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APOLLO 13
NAVIGATION PROCEDURES

Mathematical Physics Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS




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PROJECT APOLLO

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By Mathematical Physics Branch

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Approved: 
James C. McPherson, Chief
Mathematical Physics Branch

Approved: 
John P. Mayer, Chief
Mission Planning and Analysis Division

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1.0 SUMMARY AND INTRODUCTION

The procedures described in this report will be used in support of Apollo 13 (third lunar landing) navigation. Apollo 13 procedures for earth orbit, translunar, and transearth navigation are the same as used on Apollo 11 and are briefly discussed. Lunar orbit navigation procedures presented in reference 1 for descent and ascent have been revised and are presented in detail.

During ascent and descent, the performance of the powered flight navigation program and MSFN tracking data quality are monitored. These procedures are also included.

For descent targeting, the LM computer must be supplied with an estimate of LM position and landing site position. The landing site position is adjusted to compensate for known errors in the estimate of LM position at the time of powered descent.

For ascent targeting, the LM computer is furnished with the location of LM position and the CM orbit.

References 2 and 3 have further detailed procedures for data select which the procedures in this document should supplement.

2.0 SYMBOLS

ACR	Auxiliary Control Room
AGS	auxiliary guidance system
AOS	acquisition of signal
AOT	alignment optical telescope
B	bias
BDA	Bermuda
CM	command module
CMC	command module computer
CRO	Carnarvon
CSM	command/service module
CYI	Canary Island
DOI	descent orbit insertion
DSC	dynamic standby computer
FIDO	Flight Dynamics Officer
GDS	Goldstone
GWM	Guam
GYM	Guaymas
HAW	Hawaii
HSK	Honeysuckle Creek
h	altitude
\dot{h}	altitude rate
ID	identification
LGC	lunar module guidance computer

LM	lunar module
LOI	lunar orbit insertion
LOPC	lunar orbit plane change
LOS	loss of signal
LS	landing site
MAD	Madrid
MCC	midcourse correction
MED	manual entry device
MILA	Merritt Island
MOC	mission operational computer
MPT	mission plan table
MSFN	Manned Space Flight Center
• M	mass flow rate
NBE	Honeysuckle Creek wing
NOM	nominal
O.T.	operational trajectory
P	pitch angle
PBI	push button indicator
PDI	powered descent initiation
PGNCS	primary guidance, navigation, and control system
PIR	Pioneer tracking station
PFP	powered flight processor
RLS	relative landing site
RMS	root-mean-square
RR	rendezvous radar

RTCC	Real-Time Computer Complex
rev	revolution
SXT	sextant
TDP	tracking data processor
TEI	transearth injection
TLI	translunar injection
TM	telemetry
TRACK	tracking coordinator
t_{IG}	time from ignition
V	down-track position (section 5)
VCO	voltage control oscillator
W	cross-track position
$\Delta\rho$	range residual
$\dot{\Delta\rho}$	range rate residual
λ	longitude
ϕ	latitude
σ	standard deviation
Subscripts	
EPHEM	ephemeris
LS	landing site

3.0 EARTH ORBIT, TRANSLUNAR, LUNAR ORBIT, AND TRANSEARTH PROCEDURES

3.1 Earth Orbit Procedures

The CM is given an estimate of its position prior to TLI based on nearly one revolution of tracking. TLI is performed by the S-IVB based on its own navigation through launch and earth orbit. The RTCC processes MSFN data sequentially in batches, starting with the S-IVB insertion vector which is given a weight computed premission. One batch is formed for each pass of the CM over a tracker. The data rate is one frame each 6 seconds. If current data residuals indicate that the data are not being fit because the old data are too influential, then the old data are effectively downweighted by decreasing the weight on the state vector anchored at the first observation of the batch being processed. This process is sometimes necessary because of S-IVB venting model uncertainties.

3.2 Translunar Procedures

After the large TLI maneuver, MSFN Doppler data are processed with no weight on the initial conditions. Old data must be down-weighted after transposition and docking, evasive maneuvers, midcourse corrections, and for some water dumps, fuel cell purges, and so forth.

After the evasive and MCC maneuvers, the state vector weight is carried through the maneuver with nominal maneuver weights. The post-maneuver data are fit; and if the residuals are larger than normal, the maneuver weights are increased and the process is repeated until the data are properly fit. After approximately 5 hours, the data are fit again but with no weight given to the initial conditions. Both types of solutions are maintained until they converge, at which point the latter solution is used. Until this time, the vector determined by use of the weighted start vector method is recommended for flight control use. Each solution is used to predict perilune altitude. The perilune altitude solutions are monitored to evaluate the accuracy of translunar vectors.

As the vehicle approaches the moon, it is necessary to downweight MSFN range data because of known earth-moon distance ephemeris errors. To accomplish the downweighting, at least the last half hour and as much as the last few hours of pre-LOS translunar range data are discarded. Solutions with and without range may be performed to resolve questions. The data arc length is also shortened to allow the most recent data to more accurately determine the trajectory relative to the moon. A large block of two-way Doppler and range data is maintained to extract three-way Doppler biases in regions of no activity when the vehicle is not near

either body. To calculate the final Doppler bias table prior to LOI, an offline program will be used to perform a least squares fit on the Doppler bias pairs determined during the translunar phase. At the end of each shift after TLI, the Doppler biases determined during that shift will be punched on cards in the format shown in table I. These cards will be assembled during the last shift prior to LOI and the Doppler biases required by the RTCC program computed by an offline UNIVAC 1108 program and punched on cards for the RTCC to read.

S-band tracker angle data are not used shortly after TLI. Range and two- and three-way Doppler are used. The range observations are very important for accurate cislunar trajectory determination.

3.3 Transearth

Transearth and translunar procedures are similar. Entry flight-path angle is predicted for each vector determined and is monitored to assess accuracies.

3.4 Lunar Orbit

After LOS just prior to LOI, a best estimate of the pre-LOI conditions is computed from MSFN data up to LOS. After AOS following LOI, Doppler residuals are generated based on the best pre-LOI vector plus the nominal maneuver. Residuals are generated from the CMC vector and later from the best pre-LOI vector plus the confirmed LOI maneuver based on CMC estimates of the ΔV . Eight minutes of Doppler data are fit to obtain a quick estimate of perilune. After LOS, the pass 1 data are fit, and the latitude is recorded at the longitude of the landing site based on the plane computed from the pre-LOI vector plus confirmed LOI maneuver data and the local unconstrained one-pass fit. The unconstrained one-pass fit is sent to the CMC on rev 2 for DOI.

After DOI, the start vector will be based on a fit to pass 2 data and on the nominal maneuver. Post-DOI monitoring procedures are discussed later.

No weight is given to start vectors in lunar orbit for inplane elements. The TEI vector will be based on a one-pass fit two revs old.

4.0 PLANE CHANGE TARGETING

4.1 Introduction

The CM must pass close to the landing site on rev 14 for the descent and on rev 31 for the ascent. A plane change will nominally be required to bring the CM over the LM on rev 31 because of the 6° inclination of the orbit and the moon's rotation. Lunar orbit insertion is planned such that the CM and LM will pass over the landing site in rev 14.

It is necessary to empirically determine in real time the predicted latitude of the CM in revs 14 and 31 for plane changes because of the probability that the lunar potential model will not accurately predict the motions of the spacecraft's orbit plane.

The procedures for empirically targeting lunar orbit plane changes are presented below.

4.2 CSM Plane Monitoring for Targeting Plane Change Maneuvers

I. For pre-DOI plane change

- A. Criterion: if the estimated CSM plane in rev 14 differs from the landing site latitude (-3.6686°) by 0.5° or more, flight controllers are expected to schedule a plane change in rev 10 or 11.
- B. Select support
 1. Plot latitude ϕ at the longitude of landing site ($\lambda_{LS} = -17.48416^\circ$) obtained from one pass, no a priori (SSL) solutions.
 2. After the rev 7 solution, obtain an estimate of the CSM latitude (ϕ_{ACTUAL}) in rev 14 by drawing a line through data points to rev 14.
 3. If the deviation from the mean line is greater than 0.2° for peak to peak noise, inform FIDO that these data cannot be used to support a plane change maneuver.
 4. If the deviation from the mean line is less than 0.2° for peak to peak noise, obtain the difference in latitude $\Delta\phi$ in rev 14, and report to FIDO by the RTCC SELECT loop.

$$\Delta\phi = \phi_{\text{LS}} - \phi_{\text{ACTUAL}}$$

For southern latitudes, use a minus sign for latitude in all computations.

- C. FIDO: If $|\Delta\phi| > 0.5^\circ$, FIDO will compute the latitude target for the plane change maneuver by integration of the current ephemeris vector to λ_{LS} of rev 14 to obtain the ephemeris vector latitude ϕ_{EPHEM} , and algebraic addition of $\Delta\phi$ to this value.

$$\phi_{\text{TARGET}} = \phi_{\text{EPHEM}} + \Delta\phi$$

II. For lunar orbit plane change 1 (LOPC-1)

- A. Criterion: Execute LOPC-1 in rev 19 to put the CSM over ϕ_{LS} in rev 31. This maneuver will be based on a CSM state vector obtained at the end of rev 17.
- B. ACR support
1. Integrate the rev 3 SS1 vector through rev 19 with both the L1 and the best currently available lunar gravity fields.
 2. Tabulate latitudes at the time of λ_{LS} crossing for both models by the end of rev 7.
- C. Select support
1. Plot latitude differences between SS1 one-pass local solutions and L1 predicted values using the following sign convention.

$$\phi_{\text{SS1}} - \text{L1}$$

2. Draw a line through rev 3 through rev 15 data to determine the error in L1 after thirteen revolutions of propagation.
3. Determine the bias B in SS1 local latitude solution.

4. Determine the best estimate of plane propagation errors for one revolution of propagation from latitude prediction tabulation. Use the following sign convention.

$$\phi_{LL} - \phi_{SS1}$$

5. Select some CSM ephemeris vector (e.g., rev 15), integrate forward to rev 31, and stop on λ_{LS} (use orbit digitals with longitude option) to obtain $\text{PHI}_{\text{EPHEM}}$.
6. Calculate the best estimate of CSM latitude in rev 30 as follows

$$\phi_{\text{ACTUAL}} = \text{PHI}_{\text{EPHEM}} - \delta\phi$$

where

$$\delta\phi = [-n(\phi_{LL} - \phi_{SS1})_{1\text{-REV PROP}}] - B$$

n = number of revs between vector used to determine $\text{PHI}_{\text{EPHEM}}$ and rev 31

If $B < 0.08^\circ$, it is set to zero.

7. Compute $\Delta\phi$ and relay to FIDO.

$$\Delta\phi = \phi_{LS} - \phi_{\text{ACTUAL}}$$

D. FIDO: Same as I.C.

III. Second LOPC

A second LOPC will be performed in rev 40 to photograph and track Davy Rille and Censorinus. No empirical corrections are necessary for this plane change.

5.0 DESCENT TARGETING

5.1 Introduction

The LM computer must be given the location of the LM relative to the landing site (LS). The LM position is computed from pass 12 data for the rev 13 update and from pass 13 MSFN data for PDI. The position of the LS (RLS) is biased to account for known errors in the LM position at PDI. These errors result from lunar potential model errors. The errors caused by the potential model inaccuracies are examined during revs 3 through 10. This process is discussed in section 5.2. The RLS is based on pass 12 or pass 13 CM LS tracking data and the appropriate propagation offsets.

5.2 Determination of Propagation Offsets

5.2.1 Data gathering phase.-

5.2.1.1 Online: The basic form used in real time from revs 3 through 11 is shown in table II. There will be two copies of this form used for the two types of comparisons.

- a. One-pass fit propagated one rev
- b. One-pass fit propagated two revs

All comparisons will be made at the time of the landing site longitude crossing of the local fit, at the time of crossing 90°E longitude, and at the longitude of PDI minus 4 minutes. The local fit will always be put in the base column of the vector compare display so that the differences will be displayed as follows.

$$\Delta = \text{local} - \text{propagated}$$

or

$$\Delta = \text{actual} - \text{predicted}$$

This inflight study results in radial, down-track, cross-track, and flight-path angle prediction error offsets for the two cases above.

The following quantities are also to be recorded throughout the lunar orbit phase on table III.

- a. ϕ = latitude of local SSL solutions at LS longitude
- b. ψ = azimuth of local SSL solutions at LS longitude
- c. h = altitude of local SSL solutions at LS longitude

The quantity ϕ will be plotted against rev number. The following quantities are also to be plotted on this curve.

- a. The latitude at the time of LS longitude crossing of the best pre-LOI translunar state vector propagated through the confirmed LOI burn.
- b. The latitude at the time of LS longitude crossing of the best pre-DOI state vector propagated through the confirmed DOI burn.
- c. The latitude at the time of LS longitude crossing of the rev 12 SSL solution corrected with the landmark tracking data from rev 12.
- d. The latitude at the time of LS longitude crossing of the rev 13 SSL solution corrected with the landmark tracking data from rev 13.
- e. The predicted latitudes at the time of LS longitude crossing based on the rev 3 SSL solution with the L1 model.
- f. The predicted latitudes at the time of LS longitude crossing based on the rev 3 SSL solution with the best currently available potential model.

A second plot will record the differences between ϕ and quantities a through f above.

5.2.2 Computation phase.- When all samples have been obtained, a summary sheet form is completed for each of the two propagation study forms. This summary sheet (table IV) provides the algorithm used to compute the means and standard deviations for each of the two types of propagation. Nominally, the last three computed offsets will be used in the computation.

5.2.3 Decision phase.-

5.2.3.1 Radius, down-track, cross-track, and flight-path angle offsets: The radius offset determined from the propagation study will be applied. The down-track offset will not be applied to simplify N69 computations which will account for this error. The cross-track correction is applied if it is greater than 500 feet.

5.3 Landmark Tracking Validation

Landmark tracking in revs 12 and/or 13 will permit determination of the relative position of the CSM (and LM) with respect to the landing site. However, the quality of the landmark data must be determined before it can be used to target PDI. The quality of the sightings will be judged by comparing the RTCC's estimate of the landing site position based on the P22 marks and the SSL local solution vector against the premission map value of the landing site. The sightings will be judged acceptable if the following conditions are satisfied.

		<u>Site 7</u>	<u>Site 6R</u>
$ \lambda_{\text{PREMISSION}} - \lambda_{\text{RTCC}} $	<	0.02°	0.06°
$ R_{\text{PREMISSION}} - R_{\text{RTCC}} $	<	666 yd	2000 yd
$ \phi_{\text{PREMISSION}} - \phi_{\text{RTCC}} $	<	^a .06°	0.12°

The solution from the RTCC processor is recorded on table V. The differences required above are displayed on MSK 1586.

5.4 State Vector/RLS1 Computation

Two-rev propagation offsets are required for u and w for this computation. No down-track effects are considered. The down-track correction is computed because it may be used as a NOUN 69 update in the event no tracking is available on rev 14. Radial and cross-track offsets are obtained from the propagation offset study and are applied to the RLS from the rev 12 landmark solution if good marks are obtained or to the premission map value if the marks are not obtained or are judged unacceptable.

The offsets as obtained from the propagation study must be rotated to the selenographic coordinate system before they may be applied to the RLS. This rotation is accomplished by the use of a matrix which is a function of the azimuth of the velocity vector. The process is shown below.

^aSubject to plane monitoring considerations.

$$\begin{bmatrix} \Delta\phi \\ \Delta\lambda \\ \Delta R \end{bmatrix}_{\text{OFFSET}} = \begin{bmatrix} 10^{-5} & 0 & 0 \\ 0 & 10^{-5} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos \psi & \sin \psi & 0 \\ \sin \psi & -\cos \psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 \\ \Delta W \\ \Delta h \end{bmatrix}$$

where

ψ = azimuth measured from north, positive eastward, deg
(The last available value from table III is used.)

$\Delta\phi, \Delta\lambda$ = latitude and longitude offsets, deg

ΔR = radius offset, n. mi.

Δh = altitude offset, n. mi.

$\Delta V, \Delta W$ = down-track and cross-track offsets, ft
($\Delta V = 0$)

The corrections are then applied as follows.

$$\begin{bmatrix} \phi \\ \lambda \\ R \end{bmatrix}_{\text{TARGET}} = \begin{bmatrix} \phi \\ \lambda \\ R \end{bmatrix}_{\text{REV 12}} - \begin{bmatrix} \Delta\phi \\ \Delta\lambda \\ \Delta R \end{bmatrix}_{\text{OFFSET}}$$

or
MAP

These computations are recorded in table VI. The value for ΔV is retained for possible use as a NOUN 69 update. The update is computed as follows.

$$\text{NOUN 69} = -\Delta V$$

5.5 State Vector/RLS2 Computation

To complete these computations, it is first necessary to determine which set of landmark tracking will be used in the RLS determination. A landmark (crater) associated with the Fra Mauro site will be tracked on rev 12 and on rev 13. On rev 12, the CM separates from the LM and tracks from a 60- by 8-n. mi. orbit. At the beginning of rev 13, the CM orbit

is circularized to 60 n. mi. The logic used to select landmark tracking data is summarized in flow chart 1. After the landmark data to be used have been chosen, the state vector/RLS2 computations are completed using flow chart 2. The offsets for RLS2 are entered in table VI and computed in the same way as for RLS1.

5.6 State Vector/RLS3 Computation for rev 15 PDI

If PDI is cancelled on rev 14 and rescheduled for rev 15, a new state vector and RLS3 will be computed according to flow chart 3.^a Computations will be recorded in table VI.

^aAs a fail-safe measure, prior to LOS on rev 14, the Flight Dynamics Officer (FIDO) will load into the spacecraft and the RTCC the rev 13 vector and RLS1.

TABLE II.- PROPAGATION ERROR WORK SHEET

_____ REV FIT

_____ REV PROPAGATION

 Δ = Local MINUS propagated(Base vector in left hand col.,
propagated in right hand col.)

SSL base vector	Prop vector	Time of comparison	Δh , n. mi.	ΔV , ft	$\Delta \omega$, ft	$\Delta \gamma$, deg	λ , deg

NOTE: Make 3 comparisons of local vs. propagated.

1. t_1 = time of crossing $\lambda = 90^\circ E$
2. $t_2 = t_3 - 9 \text{ min}$ (FDI - 4 min)
3. t_3 = time of landing site longitude crossing based on local SSL solution

TABLE III.- PLANE CHANGE MANEUVER INFO
 (EVALUATED AT LONGITUDE OF LANDING SITE)

REV	GET hr:min:sec	LOCAL SSL		L1 PRED	$\Phi_{SSL} - \Phi_{L1}$
		ψ deg	Φ SGR, deg	Φ SGR, deg	

TABLE IV.- SUMMARY SHEET FOR PROPAGATION BIAS CORRECTIONS

_____ REV FIT

POSITION _____

A PRIORI _____

SSL base vector	PROP vector	$\Delta h,$ n. mi.	$\Delta h^2,$ (n. mi.) ²	$\Delta V,$ ft	$\Delta V^2,$ ft ²	$\Delta W,$ ft	$\Delta W^2,$ ft ²	$\Delta \gamma,$ deg	$\Delta \gamma^2,$ deg ²
9									
10									
11									
Sum = Σ									
$m = \Sigma / n$									
m^2									
nm^2									
$\Sigma \Delta^2 - nm^2$									
$\frac{\Sigma \Delta^2 - nm^2}{n - 1} = \sigma^2$									
σ									

TABLE V.- LANDMARK DATA

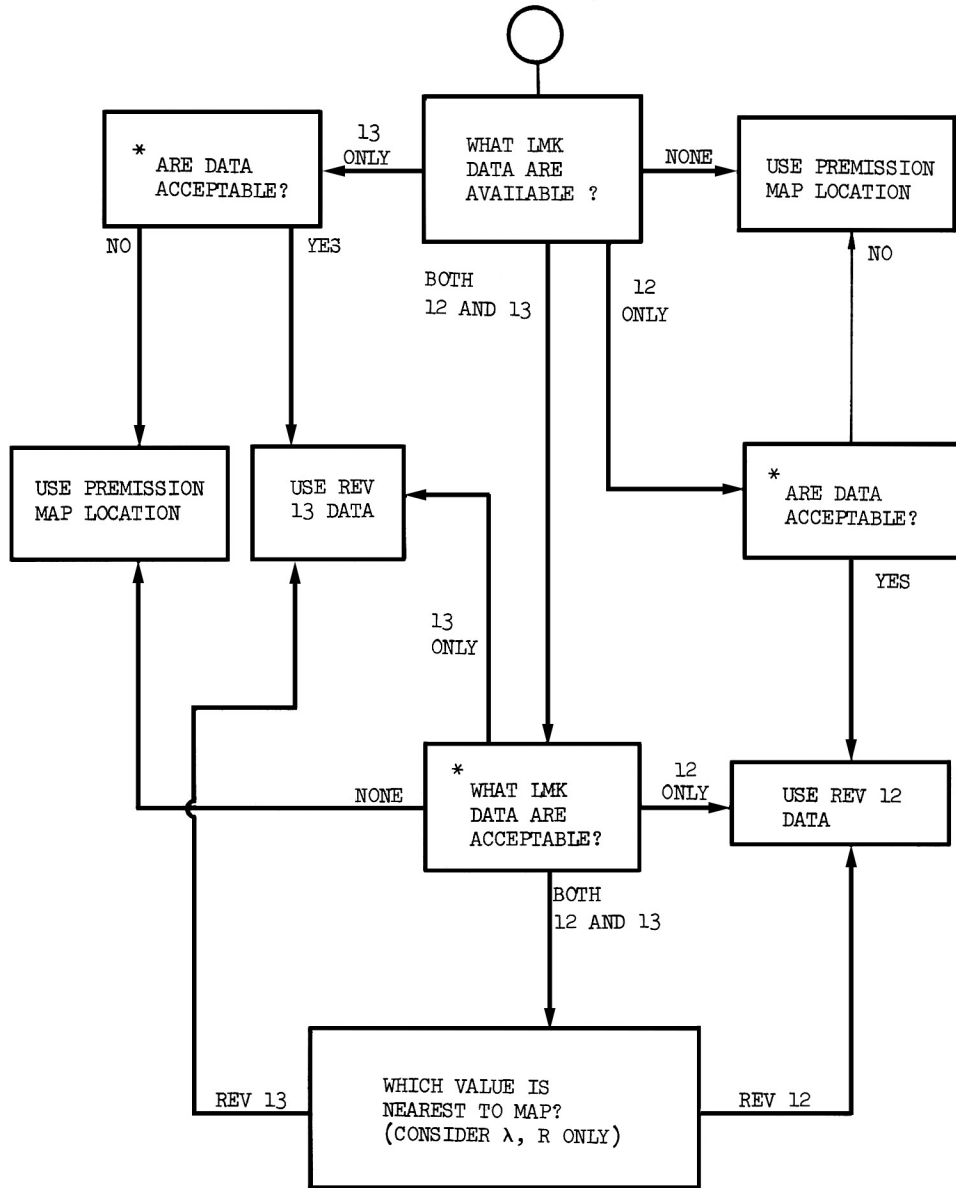
Landmark/rev	MSFN vector ID	Type solution	Landing site location		
			ϕ , deg	λ , deg	R, n. mi.

TABLE VI.- RLS COMPUTATIONS

RLS _____ computation

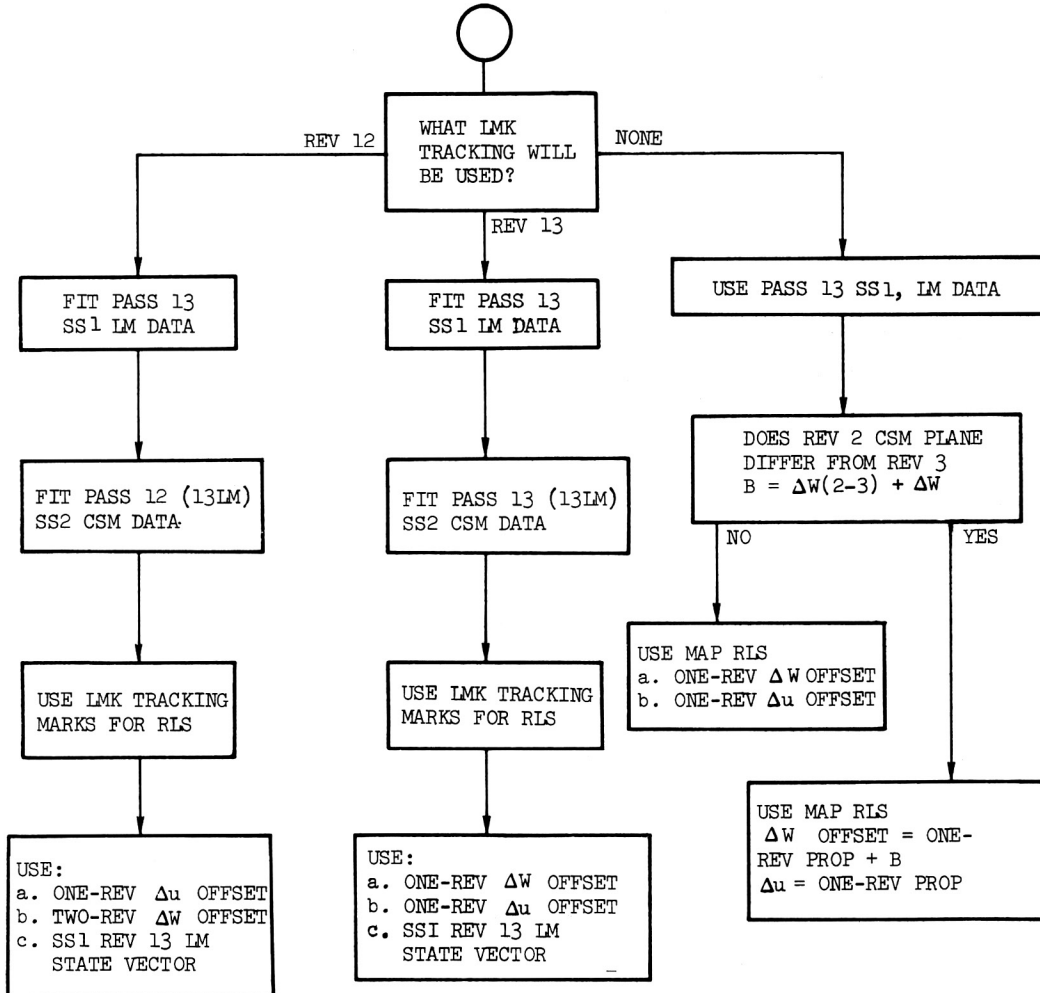
	ϕ , deg	λ , deg	R, n. mi.
Precession or rev _____			
Total corrections	Downtrack = $X \cos \psi$ =	$X \sin \psi$ =	
	Crosstrack = $X \sin \psi$ =	$X (-\cos \psi)$ =	
	Radial = $X \delta$		$X L$ =
	Sum	$X 10^{-5}$ →	$X 1$ =
Target value ^a			

$$\begin{matrix}
 \begin{pmatrix} \phi \\ \lambda \\ R \end{pmatrix} \\
 \text{TARGET}
 \end{matrix}
 =
 \begin{pmatrix} \phi \\ \lambda \\ R \end{pmatrix}
 -
 \begin{pmatrix} \Delta \phi \\ \Delta \lambda \\ \Delta R \end{pmatrix}
 \begin{matrix}
 \text{REV 12,} \\
 \text{rev 13,} \\
 \text{or map}
 \end{matrix}
 \begin{matrix}
 \text{PROP}
 \end{matrix}$$



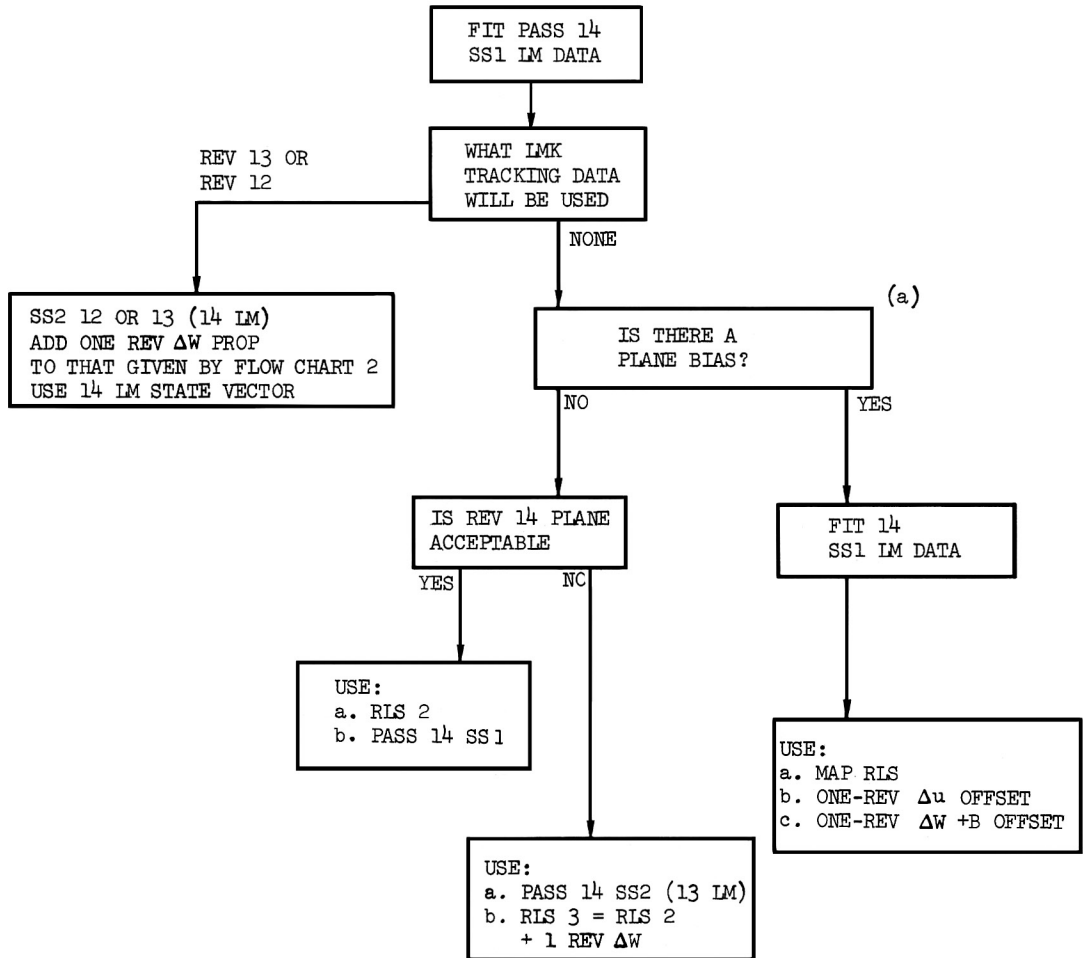
*BASED ON REV 12 LMK DATA USING 12(12 IM) SS2 AND REV 13 LMK DATA USING (13 IM) SS2

Flow chart 1.- Logic for selection of landmark tracking data for RLS 2.



The above offsets are entered in table VI

Flow chart 2.- State vector and RLS 2 computations.



(a) A PLANE BIAS IS INDICATED IF THE TWO SAMPLES, $B_1 = \Delta W(2-3) + \Delta W$ AND $B_2 = \Delta W(13-14) - \Delta W$ SHOW A SIGNIFICATE BIAS. THEN $B = \frac{B_1 + B_2}{2}$.

All ΔW 's above are first converted to $\Delta\phi$ and $\Delta\lambda$ through table VI

Flow chart 3.- State vector and RLS 3 for REV 15 PDI.

6.0 LANDING SITE TARGET UPDATE AND DESCENT MONITORING

6.1 Landing Site Target Update (NOUN 69)

At PDI plus 2 minutes, the crew will be given a correction to down-track position in feet which they are to put into the LM computer by NOUN 69. This entry will cause the LM computer to shift the targeted landing site down track or back track. A positive number will cause the target to be moved down track.

There are three sources for the NOUN 69 number: the powered flight processor (PFP), the range rate residual $\Delta\dot{\rho}$, and the range residual $\Delta\rho$.

These sources are listed in the order of priority. The range residual method would be used only if the other two are not available.

For the range rate residual method, AGS TM vectors will be used to compute residuals as soon as the RTCC enters descent phase. The down-range error determined for the AGS will be indicative of the onboard error if the AGS was properly synched to PGNCSS prior to descent phase. After approximately 30 seconds, the vector source will be switched to RTCC NOM to determine the down-range error in the ephemeris vector. The down-range error in the ephemeris vector will be the same as the onboard down-range error if the onboard vector was uplinked correctly. The ephemeris vectors will be used to compute the range rate residuals until PDI minus 30 seconds, when the PGNCSS vectors first become available and are used to compute the residuals.

After the value for NOUN 69 has been determined, the value will be adjusted to account for any flight-path angle error that exists in the ephemeris vector uplinked to the onboard system and for any down-range error resulting from propagating the ephemeris from PDI minus 4 minutes to touchdown. These errors in the ephemeris vector will be determined during revs 3 through 11.

The checklist presented in section 6.3 is used to verify that the proper tracking data are available and to provide tables for computation of NOUN 69 from the three sources.

6.2 Descent Monitoring Procedures

I. General procedures

A. After the RTCC enters the descent phase

1. Verify initialization of filter

- a. Correct sites specified for MSFN processing
- b. All sites included for processing
- c. Initial filter values correct

2. Monitor data quality bits for four MSFN sites

3. Begin monitoring line-of-sight range rate residuals for all MSFN sites as computed from AGS telemetry vectors. After approximately 30 seconds, begin using the nominal ephemeris to compute the residuals to mentally estimate the down-range error in PDI initialization vector.

B. PDI minus 5 minutes: initiation of filter processing

1. Begin monitoring all output of filter

2. Begin Δ RLS procedure using filter output and range rate residuals

C. PDI minus 30 seconds: PGNCS average g vectors available

Monitor line-of-sight range rate residuals as computed from PGNCS vectors

D. PDI minus 5 seconds: filter switches to powered flight weights. Monitor filter output closely.

E. PDI

1. Determine value of Δ RLS. Send to SELECT.

2. Begin plotting filter's estimates of altitude h , altitude rate \dot{h} , pitch angle P , mass flow rate \dot{M} .

3. Monitor residuals, rate biases, and data quality indicators for all sites.

F. Landing. Hardcopy MSK 84 for RLS determination procedures.

II. Plotting procedures for real-time evaluation of filter performance

Plots of the filter output parameters h , \dot{h} , P , and \dot{M} as determined by the filter during real time provide a quick and complete analysis of the filter performance. A smooth realistic trend on each of the plots in real time will indicate that the filter is performing nominally. A sharp unexpected discontinuity in one or more of the plots will indicate a nonoptimum performance by the filter and possibly the necessity of a program restart.

During the mission, each of the four parameters will be plotted on a graph on which the premission nominal values obtained from the Apollo 13 operation trajectory (O.T.) are already recorded. The premission values are used only as a general reference for nominal behavior and are not used to compute the real-time accuracy of the filter. A complete description of the generation of the plots and of their functions is included below.

A. Prior to the mission, the values obtained from the operational trajectory for h , \dot{h} , P , and \dot{M} from PDI minus 5 minutes to landing are plotted. These plots are presented in figures 4 through 7.

B. During the mission, after the vector to be used to initialize the filter has been determined, the vector is integrated to the times PDI minus 5 minutes, PDI minus 4.5 minutes, PDI minus 4 minutes, ..., and PDI to obtain the predescent nominal values of altitude rate for the initialization vector. These values are then plotted on figure 5. This procedure is exercised for both the back-up PDI initialization vector (rev 12 SS1) and the primary initialization vector (rev 13 SS1) as soon as each of the vectors is available.

C. From PDI minus 5 minutes until landing, the filter's estimates of altitude and altitude rate are plotted on figures 4 and 5, respectively. The differences between the filter's estimates of altitude rate and the estimates of altitude rate obtained from the initialization vector during the free flight phase are used in the Δ RLS procedure.

D. Beginning at PDI, the filter's estimates of mass flow rate and pitch angle are also plotted on figures 6 and 7, respectively. This process continues until landing.

III. Special procedures

A. Excluding sites

Exclude any site whose data are completely missing or edited for a time interval exceeding 5 seconds. For a questionable site (data in and out), exclude the site unless a serious degradation to filter output would result. Exclude only the sites whose data are questionable. Processing data from one or two sites gives a much better solution than predicting forward without data.

B. Replacing sites

If one of the four MSFN trackers being processed by the filter does not provide good data for an interval exceeding 30 seconds, replacing the site with the standby site is normally considered. However, for Apollo 13, the standby site, CYI, is at a low elevation angle for the descent; and its data, affected by refraction, will degrade the filter performance if processed. The filter can process data from only three sites. Therefore, if a site is questionable, the procedure should be as follows.

1. Exclude the site from being processed.
2. Check with the tracking coordinator (TRACK) on the expected status of both the questionable site and the standby site.
3. If the information from TRACK indicates the necessity for replacing the questionable site, insert the standby site in the slot of the questionable site in the list of sites being processed by the filter (J60 change MED). Do not process the CYI data (exclude by PBI). The remaining three-station geometry is satisfactory, and the effect of refraction on CYI data should be avoided. Having CYI in the list of sites makes its data easily accessible (PBI) in the event of another site failure.
4. If more than one site fails and the status of CYI is reported as satisfactory by TRACK, insert CYI in the list of sites and include its data for processing.

If information from TRACK does not indicate the need to change sites, the questionable site should not be replaced, but its data should continue to be excluded until a change in status occurs.

In the event of a two-way handover (change in transmitting site), all sites must be excluded and the two-way timeline changed for the new transmitter. The sites must not be respecified (J60 start MED) until TRACK informs SELECT that the new transmitter has acquired lock on the LM frequency.

C. Restarting the filter

1. The following output quantities of the filter are continuously monitored and are plotted to determine the status of the filter.

- a. Altitude h
- b. Altitude rate \dot{h}
- c. Pitch angle P
- d. Mass flow rate \dot{M}

2. The quantities \dot{h} , P , and \dot{M} are most instrumental in indicating a nonoptimum performance by the filter. However, a degradation in any of these parameters is completely recoverable by the filter. Therefore, these parameters are used to indicate a degraded performance by the filter but are not used as criteria for a program restart.

3. The parameter h gives a continuous indication of the filter performance. A serious degradation in altitude is not recoverable by the filter. Therefore, the altitude parameter is used as the final criterion for the necessity of a filter restart.

4. If necessary, a filter restart during the free-flight phase prior to PDI is a valid procedure. Beginning at the time of the restart, the program will assume a powered flight weighting structure and will begin to solve for the vehicle thrust direction, thrust magnitude, and mass. Degradation to filter output under this arrangement should be minimal.

5. In case of data dropout, sufficient time (approximately 20 sec) should always be allowed after reacquisition of data to determine if a program restart is necessary.

6.3 Apollo 13 Select Support NOUN 69 Descent Monitoring Checklist

A. Pre-AOS rev 14

	In the C. P.	In the MOC, DSC
1. High-speed data check		
a. PIR (two-way)	<input type="checkbox"/>	<input type="checkbox"/>
b. HAW	<input type="checkbox"/>	<input type="checkbox"/>
c. MIL	<input type="checkbox"/>	<input type="checkbox"/>
d. BDA	<input type="checkbox"/>	<input type="checkbox"/>
e. CYI (backup fourth site)	<input type="checkbox"/>	<input type="checkbox"/>
2. Correct two-way (2W) timeline (PIR-LM, GDS-CSM) in		
a. MOC		<input type="checkbox"/>
b. DSC		<input type="checkbox"/>
3. Low-speed data check		
a. PIR 2W		<input type="checkbox"/>
b. CYI 3W		<input type="checkbox"/>
c. HAW 3W		<input type="checkbox"/>
d. MIL 3W		<input type="checkbox"/>
e. BDA 3W		<input type="checkbox"/>
f. GDS 2W		<input type="checkbox"/>
g. GYM 3W		<input type="checkbox"/>
h. MAD 3W		<input type="checkbox"/>
4. LM data rate set to 1/6 sec		<input type="checkbox"/>

B. Post-AOS rev 141. Ranging on LM from PIR, acquisition every 2 minutes - 3

2. Doppler residuals based on ephemeris vector

a. PIR _____ Hz

b. HAW _____ Hz

c. MIL _____ Hz

d. BDA _____ Hz

e. CYI _____ Hz

3. Uplink SV2 (13-SS1) and RLS₂ to SC

4. Range residuals from PIR (EPH)

a. 13-min batch average _____ yd

b. E/M Eph correction to range, enter
observed range residual bias
from pass 13 SS1 or DE69 - DE19
(fig. 8) _____ yd

c. a - b _____ yd

d. X 3 _____ ft

5. Longitude from 1590

a. At midpoint of batch (____:____:____ g.m.t.)

$\lambda =$ _____ deg

6. Down-track error computation

a. Load range partial $-\partial \frac{DT}{\partial \rho}$

from figure 1 at λ _____

b. Load ($\Delta \rho$ AVG) step 4.d _____ ft

c. Enter product _____

d. Load expected down-track

error from prop. $\delta \Delta V_R$ (table VII) _____ ft

e. Add d and c _____ ft
($\Delta V \rho$)

f. NOUN 69 based on RANGE DATA

=

--	--	--	--	--	--

g. Expected sign on $\dot{H} - \dot{U}$

7. t_{IG} (PDI)

____:____:____ g.e.t.

8. Vector comparisons (rev 12 SSL); hard copy each

	Time, hr:min:sec	v	γ	φ	λ	u	· u
PDI - 5.0							
PDI - 4.5							
PDI - 4.0							
PDI - 3.5							
PDI - 3.0							
PDI - 2.5							
PDI - 2.0							
PDI - 1.5							
PDI - 1.0							
PDI - 0.5							
PDI							

DATA SHEET

9. Vector comparisons (rev 13 SSL); hard copy each

	Time, hr:min:sec	v	γ	ϕ	λ	u	\dot{u}	
PDI - 5.0								
PDI - 4.5								
PDI - 4.0								
PDI - 3.5								
PDI - 3.0								
PDI - 2.5								
PDI - 2.0								
PDI - 1.5								
PDI - 1.0								
PDI - 0.5								
PDI								

10. $\dot{H} - \dot{u}$ computation

a. PDI - 5.0 $\dot{H} =$ _____ fps (from 1602)
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps (load neg. of
 step 8 or 9)

b. PDI - 4.5 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

c. PDI - 4.0 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

d. PDI - 3.5 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

e. PDI - 3.0 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

f. PDI - 2.5 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

g. PDI - 2.0 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

h. PDI - 1.5 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

i. PDI - 1.0 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

j. PDI - 0.5 $\dot{H} =$ _____ fps
 (_____ : _____ : _____) + $(-\dot{u})$ _____ fps

TABLE VII.- PROPAGATION OFFSET SUMMARY SHEET

— REV PROPAGATION

Offset	Time	D	σ
Radial	$\lambda = 90^\circ \text{ E}$		
	PDI - 4		
	$\lambda = \text{LS}$		
Downtrack	$\lambda = 90^\circ \text{ E}$		
	PDI - 4		
	$\lambda = \text{LS}$		
	^a $\delta\Delta V_{\text{PR}} = \Delta V_{90} - \Delta V_{\text{LS}}$		
	^a $\delta\Delta V_{\text{PD}} = \Delta V_{\text{PDI} - 4} - \Delta V_{\text{LS}}$		
Crosstrack	$\lambda = 90^\circ \text{ E}$		
	PDI - 4		
	$\lambda = \text{LS}$		
Flight-path angle	$\lambda = 90^\circ \text{ E}$		
	PDI - 4		
	$\lambda = \text{LS}$		

^aObtained from table VIII.

NOUN 69 targeting information, ft

$\delta\Delta V_{\text{R}} = \delta\Delta V_{\text{PR}}$	
$\delta\Delta V_{\text{D}} = \delta\Delta V_{\text{PD}} - 10^5 \Delta\gamma_{\text{PDI} - 4}$	

TABLE VIII- PROPAGATION TABLE FOR $\delta\Delta V$

From table I			$\delta\Delta V_{PR}$		From table I		$\delta\Delta V_{PD}$
Local base	PROP	$\Delta V_{90^\circ E}$	ΔV_{IS}	$\Delta V_{90} - \Delta V_{IS}$	ΔV_{PDI-4}	ΔV_{IS}	$\Delta V_{PDI-4} - \Delta V_{IS}$
Average (for range)						Average (for Doppler)	

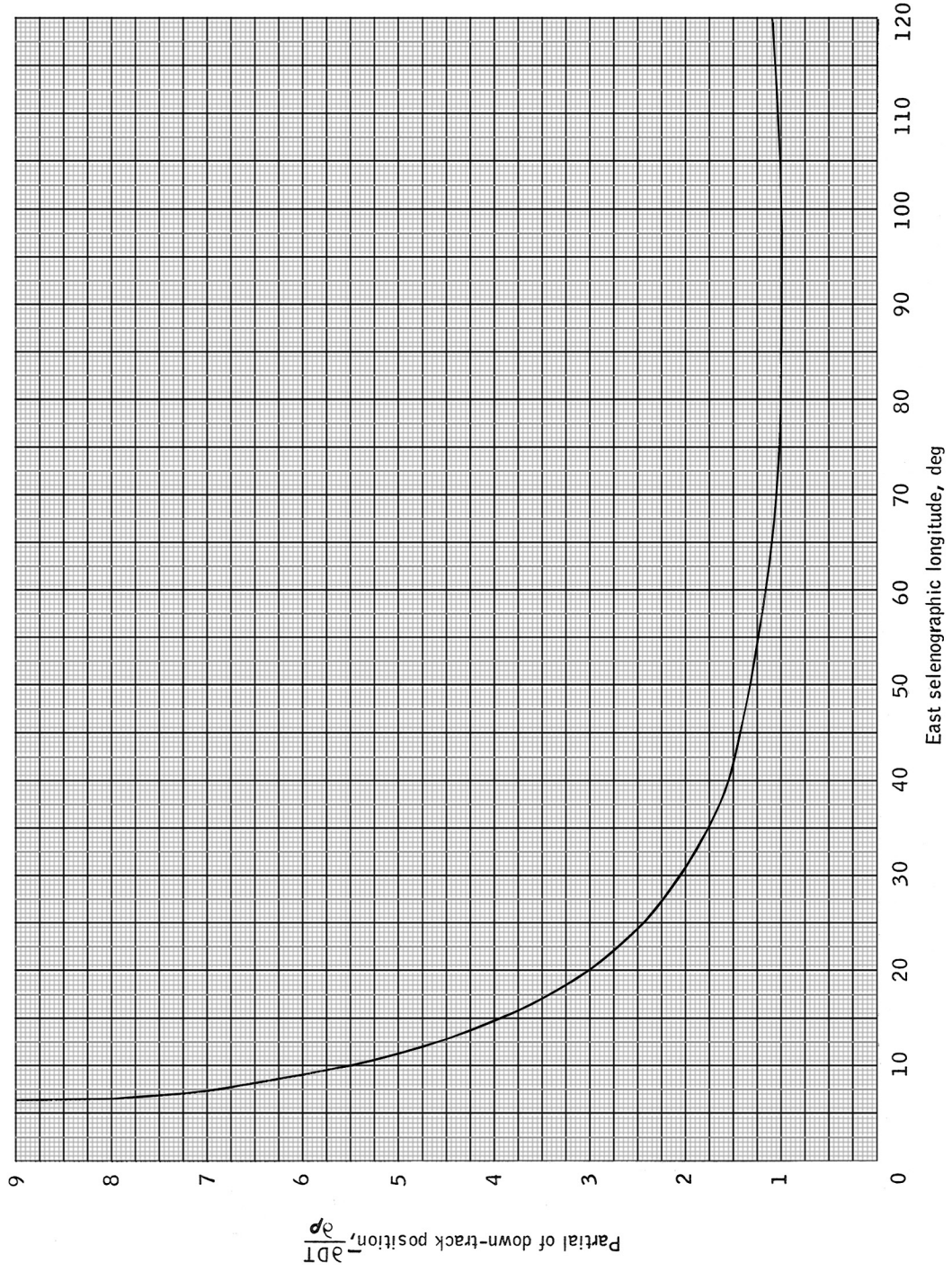


Figure 1. - Partial of down-track position with respect to range for Apollo 13 NOUN 69.

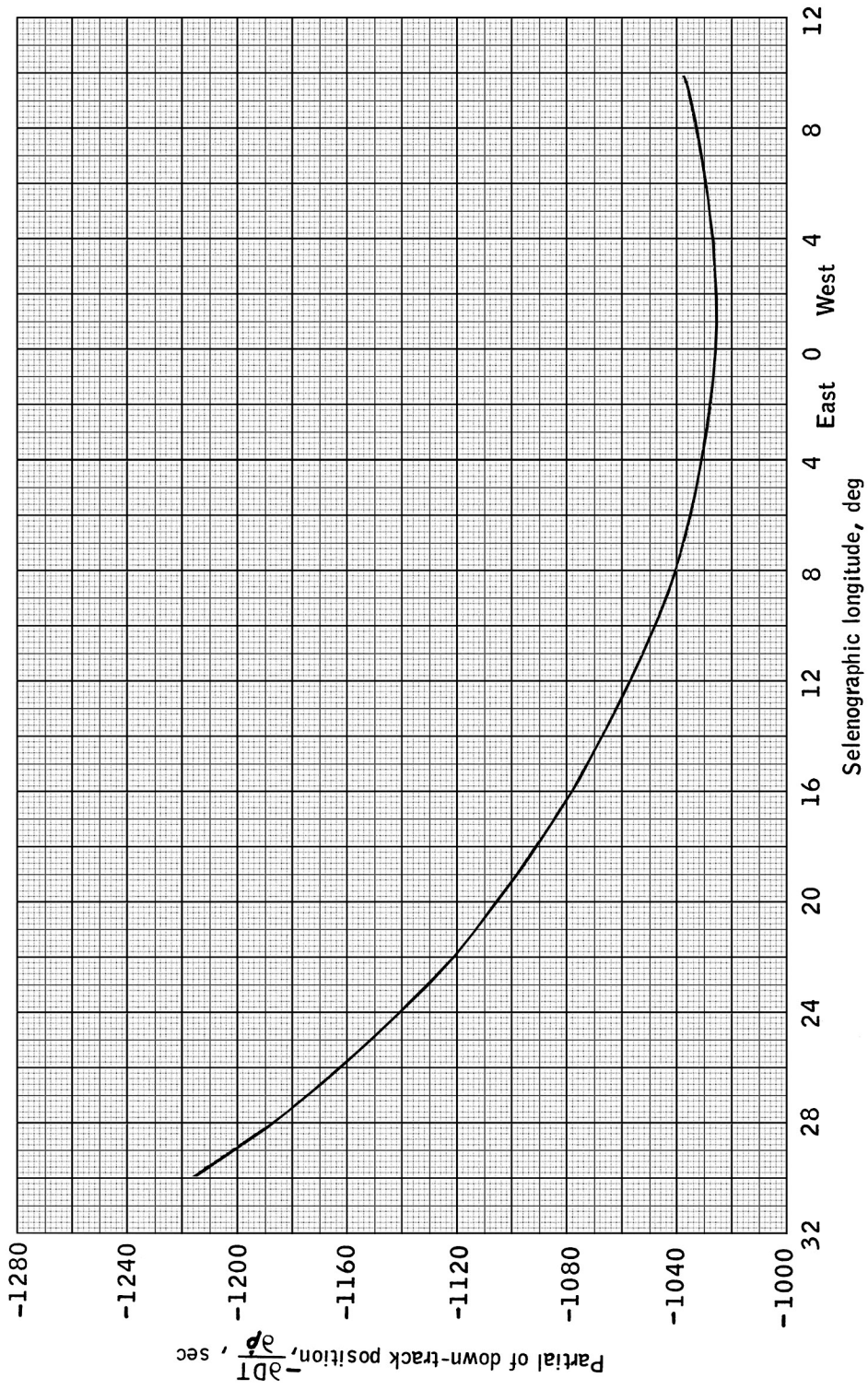


Figure 2.- Partial of down-track position with respect to range rate for Apollo 13 NOUN 69.

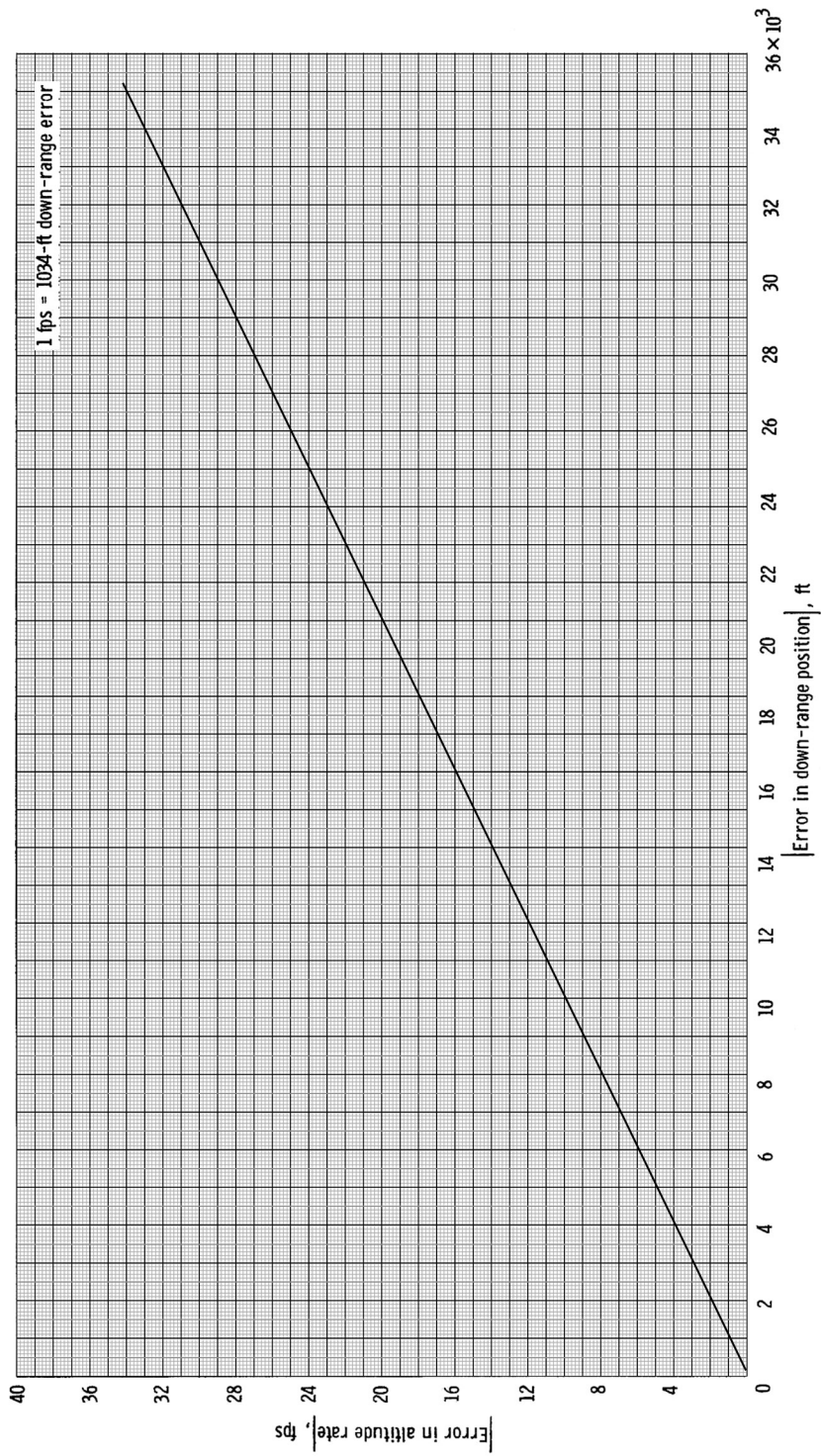


Figure 3. - Altitude rate error versus down-range error for PFP NOUN 69 for Apollo 13.

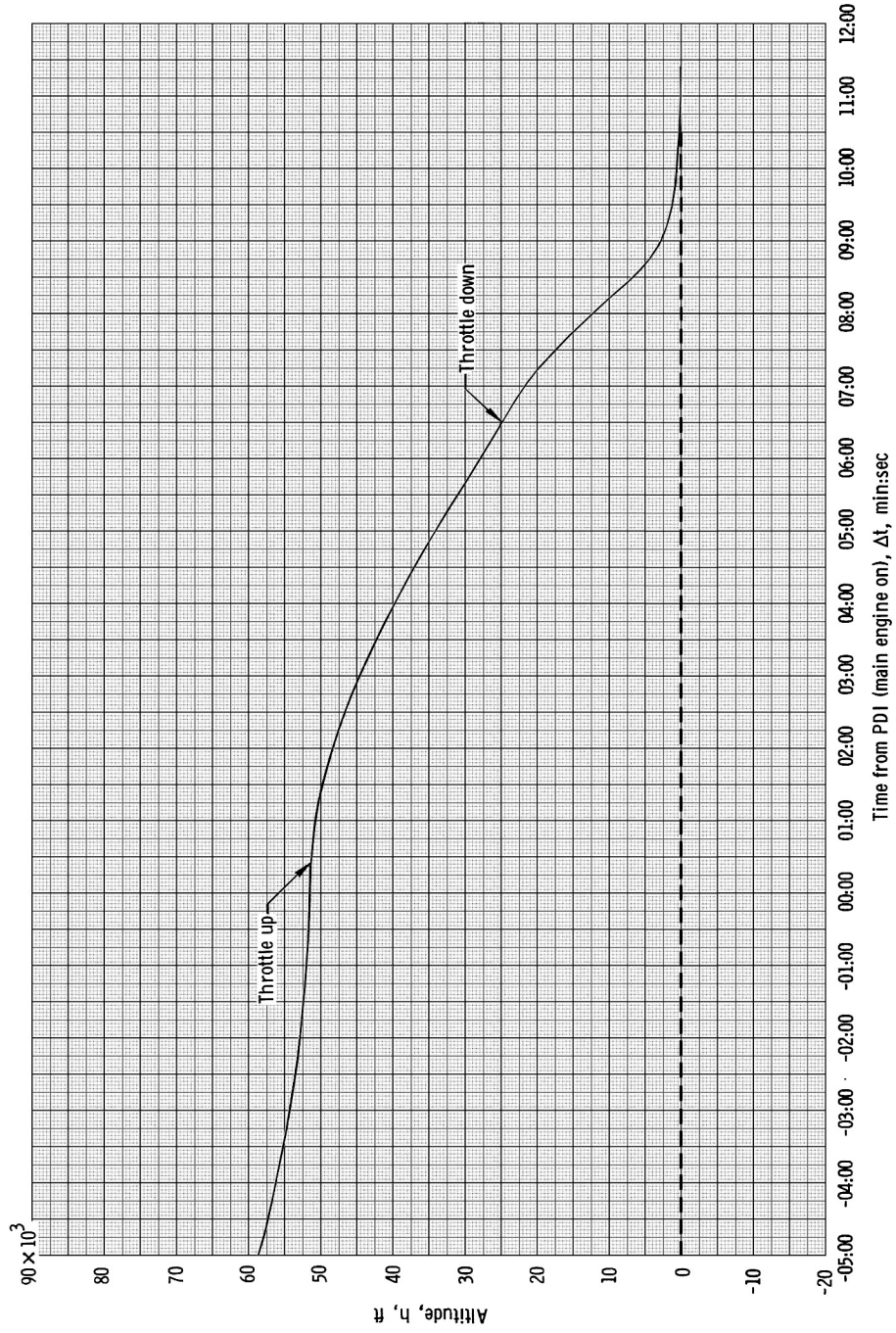


Figure 4. - Altitude versus descent time for Apollo 13.

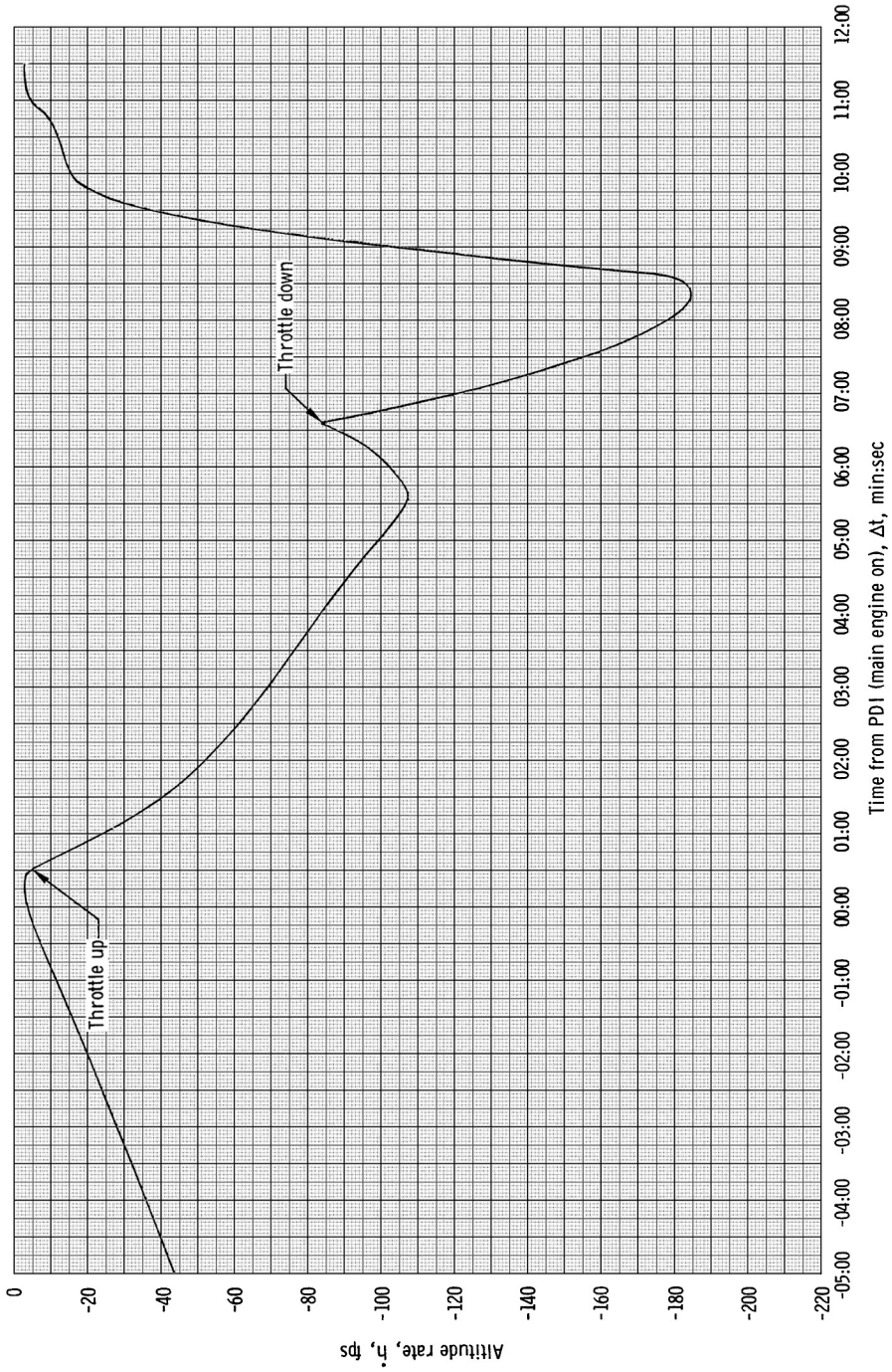


Figure 5. - Altitude rate versus descent time for Apollo 13.

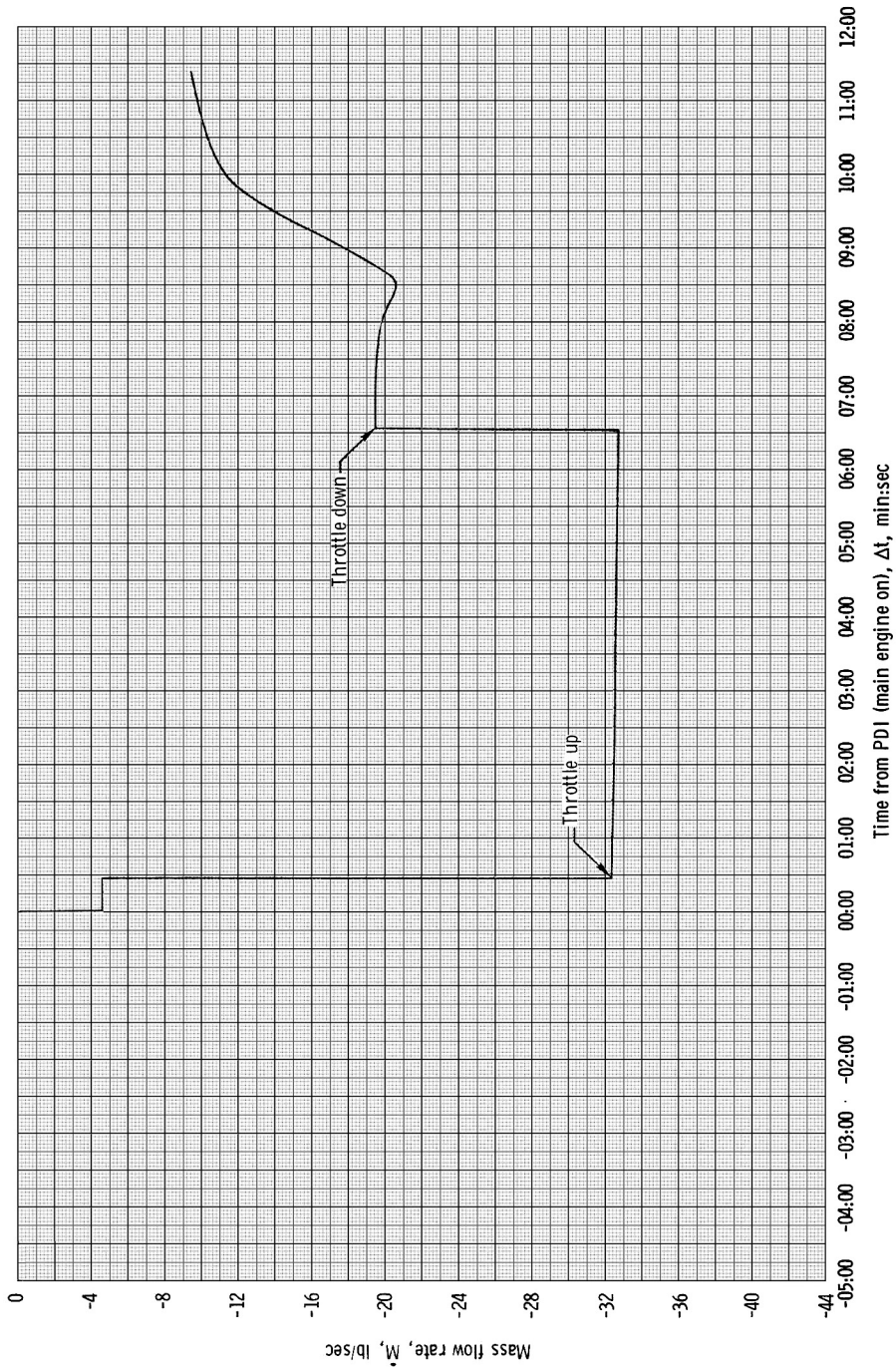


Figure 6. - Mass flow rate versus descent time for Apollo 13.

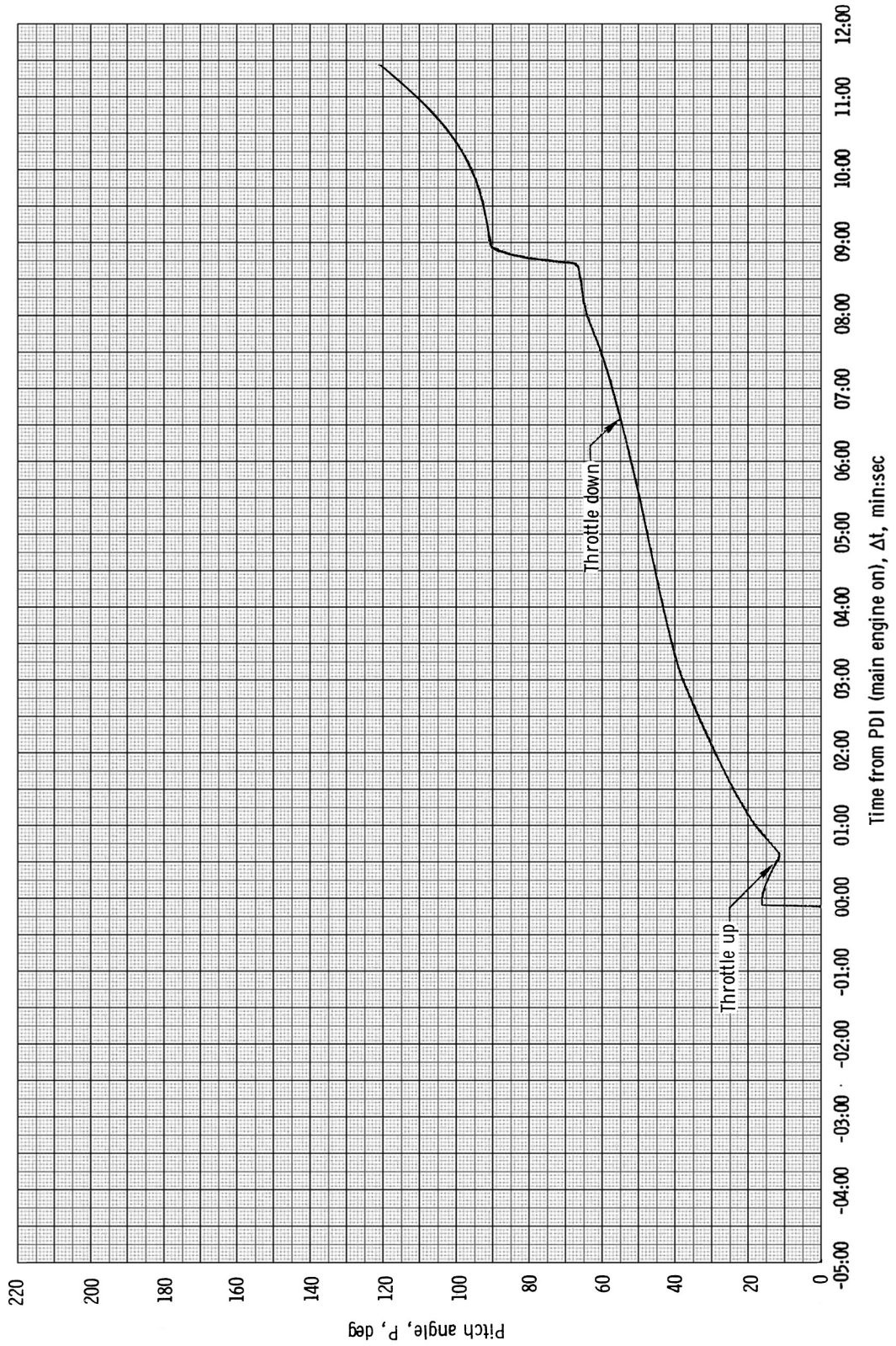


Figure 7. - Pitch angle versus descent time for Apollo 13.

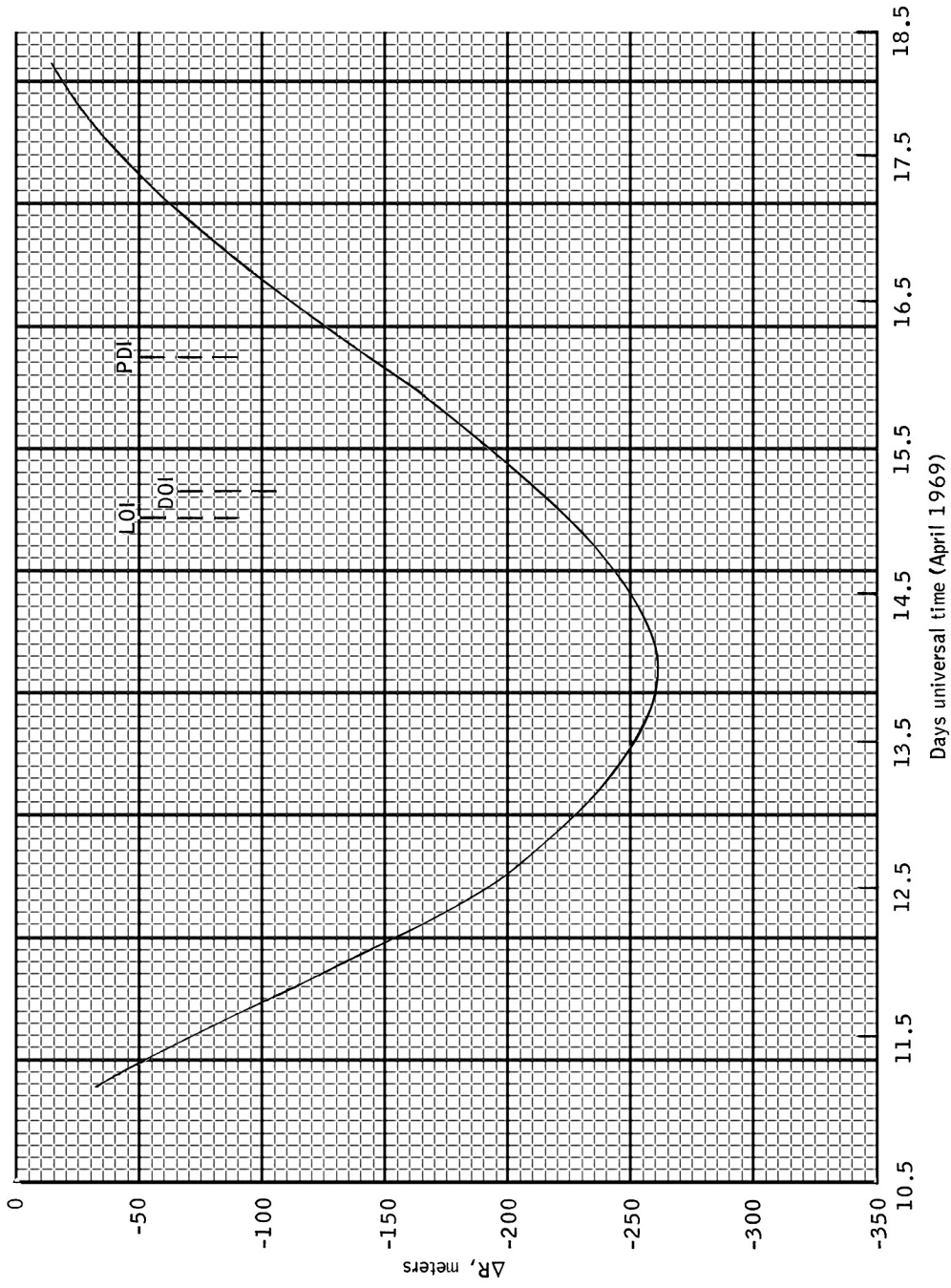


Figure 8.- Estimated radial component errors (DE 69 - DE 19).

7.0 ASCENT PHASE

7.1 Ascent Targeting and LM Position

The LM computer must be given LM position and CM orbit vector.

The CM orbit vectors for abort and nominal lift-off times are as follows.

- a. For t_1 , use pass 13 CM (13 LM) solution.
- b. For t_2 , use the same data as for t_1 ,
- c. For t_3 , use pass 14 data. If the plane is bad, use pass 14 (13 CSM); that is, pass 14 constrained to pass 13 CSM plane.
- d. For nominal lift-off, use pass 29 if plane accuracy is good; use pass 30 if it is not.

Basic ground rules for the use of LM position data and of the procedures for finding the location of the LM after landing are reviewed in this section.

A knowledge of LM position is required for the following.

- a. t_1 lift-off
- b. t_2 lift-off
- c. t_3 lift-off
- d. Nominal lift-off
- e. CM auto optics

The t_1 abort lift-off takes place immediately after landing. There will not be time to adjust the values for LM position in the RTCC and LGC for t_1 .

The t_2 abort lift-off would occur 8 minutes after landing. The LGC values for LM position are not changed. During the 8-minute interval, the LM position used by the powered flight processor for ascent monitoring will be set to the best predescent location of the landing site. For

Apollo 13, this location will be the premission value for latitude, longitude, and radius. The t_2 lift-off time sent to the crew is computed before descent based on the premission value for landing site latitude, longitude, and radius. RLS1 may also be used at FIDO's discretion.

The two candidates for LM position for the t_2 lift-off were RLS1 and the premission values. The RLS1 contains biases which correct the location of the LM relative to the LS. For t_2 lift-off time computation, the location of the CM relative to the LM is desired. CSM separation maneuver uncertainties and LM landing errors are not accounted for through RLS1 although RLS1 does account for normal down-track and cross-track errors. The premission map values for latitude and longitude were chosen because they are the simpler of the two acceptable choices.

The t_3 abort lift-off would occur 2 hours after landing. The PGNCs and RTCC will be given the best location of the LM and the best inertial knowledge of the CM orbit. Procedures used to decrease relative errors between the LM and CM location were discussed, and the simpler inertial approach was chosen. Information for relative location would have to be based on pass 12 or pass 13 data. As a result, the LM may have to make a plane change during rendezvous if there are relative cross-track errors. The 3σ relative cross-track error is 0.3° with a plane change ΔV of 30 fps, which are well within tolerances.

The best selenographic LM location and a one-pass fit determination of the CM orbit will be used for nominal ascent provided that the orbit plane errors are less than 5000 feet for peak to peak noise and 5000 feet for bias. If the noise or the bias is greater than 10 000 feet, then the LM will be located cross track relative to the CM to remove relative cross-track yaw steering errors for ascent. Errors between 5000 feet and 10 000 feet will be discussed with the flight controllers inflight. The procedure used when large plane errors occur is to request the LM to track the CM with rendezvous radar (RR) on the pass prior to ascent. The RR data are processed to determine latitude and longitude. The radius from the RR observations of the LS will be used.

The CM will attempt to track the LM on pass 17. The CM will be given the onboard map coordinates of the LM. In addition, the auto optics equipment will position the sextant on the LM by use of a relative location of the LM based on pass 15 MSFN data, RR tracking, and one-rev offsets to account for CM position prediction error.

The best sources for selenographic LM position (table IX) for the above are as follows.

- a. For t_3
 1. Crew comments for latitude and longitude, premission map for radius
 2. PGNCS latitude and longitude (table X), premission map for radius
- b. For nominal lift-off
 1. RR and SXT solution pass 15
 2. SXT solution pass 17
 3. Crew comments for latitude and longitude, premission map for radius
 4. AOT solution for latitude and longitude, premission map for radius
 5. PGNCS solution for latitude and longitude, premission map for radius

The choice will depend on inflight evaluation.

7.2 Ascent Monitoring Procedures

I. General procedures

- A. After the RTCC enters ascent phase
 1. Verify initialization of filter
 - a. Correct sites specified for MSFN processing
 - b. All sites included for processing
 - c. Initial filter values correct
 2. Monitor data quality bits for all MSFN sites
- B. Lift-off minus 10 seconds: initiation of filter processing. Begin monitoring all outputs of filter.

C. Lift-off

1. Begin plotting filter's estimate of altitude h , altitude rate \dot{h} , pitch angle P , and mass flow rate \dot{M}
2. Monitor residuals, rate biases, and data quality indicators for all sites

II. Plotting procedures for real-time evaluation of filter performance

For ascent as for descent, filter outputs will be plotted to provide a quick and complete analysis of the filter performance. The parameters analyzed during ascent are h , \dot{h} , P , and \dot{M} .

Each of the four parameters will be plotted on a graph (figs. 9 through 12) on which the premission nominal values obtained from the Apollo 13 O.T. are already recorded. The premission values provide a general reference for nominal behavior and are not used to compute the real-time accuracy of the filter. The plots will be analyzed to detect smooth, realistic behavior, which indicates nominal filter performance, or sharp discontinuities in the curves, which indicate nonoptimum performance by the filter.

III. Special procedures

A. Excluding sites

1. The same procedures for excluding sites that are applicable to descent monitoring are also applicable to ascent monitoring.
2. For both nominal and manual ascents, all sites should be included for processing at lift-off.

B. Restarting the filter

1. For ascent, altitude is the best filter output parameter upon which a filter restart decision can be based. A degraded estimate in altitude cannot be corrected by the filter, but an error in pitch, altitude rate, or mass flow rate can be completely recovered.
2. If lift-off occurs prior to the scheduled lift-off in the RTCC mission plan table, the filter will begin processing when the lift-off switch is set. No restart should be necessary.
3. If a late lift-off occurs, a real-time analysis of filter output will determine the necessity of a program restart.

7.3 Apollo 13 Select Support Ascent Monitoring Checklist

7.3.1 Rev 31 lift-off.-

A. Pre-lift-off

- | | In the
C. P. | In the
MOC, DSC |
|--|--------------------------|--------------------------|
| 1. High speed data check | | |
| a. NBE (two-way) | <input type="checkbox"/> | <input type="checkbox"/> |
| b. CRO | <input type="checkbox"/> | <input type="checkbox"/> |
| c. GWM | <input type="checkbox"/> | <input type="checkbox"/> |
| d. HAW | <input type="checkbox"/> | <input type="checkbox"/> |
| 2. Correct two-way site timeline
(NBE-LM, HSK-CSM) in | | |
| a. MOC | | <input type="checkbox"/> |
| b. DSC | | <input type="checkbox"/> |
| 3. Low-speed data check | | |
| a. NBE 2W | } LM | <input type="checkbox"/> |
| b. CRO 3W | | <input type="checkbox"/> |
| c. GWM 3W | | <input type="checkbox"/> |
| d. HAW 3W | | <input type="checkbox"/> |
| e. HSK 2W | } CSM | <input type="checkbox"/> |

B. After entering lunar orbit phase

- | | |
|--|--------------------------|
| 1. LM data rate set to 1/6 sec | <input type="checkbox"/> |
| 2. Reconfigure CRO, HAW to
dual TDP, all sites to low
speed (upon FIDO's approval) | |
| 3. Plot two-way low-speed residuals | |
| a. PGNCS | <input type="checkbox"/> |
| b. AGS | <input type="checkbox"/> |
| c. PFP | <input type="checkbox"/> |
| 4. Indicate quality of PFP solution to TRACK | |

7.3.2 Rev 15 lift-off.-

A. Pre-lift-off

	In the C. P.	In the MOC, DSC
1. High-speed data check		
a. PIR (two-way)	<input type="checkbox"/>	<input type="checkbox"/>
b. BDA	<input type="checkbox"/>	<input type="checkbox"/>
c. HAW (backup 2W)	<input type="checkbox"/>	<input type="checkbox"/>
d. MIL	<input type="checkbox"/>	<input type="checkbox"/>
e. GWM (backup fourth site)	<input type="checkbox"/>	<input type="checkbox"/>
2. Correct two-way timeline (PIR-LM, GDS-CSM) in		
a. MOC		<input type="checkbox"/>
b. DSC		<input type="checkbox"/>
3. Low-speed data check		
a. PIR 2W		<input type="checkbox"/>
b. HAW 3W		<input type="checkbox"/>
c. MIL 3W	} LM	<input type="checkbox"/>
d. GWM 3W	}	<input type="checkbox"/>
e. BDA 3W	}	<input type="checkbox"/>
f. GDS 2W	} CSM	<input type="checkbox"/>
g. GYM 3W	}	<input type="checkbox"/>
B. After entering lunar orbit phase		
1. LM data rate set to 1/6 sec		<input type="checkbox"/>
2. Reconfigure HAW, MILA, GWM to dual TDP; all sites to low speed (upon FIDO's approval)		
3. Plot two-way low-speed residuals		
a. PGNCS		<input type="checkbox"/>
b. AGS		<input type="checkbox"/>
c. PFP		<input type="checkbox"/>
4. Indicate quality of PFP to SELECT		

TABLE IX.- APOLLO 13 LMK, LS, AND LM POSITION DATA

	ϕ	λ	R
Premission RTCC	-3.66861111	-17.4841666	937.7348812
AUTO OPTICS target rev 12			
Rev 12 SXT 11(11)			
Rev 12 SXT 12(12)			
AUTO OPTICS target rev 13			
Rev 13 SXT 12(12)			
Rev 13 SXT 13(13)			
RLS 1			
RLS 2			
Crew			
PGNCS hover			
AGS hover			
MSFN hover			
Rev 14 + PGNCS PDI			
Rev 14 + AGS PDI			
Rev 14 + MSFN PDI			
PGNCS AOT + \hat{G} (two-star)			
a.			
b.			
RTCC AOT + \hat{G} (two-star)			
ACR AOT + \hat{G} (four-star)			
Rev 15 RR 14(14)			
Rev 15 RR 15(15)			
Rev 15 SXT (13-1) 14(14)			
Rev 15 SXT 15(15)			
Rev 15 SXT + RR			
AUTO OPTICS target rev 17			
Rev 17 SXT (LM) 16(16)			
Rev 17 SXT (LM) 17(17)			
Rev 30 SXT 29(29)			
Rev 30 SXT 30(30)			
Rev 30 RR 29(29)			
Rev 30 RR 30(30)			
Rev 30 SXT + RR			
ACR AOT + \hat{G} (all star)			
Best selenographic			
Ascent target			

TABLE X. - LLS DETERMINATION

R_{LLS} _____ Φ_{LLS} _____ λ_{LLS} _____

Time for MSFN comparison

Initial	U_I _____	Φ_I _____	λ_I _____
Landing	U_{TD} _____	Φ_{TD} _____	λ_{TD} _____
Best	R_B _____	Φ_B _____	λ_B _____
(INIT - TD)	ΔU <input type="text"/>	$\Delta \Phi$ <input type="text"/>	$\Delta \lambda$ <input type="text"/>
Best - Δ	R_{LLS} <input type="text"/>	Φ_{LLS} <input type="text"/>	λ_{LLS} <input type="text"/>

Time for PGNCs comparison

Initial	U_I _____	Φ_I _____	λ_I _____
Landing	U_{TD} _____	Φ_{TD} _____	λ_{TD} _____
Best	R_B _____	Φ_B _____	λ_B _____
(INIT - TD)	ΔU <input type="text"/>	$\Delta \Phi$ <input type="text"/>	$\Delta \lambda$ <input type="text"/>
Best - Δ	R_{LLS} <input type="text"/>	Φ_{LLS} <input type="text"/>	λ_{LLS} <input type="text"/>

Time for AGS comparison

Initial	U_I _____	Φ_I _____	λ_I _____
Landing	U_{TD} _____	Φ_{TD} _____	λ_{TD} _____
Best	R_B _____	Φ_B _____	λ_B _____
(INIT - TD)	ΔU <input type="text"/>	$\Delta \Phi$ <input type="text"/>	$\Delta \lambda$ <input type="text"/>
Best - Δ	R_{LLS} <input type="text"/>	Φ_{LLS} <input type="text"/>	λ_{LLS} <input type="text"/>

Notes

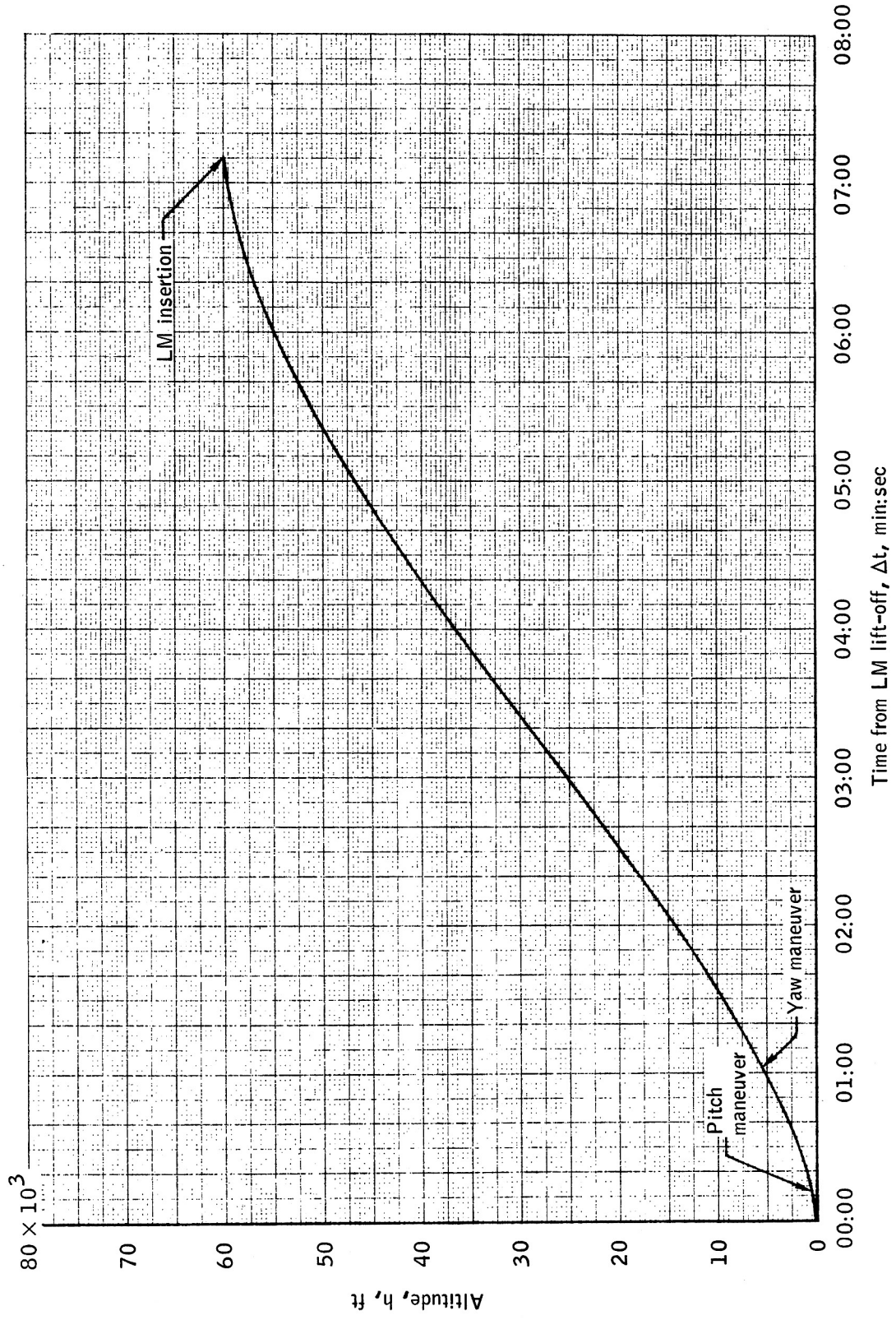


Figure 9.- Altitude versus ascent time for Apollo 13.

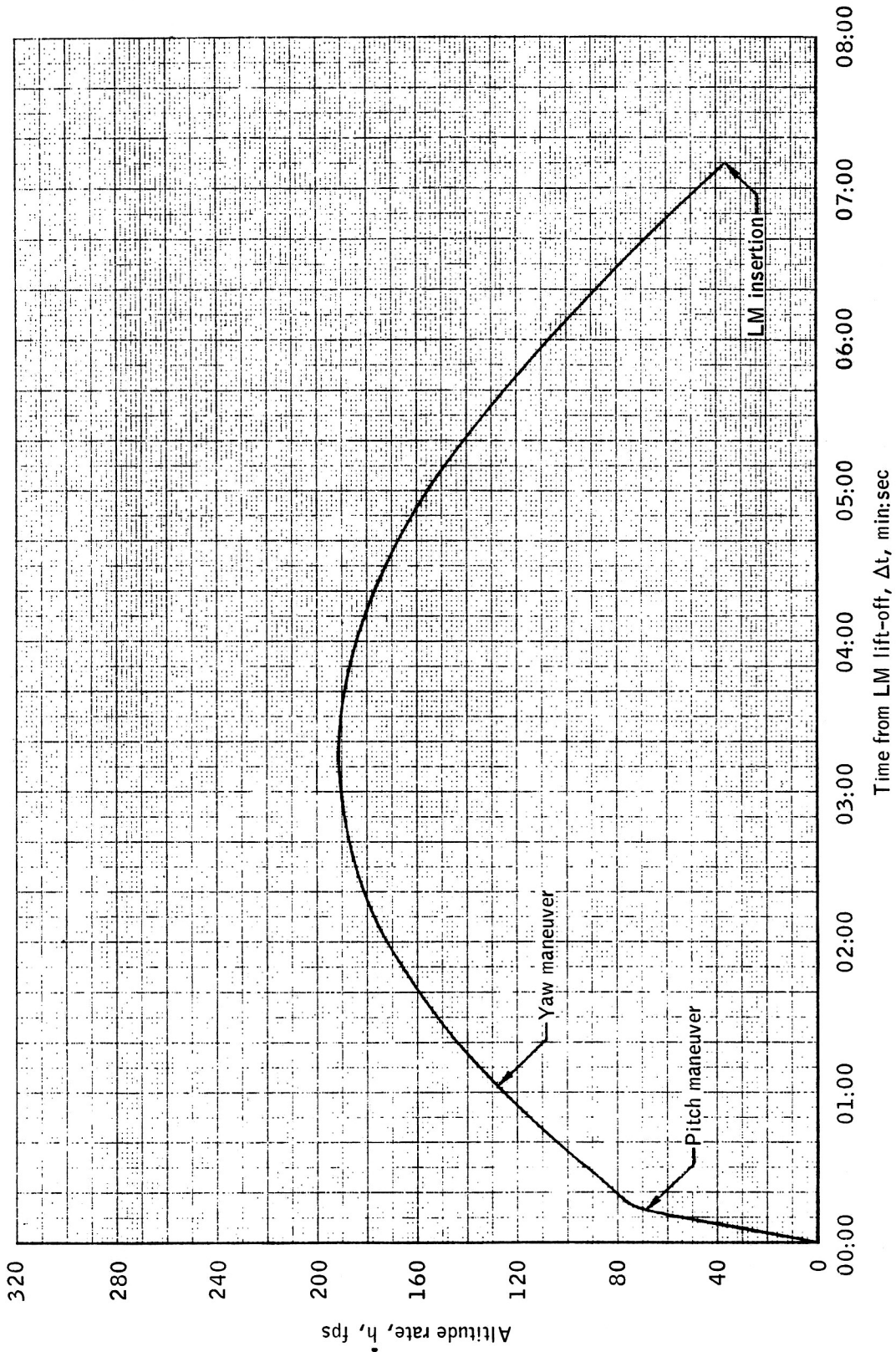


Figure 10. - Altitude rate versus ascent time for Apollo 13.

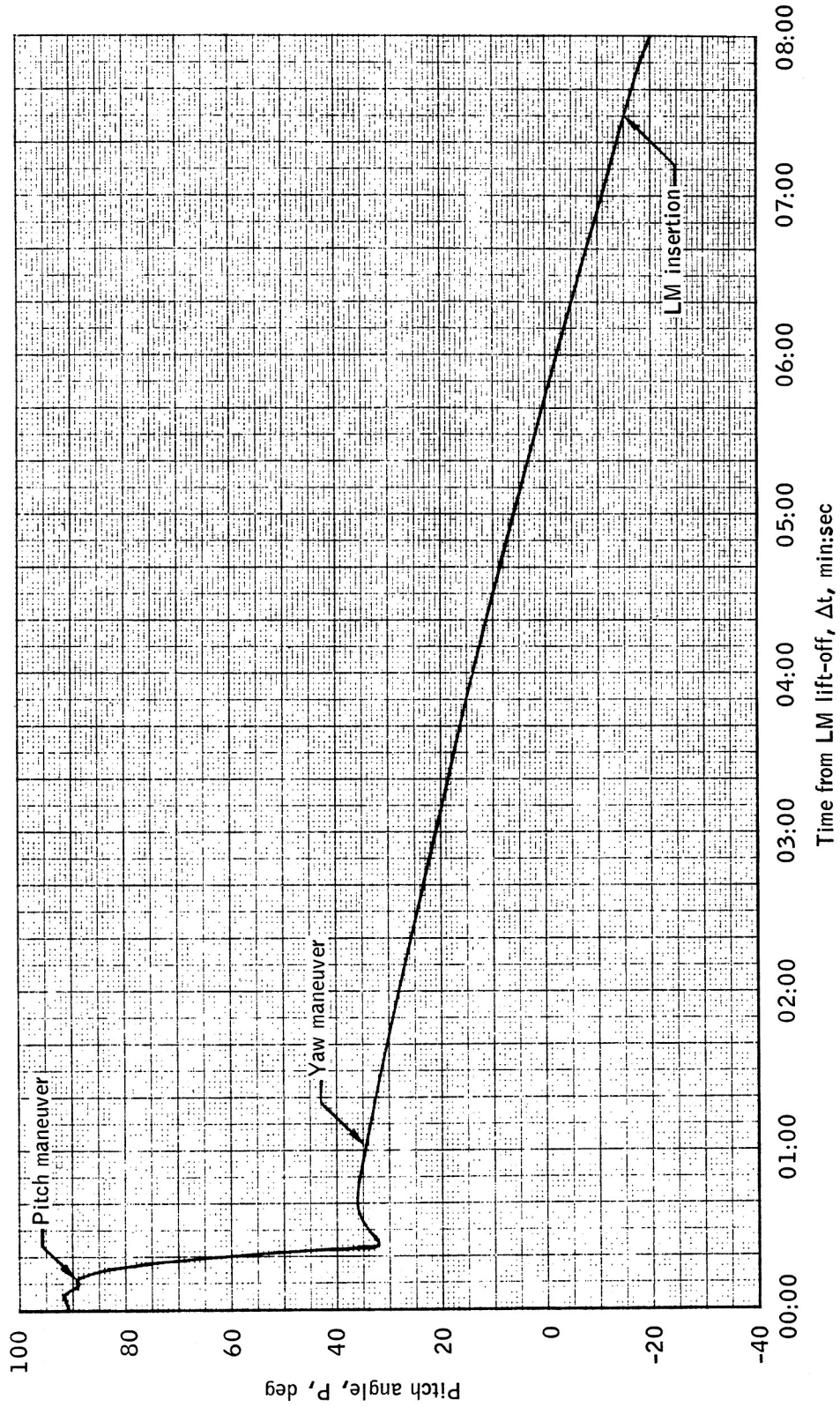


Figure 11.- Pitch angle versus ascent time for Apollo 13.

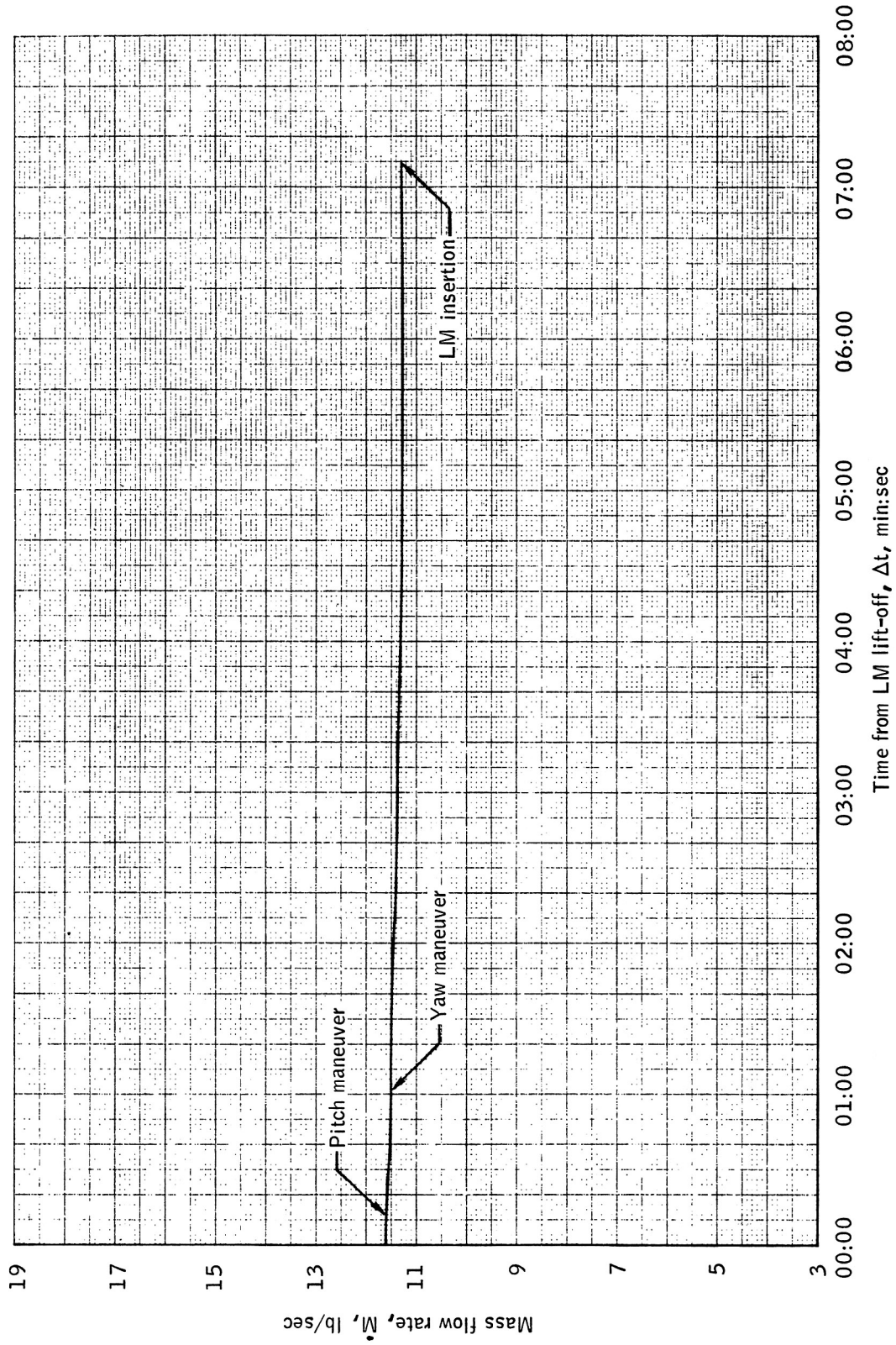


Figure 12.- Mass flow rate versus ascent time for Apollo 13.

8.0 DOI MONITORING

8.1 Introduction

In order to determine whether or not a safe perilune has been achieved after the DOI maneuver, ground monitoring of the Doppler tracking data at AOS following the DOI is required as one of three voting sources.

The prime method of monitoring the burn will be with the Doppler residuals at AOS based on a rev 2 vector with the nominal burn in the MPT. A secondary method will be to process the incoming Doppler in batches of 12 observations each with the low-speed processor to estimate perilune. This processing will continue for as long as AOS + 11 minutes using the first 4 minutes of data.

8.2 LOS rev 2

- A. Verify that rev 2 is superbatched with an SSL _____
- B. Record ID of rev 2, SSL superbatch _____

8.3 Pre-AOS rev 3 (20 min)

In preparation for DOI monitoring, check the following with Data Select:

- A. Two-way timeline _____
- B. Two-way data coming in (AOS - 15 min) GDS _____
- C. Three-way data coming in (AOS - 2 min)
 - 1. GWM _____
 - 2. HSK _____
 - 3. MIL _____
 - 4. PIR (not to be processed) _____
- D. Maneuver uncertainties set to 10 000 _____
- E. Data rate set to 1 obs/6 sec _____
- F. Batch size set to 12 observations _____

G. Confirm with FIDO and Dynamics that the burn in the MPT
is the nominal burn _____

8.4 Post AOS rev 3

In order to evaluate the DOI maneuver and the resulting perilune:

A. Monitor AOS time:

1. Nominal AOS at _____
2. Actual AOS at _____
3. Actual - nominal = _____
4. If $\Delta AOS > 20$ seconds, be prepared for a possible BAIL OUT.

B. Monitor handover criteria:

1. If lock-on (based on "go for command") is not obtained within 60 seconds of actual AOS, request handover.
2. If no two-way data is coming into the Mission Control Center, request handover.
3. If all the three-way data agrees but disagrees with the two-way data, request handover.

C. Monitor residuals based on rev 2 vector, the nominal burn and a Doppler scale of 10 cps.

Site	Batch number	Comments	AVG residuals
1.			
2.			
3.			
4.			
5.			
6. If the residuals of sites 1 through 5 are less than -30 cps, report to FIDO that MSFN is NO STAY.			

D. Exclude PIR

E. Monitor short arc solutions:

1. 2 minutes

a. Plots

1. Plot first site () based on itself _____
Residuals: RMS = _____ AVG = _____.
2. Plot second site () based on last accepted
vector _____
Residuals: RMS = _____ AVG = _____
3. Plot third site () based on last accepted
vector _____
Residuals: RMS = _____ AVG = _____
4. Plot fourth site () based on last accepted
vector _____
Residuals: RMS = _____ AVG = _____

b. Fit

1. Voice check with Data Select ID of input vector for
2-minute short arc _____
2. MSK request 1584 for DC summary _____
3. When 2-minute short arc is complete check the
following:
 - (a) SS4 indication _____
 - (b) RMS = _____ AVG = _____
 - (c) hp = _____
4. MSK request 1570 and check residuals

2. 4 minutes

a. Plots

1. Plot first site () based on 2-minute
superbatch vector _____
Residuals: RMS = _____ AVG = _____
2. Plot second site () based on 2-minute
superbatch vector _____
Residuals: RMS = _____ AVG = _____
3. Plot third site () based on 2-minute
superbatch vector _____
Residuals: RMS = _____ AVG = _____
4. Plot fourth site () based on 2-minute
superbatch vector _____
Residuals: RMS = _____ AVG = _____

b. Fit

1. Voice check with Data Select ID of input vector
for 4-minute short arc
2. MSK request 1584 for DC summary _____
3. When 4-minute short arc is complete check
the following:
 - (a) SS4 solution _____
 - (b) RMS = _____ AVG = _____
 - (c) hp = _____
4. MSK request 1570 and check residuals

5. If hp (based on 4-min short arc if available) <
3.6 n. mi., report to FIDO that MSFN is NO STAY.

F. Return to incoming Doppler residuals on regular batches.

REFERENCES

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