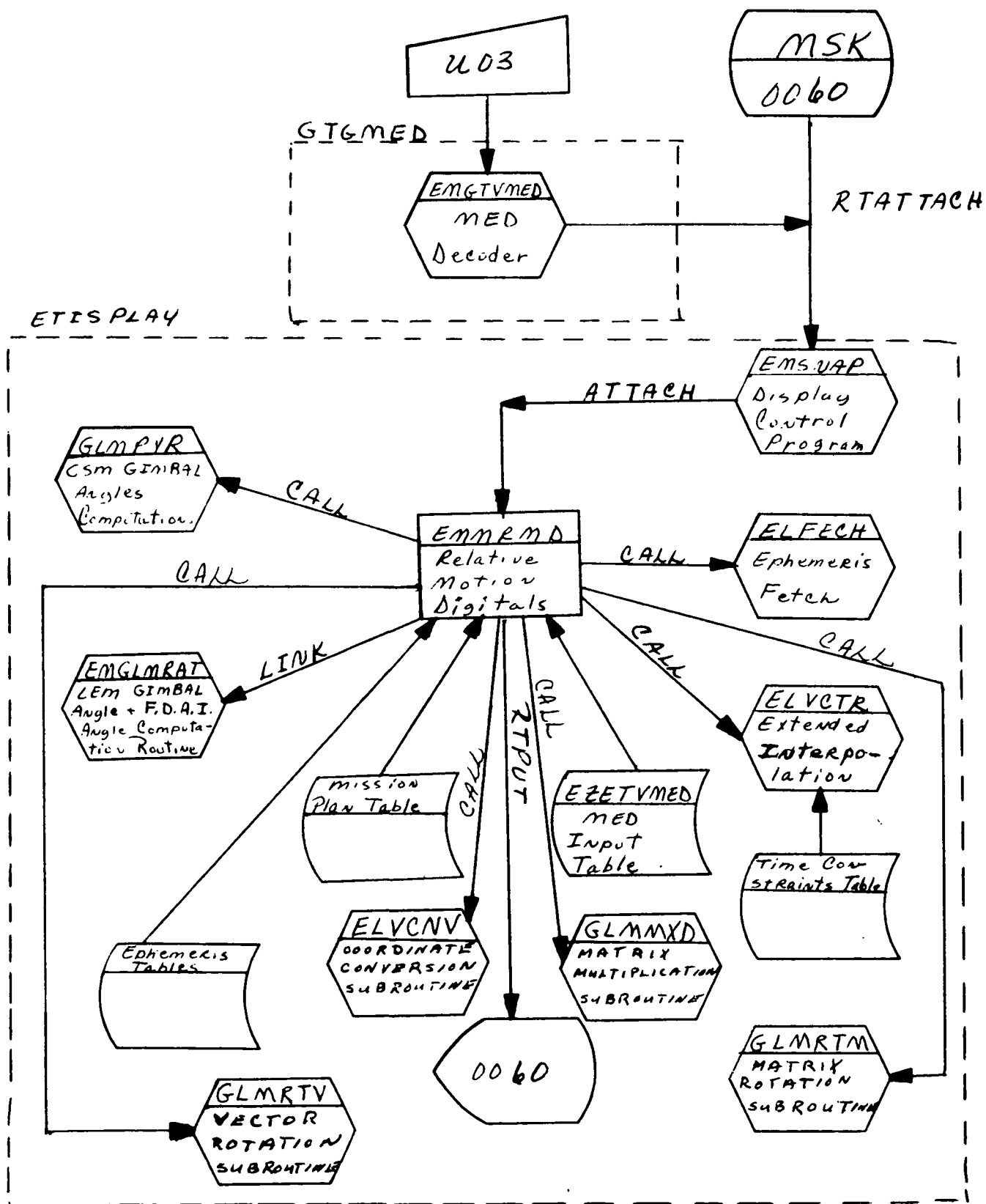


Figure 28. Relative Motion Digital Display



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MED Format Table

Task:
EP:
QNAME:
QUEID:

MED Code: U03
Purpose: Relative motion digitals
Load Module: EMGTVMED

Desc.	Item	1	2	3	4	5	6
Item Name		Chaser VEH ID	Target VEH ID	TIME	Delta Time	Refsmat Code	AXIS
Input Format		VEH	VEH	HHH:MM:SS SS	NN	AAA	AA
Input Units		EBCDIC	EBCDIC	GET	FXP (sec)	EBCDIC	EBCDIC
Program Units		See Note 6	See Note 6	decisec.	centisec.	See Note 2	EBCDIC
Scale Factor					100		
Checking Option		See Note 5 Exact	See Note 5 Exact	None	See Note (1) MINMAX	Special	See Note (4) Special
Missing Item Option		Error	Error	Error	Error	See Note 3	Error
Item Destination							

Programmer:

Initial Logic:

Final Logic: Store in block 3 of EZETVMED

Illegal Phases: All but low-speed orbit

Notes: (1) $100 \leq \Delta t \leq 180000$

(2) CUR = 1 DMT = 6

PCR = 2 DOD = 7

TLM = 3 DOK = 10

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MED = 5 AGS = 9

(3) Assume CUR (=1)

(4) If chaser VEH is CSM, item 6 must be CX
otherwise, LX or LZ must be input.

(5) CSM or LEM

(6) EBCDIC name and numeric code

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MED Format Table

Task: NA
EP: NA
QNAME: NA
QUEID: NA

MED Code: U03 (Cont'd)
Purpose: Relative Motion Digitals

Load Module: EMGTVMED

Desc.	Item	7	8	9	10	11	12
Item Name	Ref Body	Mode		Pitch	Yaw	Roll	P, Y, R GET
Input Format	A	N		nnn.nn	nnn.nn	nnn.nn	hhh:mm: ss.ss
Input Units	EBCDIC	FXP		deg.	deg.	degs.	hours
Program Units	FXP	FXP		radians	radians	radians	radians
Scale Factor				radians per degree	radians per degree	radians per degree	
Checking Option	Exact (7)	Note 8		0 - 2π	0 - 2π	0 - 2π	None
Missing Item Option	Error	Assume "1"		Note 9	Note 9	Note 9	Note 9
Item Destination							

Programmer:

Initial Logic:

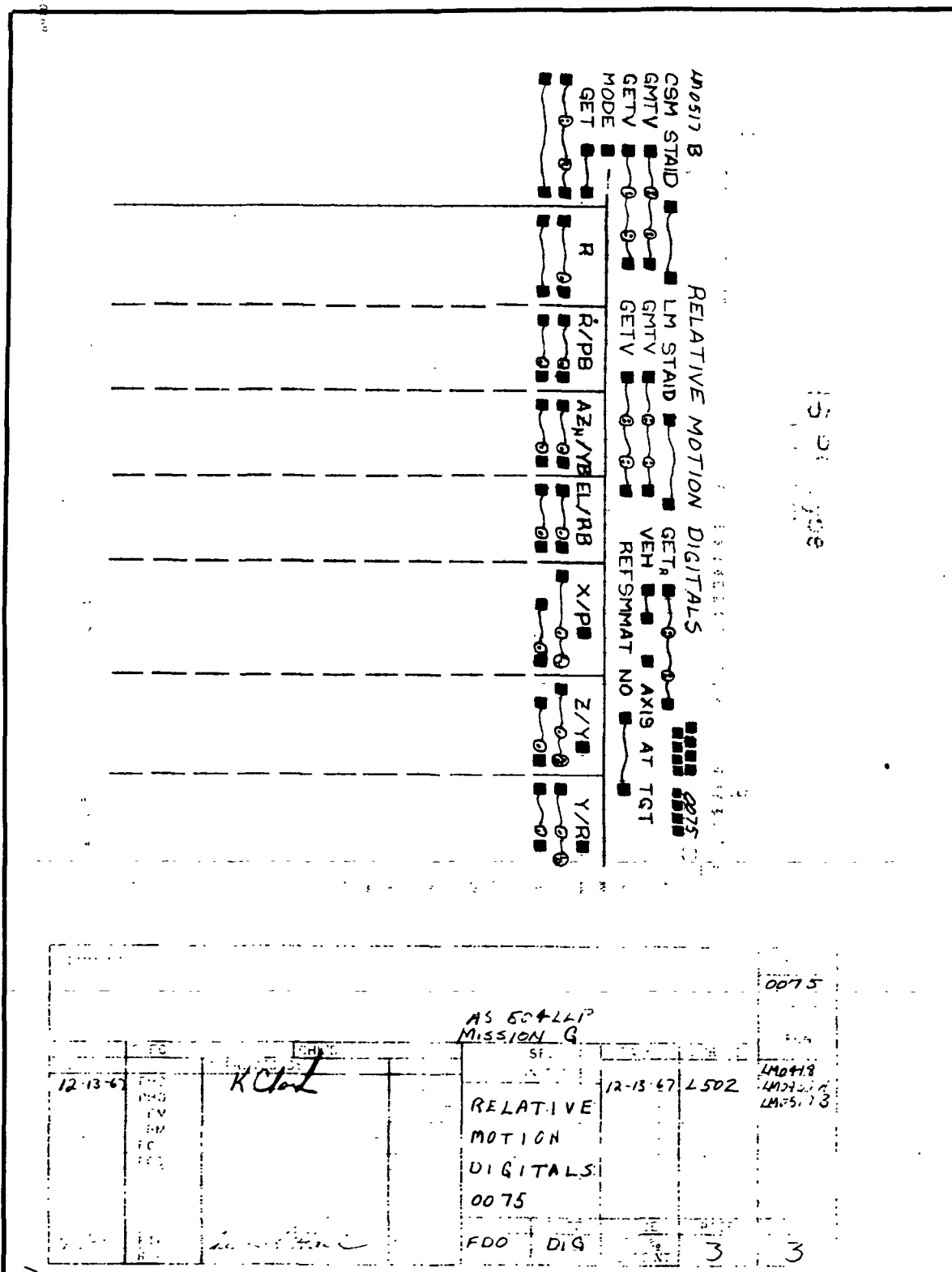
Final Logic:

Illegal Phases:

- Notes: 7. E (=0) for Earth
M (=2) for Moon
8. 1 or 2. 2 is valid only if LM is chaser and ref body is moon.
9. Items 9, 10, 11, 12 are mandatory if mode = 2, illegal is mode = 1.

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Exhibit 47



SUNRISE/SUNSET DISPLAY ELEMENT

Function

The function of this display is to provide data relative to day/night transitions that will enable astronauts to conduct experiments and will aid flight controllers in making decisions regarding recovery area selection.

Load Module/Routine Description - EMDSSMD

The principle module of this logical element is EMDSSMMD, which is comprised of three major sections. The first section, ECDSSMMD, acts as the controlling unit. The other two sections, EMMENV and ECMPAY, are mathematical units, which compute, respectively, spacecraft and subcapsule environment changes and the pitch/yaw angles for the spacecraft to rotate in order to "point" at the sun at its environment change times. Other utility programs used are as follows:

(1) ELFECH, ephemeris fetch subroutine; (2) ELVCTR, extended interpolation subroutine; (3) ELVCNV, coordinate conversion subroutine; (4) EMGPRINT, on-line print routine; and RMMASCND, ascending node computation routine. Another service program, PLEFEM, is also introduced to interpolate in the sun ephemeris table.

Requirements Interpretation

In this section, an attempt has been made to include all known requirements as of the publication date of this document. In addition to the interpretation of these requirements, a copy of the TR170 requirements has been included and annotated for direct reference to appropriate paragraphs in the interpretation section. These references have been provided where clarification or qualification was felt necessary. If any item or capability described in the TR170 document has not been provided, specific mention of this has been made in the margin adjacent to the appropriate paragraph. Parameters computed and/or displayed, or capabilities afforded but not included in the NASA requirements, have been mentioned in the margin of the TR170 and appropriately indexed to the interpretation. The abbreviation I/O refers to the Input/Output Specifications section.

ITEM

1. Requirements source

The requirements for the processing of the Sunrise/Sunset Display Element are prescribed by two sources: TR170, Section OT, par. 3.2.5, change 58 (Exhibit 48) and the Philco Format FCN #LM0651. The latter will be discussed further in the Input/Outputs sections.

2. Initialization of display

This display will be initialized by MSK request

3. Updates

There are no automatic updates associated with this display, however, it will respond to one MED, in which case all parameters are regenerated.

4. Parameters to be computed and/or displayed

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
REV. NO.	Revolution number corresponding to the earliest time displayed on each line	
GETTR	GET subcapsule enters daylight	hr:min:sec
GETSR	GET spacecraft enters daylight	hr:min:sec
θ	Spacecraft pitch angle at sunrise	deg.
Ψ	Spacecraft yaw angle at sunrise	deg.
GETTS	GET subcapsule enters darkness	hr:min:sec
GETSS	GET spacecraft enters darkness	hr:min:sec
θ	Spacecraft pitch angle at sunset	deg.
Ψ	Spacecraft yaw angle at sunset	deg.
REF DAY	Lift-off day of first vehicle	month/day/year
CEL. REF. DAY	Day celestial ephemeris begins	

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
BESSELIAN YEAR	Year to which celestial ephemeris is referenced	year
I	Orbital inclination angle	deg.
Ω_I	Inertial right ascension	deg.
T. UP.	Trajectory update number of CSM ephemeris	

5. General

- a. A total of eight sets of environment change times and corresponding pitch/yaw angles will be displayed if possible.
- b. The occulting body will be the central body associated with the sphere of influence into which the processing threshold time falls.

6. Manually driver data

This display responds to a manually entered time or revolution number.

- a. For the revolution option, the later of respective Earth or moon revolution crossing time and the time of MED entry (or MSK request) will be the processing start time.
- b. For the time option, the same logic applies; however, this option is valid for time periods where revolution numbers are not defined.

7. Computation requirements

- a. The following computation requirements have been set for logical processing limits.
 - (1) Processing will terminate when the program senses a reference switch. All data processed to that point will be displayed.
 - (2) The revolution numbers will be associated with the earliest environment change time displayed for a line.
 - (3) The display will be limited to the time frame of the main ephemeris.



- (4) Should no future Ω_I exist, XXXXXXXX will be displayed.
- (5) Should the vehicle travel in sunlight for an entire orbit, the spacecraft environment change times and corresponding pitch/yaw angles will be displayed as zero.
- (6) Should the program be unable to converge on an environment change time, the last estimate will be displayed and flagged with an asterisk. Processing will continue.

b. The mathematical requirements are as follows:

- (1) Interpolations will be performed so as not to mix free-flight and thrust vectors. When interpolation within a maneuver must be performed, vectors from different maneuver phases should not be mixed.
- (2) Environment change times must be accurate to within three seconds.
- (3) The inertial right ascension will be accurate to within two seconds.
- (4) The assumed pre-maneuver orientation of the spacecraft for pitch/yaw computation is heads-down, local-vertical
- (5) The maneuver sequence for pitch/yaw computation is yaw=pitch with the desired terminal alignment of the spacecraft X-body axis pointed toward the sun

$$\text{Pitch} = \sin^{-1} (-X_b \cdot Z_L)$$

- (6) The formulation for environment changes will be based on an iteration technique assuming two-body motion about the same central body deemed the occulter.

$$\text{Yaw} = \tan^{-1} \left(\frac{\hat{X}_b \hat{Y}_L}{\hat{X}_b \hat{X}_L} \right)$$

where the subscript "b" refers to body axes, and the subscript "L" refers to spacecraft local vertical/local horizontal axes.

- (7) For computation of day/night arrival times considering the Earth as the occulter, a geodetic Earth model will be considered (Fisher Ellipsoid). The actual formula introduced is

$$R_e = \sqrt{\frac{X^2 + Y^2 + Z^2}{X^2 + Y^2 + Z^2/b}}$$

where R_e is the computed Earth radius for any vehicle position vector whose components are X, Y, and Z respectively. The semiminor axis of the Earth, b is a system parameter.

Should the moon be the occulter, the radius value used will be that of the lunar landing site.

- (8) Secondary occultations will not be considered.
- (9) The displayable limits for the inclination angle are $0^\circ \leq i < 180^\circ$.

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Exhibit 48

PHO-TR170A
Volume 2, Change 58
19 April 1968OT 3.2.5 Sunrise/Sunset Times

- A. Purpose. To display sunrise/sunset alphanumeric acquisition data for the astronaut.
- B. Data Source. Current ephemeris, and JPL's sun/moon ephemeris.
- C. Initialization of Display. This display is initialized by manual entry of a revolution number or GET.
- D. Parameters To Be Computed and Displayed. The following quantities will be computed and displayed.

<u>QUANTITY</u>	<u>DEFINITION</u>
REV NO.	Revolution number
GETTR	GET (hr:min:sec) of terminator rise from liftoff (subcapsule entry into daylight)
GETSR	GET (hr:min:sec) of sunrise from liftoff (spacecraft entry into daylight)
θ	Pitch (deg) at sunrise
ψ	Yaw (deg) at sunrise
GETTS	GET (hr:min:sec) of terminator set from liftoff (subcapsule entry into darkness)
GETSS	GET (hr:min:sec) of sunset from liftoff (spacecraft entry into darkness)
θ	Pitch (deg) at sunset
ψ	Yaw (deg) at sunset
Trajectory Update Number	Update number associated with CSM ephemeris.
i	Orbital inclination number (deg)
Ω	Inertial right ascension (deg)

- E. Updates. There are no automatic updates associated with this display.

Approved:

NASA/FSB

PHO/PARS

Exhibit 48 (Cont'd.)

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F. Additional Information1. General

- a. The first 16 environment changes of the spacecraft and its subcapsule position following the revolution number or GET will be computed and displayed.
- b. An appropriate message will appear on the format if all information is not available. i.e., "End of Available Data."
- c. Reference day and Besselian year parameters, and their associated descriptive terms, will be dynamically driven at the bottom of the CRT.
- d. The time associated with the first celestial vector available will also be displayed in the lower portion of the CRT.
- e. Should the vehicle travel in sunlight for an entire orbit, the spacecraft environment change times and associated pitch and yaw will be displayed as zero.
- f. The revolution numbers will be associated with the earliest environment change time displayed for a line.
- g. Secondary occultations will not be considered.
- h. The environment changes will be generated assuming the occulting body to be the occulting body at vector time. If a sphere of influence change occurs during the generation, those environment changes that can be computed relative to the original occulting body will be displayed and computations will be terminated for that generation.
- i. This display will be limited to the time frame of the main ephemeris.
- j. Should the requested time be prior to current time or become current time, current time will be used.
- k. Should no future Ω exist, XXXXXXXX will be displayed. When convergence cannot be accomplished, the last guess will be displayed and will be accompanied by an on-line print stating the deviation.
- l. If cannot compute an environment change time the best estimate will be displayed with an adjacent asterisk and processing will continue.

Approved: 70 NASA/FSB PHO/PARS

Exhibit 48 (Cont'd.)

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2. Mathematical Implications

- a. The assumed orientation is heads down premaneuver. (Local-Vertical)
- b. The S/C X-body axis is pointed at the target.
- c. The maneuver sequence is yaw, pitch.

3. Restrictions and/or Limits of Design

- a. This display should not be requested prior to input of MED P80 containing reference day information.

Approved: NASA/FSB PHO/PARS

(OT) 3.2.5-3

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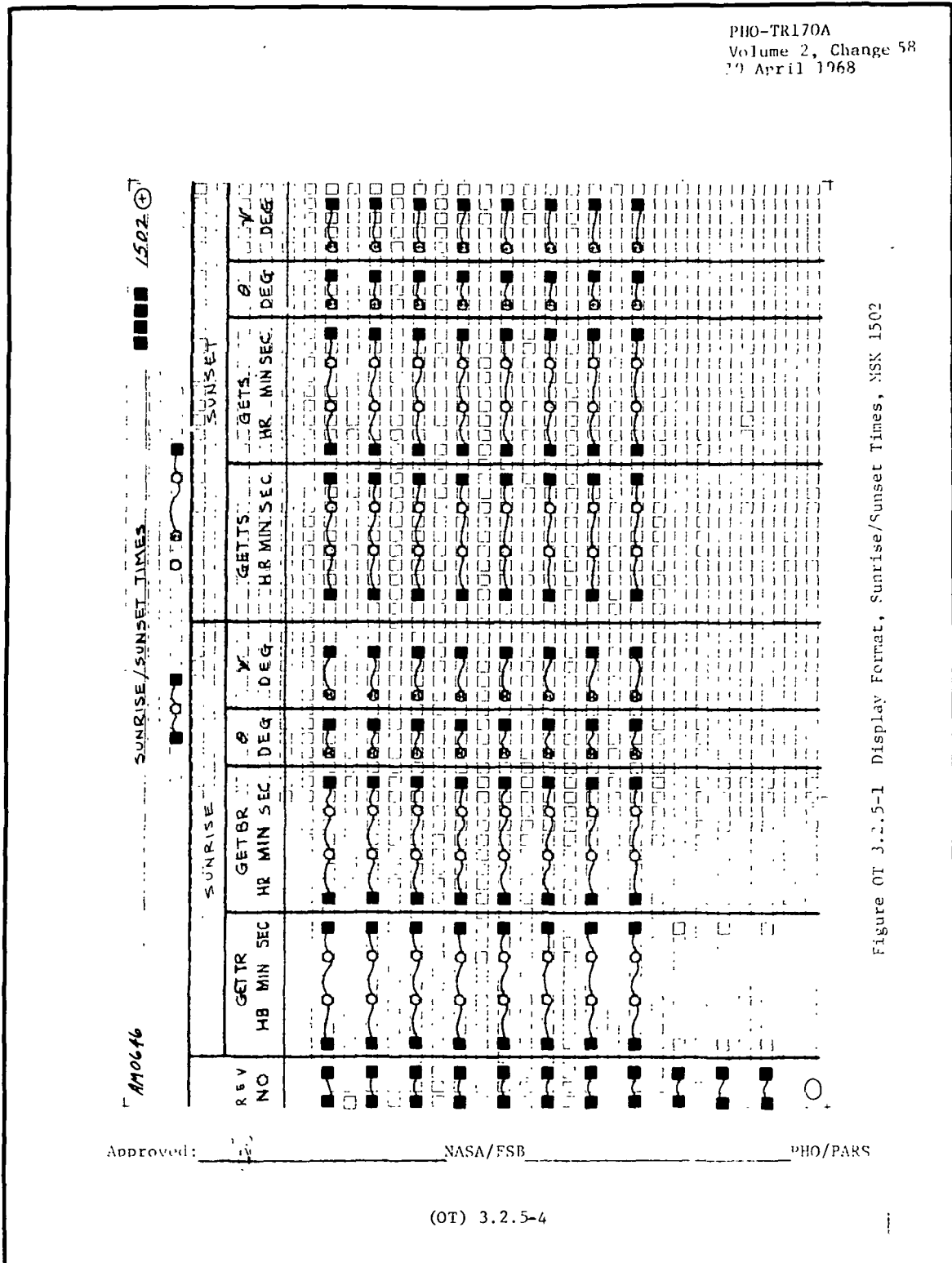
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Exhibit 49



Functional Diagrams

The Sunrise/Sunset Display, Figure 29 illustrates the interfaces of the programs in this element with other elements, units, or subsystems. Data table usage, task structure, and input/output data flow is also shown. The key to the symbols used in the diagrams may be found in the Glossary of this document.

Input/Output Specifications

The input/output specifications for the Sunrise/Sunset Display Element are shown in the display format (Exhibit 50) on-line prints, MED format, and the CRT error messages.

The following comment will be printed on line should the ascending node routine fail to converge on the inertial right ascension.

RMASCND CONVERGENCE LIMIT = (VALUE)

where "value" represents how close the displayed value is (in seconds of time) to the actual ascending node.

The following error conditions are displayed on the CRT.

1. "DATA NOT AVAILABLE"
(No CSM ephemeris or no celestial ephemeris)
2. "TABLE BEING UPDATED"
(Trajectory update in process)
3. "INCONSISTENT TABLES"
(Trajectory related tables have differing trajectory update numbers)
4. Should the ephemeris end prior to 16 future environment changes at the time the display is requested, all data that can be computed will be displayed followed by the comment "END OF AVAILABLE DATA".
5. "MED OUTDATED"
(No MED has been input, or the request is for a processing start time outside of the current CSM ephemeris)

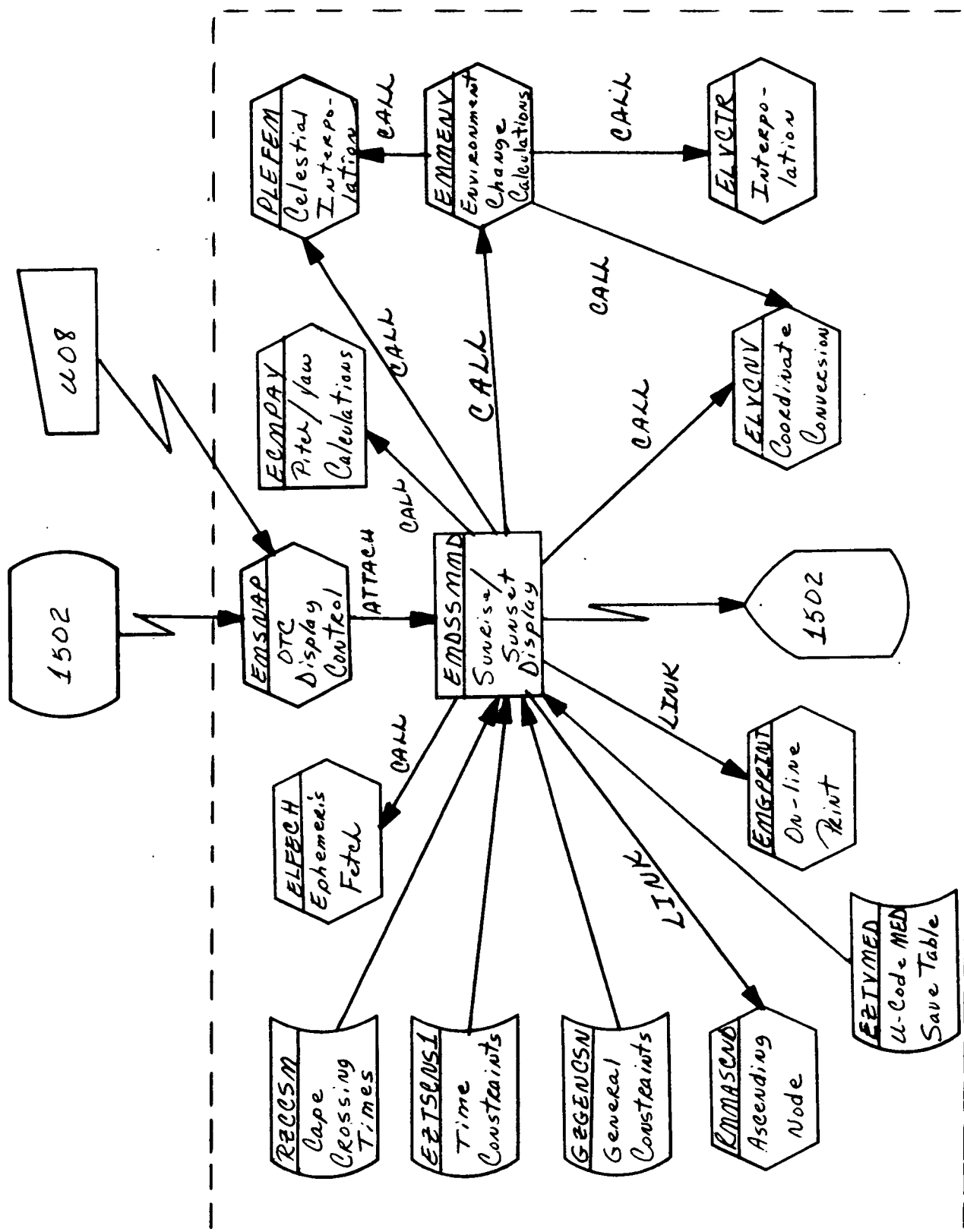
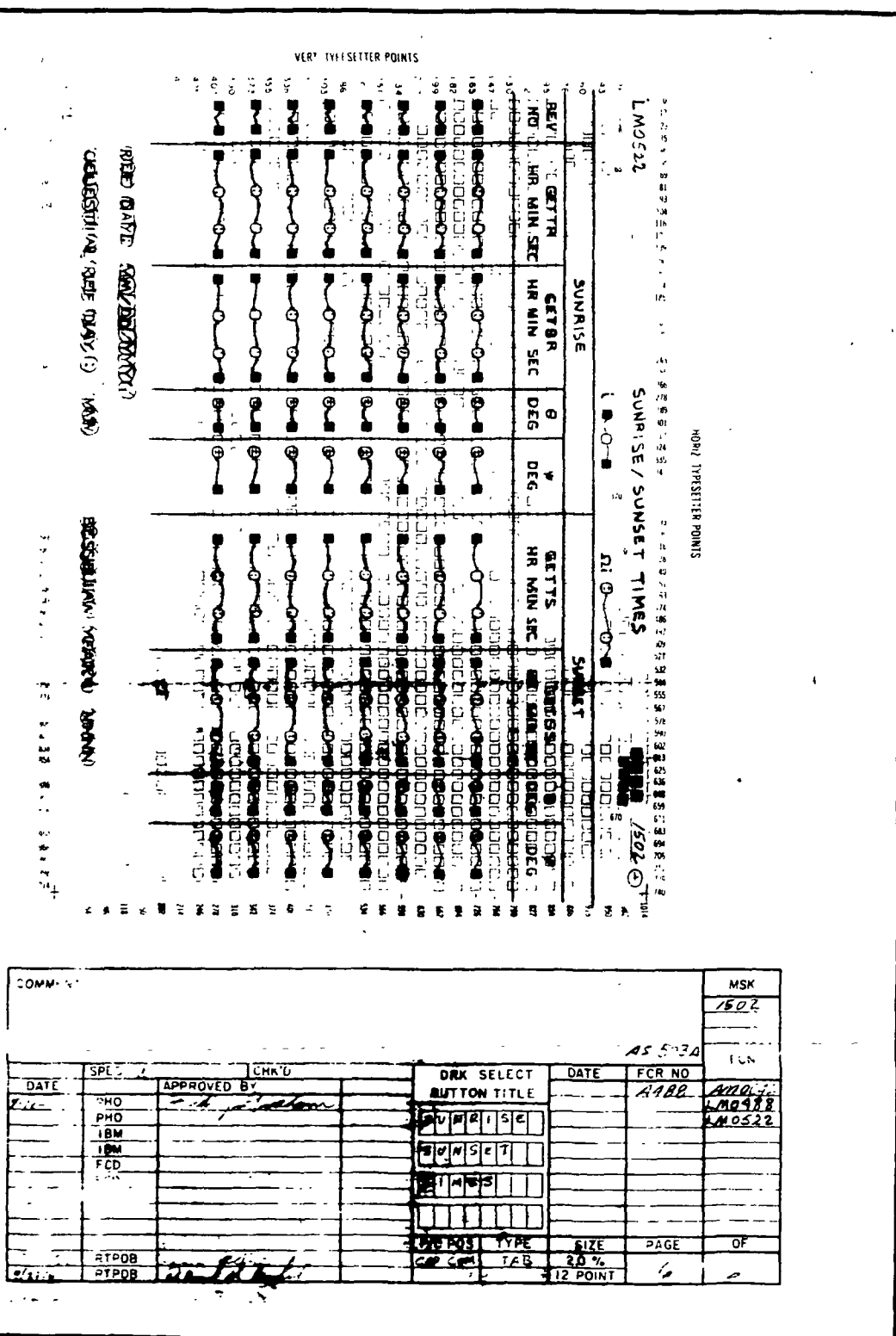


Figure 29. Sunrise/Sunset Display

Exhibit 50





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MED Format Table

MED Code: U08 Task:
 Purpose: Sunrise/Sunset Display EP:
 Load Module: EMGTVMED QNAME:
 QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name		IND	PARAH	CENTRAL BODY			
Input Format		AAA	HHH:MM: SS.SS NN	A			
Input Units		EBCDIC	hours	EBCDIC			
Program Units		Note 2	CENTISEC FXP	Note 6			
Scale Factor							
Checking Option		Exact (1)	None	Exact (5)			
Missing Item Option		Error	MINMAX (3) Note 4 Error	Note 7 Assume "E"			
Item Destination							

Programmer: S. Wright

Initial Logic:

Final Logic: Store in block

Illegal Phases:

- Notes: (1) GET if time to be input
 REV if REV to be input
 (2) GET = 1, REV = 2
 (3) Current REV \leq REV \leq last REV in Capt Table

- (4) Insert zero
 (5) E for Earth, M for moon
 (6) E = 0, M = 2
 (7) This parameter valid only when
 IND = REV

MOONRISE/MOONSET DISPLAY ELEMENT

Function

The function of this display is to provide data relative to day/night transitions that will enable astronauts to conduct experiments and will aid flight controllers in making decisions regarding recovery area selection.

Load Module/Routine Description - EMDSSMMD

The principle module of this logical element is EMDSSMMD, which is comprised of three major sections. The first section, ECDSSMMD, acts as the controlling unit. The other two sections, EMMENV and ECOMPAY, are mathematical units, which compute, respectively, spacecraft and subcapsule environment changes and the pitch/yaw angles for the spacecraft to rotate in order to "point" at the moon at its environment change times. Other utility programs used are as follows: (1) ELFECH, ephemeris fetch subroutine; (2) ELVCTR, extended interpolation subroutine; (3) ELVCNV, coordinate conversion subroutine; (4) EMGPRINT, on-line print routine; and RMMASCND, ascending node computation routine. Another service program, PLEFEM, is also introduced to interpolate in the sun/moon ephemeris table.

Requirements Interpretation

In this section, an attempt has been made to include all known requirements as of the publication date of this document. In addition to the interpretation of these requirements, a copy of the TR170 requirements has been included and annotated for direct reference to appropriate paragraphs in the interpretation section. These references have been provided where clarification or qualification was felt necessary. If any item or capability described in the TR170 document has not been provided, specific mention of this has been made in the margin adjacent to the appropriate paragraph. Parameters computed and/or displayed, or capabilities afforded but not included in the NASA requirements, have been mentioned in the margin of the TR170 and appropriately indexed to the interpretation. The abbreviation I/O refers to the Input/Output Specifications section.

ITEM

1. Requirements source

The requirements for the processing of the Moonrise/Moonset Display Element are prescribed by two sources: TR170, Section OT, par.

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3.2.4, change 58 (Exhibit 51) and the Philco Format FCN #LM0651. The latter will be discussed further in the Input/Outputs sections.

2. Initialization of display

This display will be initialized by MSK request.

3. Updates

There are no automatic updates associated with this display, however, it will respond to one MED, in which case all parameters are regenerated.

4. Parameters to be computed and/or displayed

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
REV. NO.	Revolution number corresponding to the earliest time displayed on each line	
GETTR	GET subcapsule enters moonlight	hr:min:sec
GETMR	GET spacecraft enters moonlight	hr:min:sec
θ	Spacecraft pitch angle at moonrise	deg.
ψ	Spacecraft yaw angle at moonrise	deg.
GETTS	GET subcapsule enters darkness	hr:min:sec
GETMS	GET spacecraft enters darkness	hr:min:sec
θ	Spacecraft pitch angle at moonset	deg.
ψ	Spacecraft yaw angle at moonset	deg.
REF DAY	Lift-off day of first vehicle	month/day/year
CEL. REF. DAY	Day celestial ephemeris begins	
BESSELIAN YEAR	Year to which celestial ephemeris is referenced	year
I	Orbital inclination angle	deg.
Ω_I	Inertial right ascension	deg.
T. UP.	Trajectory update number of CSM ephemeris	

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5. General

- a. A total of eight sets of environment change times and corresponding pitch/yaw angles will be displayed, if possible, using the Earth as the occulting body.
- b. Interpolations will be performed so as not to mix free-flight and thrust vectors. Where interpolation within a maneuver must be performed, vectors from different maneuver phases should not be mixed.

6. Manually driver data

This display processes based on a manually entered revolution number or GET.

- a. For the revolution option, the later of the respective Cape Crossing time and the time of MED entry (or MSK request) will be the processing start time.
- b. For the time option, the later of the MED GET and the time of MED entry (or MSK request) will be the processing start time.

7. Computation requirements

- a. The following computation requirements have been set for logical processing limits.
 - (1) Processing will terminate when the program senses data from the lunar sphere of influence. All data processed to that point will be displayed.
 - (2) The display will be limited to the time frame of the main ephemeris.
 - (3) The revolution numbers will be associated with the earliest environment change time displayed for a line.
 - (4) Should no future Ω_I exist, XXXXXXXX will be displayed.
 - (5) Should the vehicle travel in moonlight for an entire orbit, the spacecraft environment change times and corresponding pitch/yaw angles will be displayed as zero.
 - (6) This display is valid only in Earth orbit.

- (7) Should the program be unable to converge on an environment change time, the last estimate will be displayed and flagged with an asterisk. Processing will continue.
- b. The mathematical requirements are as follows:
- (1) Environment change times must be accurate to within three seconds.
 - (2) The inertial right ascension will be accurate to within two seconds.
 - (3) The assumed pre-maneuver orientation of the spacecraft for pitch/yaw computation is heads-down, local-vertical.
 - (4) The maneuver sequence for pitch/yaw computation is yaw-pitch with the desired terminal alignment of the spacecraft X-body axis pointed toward the moon.

$$\text{Pitch} = \sin^{-1} (-\hat{X}_b \cdot \hat{Z}_L)$$

$$\text{Yaw} = \tan^{-1} \left(\frac{\hat{X}_b \cdot \hat{Y}_L}{\hat{X}_b \cdot \hat{X}_L} \right)$$

where the subscript "b" refers to body axes, and the subscript "L" refers to spacecraft local vertical/local horizontal axes.

- (5) For computation of day/night arrival times, a geodetic Earth model will be considered (Fisher Ellipsoid). The actual formula introduced is

$$R_e = \sqrt{\frac{X^2 + Y^2 + Z^2}{X^2 + Y^2 + Z^2/b}}$$

where R_e is the computed Earth radius for any vehicle position vector whose components are X, Y, and Z respectively. The semiminor axis of the Earth, b is a system parameter.

- (6) The displayable limits for the inclination angle are $0^\circ \leq i < 180^\circ$.

Exhibit 51

PHO-TR170A
Volume 2, Change 58
19 April 1968

OT 3.2.4 Moonrise/Moonset Times Display

- A. Purpose. To display moonrise/moonset alphanumeric acquisition data for the astronaut.
- B. Data Sources. Current ephemeris.
- C. Initialization of Display. This display will be initialized by manual entry of a Revolution number or GET.
- D. Parameters To Be Computed and Displayed. The following quantities will be computed and displayed.

QUANTITYDEFINITION

GETTR	GET (hr:min:sec) of the terminator rise from liftoff (subcapsule entry into moonlight)
GETMR	GET (hr:min:sec) of moonrise from liftoff (spacecraft entry into moonlight)
GETTS	GET (hr:min:sec) of terminator set from liftoff (subcapsule entry into darkness)
GETMS	GET (hr:min:sec) of moonset from liftoff (spacecraft entry into darkness)

Trajectory Update Number Update number associated with CSM ephemeris.

REV NO. Revolution number corresponding to the earliest time displayed on each line.

Item 4

0	Spacecraft pitch at sunrise (deg)
ψ	Spacecraft yaw at sunrise (deg)
0	Spacecraft pitch at sunset (deg)
ψ	Spacecraft yaw at sunset (deg)
i	Orbital inclination angle (deg)
Ω	Inertial right ascension (deg)

- E. Updates. There are no automatic updates associated with this display.

F. Additional Information1. General

- a. The first 16 environment changes of the spacecraft and its subcapsule position following the Revolution number or GET will be computed and displayed.
- b. An appropriate message will appear on the display if all information is not available.
- c. Reference day and Besselian year will be dynamically driven at the bottom of the display.

Approved: 

NASA/FSB

PHO/PARS



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Exhibit 51 (Cont'd.)

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- d. The time associated with the first celestial vector available will also be displayed in the lower portion of the display.
 - e. Should the vehicle travel in moonlight for an entire orbit, the spacecraft environment change times and associated pitch and yaw will be displayed as zero.
 - f. The revolution numbers will be associated with the earliest environment change time displayed for a line.
 - g. Secondary occultations will not be considered.
 - h. This display is required in earth parking orbit only.
 - i. The environment changes will be generated assuming the occulting body to be the occulting body at the vector time. If a sphere of influence change occurs during the generation, those environmental changes that can be computed relative to the original occulting body prior to reference switch will be displayed and computations will be terminated for that generation.
 - j. The display will be limited to the time frame of the main ephemeris.
 - k. Should the requested time be prior to current time, or become current time, current time will be used.
 - l. Should no future Ω exist, XXXXXXXX will be displayed. When convergence cannot be accomplished the last guess will be displayed and will be accompanied by an online print stating the deviation.
 - m. If cannot compute an environment change time the best estimate will be displayed with an adjacent asterisk and processing will continue.
2. Mathematical Implications
- a. The assumed orientation is heads down premaneuver. (Local-Vertical)
 - b. The S/C X-body axis is pointed at the target.
 - c. The maneuver sequence is yaw, pitch.
3. Restrictions and/or Limits of Design. This display should not be requested prior to input of MED P80 containing reference day information.

Approved: 707 NASA/FSB PHO/PARS

(OT) 3.2.4-2

Functional Diagrams

The Moonrise/Moonset Display, Figure 30 illustrates the interfaces of the programs in this element with other elements, units, or subsystem. Data table usage, task structure, and input/output data flow is also shown. The key to the symbols used in the diagrams may be found in the Glossary of this document.

Input/Output Specifications

The input/output specifications for the Moonrise/Moonset Display Element are shown in the display format, on-line prints, and the CRT error messages.

The following comment will be printed on line should the ascending node routine fail to converge on the inertial right ascension.

RMMASCND CONVERGENCE LIMIT = (VALUE)

where "value" represents how close the displayed value in (in seconds of time) to the actual ascending node.

These error conditions are displayed on the CRT.

1. "DATA NOT AVAILABLE"
(No CSM ephemeris or no celestial ephemeris)
2. "TABLE BEING UPDATED"
(Trajectory update in process)
3. "INCONSISTENT TABLES"
(Trajectory related tables have differing trajectory update numbers)
4. Should the ephemeris end prior to 16 future environment changes at the time the display is requested, all data which can be computed will be displayed followed by the comment "END OF AVAILABLE DATA".
5. "VEHICLE NOT IN EARTH ORBIT"
6. "MED OUTDATED"
(No MED has been input, or request is for a processing start time outside of the current CSM ephemeris)

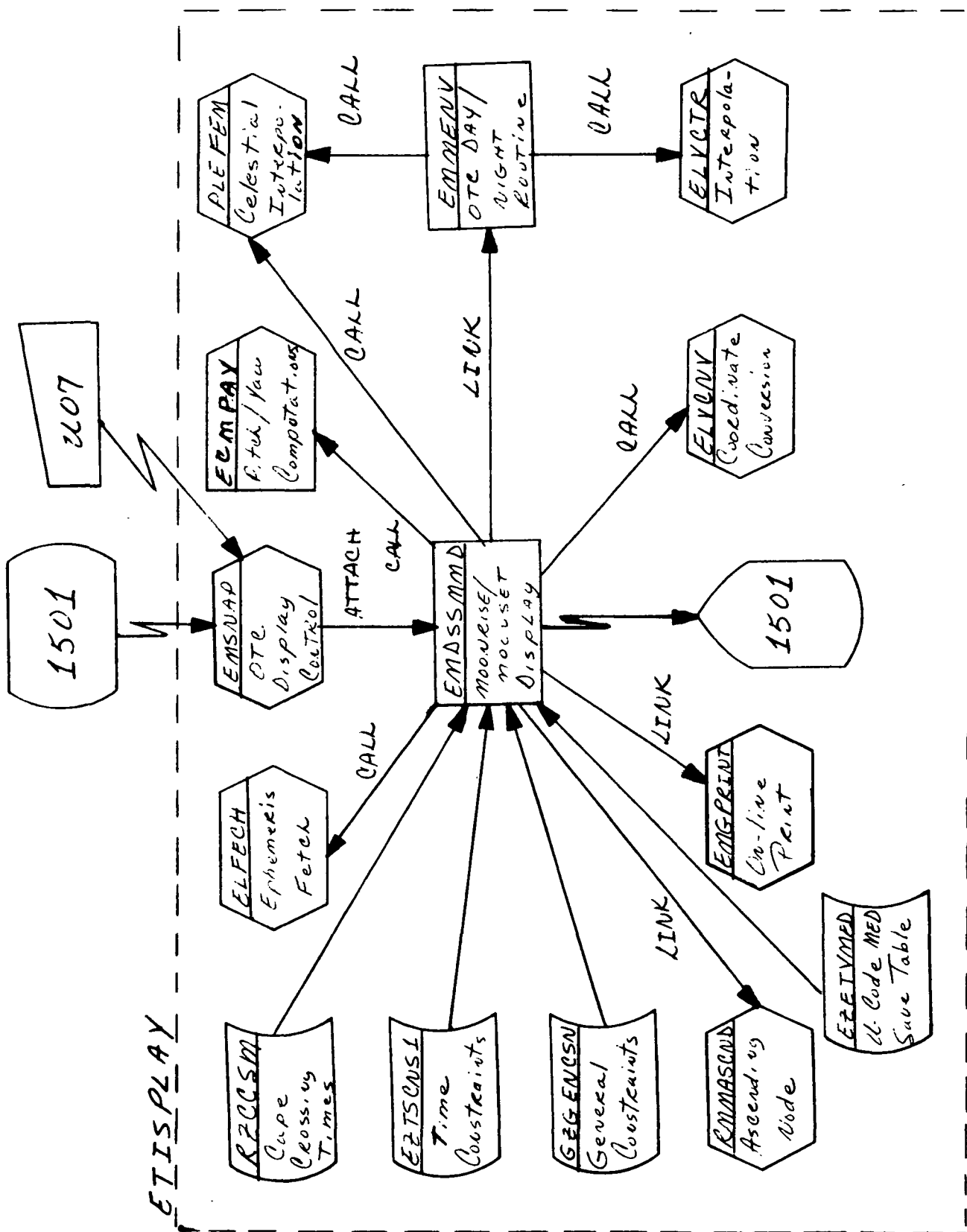


Figure 30. Moonrise/Moonset Display



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MED Format Table

MED Code: U07
 Purpose: Moonrise/Moonset Display
 Load Module: EMGTVMED
 Task:
 EP:
 QNAME:
 QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name	IND	PARAM					
Input Format	AAA	HHH:MM: SS:SS	NN				
Input Units	EBCDIC	hours	FXP				
Program Units	Note 2	centisec	FXP				
Scale Factor							
Checking Option	Exact (1)	none	MINMAX (4)				
Missing Item Option	Error	Note 3	Error				
Item Destination							

Programmer:

Initial Logic: NA

Final Logic: Store in block 7 of EZETVMED

Illegal Phases:

Notes: (1) GET if time to be input
 REV if REV to be input

(2) GET = 1, REV = 2

(3) Inzert zero

(4) Current REV ≤ REV ≤ Last REV in Cape Table

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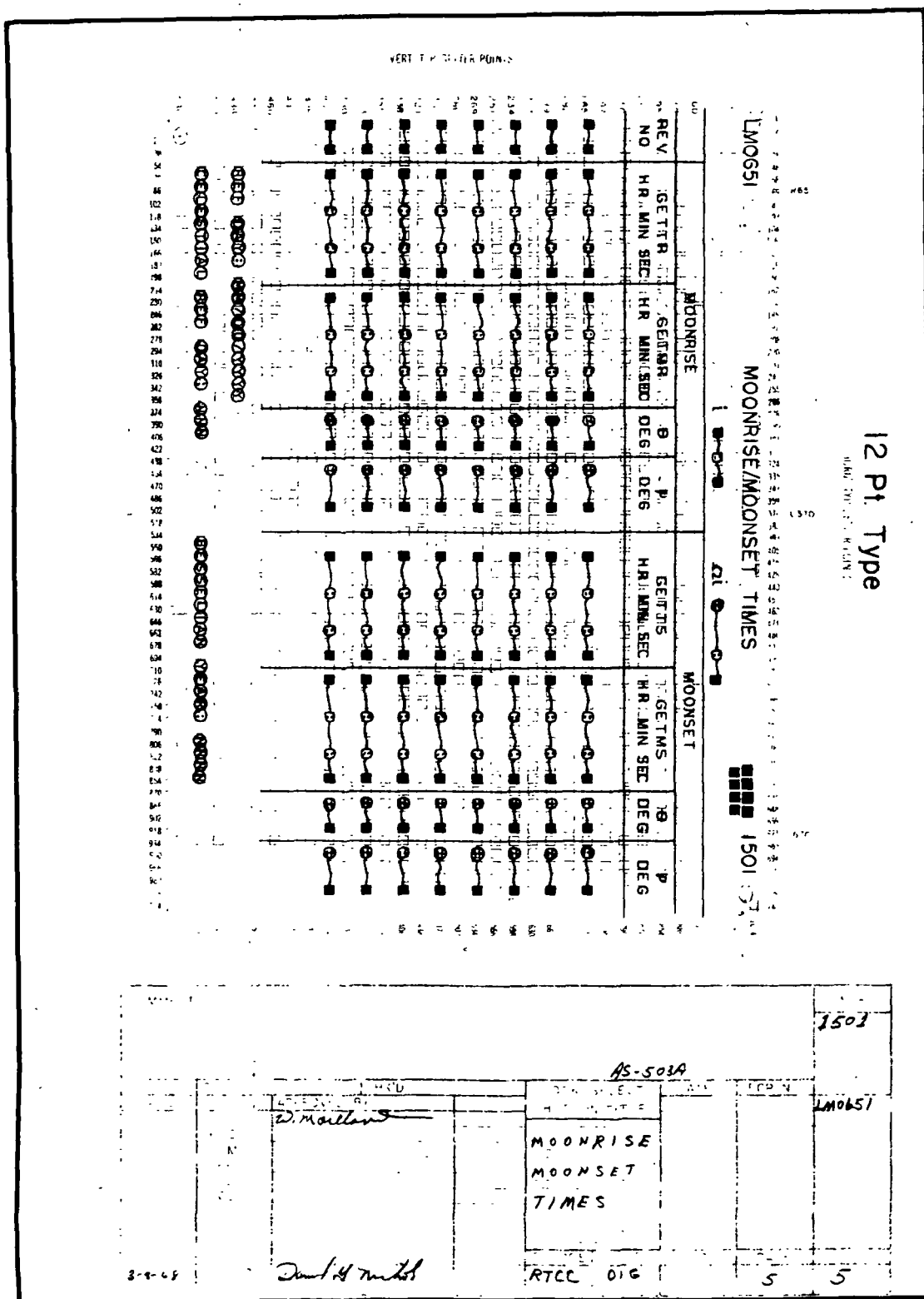
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Exhibit 52



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SPACE DIGITALS DISPLAY

Function

The function of the Space Digital Display is to compute and display parameters necessary to evaluate and monitor trajectories involving Earth-moon relationships.

Load Module/Subroutine Description - EMDSPACE

EMDSPACE contains the general logic and display features necessary to drive the Space Digital Display. In order to accomplish its total objectives, EMDSPACE enlists the services of the mission utility routines ELFECH (ephemeris fetch subroutine) and ELVCNV (vector coordinate system conversion subroutine). The mathematical programs called upon are DARSIN (arc sin), DSQRT (square root), GLQATN (arc tangent), GLMDPD (dot product), GLSSAT (subsattellite program), and EMMENV (environment change subroutine). The Encke Integrator, EMMENI, performs all necessary integrations, while PMMAPD, apogee/perigee determination program, yields apogee/perigee related data. Correct areas and weights are provided to both of these routines by PLAWDT.

Requirements Interpretation

In this section, an attempt has been made to include all known requirements as of the publication date of this document. In addition to the interpretation of these requirements, a copy of the TR170 requirements has been included and annotated for direct reference to appropriate paragraphs in the interpretation section. These references have been provided where clarification or qualification was felt necessary. If any item or capability described in the TR170 document has not been provided, specific mention of this has been made in the margin adjacent to the appropriate paragraph. Parameters computed and/or displayed or capabilities afforded but not included in the NASA requirements, have been mentioned in the margin of the TR170 and appropriately indexed to the interpretation. The abbreviation I/O refers to the Input/Output Specifications section.

ITEM

1. Requirements source

The requirements for the processing of the Space Digitals Display originate from two sources: TR170, Section OT, par 3.2.8, Change 58 (see Exhibit 53) and the Philco Format FCN #LM0899A.

2. Initialization of display

This display is initialized by MSK request. A special initialization MED is also required in order to process and display data, and also to subsequently honor any of the options on the second MED associated with this display.

3. Updates

The explicit updates associated with this display are (a) time cycle (12 sec.), (b) trajectory update, (c) MED (for driving manual columns); (d) MSK request; and (e) reinitialization (initialization MED). Time traps will be terminated in both Earth orbit and lunar orbit.

4. Parameters to be computed and/or displayed

<u>Quantity</u>	<u>Definition</u>	<u>Dimension</u>	<u>Updates</u>
TUN* PP	Current update number of subject vehicle ephemeris		(1), (2), (4), (5)
VID	Identification of last vector used to update ephemeris		(1), (2), (4), (5)
Weight	Total vehicle weight	lbs.	(1), (2), (4), (5)
GMTV	Greenwich time-tag of vector	hr:min:sec	(1), (2), (4), (5)
GETV	Ground elapsed time-tag of vector	hr:min:sec	(1), (2), (4), (5)

* Subscripts will not appear on background but will be indicated by their background positions.

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
GET Axis	GET used to define Earth-moon line in the initialization of the Earth-moon transit display	hr:min:sec	(1), (2), (4), (5)
GETR	GET reference (elapsed time of an event)	hr:min:sec	(1), (2), (4), (5)
GET	Ground elapsed time associated with present position parameters	hr:min:sec	(1)
REF_1^*	Central body computing present position parameters		(5)
V	Current inertial velocity	ft. / sec.	(1), (2), (4), (5)
γ	Current inertial flight-path angle	deg.	(1), (2), (4), (5)
h	Current altitude		(1), (2), (4), (5)
ϕ	Current geodetic/selenographic latitude	deg.	(1), (2), (4), (5)
λ	Current geodetic/selenographic longitude	deg.	(1), (2), (4), (5)
ψ	Inertial azimuth	deg.	(1), (2), (4), (5)
n	Current true anomaly	deg.	(1), (2), (4), (5)
VEH ID	Vehicle to which all display data relates		(5)

The following quantities apply to manual column #1.

GET Vector 1	GET of vector used to compute the quantities below	hr:min:sec:cs	(3)
--------------	--	---------------	-----

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
REF_2^*	Central body used to compute the vector 1 quantities		(3)
WT	Total vehicle weight at GET vector 1	lbs.	(3)
GETA	GET of first apogee following vector 1	hr:min:sec	(3)
h_a	Height of apogee	NM	(3)
h_p	Height of perigee	NM	(3)
iemp	Inclination of trajectory with respect to Earth-moon plane	deg.	(3)
h_s	Spherical altitude at GET vector 1	NM	(3)
ϕ	Geocentric/selenographic latitude at GET vector 1	deg.	(3)
Ω	Inertial right ascension of ascending node	deg.	(3)
θ_{RA}	Inertial right ascension of perigee	deg:min	(3)
K	Atmospheric density multiplier		(3)
TUN_1^*	Trajectory update number corresponding to manual column 1 data		(3)

The following quantities apply to manual column #2.

GET Vector 2	GET of base vector used to compute quantities below	hr:min:sec	(3)
-----------------	---	------------	-----

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
GETSI	First GET following Vector 2 that vehicle enters lunar sphere of influence	hr:min:sec	(3)
GETCA	GET of closest approach to moon	hr:min:sec	(3)
V_{CA}	Inertial velocity at GETCA	ft./sec.	(3)
h_{ca}	Lunar altitude at GETCA	NM	(3)
ψ_{ca}	Inertial azimuth at GETCA	deg.	(3)
ϕ_{ca}	Selenographic latitude at GETCA	deg.	(3)
λ_{ca}	Selenographic longitude at GETCA	deg.	(3)
GETMN	GET of arrival at the node defined by the planes of the approach hyperbola and the desired lunar parking orbit	hr:min:sec	(3)
ϕ_{MN}	Selenographic latitude at GETMN	deg.	(3)
λ_{MN}	Selenographic longitude at GETMN	deg.	(3)
h_{MN}	Altitude above moon at GETMN	NM	(3)
δ_{MN}	Wedge angle at GETMN	deg.	(3)
TUN_2^*	Trajectory update number corresponding to manual column 2 data		(3)

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
The following quantities apply to manual column #3.			
GET Vector 3	Time of base vector used to compute parameters below	hr:min:sec	(3)
GETSE	First time vehicle exits the lunar sphere of influence following GET Vector 3	hr:min:sec	(3)
GETEI	GET of Earth entry interface	hr:min:sec	(3)
V_{EI}	Inertial velocity at GETEI	ft. / sec.	(3)
γ_{EI}	Flight-path angle at GETEI	deg.	(3)
λ_{EI}	Geographic longitude at GETEI	deg.	(3)
ψ_{EI}	Inertial azimuth at GETEI	deg.	(3)
GETVP	GET of Earth vacuum perigee	hr:min:sec	(3)
V_{vp}	Inertial velocity at GETVP	ft. / sec.	(3)
h_{vp}	Altitude above Earth at GETVP	ft. / sec.	(3)
ϕ_{vp}	Geographic latitude at GETVP	deg.	(3)
λ_{vp}	Geographic longitude at GETVP	deg.	(3)

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<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>	<u>Updates</u>
ψ_{vp}	Inertial azimuth at GETVP	deg.	(3)
i_e	Inclination angle with respect to Earth at vacuum perigee	deg.	(3)
λ_N	Geographic longitude of Earth return ascending node	deg.	(3)
TUN_3^*	Trajectory update number corresponding to manual column 3 data		(3)

5. General

- a. There will be one MSK to process all required vehicles.
- b. Present position data will automatically update only in Translunar and Trans-Earth phases. The manual columns will be available in all phases.
- c. The vehicle for which data will be processed and displayed for present position or any manually controlled column will be determined by the last entered initialization MED.
- d. The central body to which the present position data relates will also be dictated by the initialization MED.

6. Manually driven data

These special processing requirements for manually entered data are applicable to manual columns 1, 2, and 3.

a. Vector 1 column

- (1) Column 1 will be manually driven by a MED specifying a time or maneuver code.
- (2) The data displayed will be computed from an integrated vector at the time specified or the burnout vector of the maneuver indicated.

- (3) The central body used in the computations will be that associated with the sphere of influence into which the time of concern falls.
- (4) The apogee data will relate to the first apogee following the base vector unless there is none, in which case the data will relate to the first preceding apogee.

b. Vector 2 column

- (1) Column 2 will respond to a manually entered time or maneuver code in addition to an inclination angle and ascending node defining the desired lunar parking orbit.
- (2) All data displayed will relate to the moon.
- (3) When computing parameters associated with the point of closest approach, the criterion to be met will be that of determining the first time following the "base vector" at which the flight-path angle goes to zero, after the first integration timestep within the lunar sphere of influence.
- (4) The values associated with GET_{MN} must be computed from a free-flight propagation of the base vector selected (as opposed to any targeting values).
- (5) GET_{MN} is presumed to occur within the first 20 hours (100 vectors maximum) after entering the lunar sphere of influence.

c. Vector 3 column

- (1) Column 3 will be processed upon entry of a MED specifying either a time or a maneuver code.
- (2) The data displayed in this column will relate to the return to Earth.

- (3) Vacuum perigee will be determined by detecting the first zero flight-path angle (relative to the Earth subsequent to the base vector that is below nE_r , where n will be a system parameter.

7. Computation requirements

- a. The following computation requirements have been set for logical processing limits.
 - (1) The time limit for determining any desired end condition will be the same as that incorporated in the Encke integrator.
 - (2) All parameters that relate to any end condition not occurring within the processing time limits will be displayed as zeros.
 - (3) The manual columns will not be blanked following a trajectory update; however, each column will display the trajectory update number associated with its data at the time it is completed.
 - (4) The manual columns will be blanked upon MSK request only if the display is being viewed at the monitor from which this MSK request is being made.
 - (5) Regardless of MED column or desired option, maneuvers subsequent to the "base vector" will always be ignored. However venting, if applicable, will be considered.
 - (6) Any of the three MED controlled columns may be queued by GET or maneuver code; however, if the GET option is specified, the time must fall within the time frame of the main ephemeris.
 - (7) Should the time on a GET option for any manual column fall within a maneuver, no processing will occur other than an optical indication that such a condition exists.
 - (8) For integrations performed by this display, the point at which the integrator changes to lunar equations will be the first integration step within $10 E_r$ of the moon. If the time of closest approach occurs outside of this radius, it will not be detected. The definition of GET_I and GET_E will still be determined by the appropriate system parameter (currently nine E_r).

- (9) The "base vector" chosen for the time (GET) option on any of the MED controlled columns will be the first main ephemeris output vector prior to the time on the MED. The time displayed as the vector GET for columns 2 and 3 will be the time tag of that chosen vector rather than the MED time.
- (10) There will be no restrictions on the time increments between the three vector times.
- (11) If the translunar trajectory results in lunar impact, the h_{ca} should be displayed as zero, and ϕ_{ca} , λ_{ca} would be the selenographic lunar impact position with respect to a spherical moon of landing site radius.
- (12) If the vacuum perigee altitude is less than zero, then h_{vp} will be indicated negatively with the magnitude. The quantities ϕ_{vp} , λ_{vp} would be the position of minimum radius vector.
- (13) If the lunar nodal altitude (h_{MN}) is less than zero, then h_{MN} will be indicated negatively with the magnitude. The quantity ϕ_{MN} will continue to be the lunar position of the node.
- (14) GET_{SI} and GET_{SE} will be blanked if they do not occur subsequent to the "base vector".
- (15) Entry interface for the Earth is 400,000 feet; for the moon is 35,000 feet.

b. Mathematical implications

The following represent the mathematical requirements.

- (1) All parameters will be computed based on true (ECT or MCT) vectors.
- (2) Where orbital elements are not defined for the characteristics of the existing orbit (circular, elliptical, parabolic, hyperbolic, or rectilinear), they will be displayed at "Z's".

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- (3) The nominal plane of the lunar parking orbit will be defined by the inclination angle and the longitude of ascending node (both in MCI) via MED input to this display.
- (4) All lunar heights will be computed using a spherical moon model assuming a radius equal to that of the lunar landing site. Of the Earth related altitudes displayed, present position height and h_{vp} are computed as true subsatellite. All others will be calculated spherically considering a radius equal to that at Cape Kennedy.
- (5) The displayable limits for the inclination angle on vector 1 column are $0^{\circ} \leq i < 180^{\circ}$.

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OT 3.2.8 LM and CSM Space Digitals

- A. Purpose. To provide parameters necessary to evaluate and monitor trajectories involving earth-moon relationships.
- B. Data Source. Current ephemeris and maneuver cutoff vectors.
- Item 2 C. Initialization of Display. This display will be initialized by MED request.
- D. Updates. The updates associated with this display are:
- (1) Time cycle (12 sec)
 - (2) Trajectory update
 - (3) Manual entries (3)
 - (4) MSK request
 - (5) Reinitialization

E. Parameters to be Computed and Displayed.

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSION</u>	<u>UPDATES</u>
	Trajectory update number	Update number associated with subject vehicle	None	(1), (2), (4), (5)
	Vector-ID	Identification of the last vector used to update the ephemeris	None	(1), (2), (4), (5)
	Weight	Total vehicle weight	lbs	(1), (2), (4), (5)
Item 4	GMTV	Greenwich time-tag of the vector	HHH:MM:SS.SS	(1), (2), (4), (5)
Item 4	GETV	Ground elapsed time-tag of the vector	HHH:MM:SS.SS	(1), (2), (4), (5)
Item 4	GET Axis	Ground elapsed time used to define the earth-moon line in the initialization of the earth-moon transit display	HHH:MM:SS.SS	(1), (2), (4), (5)

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	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSION</u>	<u>UPDATES</u>
Item 4	GETR	Ground elapsed time reference (elapsed time of an event)	HHH:MM:SS.SS	(1),(2),(3), (4),(5)
	GET	Current ground elapsed time for which V, γ , ϕ , λ , h_o , ψ and η were computed	HHH:MM:SS.SS	(1)
	REF	Inertial reference body used to compute V, γ , ϕ , h_o , ψ and η	None	(1),(2),(3), (4),(5)
	V	Current velocity (earth cen- tered inertial or lunar cen- tered inertial)	ft/sec	(1),(2),(4), (5)
	γ	Current inertial flightpath angle (earth or lunar ref- erence)	deg	(1),(2),(4), (5)
	h	Current altitude above an oblate earth or spherical above the moon assuming landing site radius	nm	(1),(2),(4), (5)
	ϕ	Current geodetic latitude or current selenographic latitude with respect to a spherical moon whose radius is the land- ing site.	deg	(1),(2),(4), (5)
	λ	Current earth longitude or current selenographic latitude with respect to a spherical moon whose radius is the land- ing site.	deg.	(1),(2),(4), (5)
	ψ	Current heading angle with respect to the earth or moon, measured clockwise from north	deg	(1),(2),(4), (5)
	η	Current true anomaly	deg	(1),(2),(4), (5)
	VEH ID	Vehicle for which the space digitals are computed	XXX	(2),(3),(4), (5)

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The following quantities will be computed for a specified GET or a specified maneuver in the MPT.

	QUANTITY	DEFINITION	DIMENSION	UPDATES
Items 4, 6a, and 7b	GET Vector 1	Ground elapsed time of the vector used to compute the quantities below	HHH:MM:SS.SS	(3)
	REF	The inertial reference body used to compute the quantities (i.e., if GET Vector 1 is inside the lunar sphere of influence, REF is MOON)	None	(3)
	WT	Total vehicle weight at time of GET Vector 1	lbs	(3)
	GETA	Ground elapsed time of next apogee (referenced from GET Vector 1)	HHH:MM:SS.SS	(3)
	h_a	Height of apogee above a spherical earth or height of apolune above a spherical moon whose radius is the landing site (referenced from GET Vector 1)	nm	(3)
	h_p	Height of perigee above a spherical earth or height of perilune above a spherical moon whose radius is the landing site (referenced from GET Vector 1)	nm	(3)
	i_{emp}	Inclination of the trajectory with respect to the earth-moon plane (referenced from GET Vector 1)	deg	(3)
	h_s	Altitude above a spherical earth or moon (referenced from GET Vector 1)	nm	(3)
	ϕ_s	Geocentric latitude or selenographic latitude with respect to a spherical moon of landing site radius (referenced from GET Vector 1)	deg	(3)

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	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSION</u>	<u>UPDATES</u>
Items 4, 6a and 7b	Ω	Right ascension of the ascending node (inertial)	deg	(3)
	θ_{RA}	Inertial right ascension of perigee	deg:min	(3)
	K	Density multiplier use in the computation of the above quantities	None	(3)

The following quantities will be computed for a specified GET or a specified maneuver in the MPT.

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSION</u>	<u>UPDATES</u>
Items 4, 6b, 7a, and 7b	GET Vector 2	Ground elapsed time of the vector supplied by the ephemeris and from which the quantities below will be computed	HHH:MM:SS.SS	(3)
	GETSI Sphere Entrance	The first ground elapsed time after GET Vector 2 that the vehicle will pass through the lunar sphere of influence with a negative lunar altitude rate (rate with respect to the moon is decreasing)	HHH:MM:SS.SS	(3)
	GETCA	Ground elapsed time of closest approach to the moon	HHH:MM:SS.SS	(3)
	V_{ca}	Velocity with respect to a moon-centered inertial coordinate system at the point of closest approach to the moon	ft/sec	(3)

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	QUANTITY	DEFINITION	DIMENSION	UPDATES
Items 4, 6b, 7a, and 7b	h_{ca}	Altitude at the point of closest approach to a spherical moon of landing site radius	nm	(3)
	ψ_{ca}	Heading angle at the point of closest approach to the moon, measured clockwise from north	deg	(3)
	ϕ_{ca}	Selenographic latitude with respect to a spherical moon at the point of closest approach to the moon	deg	(3)
	λ_{ca}	Selenographic latitude with respect to a spherical moon at the point of closest approach to the moon	deg	(3)
	GET-MN	Ground elapsed time of arrival at the node defined by the planes of the approach hyperbola and the desired lunar parking orbit	HHH:MM:SS.SS	(3)
	ϕ_{MN}	Selenographic latitude relative to a spherical moon at GET-MN	deg	(3)
	λ_{MN}	Selenographic latitude relative to a spherical moon at GET-MN	deg	(3)
	h_{MN}	Selenographic latitude relative to a spherical moon at GET-MN	nm	(3)
	δ_{MN}	Wedge angle between the planes of the approach hyperbola and the desired lunar parking orbit (Note: A positive sign indicates that the inclination of the desired lunar parking orbit is less than the inclination of the approach hyperbola)	deg	(3)

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The following quantities will be computed for a specified GET or a specified maneuver in the MPT.

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>DIMENSION</u>	<u>UPDATES</u>
Item 6c	GET Vector 3	Ground elapsed time of the vector supplied by the ephemeris and from which the quantities below will be computed	HHH:MM:SS.SS	(3) (2)
Item 7a	GETSE Sphere Exit	The first ground elapsed time after GET Vector 3 that the vehicle will pass through the lunar sphere of influence with a positive lunar altitude rate (Note: Altitude with respect to the moon is increasing)	HHH:MM:SS.SS	(3) (2)
Items 6c, 7a and 7b	GET _{EI}	Ground elapsed time of entry interface	HHH:MM:SS.SS	(3) (2)
	V _{EI}	Earth centered inertial velocity at entry interface	ft/sec	(3) (2)
	Y _{EI}	Inertial flightpath angle at entry interface	deg	(3) (2)
	φ _{EI}	Geodetic latitude at entry interface	deg	(3) (2)
	λ _{EI}	Earth longitude at entry interface	deg	(3) (2)
	ψ _{EI}	Heading angle with respect to the earth at entry interface	deg	(3) (2)
	GET _{VP}	Ground elapsed time of arrival at vacuum perigee	HHH:MM:SS.SS	(3) (2)
	V _{VP}	Earth centered inertial velocity at vacuum perigee	ft/sec	(3) (2)
	h _{VP}	Altitude above an oblate earth at vacuum perigee	nm	(3) (2)

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	QUANTITY	DEFINITION	DIMENSION	UPDATES
Items 6c, 7a and 7b	ϕ_{VP}	Geodetic latitude at vacuum perigee	deg	(3)
	γ_{VP}	Earth longitude at vacuum perigee	deg	(3)
	ψ_{VP}	Heading angle at vacuum perigee	deg	(3)
	i_e	Inclination angle with respect to the earth at vacuum perigee	deg	(3)
	λ_N	Geographic longitude of the earth return ascending node	deg	(3)

F. Additional Information1. General

- If the translunar trajectory results in lunar impact, the h_{ca} should be displayed as zero, and ϕ_{ca} , λ_{ca} would be the selenographic lunar impact position with respect to a spherical moon of landing site radius
- If the vacuum perigee altitude is less than zero then h_{vp} will be indicated with a negative sign with the magnitude. The quantities ϕ_{vp} , λ_{vp} would be the position of minimum radius vector.
- If the lunar nodal altitude (h_{MN}) is less than zero then h_{MN} will be indicated with a negative sign with the magnitude. The quantity ϕ_{MN} will continue to be the lunar position of the node.
- The manual columns will not be blanked following a trajectory update; however, each column will display the trajectory update number associated with its data at the time it is completed.
- The manual columns will be blanked upon MSK request only if the display is being viewed at the monitor from which this MSK request is being made.
- Regardless of MED column or desired option, maneuvers subsequent to the "base vector" will always be ignored.

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- g. Any of the three MED controlled columns may be queued by GET or Maneuver Code, however, if the GET option is specified, the time must fall within the time frame of the main ephemeris.
- h. Should the time on a GET option for any manual column fall within a maneuver, no processing will occur other than an optical indication that such a condition exists.
- i. The "base vector" chosen for the time (GET) option on any of the MED controlled columns will be the first main ephemeris output vector prior to the time on the MED. The time displayed as the vector GET for columns 2 and 3 will be the time-tag of that chosen vector rather than the MED time.
- j. When computing parameters associated with the point of closest approach (VECTOR 2) the criterion to be met will be determining the first time following the "base vector" at which the flight path angle goes to zero.
- k. The values associated with GET_{MN} must be computed from a freeflight propagation of the base vector selected (as opposed to any targeting values).
- l. GET_{SE} or GET_{SI} will be blanked if either occurred prior to the time-tag of the "base vector", or if they never occur.
- m. Entry Interface for the earth is 400,00 feet for the moon is _____.
- n. The nominal plane of the lunar parking orbit will be defined by the inclination angle and the longitude of ascending node.
- o. If the semi-major axis (VECTOR 1) is negative it will be blanked.
- p. Present position data will only be available in Translunar, Transearth and Translunar Abort phases. The manual columns will be available in all phases.
- q. A test of vector radius magnitude will be used for computing the vacuum perigee data. When computing vacuum perigee data and a flightpath angle of zero is found, the radius vector magnitude at that point should be less than X earth radii before using that vector for the vacuum perigee computation. The X E.R. value will be a system parameter.

Item 7a

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r. Manual Inputs

<u>MANUAL INPUT</u>	<u>EFFECT</u>
Code, REF, VEH	Initialize space digitals with present position information, i.e., $(V, \gamma, \phi, \lambda, h, \psi, \eta, \text{trajectory update number, vector ID, weight, GMTV, GETV, GET AXIS, GETR, GET})$
Code, GET or MNVID	Compute in manual column No. 1 the following: GET of vector, REF, WT, $\text{GET}_a, h_a, h_p, i_{emp}, h_s, \phi_s, V, \gamma, h, \phi, \lambda, \eta, a, e, i, \ell, \omega, \Omega, \Theta_{RA}, K.$
Code, GET or MNVID, i, λ_{AN}	Compute in manual column No. 2 the following: GET of vector, GETSI, $\text{GETCA}, V_{ca}, h_{ca}, \psi_{ca}, \phi_{ca}, \lambda_{ca}, \text{GETMN}, \phi_{MN}, \lambda_{MN}, h_{MN}, \delta_{MN}$
Code, GET or MNVID	Compute in manual column No. 3 the following: GET of vector, GETSE, $\text{GET}_{EI}, V_{EI}, \gamma_{EI}, \phi_{EI}, \lambda_{EI}, \psi_{EI}, \text{GET}_{EI}, h_{VP}, \phi_{VP}, \lambda_{VP}, \psi_{VP}, i_e, \lambda_{\eta}$

- s. All parameters relating to any end condition which does not occur within the processing time limits will be displayed as zeros.
- t. All parameters will be computed based on true (ECT or MCT) vectors.
- u. The time limit for determining any desired end condition will be the same as that incorporated in the Encke integrator.
- v. Orbital elements which are not defined for particular orbits will be blanked.

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Functional Diagrams

The Space Digitals Display, Figure 31, shows the interfaces of the programs in this element with other elements, units, or subsystems. Also included are data table usage, task structure, and input/output data flow. The key to the symbols used in the diagram may be found in the Glossary of this document.

Input/Output Specifications

This section is divided into four groupings of data: MED formats (U00 and U01), display formats, and cathode-ray tube (CRT) error indications.

CRT Error Indications: The following error conditions are detected and indicated by an asterisk on the CRT accompanied by corresponding numerical code.

1. The display has not been initialized via MED U00.
2. The trajectory for subject vehicle is not generated.
3. The time on the U01 exceeds the end of the ephemeris.
4. The time on the U01 precedes the start of the ephemeris.
5. The main ephemeris is in an update status.
6. The Mission Plan Table is either in an update state or is inconsistent with the trajectory update number.
7. The time on the U01 falls within a maneuver.
8. The maneuver number requested is greater than the number of maneuvers in the Mission Plan Table.
9. Maneuver on U01 not integrated through.
10. No precession/nutation is available for subject time.
11. Base vector rejected by Enke Integrator.
12. The base vector selected for apogee/perigee computation was rejected by the analytical ephemeris generator.

These error codes have been selected based on the best information available to date.

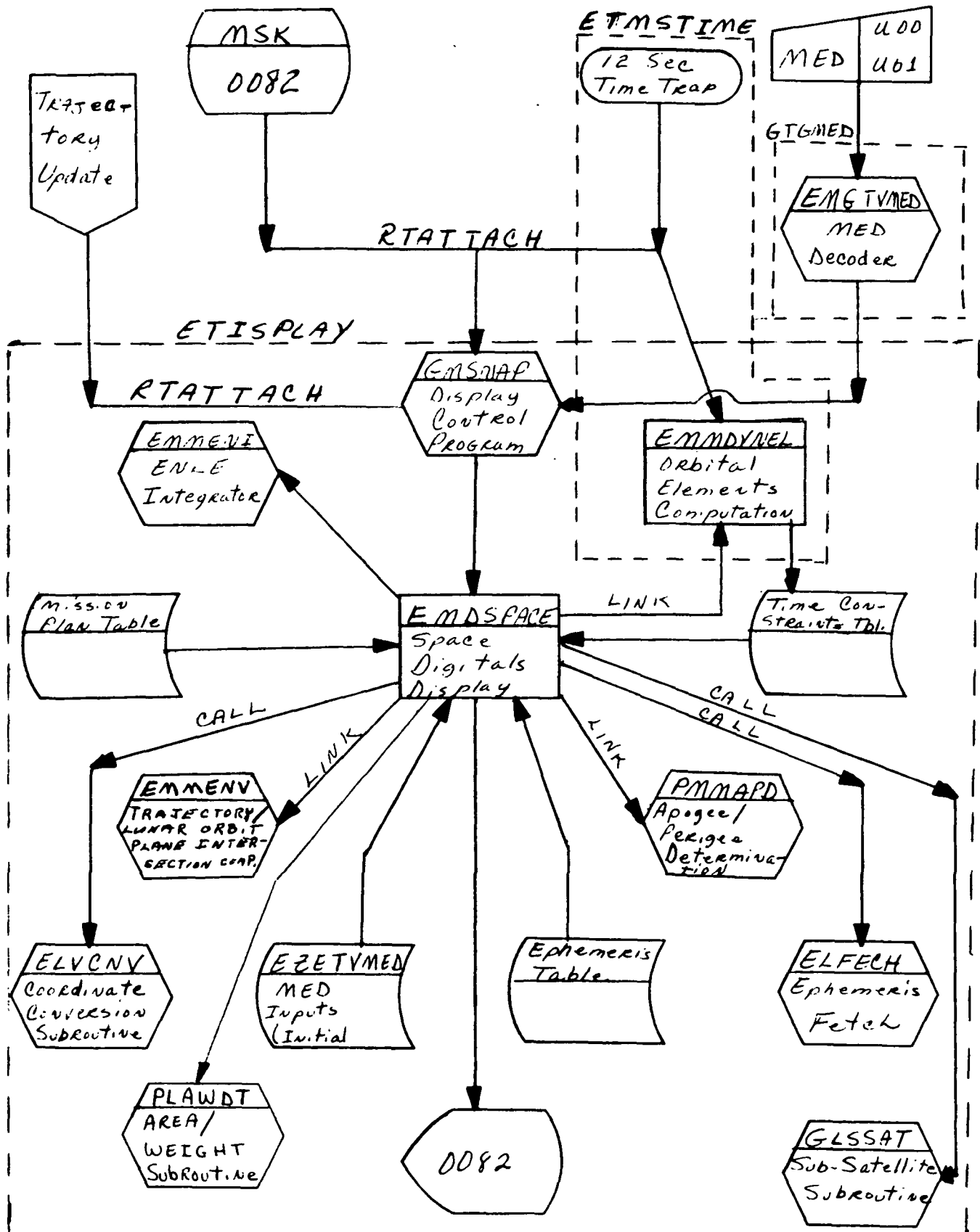


Figure 31. Space Digitals



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MED Format Table

MED Code: U00 Task: NA
 Purpose: Space digitals initialization EP: NA
 Load Module: EMGTVMED QNAME: NA
 QUEID: NA

Desc.	Item	1	2	3	4	5	6
Item Name	VEH ID	CENTRAL BODY					
Input Format	VEH	A					
Input Units	EBCDIC	EBCDIC					
Program Units	Note 3	FXP (2)					
Scale Factor							
Checking Option	Exact (1)	Exact (2)					
Missing Item Option	Error	Assume "E"					
Item Destination							

Programmer: S. Wright

Initial Logic:

Final Logic: Store in block 3 of EZETVMED

Illegal Phases:

Notes: (1) CSM or LEM

(2) E for Earth (=1)

M for moon (=3)

(3) EBCDIC name and numeric code

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MED Format Table

Task: NA
EP: NA
QNAME: NA
QUEID: NA

MED Code: U01
Purpose: Space digitals
Load Module: EMGTVMED

Desc.	Item	1	2	3	4	5	6
Item Name		MANUAL COLUMN	OPTION IND	PARAM-ETER	INCLINATION	ASCENDING NODE	
Input Format	N	AAA	HHH:MM:SS.SS OR NN	NNN.NNN	DOD:MM:SS		
Input Units	FXP	EBCDIC	hours OR FXP	deg	LONG		
Program Units	FXP		hours OR FXP	radians	radians		
Scale Factor				radians per degree			
Checking Option	MINMAX ⁽¹⁾	Exact ⁽²⁾	None	MINMAX ⁽⁴⁾	None		
Missing Item Option	Error	Error	Error	None 3	None 3		
Item Destination							

Programmer: S. Wright

Initial Logic: NA

Final Logic: Set up SP2 for special queue to ETISPLAY

Illegal Phases:

Notes: (1) $1 \leq N \leq 3$

(2) GET

MNV

(3) Mandatory when manual column = 2,
otherwise illegal(4) $-\pi/2$ to $\pi/2$

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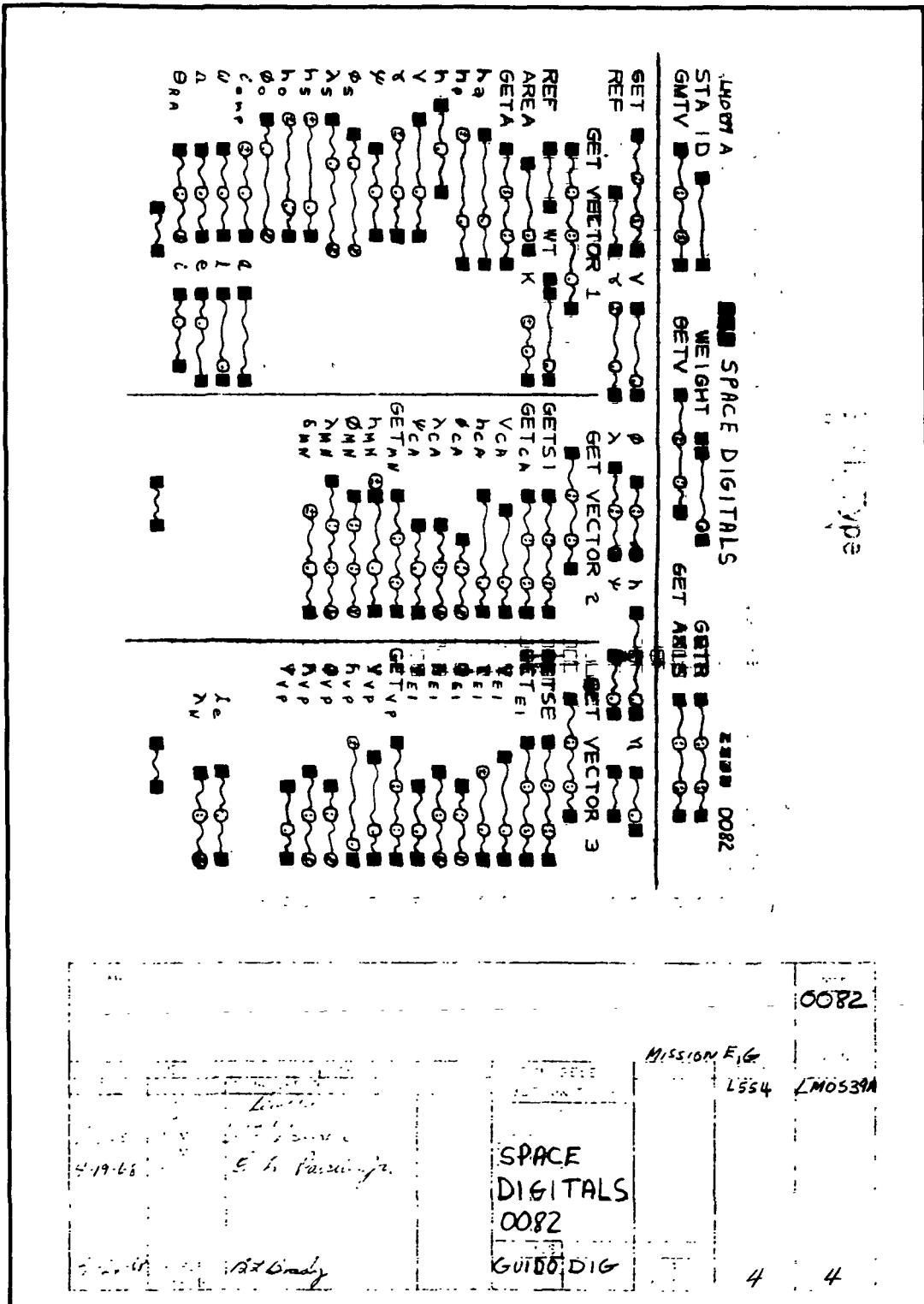
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Exhibit 54



LANDMARK ACQUISITION DISPLAY

Function

The function of the Landmark Acquisition Display is to compute spacecraft acquisition and local sunrise/sunset data for specified Earth and lunar landmarks.

Load Module/Subroutine Description - EMDLANDM

EMDLANDM contains the necessary logic and display features to generate the Land Mark Acquisition Display. The GET of local sunrise and sunset, the angle from the vehicle to the landmark site at GET_{CA}, and the spacecraft altitude at GET_{CA} in moon reference are calculated within the routine. The times of GET_{AOS}, GET_{LOS}, and GET_{CA} are calculated by EMXING via EMGENGEN.

Other programs used are as follows: ELNMVC, vector count subroutine; ELFECH, ephemeris fetch subroutine; ELVCNC, coordinate conversion subroutine; ELVCTR, extended interpolation subroutine; PLEFEM, interpolation in the sun/moon ephemeris table subroutine; and GLSSAT, subsatellite subroutine for the oblate height above the Earth.

Requirements Interpretation

In this section, an attempt has been made to include all known requirements as of the publication date of this document. In addition to the interpretation of these requirements, a copy of the TR170 requirements has been included and annotated for direct reference to appropriate paragraphs in the interpretation section. These references have been provided where clarification or qualification was felt necessary. If any item or capability described in the TR170 document has not been provided, specific mention of this has been made in the margin adjacent to the appropriate paragraph. Parameters computed and/or displayed or capabilities afforded but not included in the NASA requirements, have been mentioned in the margin of the TR170 and appropriately indexed to the interpretation. The abbreviation I/O refers to the Input/Output Specifications section.

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ITEM

1. Requirements source

The requirements for the processing of the Landmark Acquisition Display originate from two sources: TR170, sec. O. T., par. 2.2.4, change 58 (See Exhibit 55) and the Philco Format FCN # LM0601.

2. Initialization of display

This display is initialized by MSK request.

3. Updates

There are no automatic updates associated with this display; however, it will respond to one MED, in which case all parameters are regenerated.

4. Parameters to be computed and/or displayed.

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
Vector ID	Identification of last vector used to update the ephemeris	
STA ID	Identification of landmark	
GET _{AOS}	GET of acquisition of landmark site by vehicle	hr:min:sec
GET _{LOS}	GET of loss of sight of the landmark by the vehicle	hr:min:sec
GET _{CA}	GET of closest approach of the vehicle to the landmark	hr:min:sec
GET _{SR}	GET of local sunrise	hr:min
GET _{SS}	GET of local sunset	hr:min
λ	Viewing angle from the vehicle to the landmark site at GET _{CA}	deg.

<u>Quantity</u>	<u>Definition</u>	<u>Dimensions</u>
h	Spacecraft altitude at GET _{CA}	NM
Page #	Page of display currently being viewed	
TUN	Trajectory update number of subject vehicle ephemeris	

5. General

- a. This display will process for the primary vehicle only.
- b. Earth site contact data will be driven for any phase.
- c. Moon site contact data will be processed only if the vehicle is within nEr of the moon, where n will be a system parameter to be defined later.

6. Manually driven data

- a. The display will begin processing data at a time specified via MED entry.
- b. If a contact is found, the first local sunrise/sunset for that landmark within the ΔT specified on the MED following the threshold time will be computed and displayed.

7. Computation requirements

- a. The following computation requirements have been set for logical processing limits.
 - (1) If no contacts are discovered for a ground point, no entry is required on the display for that landmark.
 - (2) A maximum of 12 ground points will be processed.
 - (3) Site identification will be displayed as four alphanumeric characters.

- (4) Should only one environment change occur in the 24 hour period following the threshold time, the sunrise or sunset time will be displayed in the appropriate area while the other will be blanked.
- (5) A maximum of 12 ground points will be processed. The contacts displayed will be those encountered earliest by AOS.
- (6) For partial contacts processing, boundary times will be displayed for the missing AOS or LOS and flagged with an asterisk.
- (7) Should a landmark contacted be in constant daylight, the words "TOTAL DAY" will be displayed in place of local sunrise/sunset times. Should the site be in constant darkness, the words displayed will be "TOTAL NIGHT".
- (8) A maximum of three "pages" will be available. However, a maximum of five contacts for any single landmark will be displayed.
- (9) Earth or moon sites may be loaded into the ground point table, but they cannot be mixed.

b. The mathematical requirements are as follows:

- (1) The local sunrise/sunset times must be accurate to within 30 seconds.
- (2) The time of closest approach is defined as the time of maximum elevation.
- (3) AOS/LOS times must be accurate to within three seconds.

λ is computed as the subtended angle (viewing angle in degrees to the nearest tenth) between the spacecraft nadir and the landmark at the closest approach. The formulation used is:

$$\lambda = \cos^{-1} (\hat{p} \cdot \hat{r}) \text{ where}$$

\hat{p} = unit vector from station to spacecraft

\hat{r} = unit radius vector of spacecraft

Exhibit 55

PHO-TR170A
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OT 2.2.4 Land Mark Acquisition Display

A. Purpose. To supply flight crew with pointing data that will aid them meeting operational or experimental objectives.

B. Data Source.

- Current ephemeris
- Sun ephemeris
- Ground point table (earth and moon)

C. Initialization of Display. This display will be initialized upon manual input of the following quantities:

<u>QUANTITY</u>	<u>DEFINITION</u>
GET	Time to start looking for a station
Δt	Time that GET will be incremented, not to exceed 24 hours
(E or M)	E equals earth reference; M equals moon reference

D. Parameters to be Computed and Displayed. The following quantities will be computed and displayed.

<u>QUANTITY</u>	<u>DEFINITION</u>
VECTOR ID	ID of anchor vector
STA ID	A 5-digit code indicating the station (earth or lunar) which will come in view of the spacecraft
GET _{AOS}	The time the station comes within view of the spacecraft (hr:min:sec)
GET _{LOS}	The time the station passes from the view of the spacecraft (hr:min:sec)
GET _{CA}	The time the longitude of the station passes under the spacecraft (hr:min:sec). This is the same as the time of maximum elevation (E_{MAX}).

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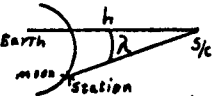
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QUANTITY	DEFINITION
GET _{SR}	The time the station passes through the terminator into the daylight (local sunrise) (hr:min)
GET _{SS}	The time the station passes through the terminator into darkness (local sunset) (hr:min)
λ	The subtended angle (viewing angle in degrees to the nearest tenth) between the spacecraft nadir and the station measured at the spacecraft at the time of closest approach
	
h	The spacecraft altitude at the time of closest approach (nm). The altitude is oblate with respect to the earth and spherical with respect to the moon.
Page No.	In some cases, the monitor may not be able to display all of the information requested. In these instances, several "pages" may be required to display all of the information. This will indicate which "page" is being viewed. (Max of 3 pages)

Update Number

E. Updates. This display has no automatic updates.F. Additional Information.

1. The computation for a station should begin following the GET input time and proceed automatically for the specified input Δt or a maximum of 24 hours.
2. A maximum of 12 ground points is allowed in the ground point table.
3. This display is for the primary vehicle only.
4. If no contacts can be found for a ground point, then no GET_{SR} or GET_{SS} will be displayed for that point.
5. Earth or moon sites can be loaded into the Ground Point Table but cannot be mixed.

Approved: 

NASA/FSB

PHO/PARS

(OT) 2.2.4-2

Exhibit 55 (Cont'd.)

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6. Earth site contact information will be available in earth orbit, translunar and transearth coast, lunar orbit phase and during lunar stay.
7. Moon site contact data can only be requested if the primary vehicle is X earth radii from the moon. This X E.R. will be a system parameter and will be the same one that affects ESAD.

Approved: NASA/FSB PHO/PARS

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Exhibit 56

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Figure OT 2.2.4-1 Land Mark Acquisition Display

(To be provided)

Approved: PH

NASA/FSB

PHO/PARS

(OT) 2.2.4-4

Functional Diagrams

Figure 32 illustrates the interfaces of the programs in the Landmark Acquisition Display Element with other elements, units, or subsystems. Data table usage, task structure, and input/output data flow are also included. The symbols used in the diagrams are defined in the Glossary of this document.

Input/Output Specifications

This section contains the U17 MED format, the landmark Acquisition Display format, and a list of CRT error indications.

The following error conditions are detected and indicated by an asterisk on the CRT accompanied by the corresponding numerical code.

1. MED input required
2. No ephemeris available for subject vehicle
3. Ephemeris update in process
4. Precession/nutation matrix not available for time of concern.
5. Threshold time not in ephemeris
6. Landing site table not initialized
7. Vehicle out of lunar range at threshold time (lunar ground point request)
8. No station contacts for allotted time

These error codes have been selected based on the best information available to date.

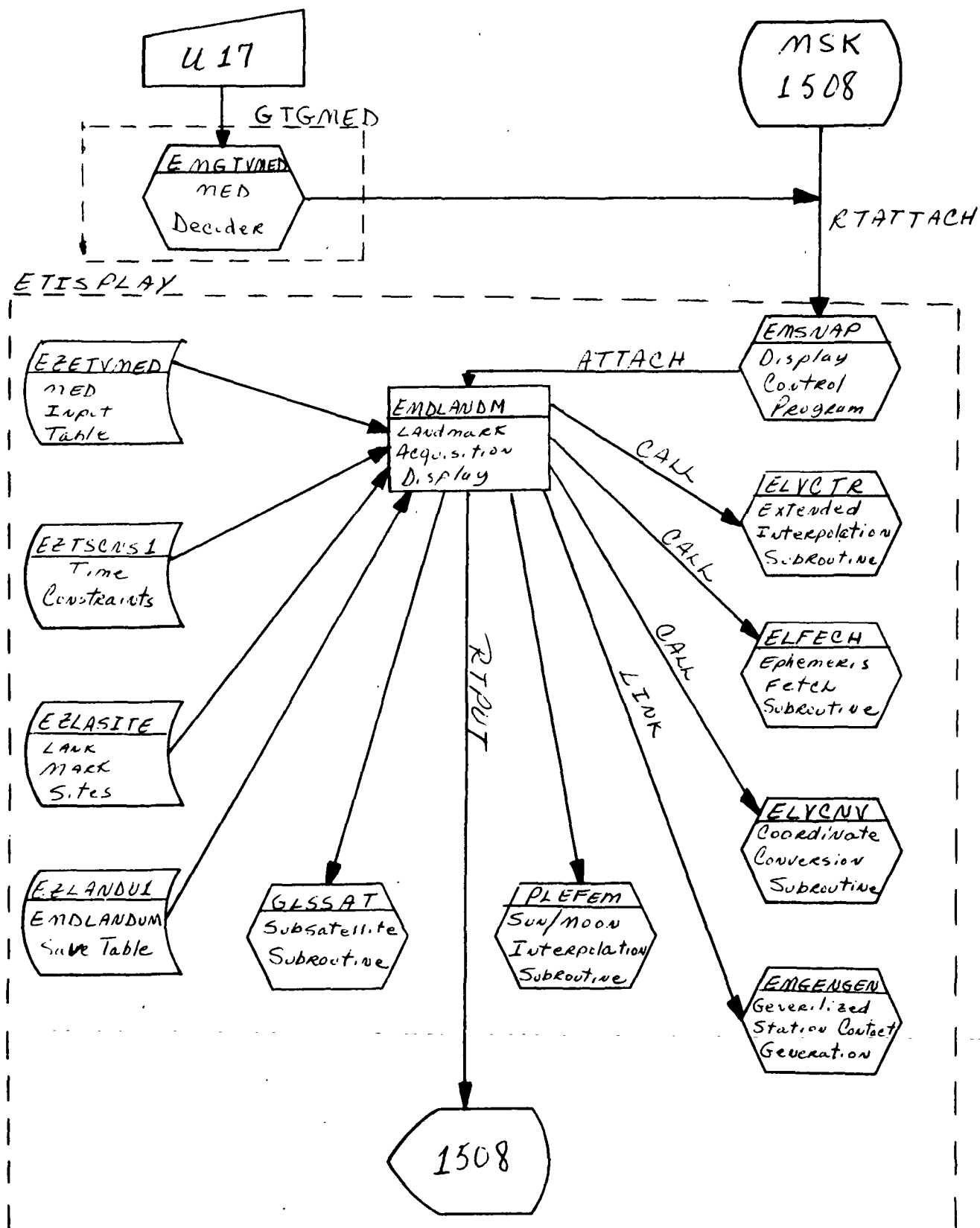


Figure 32. Landmark Acquisition Display



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MED Format Table

MED Code: U17
 Purpose: Landmark acquisition
 Load Module: EMGTVMED
 Task: NA
 EP: NA
 QNAME: NA
 QUEID: NA

Desc.	Item	1	2	3	4	5	6
Item Name	VEH ID	TIME	Δ TIME	REF			
Input Format	AAA	HHH:MM:SS.SS	HHH:MM:SS.SS	A			
Input Units	EBCDIC	GET	GET	EBCDIC			
Program Units	Note 1	hours	hours	Note 5			
Scale Factor							
Checking Option	Exact (2)	None	MINMAX ⁽³⁾	Exact (4)			
Missing Item Option	Error	Error	Error	Assume "E"			
Item Destination							

Programmer: S. Wright

Initial Logic:

Final Logic: Store in block 17 of EZETVMED

Illegal Phases:

Notes: (1) EBCDIC name and numeric code

(2) CSM

(3) $0 \leq \Delta t \leq 24$ hours

(4) E, M (for Earth or moon)

(5) E = 0, M = 2

66-2656-1

GUIDANCE OPTICS AND SIGHTINGS UNIT

SCOPE

The GOST (Guidance Optics and Sightings) Unit includes programs that aid flight controllers in accomplishing the following mission objectives.

To provide RTCC calculated crosschecks of CSM/LM inertial measurement unit (IMU) alignments. Whenever the astronauts have gone through a procedure to determine, check and/or realign the spacecraft's platform, flight controllers may request the RTCC to compute an alignment that compares with the on-board solution. The following on-board procedures are simulated:

1. Launch alignment - platform alignment based on guidance reference release time and launch azimuth (CSM)
2. Orbit/deorbit maneuver alignment - platform alignment based on spacecraft state, thrust direction, and engine nozzle trim at burn initiate (CSM/LM)
3. Local vertical alignment - platform alignment based on spacecraft state at alignment time (CSM/LM)
4. Star sighting alignment - platform alignment based on sighting equipment angles to two stars whose inertial direction is recognized by the on-board system (CSM/LM)
5. Docked alignment - platform alignment based on relationship to docked vehicle whose alignment is known (LM)
6. Lunar local alignment - platform based on local alignment with the moon during lunar stay (LM)
7. Vehicle observation alignments - platform based on CSM sextant sightings to the landed LM or landed LM rendezvous radar readings to the lunar orbiting CSM (LM)

To maintain tables (lockers) of spacecraft (CSM/LM) platform alignments obtained from various sources that will be available to flight controllers and the RTCC system for one or more of the following applications in this and other RTCC subsystems:



1. Transformation of telemetry data sent in the spacecraft platform coordinate system into inertial coordinate systems
2. Computation of platform (IMU) attitudes (P, Y, R) that describe a spacecraft's body attitude during a mission function, such as orbit and deorbit maneuvers, body alignment checks, pointing and sighting experiments, target acquisitions, etc.
3. Cross-checks to verify the spacecraft's platform alignment throughout a mission
4. Digital Command System's loading of the on-board computer in contingency cases.

To meet these ends, the following categories of IMU alignments can be collected, computed, and/or maintained by the GOST unit:

<u>Alignment (symbol)</u>	<u>Spacecraft</u>	<u>Source</u>
Current (CUR)	CSM/LM	Selected (from RTCC locker) by flight control as a verified representation of the spacecraft's present mission IMU alignment
Previous (PCR) Current	CSM/LM	One history CUR kept for quick access
Telemetry (TLM)	CSM/LM	Alignment received from high-speed or low-speed telemetry inputs from the spacecraft's on-board computer memory would represent the product of an on-board procedure to determine the IMU alignment
Optical (OST) Sighting	CSM/LM	The results of an RTCC computation done to simulate one of several on-board procedures used to calculate IMU alignment from two celestial targets whose inertial direction is known to the on-board system
Manually (MED) Entered	CSM/LM	Any IMU alignment entered by RTCC MED

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Detailed (DMT) Maneuver Testing	CSM/LM	Any alignment used in an orbit maneuver plan including the preferred or desired alignment (DES) calculated by RTCC for a specific maneuver to simulate the on-board procedure
Deorbit (DOD) Maneuver Digitals	CSM/LM	Any alignment used in a MANUAL or spacecraft SETTING deorbit maneuver plan or in a PRIMARY or MANUAL return-to-Earth maneuver plan including the preferred or desired alignment (DES) calculated by RTCC for a specific maneuver to simulate the on-board procedure
Docked (DOK)	LM	The results of an RTCC computation performance to simulate the on-board procedure of determining the LM IMU alignment via its docked relationship to the CSM whose inertial body attitude is known
Local (LCV) Vertical	CSM/LM	The results of an RTCC computation performed to simulate the on-board procedure of aligning the platform to the Earth or moon local horizontal/local vertical at a specific mission time
Abort (AGS) Guidance System	LM	Selected (from RTCC locker) by flight control as a verified representation of the spacecraft's present mission AGS "strapped down" platform alignment
Lunar (LLA) Launch Actual	LM	Last alignment generated on the Lunar Surface Alignment Display and saved (from sighting, local, or rendezvous radar)
Lunar Launch Desired	LM	Last alignment generated on the Lunar Surface Alignment Display and saved (from landing site and CSM orbit)

To provide TV displays for the guidance controllers, which display IMU alignments and their source data for spacecraft cross-check, and to select and display equipment sighting angles to targets in view at a particular inertial body attitude that will be voiced to the astronaut to visually check his spacecraft attitude.

To provide TV displays for experiments using sensory and optical equipment to sight the following:

1. Earth targets (landmarks, weather phenomena, aircraft, rocket ejected vapor clouds, etc.)
2. Lunar targets (landmarks, landed vehicles, etc.)
3. Orbiting vehicles (any whose ephemeris is stored by RTCC)
4. Celestial phenomena (rays, etc.)
5. Stars.

To provide TV display of the LM lunar landing site as computed from a lunar local vertical/local horizontal IMU or from a LM body alignment and a LM sensed lunar gravity vector.



INERTIAL MEASUREMENT UNIT ALIGNMENT LOCKER MAINTENANCE ELEMENT (CSM/LM)

Function

The function of this element is to obtain CSM launch (GRR) platform alignment for storage in the locker as an automatic CUR matrix at entry into Orbit phase processing and to handle manually input alignments (MED) for the CSM and LM. This element will also handle alignment locker movements — MED inputs to move alignments from one locker position to another for CSM and LM, and will provide locker storage, matrix ID word updates (CUR001, TLM006, etc.), and on-line printing for all GOST elements.

Load Modules/Routines Descriptions

GOST General Locker Maintenance - EMGSTGEN

This load module initializes current CSM REFSMMAT at orbit initialization, accomplishes REFSMMAT locker movements and provides MED matrix capability.

GOST Matrix Storage and Print - EMGSTSTM

The function of this program is to store a given REFSMMAT in the GOST REFSMMAT lockers with ID and associated time and to print a matrix on line.

Requirements Interpretation

Exhibit 57 represents TR170 requirements applicable to this element as of the date of this Functional Specification. Reference item numbers have been affixed to the TR170 pages in the left margin which correspond to included paragraphs of our comments (e.g., amendments, additions, and/or interpretations).

In the case of TV display output items, an additional reference column has been affixed to the TR170 pages in the right margin, which references four sections of output clarification:

- A — when item is displayed
- B — errors associated with item when displayed
- C — when item is not displayed
- D — errors associated with item when not displayed.

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Exhibit 57

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ITEM:

<u>QUANTITY</u>	<u>DEFINITION</u>
GET	Time for which line-of-sight to earth or moon landmark or center of sun is computed
RA	Right ascension of landmark LOS or specified star
DEC	Declination of landmark LOS or specified star
SC	Sighting code. First two spaces indicate vehicle (C,L) and number. Third space indicates body sighted (E,M,S)
ix, iy, iz	Unit vector in octal of landmark LOS or of specified star
SC	Star for which unit vector and RA, DEC are displayed. Displayed in same position as sighting code.

E. Update. This display will be updated on manual entry initializing the display. Star information is computed based on the matrices specified in this entry.

F. Additional Information

1. The manual entries which control this display and its associated displays and functions are described in OT 4.1.1.
2. The REFSMMAT computed at guidance reference release during Launch phase will be established as the first current REFSMMAT upon entering Orbit phase.
3. For a specified time, REFSMMAT, and attitudes, the real-time program will compute the IMU inner gimbal angle (IGA) required to place the CSM X-axis tangent to the horizon of the central body. A search will be made of the star catalogue in an attempt to find two stars which can be placed in the scanning telescope FOV with one star on the R line and one star on the M line. A search will also be made in an attempt to find two stars which occur in the boresight FOV. Such sighting as is found will be displayed.

Approved: 

NASA/FSB

PHO/PARS

(OT) 4.2.1-3

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4. A star catalogue of 400 star locations will be maintained. The first 391 locations will be fixed and nonchangeable in real-time. The last nine locations may be defined by MED in real-time.
5. The real-time program will select for display only those stars in the first 397 which are not occulted by the earth, moon or sun. The occultation test will not be made for the last 3 locations.
6. The following REFSMMATS will be maintained in the CSM REFSMMAT locker. A REFSMMAT's ID number will be incremented when the REFSMMAT is updated.
 - a. Current (CUR). The current REFSMMAT is established as current by MED control upon instruction by the Guidance Officer. Any other REFSMMAT in the locker can be made current. The CUR best specifies the orientation of the IMU platform as such is used for processing telemetry data based on platform alignment.
 - b. Previous Current (PCR). One history REFSMMAT is maintained.
 - c. Manual Entry (MED). A REFSMMAT manually entered.
 - d. Telemetry (TLM). A REFSMMAT saved from S/C telemetry.
 - e. Maneuver (DMT). Any other REFSMMAT specified as the DMT for a particular maneuver or a desired alignment computed to give a required set of initial attitudes for a particular maneuver.
 - f. Optical Sighting (OST). A REFSMMAT computed either from telemetry optics or manually entered optics.
 - g. Local Vertical (LCV). A REFSMMAT computed to place the spacecraft heads-up, wings-level with zero attitudes at a specified time.
 - h. Deorbit (DOD). A REFSMMAT saved from either the primary or manual column of the Return-to-Earth Digitals, the manual column of the Retrofire Digitals, or the Spacecraft Setting (which is the same for both the Return-to-Earth and the Reentry Digitals).
7. The automatic time-to-fire calculation will use the current REFSMMAT.
8. When an OST REFSMMAT is computed, the angle between the line-of-sight vectors defined by the input data will be computed and printed on-line. In addition the angle between the two stars will be computed from the RTCC star catalogue and printed on-line.

Approved: 6 NASA/FSB PHO/PARS

(OT) 4.2.1-4

Exhibit 57 (Cont'd.)

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2. Option Available in All Modes

- a. Two REFSMMATS must be designated in the display initialization MED and an additional code for this option included.
- b. When the option code is included in the initialization MED, realignment attitudes, both in gimbal angles and in FDAI angles, will be computed and displayed.
- c. The realignment attitudes will give angles in the coordinate system, described by MAT 1, to align the spacecraft body axis to the coordinate system, described by MAT 2. This will be essential for the AGS mode when the out-of-plane constraint is violated.
- d. The second matrix (MAT 2) will probably be a local vertical alignment computed and saved at an earlier time, or it may come from the DMT (for AGS mode).
- e. The realignment attitudes will give a comparison of any two matrices available even when no realignment may be considered.

3. LM REFSMAT Locker. This locker will store the following matrices:

- DMT Computed for selected maneuver from the Detailed Maneuver Table
- LCV Computed for local vertical/horizontal alignment at some specified time
- DOK Computed while LM and CSM are docked
- OST Computed from star sightings
- TLM Obtained from telemetry downlink
- MED Manually entered in the processor from data furnished by the Guidance Officer
- CUR Any other REFSMMAT chosen by the Guidance Officer to be used to generate attitudes for maneuvers, process telemetry vectors, and to best specify present alignment
- PCR Previous current REFSMMAT - matrix last used as current

Approved: NASA/FSB _____ PHO/PARS

Exhibit 57 (Cont'd.)

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- DOD Saved from Retrofire Digitals or Return-to-Earth Digitals
 - LLA Lunar Launch Actual saved from LSAD
 - LLD Lunar Launch Desired saved from LSAD
 - AGS Chosen by the Guidance Officer to be used to generate AGS attitudes for LM maneuvers, process AGS telemetry vectors, and to best specify present AGS alignment.
4. Present stored attitudes will be displayed on initialization of the display.
 5. Generally, error comments will appear in the space on the display where requested data would have appeared.
 6. The AOT (Alignment Optical Telescope) is a 60 degree field-of-view instrument mounted with its LOS permanently set about 45 degrees above the LM Y-Z plane. It can be used in six detent positions. Detent 1 is forward with 2, 3, 4, 5 and 6 counted clockwise about the LM x axis in increments of 60 degrees.
 7. The COAS (Crewman Optical Alignment Sight) is a 10 degree field-of-view instrument which can be mounted in either the overhead or forward window.
 8. Any time GETHORIZ is entered the display is in CHK mode. If GETHORIZ is omitted, the mode is determined by MATRIX 1.
 9. The LM Optics Support Table will use the same star catalogue as the CSM GDO Optics Support Table.
 10. If attitudes are manually entered, at least one angle must be other than zero.
 11. When an OST REFSSMAT is computed, the angle between the line-of-sight vectors defined by the input data will be computed and printed on-line. In addition the angle between the two stars will be computed from the RTCC star catalogue and printed on-line.

Approved: *[Signature]* NASA/FSB PHO/PARS

Item 1

A queue to establish the initial CSM CUR from the launch GRR (P12) orientation will be sent to this element at Orbit phase initialization. If the GRR matrix has not been RTCC computed, CUR000 for the CSM will be set to identity. For the LM, initial data in the LM locker will provide an identity matrix for the LM CUR and AGS slots (CUR000 and AGS000). The P12 MED will be rejected by the RTCC if entered after the first G00 MED to establish a CSM CUR.

Functional Diagrams

Figure 33 shows the interfaces of the programs in the CSM/LM REFSMMAT Locker Maintenance Element with other elements, units, or subsystem. Also illustrated are data tables usage, task structure, and input/output data flow. The symbols used in the diagrams are defined in the Glossary of this document.

Input/Out Specifications

This section contains G00 and G01 MED's and the on-line prints that will be provided by this element. The text of the on-line printouts, its meaning and the recovery procedure, if applicable, follows.

1. REFSMAT NOT AVAILABLE

Input of GOST MED's G00, G02, G11, G21, or G23 when the referenced REFSMMAT has not been defined in the CSM or LM locker. The platform alignment (REFSMMAT) must be defined with one of the GOST procedures.

2. NEW IMU MATRIX AAANN AAA GET=NNN:NN:NN

±. NNNNNN ±. NNNNNNN ±. NNNNNNNN
 ±. NNNNNN ±. NNNNNNN ±. NNNNNNNN
 ±. NNNNNN ±. NNNNNNN ±. NNNNNNNN

This message is printed with appropriate matrix ID (ex. "CUR001, TLM014") whenever a new CSM or LM alignment is created and saved.

3. GRR MATRIX NOT AVAILABLE

This message is printed if Orbit phase processing is initiated, and a launch GRR platform alignment for the CSM has not been computed.

Functions: CSM CUR 001
MED Refsmmat
Refsmmat locker
movements
(Locker storage/print)

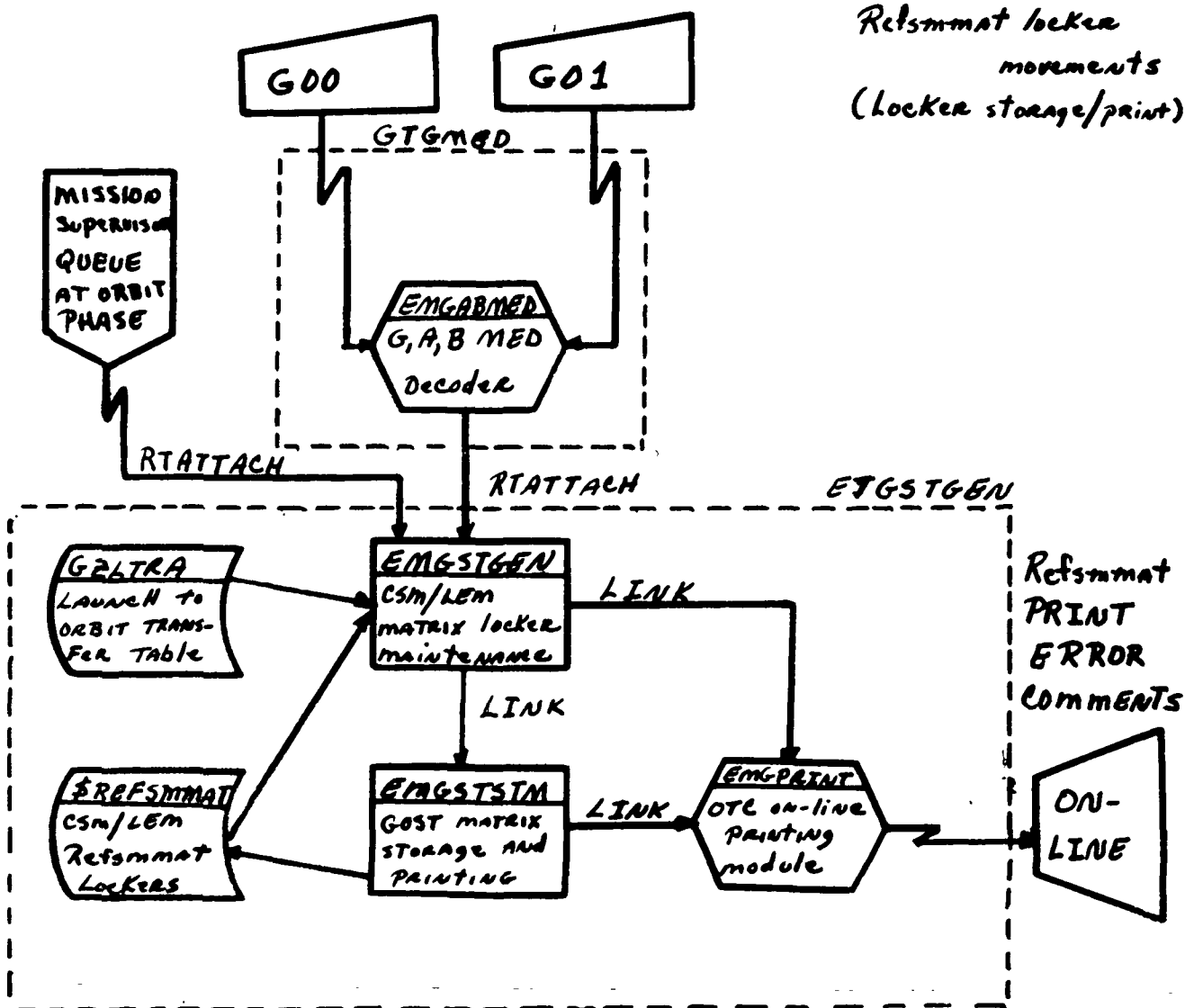


Figure 33. CSM/LM REFSMMAT Locker Maintenance

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MED Format Table

MED Code: G00 Task: ETGSTGEN
 Purpose: CSM/LM REFSMMAT locker movement EP: EMGSTGEN
 Load Module: EMGABMED QNAME:
 QUEID: 2
 DPRIOR: MKDGMF

Desc.	Item	1	2	3	4	5	6
Item Name		CSM/LEM Vehicle	Matrix 1	CSM/LEM Vehicle	Matrix 2	GET	
Input Format		XXX	XXX	XXX	XXX	XXX:XX:XXXX	
Input Units		EBCDIC	EBCDIC	EBCDIC	EBCDIC	HRS:MIN:SEC	
Program Units		Numeric Code	Numeric Code	Numeric Code	Numeric Code	Hours	
Scale Factor							
Checking Option		Exact	Exact	Exact	Exact	≤ Current Time	
Missing Item Option		Error	Error	Error	Error	= Current Time	
Item Destination		Disp. 0 H	Disp. 2 H	Disp. 4 H	Disp. 6 H	Disp. 8 D	

Programmer: J. Emrick
 Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low), PLII, Reentry, Transit, Stay

Notes:

For matrix 1, valid codes are CUR, PCR, TLM, OST, MED, DMT, DOK, LCV, DOD, LLA, LLD, AGS for the LEM and CUR, PCR, TLM, OST, MED, DMT, DOD, and LCV for the CSM. For matrix 2, valid codes are CUR, PCR, TLM, MED and LCV for the CSM and CUR, PCR, TLM, MED, LCV, LLA, and AGS for the LEM.



MED Format Table

MED Code: G01
 Purpose: Enter manual IMU matrix
 Load Module: EMGABMED
 Task: ETGSTGEN
 EP: EMGSTGEN
 QNAME:
 QUEID: 3
 DPRIOR: MKDGMF

Desc.	Item	1	2	3	...	11
Item Name	CSM or LEM Vehicle	Matrix	Element 1			Element 9
Input Format	XXX	XXX	+.xxxxxxxxxx	+.xxxxxxxxxx	...	+.xxxxxxxxxx
Input Units	EBCDIC	EBCDIC	FLP	FLP	...	FLP
Program Units						
Scale Factor						
Checking Option	Exact	Exact	$1 \geq 0 \geq -1$	$1 \geq 0 \geq -1$...	$1 \geq 0 \geq -1$
Missing Item Option	Error	Insert	Insert	Insert	...	Insert
Item Destination	Disp. 74 H	Disp. 72 H	Disp. 0 D	Disp. 64 D	...	

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low), PLII, reentry, transit, stay, PLI

Notes: 1. Vehicle must be input on each entry. Any or all items may be input on an entry.

When all 11 items are input, the matrix will be checked to see if it is orthogonal. If it is, then the matrix will be sent.

2. Valid inputs for matrix are PCR, TLM, MED, and LCV for both CSM/LM and LLA for LM only.

GUIDANCE OPTICS SUPPORT ELEMENT (CSM)

Function

This element collects and saves CSM optics and attitudes data from the following sources for various applications:

1. High-speed and low-speed telemetry REFSMMAT (TLM)
2. High-speed and low-speed telemetry optics and attitudes from an on-board celestial IMU fine alignment
3. High-speed and low-speed telemetry live IMU attitudes
4. Orbit, deorbit, and return-to-Earth maneuver planning REFSMMAT's, attitudes and associated data (DMT/DOD)
5. Manually entered optics and attitudes to simulate the on-board celestial IMU fine alignment procedure.

In addition, this element computes and saves an optical sighting (OST) REFSMMAT from either telemetry or manually input optics and attitudes (CSM), as well as computes data and formats the CSM Guidance Optics Support Table TV display (MSK 229).

Load Modules/Routines/Descriptions

GOST CSM Optics Support Data Collection - EMSGSUPP

This load module receives and processes manual inputs requesting collection or computation of the following items:

1. High-speed or low-speed telemetry matrix from telemetry/trajectory interface tables
2. OST matrix from telemetry or manual optics computation
3. DMT matrix and attitudes from the Mission Plan Table
4. High-speed or low-speed telemetry optics and attitudes from telemetry/trajectory interface tables
5. High-speed or low-speed telemetry live attitudes from telemetry/trajectory interface tables
6. DOD matrix and attitudes from the Deorbit Planning tables - (MANUAL or SPACECRAFT SETTING column) or Return-to-Earth tables - (PRIMARY or MANUAL column)
7. Manually entered optics and attitudes.
8. Computation and storage of manually entered targets to be added to the GOST star/target catalog.

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GOST CSM Optics Support Display Mathematics - EMMGSTMP

This program computes a pool of data for MSK 229 based on an input MED. Specifically it computes star sighting angles for the CSM scanning telescope, sextant, and boresight and related quantities as requested by the MED.

GOST CSM Optics Support Display Formatter - EMDGSUPP

This program formats TV display MSK 229 based on indicators and data given by subpool built by EMMGSTMP.

Requirements Interpretation

Exhibit 58 represents TR170 requirements applicable to this element as of the date of this Functional Specification. Reference item numbers have been affixed to the TR170 pages in the left margin which correspond to included paragraphs of our comments (e. g., amendments, additions, and/or interpretations).

In the case of TV display output items, an additional reference column has been affixed to the TR170 pages in the right margin which references four sections of output clarification:

- A - when item is displayed
- B - errors associated with item when displayed
- C - when item is not displayed
- D - errors associated with item when not displayed.

Our interpretation of the numbered items in the left column is given below.

ITEM (See TR170 copy)

1. Display will be active from Earth orbit insertion to Earth deorbit, including descent, stay, and ascent for the LM.
2. For OST REFSMMAT's, both from telemetry optics or manual optics, two sets of IMU attitudes will be used.
3. Distinct locker space will be maintained for the following:
 - a. Manual attitudes
 - b. Telemetry live attitudes
 - c. Telemetry optics attitudes
 - d. Orbit maneuver attitudes



Exhibit 58

PHO-TR170A
Volume 2, Change 45
15 Jan. 1968

ITEM:

OT 4. OPTICS

OT 4.2 Optics OutputOT 4.2.1 GDO Optics Support Table (GOST)

A. Purpose. To evaluate CSM IMU alignments and provide ground support for optical sightings to attain backup attitude orientations.

B. Data Sources. The following sources will be used:

- Mission Plan Table
- Deorbit Digital Table
- S/C Telemetry (high-speed or teletype on format)
- Detailed Maneuver Table
- Return to Earth Digitals.

1 C. Initialization of Display. This display will be initialized only by manual entry.

D. Parameters To Be Computed and Displayed

	<u>QUANTITY</u>	<u>DEFINITION</u>
7	Code	Identification of maneuver to be performed
	S1 and S2	Sextant stars to be sighted
	SFT	Sextant optics shaft angular setting for star sighting (deg)
	TRN	Sextant optics trunnion angular setting for star sighting (deg)
	S1 and S2	Scanning telescope stars to be sighted
	SFT	Scanning telescope optics shaft angular setting for sighting (deg)
	TRN	Scanning telescope optics trunnion angular setting for star sighting (deg)

A B C D

7	-	3	-
2	-	2	2
		3	
2	-	2	2
		3	
2	-	2	2
		3	
3	-	2	3
		3	
3	-	2	3
		3	
		5	

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Exhibit 58 (Cont'd.)

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ITEM	QUANTITY	DEFINITION	A	B	C	D
	RA	Right ascension of scanning telescope star.	3	-	2 3 5	3
	DEC	Declination of scanning telescope star	3	-	2 3 5	3
	M, R	Linear coordinates on the scanning telescope reticle specifying the desired placement of stars in the field of view during backup attitude orientation	3	-	2 3 5	3
	S1 and S2	Boresight stars to be sighted	4	1	2 3 5	3
	SPA, SXP	Boresight star pitch angle specifying pitch of boresight to place star on the reticle horizontal X-line and position of star on the X-line during backup attitude orientation	4	1	2 3 5	3
	RA	Right ascension of boresight star	4	1	2 3 5	3
	DEC	Declination of boresight star	4	1	2 3 5	3
	θ_H, ψ_H, ϕ_H	Pitch, yaw and roll attitudes for the maneuver referenced to the IMU aligned to a local vertical orientation. Associated with DMT REFSMMAT.	7	-	3	-
	GETAC	Ground elapsed time of alignment check	5	-	2 3 5	3
8	IGA	Inner IMU gimbal angle computed to place the S/C X-axis tangent to earth horizon at GETAC with MGA and OGA = 0	5	-	2 3 6	3 5
	IRA	Inertial reference alignment of IGA computation. Same REFSMMAT used in generating SCT data.	5	-	2 3 6	3 5
	MAT	Identification code and the nine elements of the REFSMMAT displayed. This transformation matrix takes reference coordinates into stable member coordinates. The first row is the X stable member axis projected onto the Reference coordinate system. The second and third rows are the Y and Z axes respectively.	6	-	3 4	4
	P, Y, R	The requested stored IMU gimbal angles. May be telemetry, optics associated, maneuver associated, or manually entered. May be one set or two sets.	6	-	3 4	4

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(OT) 4.2.1-2

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Exhibit 58 (Cont'd.)

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		A B C D			
<u>QUANTITY</u>	<u>DEFINITION</u>				
GET	Time for which line-of-sight to earth or moon landmark or center of sun is computed	8	-	1 2 3	6
RA	Right ascension of landmark LOS or specified star	8	-	1 2 3	6
DEC	Declination of landmark LOS or specified star	8	-	1 2 3	6
SC	Sighting code. First two spaces indicate vehicle (C,L) and number. Third space indicates body sighted (E,M,S)	8	-	1 2 3	6
ix, iy, iz	Unit vector in octal of landmark LOS or of specified star	8	-	1 2 3	6
SC	Star for which unit vector and RA, DEC are displayed. Displayed in same position as sighting code.	8	-	1 2 3	6
E. <u>Update</u> . This display will be updated on manual entry initializing the display. Star information is computed based on the matrices specified in this entry.					

F. Additional Information

1. The manual entries which control this display and its associated displays and functions are described in OT 4.1.1.
2. The REFSMMAT computed at guidance reference release during Launch phase will be established as the first current REFSMMAT upon entering Orbit phase.
3. For a specified time, REFSMMAT, and attitudes, the real-time program will compute the IMU inner gimbal angle (IGA) required to place the CSM X-axis tangent to the horizon of the central body. A search will be made of the star catalogue in an attempt to find two stars which can be placed in the scanning telescope FOV with one star on the R line and one star on the M line. A search will also be made in an attempt to find two stars which occur in the boresight FOV. Such sighting as is found will be displayed.

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Exhibit 58 (Cont'd.)

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Volume 2, Change 58
19 April 1968

ITEM:

4. A star catalogue of 400 star locations will be maintained. The first 391 locations will be fixed and nonchangeable in real-time. The last nine locations may be defined by MED in real-time.
5. The real-time program will select for display only those stars in the first 397 which are not occulted by the earth, moon or sun. The occultation test will not be made for the last 3 locations.
6. The following REFSMMATS will be maintained in the CSM REFSMMAT locker. A REFSMMAT's ID number will be incremented when the REFSMMAT is updated.
 - a. Current (CUR). The current REFSMMAT is established as current by MED control upon instruction by the Guidance Officer. Any other REFSMMAT in the locker can be made current. The CUR best specifies the orientation of the IMU platform as such is used for processing telemetry data based on platform alignment.
 - b. Previous Current (PCR). One history REFSMMAT is maintained.
 - c. Manual Entry (MED). A REFSMMAT manually entered.
 - d. Telemetry (TLM). A REFSMMAT saved from S/C telemetry.
 - e. Maneuver (DMT). Any other REFSMMAT specified as the DMT for a particular maneuver or a desired alignment computed to give a required set of initial attitudes for a particular maneuver.
 - 2 f. Optical Sighting (OST). A REFSMMAT computed either from telemetry optics or manually entered optics.
 - g. Local Vertical (LCV). A REFSMMAT computed to place the spacecraft heads-up, wings-level with zero attitudes at a specified time.
 - h. Deorbit (DOD). A REFSMMAT saved from either the primary or manual column of the Return-to-Earth Digitals, the manual column of the Retrofire Digitals, or the Spacecraft Setting (which is the same for both the Return-to-Earth and the Reentry Digitals).
7. The automatic time-to-fire calculation will use the current REFSMMAT.
8. When an OST REFSMMAT is computed, the angle between the line-of-sight vectors defined by the input data will be computed and printed on-line. In addition the angle between the two stars will be computed from the RTCC star catalogue and printed on-line.

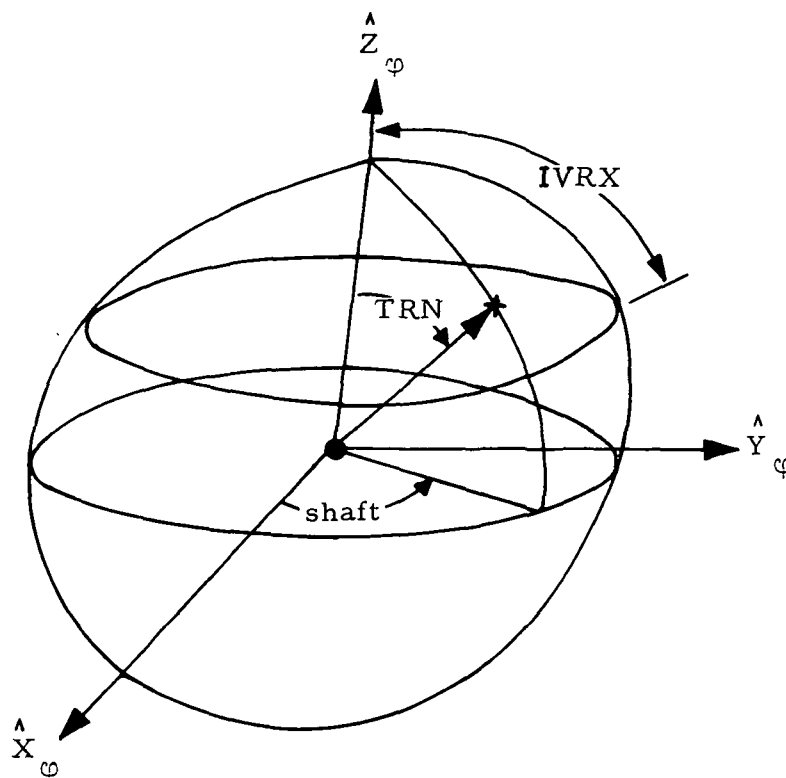
3 }
4 }
5 }
6 }

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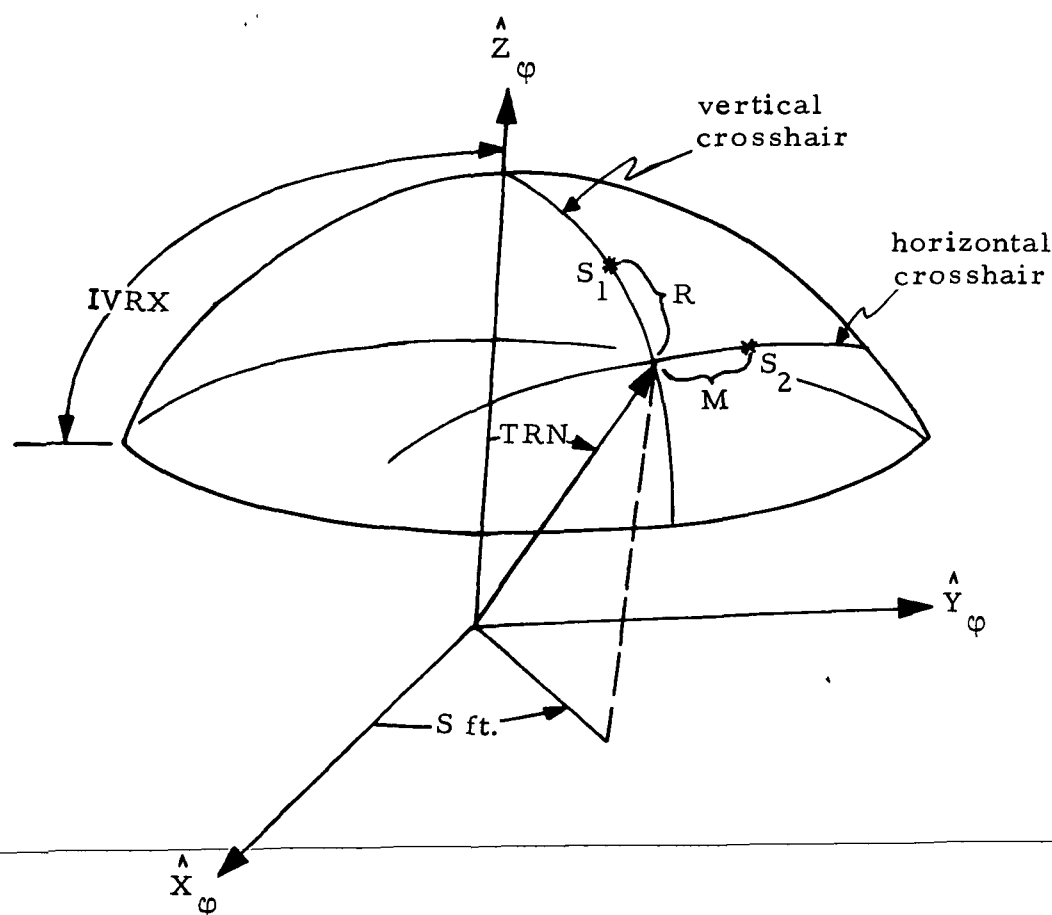
PHO/PARS

- e. Deorbit maneuver attitudes for each vehicle
 - f. Manual optics
 - g. Telemetry optics.
4. The sextant optics data (shaft and trunnion angles) is computed when desired, with the following considerations:



The coordinate system $(\hat{X}_\phi, \hat{Y}_\phi, \hat{Z}_\phi)$ is fixed with respect to the body axes with $\hat{Y}_\phi = \hat{Y}_b$ and with the \hat{X}_ϕ and \hat{Z}_ϕ axes in the $\hat{X}_b - \hat{Z}_b$ plane at some constant pitch angle. The trunnion angle is given as the angle from \hat{Z}_ϕ to the sextant LOS, and the shaft angle, as the rotation of the instrument from the positive $\hat{X}_\phi - \hat{Z}_\phi$ plane about \hat{Z}_ϕ . While the actual field of visibility for the sextant is that portion of the unit sphere with the trunnion angle less than the angle (IVRX), the program will compute sextant optics data without regard to this physical restriction, nor will it take occultation into account. Hence the sighting angles are given for two specified stars without regard to whether or not they are actually visible.

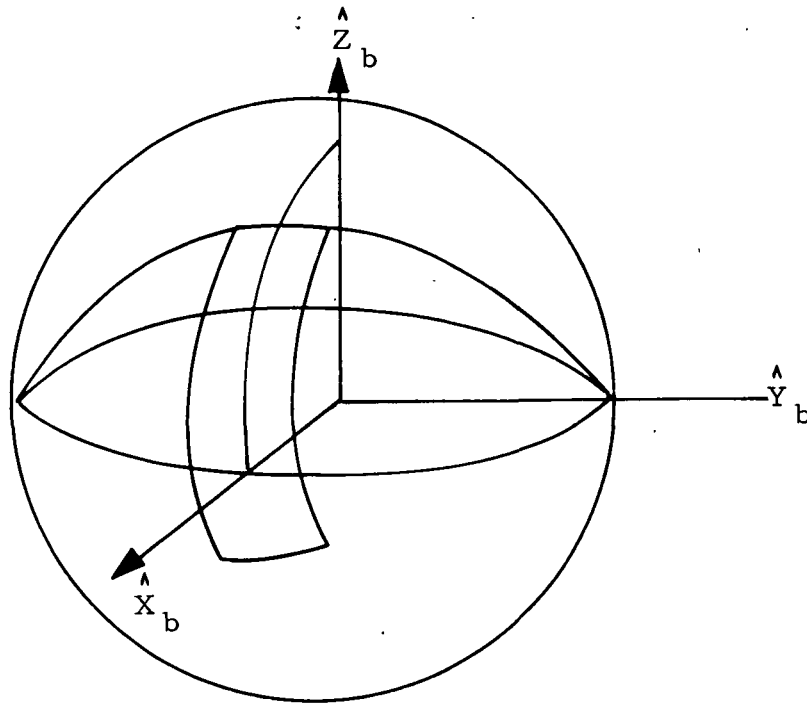
5. If scanning telescope data is desired, then the program searches the star table beginning with the starting star specified on the input queue for a pair of stars visible in the SCT at the same time. It then computes the shaft and trunnion angles necessary to place one star on the vertical crosshair and one on the horizontal crosshair. If the pair cannot be placed on the reticle lines, then another pair is sought. If no pair is found which can be placed on the reticle lines, then the last pair visible in the SCT is output. The SCT is considered to have the same field of visibility as the SXT with the instrument viewing angles defined in the same manner. But now only those stars actually visible are considered.



With a pair of stars as shown above, the data output is the instrument viewing angles and the M-R coordinates of the star pair.

Starting with LOTS(D'), the SCT logic will be modified to output the first two stars found in the SCT total field of view that are not occulted. If both can be placed on the crosshairs, they will be. If not, the first star will be positioned at the top of the vertical crosshair, and M and R coordinates will be output for the second star. (These may indicate that the second star lies outside the reticle for this shaft/trunnion position).

6. If boresight data is desired, then the program searches the star table beginning with the starting star for up to two stars available in the instrument visibility range. This range is defined as a rectangular area on the unit sphere with its longitudinal axis in the $\hat{X}_b - \hat{Z}_b$ plane.



The output viewing angles are the pitch angle to place the instrument horizontal crosshair on the star and the great circle arc along horizontal crosshair to the star. Data is output only for those stars actually visible in the instrument.

7. The maneuver code will be eight characters.
8. The IGA will be changed to represent the positive counter-clockwise rotation about the Y-body axis at GETAC to place the X-body axis on the reference body visual horizon. The horizon requiring the least actual IGA movement will be selected ($0 \leq \text{IGA} \leq 360$).

Our interpretation of TV display output items is presented below:

A, B, C, D (see TR170 copy-right columns)

- A = when item is displayed
- B = associated error output when item is displayed
- C = when item is not displayed
- D = associated error output when item is not displayed

for A

1. Whenever display is properly initialized with required MED
2. Requesting sextant information
3. Requesting scanning telescope information
4. Requesting boresight information
5. Requesting boresight and/or scanning telescope information
6. Requesting a matrix
7. Requesting boresight and/or scanning telescope information with DMT or DOD data
8. Whenever target information requested by MED.

for B

1. Display error message 3 under D below
2. Display error messages 2, 3, 4, and 6 under D below.

for C

1. When display is not properly initialized by MED input
2. When needed parameters are not available
3. When the quantity is not requested
4. When the needed matrix is not available
5. When no stars can be found to output
6. When quantity cannot be computed.

for D (Error message numbers for messages listed below)

1. 5
2. 1, 4, 5, 6 and 7
3. 1, 2, 3, 4, 5 and 6
4. 4
5. Blanked
6. *

(Messages)

1. "NO OPTICS THIS VEHICLE"
2. "EPHEMERIS NOT AVAILABLE"
3. "TWO STARS NOT AVAILABLE"
4. "MATRIX NOT AVAILABLE"
5. "MED INPUT REQUIRED"
6. "ATTITUDES NOT AVAILABLE"
7. "OPTICS NOT AVAILABLE".

Functional Diagrams

Figures 34 and 35 show the interfaces of the programs in the CSM Guidance Optics Support Element with other elements, units, or subsystems. They further provide the general logic necessary of the processing of this element. Data table usage, task structure, and input/output data flow are shown. The key to the symbols used in the diagrams may be found in the Glossary of this document.

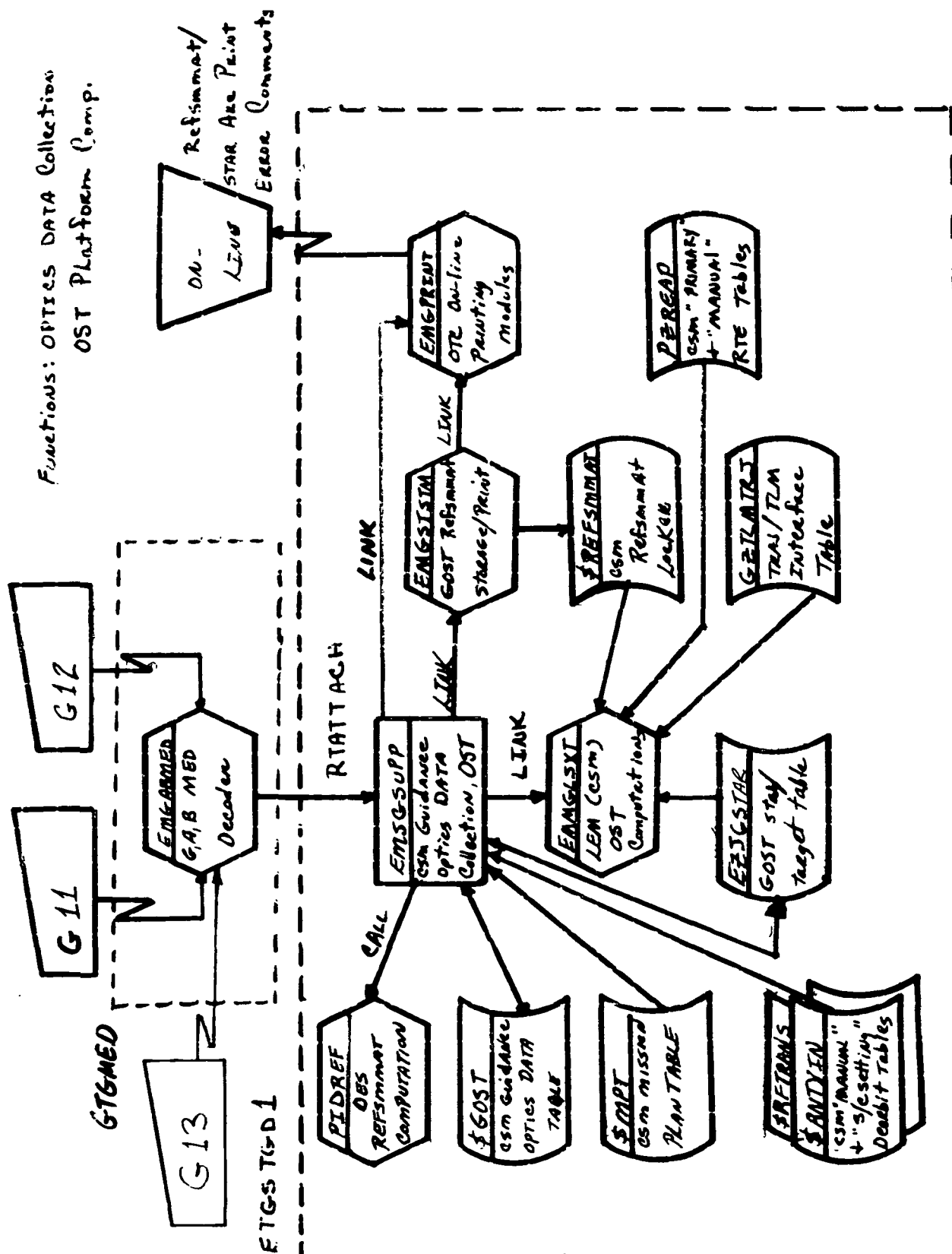
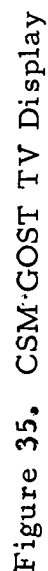


Figure 34. Optics Data and REFSMMAT Collection



Input/Output Specifications

The Input/Output Specifications for this element can be grouped into three categories: MED inputs, TV formats, and on-line prints.

Manual Inputs: The MED's included here are G10, which generates the Guidance Optics Support Table; G11, which acquires and saves CSM IMU matrix/optics; G12, which enters CSM sextant optics and IMU attitudes; G13, which enters targets for the GOST star catalog; and G14, which initializes the Guidance Optics Support Tables special target display.

TV Formats: The Guidance Optics Support Table, which represents the latest format for mission LLP, FCN #LM 0907 B, is found on the page following the MED inputs (see Exhibit 59).

On-Line Prints: The text of these on-line printouts, its meaning, and the recovery procedure, if applicable, are covered below.

1. REFSMMAT NOT AVAILABLE

This message is the result of an input of GOST MED's G00, G02, G11, G21, or G23 when the referenced REFSMMAT has not been defined in the CSM or LM locker. The platform alignment (REFSMMAT) must be defined with one of the GOST procedures.

2. ATTITUDES NOT AVAILABLE

This message results from an input of GOST MED's G11, G21, or G23 when the referenced IMU attitudes have not been defined in the guidance optics tables for the CSM or LM. The needed attitudes must be defined with the appropriate GOST MED input.

3. OPTICS NOT AVAILABLE

This message occurs if there is an input of GOST MED's G11, or G21 for OST computation when the indicated set of optics data has not been defined in the guidance optics tables for the CSM or LM. The needed optics must be defined with the appropriate GOST MED.

4. MANEUVER NOT IN PLAN

This message results from a GOST MED input G11 or G21 for saving A DMT set of REFSMMAT data when the maneuver has not been defined for CSM or LM. A defined maneuver number must be referenced. Message will also be printed if mission plan is in an update state.



MED Format Table

MED Code: G10
 Purpose: Generate Guidance Optics Support Table
 Load Module: EMGABMED

Task: ETISPLAY
 EP: EMSNAP
 QNAME:
 QUEID:
 DPRIOR: MKDGLD

Desc.	Item	1	2	3	4	5	6
Item Name		CSM Vehicle	GET	Starting Star	(MTX) - (AT)	(MTX) - (OP)	(MTX) - (AT)
Input Format		XXX	xxx:xx:xx.xx	XXX	XXX-XX	XXX-X	XXX-XX
Input Units		EBCDIC	HR:MIN:SEC	Integer	EBCDIC	EBCDIC	EBCDIC
Program Units		Numeric Code	hours	Numeric Code	Numeric Code	Numeric Code	Numeric Code
Scale Factor							
Checking Option		Exact		1 to star table limit	Exact	Exact	Exact
Missing Item Option		Error	= 0	= 1	At least one item must be specified. Legally missing items set to zero.		
Item Destination		Disp. 8 H	Disp. 0 D	Disp. 10 H	Disp. 12, 14 H, H	Disp. 16, 18 H, H	Disp. 20, 22 H, H

Programmer: J. Emrick

Initial Logic:

Final Logic: Output put in data table EZGSTMED, blocks 1-4

Illegal Phases: All except orbit, PLII, transit, stay, and PLI

Notes: 1. GET must be specified if item 4 is inserted

2. Valid MTX codes are CUR, PCR, TLM, OST, MED, DMT, DOD, LCV

3. Valid AT codes are MM, OP, LV, PP, DD

4. Valid OP codes are M or T



MED Format Table

MED Code: G11 Task: ETGSTGDI
 Purpose: Acquire and save CSM IMU matrix/optics EP: EMSGSUPP
 Load Module: EMGABMED QNAME:
 QUEID: 1
 DPRIOR: MKDGMF

Desc.	Item	1	2	3.1	3.2	3.3
Item Name		CSM Vehicle	Code	Maneuver Number	Matrix	Heads up/Down
Input Format		XXX	XXX or XXX-X	XX	XXX	X
Input Units		EBCDIC	EBCDIC	FXP	EBCDIC	EBCDIC
Program Units		Numeric Code	Numeric Code		Numeric Code	Numeric Code
Scale Factor						
Checking Option		EXACT	EXACT	$\geq 1, \leq 15$	EXACT	EXACT
Missing Item Option		ERROR	ERROR	If code in item 2 is DMT, all must be specified. Otherwise, ignore.		
Item Destination		Disp. 0 H	Disp. 2,4 H,H	Disp. 6 H	Disp. 8 H	Disp. 10 H

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low), PLII, transit, stay, and PLI

- Notes:
- Valid codes for item 2 are TMH, TML, OST-M, OST-T, DMT, DOS, DOM, OPH, OPL, ATH, ATL, REP, REM
 - Valid matrix codes are CUR, PCR, TLM, OST, MED, DMT, DOD, LCV, DES
 - Item 3.3 may be U or D

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MED Format Table

MED Code: G12 **Task:** ETGSTGD1
Purpose: Enter CSM sextant optics and IMU attitudes **EP:** EMSGSUPP
Load Module: EMGABMED **QNAME:**
 QUEID: 2
 DPRIOR: MKDGMF

Desc.	Item	1	2.1	2.2	2.3	2.4	2.5
Item Name	CSM vehicle	Star 1	Shaft 1	Trunnion 1	Star 2	Shaft 2	
Input Format	XXX	XXX	xxx.xxxxx	xxx.xxxxx	XXX	xxx.xxxxx	
Input Units	EBCDIC	Exp.	degrees	degrees	Exp.	degrees	
Program Units	Numeric code		radians	radians		radians	
Scale Factor			radians per degree	radians per degree		radians per degree	
Checking Option	Exact	1 to star table limit	$\geq 0, < 2\pi$	$\geq 0, < 2\pi$	1 to star table limit	$\geq 0, < 2\pi$	
Missing Item Option	Error	= 0	= 0	= 0	= 0	= 0	
Item Destination	Disp. 4 F	Disp. 8 F	Disp. 16 D	Disp. 24 D	Disp. 32 F	Disp. 40 D	

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low), PLL, transit, stay, and PLI

Notes:



MED Format Table

MED Code: G12 (continued)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: EMGABMED

Desc.	Item	2.6	3.1	3.2	3.3	4.1	4.2
Item Name		Trunnion 2	IMU Pitch 1	IMU Yaw 1	IMU Roll 1	IMU Pitch 2	IMU Yaw 2
Input Format		xxxx. xxxxxx	xxxx. xxxxxx	xxxx. xxxxxx	xxxx. xxxxxx	xxxx. xxxxxx	xxxx. xxxxxx
Input Units		degrees	degrees	degrees	degrees	degrees	degrees
Program Units		radians	radians	radians	radians	radians	radians
Scale Factor		radians per degree	radians per degree	radians per degree	radians per degree	radians per degree	radians per degree
Checking Option		$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$
Missing Item Option		= 0	= 0	= 0	= 0	= 0	= 0
Item Destination		Disp. 48 D	Disp. 56 D	Disp. 64 D	Disp. 72 D	Disp. 80 D	Disp. 88 D

Initial Logic:

Final Logic:

Illegal Phases:

Notes:



MED Format Table

MED Code: G12 (continued)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: EMGABMED

Desc.	Item	4.3						
Item Name	IMU Roll 2							
Input Format	xxx. xxxxx							
Input Units	degrees							
Program Units	radians							
Scale Factor	radians per degree							
Checking Option	$\geq 0, \leq 2\pi$							
Missing Item Option	= 0							
Item Destination	Disp. 96 D							

Initial Logic:

Final Logic:

Illegal Phases:

Notes:

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MED Format Table

MED Code: G13

Task: ETGSTGDI

Purpose: Enter target for GOST star catalog

EP: EMSGSUPP

QNAME:

QUEID: 3

Load Module: EMGABMED

Desc.	Item	1	2	3	4	5	6
Item Name		Position	Right Ascension	Declination			
Input Format		XXX	XX:XX:XX	XX:XX:XX ^N _S			
Input Units		FXP	hr:min:sec	deg:min:sec			
Program Units		FXP	radians	radians			
Scale Factor			radians per time unit	radians per degree			
Checking Option		≥ 392 , ≤ 400	≥ 0 , $\leq 2\pi$	$\geq -\pi/2$, $\leq \pi/2$			
Missing Item Option		Error	Error	Error			
Item Destination		Disp 0 F	Disp 8 D	Disp 16 D			

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low), PLII, transit, stay, and PLI

Notes:

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MED Format Table

MED Code: G14 Task: ETISPLAY
 Purpose: Initialize MSK 229 display of special targets EP: EMSNAP
 Load Module: EMGABMED QNAME:
 QUEID:

Desc.	Item	1	2	3	4	5.1	5.2
Item Name		VEHICLE	POSITION	RB	GET	LAT	LON
Input Format		XXX	XXX	X	XXX:XX: XX,XX	XX:XX:XX ^N XX,XX ^S	XXX:XX:XX ^E XX,XX ^W
Input Units		EBCDIC	EBCDIC or FXP	EBCDIC	hr:min:sec	deg:min:sec	deg:min:sec
Program Units		Numeric code	Numeric code or FXP	Numeric Code	hours	radians	radians
Scale Factor						radians per degree	radians per degree
Checking Option		Exact	$\geq 1, \leq 400$	Exact		$\geq -\pi/2,$ $\leq \pi/2$	$\geq 0,$ $\leq 2\pi$
Missing Item Option		Error	=0	(One of these two items must be input.)		(Each element in Item 5 must be specified if →	
Item Destination		Disp. 4 F	Disp. 0 H	Disp. 2 H	Disp. 32 D	Disp. 8 D	Disp. 16 D

Programmer: J. Emrick

Initial Logic:

Final Logic: Output placed in data table EZGSTMED, Blocks #91-95

Illegal Phases: All except orbit (low), PLII, transit, stay, and PLI

Notes: Item 3 is ignored if item 2 is input.

66-2656-1

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MED Format Table

MED Code: G14 (continued)

Purpose:

Load Module:

Task:
EP:
QNAME:
QUEID:

Desc.	Item	5.3							
Item Name		HGT							
Input Format		XXXX							
Input Units		feet							
Program Units		feet							
Scale Factor									
Checking Option									
Missing Item Option		←Item 3 equal "E" or "M"							
Item Destination		Disp: 24 D							

Programmer:

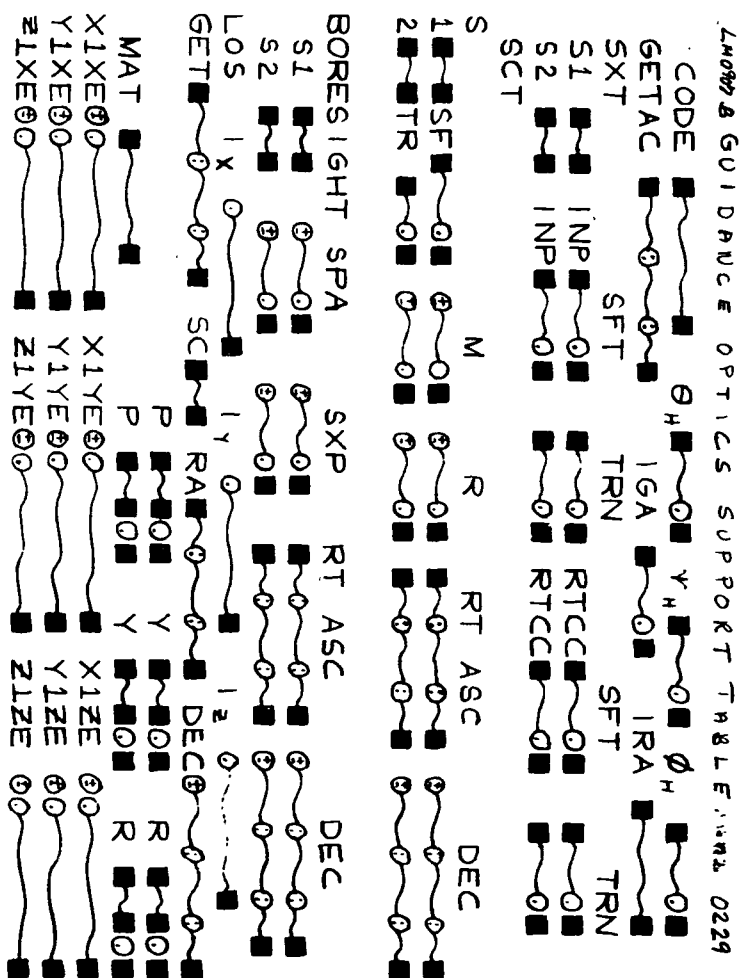
Initial Logic:

Final Logic:

Illegal Phases:

Notes:

Exhibit 59



0229

D.F.G

OPTICS
SUPPORT
TABLE
0229

GUIDO DIG

LM0453
LM0599A
LM0657B
LM0907C

4 4



5. DOD NOT VALID FOR SAVE

This message results if a GOST MED input G11 or G21 is made for the CSM to save a set of DOD REFSMMAT data when the associated data (manual or spacecraft setting) is not available in the DOD display. DOD display with the needed deorbit plan must be generated.

6. TLM DATA NOT VALID FOR SAVE

This message occurs if there is an input of GOST MED's G11 or G21 when the requested data is not available error free in the trajectory/telemetry interface tables.

7. TABLED STAR ARC - NNN.NNN DEGREES
S/C SIGHTING ARC - NNN.NNN DEGREES

This message is printed whenever G11 or G21 GOST input calls for an OST matrix computation from star sighting information for CSM or LM. If the two arcs differ, the sighting data is invalid, and the resulting OST alignment is not valid.

8. NEW IMU MATRIX AAANNN AAA GET=NNN:NN:NN
±. NNNNNN ±. NNNNNNNN ±. NNNNNNNN
±. NNNNNN ±. NNNNNNNN ±. NNNNNNNN
±. NNNNNN ±. NNNNNNNN ±. NNNNNNNN

The above message is printed with appropriate matrix ID (ex. "CUR001, TLM 014") whenever a new CSM or LM alignment is created and saved.

9. RTE DIGITALS NOT VALID FOR SAVE

This message is printed when GOST MED input G11 or G21 is made for the CSM/LM to save a set of DOD Refsamat data, and the associated data (manual or primary) is not available in the RTE display. RTE Digital Display with the needed RTE plan must be generated.

10. OST REFSMMAT STAR OPTICS NOT VALID

This message is printed when GOST MED G11 is made for computation of an OST REFSMMAT and the optics contains either two identical star ID's or two identical sets of equipment angles.

GUIDANCE OPTICS SUPPORT ELEMENT (LM)

Function

This element collects and saves LM optics and attitudes data from the following sources for various applications:

1. High-speed and low-speed telemetry REFSMMAT (TLM)
2. High-speed and low-speed telemetry optics and attitudes from an on-board celestial IMU fine alignment.
3. High-speed and low-speed telemetry live IMU attitudes
4. Orbit, deorbit, and return-to-Earth maneuver planning REFSMMAT's attitudes, and associated data (DMT/DOD)
5. Manually entered optics and attitudes to simulate the various on-board celestial IMU fine alignment procedures.

The Guidance Optics Support Element also computes and saves an optical sighting (OST) REFSMMAT from either telemetry or manually input optics and attitudes (LM), as well as a docked configuration (DOK) REFSMMAT from manually entered or telemetry configuration data (LM). Data is computed, and the LM Guidance Optics Support Table display is formatted (MSK239).

Load Modules/Routines Descriptions

GOST LM Optics Support Data Collection - EMSLSUPP

The function of this program is to receive and to process manual inputs requesting collection or computation of the following items:

1. High-speed or low-speed telemetry matrix from telemetry/trajectory interface tables
2. OST matrix from telemetry or manual optics computation
3. DMT matrix and attitudes from the Mission Plan Table
4. High-speed or low-speed telemetry optics and attitudes from telemetry/trajectory interface tables
5. High-speed or low-speed telemetry live attitudes from telemetry/trajectory interface tables
6. Manually entered optics and attitudes

7. DOK matrix from manual or TLM configuration data
8. DOD matrix and attitudes from the Deorbit Digitals (MANUAL, SPACE-CRAFT SETTING) or RTE Digitals (PRIMARY, MANUAL).
9. LLA and LLD matrices from the Lunar Surface Alignment Display (LSAD).

GOST LM Optics REFSMMAT Data Collector - EMMGLSXT

This load module collects and converts telemetry or MED optics data necessary to compute and store a LM OST REFSMMAT with associated time and mode indicator (LUN, FLT, AGS).

GOST LM Optics REFSMMAT Computation - EMMGSTMX

This load module computes and stores both LM and CSM OST REFSMMAT's and related data from star unit vectors in the platform system.

GOST LM Optics Support Display Mathematics - EMMGLMST

This program computes data for MSK 239. It operates in six distinct modes (DOK, FLT, CHK, LUN, AGS, and MAT). The following items are output for all six modes: matrices requested on latest display MED, presently stored attitudes (manual and live telemetry), and realignment attitudes.

In AGS mode, a check is made to see if the AGS constraint is violated as well as AGS OST display. In CHK mode, star sighting information for two stars at alignment check time (for both the AOT and COAS) as well as the OGA are required to put the spacecraft's Z-body axis on the horizon at alignment check time. In DOK, FLT, LUN, and AGS mode, the data used for computation of DOK and OST matrices is displayed. In MAT mode, just the requested matrix is displayed.

GOST Occultation Check - EMMGSTCK

This program determines if the target input is occulted by the Earth, moon, and/or sun at the input spacecraft's state and time.

GOST LM IMU/FDAI Attitudes Computation - EMMGLMRAT

For input platform and body axes matrices, this program computes IMU and FDAI angles to rotate platform alignment to body alignment.

GOST LM Optics Support Display Formatter - EMDGLMST)

This program formats LM orbital, lunar surface, and ground computed platform and body alignment checking data for MSK 239.

Requirements Interpretation

Exhibit 60 represents TR170 requirements applicable to this element as of the date of this Functional Specification. Reference item numbers have been affixed to the TR170 pages in the left margin which correspond to the included paragraphs of our comments (e.g. amendments, additions, and/or interpretations).

In the case of TV display output items, an additional reference column has been affixed to the TR170 pages in the right margin, which references four sections of output clarification:

- A — when item is displayed
- B — errors associated with item when displayed
- C — when item is not displayed
- D — errors associated with item when not displayed.

The following items from TR170 are discussed below.

Item (See TR170 copy - left column)

1. The display will be updated whenever the initialization MED or MSK 239 is input. The display will be active from Earth orbit insertion to Earth deorbit phase initialization.
2. Four characters of the form "LEMN"
3. Three characters depending on the mode the display is in - "DOK, FLT, CHK, AGS, MAT, or LUN"
4. TLM=last saved set of live telemetry attitudes whether from high-speed or low-speed
MED-first of last two sets entered via MED
5. Six characters of standard form - example: "CUR003, TLM014, etc."
MAT1 must be requested in the input MED, or the display is not generated.
6. Associated matrix times:
 - CUR - GET alignment obtained aboard the spacecraft
 - PCR - Same as CUR
 - TLM - Time that associated MED was input

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Exhibit 60

PHO-TR170A

Volume 2, Change 57

15 April 1968

ITEM:OT 4.2.2 LM Optics Support Table

A. Purpose. To evaluate orbital IMU alignments and provide ground support for alignment checks, docked alignments, and backup AGS alignments. The primary destination of the display will be the MOCR and SSR guidance consoles.

B. Data Sources. The following sources will be used.

- Detailed Maneuver Table
- Mission Plan Table
- LM telemetry
- CSM telemetry
- LM Ephemeris Table

1 C. Initialization of Display. This display will be initialized on manual entry only.

D. Parameters To Be Computed and Displayed

	<u>QUANTITY</u>	<u>DEFINITION</u>
2	VEH	Vehicle type and number for which data are being processed. This designation allows multiple LM-type vehicle capability.
3	MODE	Indicates type of computations for which the display is being used.
4	PRESENTLY STORED AT	Telemetry and MED attitudes, pitch, yaw, and roll, stored by the LOST program.
5	MATRIX 1 and MATRIX 2	Any two matrices stored in the LM REFSMMAT locker, and their code identifications, which are to be displayed in positions 1 and 2 on the LOST display.

A B C D

1	-	1	1
1	-	1	1
1	-	5	7
1	3	2	2

Approved: AD

NASA/FSB

PHO/PARS

(OT) 4.2.2-1

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	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
6	MAT GET	An associated GET of any matrix display, such as time computed, time made current, or time saved (the most meaningful time will be used in each case).	8	-	2	2
	REALIGN ATTITUDES	The attitudes pitch, yaw, and roll in the coordinate system described by MAT 1 to align the spacecraft body axis to the coordinate system described by MAT 2. Attitudes will be given as gimbal angles and FDAI angles.	1	-	2	2
	GIMB ANG	Realign attitudes specified in gimbal angles.	1	-	2	2
	FDAI ANG	Realign attitudes specified in FDAI angles.	1	-	2	2
	P, Y, and R	LM and CSM pitch, yaw, and roll IMU gimbal angles used in computing LM-docked REFSMMAT (will have special position on display).	2	-	7	-
7	P, Y, and R	Pitch, yaw, and roll LM gimbal angles or AGS angles used in alignment checks. The attitudes will be those related to star-sighting data in CHK, LUN, and AGS modes.	9	-	7	-
	DKAN	The docking angle obtained from the interface of the LM and CM docking hatches, indicating the relative rotation of one vehicle from the other about the spacecrafts' X axes.	2	-	2	2
8	S1 and S2	AOT stars used or to be used in optical sightings.	10	1	6	6
	i_x , i_y , and i_z	Components of the line-of-sight unit vectors to each star used for an inflight IMU alignment. Unit vectors will be available from telemetry downlink.	3	1	2	2
	MAT USED	The CSM REFSMMAT used in docked alignment computations if display is in docked mode; the LM REFSMMAT used in optics computations for an alignment check if display is in check mode; or the REFSMMAT indicating the desired alignment for the AGS if the display is in the AGS mode.	11	-	8	2

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<u>QUANTITY</u>			<u>DEFINITION</u>				A	B	C	D
9	GETHORIZ	Ground elapsed time of alignment check by star sightings and/or horizon sighting.	4	-	8	4				
25	OGA	The outer gimbal angle required to put the spacecraft plus Z axis line-of-sight tangent to the horizon at GETHORIZ.	4	-	8	7				
27										
	RA	Right ascension of star	4	1	6	6				
	DEC	Declination of star	4	1	6	6				
	D	AOT detent position, 1 through 6.	9	1	6	6				
	L	AOT reticle line to be superimposed with star S1 or S2.	9	1	6	6				
	A1	The AOT reticle angle counter position to superimpose target star and Line L.	9	1	6	6				
	A2	The AOT reticle angle counter position to superimpose target star and spiral.	9	1	6	6				
	AXIS	Indication that the COAS zero elevation LOS is either along the LM +X or +Z body axis.	4	1	6	6				
11	EL	The COAS elevation angle ranging between plus and minus 40 degrees to place star on horizontal X-line. A positive angle displaces the COAS LOS counter-clockwise about the LM +Y axis.	4	1	6	6				
23										
12	SXP	The Star-X-Position coordinate ranging between plus and minus 5 degrees. The right side of the reticle is plus giving a star on the +Y side of the LM X-Z plane a positive SXP.	4	1	6	6				
23										
E.	Update. This display will be updated only on manual entry initializing the display or MSK rerequest.									

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- (3) The computed OST REFSMMAT will be displayed on initialization of display by MED with OST specified as one of the matrices. If the OST REFSMMAT is specified as MAT 1 and GETHORIZ is omitted, the parameters used in its computation will also be displayed. In addition, the mode FLT will be displayed, because the OST was computed using star unit vectors.
- (4) Refer to F2. for additional option available in all modes.
- c. CHK (Alignment Check) Mode
 - (1) Required LM attitudes must be made available to the processor.
 - (2) Star-sighting information will be computed and displayed on entry by MED of time for the alignment check (GETHORIZ), star identification codes if specific stars are to be used, LM REFSMMAT to be used, AOT detent to be searched, COAS axis to be searched, and instructions as to what set of IMU attitudes are to be used.
 - 13 (3) If no stars are specified and the AOT is to be searched the RTCC will search for two unocculted stars in the AOT specified detent position. If stars are specified, the program will attempt to place them in the requested detent position. If only one star is available, sighting data for it will be displayed. If no stars are available or the requested stars cannot be placed in the field of view, the comment "NO STARS AVAILABLE" will be displayed.
 - 14 (4) If no stars are entered and the COAS is to be searched, the RTCC will search for two unocculted stars in the COAS specified axis field of view. If stars are specified, the program will attempt to place them in the requested axis field of view. Failure conditions are as specified in (3) above.
 - (5) Sighting data for AOT stars will include the star identification code, right ascension and declination, detent position, AOT reticle line requiring minimum rotation of reticle from zero position to superimpose the star and line, A1 and A2. In addition, the attitudes for which the sighting data have been computed and the mode identification CHK will be displayed.

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Exhibit 60 (Cont'd.)

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F. Additional Information

1. The display will be used in the following five modes, which are further described in the next five paragraphs.

- DOK = Docked mode
- FLT = Inflight alignment confirmation mode
- CHK = Alignment check mode
- AGS = AGS alignment mode
- MAT = Matrix display and comparison mode.

a. DOK (docked) Mode Procedures

- (1) LM attitudes, or instructions to save LM telemetry attitudes, will be entered by MED.
- (2) CSM attitudes, or instructions to save CSM telemetry attitudes, will be entered by MED.
- (3) A DOK REFSMMAT will be computed and saved on entry by MED of the docking angle; identification code of the CSM REFSMMAT to be used in the computation; type of attitudes, manually entered or saved telemetry, to be used for each vehicle; and vehicle identification codes.
- (4) The DOK REFSMMAT will be displayed on initialization of display by MED with DOK specified as one of the matrices. If the DOK REFSMMAT is entered as Mat 1, the parameters used to compute the DOK REFSMMAT and the mode identification code DOK will also be displayed.
- (5) Refer to F2. for additional option available in all modes.

b. FLT (Inflight Alignment Confirmation) Mode

- (1) LM optics in the form of star line-of-sight unit vectors will be saved on instructions by MED.
- (2) An OST REFSMMAT based on the saved optics will be computed and saved on instructions by MED.

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- (6) Sighting data for COAS stars will include the star identification code, axis along which COAS is mounted, elevation angle and position on COAS X-line. In addition, the attitudes for which the sighting data have been computed and the mode identification CHK will be displayed.
- (7) Only one set of IMU attitudes will be used for AOT and COAS per display generation.
- (8) The outer gimbal angle, OGA, required to point the LM +Z-axis at the horizon while holding the inner and middle gimbal angles constant will be computed and displayed for GETHORIZ whenever the display is initialized in CHK mode.
- (9) Refer to F2. for additional option available in all modes.

d. AGS (Abort Guidance Section Alignment) Mode

- (1) Optics and attitudes will be entered by MED. Both stars will be in the same detent position with Star 1 located at the center of the AOT reticle and Star 2 superimposed with one of the four AOT reticle lines. Star 2 will have some A1 specified by the crew, while its A2 will be provided by the RTCC. During the optical sightings, a body axis alignment may have been performed, in which case all attitude angles will have been set to zero.
- (2) An OST REFSMMAT based on manually entered optics will be computed and saved on instruction by MED.
- (3) The computed OST REFSMMAT will be displayed on initialization of the display by MED with OST specified as one of the two matrices. If the OST is specified as MAT 1 and GETHORIZ is omitted, the parameters used in its computation will also be displayed. In addition, because the OST was computed using data labeled as AGS-type optics in the MED that entered it, the mode identification AGS will be displayed.

Approved: J. S. NASA/FSB PHO/PARS

(OT) 4.2.2-6

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- (4) In the AGS mode, the RTCC will determine whether the X-Z plane of the AGS alignment, as indicated by MAT 1 is more than 65 degrees (value subject to change) from the LM orbital plane. An appropriate comment will be displayed to indicate whether the constraint is violated.
- (5) Refer to F2. for additional option available in all modes. This option is extremely important for the AGS mode.

e. MAT (Matrix Display) Mode

- (1) Initialize the display omitting GETHORIZ with MAT 1 specified as CUR, PCR, TLM, MED, or DMT, and MAT 2 specified as any other REFSMMAT available in the LM REFSMMAT locker.
- (2) The specified REFSMMATS will be displayed with no associated parameters, as in the case when MAT 1 is DOK or OST.
- 24 (3) If the DMT REFSMMAT is specified as MAT 1, the associated attitudes will also be displayed.
- (4) Refer to F2. for additional option available in all modes.

f. LUN (Lunar Alignment) Mode

- 20 (1) Optics and attitudes will be entered by MED. Each star will have an A1 to place it on the +Y line, an A2 to place it on the spiral, and a detent position.
- (2) An OST REFSMMAT based on manually entered optics will be computed and saved on instruction by MED.
- (3) The computed OST REFSMMAT will be displayed on initialization of the display by MED with OST specified as one of the two matrices. If the OST is specified as MAT 1 and GETHORIZ is omitted, the parameters used in its computation will also be displayed. In addition, because the OST was computed using data labeled as LUN-type optics in the MED that entered it, the mode identification LUN will be displayed.
- (4) Refer to F2. for additional option available in all modes.

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2. Option Available in All Modes

- a. Two REFSMMATS must be designated in the display initialization MED and an additional code for this option included.
- b. When the option code is included in the initialization MED, realignment attitudes, both in gimbal angles and in FDAI angles, will be computed and displayed.
- c. The realignment attitudes will give angles in the coordinate system, described by MAT 1, to align the spacecraft body axis to the coordinate system, described by MAT 2. This will be essential for the AGS mode when the out-of-plane constraint is violated.
- d. The second matrix (MAT 2) will probably be a local vertical alignment computed and saved at an earlier time, or it may come from the DMT (for AGS mode).
- e. The realignment attitudes will give a comparison of any two matrices available even when no realignment may be considered.

3. LM REFSMMAT Locker. This locker will store the following matrices:

- | | |
|----|--|
| 18 | <ul style="list-style-type: none"> ● DMT Computed for selected maneuver from the Detailed Maneuver Table ● LCV Computed for local vertical/horizontal alignment at some specified time ● DOK Computed while LM and CSM are docked |
| 19 | <ul style="list-style-type: none"> ● OST Computed from star sightings ● TLM Obtained from telemetry downlink ● MED Manually entered in the processor from data furnished by the Guidance Officer ● CUR Any other REFSMMAT chosen by the Guidance Officer to be used to generate attitudes for maneuvers, process telemetry vectors, and to best specify present alignment ● PCR Previous current REFSMMAT - matrix last used as current |

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- DOD Saved from Retrofire Digitals or Return-to-Earth Digitals
 - LLA Lunar Launch Actual saved from LSAD
 - LLD Lunar Launch Desired saved from LSAD
 - AGS Chosen by the Guidance Officer to be used to generate AGS attitudes for LM maneuvers, process AGS telemetry vectors, and to best specify present AGS alignment.
4. Present stored attitudes will be displayed on initialization of the display.
 5. Generally, error comments will appear in the space on the display where requested data would have appeared.
 6. The AOT (Alignment Optical Telescope) is a 60 degree field-of-view instrument mounted with its LOS permanently set about 45 degrees above the LM Y-Z plane. It can be used in six detent positions. Detent 1 is forward with 2, 3, 4, 5 and 6 counted clockwise about the LM x axis in increments of 60 degrees.
 7. The COAS (Crewman Optical Alignment Sight) is a 10 degree field-of-view instrument which can be mounted in either the overhead or forward window.
 8. Any time GETHORIZ is entered the display is in CHK mode. If GETHORIZ is omitted, the mode is determined by MATRIX 1.
 9. The LM Optics Support Table will use the same star catalogue as the CSM GDO Optics Support Table.
 10. If attitudes are manually entered, at least one angle must be other than zero.
 11. When an OST REFSMMAT is computed, the angle between the line-of-sight vectors defined by the input data will be computed and printed on-line. In addition the angle between the two stars will be computed from the RTCC star catalogue and printed on-line.

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- | | |
|------------------------------------|-------------------------|
| OST - Same as telemetry | LLA - Same as telemetry |
| MED - Same as telemetry | LLD - Same as telemetry |
| DMT - GETBI | |
| DOD - Same as DMT | |
| LCV - GET for which local vertical | |
| AGS - Same as CUR | |
| DOK - Same as telemetry | |
- 7 Space will be provided on the display format for two sets of attitudes (P, Y, R) for LUN mode data, with same space being used for one set of DMT or DOD attitudes when matrix 1 is DMT or DOD.
 - 8 Star/target catalog numbers (1 to 400)
 - 9 Must be supplied in initialization MED if CHK mode data is desired.
 - 11, 12 An Earth, sun, and moon occultation check is included in the determination of these values, except for targets 397 through 400.
 - 16 For both AOT and COAS data in CHK mode, a starting star may be input indicating where in the star table the search is to begin; two specific stars may be input. In both cases, the input star or stars will apply to both AOT and COAS (if requested). Sun, moon, and Earth occultation checks will be made, except for targets 397 through 400.
 - 17 An error condition will always exist if MAT1 is not requested; MAT2 may or may not be present without penalty when the realignment option is not specified; MAT2 must be present if the realignment option is requested.
 - 18 Matrix is selected/computed (DES) and stored in the locker along with the IMU attitudes to put the spacecraft in maneuver burn attitude for a specific maneuver.
 - 19, 20 Will be computed in LUN mode, from two spacecraft attitudes and two sets of IMU gimbals.
 - 23 These computational considerations are used by the GOST unit in determining output data.

AOT — The AOT is considered capable of occupying only discrete detent positions described by given shaft and trunnion angles about \hat{X}_b .

The reticle pattern consists of a vertical crosshair (Y), a horizontal crosshair (X), and an Archimede's spiral. The zero position of the Y crosshair is along the great circle arc joining \hat{LOS} and Z_b , regardless of detent position. The output viewing angles are then shaft and trunnion angles about \hat{LOS} . The shaft angle is displayed as the rotation of (Y) to place the nearest crosshair on the target and an identification of

Item

the crosshair used. The trunnion angle is displayed in terms of the rotation of (Y) about $\hat{L}\hat{O}\hat{S}$ to place the Archimedes spiral on the target.

COAS — The COAS is considered capable of being mounted on the \hat{X}_b or \hat{Z}_b axes. For computation purposes, it is given a rectangular field of view on the unit sphere. Output viewing angles are the elevation angle to place the horizontal crosshair on the target and the arc along the crosshair to the target. (See Figures 36 and 37.)

OST — Input optics sighting angles and attitudes are used to determine two target vectors in the platform system, and an arbitrary coordinate system is defined in terms of these vectors. The cataloged vectors for these two targets on the star table are then used to define a second coordinate system in the same manner as the first. The OST REFSMMAT is then the transformation matrix between these two systems.

DOK — The docking angle is considered as a clockwise rotation about the CSM \hat{X}_b axis and is zero when the CSM and LM \hat{Y}_b axes are at an angle of 60° , such that

$$\begin{bmatrix} \hat{X}_b^T \\ \hat{Y}_b^T \\ \hat{Z}_b^T \end{bmatrix}_{LM} = R_Y(180)R_X(60-D) \begin{bmatrix} \hat{X}_b^T \\ \hat{Y}_b^T \\ \hat{Z}_b^T \end{bmatrix}_{CSM}$$

24 Also DOD REFSMMAT.

25 In addition to the OGA, an angle LPD will be computed and displayed. (This angle is not on the included display format, see Exhibit 61.) LPD is computed positive clockwise ($-180^\circ \leq \text{LPD} \leq 180^\circ$) about Y of the CHK body to place Z-body on the nearest reference body horizon. The window mark limits (initially -20° and $+70^\circ$) will be defined as system parameters. Both horizons in the X/Z body plane will be considered; if only one lies in the window, it will be selected in favor of the nearer. LPD will be blank if not possible.

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- 26 The capability is provided to change the AOT azimuth and elevation mounting angles for all applications involving this instrument. (See G24 MED in this element.)
- 27 The OGA angle will be modified to represent the positive counterclockwise rotation around the X-body axis (the body as defined at GETHORIZ with input P and R, $Y = 0$) to place the Z-body axis on the visual horizon of the reference body. The horizon requiring the least actual movement from input Y to output OGA will be selected ($0 \leq \text{OGA} \leq 360$).

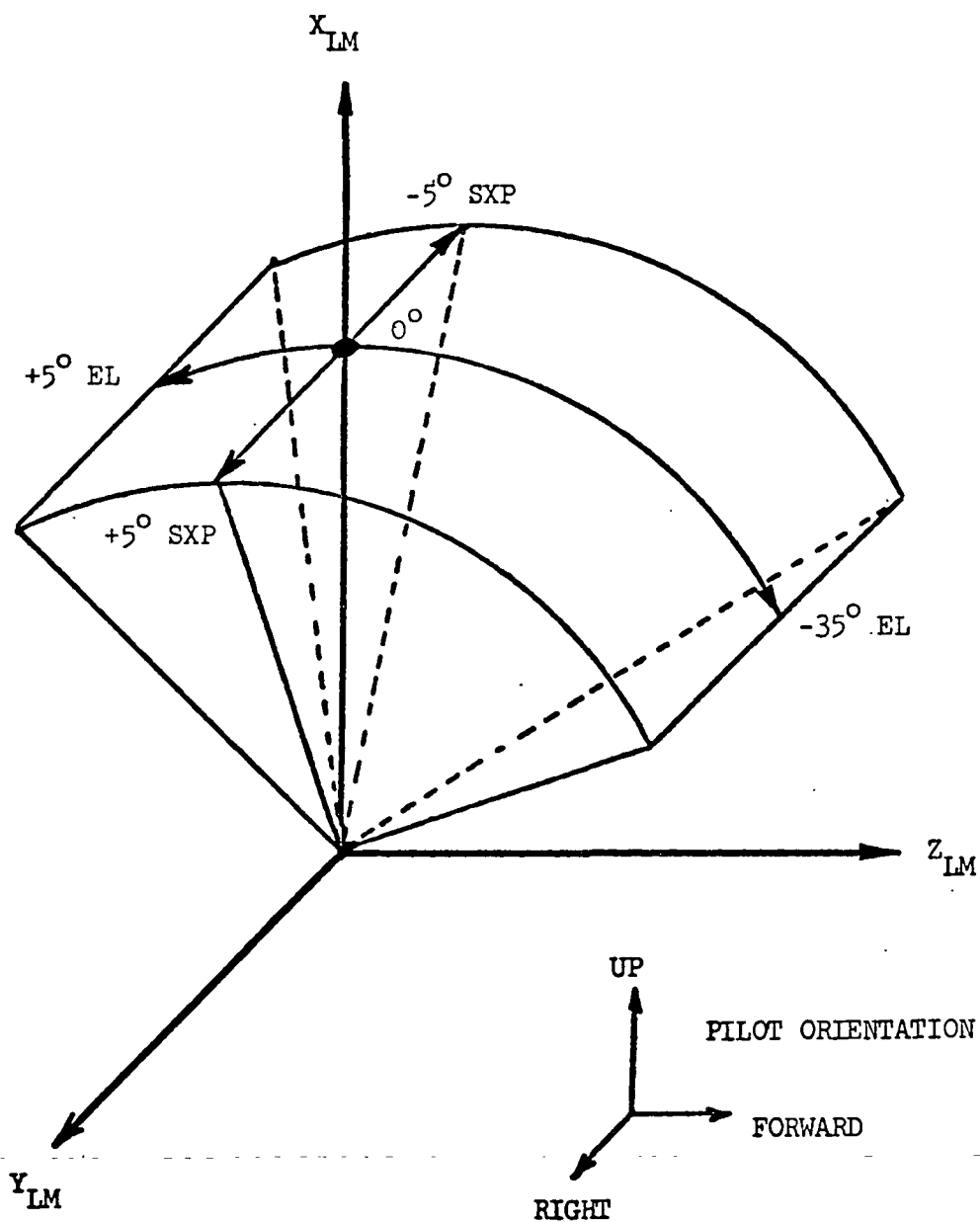


Figure 36. COAS Overhead Window Mount (X-Axis)
(Target at Infinite Distance)

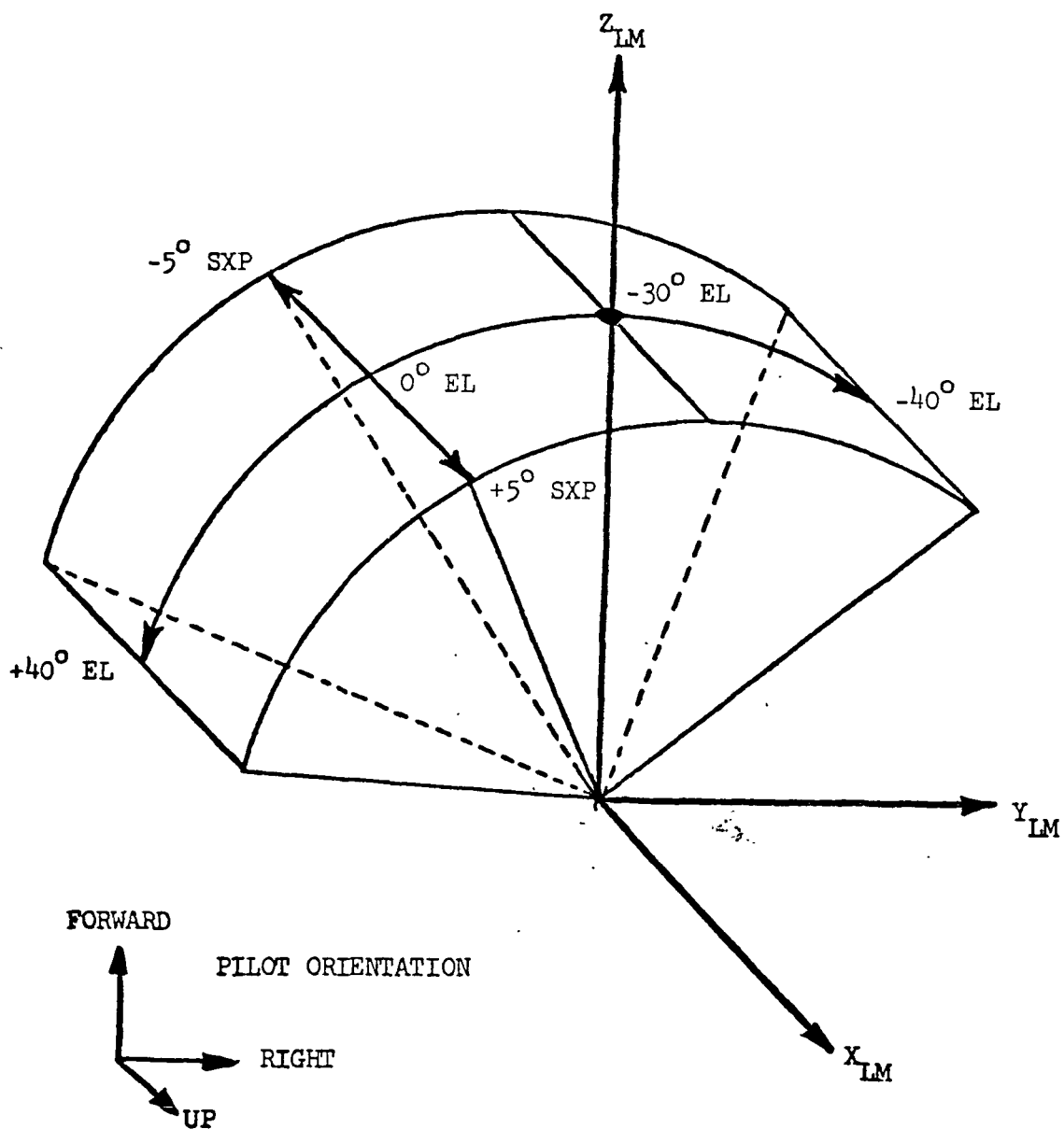


Figure 37. COAS Forward Window Mount (Z-Axis)
(Target at Infinite Distance)

Our interpretation of TV display output items is presented below

A, B, C, D (See TR170 copy - right columns)

A = when item is displayed

B = associated error output when item is displayed

C = when item is not displayed

D = associated error output when item is not displayed

for A

1. Whenever display is properly initialized with required MED
2. DOK mode
3. FLT mode
4. CHK mode
5. AGS mode
6. MAT mode
7. LUN mode
8. Whenever matrix is displayed
9. Modes 4, 7, and 5
10. Modes 3, 4, 5, 7
11. Modes 2, 4, 5

for B

1. Indicating only one star available by display error message "ONLY ONE STAR AVAILABLE"
2. Indicates 65° constraint alignment error with appropriate message "ALIGN VIOLATES 65 DEGREES CONSTRAINT"
3. Matrix 1 is displayed but matrix 2 may not be available causing message "MATRIX NOT AVAILABLE" to be displayed for MAT 2.

for C

1. When display not properly initialized by MED entry
2. When matrix not available on request
3. When trajectory update is in progress
4. When GETHORIZ not available
5. When requested attitudes not available
6. When none of requested stars available or when only one star (the first star displayed) is available
7. When not in right mode
8. When not available
9. When not in error mode

for D

1. "G20 MED REQUIRED"
2. "---MATRIX NOT AVAILABLE" (CUR, PCR, TLM, OST, MED, DMT, DOK, LCV, AGS)
3. "*"
4. "GETHORIZ NOT AVAILABLE"
5. "REQUESTED ATTITUDES NOT AVAILABLE" or
6. "NO STARS AVAILABLE" or "ONLY ONE STAR AVAILABLE" or "NOT AVAILABLE" (when one or both of boresight stars are unavailable)
7. Blank

Functional Diagrams

Figures 38 and 39 show the interfaces of the programs in the LM Guidance Optics Support Element with other elements, units, or subsystems. Data table usage, task structure, and input/output data flow are also illustrated. The symbols used in the diagrams are defined in the Glossary of this document.

Input/Output Specifications

The following categories of data will be provided by the LM Guidance Optics Support Element.

MED Inputs: The following MED formats are included.

1. G20, which generates the LM Optics display
2. G21, which acquires and saves LM IMU matrix/optics
3. G22, which enters LM optics and attitudes
4. G23, which computes the DOK REFSMMAT.

TV Formats: The LM Optical Support Table represents the latest format for mission LLP (Exhibit 61).

On-Line Prints: The text of the printouts, its meaning and the recovery procedure, if applicable, are discussed below.

1. REFSMMAT NOT AVAILABLE

This message results from an input of GOST MED's G00, G02, G11, G21, or G23 when the referenced REFSMMAT has not been defined in the CSM or LM locker. The platform alignment (REFSMMAT must be defined with one of the GOST procedures,

2. ATTITUDES NOT AVAILABLE

This message results from an input of GOST MED's G11, G21, or G23 when the referenced IMU attitudes have not been defined in the guidance optics tables for the CSM or LM. The needed attitudes must be defined with the appropriate GOST MED input.

3. OPTICS NOT AVAILABLE

This message is printed if there is an input of GOST MED's G11, or G21 for OST computation when the indicated set of optics data has not been defined in the guidance optics tables for the CSM or LM. The needed optics must be defined with the appropriate GOST MED.

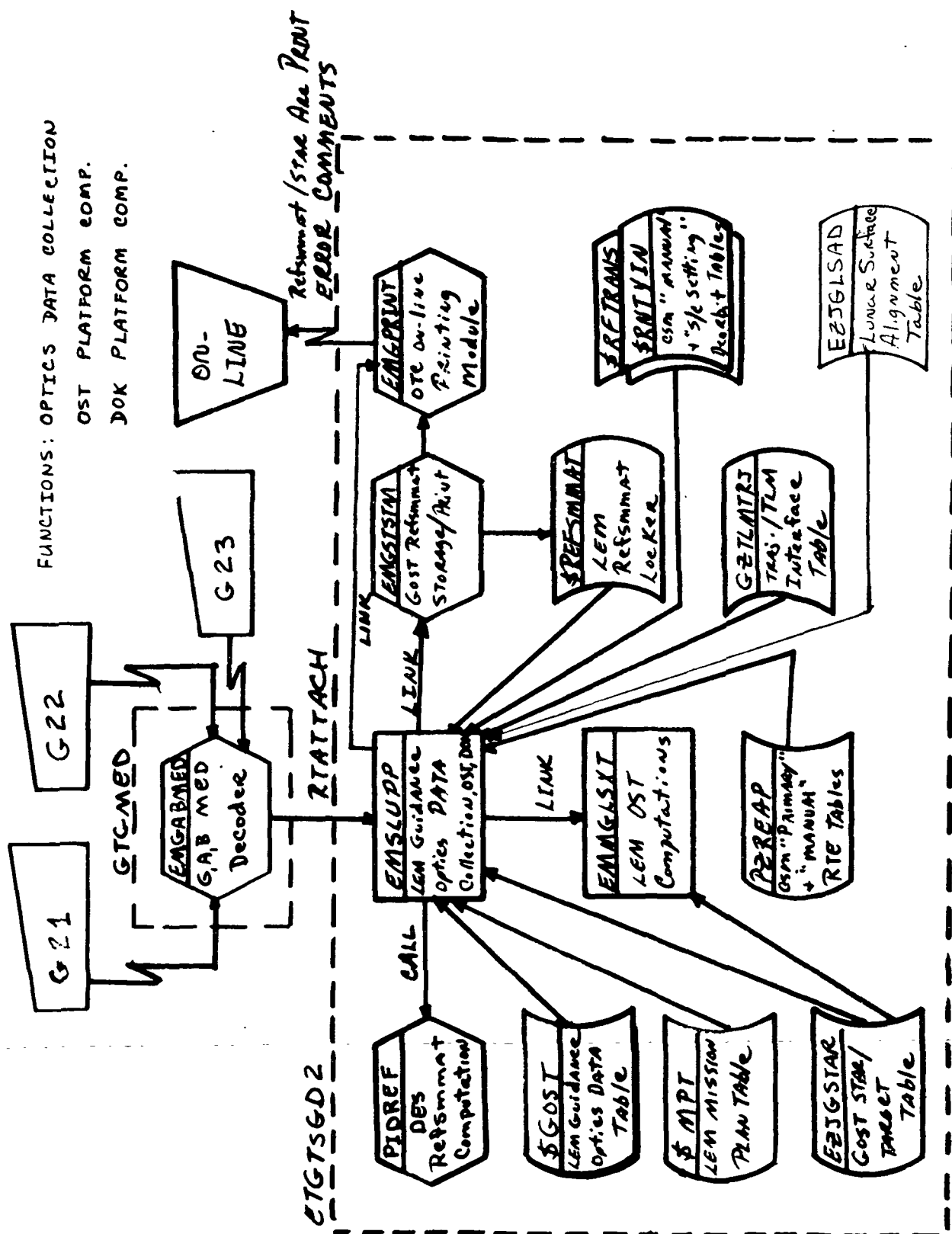


Figure 38: Optics Data and REFSMMAT Collection

FUNCTIONS: LEM GUIDANCE OPTICS TV DISPLAY

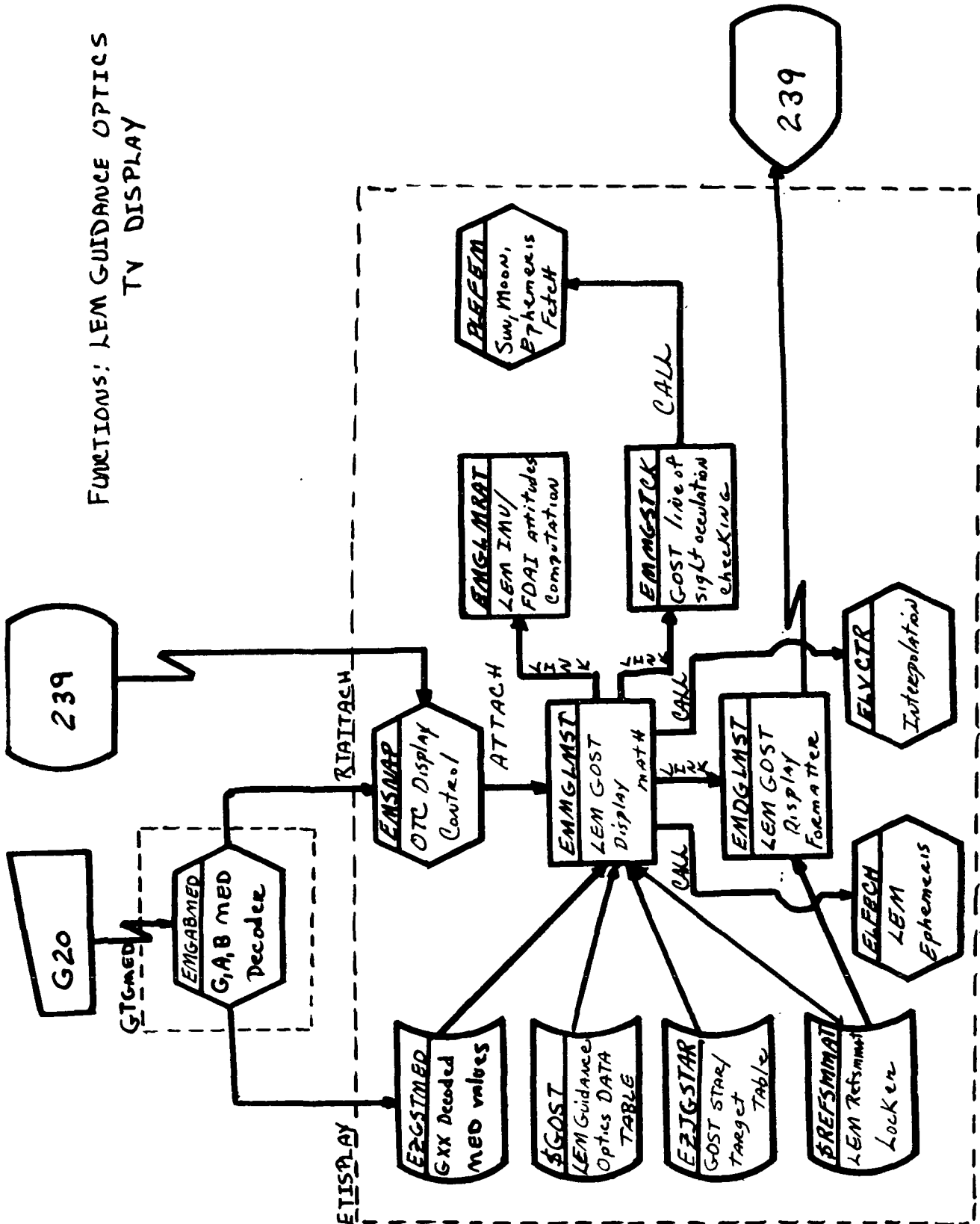


Figure 39. LM GOST TV Display

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MED Format Table

Task: ETISPLAY

EP: EMSNAP

QNAME:

QUEID:

DPRIOR: MKDGLD

MED Code: G20

Purpose: Generate LM Optics Display

Load Module: EMGABMED

Desc.	Item	1	2	3	4	5	6
Item Name		LEM Vehicle	GET	Star 1	Star 2	Starting Star	(MTX1) - (AT)
Input Format		XXX	xxx:xx:xx.xx	XXX	XXX	XXX	XXX
Input Units		EBCDIC	HRS:MIN:SEC	FXP	FXP	FXP	EBCDIC
Program Units		Numeric Code	hours	Numeric Code	Numeric Code	Numeric Code	Numeric Code
Scale Factor							
Checking Option		Exact		1 to star table limit	1 to star table limit	1 to star table limit	Exact
Missing Item Option		Error	= 0	= 0	= 0	= 1	Error
Item Destination		Disp. 16 H	Disp. 0 D	Disp. 8 F	Disp. 12 F	Disp. 18 H	Disp. 20, 22 H, H

Programmer: J. Emrick
Initial Logic:

Final Logic: All output shall be stored in data table EZGST MED, blocks 6-99.

Illegal Phases: All except orbit (low), PLI, transit, stay, and PLI

Notes: 1. Valid codes for matrix 1 and 2 are CUR, PCR, TLM, OST, MED, DMT, DOD,

LCV, AGS, DOK, LLA, LLD.

2. Valid attitudes codes for item 6 are MM, OP, LV, PP, DD

3. Item 8 code is R

4. Item 9 codes are PX and PZ



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MED Format Table

MED Code: G20 (continued)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: EMGABMED

Desc.	Item	7	8	9	10		
Item Name		Matrix 2	Realignment Option	Axis	Detent Code		
Input Format		XXX	X(R)	XX	X		
Input Units		EBCDIC	EBCDIC	EBCDIC	FXP		
Program Units		Numeric Code	Numeric Code	Numeric Code	Numeric Code		
Scale Factor							
Checking Option		Exact	Exact	Exact	$\geq 1, \leq 6$		
Missing Item Option		= 0	= 0	= 0	Error if item 2 input		
Item Destination		Disp. 24 H	Disp. 26 H	Disp. 28 H	Disp. 30 H		

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes:

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MED Format Table

MED Code: G21 Task: ETGSTGD2
 Purpose: Acquire and save LM IMU matrix/optics EP: EMSLSUPP
 Load Module: EMGABMED QNAME:
 QUEID: 1
 DPRIOR: MKDGMF

Desc.	Item	1	2	3.1	3.2	3.3
Item Name	LEM vehicle		Code	Maneuver number	Matrix	Heads up or down
Input Format	XXX	XXX or XXX-X		XX	XXX	X
Input Units	EBCDIC	EBCDIC		FXP.	EBCDIC	EBCDIC
Program Units	Numeric Code	Numeric Code			Numeric Code	Numeric Code
Scale Factor						
Checking Option	Exact	Exact		$\geq 1, \leq 15$	EXACT	EXACT
Missing Item Option	Error	Error		If code in item 2 is DMT, all must be specified. Otherwise, ignore.		
Item Destination	Disp. 0 _H	Disp. 2 & 4 _{H, H}	Disp. 6 _H	Disp. 8 _H	Disp. 10 _H	

Programmer: J. Emrick
 Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low), PLII, transit, stay, and PLI

Notes: 1. Valid codes for item 2 are TMH, TML, OST-T, OST-M, DMT, DOS,

DOM, OPH, OPL, ATH, ATL REP, REM, LLA, LLD.

2. Valid matrix codes are CUR, PCR, TLM, OST, MED, DMT, DOD, LCV, AGS, DES, DOK, LLA, LLD.

3. Item 3.3 may be U or D



MED Format Table

MED Code: G22

Purpose: Enter LM optics and attitudes

Task: ETGSTGD2

EP: EMSLSUPP

QNAME:

QUEID: 2

DPRIOR: MKDGMF

Load Module: EMGABMED

Desc.	Item	1	2	3.1	3.2	3.3	3.4
Item Name	LEM Vehicle		Mode	Star 1	Detent Position	Sighting Angle	Sighting Angle
Input Format	XXX	XXX	XXX	XXX	X	xxx.xxxxx	xxx.xxxxx
Input Units	EBCDIC	EBCDIC	EBCDIC	FXP.	EBCDIC	degrees	degrees
Program Units	Numeric Code	Numeric Code	Numeric Code	Numeric Code	Numeric Code	radians	radians
Scale Factor						radians per degree	radians per degree
Checking Option	Exact	Exact	Exact	1 to star table limit	Exact	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$
Missing Item Option	Error	Error	Error	= 0	= 0	= 0	= 0
Item Destination	Disp. 6 H	Disp. 4 H	Disp. 8 F	Disp. 16 F	Disp. 24 D	Disp. 32 D	

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low speed), PLI, transit, stay, and PLI

Notes:

1. Item 2 - LUN and AGS modes only. Code: LUN = 4, AGS = 5

2. Item 3.2 - input 1 → 6

3. Item 3.6 input PX, -X, PY, -Y, 1 → 6 Code: PX = 1, -X = 2, PY = 3, -Y = 4

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MED Format Table

MED Code: G22 (continued)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: EMGABMED

Desc.	Item	3.5	3.6	3.7	3.8	4.1	4.2
Item Name	Star 2		Detent or line position	Sighting Angle	Sighting Angle	Pitch 1	Yaw 1
Input Format	XXX	XX	XXX. XXXXX	XXX. XXXXX	XXX. XXXXX	XXX. XXXXX	XXX. XXXXX
Input Units	FXP.	EBCDIC	degrees	degrees	degrees	degrees	degrees
Program Units	Numeric code	Numeric code	radians	radians	radians	radians	radians
Scale Factor			radians per degree	radians per degree	radians per degree	radians per degree	radians per degree
Checking Option	1 to star table limit	Exact	$\geq 0, \leq 2$	$\geq 0, \leq 2$	$\geq 0, \leq 2$	$\geq 0, \leq 2$	$\geq 0, \leq 2$
Missing Item Option	= 0	= 0	= 0	= 0	= 0	= 0	= 0
Item Destination	Disp. 40 F	Disp. 48 F	Disp. 56 D	Disp. 64 D	Disp. 72 D	Disp. 80 D	

Initial Logic:

Final Logic:

Illegal Phases:

Notes:



MED Format Table

MED Code: G22 (continued)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: EMGABMED

Desc.	Item	4. 3	5. 1	5. 2	5. 3	
Item Name		Roll 1	Pitch 2	Yaw 2	Roll 2	
Input Format		xxx. xxxxx	xxx. xxxxx	xxx. xxxxx	xxx. xxxxx	
Input Units		degrees	degrees	degrees	degrees	
Program Units		radians	radians	radians	radians	
Scale Factor		radians per degree	radians per degree	radians per degree	radians per degree	
Checking Option		$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	
Missing Item Option		= 0	= 0	= 0	= 0	
Item Destination		Disp. 88 D	Disp. 96 D	Disp. 104 D	Disp. 112 D	

Initial Logic:

Final Logic:

Illegal Phases:

Notes:



MED Format Table

MED Code: G23
 Purpose: Compute DOK REFSMMAT
 Load Module: EMGABMED
 Task: ETGSTGD2
 EP: EMSLSUPP
 QNAME:
 QUEID: 3
 DPRIOR: MKDGMF

Desc.	Item	1	2	3	4	5	6
Item Name		CSM vehicle	(MTX) - (AT)	Docking Angle	LEM Vehicle	LEM Attitudes	
Input Format		XXX	XXX-XX	xxx, xxxxx	XXX	XX	
Input Units		EBCDIC	EBCDIC	degrees	EBCDIC	EBCDIC	
Program Units		Numeric code	Numeric code	radians	Numeric code	Numeric code	
Scale Factor				radians per degree			
Checking Option		Exact	Exact	$\geq -2\pi$, $\leq 2\pi$	Exact	Exact	
Missing Item Option		Error	Error	Error	Error	Error	
Item Destination		Disp. 4 F	Disp. 8,10 H,H	Disp. 16 D	Disp. 28 F	Disp. 32 F	

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low), PLII, transit, stay, and PLI

Notes:

1. Valid MTX codes are CUR, PCR, TLM, OST, MED, DMT, DOD, LCV
2. Valid AT codes and LEM attitude codes are MM, OP, LV, PP, DD

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MED Format Table

MED Code: G24

Purpose: Change LM AOT Azimuth/Elevation Angles

Task: NA

EP: NA

QNAME: NA

QUEID: NA

Load Module: EMGABMED

Desc.	Item	1	2	3	4	5	6
Item Name	Detent		Azimuth	Elevation			
Input Format	X		±XXX.XXXX	±XX.XXXX			
Input Units	FXP		degrees	degrees			
Program Units	Numeric		radians	radians			
Scale Factor			radians per degree	radians per degree			
Checking Option	$\geq 1, \leq 6$		$-\pi \leq \pi$	$-\pi/2 \leq \pi/2$			
Missing Item Option	Error		(At least one must be input)				
Item Destination			See Note 1	See Note 2			

Programmer: J. Emrick

Initial Logic:

Final Logic:

Illegal Phases: REJMASK = FBE9AFFE

Notes: 1. Value will be stored in system parameter MDGTCD

2. Value input will be changed to $\pi/2$ - (elevation input) and will be stored in the system parameter MDGETA.

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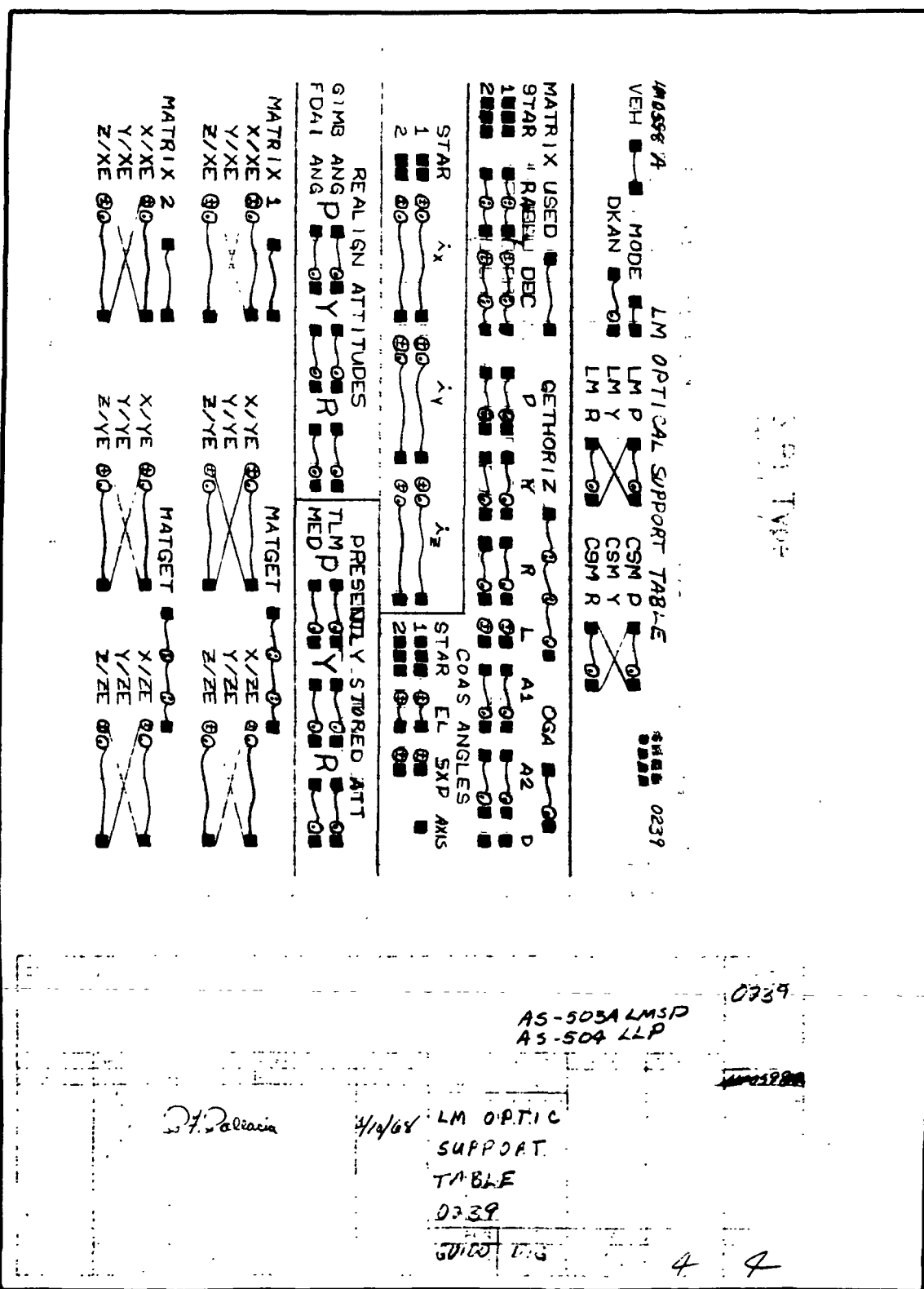
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4. MANEUVER NOT IN PLAN

This message is printed if GOST MED G11 or G21 is input for saving a DMT set of REFSMMAT data when the maneuver has not been defined for CSM or LM. A defined maneuver number must be referenced. Message will also be printed if mission plan is in an update state.

5. DOD NOT VALID FOR SAVE

This message is printed when GOST MED input G11 or G21 is made for the LM to save a set of DOD REFSMMAT data and the associated data (MANUAL or SPACECRAFT SETTING) is not available in the DOD display. DOD display with the needed deorbit plan must be generated.

6. TLM DATA NOT VALID FOR SAVE

This message is printed if there is an input of GOST MED's G11 or G21 when the requested data is not available error free in the trajectory/telemetry interface tables.

7. TABLED STAR ARC - NNN.NNN DEGREES S/C SIGHTING ARC - NNN.NNN DEGREES

This message is printed whenever G11 or G21 GOST input calls for an OST matrix computation from star sighting information for CSM or LM. If the two arcs differ, the sighting data is invalid, and the resulting OST alignment is not valid.

8. NEW IMU MATRIX AAANNN AAA GET = NNN:NN:NN

±.NNNNNNN ±.NNNNNNNN ±.NNNNNNNN
±.NNNNNNN ±.NNNNNNNN ±.NNNNNNNN
±.NNNNNNN ±.NNNNNNNN ±.NNNNNNNN

This message is printed with appropriate matrix ID (ex. "CUR001, TLM014") whenever a new CSM or LM alignment is created and saved.

9. RTE DIGITALS NOT VALID FOR SAVE

This message is printed when GOST MED input G11 or G12 is made for the CSM/LM to save a set of DOD REFSMMAT data and the associated data (MANUAL or PRIMARY) is not available in the RTE display. The RTE digitals display with the needed RTE plan must be generated.

10. OST REFSMMAT STAR OPTICS NOT VALID

This message is printed when GOST MED G21 is made for computation of an OST REFSMMAT and the optics contains either two identical star ID's or two identical sets of equipment angles.

SPACECRAFT POINTING DISPLAY ELEMENT (CSM/LM)

Function

This element computes and displays acquisition of sight (AOS/LOS) times for input Earth, lunar, and celestial targets. It also computes and displays sighting angles and line-of-sight occultation data for a specified spacecraft, target, instrument, and time period.

Load Modules/Routines Descriptions

GOST CSM/LM Spacecraft Pointing Display Formatter - EMDGPING

This program will perform initialization functions and LINK to EMGSCPNG to compute needed data. It will also format data for MSK 1504 requests.

GOST CSM/LM Spacecraft Pointing Display Mathematics - EMGSCPNG

The function of this program is to compute necessary sighting angles and needed information for the requested display mode and target. If AOS/LOS information is needed it will be computed.

GOST Target AOS/LOS Times Computation - EMGEARLA

This program computes AOS/LOS times for an input Earth, lunar, or celestial target within a ten hour period starting at a given threshold time.

GOST Earth/Moon Target Direction Computation - EMGSDEMT

This program computes inertial sighting unit vector direction for a specified Earth or moon target.

Requirements Interpretation

Exhibit 62 represents TR170 requirements applicable to this element as of the date of this Functional Specification. Reference item numbers have been affixed to the TR170 pages in the left margin which correspond to the included paragraphs of our comments (e.g., amendments, additions, and/or interpretations).

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Exhibit 62

PHO-TR170A
Volume 2, Change 58
19 April 1968

ITEMS:OT 4.2.3 Spacecraft Pointing Display

- 1 A. Purpose. To provide mission controllers with pointing angles that will allow the crew to point a spacecraft instrument at an orbiting, celestial or ground target for the purpose of obtaining experimental data.
- B. Data Sources. The following sources will be used.
 - CSM Ephemeris Table
 - LM Ephemeris Table
 - Ephemeris Tables for other mission vehicles
 - GDO Optics Support Table
 - LM Optics Support Table
 - Sun Ephemeris Table
 - Moon Ephemeris Table
- 1 C. Initialization of Display. This display will be initialized on manual entry only.
- D. Parameters to be Computed and Displayed.

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
1	INST	ID of instrument to be pointed at the target.	1	-	1	1
2	TARGET	Alphanumeric identification code of target.	1	-	1	1
3, 4	LAT, LONG	Geodetic latitude and longitude of earth target or selenographic latitude and longitude of moon target for MODE 1. Subsatellite position of target vehicle with respect to its reference body in MODE 4 at T_1 .	2	-	3	-
			5		4	
5	ALT _{NM}	Altitude of earth target above oblate body or of moon target above spherical body in MODE 1. Altitude of vehicle target above its reference body in MODE 4 at T_1 .	2	-	3	-
			5		4	
6	REV	Revolution in which AOS occurs.	6	-	6	2
7	RA	Right ascension of a celestial target.	3	-	2	-
			4		5	
8	DEC	Declination of a celestial target.	3	-	2	-
			4		5	
9	AOS	GET and GMT of acquisition of target.	7	1	7	3
						4

Approved: 647

NASA/FSB

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ITEM:

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
10	MODE	One of four modes in which display is being used.	1	-	1	1
11	LOS	GET and GMT of loss of target.	7	2	7	3
12	ROLL, PITCH YAW	Attitudes required of the spacecraft in order to point the line-of-sight of the specified instrument to the target. Displayed for T ₁ through T ₅ . Attitudes will be as nearly heads up as possible to the body containing ground target. For other targets, attitudes will be as nearly heads up as possible to the reference body at the time of sighting.	6	-	1	1
13	AT REF	Code to indicate that the displayed attitudes are referenced to the CSM IMU, the LM IMU, or the LM FDAI.	1	-	1	1
14	DR, DP, DY	Differences in roll, pitch and yaw between time intervals.	6	-	1	1
15	EL	Elevation angle of the spacecraft from a ground target. Displayed for T ₁ through T ₅ .	2	-	3	-
16	ALT _{NM}	Spacecraft altitude in nautical miles above spherical reference body. Displayed for T ₁ through T ₅ .	2	-	3	-
17	RNG _{NM}	Slant range to ground target. Displayed for T ₁ through T ₅ .	2	-	3	-
18	SUN ANG	The angle in degrees between the spacecraft-sun-line and the instrument line-of-sight. Displayed for T ₁ through T ₅ .	6	-	1	1
19	MOON ANG	The angle in degrees between the spacecraft-nearest moon horizon-line and the instrument line-of-sight. Displayed for T ₁ through T ₅ .	6	-	1	1
20	EARTH ANG	The angle in degrees between the spacecraft-nearest earth horizon-line and the instrument line-of-sight. Displayed for T ₁ through T ₅ .	6	-	1	1
21	T ₁ , T ₂ , T ₃ , T ₄ , T ₅	Evenly spaced times from T ₁ to T ₅ at which attitude data are generated.	6	3	8	3
22	REFSMAT	Identification code of REFSMAT used in generating the display.	1	-	1	5
23	RA, DEC	Direction of CSM +X-axis if INST is CSM type. Direction of LM +Z-axis if INST is LM type.	6	-	8	4

Approved: A'

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Exhibit 62 (Cont'd.)

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ITEM:QUANTITYDEFINITION

A B C D

- | ITEM | QUANTITY | DEFINITION | A | B | C | D |
|------|----------|---|---|---|---|---|
| 24 | STAR | Identification code of star in COAS field-of-view at T ₁ . (CSM COAS if CSM INST is specified, LM COAS if LM INST is specified). | 6 | - | 9 | 6 |
| 25 | SPA | COAS star-pitch-angle for CSM, COAS elevation angle for LM. | 6 | - | 9 | 6 |
| 26 | SXP | COAS star-X-position. | 6 | - | 9 | 6 |
- 1 E. Update. This display will be updated on manual entry initializing the display.

F. Additional Information.

1. Three manual entries are required for this display.
 - a. Target specification MED consisting of MODE, INSTRUMENT, TARGET, LAT, LONG, ALT, RA, DEC, REFSMMAT, AT REF, AND DOCKING ANGLE.
 - b. Initialization MED consisting of T₁, T₅, and T START. T₁ and T₅ causes generation of pointing data. T START is for AOS/LOS search.
 - c. Instrument definition and geometry MED specifying instrument code, code to add or delete. R1 counterclockwise rotation about X Body (Angle out of X-Z plane), R2 counterclockwise rotation about Y Body (Angle out of Y-Z plane). If R1 and R2 equal zero the LOS is along the vehicle Z-axis.
2. The Spacecraft Pointing Display can be used in four target modes.

<u>MODE</u>	<u>TYPE OF TARGET</u>	<u>INPUTS</u>
1	Ground	MODE, INST, TARGET, LAT, LONG, ALT, REFSMMAT, AT REF, DKAN
2	General Celestial	MODE, INST, TARGET, RA, DEC, REFSMMAT, AT REF, DKAN
3	GOST Star	MODE, INST, TARGET, REFSMMAT, AT REF, DKAN
4	Orbiting Object	MODE, INST, TARGET, REFSMMAT, AT REF, DKAN

Approved: AS NASA/FSB PHO/PARS

(OT) 4.2.3-3

Exhibit 62 (Cont'd.)

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ITEM:

3. In MODE 1, the last space of the target code must be either E for earth ground target or M for moon ground target.

In MODE 2, the target code is for bookkeeping purposes only.

In MODE 3, the last 3 spaces of the TARGET code must be one of the GOST STAR ID's.

In MODE 4, the last 4 spaces of the TARGET code must indicate the mission vehicle to be sighted.

The first 4 spaces in the TARGET code are for experiment identification and no computations are based upon them.
4. All instruments will be entered in real-time. The table of instruments will contain at any time a maximum of twelve. The last four letters of the instrument ID will indicate the vehicle on which the instrument is mounted.
5. The initialization MED specifies a time span T_1 to T_5 to be used in obtaining five evenly time spaced sets of pointing data for the target last entered.
6. A check will be made to determine if the line-of-sight to the target passes through the earth, earth's air glow, moon, or sun. A comment will appear below any time at which these conditions occur. Complete data will be generated at these times even though occultation occurs.
7. The initialization MED may also specify a T START which indicates the time to begin search for AOS. If the target is available at T START, T START will be used as AOS. An asterisk will be displayed with it to indicate true AOS occurred some time prior. If the target is not available at T START, a search will be made for the next AOS. The search will be terminated if AOS is not found prior to T START plus 10 hours. If an AOS is found (or T START is to be used as AOS), an LOS will be sought that is prior to T START plus 10 hours. If LOS is not found in this time interval, T START plus 10 hours will be used as LOS with an asterisk to indicate the target is available after this time.
8. This display cannot look forward of the main ephemeris.
9. Air glow extends to 400,000 feet.

Approved: LO'

NASA/FSB

PHO/PARS

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ITEM:

10. In docked configuration AT REF determines ephemeris to use. Docking angle must be input if AT REF and INST are not for same vehicle.
11. COAS star is checked for occultation in same manner as stars for optics support tables.
12. AOS/LOS solutions for earth targets will be computed for requested times corresponding to earth orbit, transit and lunar orbit phases. The station contacts program will be used for solutions.
13. AOS/LOS solutions for lunar targets will be computed for requested times corresponding to lunar orbit and earth orbit. The lunar experimental sites acquisition program will be used for solutions when requested times correspond to lunar orbit. The moonrise/moonset program will be used for approximate solutions when requested times correspond to earth orbit. Lunar orbit for purposes of optics AOS/LOS solutions will extend to lower than 30,000 feet above a spherical moon.
14. AOS/LOS solutions for celestial targets will be computed for requested times corresponding to orbit phases. The sunrise/sunset program will be used for solutions.
15. AOS/LOS solutions will not be computed for orbiting object targets.
16. The AOS/LOS criteria in 12 through 15 are a minimum. If the solution obtaining programs can function in other situations, the additional capability should be taken advantage of by the optics programs.
17. If the heads-up attitudes computed for the target sightings result in a middle gimbal angle between 70 and 110 or between 250 and 290, the spacecraft will be rolled about the target line-of-sight to minimize the middle gimbal angle.

1 }
 2 }
 3 }
 4 }

Approved: AS NASA/FSB PHO/PARS



In the case of TV display output items, an additional reference column has been affixed to the TR170 pages in the right margin, which references four sections of output clarification:

- A — when item is displayed
- B — errors associated with item when displayed
- C — when item is not displayed
- D — errors associated with item when not displayed.

The items listed below reflect our interpretation of the TR170A requirements. Each subheading corresponds to the one in the requirements. Then items are referenced from the left column of numbers in TR170A.

ITEMS

1 Purpose

Some of the experiments will involve the use of sensors and infra-red camera equipment, which must be mounted and pointed at the experiment target.

1 Initialization of Display

The display will be available from Earth orbit insertion to CSM deorbit and for the LM as long as ephemeris is available.

1 Parameters to be Computed and Displayed

Six characters - first two optional to indicate instrument type; last four indicate which vehicle in mission standard form (CSMN, LEMN,).

- 2 Eight characters - construction of the alpha numeric code depends on the type of target it identifies. An explanation will be provided later.

- 3-5 Input target quantities are displayed in Mode 1; output target quantities, in Mode 1 and Mode 4. Neither are displayed in Modes 2 and 3.

- 6 Will be displayed for T_1 as available according to the mission standard.

- 7, 8 Input target quantities are displayed in Mode 2; output target quantities, in Mode 2 and Mode 3. Neither are displayed in Modes 1 and 4.

- 12 Attitudes will be computed to have the spacecraft as close to heads up as possible at the sighting time. If gimbal lock is violated in reaching this orientation (MGA in ranges 70° - 110° or 250° - 290°), then the orientation giving the smallest possible MGA will be used. The MGA is uniquely determined by the input initial orientation of the platform and the final orientation used for sighting. Gimbal lock will occur if the the X-body axis in the final orientation is within 20° of the input

ITEM:

platform axis. If \hat{X}_b cannot be rotated about \hat{LOS} out of this range, then gimbal lock may not be avoided

- 13 Six characters - first two IM (for IMU) or FD (for FDAI); last four indicate which vehicle in mission standard form (CSM N, LEMN,)
- 14 Displayed rounded to nearest degree
- 15 The elevation will be displayed from 0° to $\pm 90^\circ$; may be negative when the spacecraft is viewing the target from below the target's local horizontal plane
- 17 Range will be output in Mode 4 as well as Mode 1;
- 18 Sun angle will be measured from instrument line-of-sight to sun center (0° to 180°)
- 19 Moon angle and Earth angle will be measured from instrument line-of-sight to moon's/Earth's nearest visual horizon, where 0° indicates that the line-of-sight is to a moon/Earth visual horizon; $-N^\circ$ to moon/Earth center; $180^\circ - N^\circ$ away from moon/Earth center
- 21 Six characters - mission standard form (CUR003, TLM001,)
- 24 Numeric - 1 to 400

Update

- 1 The display will be regenerated for every MSK request. Even if new manual entries have not been made to initialize the display, updates to data that it uses will cause the display values to change.

Additional Information

- 1 If a CSM instrument is specified, and the spacecraft is not docked, the ATREF input must be CSM IMU or CSM FDAI. The RA and DEC will be displayed for the boresight in zero position, and a star will be displayed if found in the boresight field-of-view at T_1 . A check for sun, moon, and Earth occultation will be made for the star.

If a LM instrument is specified, and the spacecraft is not docked, the ATREF input must be LM IMU or LM FDAI. The RA and DEC will be displayed for COAS in zero position along the Z-axis mount field-of-view at T_1 . A check for sun, moon, and Earth occultation will be made for the star.

An additional parameter on the initialization MED will specify the docking angle. If this angle is input, the spacecraft is assumed to be docked.

ITEM:

- The ATREF input will specify which vehicle ephemeris to use. The instrument input will determine which vehicle boresight RA, DEC, and star to output.
2. The following items of input/output will be limited in size only to display format space (999999NM): input ALT, outputALT, output RNG.
 3. Mode 4 subsatellite output for the target vehicle (lat., long., alt.) will be referenced to the body being orbited by the target (i.e., according to reference switch times).
 4. All mode P, Y, R output (IMU and FDAI) will be calculated to place the spacecraft heads up to the reference body being orbited during the sighting (i.e., according to reference switch times) for celestial targets and heads up to the target for Earth and moon targets.
 5. Sun occultation will not be checked.
 6. Lunar AOS/LOS times will be computed as for Earth targets using the station contacts process.
 7. For celestial AOS/LOS times, passage across reference switch is a cut-off condition. This will result in either "NO SOLUTION AVAILABLE" or an *LOS time.

Presented below is our interpretation of the TV display output items

A, B, C, D (reference TR170 copy - right columns)

- A — when displayed
- B — associated error output when displayed
- C — when not displayed
- D — associated error output when not displayed

for A

1. Whenever display is properly initialized with three required MED's
2. Mode 1 solution ($T_1 \rightarrow T_5$)
3. Mode 2 solution ($T_1 \rightarrow T_5$)
4. Mode 3 solution ($T_1 \rightarrow T_5$)
5. Mode 4 solution ($T_1 \rightarrow T_5$)
6. Any mode solution ($T_1 - T_5$)
7. Modes 1, 2, and 3.

for B

1. * indicating that AOS prior to TSTART
2. * indicating that LOS occurred after TSTART + 10 hours
3. "IN AIR GLOW"
"OCCULTED E, M, ?, ?"

for C

1. When display has not been properly initialized with three required MED's
2. Mode 1 solution ($T_1 - T_5$)
3. Mode 2 solution ($T_1 - T_5$)
4. Mode 3 solution ($T_1 - T_5$)
5. Mode 4 solution ($T_1 - T_5$)
6. When revolution is not computed by mission standards
7. When AOS/LOS solution not requested or not computed
8. When $T_1 \rightarrow T_5$ solution not computed
9. When star not available in instrument field-of-view.

for D

1. "(TARGET) MED INPUT REQUIRED"
(TIME)
(INSTR.)
2. Zero's
3. "(CSM) EPHEMERIS NOT AVAILABLE"
(LEM)
(VEH)
4. "NO SOLUTION AVAILABLE"
5. "REFSMMAT NOT AVAILABLE"
6. "NO STAR FOUND"

Functional Diagrams

Figure 40 illustrates the interfaces between the programs in the CSM/LM Spacecraft Pointing Element and other elements, units, or subsystems. Data table usage, task structure, and input/output data flow is also shown. The symbols used in the diagrams are defined in the Glossary of this document.

Input/Output Specifications

The input/output specifications provided by this element are MED formats, G40, G41 and G42, and the Spacecraft Pointing Display. The latter represents the latest format for the LLP mission.

[illegible]

Figure 40. CSM/LM Spacecraft Pointing

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MED Format Table

MED Code: G40 Task: NA
 Purpose: Initialize data for spacecraft pointing display EP: NA
 Load Module: EMGABMED QNAME: QUEID:

Desc.	Item	1	2	3	4.1	4.2	4.3
Item Name	Mode		Inst. ID	Target NM	Latitude	Longitude	Height
Input Format	X	XXXXXX	EBCDIC	XXXXXXXXXX	xx:xx:xx ^E _W	xxx:xx:xx ^E _W	xxxxxx.xx
Input Units	FXP.	EBCDIC	EBCDIC	EBCDIC	degrees	degrees	nautical miles
Program Units	Numeric Code	EBCDIC	EBCDIC	EBCDIC	radians	radians	nautical miles
Scale Factor					radians per degree	radians per degree	
Checking Option	$\geq 1, \leq 4$	Exact (3-6)	Exact (5-8)		$-\pi/2 \leq 0$ $\leq \pi/2$	$\geq 0, \leq 2\pi$	
Missing Item Option	Error	Error	Error	Error	Error if all items not specified for mode 1		
Item Destination	Disp. 0 F	Disp. 8, 4 D, H	Disp. 16, 6 D, H	Disp. 24 D	Disp. 32 D	Disp. 40 D	

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be stored in data table EZGSTMED, blocks 26-35

Illegal Phases: All except orbit (low), PL II, transit, stay, and PLI

- Notes:
- For item 2, the last 3 characters must be CSM or LEM
 - For item 3: mode 1 - the last character must specify reference body E (Earth) or M (Moon); mode 3 - the last 3 characters must specify valid star number; mode 4 - the last 4 characters must specify valid vehicle CSM or LEM



MED Format Table

MED Code G40 (continued)

Purpose:

 Task:
 EP:
 QNAME:
 QUEID:

Load Module: EMGABMED

Desc.	Item	5.1	5.2	6	7	8
Item Name		Right Ascension	Declination	Matrix	ATREF	Docking Angle
Input Format		xx:xx:xx	xx:xx:xx ^N _S	XXX	XXXXXX	xxx. xxxxx
Input Units		hr:min:sec	deg:min:sec	EBCDIC	EBCDIC	degrees
Program Units		radians	radians	Numeric Code	Numeric Code	radians
Scale Factor		radians per time unit	radians per degree			radians per degree
Checking Option		$\geq 0, \leq 2$	$-\pi/2 \leq 0$ $\leq \pi/2$	Exact	Exact	$-2\pi \leq 0$ $\leq 2\pi$
Missing Item Option		Error if any item missing for mode 2		Error	Error	= 100
Item Destination		Disp. 48 D	Disp. 56 D	Disp. 64 F	Disp. 68 F	Disp. 72 D

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes:

- Matrix codes may be CUR, PCR, TLM, OST, MED, DMT, LCV, DOD, and depending upon vehicle DOK, AGS, LLA, or LLD
- ATREF may be IMCSM, IMLEM, FDCSM, FDLEM

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MED Format Table

MED Code: G41

Purpose: Add, delete, or replace instrument for spacecraft pointing display

Load Module: EMGABMED

 Task: NA
 EP: NA
 QNAME:
 QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name		Instrument ID	Action Code	RX	RY		
Input Format		xxxxx	x	xxx. xxxxx	xxx. xxxxx		
Input Units		EBCDIC	EBCDIC	degrees	degrees		
Program Units		EBCDIC		radians	radians		
Scale Factor				radians per degree	radians per degree		
Checking Option		Exact (3-6)	Exact	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$		
Missing Item Option		Error	Error	= 0	= 0		
Item Destination		Disp. 0		Disp. 8	Disp. 16		
		D		D	D		

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be stored in data table EZGSTMED, blocks 38-73.

Illegal Phases: All except orbit (low), PLI, PLII, transit, and stay

Notes: 1. For item 1, the last 3 characters must be CSM or LEM.

2. For item 2, valid codes are A (add), D (delete), R (replace).

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MED Format Table

MED Code: G42

Purpose: Queue spacecraft pointing display

Task: ETISPLAY

EP: EMSNAP

QNAME:

QUEID: 2

DPRIOR: MKDGLD

Load Module: EMGABMED

Desc.	Item	1	2	3	4	5	6
Item Name		GET1	GET5	GETT			
Input Format		xxx:xx:xx.xx	xxx:xx:xx.xx	xxx:xx:xx.xx			
Input Units		hr:min:sec	hr:min:sec	hr:min:sec			
Program Units		hours	hours	hours			
Scale Factor							
Checking Option							
Missing Item Option		Error	Error	= GET1			
Item Destination		Disp. 0 D	Disp. 8 D	Disp. 16 D			

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall be stored in data table EZGSTMED, blocks 77-79.

Illegal Phases: All except orbit (low), PLI, PLII, transit, and stay

Notes: GET5 must be greater than or equal to GET1.

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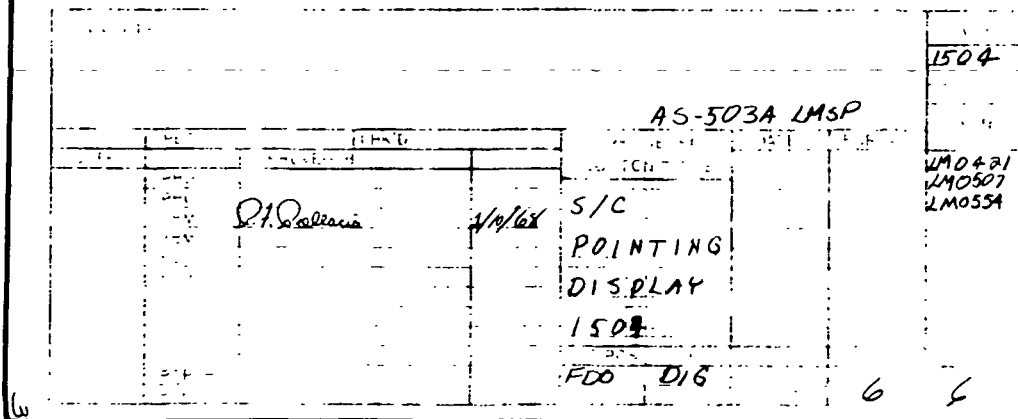
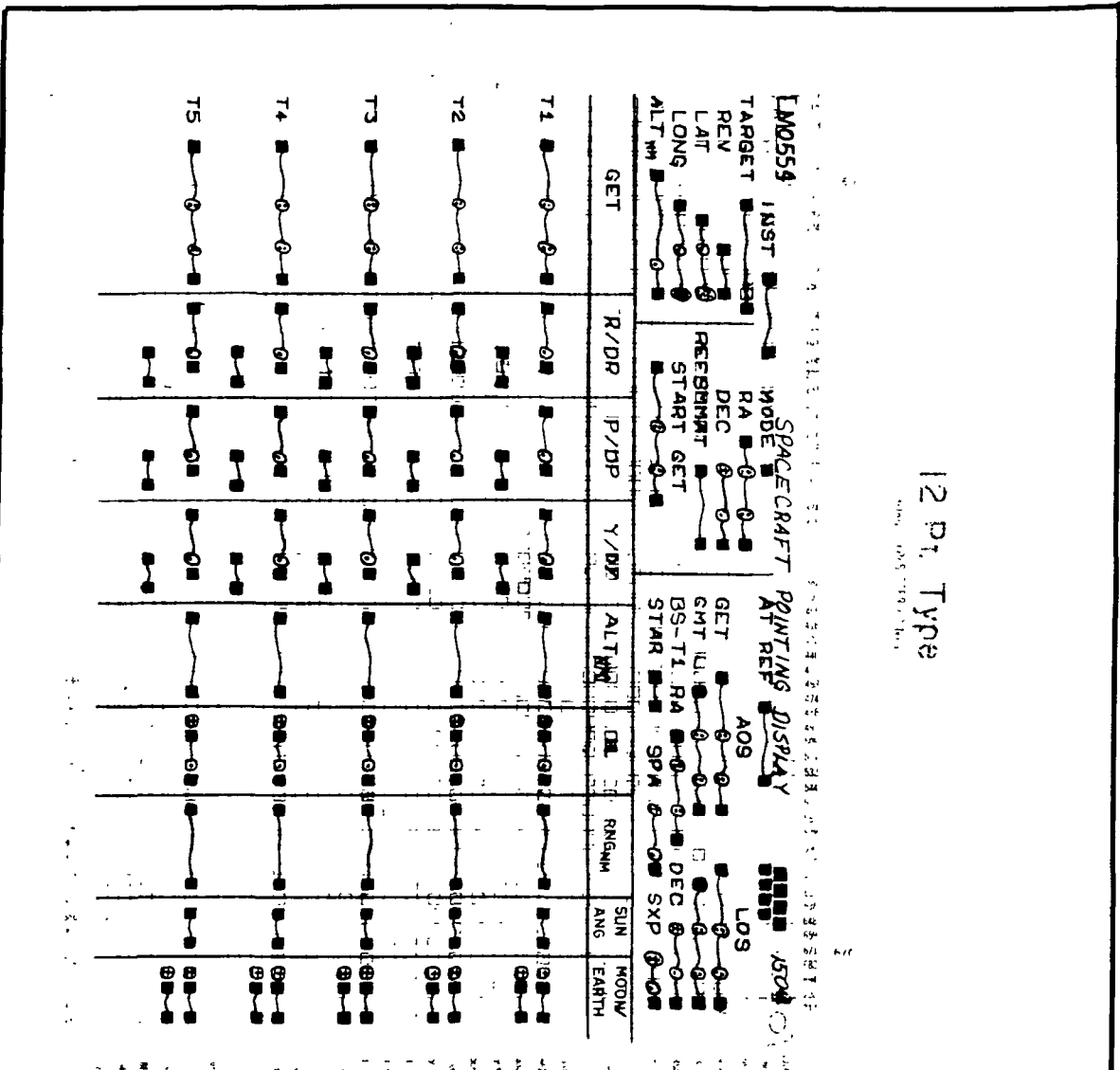
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Exhibit 63



STAR SIGHTING DISPLAY ELEMENT (CSM)

Function

For input Earth or moon ground targets, this element will compute and display sighting data for the CSM sextant based on the criterion that the first ascending line-of-sight at a specified elevation, which occurs after an input threshold time, is the desired one. For input celestial targets, this element will compute and display sighting data for the CSM sextant based on the criterion that the first ascending line-of-sight to the target not occulted by the Earth or its atmosphere is the desired one.

Load Modules/Routines Descriptions

GOST CSM Star Sighting Display Formatter - EMDGSING

This program will display data generated by EMGSTSNG for MSK 53 in the proper format.

GOST CSM Star Sighting Display Mathematics - EMGSTSNG

The purpose of this program is to compute data required for MSK 53 in one of four modes:

1. Ground target mode
2. Celestial target mode with fixed instrument
3. Celestial target mode with fixed line-of-sight
4. Celestial target mode with moveable instrument

GOST Station Characteristics Block Generator - EMGGPCHR

This program builds a ground target (Mode 1) characteristics block in the format needed by the horizon crossing station contact process, which is used by the display to calculate ground target solutions.

Requirements Interpretation

Exhibit 64 represents TR170 requirements applicable to the element as of the date of this Functional Specification. Reference item numbers have been affixed to the TR170 pages in the left margin which correspond to the included paragraphs of our comments (e.g., amendments, additions, and/or interpretations).

Exhibit 64


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ITEMS:

OT 4.2.4 Star Sighting Table

- A. Purpose. To provide the flight controller with pointing data required to align the spacecraft or sextant to a specified point in inertial space.
- B. Data Sources. The following sources will be utilized:
- Current ephemeris
 - GDO optics Support Table
 - Manual input of target line-of-sight coordinates
- C. Initialization of Display. This display will be initialized only by manual entry.
- D. Parameters To Be Computed and Displayed. The following quantities will be computed and displayed.

<u>QUANTITY</u>		<u>DEFINITION</u>	A	B	C	D
1	TGTID	Identification associated with a celestial or ground target.	1	-	1	1
2	TGT DEC	The declination of the target point.	3	-	8	
3	TGT RT ASC	The right ascension of the target point.			9	-
4	R _O	The outer CDU gimbal angle associated with the required S/C attitude.	5		11	
5	P ₁	The inner CDU gimbal angle associated with the required S/C attitude.			2	3
6	Y _m	The middle CDU gimbal angle associated with the required S/C attitude.	6	-	3	4
7	SFT	The sextant shaft angle determined for the sighting.			4	5
8	TRN	The sextant trunnion angle determined for the sighting.	6	-	2	3
9	ω _d	Central angle between the S/C at GET and the celestial point (decimal degrees).			3	4
10	GET	GET of central angle (hr:min:sec)	4	-	6	6
	GETT	Threshold time to begin search for target.			3	4
			5	-	2	3
					4	5
			6	-	3	4
					4	5

Approved:  NASA/FSB PHO/PARS

Approved: [Signature] NASA/FSB PHO/PARS

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	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>A B C D</u>			
11	REV	The revolution in which sighting is performed.. Will be displayed as available.	6	-	5	2
12	λ_{LOS}	The subsatellite longitude with respect to the reference body when a line of sight is available to the target. For earth reference body and targets other than earth ground targets, the line of sight cannot be occulted by the earth's atmosphere.	6		1	2 3 4
13	GET λ_{LOS}	The time of arrival at LOS.				
14	LOS DEC	The declination of the LOS defined by the REFSMMAT shaft and trunnion angles, and S/C attitudes.	3			
15	LOS RT ASC	The right ascension of the LOS defined by the REFSMMAT, shaft and trunnion angles, and S/C attitudes.	4	-	6	-
16	REFSMMAT	The 3 by 3 matrix defining the orientation of the IMU coordinate system and its identification code.	6	-	3	4
17	$\theta_X, \theta_Z, \theta_Y$	The set of angles relating the IMU inertial orientation represented by the transformation matrix to the ECI reference system. The three angles displayed will represent the IMU to ECI conversion done in the following order: (1) Rotation about the IMU X axis. (2) Rotation about the IMU Z axis. (3) Rotation about the IMU Y axis.	6	-	3	4
18	ϕ, λ	Geodetic latitude and longitude of earth ground target or selenographic latitude and longitude of lunar ground target.	2			
19	h	Altitude of ground target above oblate earth or spherical moon.	7		7	
20	E	Elevation of spacecraft above ground target's local horizontal plane.				
	VEH	Mission vehicle for which data was generated.	1	-	1	1

E. Updates. The display quantities will be computed upon the manual entry to initialize the display or MSK rerequest.

F. Additional Information.

1. Computation Requirements. Earth atmosphere will be computed as the radius above a spherical earth plus Δh , where Δh is equal to 400k.

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(OT) 4.2.4-2

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Exhibit 64 (Cont'd.)

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2. Manual Inputs. With the manual input of a set of one of the following sets, the computation of the corresponding set will be required.

MODE	MANUAL INPUT	COMPUTE
0	$\phi, \lambda, h, E, \text{GETT, TGID, } P_1, R_o, Y_m, \text{MATRIX ID}$	SFT, TRN, GET $\lambda_{\text{LOS}}, \lambda_{\text{LOS}}, \theta_x, \theta_y, \theta_z, \text{REV}$
1	$\phi, \lambda, h, E, \text{GETT, TGID, SFT, TRN, MATRIX ID}$	$P_1, R_o, Y_m, \text{GET}\lambda_{\text{LOS}}, \lambda_{\text{LOS}}, \theta_x, \theta_y, \theta_z, \text{REV}$
2	RT ASC, DEC, GETT, TGID, SFT, TRN, MATRIX ID	$P_1, R_o, Y_m, \text{LOS, GET}\lambda_{\text{LOS}}, \lambda_{\text{LOS}}, \text{LOS DEC, LOS RT ASC, } \theta_x, \theta_y, \theta_z, \text{REV}$
3	$P_1, R_o, Y_m, \text{SFT, TRN, TGID, GETT, MATRIX ID}$	RT ASC, DEC, GET $\lambda_{\text{LOS}}, \lambda_{\text{LOS}}, \text{LOS DEC, LOS RT ASC, } \theta_x, \theta_y, \theta_z, \text{REV}$
4	$P_1, R_o, Y_m, \text{DEC, RT ASC, TGID, GETT, MATRIX ID}$	SFT, TRN, $\lambda_{\text{LOS}}, \text{GET}\lambda_{\text{LOS}}, \lambda_{\text{LOS}}, \text{LOS DEC, LOS RT ASC, } \theta_x, \theta_y, \theta_z, \text{REV}$

3. REV displayed as available.
4. The last character of TGID will indicate body, E = earth, M = moon for Modes 1 and 0.
5. The required first sighting conditions after GETT (GET $\lambda_{\text{LOS}}, \lambda_{\text{LOS}}$) will be computed for applicable targets in the same cases and the same manner as AOS/LOS solutions are computed for the Spacecraft Pointing Display.
- 23 6. For cases other than those specified by Paragraph 5, a sighting will be computed at GETT if possible. Occultation by earth, moon and sun will be considered.
- 23 7. If no solution can be found, the vehicle code, target ID and GETT will be displayed. A comment will also be displayed to indicate why a sighting was not possible.
8. Elevation will be an output parameter for ground sightings when not in an orbit phase.
9. AOS/LOS solutions are generated with only the reference body considered as an occulter. Therefore, celestial target solutions will be checked for secondary body occultation. The solution will be displayed along with comment specifying occulting body in the event secondary occultation occurs.

21

22

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In the case of TV display output items, an additional reference column has been affixed to the TR170 pages in the right margin, which references four sections of output clarification:

- A — when item is displayed
- B — errors associated with item when displayed
- C — when item is not displayed
- D — errors associated with item when not displayed

The following listing describes the numbered items appearing in the left column.

ITEM: (see TR170 copy)

- 1 Three characters - for bookkeeping purposes only
- 2, 3 Will equal LOS DEC, LOS RT ASC in modes 2 and 4; not displayed in modes 0, 1 and 3
- 4, 5, 6 Input in modes 0, 3 and 4; output in modes 1 and 2 - associated with REFSMMAT displayed at bottom of page
- 7, 8 Input in modes 1, 2 and 3; output in mode 0 and 4
- 9 Central angle between the spacecraft at GETCA and the celestial target (decimal degrees); no mode 0 and 1 output. W_D will be referenced to the orbited body (i. e. according to reference switch times).
- 10 "GETCA" - time of closest approach, i. e., time in REV when W_D is minimum; no mode 0 and 1 output
- 11 An output item only if being computed by mission standards at display solution time. "GETT" will also be displayed; input threshold time - the next ascending solution for ground or celestial targets - will be output and assigned an output rev
- 12, 13 For celestial solutions, this is the first ascending LOS after GETT; for ground targets, see item 21
- 14, 15 Not displayed in mode 0 and 1, equal to input in modes 2 and 4; computed in mode 3
- 16 Matrix ID (ex. CUR003) will be output to identify the REFSMMAT being used
- 20 Elevation determines the solution output for ground targets. $GET\lambda_{LOS}$ will equal the first time in the period following GETT that the spacecraft LOS to the ground target ascends through the input elevation.
- 21 All λ_{LOS} output will be referenced to the orbited body (i. e., according to reference switch times).

22. All heads up P, Y, R will be referenced to the orbited body (i. e., according to reference switch times) for celestial targets and will be heads up to the target body for Earth and lunar targets.
23. Whenever GET λ LOS cannot be computed:
 - a. No ascending AOS
 - b. Always primary body occulted
 - c. Passage of reference switch prior to AOS
 - d. When celestial target in sight at GETT (with respect to primary body), a sighting will be computed at GETT with occultation comment; W_D will be output; GETCA will not be output.

Our interpretation of TV display output items is presented below.

A, B, C, D (see TR170 copy - right columns)

- A — when displayed
- B — errors associated when displayed
- C — when not displayed
- D — errors associated when not displayed

for A

1. Whenever display is properly initialized by MED input
2. For mode 1 solutions
3. For mode 2 solutions
4. For mode 3 solutions
5. For mode 4 solutions
6. Any mode solutions
7. For mode 0 solutions.

for B

1. When GET λ LOS conditions are not met for a ground target or for a celestial target throughout the ephemeris being considered, output GET λ LOS will equal GETT.

for C

- | | |
|--|--------------------------------------|
| 1. When display has not been properly initialized by MED | 7. For celestial solutions (2, 3, 4) |
| 2. When input MED vehicle does not have stored ephemeris | 8. For mode 0 solutions |
| 3. When input MED REFSMMAT is not in vehicle locker | 9. For mode 1 solutions |
| 4. When GETCA cannot be computed for a celestial target | 10. For mode 2 solutions |
| 5. When mission standard revolution is not computed | 11. For mode 3 solutions |
| 6. For mode 0 and 1 solutions | 12. For mode 4 solutions |

for D

1. "MED INPUT REQUIRED"
2. Zero
3. "EPHEMERIS NOT AVAILABLE"
4. "MATRIX NOT AVAILABLE"
5. Blank

Functional Diagrams

The CSM Star Sighting TV Display shows the interfaces of the programs in the CSM Star Sighting Element with other elements, units, or subsystems. Also included are data table usage, task structure, and input/output data flow. The key to the symbols used in the diagrams may be found in the Glossary of this document.

Input/Output Specifications

The input/output specifications for this element are MED G30 and the Star Sighting Table format, which represents the latest format for the LLP mission.



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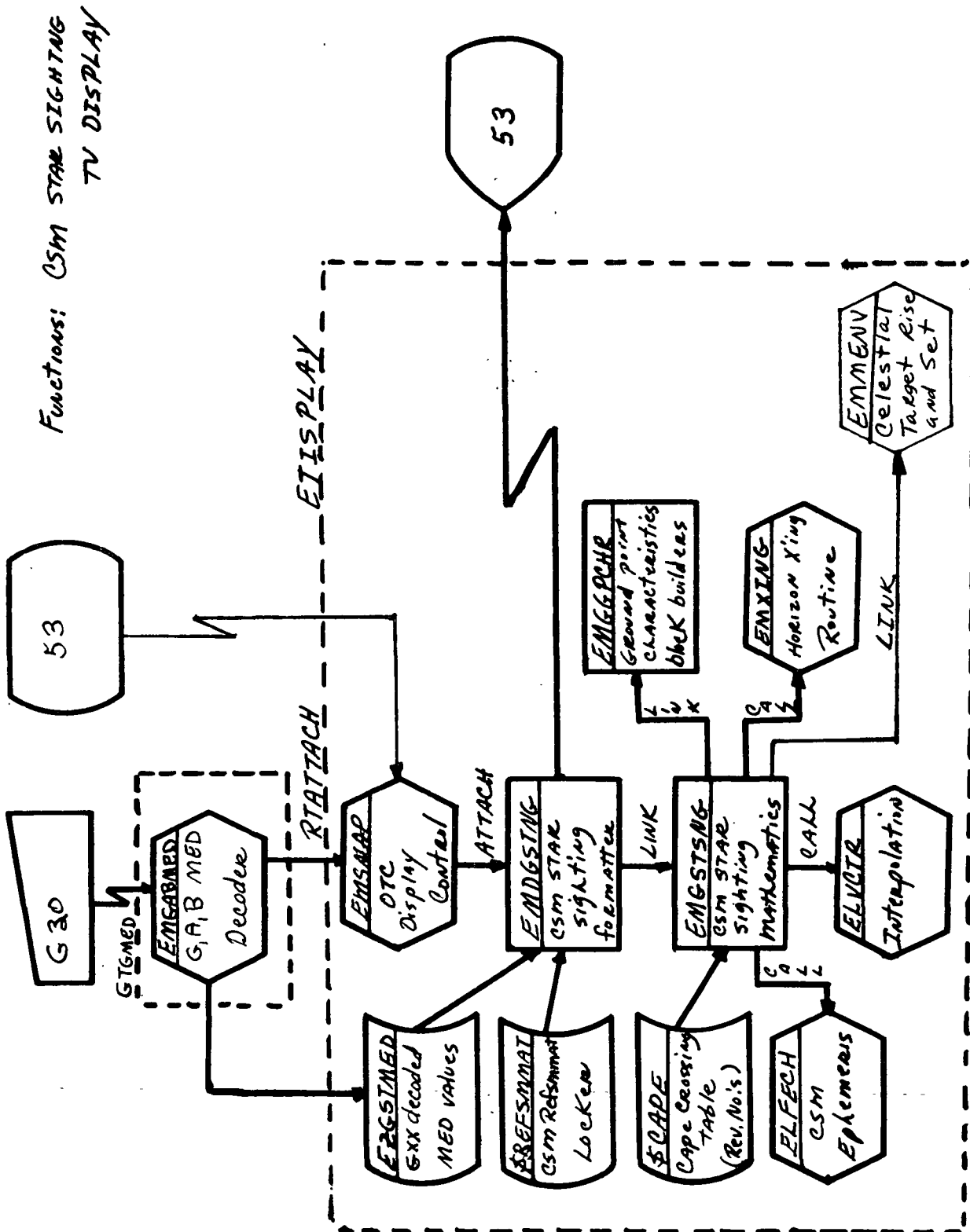


Figure 41. CSM Star Sighting TV Display



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MED Format Table

MED Code: G30 Task: ETISPLAY
 Purpose: Generate guidance optics star sighting table EP: EMSNAP
 Load Module: EMGABMED QNAME:
 QUEID:
 DPRIOR: MKDGLED

Desc.	Item	1	2	3	4	5	6.1
Item Name	CSM Vehicle		Mode	TGTID	GETT	Matrix	Latitude
Input Format	XXX		X	XXX	xxx:xx:xx.xx	XXX	xx:xx:xx ^N _S
Input Units	EBCDIC		FXP.	EBCDIC	HR:MIN:SEC	EBCDIC	deg:min:sec
Program Units	Numeric code		Numeric code	EBCDIC	hours	Numeric code	radians
Scale Factor							radians per degree
Checking Option	Exact		$\geq 0 \leq 4$			Exact	$-\pi/2 \leq 0 \leq \pi/2$
Missing Item Option	Error		Error	Note 2	Error	Error	→
Item Destination	Disp. 88 _F		Disp. 92 _F	Disp. 104 _F	Disp. 96 _D	Disp. 108 _F	Disp. 0 _D

Programmer: J. Emrick
 Initial Logic:

Final Logic: All output shall be stored in data table EZGSTMED, blocks 11-24

Illegal Phases: All except orbit (low), PL II, transmit, stay, and PLI

Notes: 1. Valid matrix codes are CUR, PCR, TLM, OST, MED, DMT, DOD, LCV

2. For modes 0 & 1, the third character must either be "E" for an Earth target or "M" for a lunar target



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MED Format Table

MED Code: G30 (continued)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: EMGABMED

Desc.	Item	8.1	8.2	8.3	9.1	9.2
Item Name		IMU Pitch	IMU Yaw	IMU Roll	Shaft	Trunnion
Input Format		xxx. xxxxx	xxx. xxxxx	xxx. xxxxx	xxx. xxxxx	xxx. xxxxx
Input Units		degrees	degrees	degrees	degrees	degrees
Program Units		radians	radians	radians	radians	radians
Scale Factor		radians per degree	radians per degree	radians per degree	radians per degree	radians per degree
Checking Option		$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$
Missing Item Option		Error if any item missing for modes 0, 3, or 4	Error if any item missing for	Error if any item missing for modes 1, 2, or 3		
Item Destination		Disp. 48 D	Disp. 56 D	Disp. 64 D	Disp. 72 D	Disp. 80 D

Initial Logic:

Final Logic:

Illegal Phases:

Notes:



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MED Format Table

MED Code: G30 (continued)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module: EMGABMED

Desc.	Item	6.2	6.3	6.4	7.1	7.2
Item Name		Longitude	Height	Elevation	Right Ascension	Declination
Input Format		xxx:xx:xx ^E _W	xxxxx	xxx	xx:xx:xx ^N _S	xx:xx:xx ^N _S
Input Units		deg:min:sec	feet	degrees	hr:min:sec	deg:min:sec
Program Units		radians	feet	radians	radians	radians
Scale Factor		radians per degree		radians per degree	radians per time unit	radians per degree
Checking Option		$\geq 0, \leq 2\pi$		$\geq 0, \leq \pi/2$	$\geq 0, \leq 2\pi$	$-\pi/2 \leq 0$ $\pi/2$
Missing Item Option		(Each element must be available for mode 0 & 1; otherwise, ignore)				
Item Destination		Disp. 8 D	Disp. 16 D	Disp. 24 D	Disp. 32 D	Disp. 40 D

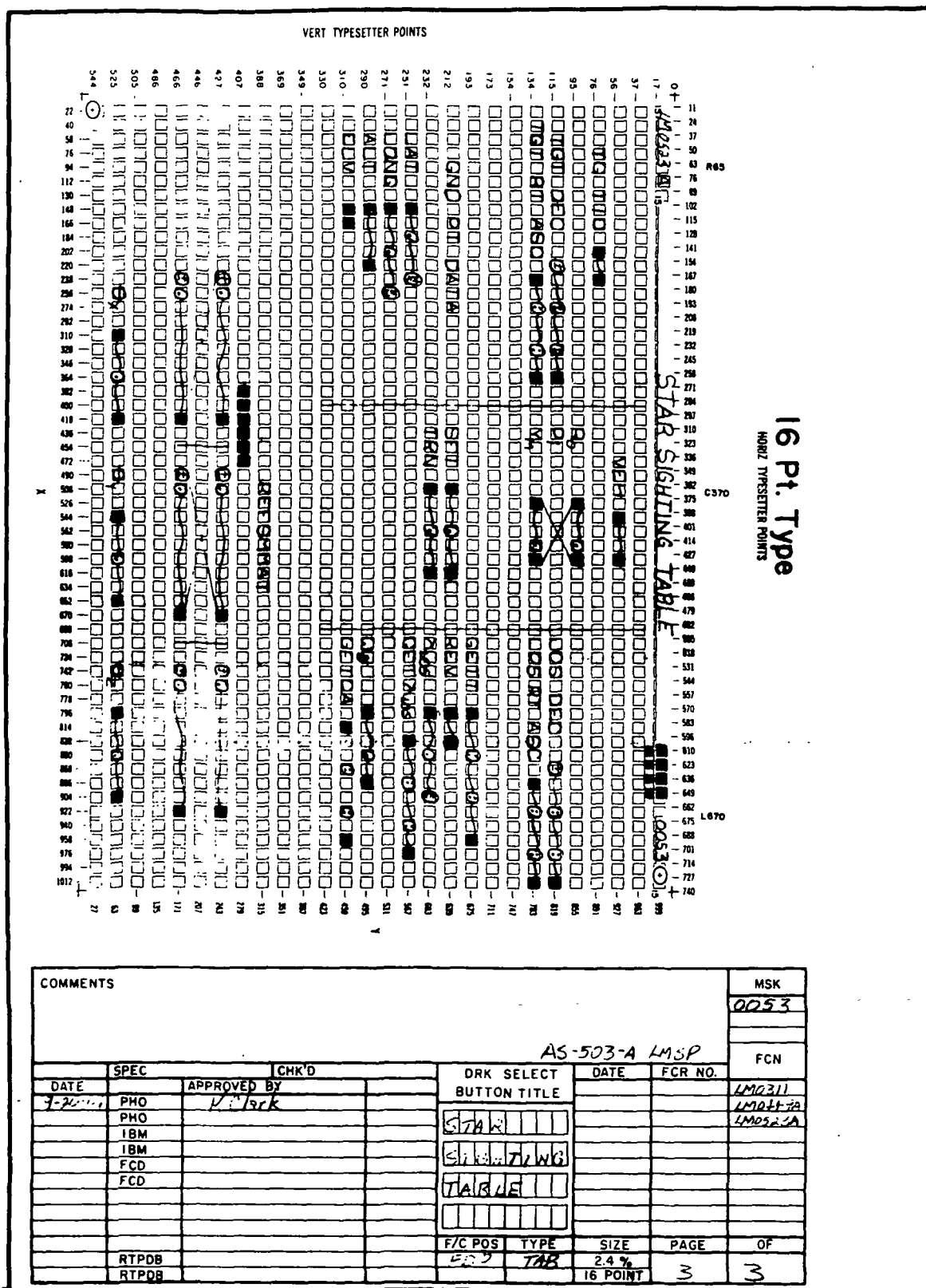
Initial Logic:

Final Logic:

Illegal Phases:

Notes:

Exhibit 65



MISCELLANEOUS REFSMMAT OPERATIONS (CSM/LM)

Function

This element computes and saves (in the CSM/LM REFSMMAT lockers) a platform alignment that is local vertical/local horizontal to the specified reference body (Earth or moon) at the specified mission time. It selects and transmits any platform alignment specified (from the CSM/LM REFSMMAT lockers) to the ACR via teletype.

Load Modules/Routines Descriptions

GOST CSM/LM LCV Computation - EMMGLCVP

This program computes the local vertical platform alignment for either the CSM or LM at the requested calculation time.

GOST CSM/LM ACR TTY Transmission - EMGTELTR

Upon MED request, this program fetches the specified reference matrix and transmits it to the ACR via teletype.

Requirements Interpretation

Exhibits 66 and 67 represent TR170 requirements applicable to this element as of the date of this Functional Specification. Reference item numbers have been affixed to the TR170 pages in the left margin which correspond to the included paragraphs of our comments (e. g. amendments, additions, and/or interpretations).

In the case of TV display output items, an additional reference column has been affixed to the TR170 pages in the right margin, which references four sections of output clarifications:

- A - when item is displayed
- B - errors associated with item when displayed
- C - when item is not displayed
- D - errors associated with item when not displayed.

Exhibit 66

PHO-TR170A
Volume 2, Change 21
2 June 1967

ITEM:

The desired alignment for the IMU stable member is

$$\begin{aligned}\hat{X}_{SM} &= \hat{X}_B \\ \hat{Y}_{SM} &= \hat{Y}_B \\ \hat{Z}_{SM} &= \hat{Z}_B\end{aligned}$$

This alignment results in the following initial attitudes.

Propulsion System	P	Y	R
DPS	0°	0°	0°
APS	0°	0°	0°
RCS + X translation	0°	0°	0°
RCS - X translation	180°	0°	180°

- 1 3. Local Vertical Alignment for the CSM IMU Inertial Platform.
 The CSM IMU stable member may be aligned to the local vertical
 at a specified time.

The stable member axes are given by:

$$\begin{aligned}\hat{X}_{SM} &= \hat{Y}_{SM} \times \hat{Z}_{SM} \\ \hat{Y}_{SM} &= \text{unit } (\vec{V} \times \vec{R}) \\ \hat{Z}_{SM} &= \text{unit } (-\vec{R})\end{aligned}$$

where \vec{v} = velocity vector

 \vec{R} = geocentric position vector

4. Local Vertical Alignment for the LM IMU Inertial Platform. The LM IMU stable member may be aligned to the local vertical at a specified time.

The stable member axes are given by:

$$\begin{aligned}\hat{X}_{SM} &= \text{unit } (\vec{R}) \\ \hat{Y}_{SM} &= \text{unit } (\vec{V} \times \vec{R}) \\ \hat{Z}_{SM} &= \hat{X}_{SM} \times \hat{Y}_{SM}\end{aligned}$$

Approved:

NASA/FSB

PHO/PARS

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Exhibit 67

PHO-TRI70A
Volume 2, Change 41
11 Dec. 1967

OT 5.2.8 Real-Time Auxiliary Computer Facility REFSMAT.

The format of the RTACF REFSMAT is contained in the Apollo Tracking Data Format Control Book, Section 2.4.2.

Approved: FSB NASA/FSB PHO/PARS

(OT) 5.2.8-1

These items represent our interpretation of the TR170A requirements.

ITEM (reference TR170 copy - left column)

- 1 A platform alignment that is local vertical/local horizontal at a specified manually input GET will be computed and saved for either the CSM or LM REFSMMAT lockers. It will be referenced as requested to either the Earth or the moon. The alignment will have:
 - One axis parallel to spacecraft radius vector from Earth/moon
CSM - Z-axis LM - X-axis
 - One axis perpendicular to a. in the direction of spacecraft motion
CSM - X-axis LM - Z-axis
 - Third axis forming right-handed or the normal triad
CSM - Y-axis LM - Y-axis
- 2 Any REFSMMAT available in CSM or LM lockers will be available upon MED request to be teletyped to the auxiliary computer room (ACR).

Functional Diagrams

The Miscellaneous REFSMMAT Operations, Figure 42, shows the interfaces between the programs in this element and other elements, units, or subsystems. Included are data table usage, task structure, and input/output data flow. The key to the symbols used in the diagrams may be found in the Glossary of this document.

Functions: LCV ALIGNMENT
ACR TTY

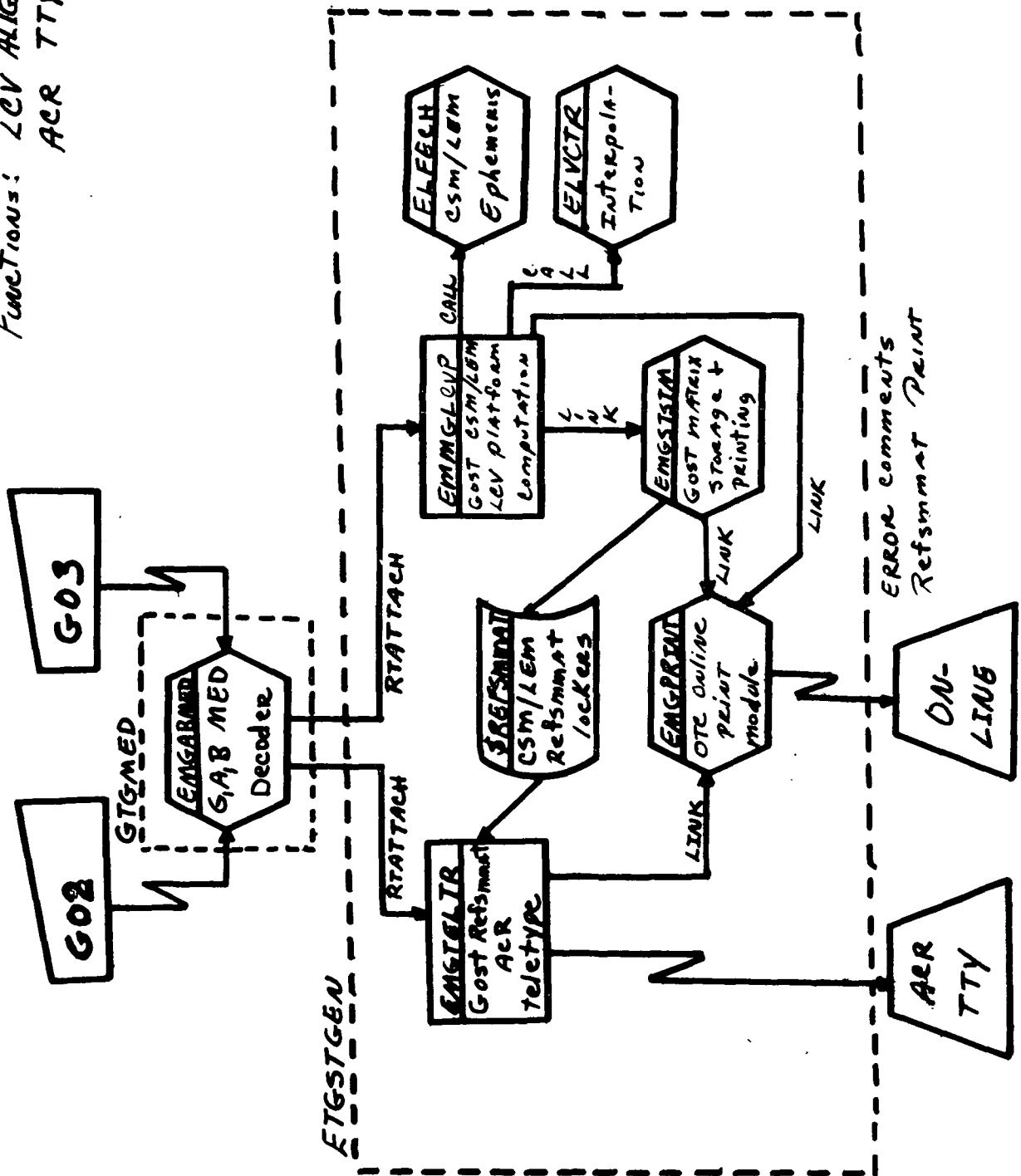


Figure 42. Miscellaneous REFSMMAT Operations

Input/Output Specifications

The input/output specifications for this element are fulfilled by MED's G02 and G03, which transmits GOST REFSMMAT to ACR and computes local vertical CSM/LM platform alignment, respectively. The specifications are further met by the ACR Reference Matrix Format (See Exhibit 68) and on-line print.

The following listing describes the text of each on-line print, its meaning and the recovery procedure, if applicable.

1. REFSMMAT NOT AVAILABLE

This message results from an input of GOST MED's G00, G02, G11, G21, or G23 when the referenced REFSMMAT has not been defined in the CSM or LM locker. The platform alignment (REFSMMAT) must be defined with one of the GOST procedures.

2. EPHEMERIS NOT AVAILABLE

This message results from an input of GOST MED G03 for LCV platform computation when CSM or LM ephemeris is not available at the input GET. Input time must be corrected.

3. RADIAL FLIGHT CONDITIONS

This message results from an input of GOST MED G03 for LCV platform computation when CSM or LM state at input GET is such that $\hat{r} = \hat{v}$. A LCV platform cannot be defined at this time.

4. NEW IMU MATRIX AAANNN AAA GET = NNN:NN:NN

\pm . <u>NNNNNNN</u>	\pm . <u>NNNNNNNN</u>	\pm . <u>NNNNNNNN</u>
\pm . <u>NNNNNNN</u>	\pm . <u>NNNNNNNN</u>	\pm . <u>NNNNNNNN</u>
\pm . <u>NNNNNNN</u>	\pm . <u>NNNNNNNN</u>	\pm . <u>NNNNNNNN</u>

This message is printed with appropriate matrix ID (ex. "CUR001, TLM014") whenever a new CSM or LM alignment is created and saved.

5. VEH. REFSMMAT REFSMMAT SENT TO THE RTACF

This message is printed whenever a REFSMMAT from either the CSM or LM lockers is teletyped to the RTACF via MED G02.



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MED Format Table

MED Code: G02
 Purpose: Transmit GOST REFSMMAT to RTACF
 Load Module: EMGABMED
 Task: ETGSTGEN
 EP: EMGTETLR
 QNAME:
 QUEID:
 DPRIOR: MKDGMF

Desc.	Item	1	2	3	4	5	6
Item Name		CSM or LEM Vehicle	Matrix				
Input Format		XXX	XXX				
Input Units		EBCDIC	EBCDIC				
Program Units		Numeric Code	Numeric Code				
Scale Factor							
Checking Option		Exact	Exact				
Missing Item Option		Error	Error				
Item Destination		Disp. 2	Disp. 0				
		H	H				

Programmer: J. Emrick
 Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low) reentry, PLIL, transit, stay, and PLI

Notes: 1. Vehicle name stored at a displacement of 4

2. Valid codes for matrix are CUR, PCR, TLM, OST, MED, DMT, DOD, LCV for the CSM. CUR, PCR, TLM, OST, MED, DMT, DOD, LCV, AGS, DOK, LLA, LLD for the LEM.



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MED Format Table

MED Code: G03
 Purpose: Compute and save local vertical
 CSM/LM platform alignment
 Load Module: EMGABMED
 Task: ETGSTGEN
 EP: EMMGLCVP
 QNAME:
 QUEID:
 DPRIOR: MKDGMF

Desc.	Item	1	2	3	4	5	6
Item Name		CSM or LEM Vehicle	GET	RB			
Input Format		XXX	xxx:xx:xx.xx	X			
Input Units		EBCDIC	HRS:MIN:SEC	EBCDIC			
Program Units		Numeric Code	hours	Numeric Code			
Scale Factor							
Checking Option		Exact		Exact			
Missing Item Option		Error	Error	Error			
Item Destination		Disp. 8 H	Disp. 0 D	Disp. 10 H			

Programmer: J. Emrick
 Initial Logic:

Final Logic: All output shall be passed in subpool 1

Illegal Phases: All except orbit (low), PLII, transit, stay, and PLI

Notes: For item 3, E (Earth) or M (Moon) for reference body

Exhibit 68

2-84

ACR Reference Matrix Format:

Line No.		
1	+++++<<=+	<div style="text-align: center;">↑ Header Provided by CP ↓</div>
2	***+\$\$\$+#+++++<<=+	
3	**Δ***<<=+	
4	**Δ*** Δ+\$\$\$<<=+	
5	\$\$/\$\$\$\$+Z<<=+	
	<div style="display: flex; justify-content: space-around; align-items: center;"> <div>Refsmat ID</div> <div>Veh. ID</div> </div>	
1	MATRIX Δ***+\$\$\$+***+ \$<<=+	
2	XIXE+S. \$\$\$\$\$\$ΔΔ+XIYE+S. \$\$\$\$\$\$ΔΔ+XIZE+S. \$\$\$\$\$\$<<=+	
3	YIXE+S. \$\$\$\$\$\$ΔΔ+YIYE+S. \$\$\$\$\$\$ΔΔ+YIZE+S. \$\$\$\$\$\$<<=+	
4	ZIXE+S. \$\$\$\$\$\$ΔΔ+ZIYE+S. \$\$\$\$\$\$ΔΔ+ZIZE+S. \$\$\$\$\$\$	
1	<<=+	<div style="text-align: center;">↑ Ending Provided by CP ↓</div>
2	\$\$/\$\$\$\$+ZΔ***Δ***	
3	<<=====	
4	+#++++++++	

NOTES:

1. Refsmat ID -- 3 - letter, 3 - number, reference matrix ID.
2. Vehicle ID -- CSM = command - service module
LEM = lunar module
3. Vehicle No.-- Used when more than one vehicle of one type are in orbit at a given time. First vehicle is number zero.
4. All reference matrix components are in decimal numbering with decimal point shown. All components are preceded by a sign indicator: & = plus; - = minus.

LUNAR SURFACE ALIGNMENT DISPLAY ELEMENT (LM)

Function

This element collects and saves:

1. Manually entered launch data
2. Manually entered orientation data
3. Orientation data from TLM interface
4. Orientation data from DC interface
5. Manually entered LM attitudes in the form of gimbal angles, FDAI angles or IMU erection data.

This element also computes:

1. Desired launch REFSMMAT and launch azimuth
2. Actual launch REFSMMAT
3. Star-sighting data for LM AOT and COAS for a given orientation
4. Realignment attitudes between a specified input REFSMMAT, and the computed desired and actual launch orientations.

The element is capable of displaying any of the above computed or collected data as manually requested.

Load Modules/Routines Descriptions

GOST LM Desired Lunar Launch REFSMMAT Processor - EMGSTLLD

This program will compute the desired lunar launch matrix and parallel launch azimuth, given the launch site, lift-off time and CSM orbit definition.

GOST LM Actual Lunar Launch REFSMMAT Processor - EMGSTLLA

Given the LM orientation data and attitudes, this program will compute the LM LLA REFSMMAT and the LM body axes with respect to the MCT system.

GOST LM Lunar Surface Alignment Supervisor - EMSGLSAD

This program receives and executes manual requests to collect and store orientation data, launch data, and reference attitudes. It also receives requests to compute the LLD REFSMMAT.

GOST LM Lunar Surface Alignment Math Processor - EMGMLSAD

This program interprets and executes the processing required to compute the display items as requested by the display MED. It is responsible for outputting the LLA REFSMMAT to the LSAD data table and the items to be displayed to the display formatter.

GOST LM Lunar Surface Alignment Display Formatter - EMGDLSAD

This program interprets and formats the data output by EMGMLSAD for display.

GOST LM Lunar Surface LCV Subroutine - ELGLCV

This subroutine computes a LM position vector on the lunar surface and a local horizontal REFSMMAT with the X-axis along the local vertical and the Z-axis directed north.

GOST LM IMU/FDAI Angle Conversion - EMMGFDAI

This program takes either IMU or FDAI angles as input and outputs the other set.

Requirements Interpretation

Exhibit 69 represents the TR170 requirements applicable to this element as of the date of this Functional Specification. Reference item numbers have been affixed to the TR170 pages in the left margin which correspond to the included paragraphs of our comments. In the case of TV display output items, an additional reference column has been affixed to the TR170 pages in the right margin which references four sections of output clarification

- A — when item is displayed
- B — errors associated with item when displayed
- C — when item is not displayed
- D — errors associated with item when not displayed

The items listed below reflect our interpretation of the TR170A requirements. Each subheading corresponds to the one in the requirements. The items are referenced from the left-hand column numbers in TR170A.

ITEM:

Parameters

- 2-4 Input via MED to give the lunar launch definition for LLD and LLA REFSMMAT computations. The CSM vector acquired by MED input will be saved; a new vector will not be fetched for each display request by MSK.

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Exhibit 69

PHO-TR170A
Volume 2, Change 57
15 April 1968

ITEM:OT 4.2.5 Lunar Surface Alignment Display

- 1 A. Purpose. To provide the GDO with guidance related lunar launch parameters to evaluate lunar surface IMU and LM body orientation and to provide actual and desired REFSMMATS.

- B. Data Sources. The following sources of data will be used.

- 1 • Manual entries
- 2 • LM trajectory/telemetry interface table
- 3 • LM ephemeris
- 4 • CSM ephemeris
- 5 • Elements of GOST
- 6 • DC platform alignment processor.

- 1 C. Initialization of Display. This display will be initialized by manual entry.

D. Parameters

	<u>QUANTITY</u>	<u>DEFINITION</u>				
			A	B	C	D
1	CSM STA ID	Standard anchor vector identification for CSM ephemeris	3	-	2	-
2	GMTV, GETV	GMT and GET of vector from main ephemeris used to define CSM orbit plane. GETV specified on MED.	2	1	1	1
3	GETLO	Input GET of launch from lunar surface	2	-	1	-
4	ϕ_{LM} , λ_{LM}	Input selenographic coordinates of lunar landing site	2	-	1	-
5	GETR	System GET of zero phase elapsed time	8	-	3	-
6	LAUNCH AZ	Computed parallel launch azimuth for LM from lunar surface based on CSM orbit and input GETLO, ϕ_{LM} , λ_{LM} . This value is for general information only and is computed from equations contained in MSC Internal Note No. 68-FM-67 dated March 8, 1968.	5	-	4	-

Approved: SP NASA/FSB PHO/PARS

(OT) 4.2.5-1

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Exhibit 69 (Cont'd.)

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11 March 1968

ITEM:

QUANTITY		DEFINITION	A B C D																			
7	MODE	Specified on input to display parameters associated with particular sets of stored data	1	-	5	4																
		<table><tr><th>MED MODE</th><th>DISPLAYED</th></tr><tr><th>INPUT</th><th>AS MODE ID</th></tr><tr><td>AOT</td><td>"AOT ONE STAR USED" or "AOT TWO STARS USED"</td></tr><tr><td>COAS</td><td>"COAS ONE STAR USED" or "COAS TWO STARS USED"</td></tr><tr><td>TLM</td><td>"TLM HIGH SPEED OPTICS" or "TLM LOW SPEED OPTICS"</td></tr><tr><td>RR</td><td>"RR" "NNLNN" RR BATCH NO. NUMBER OF TIMES PROCESSED Y-IF GRAVITY VECTOR USED N-IF NOT</td></tr><tr><td>LVLH</td><td>"LVLH"</td></tr><tr><td>REF</td><td>"REF" plus "REFSMMAT ID"</td></tr></table>	MED MODE	DISPLAYED	INPUT	AS MODE ID	AOT	"AOT ONE STAR USED" or "AOT TWO STARS USED"	COAS	"COAS ONE STAR USED" or "COAS TWO STARS USED"	TLM	"TLM HIGH SPEED OPTICS" or "TLM LOW SPEED OPTICS"	RR	"RR" "NNLNN" RR BATCH NO. NUMBER OF TIMES PROCESSED Y-IF GRAVITY VECTOR USED N-IF NOT	LVLH	"LVLH"	REF	"REF" plus "REFSMMAT ID"				
MED MODE	DISPLAYED																					
INPUT	AS MODE ID																					
AOT	"AOT ONE STAR USED" or "AOT TWO STARS USED"																					
COAS	"COAS ONE STAR USED" or "COAS TWO STARS USED"																					
TLM	"TLM HIGH SPEED OPTICS" or "TLM LOW SPEED OPTICS"																					
RR	"RR" "NNLNN" RR BATCH NO. NUMBER OF TIMES PROCESSED Y-IF GRAVITY VECTOR USED N-IF NOT																					
LVLH	"LVLH"																					
REF	"REF" plus "REFSMMAT ID"																					
8	P _{ID} , Y _{OD} , R _{MD}	Computed inner, outer and middle IMU gimbal angles with LM body axes aligned to the axes of the desired REFSMMAT and the IMU aligned to the displayed REFSMMAT	4 5	- 6	4 6	-																
9	P _{IA} , Y _{OA} , R _{MA}	Computed inner, outer and middle gimbal angles with LM body axes as defined by MODE associated data and the IMU aligned to the displayed REFSMMAT	4 6	- 7	6 7	-																
10	P _{IF} , Y _{OF} , R _{MF}	Computed FDAI pitch, yaw and roll corresponding to P _{IA} , Y _{OA} and R _{MA}	4 6	- 7	6 7	-																

Approved: 

NASA/FSB

PHO/PARS

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Exhibit 69 (Cont'd.)

PHO-TR170A
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ITEM:

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
11	Y_H	Computed angle from lunar north to the projection of the LM Z body axis onto the local horizontal plane, measured negatively about the local vertical vector. Based on MODE associated data. Was directly input if in LVLH MODE	5 6	- 7	4 7	- -
12	P_H	Computed angle from the local horizontal plane to the LM Z body axis measured in the LM XZ plane by a positive rotation about the LM Y body axis. Was directly input if in LVLH MODE	5 6	- 7	4 7	- -
13	R_H	Computed angle from the local horizontal plane to the LM Y body axis measured in the LM XY plane by a positive rotation about the LM Z body axis. Was directly input if in LVLH MODE	5 6	- 7	4 7	- -
14	$\text{SIN } \delta_L, \text{COS } \delta_L$	Computed sine and cosine of the angle from the AGS Y axis to the projection of the LM Z axis onto the AGS YZ plane, measured positively about the AGS X axis. The functions will be computed assuming the AGS inertial coordinate system is coincident with the desired REFSMMAT. The LM body is defined by MODE associated data	5 6	- 7	4 7	- -
15	047, 053	Computed equivalent DEDA octal for computed $\text{SIN } \delta_L$ and $\text{COS } \delta_L$ respectively. The algorithm for conversion is presented in Section F	5 6	- 7	4 7	- -
16	$\text{SIN } \delta_L, \text{COS } \delta_L$	Input to define orientation of AGS Z axis in local horizontal plane or computed from input 047, 053	7	-	8	-
17	047, 053	Input to define orientation of AGS Z axis in local horizontal plane or computed from input $\text{SIN } \delta_L, \text{COS } \delta_L$	7	-	8	-
18	GET ERECT	Input time of vertical erection of AGS. AGS X axis is along landing site radius vector. AGS YZ plane is local horizontal with Z defined by input parameters $\text{SIN } \delta_L, \text{COS } \delta_L$ or 047, 053	7	-	8	-

Approved: SP

NASA/FSB

PHO/PARS

(OT) 4.2.5-3

Exhibit 69 (Cont'd.).

PHO-TR170A
Volume 2, Change 58
19 April 1968

ITEM:

QUANTITY		DEFINITION	A	B	C	D
19	P, Y, R	Input pitch, yaw and roll attitudes to be used in defining actual REFSMMAT except in REFSMMAT and TLM MODE in which case attitudes are required for determining body attitude on lunar surface.	7	-	8	-
20	AT REF	Input indicator to identify input P, Y, R as IMU or FDAI angles	7	-	8	-
21	GET	Input GET when P, Y, R are valid	7	-	8	-
22	REFSMMAT	Specified in initialization MED. May be actual, desired or any REFSMMAT from LM REFSMMAT locker. ID is ACTUAL, DESIRED or STANDARD ID code	1	-	6	3
23	ix, iy, iz	Components of the star line-of-sight unit vector in stable member coordinates. Two sets are saved from the trajectory/telemetry interface table upon manual entry of instruction to save from high or low speed. Associated Star ID's are also saved	9	-	10	-
24	GET S	GET of telemetry frame from which star unit vectors were saved	9	-	10	-
25	STAR 1, STAR 2	Identification number 1 to 400 of stars used in sightings. A different set can be associated with telemetry unit vectors, AOT input and output data, and COAS input and output data	10	-	10	-
26	GETCHK	Input time required for star sighting for AOT	11	-	11	-
27	GETCHK	Input time required for star sighting for COAS	11	-	11	-
28	PETCHK	Phase elapsed time of GETCHK	11	-	11	-
29	GETMARK	Time associated with each input star sighting	12	-	12	-
30	AXIS	Axis along which COAS is mounted, either X or Z	13	-	13	-
31	EL	COAS rotation which places star on reticle crossline	13	-	13	-

Approved: NASA/FSB PHO/PARS

(OT) 4.2.5-4

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Exhibit 69 (Cont'd.)

PHO-TR170A
Volume 2, Change 53
11 March 1968

ITEM:

	<u>QUANTITY</u>	<u>DEFINITION</u>	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
32	SXP	Position of star on COAS reticle crossline	13-		13-	
33	DETENT	AOT detent in which star appears	12-		12-	
34	A1	AOT reticle rotation required to place star on one of four lines, $\pm X$, $\pm Y$	12-		12-	
35	A2	AOT reticle rotation required to place star on spiral	12-		12-	
36	L_Y	Equivalent trunnion angle of star (angular distance of star from center)	12-		12-	

E. Updates

1. No automatic updates will occur.
2. The display may be recomputed or output data changed by re-entering the initialization MED.
3. The display may be recomputed based on the last initialization MED by re-requesting the display via the MSK.
4. Stored data may be changed by MED at any time without changing the data currently being displayed.

F. Additional Information

1. The manual entries associated with this display are OT 4.1.1 0 through R.
2. If the display MODE is TLM or LVLH, the saved or input data will be displayed.
3. If the display MODE is AOT and no AOT check data has been requested, the input data will be displayed.
4. If the display MODE is COAS and no COAS check data has been requested, the input data will be displayed.
5. If star check data is generated and displayed an associated GETCHK is displayed. If input star data is displayed, associated mark times are displayed (except for TLM MODE which shows time of frame).

Approved: LD? NASA/FSB PHO/PARS

(OT) 4.2.5-5

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Exhibit 69 (Cont'd.)

PHO-TR170A
Volume 2, Change 53
11 March 1968

ITEM:

- 6 6. Generation of Star data for the LSAD is to be performed in the same way as is done for the LM Optics Support Table.
- 7 7. Either the parameters AT REF, P, Y, R, GET or the parameters GETERECT, SIN δ_L , COS δ_L , 047, 053 will be maintained and not both. The last set entered will be saved.
- 8 8. The mark times on entered data will not necessarily be the same.
- 9 9. If only one star is entered for AOT or COAS MODE, it is to be assumed that the X axis of the IMU is erected vertically along the radius vector of the landing site at time of mark.
- 10 10. If check data is requested, the MODE associated data will be used to define the LM body.
- 11 11. If the actual REFSMMAT is requested for saving in the LM REFSMMAT Locker, the one associated with the current MODE of display will be saved. The ID will be LLA.
- 12 12. Only one desired can be available at any time and will be saved upon request. The ID will be LLD.
- 13 13. The desired REFSMMAT is defined as follows:

$$\begin{aligned}\hat{X}_{SM} &= \text{unit } \vec{R}_{LS} \text{ at GETLO} \\ \hat{Y}_{SM} &= \hat{Z}_{SM} \times \hat{X}_{SM} \\ \hat{Z}_{SM} &= \text{unit } [(\vec{R}_{CSM} \times \vec{V}_{CSM}) \times \hat{X}_{SM}]\end{aligned}$$

where \vec{R}_{LS} is the landing site radius vector

\vec{R}_{CSM} and \vec{V}_{CSM} are CSM position and velocity vectors which define the CSM orbit at liftoff.

- 14 14. Check stars will be determined for the specified AOT detent and/or COAS AXIS beginning with the star number indicated in initialization MED.

Approved: SP NASA/FSB PHO/PARS

(OT) 4.2.5-6

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Exhibit 69 (Cont'd.)

PHO-TR170A
Volume 2, Change 57
15 April 1968ITEM:

- 15 15. Decimal-to-DEDA Octal Conversion. The algorithm to convert decimal functions of δ_L to DEDA octal is as follows:

STEPSEXAMPLE

- | | |
|--|--|
| (1) Start with decimal value | $\text{SIN } \delta_L = -0.5625 _{10}$ |
| (2) Convert to <u>15</u> bit binary | $-.100\ 100\ 000\ 000\ 000 _2$ |
| (3) Shift binary point one place to left (for DEDA B1 scaling) | $-.010\ 010\ 000\ 000\ 000 _2$ |
| (4) <u>Iff</u> number is negative, convert to 2's complement by inverting all bits to left of least significant bit which is a one | $-.101\ 110\ 000\ 000\ 000 _2$ |
| (5) Convert to octal | $-.56000 _8$ |
| (6) Drop octal point | -56000 |

The DEDA octal is always of the form +XXXXX.

Converting from DEDA octal to decimal is the reverse process.

- 16 16. The data supplied from the DC platform processor will be three angles α_1 , α_2 , α_3 referenced to a coordinate system with its X axis along the landing site radius vector and Z axis north. The angles rotate by sequence the defined coordinate system into the LM body coordinate system. The first rotation is about X by α_1 . The second rotation is about displaced Y by α_2 . The third rotation is about displaced Z by α_3 .
- 17 17. The DC platform processor requires a first guess in order to converge on a solution. The LSAD will supply DC upon request an α_1 , α_2 , α_3 as defined above. A MED will define the best knowledge of LM attitude by specifying which MODE's data to use for computing and saving α_1 , α_2 , α_3 for DC.
- 18 18. The LSAD will initially contain zero IMU attitudes. To change attitudes by MED, one angle must be entered other than zero.

19

20

Approved: 2/27 NASA/FSB PHO/PARS

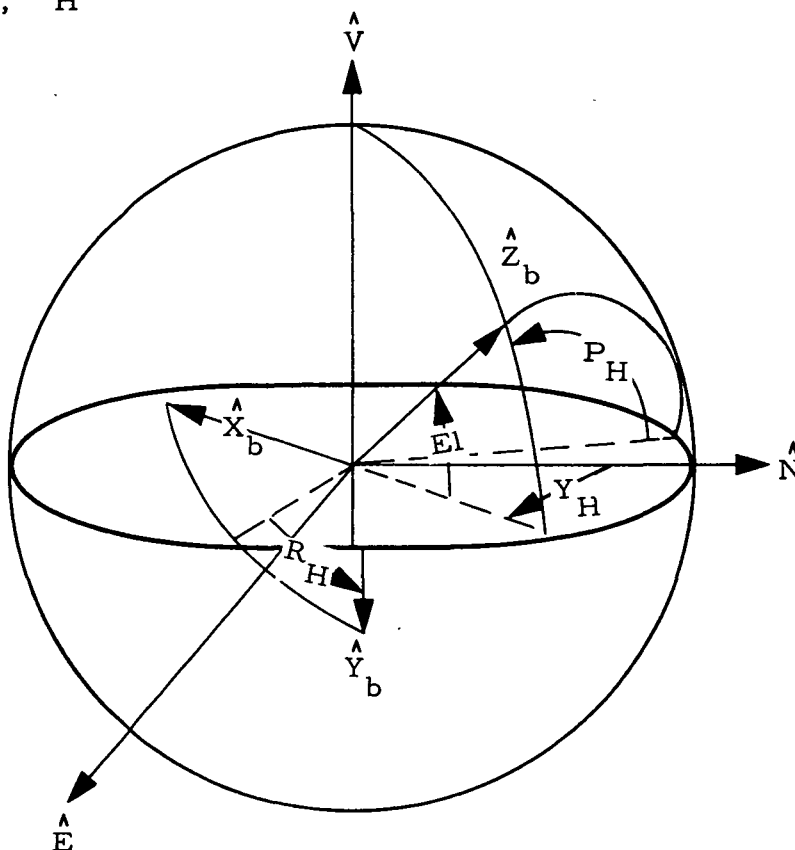
ITEM:

- 7 The mode is given on the input MED and the orientation data on the LSAD data table associated with this mode is used to compute the LLA REFSMMAT, actual realignment gimbals and computed erect data. The mode ID displayed gives additional information about the type of orientation, data used to compute the LLA REFSMMAT.
- 8-10 The displayed REFSMMAT may be any available REFSMMAT from the LM REFSMMAT locker, as well as the desired REFSMMAT computed from the LSAD launch definition or the actual REFSMMAT computed from the mode associated data.

The output P_{ID} , Y_{OD} , R_{MD} will be in FDAI angles rather than IMU angles.

11-13 Y_H , P_H , R_H

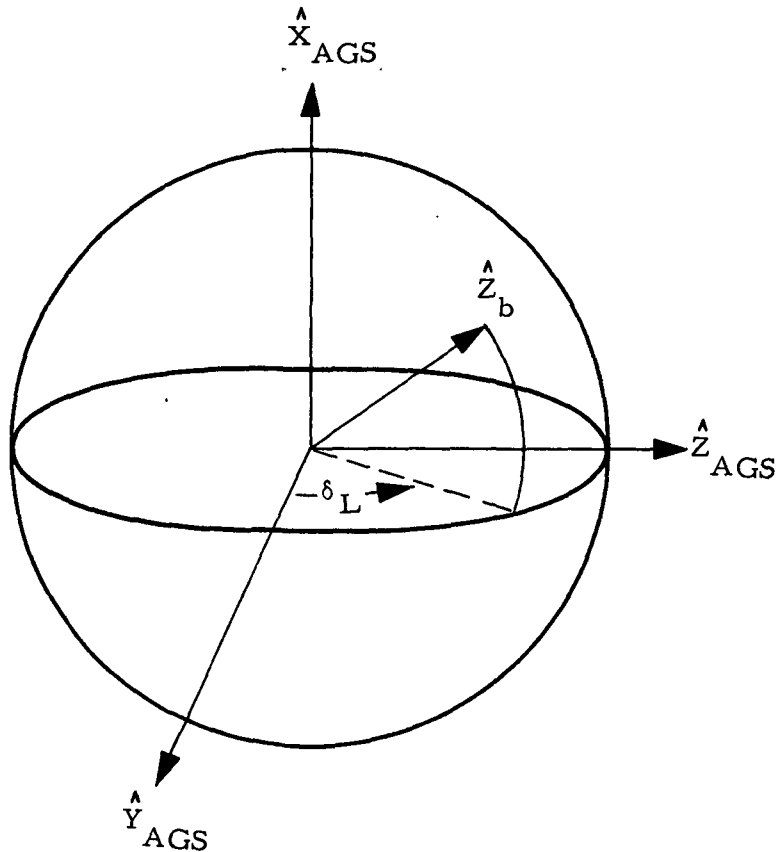
(Pilot Attitudes)



The pilot attitudes are not to be taken as the normal Yaw-Pitch-Roll sequential rotations, but rather as shown in the diagram with Yaw being a clockwise rotation about the vertical axis and Pitch and Roll being counter-clockwise angles about the final orientation of the Y- and Z-axes respectively.

ITEM:14 $\sin \delta_L, \cos \delta_L$

(Computed)



where $\hat{X}_{AGS} = \hat{r}_{LS}$ { i. e. along landing site radius vector

$\hat{Z}_{AGS} = \hat{Z}_{LLD}$ { i. e. along desired Z stable member axis

$$\text{then } \delta_L = \tan^{-1} \left\{ \frac{\hat{Z}_b - \hat{Z}_{AGS}}{\hat{Z}_b - \hat{Y}_{AGS}} \right\}$$

16 $\sin \delta_L, \cos \delta_L$, (input) used to define the AGS matrix as in the above diagram for all but TLM and REF modes.

34 A1 displayed is the angle that the +y reticle axis makes when the displayed reticle line is superimposed on the star. For example, if the angle input via MED (A1') is 100° , then the reticle line displayed would be +x, and the angle A1 displayed would be 10° .

ITEM:

- 36 The trunion angle Ly is related to $A1$ and $A2$ according to:

$$Ly = \frac{\{A2 - A1'\}_{0-2\pi}}{12}$$

where $A1'$ is the shaft angle required to place +y on the star.

Additional Information

- 2-5 Input data (i. e. on the LSAD table), is to be displayed only for the mode in which the display is generated. However CHK data may be computed in any mode and will be displayed in preference to input data in AOT and COAS modes when requested.
- 9 As with the OST matrices, the LLA REFSMMAT may be computed regardless of whether or not the input star data is correct. In the case of a single input star with the IMU X-axis vertical, the angle between the actual star vector and the vector defined by the input will be printed on-line. If both stars are input, then the angle between the star vectors on the star table and between the input stars are both printed on-line as with the OST matrix computations. If only one star is entered for AOT or COAS mode, it is assumed that the X-axis of the IMU is erected vertically along the radius vector of the landing site at the time of the input gimble angles and not at the time of mark.
- 19 The capability is provided to change the AOT azimuth and elevation mounting angles for all applications involving this instrument. (See G24 MED page 377a.)
- 20 Two additional TV display items shown on the display format (see Exhibit 70) but not referenced in TR170 are computed and displayed as follows:
- RTA/DEC — The right ascension and declination of the center of the AOT reticle when CHK mode AOT data is requested.
- ADC — Aid to Dependent Controller angle; effectively a trunion angle $(A2 - A1/12)$.

Our interpretation of the TV display output items is presented below:

- A — when displayed
- B — errors when displayed
- C — when not displayed
- D — errors when not displayed

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for A

1. Whenever the display initialization MED has been properly input
2. Whenever input on the launch definition MED
3. Whenever available on the time constraints table
4. When display matrix is available
5. When launch definition is complete
6. When LM body orientation is defined
7. When input on last reference attitude MED
8. When GMT of phase initiation is available
9. When TLM data is available on LSAD table
10. When display is in TLM mode
11. When CHK data is requested
12. When display is in AOT mode
13. When display is in COAS mode.

for B

1. Error Message "CSM EPHEMERIS NOT AVAILABLE"

for C

1. When not input on launch definition
2. When not available on the time constraints table
3. When phase initiation time is not available on system
4. When launch definition is incomplete
5. When display MED not properly input
6. When the display REFSMMAT is not available
7. When the LM orientation is not defined
8. When not input on last reference attitude MED
9. When not available on LSAD table
10. When not in TLM mode
11. When CHK data has not been requested
12. When not in AOT mode
13. When not in COAS mode.

for D

Error Messages

1. "CSM EPEM NOT AVAILABLE"
2. "G52 MED REQUIRED"
3. "REFSMMAT NOT AVAILABLE"
4. "DATA NOT AVAILABLE FOR MODE"

Functional Diagrams

Figures 43 and 44 illustrate the interfaces between the LSAD program elements and other elements, units or subsystems. Data table usage, task structure and I/O data flow is also shown. The symbols used are defined in the glossary of this document.

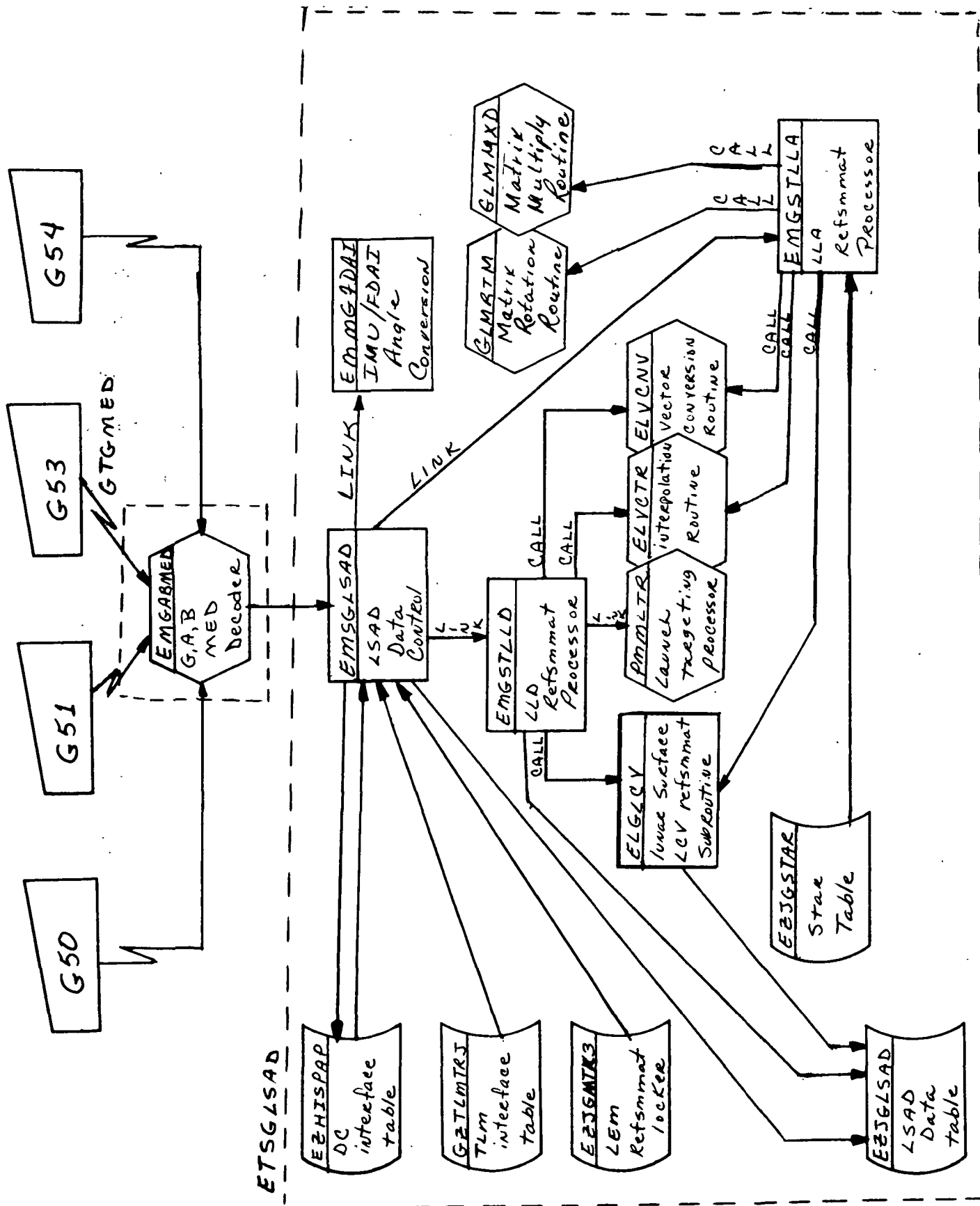


Figure 43. Lunar Surface Alignment Data Collection

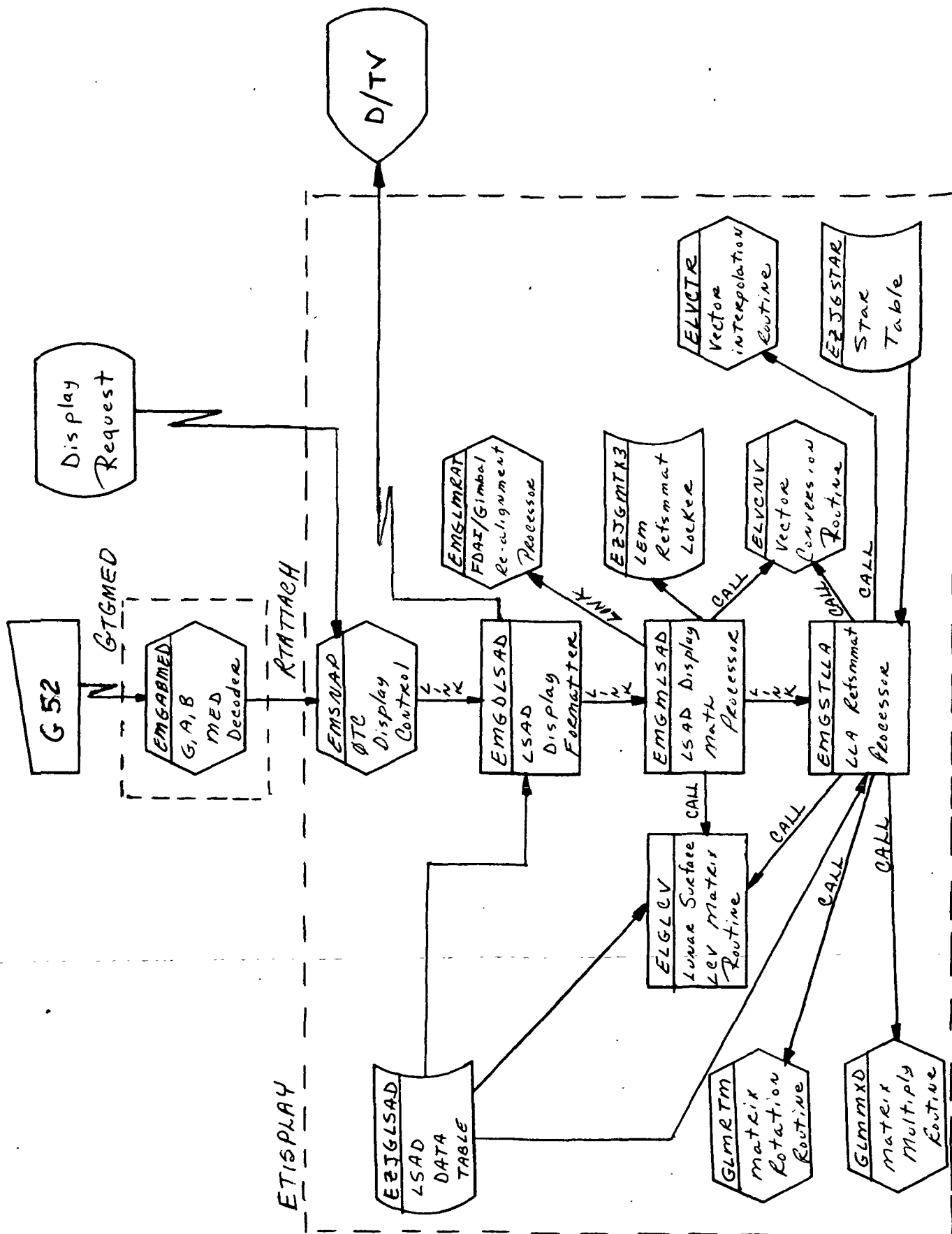


Figure 44. Lunar Surface Alignment Display

Input/Output Specifications

The input/output specifications provided by this element are MED formats G50, G51, G52, G53 and G54, the Lunar Surface Alignment Display and the following on-line prints:

1. "TABLED STAR ARC - NNN.NNN DEGREES"
"S/C SIGHTING ARC - NNN.NNN DEGREES"
when an LLA REFSMMAT is computed from star sighting data
2. "LSAD----MODE ORIENTATION NOT DEFINED"
when unable to compute RR angles for first guess.
3. "RR DATA NOT VALID FOR SAVE"
when G53 entered and rendezvous radar data is not available from DC.
4. "TLM DATA NOT VALID FOR SAVE"
when G53 entered and requested high speed or low speed data is not available from the downlink.
5. "REFSMMAT NOT AVAILABLE"
when G53 entered and the specified REFSMMAT is not in the LM locker.
6. "LSA LANDING SITE NOT DEFINED"
when trying to compute RR first guess with no landing site defined by G50 input.
7. "OST REFSMMAT STAR OPTICS NOT VALID"
when an LLA REFSMMAT is to be computed from data for two stars and the optics contains either two identical star ID's or two identical sets of equipment angles.



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MED Format Table

MED Code: G50

Purpose: LSAD launch definition

Task: ETSGLSAD

EP: EMSGLSAD

QNAME:

QUEID: 0

Load Module: EMGADMED

Desc.	Item	1	2	3	4	5	6
Item Name		LEM VEH	GETLO	GETV	Selenographic latitude	Selenographic longitude	
Input Format		XXX XXX:XX:XX.XX XXX:XX:XX.XX XXX:XX:XX.XX N XXX:XX:XX.XX E W					
Input Units		EBCDIC	HRS:MIN:SEC	HRS:MIN:SEC	DEG:MIN:SEC	DEG:MIN:SEC	
Program Units		Numeric Code	hours	hours	radians	radians	
Scale Factor							
Checking Option		Exact			$-\pi/2 < \phi < \pi/2$	$0 < \lambda < 2\pi$	
Missing Item Option		Error	$= 0$	$= 0$	$= -\pi$	$= -\pi$	
Item Destination		DISP 32 H	DISP 0 D	DISP 8 D	DISP 16 D	DISP 24 D	

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall go to subpool 1.

Illegal Phases: All except orbit (low), PLI, PLII, transit, and stay

Notes:



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MED Format Table

MED Code: G51 Task: ETSGLSAD
 Purpose: Compute rendezvous radar first guess EP: EMSGLSAD
 for DC QNAME:
 Load Module: EMGABMED QUEID: 1

Desc.	Item	1	2	3	4	5	6
Item Name		Vehicle	Mode				
Input Format		XXX	XXXX				
Input Units		EBCDIC	EBCDIC				
Program Units		Numeric Code	Numeric Code				
Scale Factor							
Checking Option		Exact	Exact				
Missing Item Option		Error	Error				
Item Destination		DISP0 H	DISP2 H				

Programmer: J. Emrick

Initial Logic:

Final Logic: All output shall go to subpool 1

Illegal Phases: All except orbit (low), PLI, PLII, transit, and stay

Notes: Mode = 1 - AOT

2 - COAS

3 - TLM

4 - LVLH

5 - RR

6 - REF

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MED Format Table

MED Code: G52 Task: ETISPLAY
 Purpose: Generate Lunar Surface Alignment Display EP: EMSNAP
 Load Module: EMGABMED QNAME:
 QUEID:

Desc.	Item	1	2	3	4	5	6
Item Name		VEH	GETCHK	Detent	Axis	Mode	Matrix
Input Format		XXX	XXX:XX:XX.XX	X	XX	XXXX	XXX
Input Units		EBCDIC	HRS:MIN:SEC	FXP	EBCDIC	EBCDIC	EBCDIC
Program Units		Numeric Code	hours	Numeric Code	Numeric Code	Numeric Code	Numeric Code
Scale Factor		—	—	—	—	—	—
Checking Option		Exact			Exact	Exact	Exact
Missing Item Option		Error	=0	=0	=0	Error	Error
Item Destination		DISP18 H	DISP0 D	DISP8 H	DISP10 H	DISP12 H	DISP14 H

Programmer: J. Emrick

Initial Logic:

Final Logic: All outputs go to EZGSTMED

Illegal Phases: All except orbit (low), PLI, PLII, transit, and stay

Notes:

1. Item 8 input - 1-6
2. Item 4 input PX and PZ. PX=1 PZ=2
3. Item 5 Mode = 1-AOT, 2-COAS, 3-TLM, 4-LVLH, 5-RR, 6-REF
4. Item 6 Matrix may be any standard ID, A, D A=13, D=14



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MED Format Table

MED Code: G52 (Cont'd)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	7						
Item Name		Starting Star						
Input Format		XXX						
Input Units		FXP						
Program Units		Numeric Code						
Scale Factor		—						
Checking Option		1 to Star table limit						
Missing Item Option		=1						
Item Destination		DISP 16 H						

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes:



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MED Format Table

MED Code: G53

Purpose: Input LSAD orientation data

Load Module: EMGABMED

 Task: ETSGLSAD
 EP: EMSGLSAD
 QNAME:
 QUEID: 3

Desc.	Item	1	2	/ 3	3.1	3.2	3.3
Item Name		VEH	MODE	GETMARK	STAR 1	DETENT/ AXIS	A1
Input Format		XXX	XXXX	XXX:XX:XX: XX	XXX	X/XX	XXX.XX
Input Units		EBCDIC	EBCDIC	hr:min:sec.	FXP	FXP/ EBCDIC	degrees
Program Units		Numeric code	Numeric code	hours	Numeric code	Numeric code	radians
Scale Factor							
Checking Option		Exact	Exact		1 to star table limit	1-6/PX, PZ	$-\pi/2-2\pi$
Missing Item Option		Error	Error		(Error if mode is AOT or COAS)		
Item Destination		Disp. 0 F	Disp. 4 F	Disp. 8 D	Disp. 16 F	Disp. 32 D	Disp. 24 D

Programmer: J. Emrick

Initial Logic:

Final Logic: All outputs go to subpool 1

Illegal Phases: All except orbit (low), PLL, PLLI, transit, and stay

Notes: 1. Item 2 Mode 1 - AOT

2 - COAS

#3 - TMH/L

4 - LVLH

6 + REF Code - REF

5 - RR

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MED Format Table

MED Code: G53

Purpose: Input LSAD orientation data

Task: ETSGLSAD

EP: EMSGLSAD

QNAME:

QUEID: 3

Load Module: EMGABMED

Desc.	Item	3.4	3.5	3.6	3.7	3.8	3.9 /
Item Name	A2		GETMARK	STAR2	DETENT/ AXIS	A1	A2
Input Format	XXX.XX	XXX:XX XX.XX	XXX:XX: XX.XX	XXX	X/XX FXP/	±XXX.XX	±XXX.XX
Input Units	degrees	degrees	hr:min:sec	FXP	EBCDIC	degrees	degrees
Program Units	radians	radians	hours	Numeric code	Numeric code	radians	radians
Scale Factor							
Checking Option	$-\pi/2-2\pi$			1 to star table limit	1-6/PX,PZ	$-\pi/2-2\pi$	$-\pi/2-2\pi$
Missing Item Option	\longrightarrow)		= 0	= 0	= 0	= 0	= 0
Item Destination	Disp. 32 D	Disp. 40 D	Disp. 48 F	Disp. 52 F	Disp. 56 D	Disp. 64 D	

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 2. Item 3 must be input in AOT and COAS modes, and is not to be processed in other mode. When item 3 is allowed, all data for Star 1 must be input.

3. Item 4 must be input in LVLH mode and is not to be processed in any other mode.

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MED Format Table

MED Code: G53

Purpose: Input LSADP orientation data

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	4.0	4.1	4.2 /			
Item Name		Pilot Pitch	Pilot Yaw	Pilot Roll			
Input Format		XXX.XX	XXX.XX	XXX.XX			
Input Units		degrees	degrees	degrees			
Program Units		radians	radians	radians			
Scale Factor							
Checking Option		0 - 2 π	0 - 2 π	0 - 2 π			
Missing Item Option		(Error if mode is LVLH \longrightarrow)					
Item Destination		Disp. 16 D	Disp. 8 D	Disp. 24 D			

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes:

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MED Format Table

Task: ETSGLSAD
EP: EMSGLSAD
QNAME:
QUEID: 4

MED Code: G54
Purpose: Define LM attitudes for LSAD

Load Module:

Desc.	Item	1	2.0	2.1	2.2	2.3	2.4
Item Name		VEH	GET	Pitch	YAW	ROLL	AT REF
Input Format		XXX	XXX:XX:XX.XX	XXX.XX	XXX.XX	XXX.XX	X
Input Units		EBCDIC	HR:MIN:SEC	degrees	degrees	degrees	EBCDIC
Program Units		Numeric Code	hours	radians	radians	radians	Numeric Code
Scale Factor		—	—				
Checking Option		Exact	—	$0-2\pi$	$0-2\pi$	$0-2\pi$	Exact
Missing Item Option		Error	=0	=0	=0	=0	=0
Item Destination		DISP0 F	DISP8 D	DISP16 D	DISP24 D	DISP32 D	DISP4 F

Programmer: J. Emrick

Initial Logic:

Final Logic: All outputs go to subpool 1

Illegal Phases: All except orbit (low), PLI, PLII, transit, and stay

1. At REF - F=2

G=1

Notes:

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MED Format Table

MED Code: G54

Purpose: Defined LM attitudes for LSAD

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	3.0	3.1	3.2	3.3	3.4
Item Name	GET	ERECT	047	053	Sin S _L	Cos S _L
Input Format	XXX:XX:XX.XX	+XXXXXX	+XXXXXX	+XXXXXX	+XXXXXX	+XXXXXX
Input Units	HR:MIN:SEC	OCTAL	OCTAL	OCTAL	FLP	FLP
Program Units	hours	HEX	HEX	HEX	FLP	FLP
Scale Factor	—					
Checking Option					-1 ≤ s _L	-1 ≤ s _L
Missing Item Option	=0	=0	=0	=0	=0	=0
Item Destination	DISP40 D	DISP48 F	DISP52 F	DISP56 D	DISP64 D	

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes:

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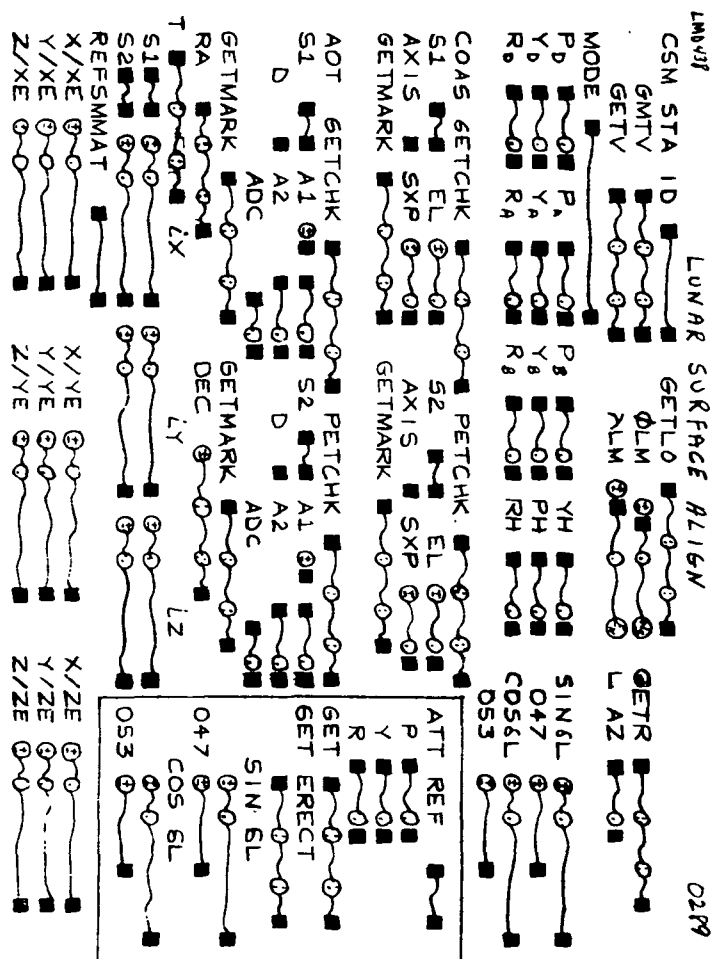
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Exhibit 70



0289

G Mission

LMO43P

0279

LUNAR
SURFACE
ALIGN
0279

GUIDO DIG

4 4

LUNAR POSITION DISPLAY ELEMENT (LM)

Function

This element computes a lunar landing site latitude and longitude from one of the following specified sources:

1. A specified REFSMMAT in the LM locker, which is assumed to be lunar local vertical/local horizontal at a specified time.
2. A specified LM body alignment (in terms of a LM locker REFSMMAT, IMU gimbal angles; and a time) and a specified LM gravity vector from manual or telemetry sources.

The element will provide a TV display of up to two of these solutions along with related input items.

Load Module/Routine Description - EMDGSITE

The GOST Lunar Position Display module will compute and display all items necessary for the element.

Requirements Interpretation

Exhibit 71 represents the TR170 requirements applicable to this element as of the date of this Functional Specification. Reference item numbers have been affixed to the TR170 pages in the left margin that correspond to the included paragraphs of our comments. In the case of TV display output items, an additional reference column has been affixed to the TR170 pages in the right margin that references four sections of output clarification

- A — when item is displayed
- B — errors associated with item when displayed
- C — when item is not displayed
- D — errors associated with item when not displayed

The items listed below reflect our interpretation of the TR170A requirements. Each subheading corresponds to one in the requirements. The items are referenced from the left-hand column numbers in TR170A.

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Exhibit 71

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11 October 1968

ItemOT 4.2.6 Lunar Position Display

- 1 A. Purpose. To provide the GDO with a solution of the lunar landing position based on LM determination of the local gravity vector or a vertical alignment of the platform.
- B. Data Sources. The following sources of data will be used:
- 1 • Manual entries
- 2 • LM REFSMMAT locker
- 3 • DC gravity vector table.
- 1 C. Initialization of Display. This display will be initialized by manual entry.
- D. Parameters

	<u>Quantity</u>	<u>Definition</u>		A	B	C	D
1	MODE	Either GV for gravity vector mode or VA for vertical alignment mode.	}	1		1	2a
						2	1
						4	2c
						5	2b
2	LAT, LON	Computed latitude and longitude of lunar landing position.	}	2		6	2e
						7	2d
3	REFSMMAT	Standard ID code of REFSMMAT used in computation.				1	2a
						2	1
4	GV CODE	ID code of gravity vector obtained from the DC gravity vector table. Used and displayed only in GV mode.	}	1		3	1
						4	2c
						5	2b
						6	2e
5	GET, GMT	GET and GMT of the attitude angles in GV mode. GET and GMT of vertical alignment in VA mode.	}	4		7	2d
						1	2a
6	PI, YO, RM	Inner, outer, and middle IMU gimbal angles.				2	1
						4	2c
7	PB, YB, RB	FDAI angles equivalent to PI, YO, and RM.	}	1		5	2b
						6	2e
						7	2d
						8	1
8	SOLUTION NO	Solution number of current data. Number is incremented upon each MED input.	}	1		1	2a
						2	1
						4	2c
						5	2b
9	GETGEN	GET of generation of solution. Equal to time MED entered.	}	1		6	2e
						7	2d

Approved: *[Signature]*

NASA/FSB

PHO/PARS

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Exhibit 71 (Cont'd.)

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ItemQuantityDefinition

A B C D

- | | | | | | | |
|----|-----|--|---|---|---|----|
| 10 | GVX | Components of gravity vector obtained from DC table and used in computation. Used and displayed only in GV mode. | 2 | { | 1 | 2a |
| | GVY | | | | 3 | 1 |
| | GVZ | | | | 4 | 2c |
| | | | | | 5 | 2b |
| | | | | | 6 | 2e |
| | | | | | 7 | 2d |
| | | | | | | |

- 1 E. Updates. Each column of the display will be updated only upon MED input. The solutions will not be recomputed upon MSK rerequest.

F. Additional Information.

- 1 1. The display will have two independent columns. Either column may be generated in either GV or VA mode.
- 2 2. Required formulation is presented in MSC Internal Note No. 68-FM-195, dated September 24, 1968.
- 3 3. LM attitude with respect to REFSMMAT may be entered as IMU angles or FDAI angles. Regardless of which angles are entered, the other set will be computed and both sets will be displayed.

- 4 4. One manual entry of the following form will be used:

GXX, VEH, GET, COLUMN, REFSMMAT, AT REF, P, Y, R, GV CODE;

where VEH = LM

REFSMMAT = Any valid LM REFSMMAT

GV CODE = T (telemetry), M (Manually entered)

AT REF = F (FDAI), I (IMU)

P, Y, R = 0 to 360

COLUMN = 1, 2

- 5 5. The MED will be decoded as follows:

- a. GV CODE required input for mode to be GV mode; otherwise mode is VA.
- b. AT REF, P, Y, R may be entered or missing for VA mode. If entered, other set of angles will be computed and both sets displayed although angles are not required in computation.
- c. VEH, GET, COLUMN, REFSMMAT required on all inputs.

6

7

Approved: NASA/FSB PHO/PARS

(OT) 4.2.6-2

ITEM:Initialization of Display

- 1 An MSK request does not regenerate the display data. Only the column requested on an MED entry will be recomputed for displaying.

Parameters

- 1 MODE will be displayed as GbV or VbA; i. e., the two letters will be separated by a blank.
- 4 GV CODE will be displayed as GTLMNNN for the telemetry gravity vector; this code is obtained from the DC table. GV CODE will be displayed as GMEDbbb for the manually entered vector; no indexed code is maintained in the DC table.
- 8 SOLUTION NO. reflects the number of times a mode (VA or GV) has been generated; not the number of times a column has been generated. The first solution for each type will be number 1 and will increment only upon MED request for the same mode.
- 10 The gravity vector will be displayed in the LM body coordinate system.

Additional Information

- 6 The gravity vector selected will be checked for unity - the vector magnitude (g) must be such $|1 - g| \leq .001$. If the vector is not unity, then the GV solution will not be computed, and an error message will be displayed in the requested column.
- 7 The display will accept input of a PYR set and output both IMU and FDAI angles in the requested display column without generating lunar landing site data.

Our interpretation of the TV display output items is presented below. See TR170 copy - right columns

- A — when displayed
- B — errors when displayed
- C — when not displayed
- D — errors when not displayed

for A

1. When the column has been properly initialized by MED in either GV or VA mode
2. When the column has been properly initialized by MED in GV mode
3. When the column has been properly initialized in VA mode
4. When the column has been properly initialized by MED and a PYR set and ATREF are supplied

for B

None

for C

1. MED has not been entered properly for the column
2. Column is not in GV or VA mode but has only PYR data displayed
3. Column is not in GV mode
4. REFSMMAT not in locker in GV or VA mode
5. Gravity vector not in DC table in GV mode
6. Time input outside the range of system sun/moon ephemeris and libration in GV or VA mode
7. Gravity vector not unity in GV mode
8. PYR and ATREF not input

for D

1. Item blanked
2. Entire column blanked with message:
 - a. "MED INPUT REQUIRED
 - b. "GRAVITY VECTOR NOT AVAILABLE
 - c. "REFSMMAT NOT AVAILABLE"
 - d. "GRAVITY VECTOR NOT VALID"
 - e. "TIME OUTSIDE THE RANGE OF DATA FOR VECTOR CONVERSION

Functional Diagrams

Figure 45 illustrates the interfaces between LPOS program elements and other elements, units, or subsystems. Data table usage, task structure and I/O data flow is also shown. The symbols used are defined in the Glossary of this document.

Input/Output Specifications

The input/output specifications for this element consist of the G60 MED and the Lunar Position Display format, which represents the latest format for the LLP mission.

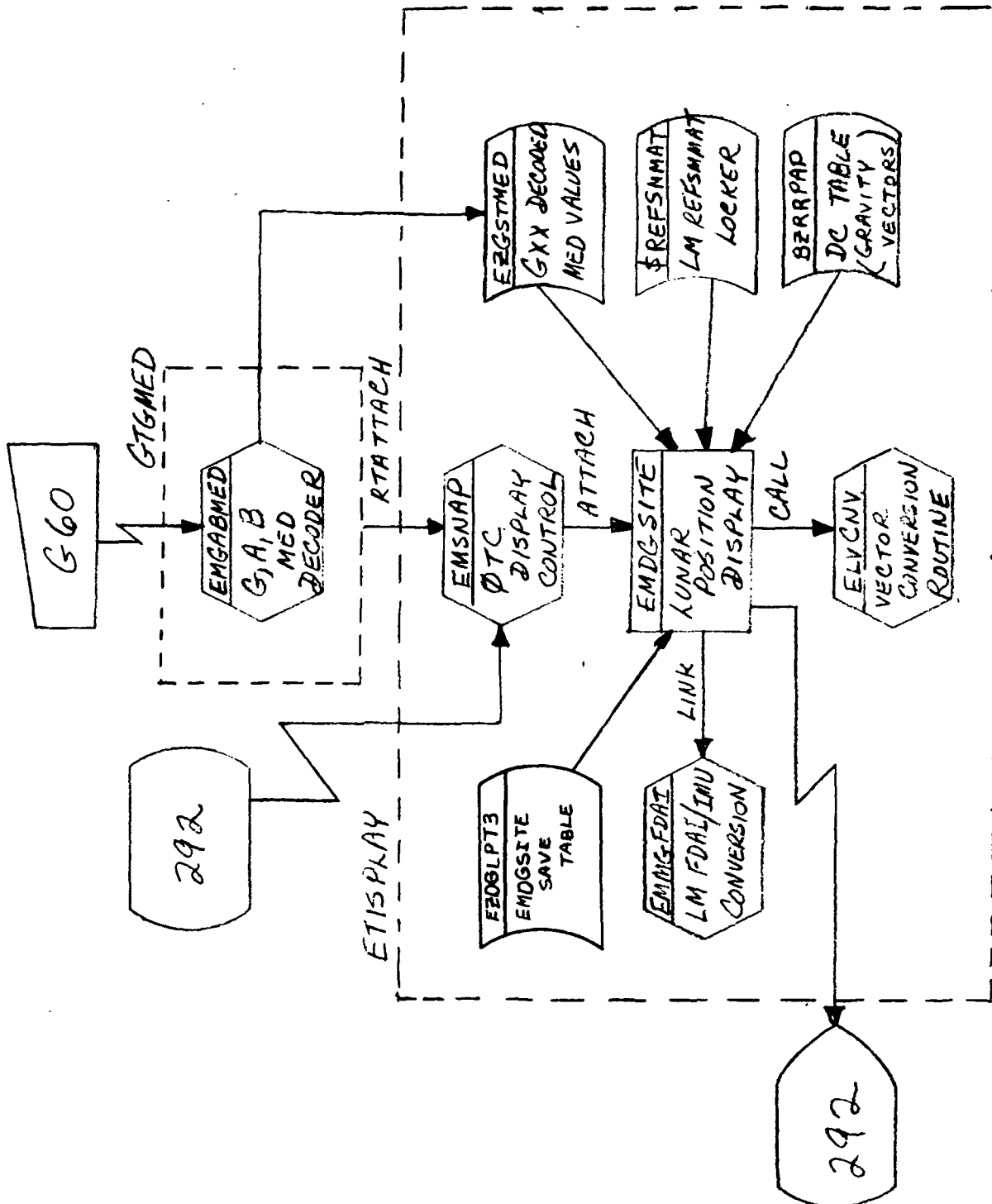


Figure 45. Lunar Position Display

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MED Format Table

MED Code: G60

Purpose: Generate lunar position display

Load Module: EMGABMED

Task: ETISPLAY

EP: EMSNAP

QNAME: NA

QUEID: NA

DPRIOR: MKDGLD

Desc.	Item	1	2	3	4	5.1	5.2
Item Name		LEM Vehicle	Column	GET	Matrix	At Ref	Pitch
Input Format		xxx	x	xxx:xx:xx.xx	xxx	x	xxx, xxxxxx
Input Units		EBCDIC	fx.pt.	hrs:min:sec	EBCDIC	EBCDIC	degrees
Program Units		Numeric Code	Numeric Code	hours	Numeric Code	Numeric Code	radians
Scale Factor							radians per degree
Checking Option		Exact	1 or 2		Note 1	Note 2	$\geq 0, \leq 2\pi$
Missing Item Option		Error	Error	= 0 if neither input Error if only one input		Note 3	= 0
Item Destination		H Disp. 6	H Disp. 0	D Disp. 16	H Disp. 2	F Disp. 8	D Disp. 24

Programmer: J. Emrick

Initial Logic:

Final Logic: All output will be stored in data table EZGSTMED Blks 101-106

Illegal Phases: REJMASK = FBE9AFFE

Notes: 1. Any matrix in LEM REFSMMAT locker (i.e., CUR, PCR, TLM, etc.)

2. "F" = FDAI = 2; "I" = IMU = 1

3. = 0 if item 5 missing; Error if any part of item 5 but not 5.1 is input

4. "M" = MED = 1; "T" = Telemetry = 2



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MED Format Table

MED Code: G60 (Cont'd.)

Purpose:

Task:

EP:

QNAME:

QUEID:

Load Module:

Desc.	Item	5. 3	5. 4	6			
Item Name		Yaw	Roll	GV Code			
Input Format		xxx,xxxxxx	xxx,xxxxxx	x			
Input Units		degrees	degrees	EBCDIC			
Program Units		radians	radians	Numeric code			
Scale Factor		radians per degree	radians per degree				
Checking Option		$\geq 0, \leq 2\pi$	$\geq 0, \leq 2\pi$	Note 4			
Missing Item Option		= 0	= 0	= 0			
Item Destination		D Disp. 32	D Disp. 40	H Disp. 4			

Programmer:

Initial Logic:

Final Logic:

Illegal Phases:

Notes: 5. All items must be input if item 6 is input

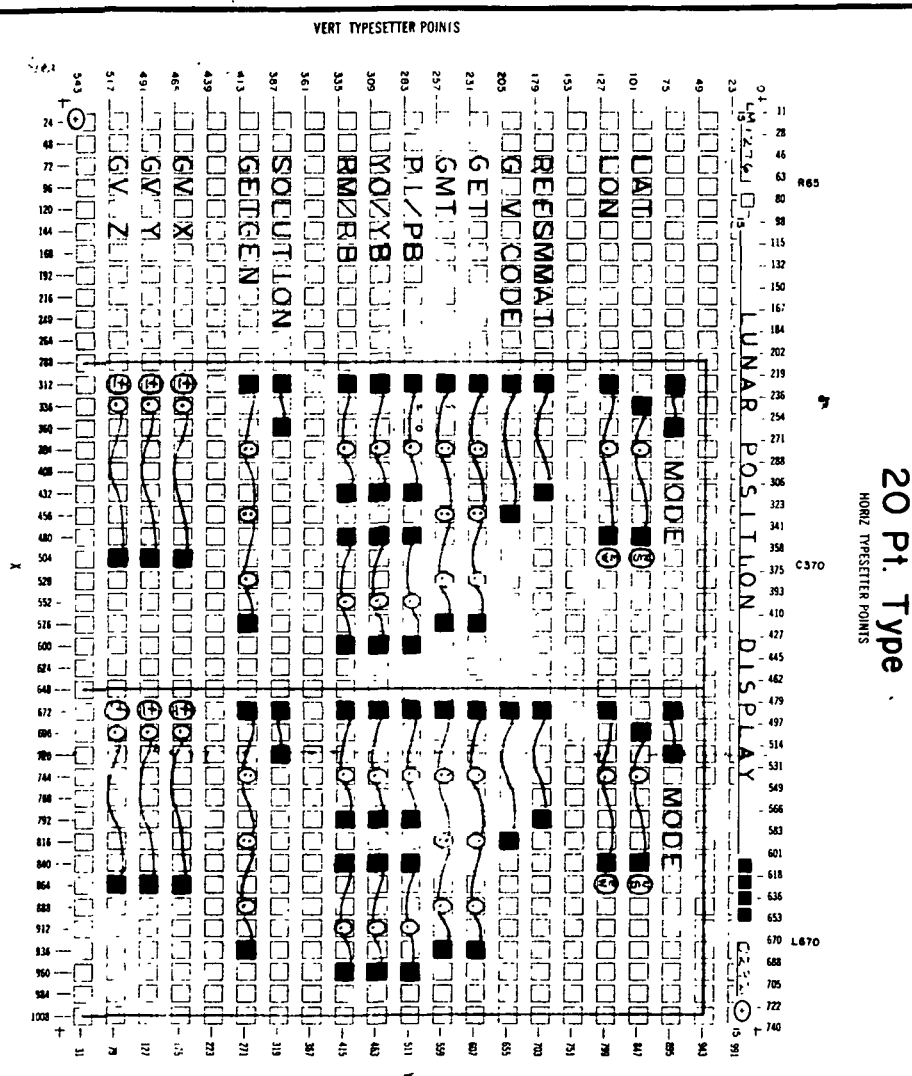
6. Some other items than 1 and 2 must be input

7. Current time (GET centiseconds) will be stored at Disp. 12.

66-2656-1



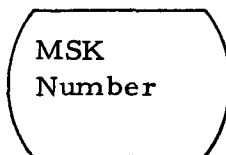
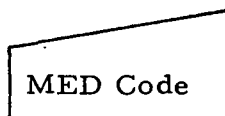
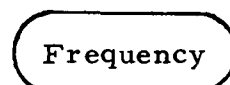
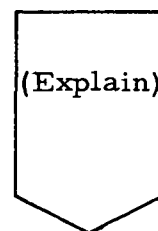
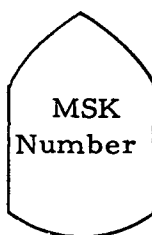
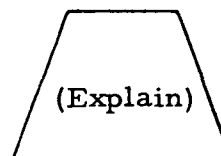
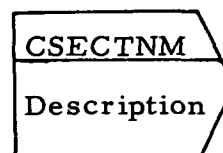
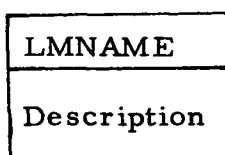
Exhibit 72

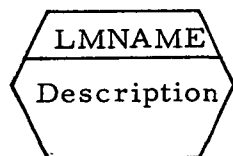
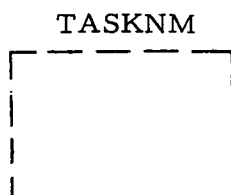
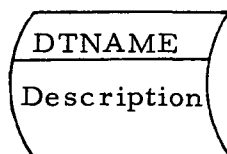


COMMENTS						MISSION FG		MSK 0192	
DATE						SPEC		CHK'D	
APPROVED BY						DRK SELECT		DATE	
PHO						BUTTON TITLE		FCR NO.	
PHO						LUNAR		1M1276	
IBM						POSITION			
IBM						DISPLAY			
FCD						0292			
FCD						F/C POS		TYPE	
RTPDB						SIZE		PAGE	
RTPDB						32 %		3	
						20 POINT		OF	
								3	

APPENDIX A

KEY TO LOGICAL ELEMENT DIAGRAMS (GLOSSARY)

1. External Inputs:MSKMEDTIME QUEUEMISC.2. External Outputs:TV, PLOTOTHER3. Load Modules and Major CSECT's (this element):

4. Load Modules (other elements, units, SS):5. Tasks:6. Data Tables:7. Logical Flow:

Pgm. Linkages: (RTATTACH, ATTACH, LINK, ETC...): (LINKAGE) →

DTREAD: ←

DTWRITE: →

DTREAD/WRITE: ←

Other I/O: ⇄

APPENDIX B

SPECIFICATION AMENDMENTS

This appendix provides a convenient list of those items described in this specification, but not provided for the Lunar Orbit Trajectory System (LOTS) and the Lunar Orbit Rendezvous System (LORS)

EPHEMERIS GENERATION AND CONTROL

<u>ITEM</u>	<u>NON-APPLICABLE SYSTEMS</u>
1. Lunar Surface Ephemeris Generation and Maintenance	LOTS/LORS
2. Lunar Ascent/Descent Capability	LOTS/LORS

EVALUATION DISPLAYS

<u>ITEM</u>	<u>NON-APPLICABLE SYSTEMS</u>
1. Relative Motion Digitals Mode II	LOTS/LORS
2. Relative Motion Digitals MCI Option	LOTS

GUIDANCE OPTICS AND SIGHTINGS

<u>ITEM</u>	<u>NON-APPLICABLE SYSTEMS</u>
1. Manual Entry for AOT Azimuth and Elevation	LOTS
2. Computations of LPD Angle for the LM Guidance Optics Support Table (MSK 239)	LOTS
3. Lunar Surface Alignment Display Element (LM)	LOTS/LORS
4. Redefinition of the IGA Angle for CSM Guidance Optics Display (MSK 229)	LOTS
5. Redefinition of the OGA Angle for LM Guidance Optics Support Table Display (MSK 239)	LOTS
6. Lunar Position Display Element (LM)	LOTS/LORS