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PROJECT APOLLO  
TASK MSC/TRW A-50

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APOLLO MISSION 11, TRAJECTORY  
RECONSTRUCTION AND POSTFLIGHT ANALYSIS  
VOLUME 1

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS  
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## FOREWORD

This report is submitted to the NASA Manned Spacecraft Center in accordance with MSC/TRW Task A-50 Contract NAS 9-8166. This report contains the postflight analysis performed in conjunction with the Apollo 11 mission and is issued as supplement one to the Apollo 11 Mission Report (NASA/MSC Report MSC-00171, Nov. 1969).

The report is issued in two volumes. Volume I contains details of the analysis and results obtained, including appendixes. Volume II contains a listing of the 45-day best estimated trajectory (BET) for the Apollo 11 mission in the NASA Apollo Trajectory (NAT) format. The listing is not generally distributed but is available from NASA/MSC upon request. Requests should be made to:

NASA/MSC Computations and Analysis Division  
Central Metric Data File  
Code ED-5, Building 12, Room 133  
Houston, Texas 77058

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## 7.0 APOLLO MISSION 11 TRAJECTORY RECONSTRUCTION AND POSTFLIGHT ANALYSIS

### 7.1 INTRODUCTION AND SUMMARY

#### 7.1.1 Apollo 11 Mission

The Apollo 11 mission was launched from the Kennedy Space Center at 13:32:00 (hrs:min:sec) Greenwich Mean Time on 16 July 1969. Apollo 11 was the third manned lunar mission and the first to attempt and accomplish a landing on the lunar surface. A summary of the major events is presented in Table 7.1.

The descent phase of the mission was initiated during the thirteenth revolution of the moon at approximately  $100^{\text{h}}\ 07^{\text{m}}$  Ground Elapsed Time (GET). The lunar module (LM) successfully landed on the lunar surface at approximately  $102^{\text{h}}45^{\text{m}}$  GET.

The rendezvous phase began with ascent ignition during the 25<sup>th</sup> CSM revolution and ended with docking at  $128^{\text{h}}03^{\text{m}}$  GET. A summary of the CSM and LM maneuvers performed during descent and rendezvous is presented in Table 7.2 and a graphical representation of these phases of the mission which depicts the motion of the LM relative to the CSM is shown in Figures 7-1a and 7-1b.

#### 7.1.2 Postflight Analysis

The objective of the postflight analysis task was, in general, to generate trajectory parameters and data for the command and service modules (CSM) and LM from S-IVB/CSM separation to the end of mission. As in the Apollo missions 9 and 10, a preliminary trajectory was generated from the best available RTCC vectors. The bulk of the postflight analysis effort was then concentrated on reconstruction of the two periods of flight from LM/CSM undocking to LM touchdown (descent phase) and from LM ascent to LM/CSM docking (rendezvous).

The RTCC vectors used to generate the preliminary NAT (NASA Apollo Trajectory) are summarized in Appendix A. Most of the lunar trajectories were generated using RTCC SS2 (inclination constrained) solution vectors rather than SS1 (no a priori) solution vectors. Unlike the Apollo 10

SS2 vectors which were constrained to the pre-LOI1, rev 18, and rev 29 planes, the Apollo 11 SS2 vectors were constrained on a rev to rev basis. Each SS2 vector contained two revs of data and was constrained to the SS1 solution plane of one of these two revs (exceptions existed at maneuvers). This technique prevented the accumulation of a large error in the out-of-plane component of position. The lunar potential model used in the generation of the preliminary NAT and for propagation of RTCC vectors was the Boeing R2 model defined in Appendix B.

The final NAT was produced by updating the preliminary NAT to include reconstructions of critical maneuvers for which telemetered acceleration data was available and to reflect the results of the trajectory reconstruction efforts performed on the descent and rendezvous periods of the mission. These reconstructions will be discussed in detail in the following sections.

In general, the postflight analysis was accomplished without difficulty. Coincident with the trajectory reconstruction activities, analyses were performed to determine the quality of the onboard tracking data (LM rendezvous radar, CSM sextant, CSM VHF ranging, and LM landing radar). The results of these analyses are also included in this report.

Table 7.I Apollo 11 Sequence of Events

	GET h:m:s	GMT d:h:m:s
Range Zero	00:00:00	16:13:32:00
Insertion	00:11:49.3	16:13:43:49.3
Translunar Injection Ignition	02:44:16.2	16:16:16:16.2
S-IVB/CSM Separation	03:17:04.6	16:16:49:04.6
First Docking	03:24:03.1	16:16:56:03.1
Spacecraft Ejection	04:16:59.1	16:17:48:59.1
Midcourse Correction #1	26:44:58.7	17:16:16:58.7
Lunar Orbit Insertion #1	75:49:50.4	19:17:21:50.4
Lunar Orbit Insertion #2	80:11:36.8	19:21:43:36.8
Undocking	100:12:00	20:17:44:00
CSM Separation	100:39:52.9	20:18:11:52.9
Descent Orbit Insertion	101:36:14	20:19:08:14
Powered Descent Initiation	102:33:05.2	20:20:05:05.2
Touchdown	102:45:39.9	20:20:17:39.9
Liftoff	124:22:00.8	21:17:54:00.8
Coelliptic Sequence Initiation	125:19:36	21:18:51:36
Constant Differential Height	126:17:49.6	21:19:49:49.6
Terminal Phase Initiation	127:03:51.8	21:20:35:51.8
Terminal Phase Finalization	127:46:09.8	21:21:18:09.8
Second Docking	128:03:00	21:21:35:00
Final Separation	130:30:01	22:00:02:01
Transearth Injection	135:23:42.3	22:04:55:42.3
Midcourse Correction #2	150:29:57.4	22:20:01:57.4
CM/SM Separation	194:49:12.7	24:16:21:12.7
Entry Interface	195:03:05.7	25:02:35:05.7

**Table 7.2** Descent and Rendezvous Maneuver Summary for Apollo 11

Maneuver	Type of Maneuver	Ignition Time (h:m:s) GET	Cutoff Time (h:m:s) GET	T/M Coverage	$\Delta V$ (FPS)
SEPARATION	CSM/RCS	100:39:52.9	100:40:01.9	Yes	2.6
DOI	LM/DPS	101:36:14.0	101:36:44.0	No	76.4
PDI	LM/DPS	102:33:05.0	102:45:42.2	Yes	6775.8
ASCENT	LM/APS	124:22:00.8	124:29:15.7	Yes	6070.1
CSI	LM/RCS	125:19:36	125:20:23	No	51.5
CDH	LM/RCS	126:17:49.6	126:18:07.4	Yes	19.9
TPI	LM/RCS	127:03:51.8	127:04:14.5	Yes	25.3
TPF	LM/RCS	127:46:09.8	127:46:38.1	No	31.4

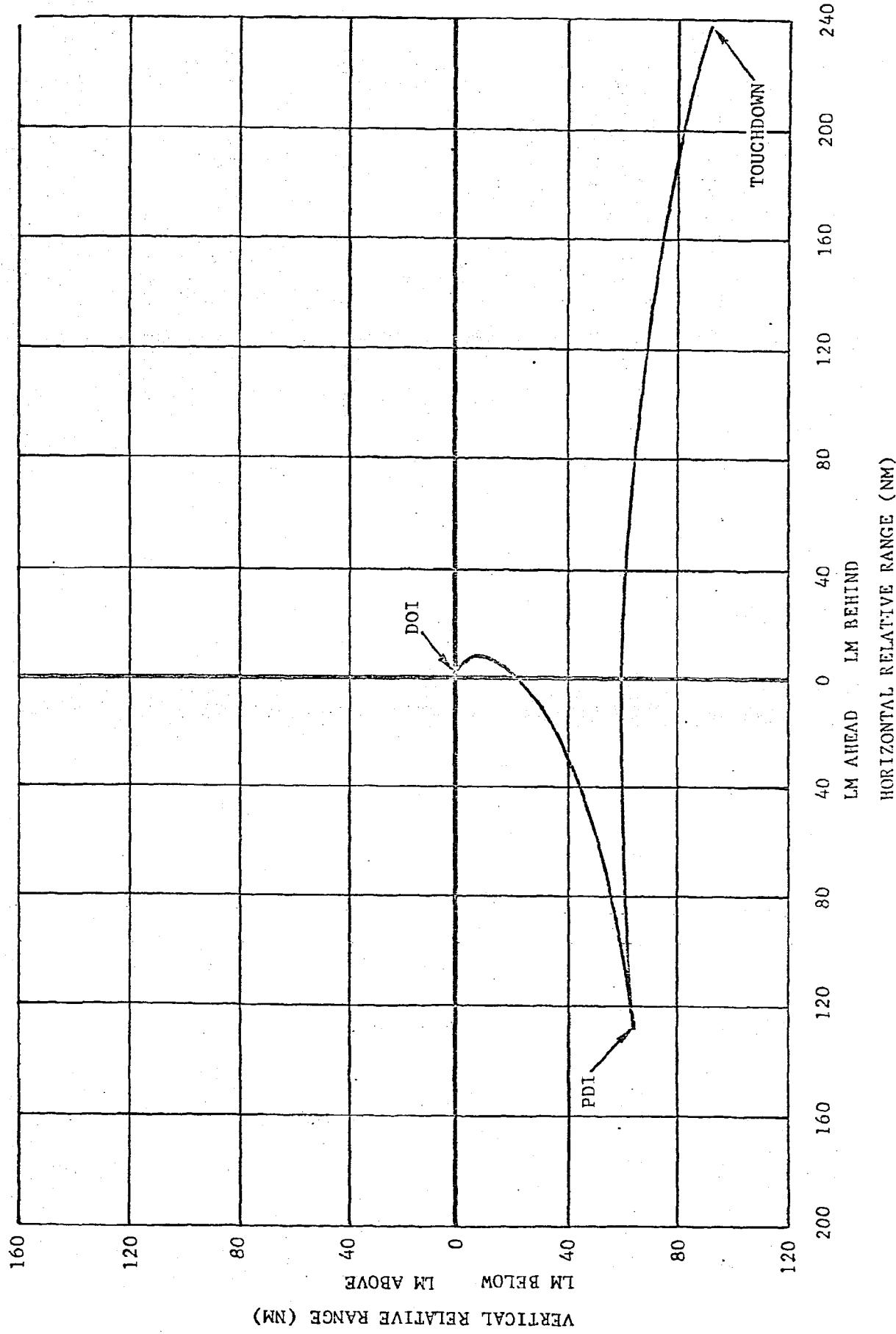


Figure 7-1a Relative Motion of the LM for Apollo 11 Descent - DOI to landing (CSM Centered)

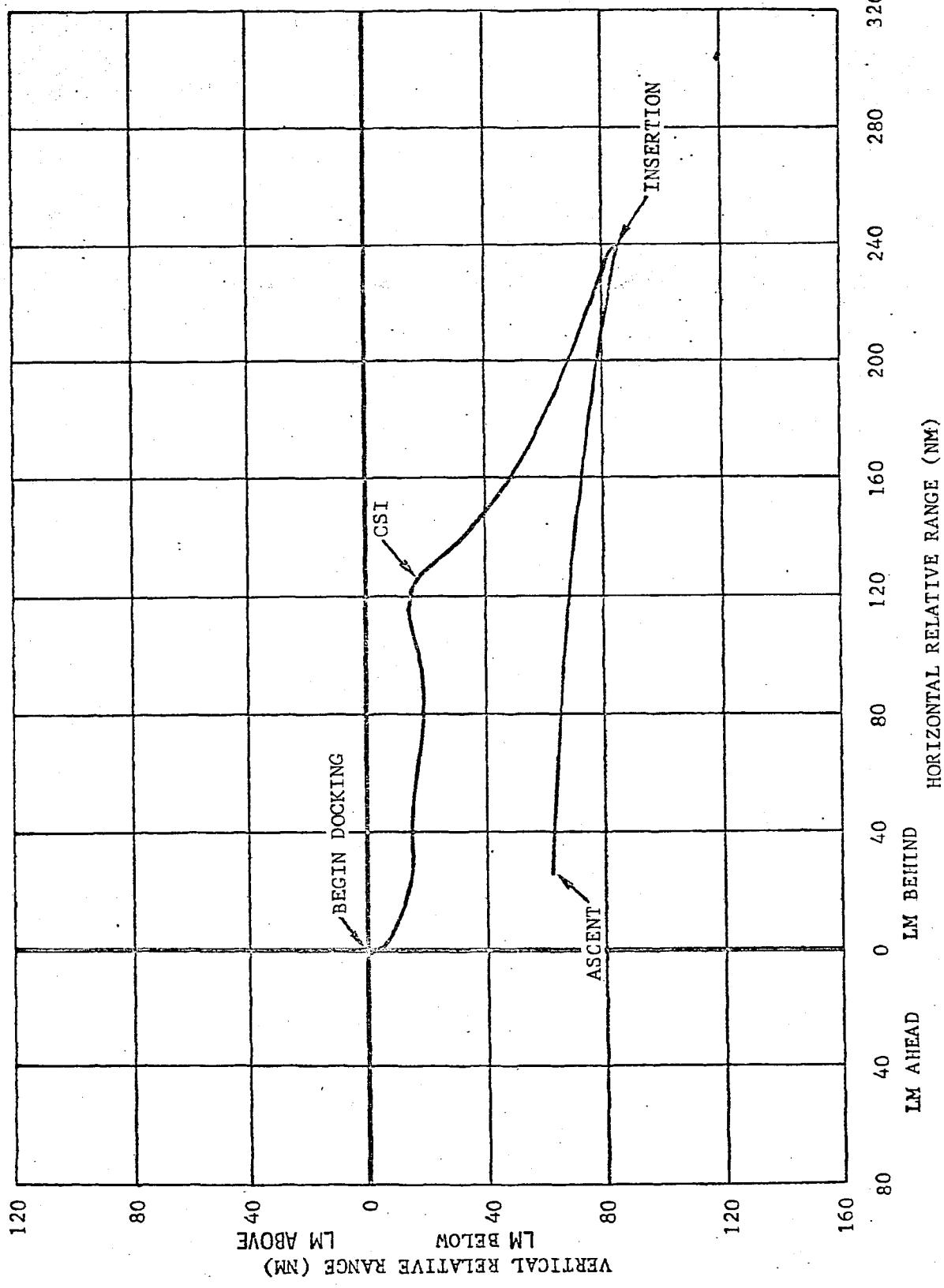


Figure 7-1b Relative Motion of the LM for Apollo 11 Rendezvous - Ascent to Docking (CSM Centered)

## 7.2 ORBIT ANALYSIS

### 7.2.1 Methods of Reconstruction

The HOPE Program was used as the basic orbit determination tool. The program utilizes a weighted least squares differential correction technique to regress on a large set of parameters. It is capable of handling two vehicles, and can use both ground based and onboard tracking data. An additional capability is the IGS (Inertial Guidance System) burn option which models the Apollo inertial measurement unit and uses telemetered acceleration data to reconstruct maneuvers.

The orbit determination was accomplished using four basic fit techniques. These techniques are described as follows:

- a) MSFN free flight - regression on the state vector over free flight intervals as defined by spacecraft maneuvers using MSFN data.
- b) MSFN IGS - regression on the state vector using, at maximum, one revolution of MSFN data and incorporating the spacecraft maneuvers which had telemetry coverage by means of the HOPE IGS burn model.
- c) Onboard free flight - regression on the state vector over free flight intervals using available onboard tracking data to correct the LM trajectory with respect to a fixed CSM trajectory (MSFN fits).
- d) Onboard IGS - regression on the state vector using available onboard data to correct the LM trajectory with respect to a fixed CSM trajectory and incorporation of the LM maneuver (which had telemetry coverage) by means of the HOPE IGS burn model.

More accurate trajectories are usually produced with techniques (b) and (d) since they take advantage of longer tracking data arcs. This factor is important in descent and rendezvous trajectory reconstruction since the tracking intervals between some maneuvers are too short to produce a representative trajectory over the whole segment.

As a result of the analysis of various lunar potential models contained in Reference 7, and on the basis of improved observation residuals and propagation characteristics, the L1 model (Langley Model 1) was used

in the orbit analysis. This model is basically the Boeing R2 model augmented by a C33 term. Table 7.3 shows improvements in propagation characteristics of the L1 over the R2 model. Both models are defined in Appendix B.

The trajectories for both Apollo 11 vehicles during descent and rendezvous were reconstructed using the methods summarized above. The data used in these reconstruction activities primarily included low speed MSFN, high speed MSFN, rendezvous radar, VHF ranging, and sextant data. Telemetered acceleration data were used to reconstruct maneuvers where available and applicable. Table 7.2 lists the maneuvers performed during the descent and rendezvous periods. Figure 7-2 shows the tracking data arcs (which were available over the periods of interest) as a function of ground elapsed time. In Figure 7-2, the solid bars represent the transmitting (two-way) MSFN station and the numbers represent the number of observations upon which final fits were based. Note that some stations operated in the dual mode (simultaneous tracking of both the CSM and the LM).

The following paragraphs describe the trajectories which were used as the final BET for both vehicles.

#### 7.2.2 CSM Best Estimate of Trajectory

The trajectories for the CSM lunar revolutions 13, 14, 25 and 26 were reconstructed from low speed MSFN tracking data compacted to a rate of two samples per minute or, in the case of stations operating in the dual mode, one sample every 36 seconds. The data used are summarized in Figure 7-2. The quantity of data obtained for revolutions 13 and 26 was good. Because of the partial data arcs from some stations on revolutions 14 and 25, the data quantity in these revs could only be rated as fair. Inclusion of data from a southern hemisphere station (Ascension) enhanced the geometry of the active tracking network configuration and contributed to the quality of all the fits.

Two reconstruction techniques were used to obtain the CSM BET's. The MSFN IGS fit technique was used on revolution 13 because of the presence of telemetered acceleration data from the CSM separation burn performed

in the MSFN data arc. BET's for the remaining orbits of interest (14, 25 and 26) were obtained from MSFN free flight fits.

In general, the CSM BET's were of good quality. This is illustrated to some extent by the good position and velocity comparisons between revolutions (Table 7.4) and by the residual statistics listed for each fit in Appendix B. These statistics (standard deviation of .1 to .25 cycles per second) compare very well with Apollo 8 (standard deviations between .3 and .6 cycles per second) and Apollo 10 (standard deviations between .2 and .4 cycles per second). A portion of this improvement may be attributed to the better fit produced by the L1 lunar potential model.

Table 7.4 contains a summary of the final BET's giving fit type (technique), data interval, NAT trajectory interval, and position and velocity differences at matchpoints between segments.

### 7.2.3 LM Best Estimate of Trajectory

A major portion of the postflight analysis effort was directed towards reconstruction of the LM trajectories from undocking to landing and from liftoff through rendezvous. A discussion of the origin and quality of the final trajectories is included in the following paragraphs.

#### 7.2.3.1 Descent Phase Trajectories

The descent phase was reconstructed in three segments; undocking to DOI, DOI to PDI, and PDI to Touchdown. The BET for undocking to DOI was obtained from a MSFN free flight fit based upon the entire data arc from revolution 13. The quantity of data was considerably better than for the CSM since five stations were tracking the LM. Residual statistics (summarized in Appendix B) compare well with the MSFN residual statistics obtained from the CSM fits. Note from Figure 7-2, which shows the tracking history, that the tracking station geometry was good.

The BET for the period from DOI to PDI was obtained from an onboard free flight fit based on CSM sextant and VHF ranging data taken prior to PDI. As can be seen in Figure 7-2 the data quantity was good, with 18 VHF ranging observations and 13 sextant sightings. Data quality is discussed more thoroughly in Section 7.3. The CSM trajectory which was used as the reference trajectory was the revolution 14 BET discussed in paragraph 7.2.2.

The BET for the powered descent segment of the flight was originally based on a fit obtained from low speed MSFN data taken from revolution 14 acquisition of signal to touchdown. The trajectory obtained from this fit was modified to force the landing point to coincide with the current best estimate of landing site location. Landing site parameters obtained from this descent trajectory (BET #3) were  $.6358^{\circ}$  latitude,  $23.4938^{\circ}$  longitude, and -8557 feet altitude (referenced to the mean lunar radius). These figures compare well with the value published in Reference 10 as the best estimate (latitude  $.647^{\circ}$  and longitude  $23.505^{\circ}$ , determined from postflight photo reduction).

Since the BET #3 was constrained to impact a desired landing site, the quality of the trajectory at PDI is not the best available. A subsequent reconstruction using a combination of onboard plus high speed MSFN data is discussed in Section 7.4 of this report. This combination of high speed data from acquisition of signal to landing and relative tracking data obtained prior to PDI produces a consistent and continuous representation of the LM trajectory from DOI to touchdown.

#### 7.2.3.2 Rendezvous Trajectories

The BET for LM ascent was initialized with landing site coordinates of  $.6357^{\circ}$  latitude,  $23.4701^{\circ}$  longitude, and a height of -8607 feet above the mean lunar radius. These initial conditions were then propagated to insertion using accelerometer data to model the ascent burn.

The LM BET for the period from insertion to TPP was reconstructed in two segments; insertion to CSI and CSI to TPP. The trajectory for the insertion to CSI segment was obtained from a MSFN free flight fit. The data arc and trajectory interval are described in Table 7.4. The MSFN data was good both quantitatively and qualitatively as can be seen in Figure 7-2. The residual statistics, summarized in Appendix B, show that the standard deviations of the doppler residuals are larger in this segment than in segments which have a less severe orbital geometry. This characteristic also existed in the Apollo 10 postflight results.

The second rendezvous segment covered the period from CSI to TPF. The BET chosen was obtained from an onboard data, IGS fit. The data used in the fit included LM rendezvous radar, CSM sextant, and CSM VHF ranging observations. In addition, telemetered acceleration data was used in the IGS burn option of HOPE to reconstruct the CDH and TPI burns. The data arcs are shown in Figure 7-2, and the residual statistics are summarized in Appendix B. Data quality was good, and the resulting BET produced an accurate relative trajectory. The CSM trajectory chosen as the reference for the relative observations was the revolution 26 trajectory described in paragraph 7.2.2. (The quality of the data and the reconstruction are discussed in more detail in Section 7.3 of this report.)

Table 7.3 Matchpoint Comparisons of Trajectories Produced  
with R2 and L1 Lunar Potential Models

Revolutions Compared	R2		L1	
	POS RSS (ft)	VEL RSS (ft/sec)	POS RSS (ft)	VEL RSS (ft/sec)
11-12	10,637	7.187	7544	5.756
12-13	9,936	8.178	4817	3.046
13-14	8,643	8.723	1555	2.53
25-26	9.595	9.139	2147	3.173

RSS = Square root of the sum of the squares of the differences  
between position (POS) or velocity (VEL) components.

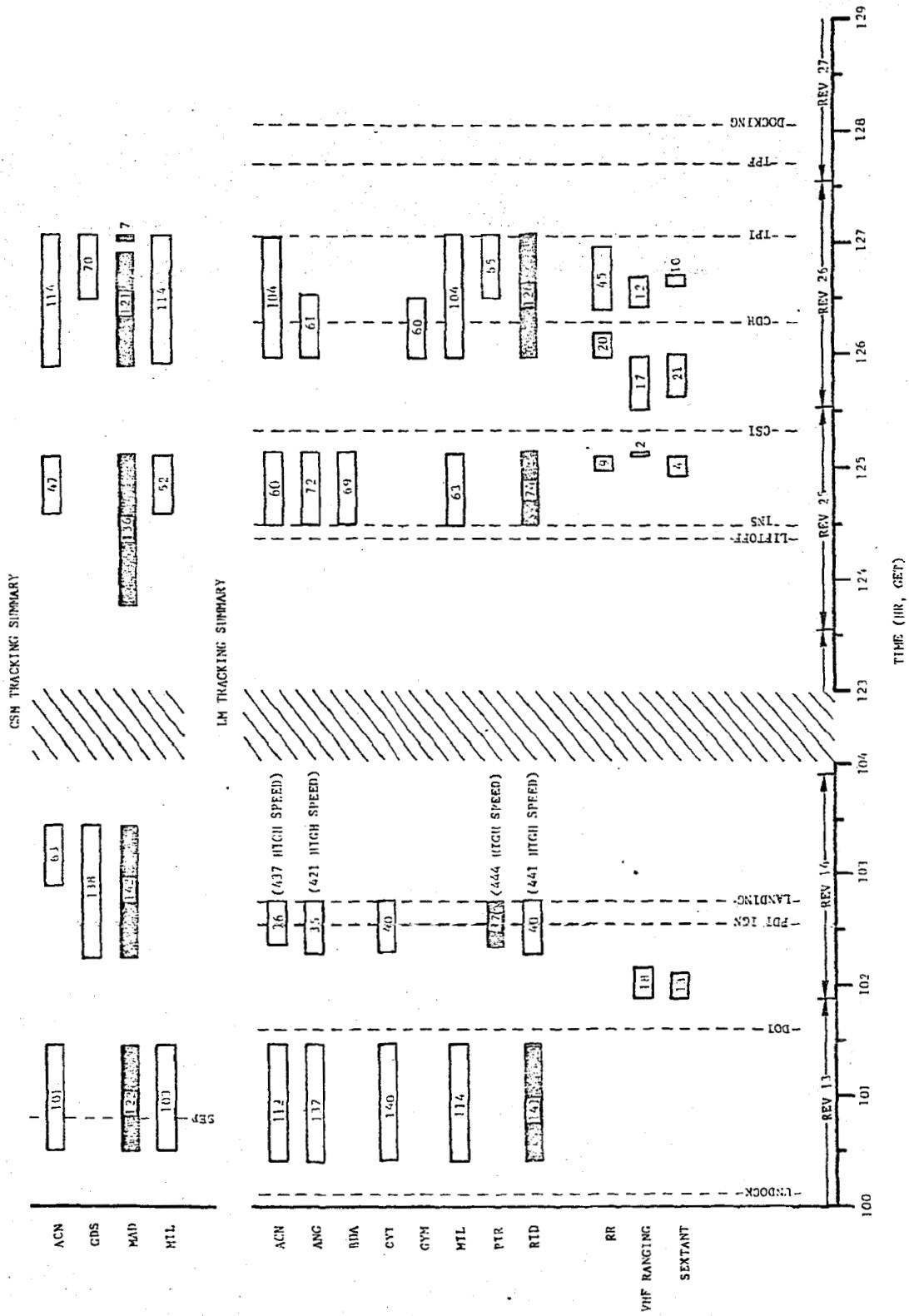


Figure 7-2 Tracking Data (Onboard and Ground Based) Timeline for Apollo 11 Descent and Rendezvous

Table 7.4 - Apollo Mission 11 BET Summary

Vehicle	Flight Segment	Fit Type	Data Interval (d:h:m:s)		Trajectory Interval (d:h:m:s)		$\Delta R$ ft	$\Delta V$ ft/sec
			GMT	GMT	GMT	GMT		
LM	Undock to DOI	MSFN F.F.	20:17:48:45	20:18:59:57	20:17:39:00	20:19:08:14.7	---	---
LM	DOI to PDI	O/B, F.F.	20:19:25:03	20:19:43:56	20:19:08:44.5	20:20:04:00	2007.	75.9*
LM	Powered Descent	Modified	20:19:48:51	20:20:17:45	20:20:04:37.2	20:20:17:45.2	N/A	N/A
		MSFN IGS	---	---	21:17:53:58.9	21:18:03:08.9	---	---
LM	Ascent	IMU only	21:18:03:03	21:18:40:15	21:18:01:21	21:18:51:36	N/A	N/A
LM	Insertion to CSI	MSFN F.F.	21:19:02:17	21:20:29:38	21:18:52:00	21:21:15:08	4253.	50.8**
LM	CSI to POST TPI	O/B IGS						
CSM	Revolution 13	MSFN IGS	20:17:54:24	20:18:59:36	20:17:22:00	20:19:22:00	---	---
CSM	Revolution 14	MSFN F.F.	20:19:47:27	20:20:58:21	20:19:22:00	20:21:17:00	1555.	2.5
CSM	Revolution 25	MSFN F.F.	21:17:27:51	21:18:38:33	21:16:57:00	21:18:57:00	---	---
CSM	Revolution 25	MSFN F.F.	21:19:26:15	21:20:36:51	21:18:57:00	21:20:57:00	2147.	3.2

\*DOI Burn  $\Delta V = 76.4$  ft/sec

\*\*CSI Burn  $\Delta V = 51.5$  ft/sec

### 7.3 ONBOARD TRACKING DATA ANALYSIS

#### 7.3.1 Introduction

Analysis of the LM rendezvous radar data from Apollo missions 9 and 10 and CSM VHF ranging data from Apollo 10 resulted in the conclusions that both data types were of high quality and, in general, produced trajectories consistent with those obtained from ground based tracking data (References 1 and 5).

A similar analysis of the onboard tracking data obtained during the Apollo 11 mission was performed with the following objectives:

- a) Determine the consistency of the LM rendezvous radar data and the CSM VHF ranging data with similar data from Apollo missions 9 and 10.
- b) Using these data as a standard of comparison, evaluate the LM sightings made with the CSM sextant.
- c) Determine the consistency of all onboard data with the ground based data.
- d) Use the onboard data to construct a more accurate LM rendezvous trajectory.

The onboard tracking data were obtained from the downlink telemetry tapes by a special purpose computer program designed to read the tape, and output the desired observations and associated information on punched cards. The format of the punched cards was the specified input to the HOPE Program. Editing of bad data was performed manually.

Onboard tracking data yields a measure of the position and velocity of one vehicle relative to another. It is necessary, therefore, to obtain a good, independent estimate of the trajectory of one vehicle and fix this as a reference trajectory. Since the LM trajectory is perturbed by several maneuvers during the descent and rendezvous mission periods, it is logical to fix the trajectory of the relatively quiescent CSM as the reference.

As discussed in Section 7.2, the CSM trajectory was reconstructed in four single revolution fits from MSFN tracking data. The three segments of interest here were MSFN free flight fits on revolutions 14, 25, and 26.

Trajectories for the LM free flight segments were also reconstructed from MSFN tracking data. The ground based MSFN tracking available for use during the periods of interest are summarized in timeline form in Figure 7-2.

The CSM trajectory was fixed as the reference, and the LM MSFN free flight trajectories were then used to initialize fits based on onboard data in the four segments where relative data were available. A priori confidence values of 10,000 feet were placed on each component of position and 10 feet per second on each component of velocity in the initial conditions.

The reconstruction activities will be discussed in more detail in the following sections. In addition, various tables and figures are included which serve to describe the operations performed and show the accuracy and validity of the data.

### 7.3.2 Onboard Measurements

Rendezvous radar data were obtained during three periods of the Apollo 11 mission; these were Insertion to CSI (9 observations), CSI to CDH (20 observations), and CDH to TPI (45 observations). As in previous missions, the amount of rendezvous radar data obtained was limited to those periods when telemetry coverage was available.

VHF ranging data were obtained from the CSM during four segments of the flight; these were DOI to PDI (18 observations), insertion to CSI (2 observations), CSI to CDH (17 observations), and CDH to TPI (12 observations). Since only two observations were obtained from Insertion to CSI, no meaningful statistics could be obtained.

Sextant data were obtained during the same periods of flight as were VHF ranging data; 13 observations between DOI and PDI, 4 observations from insertion to CSI, 21 observations from CSI to CDH, and 10 observations between CDH and TPI. Listings of all the data are included in Appendix D.

### 7.3.3 Evaluation of Onboard Tracking Data

#### Rendezvous Radar Data

In order to determine the quality of the rendezvous radar data, the residuals (differences between the actual measured value and a measurement

value computed from given CSM and LM trajectories) were examined. The CSM trajectories used in obtaining these residuals were the BET's discussed in Section 7.2 of this report (one rev MSFN free flight fits). The LM trajectories were obtained by using technique (c) described in paragraph 7.2.1 (onboard free flight fits). All available onboard data were used in these fits.

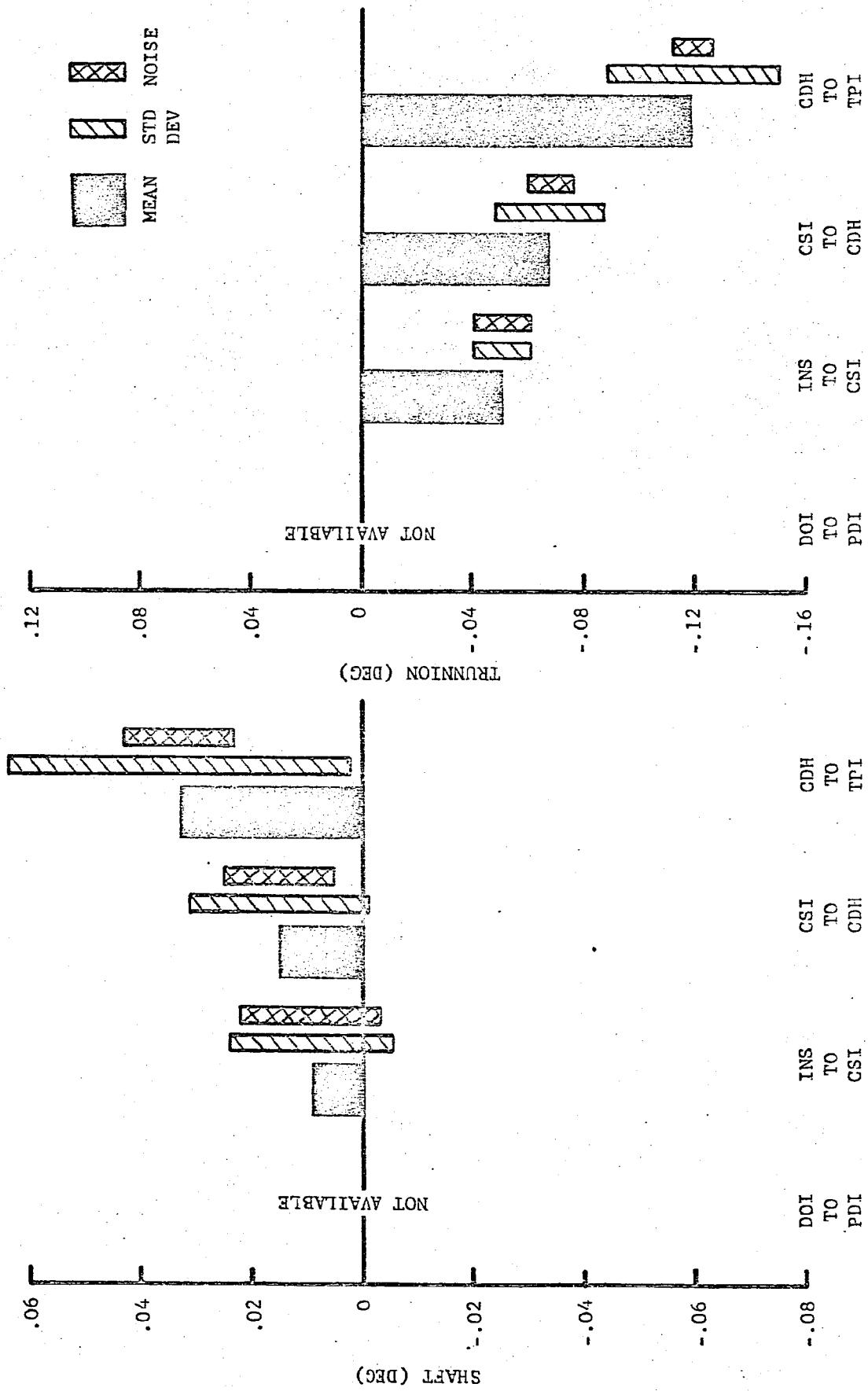
Table 7.5 lists residual statistics (mean, standard deviation, one-sigma noise estimate) computed from the onboard free flight fits of each segment and Figures 7-3a and 7-3b illustrate the results graphically. The data were generally well behaved as can be seen in the residual plots (Figures 7-4 through 7-6). The relatively large differences between the standard deviation and noise computed for shaft and trunnion in the CSI to CDH and CDH to TPI periods can partly be attributed to the fact that both rendezvous radar and sextant data were used in the fit. As the two data sets become more equal in size (weighted effect) or the sampling arcs more coincident, residual statistics deteriorate. This effect is demonstrated by the statistics listed in Table 7.6 which were obtained from fits made with only rendezvous radar data included. Note that when sextant data is eliminated, the RR shaft and trunnion means and deviations decrease in all segments. The shaft statistics are still relatively high (especially in the CDH and TPI period), indicating that a systematic error is still present in the shaft measurement. It should also be noted that the rendezvous radar residual statistics from Apollo 10 exhibited a similar characteristic (Reference 1). In Apollo 10, the standard deviations for both shaft and trunnion measurement are relatively large in the CDH to TPI period (no sextant data were included in Apollo 10 solutions). The large mean values seen in Table 7.5 are also a result of the inclusion of sextant data in the solution data sets. When only rendezvous radar data was included, the mean values decreased to near zero values.

The range residual statistics exhibited characteristics similar to the Apollo 10 data. When VHF ranging data is removed from the solution data set, standard deviations decrease and become, in two segments, almost equal to noise estimates. The mean values also approach zero, indicating that no bias is present.

Table 7.5 Summary of Rendezvous Radar Residual Statistics

	Insertion To CSI	CSI To CDH	CDH To TPI	
Shaft (deg)	.009	.015	.033	Mean
	.015	.016	.031	S. Dev.
	.013	.010	.010	Noise
Trunnion (deg)	-.051	-.068	-.119	Mean
	.010	.019	.031	S. Dev.
	.010	.008	.007	Noise
Range (feet)	79.	75.	55.	Mean
	144.	63.	92.	S. Dev.
	39.	37.	27.	Noise
Range Rate (fps)	.604	-.243	-.305	Mean
	.173	.339	.277	S. Dev.
	.6278	.6278	.6278	Q. E.*

\* Quantization Error.



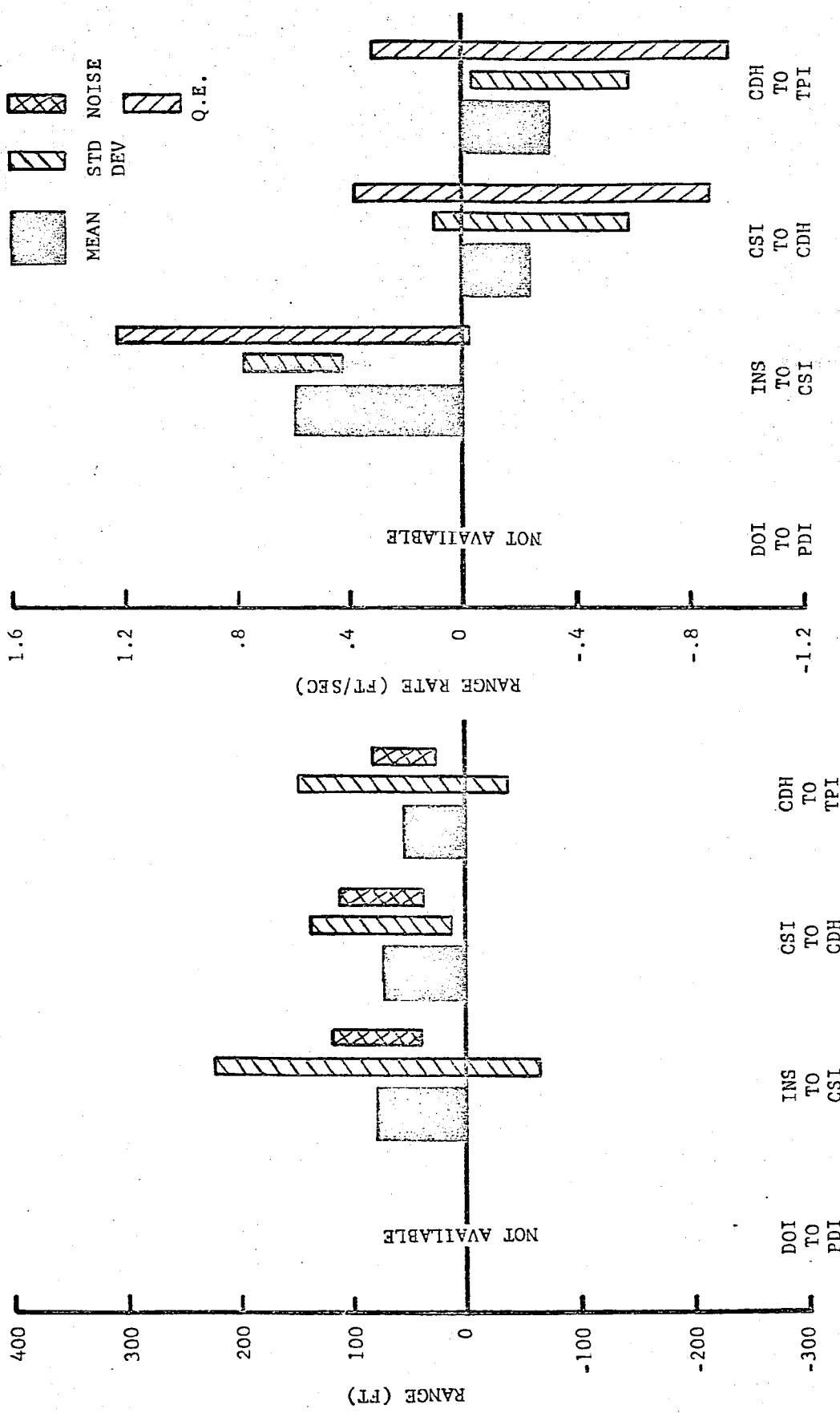


Figure 7-3b Rendezvous Radar Range and Range Rate Residual Statistics

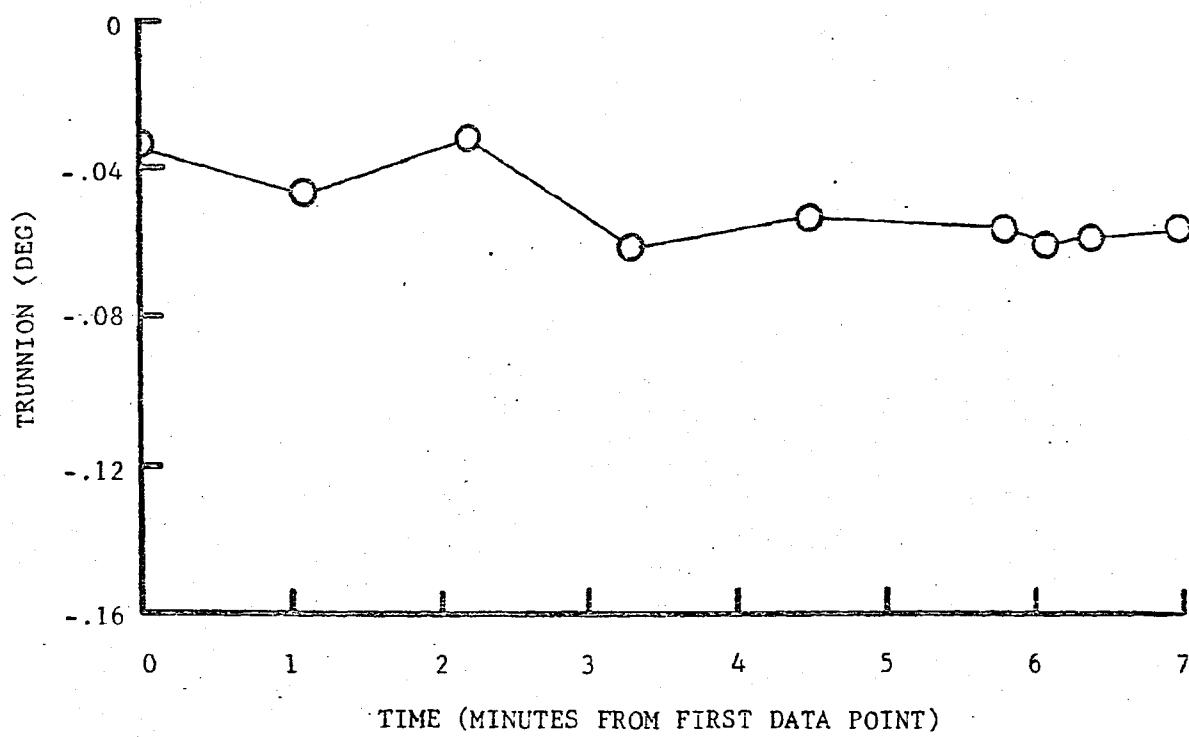
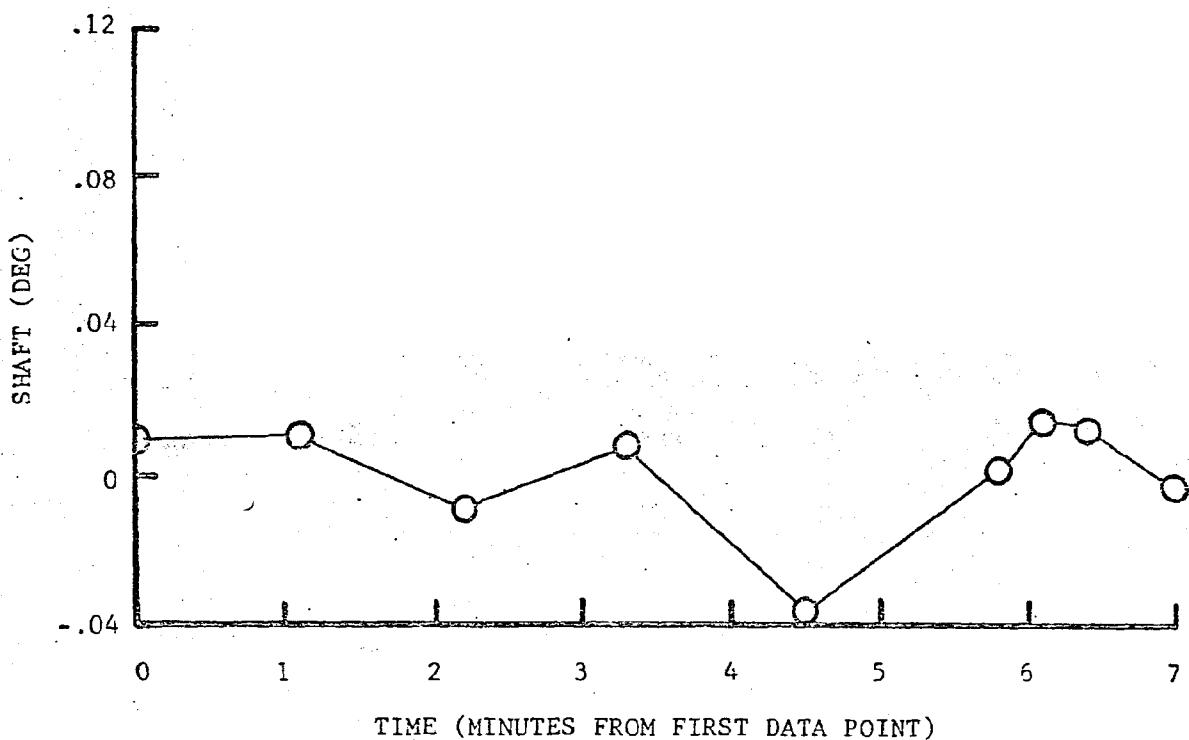


Figure 7-4 Rendezvous Radar Residuals (Insertion to CSI)

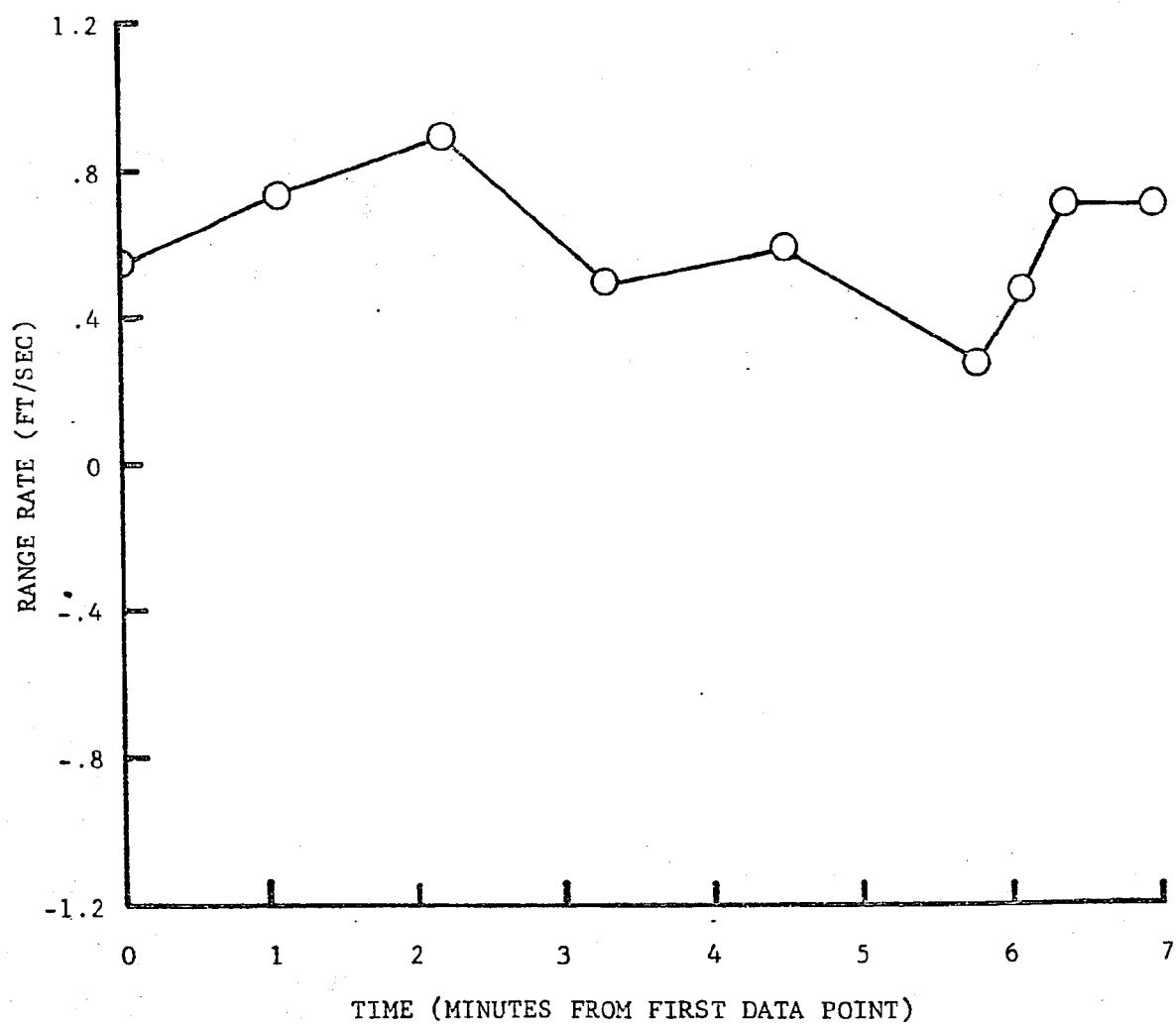
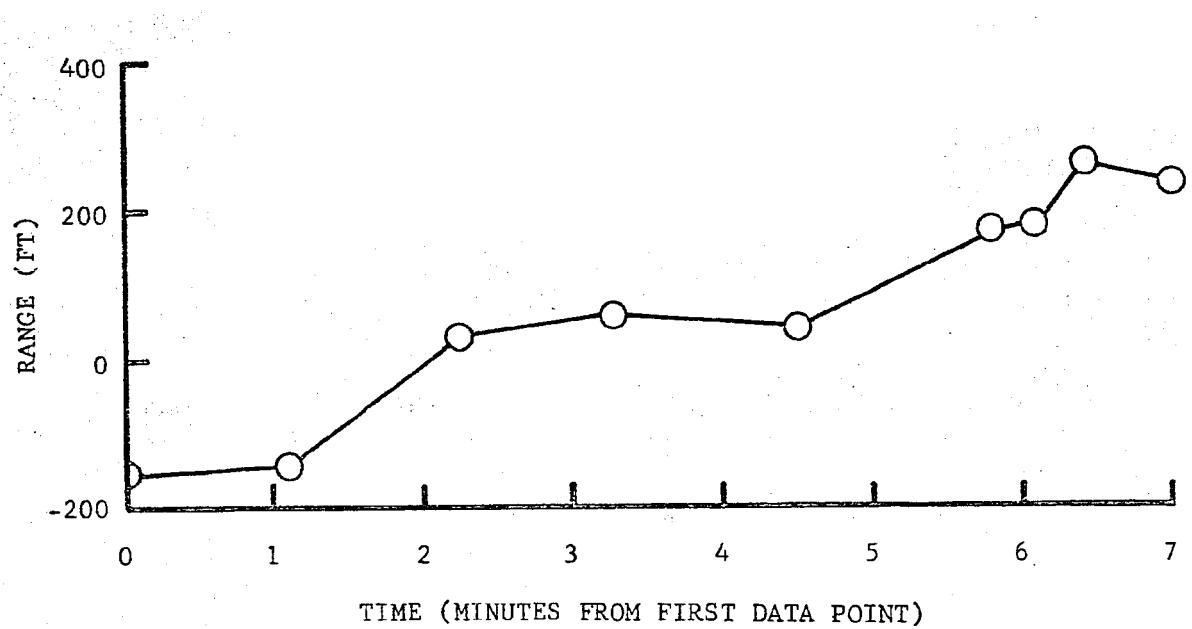


Figure 7-4 Concluded

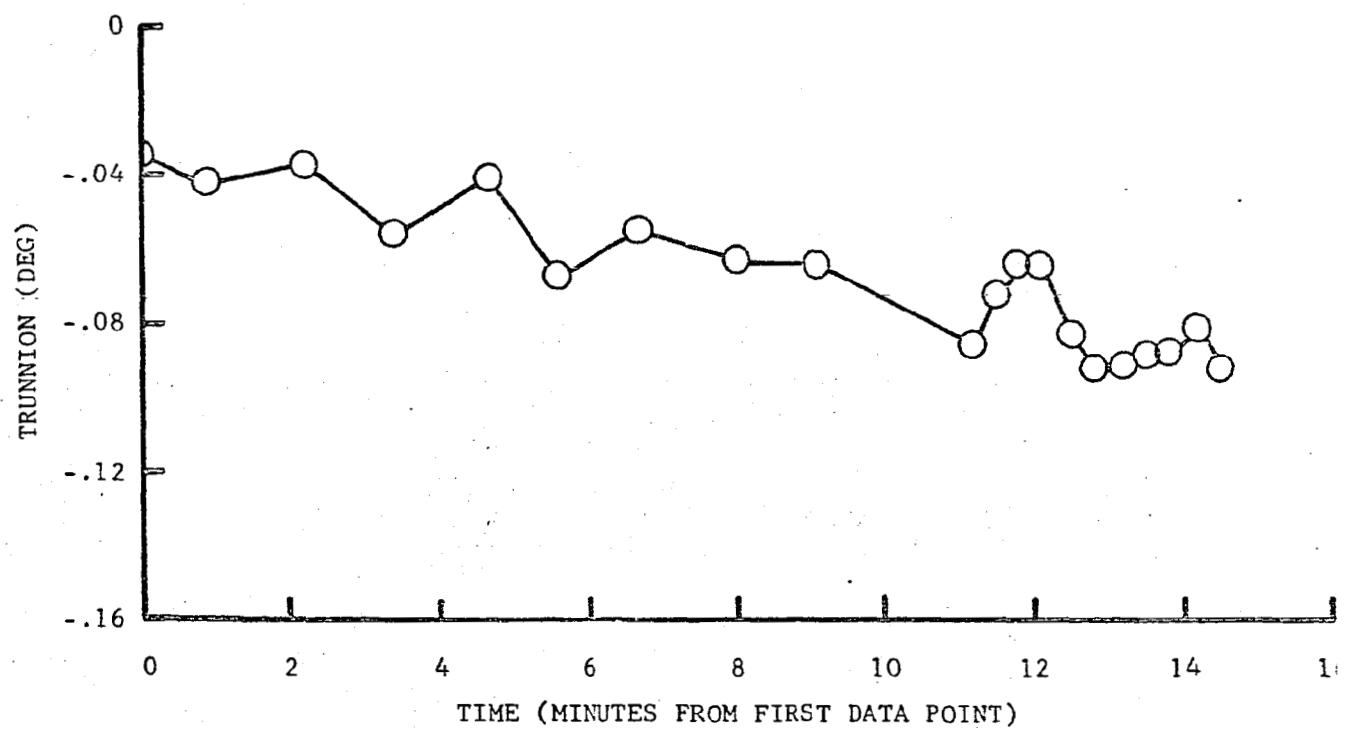
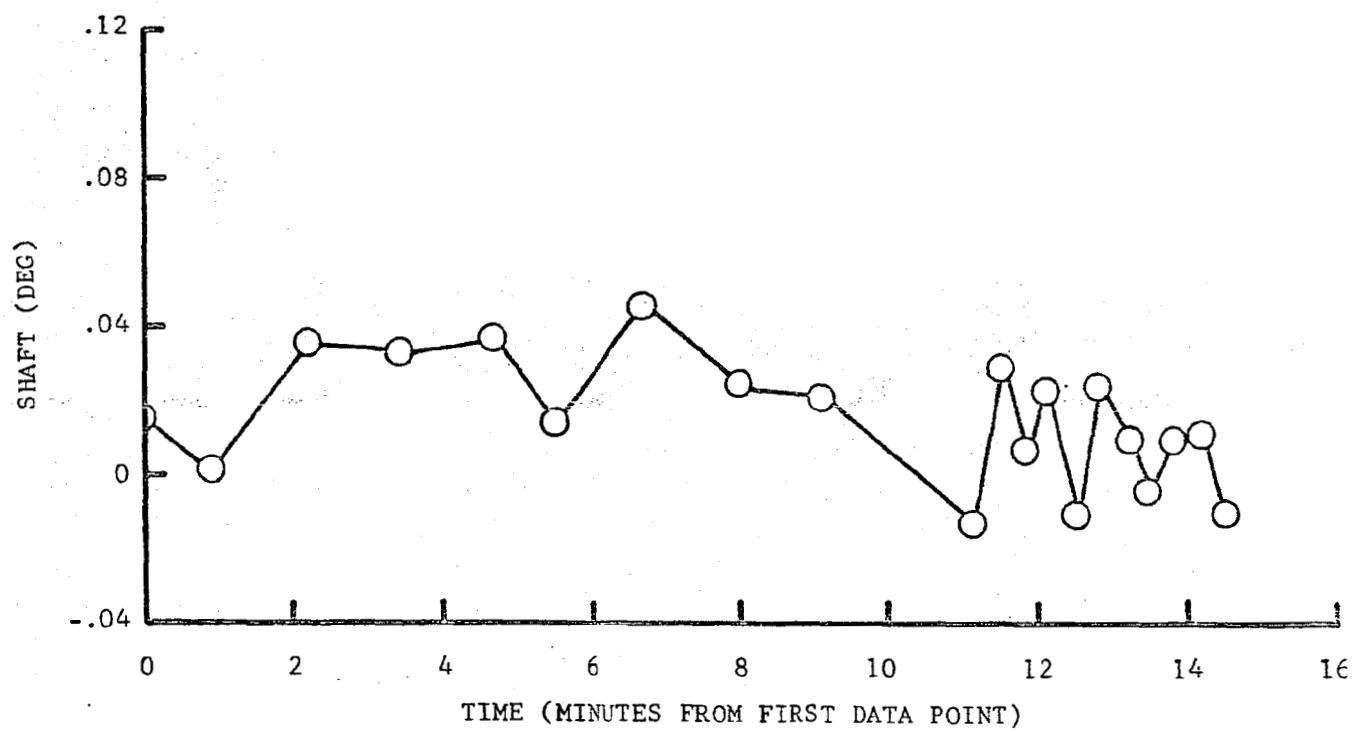


Figure 7-5 Rendezvous Radar Residuals (CSI to CDH)

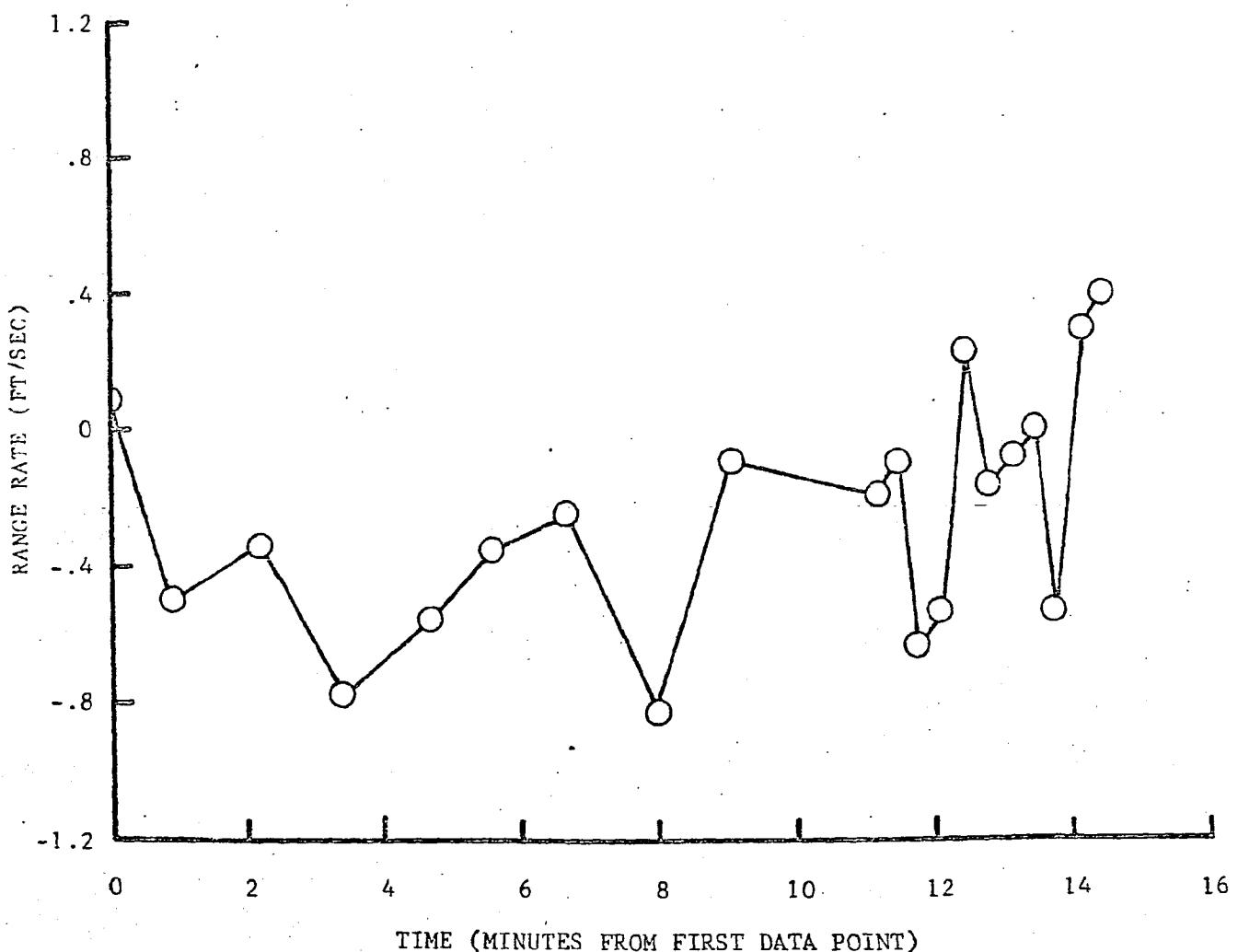
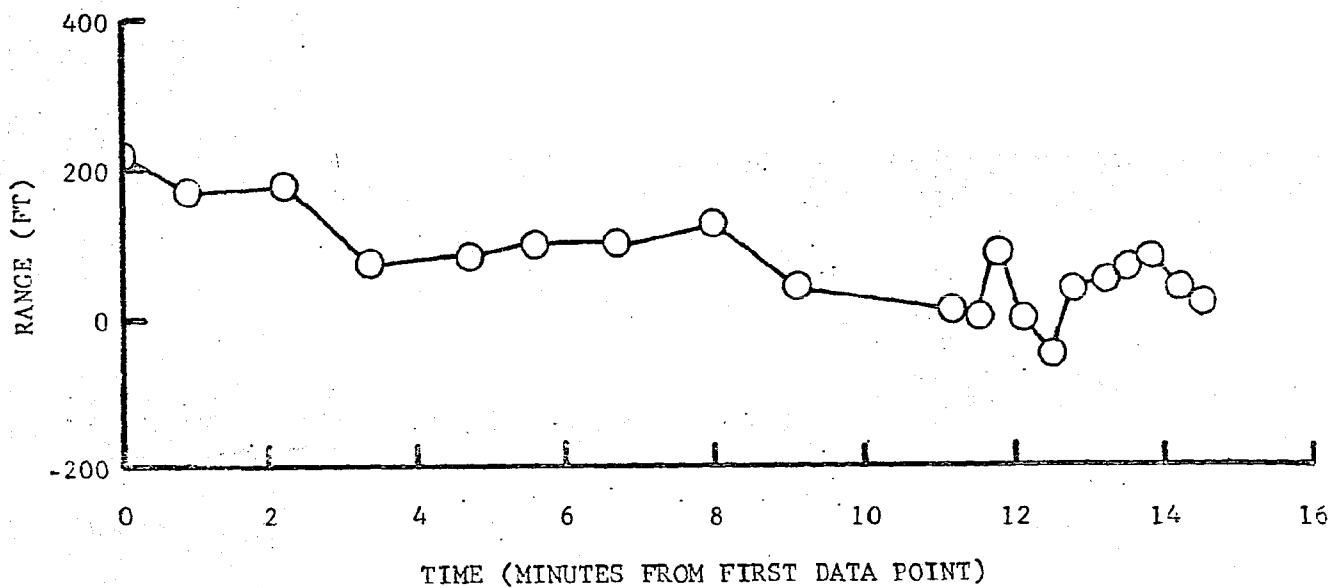


Figure 7-5. Concluded

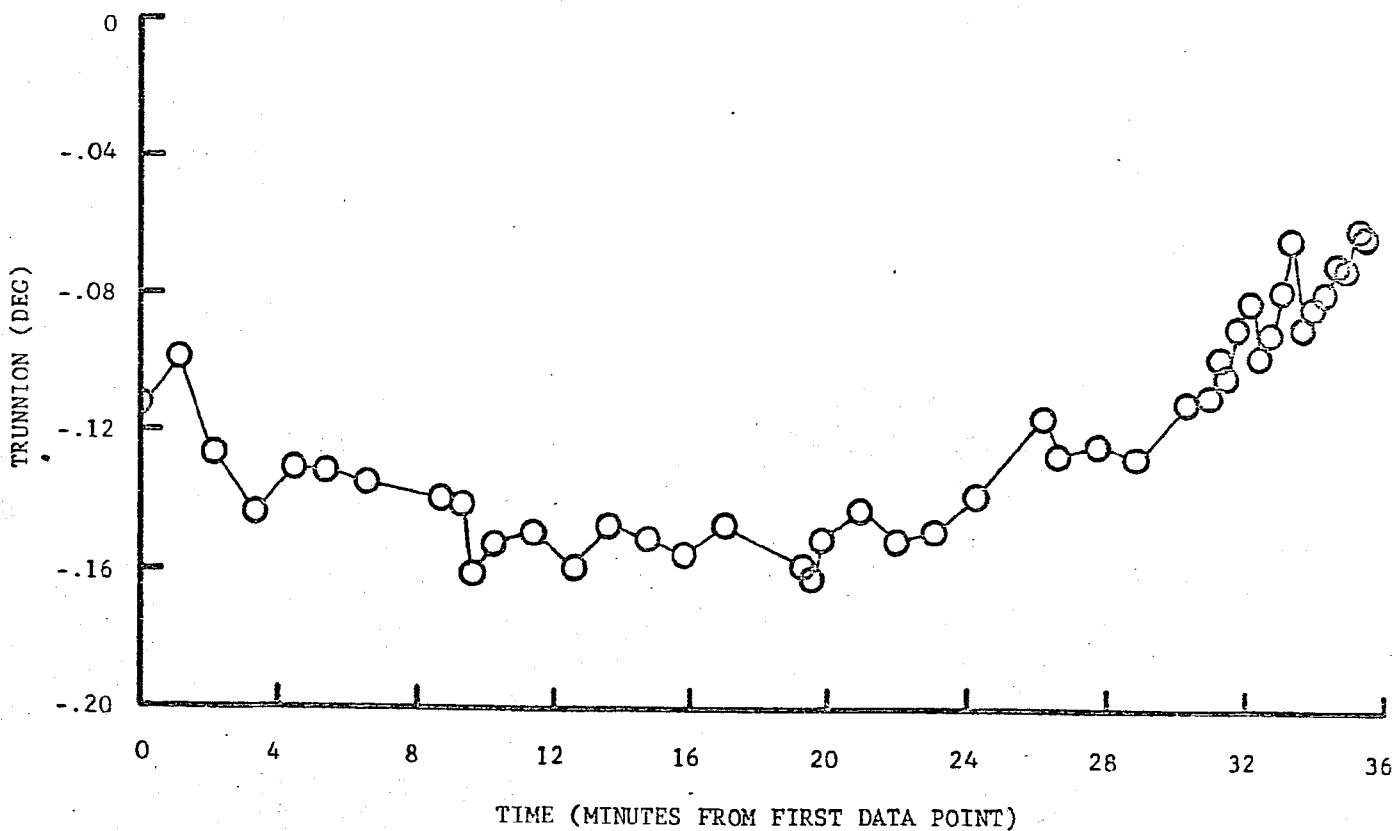
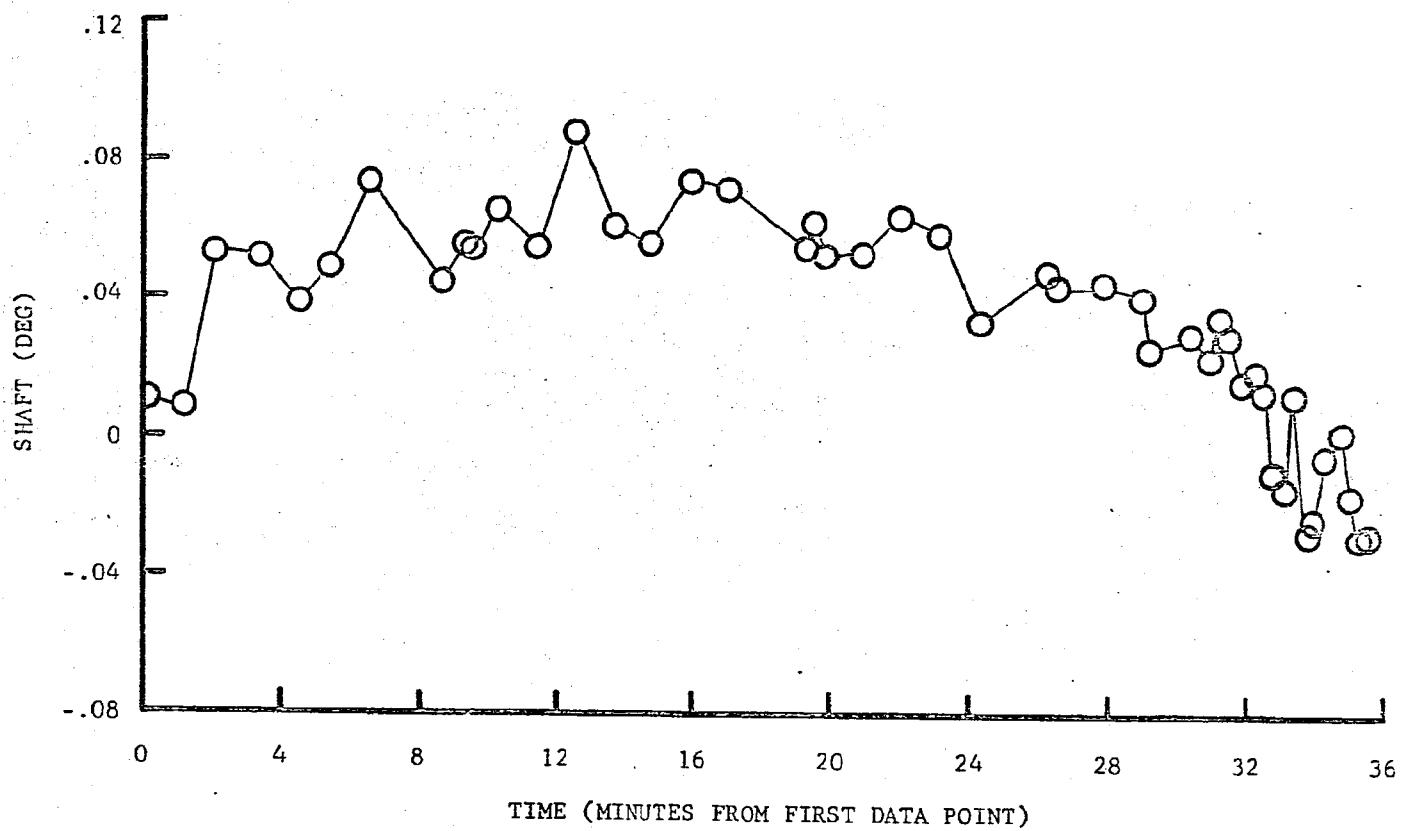


Figure 7-6 Rendezvous Radar Residuals (CDH to TPI)

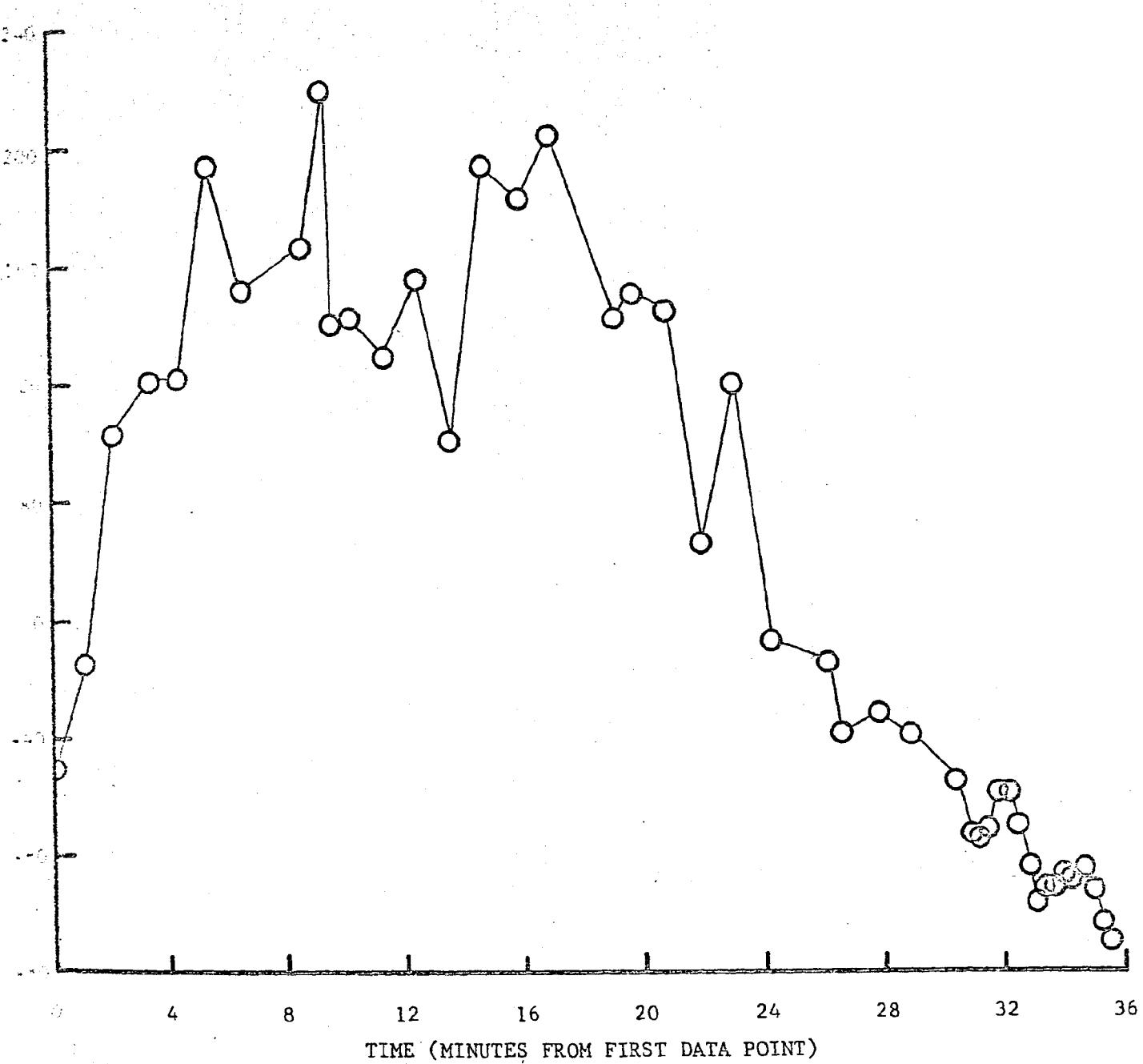


Figure 7-6 Continued

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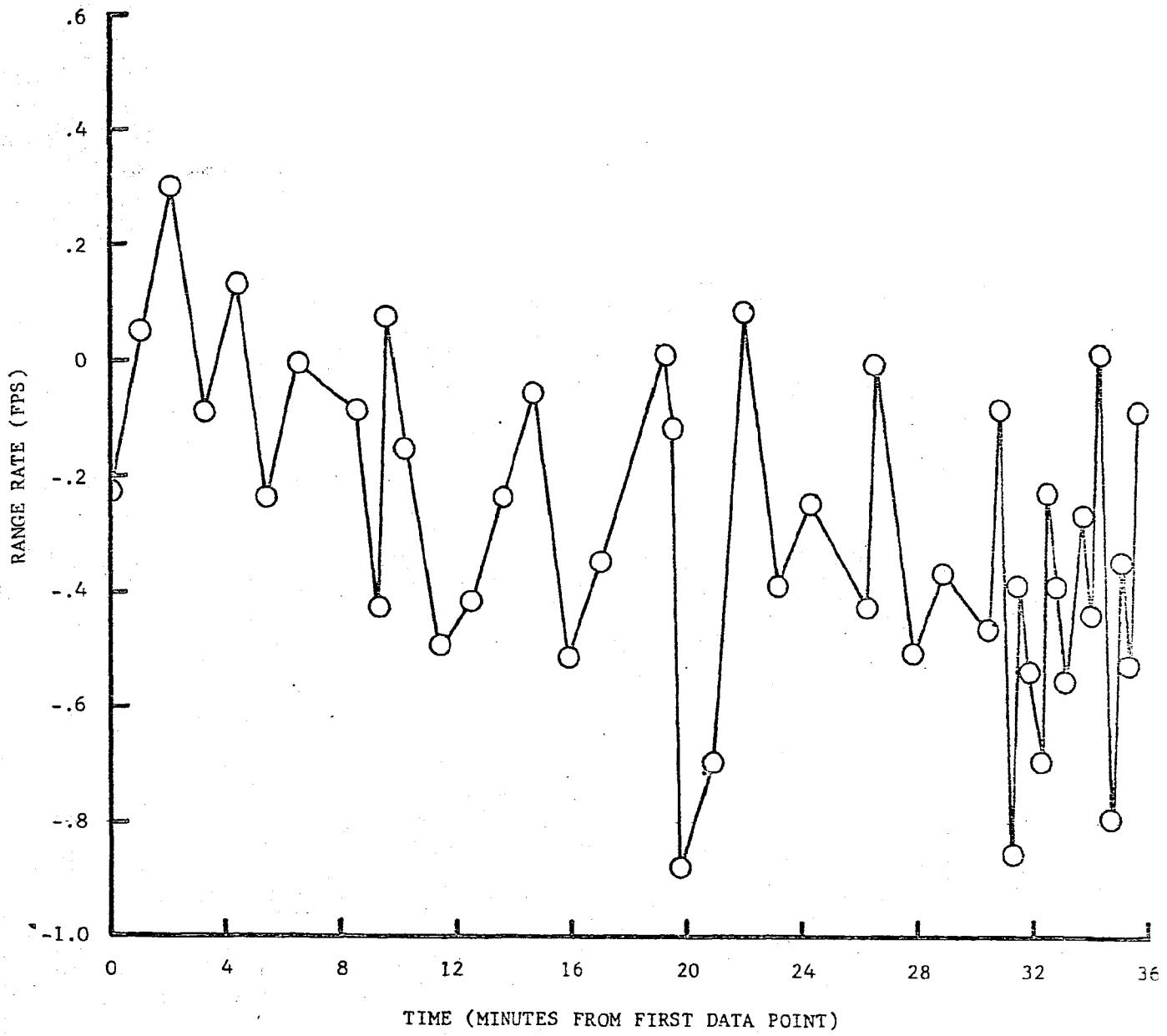


Figure 7-6 Concluded

Table 7.6 Rendezvous Radar Only Solution Residual Statistics

	INS-CSI	CSI-CDH	CDH-TPI	
Shaft	-.00007	.00028	.018	Mean
	.015	.014	.031	S. Dev.
Trunnion	-.00013	.00002	-.0005	Mean
	.0066	.0074	.0085	S. Dev.
Range	.55	.026	2.89	Mean
	39.	37.2	72.45	S. Dev.
Range Rate	-.343	-.105	-.196	Mean
	.187	.314	.304	S. Dev.

The range rate residuals were also of good quality. Mean values were all less than the downlink readout error (.6278 fps).

One sigma noise calculations for shaft, trunnion, and range rate from three missions are plotted as a function of average range in Figures 7-7 through 7-9. These figures show that the Apollo 11 noise estimates compare well with similar estimates from missions 9 and 10. Note that no definite trend is apparent in the angular noise as relative range varies. Figure 7-9 does seem to indicate, however, that the noise estimate for the range measurement does increase as average range increases. The Apollo 11 noise estimates for all three observables appear to be generally smaller than those obtained from previous missions.

#### VHF Ranging Data

Table 7.7 contains a summary of VHF ranging data residual statistics obtained from onboard free flight fits made over the three segments where adequate amounts of data were available. Figures 7-10, 7-11, and 7-12 contain plots of these residuals. Since only two observations were obtained from the insertion to CSI segment, only the DOI to PDI (18 observations), CSI to CDH (17 observations), and CDH to TPI (12 observations) segments are considered.

The VHF ranging data were generally of good quality. As expected, the smallest mean value was obtained during the DOI to PDI period when VHF ranging was the only range data type measuring the distance between vehicles. The mean values become increasingly large as more rendezvous radar data are included in the data set or as the data arcs become coincident in time. This can be seen in the large mean value for the CDH to TPI period. This large mean, however, is still within the bias specification limit of  $\pm 270$  feet.

Figure 7-13 shows that the calculated noise values compare favorably with Apollo 10 results and are relatively constant when compared to those obtained from Apollo 10. The residual statistics listed in Table 7.7 are illustrated graphically in Figure 7-14.

#### Sextant

The residual statistics shown in Table 7.8 indicate that the CSM sextant is a very accurate instrument. Sextant observations were obtained

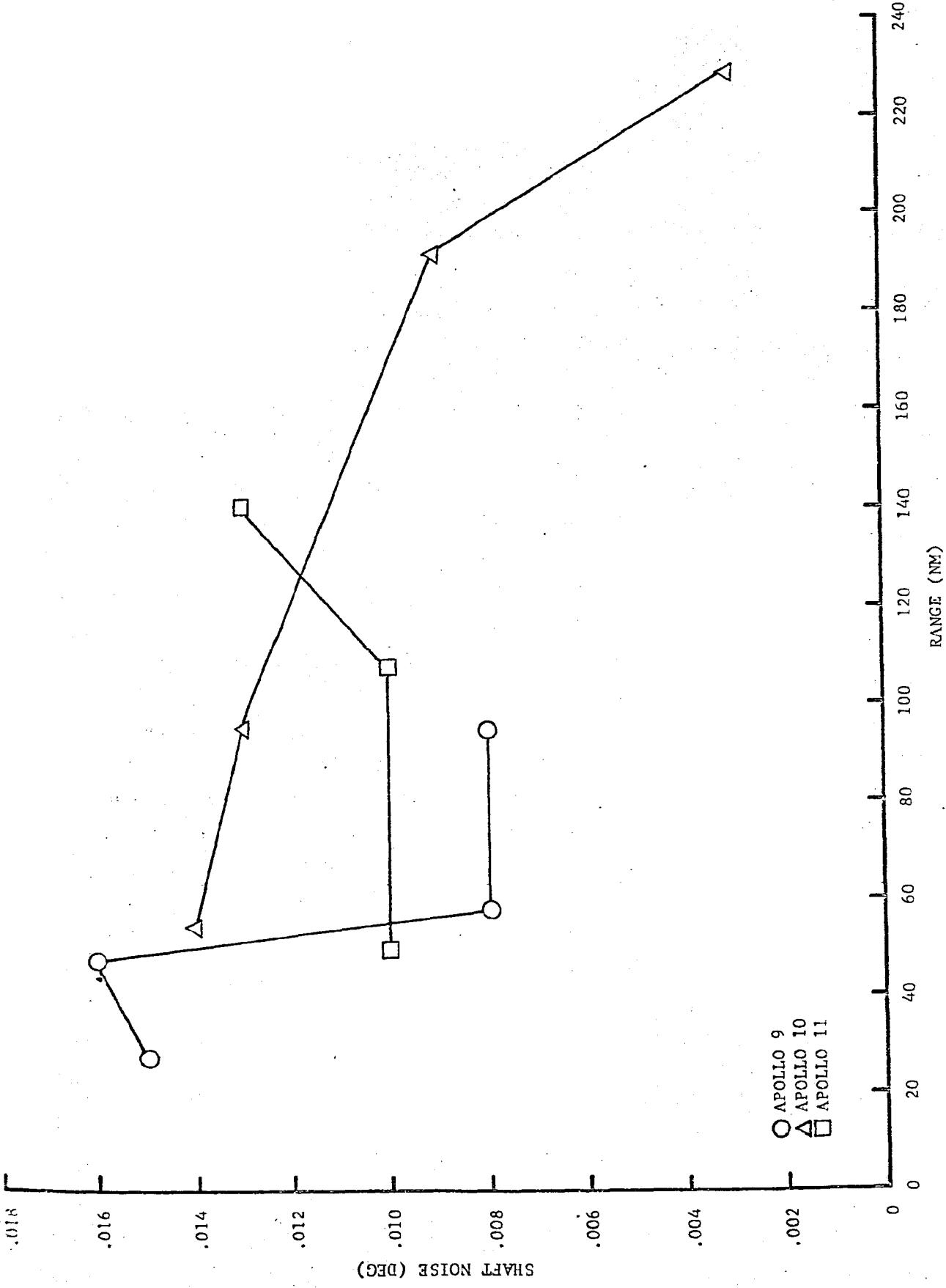


Figure 7-7 Rendezvous Radar Shaft Noise as a Function of Average Range

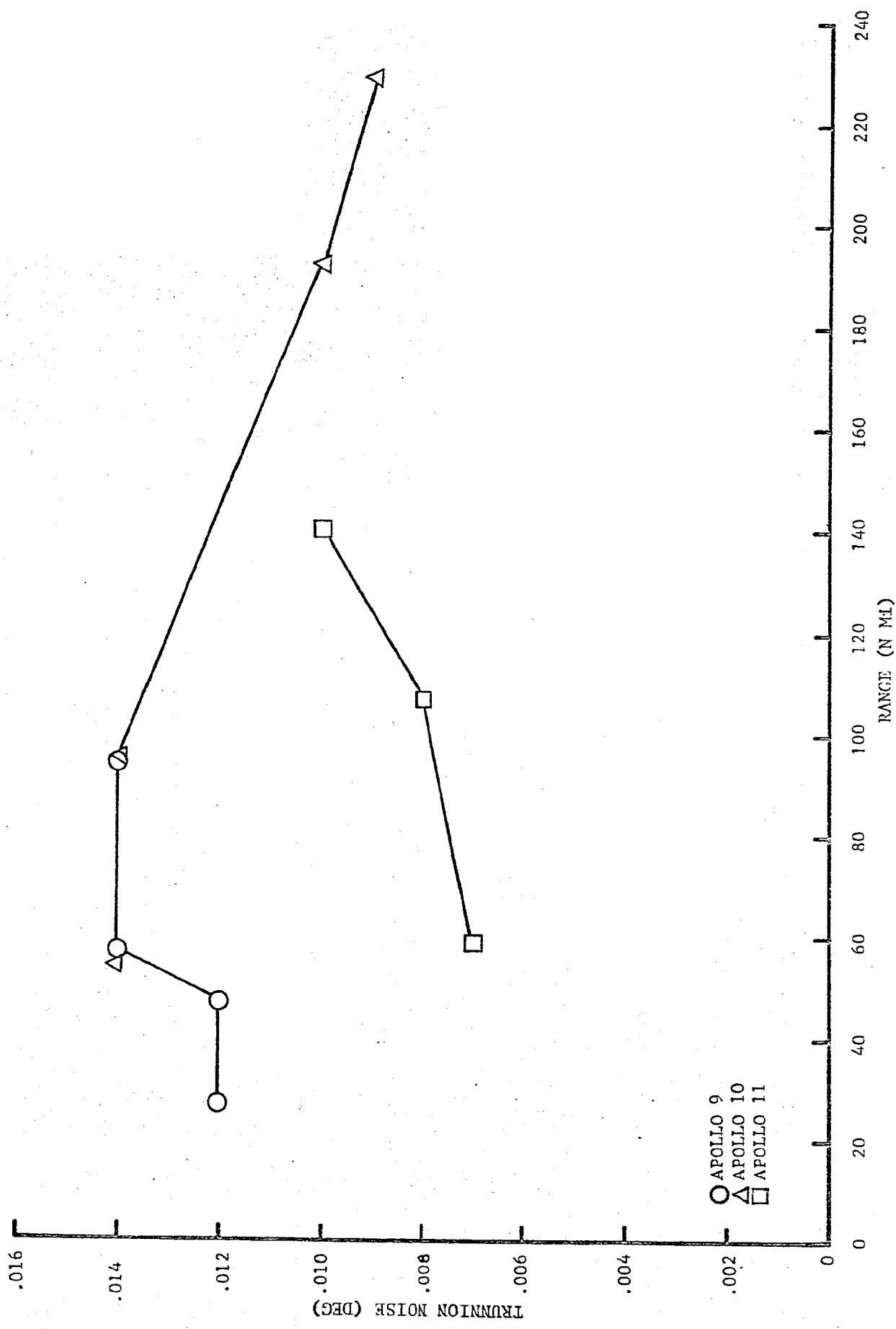


Figure 7-8 Rendezvous Radar Trunnion Noise as a Function of Average Range

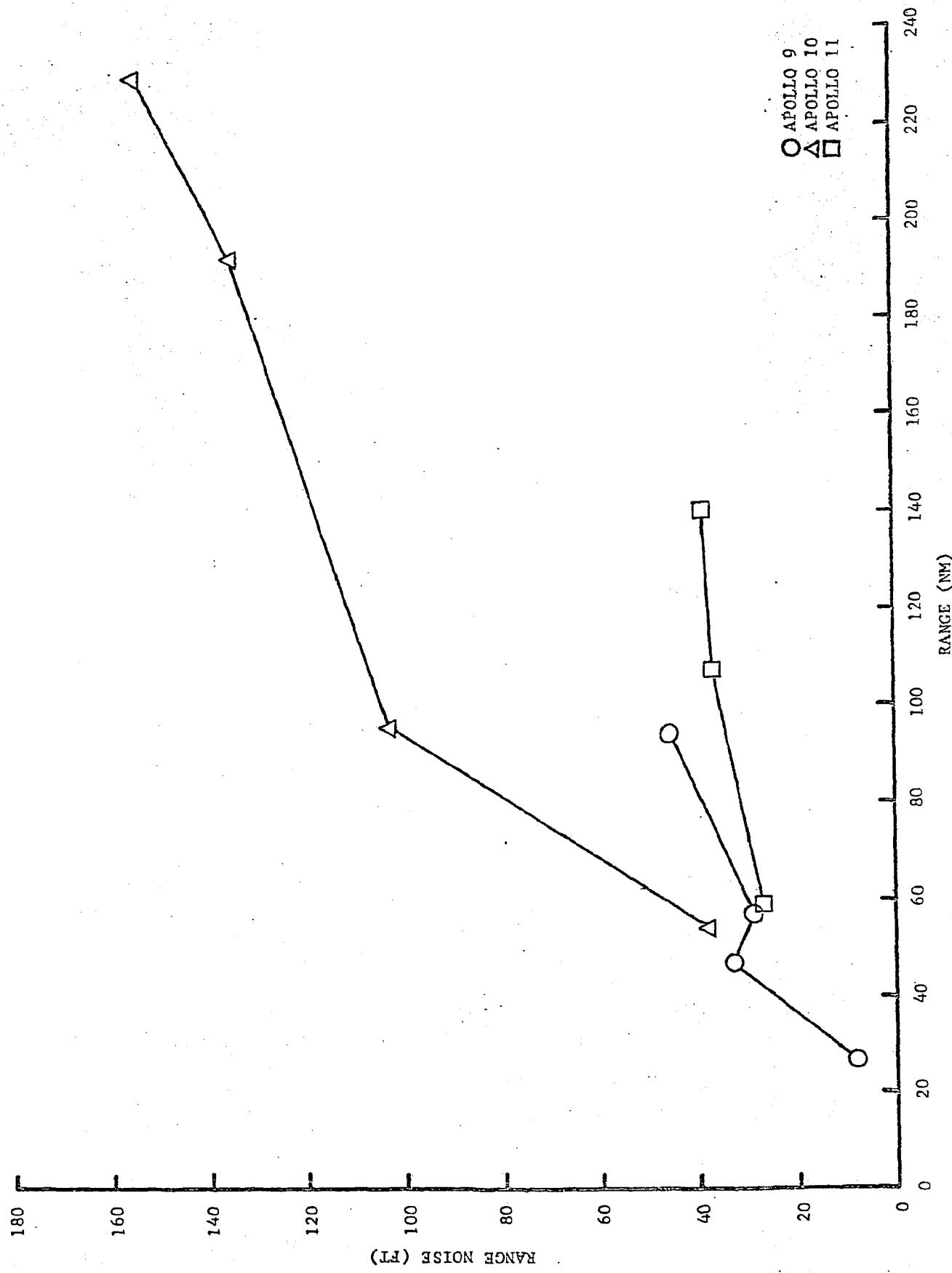


Figure 7-9 Rendezvous Radar Range Noise as a Function of Average Range

**Table 7.7 Summary of VHF Ranging Residual Statistics**

Range (feet)	DOI-PDI	CSI-CDH	CDH-TPI	
	-26.	-86.	-216.	Mean
	74.	104.	48.	S. Dev.
	23.	23.	19.	Noise

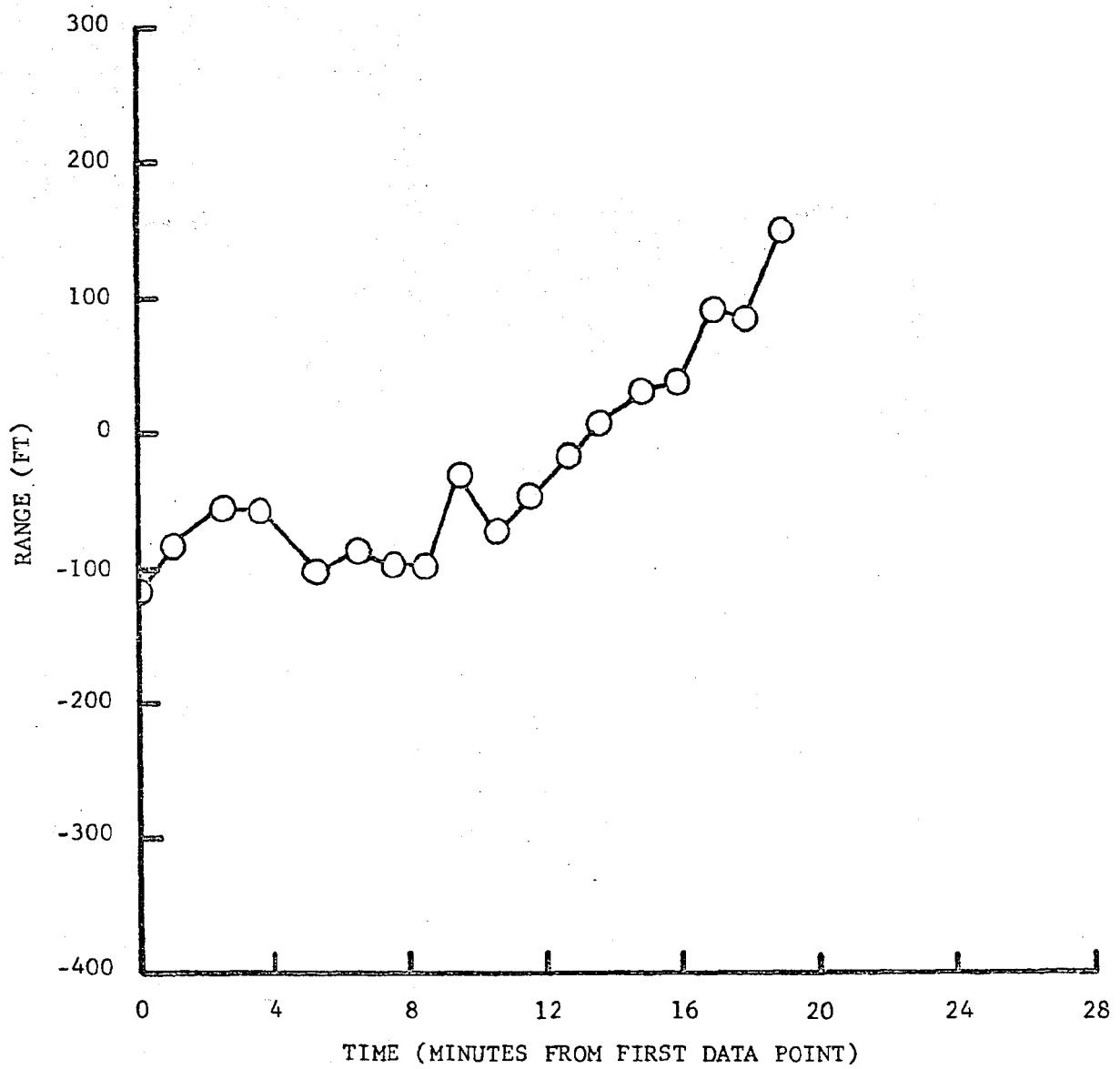


Figure 7-10 VHF Ranging Residuals (DOI to PDT)

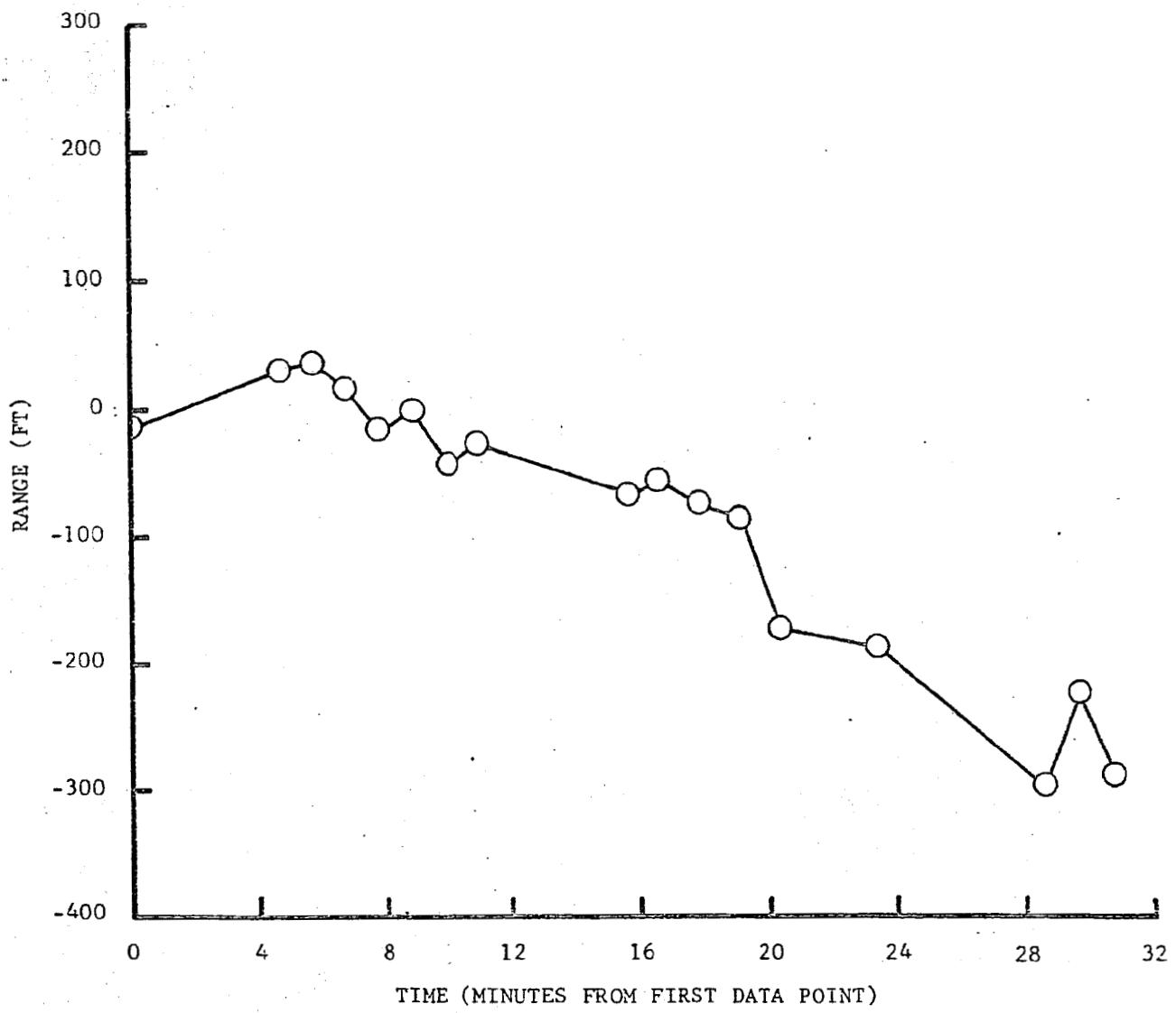


Figure 7-11 VHF Ranging Residuals (CSI to CDH)

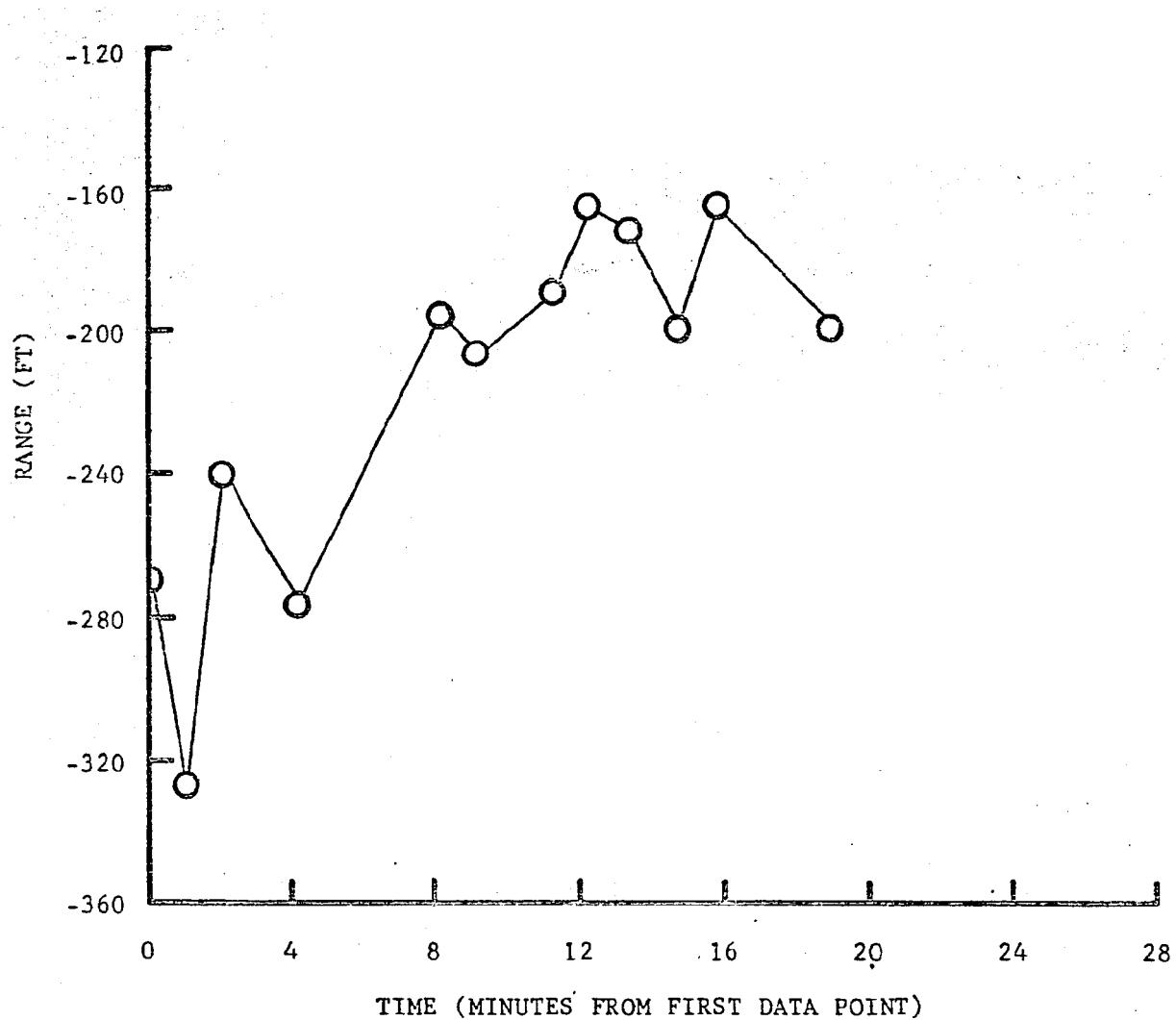


Figure 7-12 VHF Ranging Residuals (CDH to TPI)

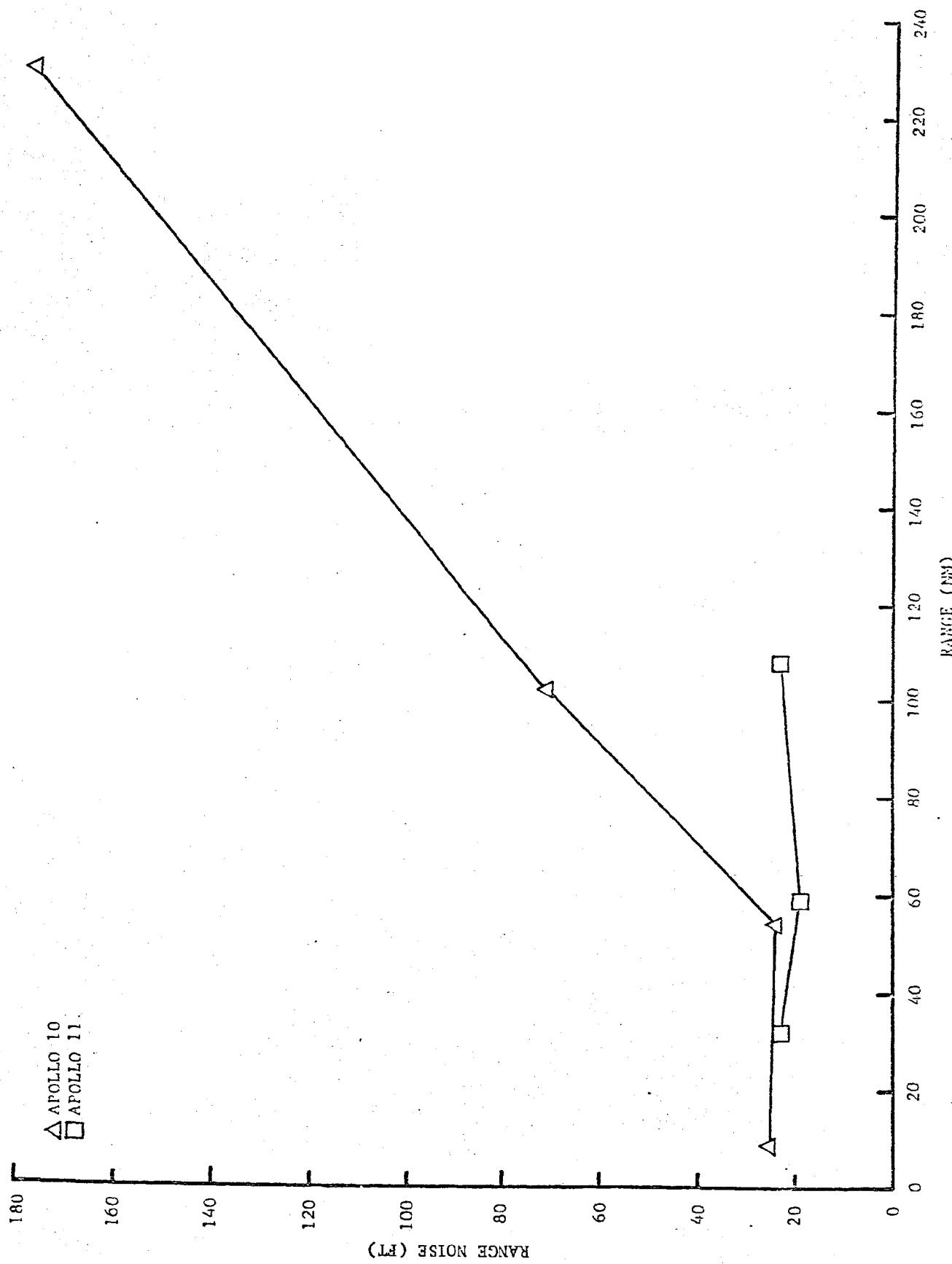


Figure 7-13 VHF Ranging Noise as a Function of Average Range

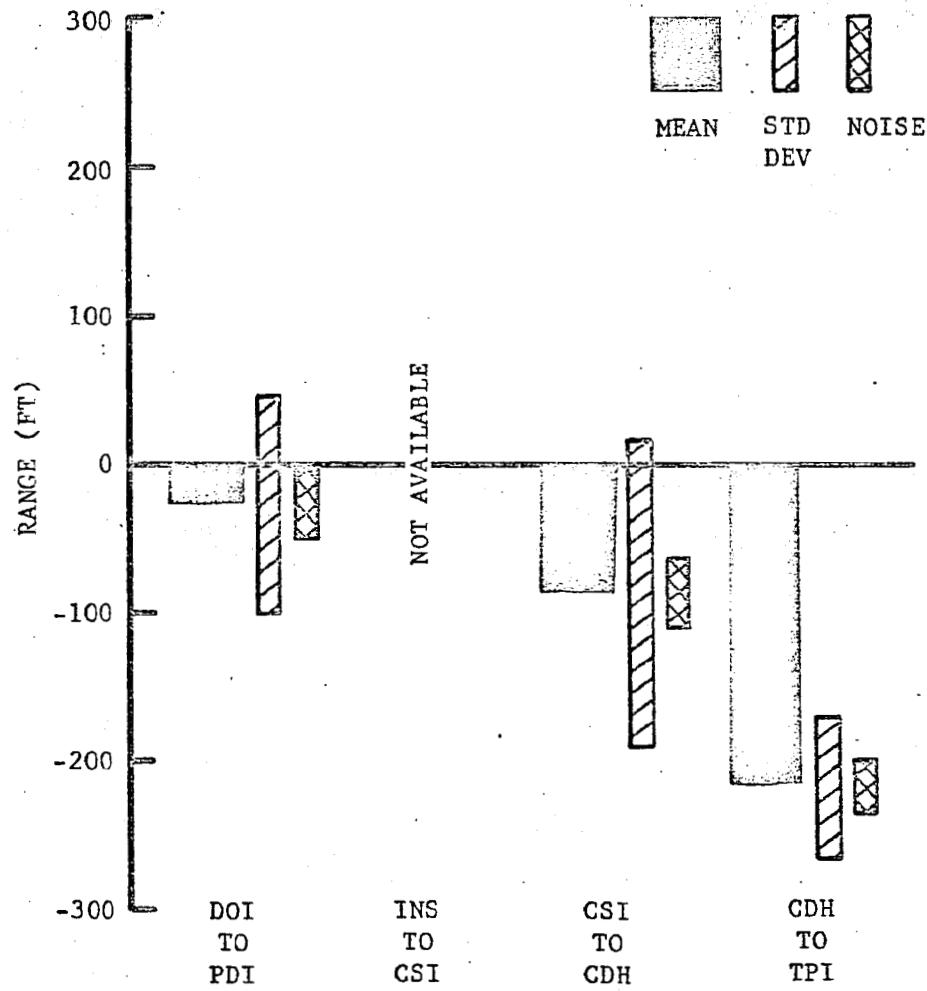


Figure 7-14 VHF Ranging Residual Statistics

Table 7.8 Summary of Sextant Residual Statistics

		Insertion To CSI	CSI To CDH	CDH To TPI	Mean
Shaft (deg)	DOI To PDI	.0005	.0002	.0017	
	.015	.005	.011	.013	S. Dev.
	.014	Insufficient Data	.010	.011	Noise
Trunnion (deg)					Mean
	-.0004	-.000009	.0004	-.001	
	.004	.003	.006	.008	S. Dev.
	.003	Insufficient Data	.006	.011	Noise

in four of the free flight segments; DOI to PDI (13 sightings), insertion to CSI (4 sightings), CSI to CDH (21 sightings), CDH to TPI (10 sightings).

The close agreement of the standard deviations with the noise estimates and the very small means listed indicate that there are essentially no biases in either angle.

The residual patterns (Figures 7-15 through 7-18) are very well behaved. The random noise estimates (Figure 7-19) compare well with rendezvous radar angular noise estimates and no trend can be identified with respect to average range. Note the good agreement with the Apollo 9 noise estimates plotted in Figure 7-19.

#### Onboard Tracking Data Consistency

In order to determine the consistency of trajectories reconstructed from onboard tracking data with those obtained from MSFN tracking data, state vector comparisons were made over the propagation intervals. These comparisons were made in a UVW-type coordinate system and the results are presented in graphic form. In the figures presented, RZ is the negative of the U or radial component, RX is the V or downrange component, and RY is the negative of the W or crossrange component of a system centered at the CSM. RXD, RYD and RZD are the respective velocities.

Three LM trajectories were obtained for the period from DOI to PDI. Figure 7-21 plots (as a function of time) the out-of-plane component of LM position relative to the CSM for a MSFN free flight trajectory, an onboard data free flight trajectory, and the final BET (combined high speed MSFN and onboard tracking data). It can be seen that the addition of onboard tracking data drastically improves this component of position. Figures 7-22 and 7-23 show the differences between relative trajectories obtained from the MSFN and from the onboard tracking free flight fits. There are large differences in the trajectories which are primarily due to the poor quality of the MSFN free flight fit, but the comparisons do show that the downrange and radial components compare fairly well inside the MSFN data arc.

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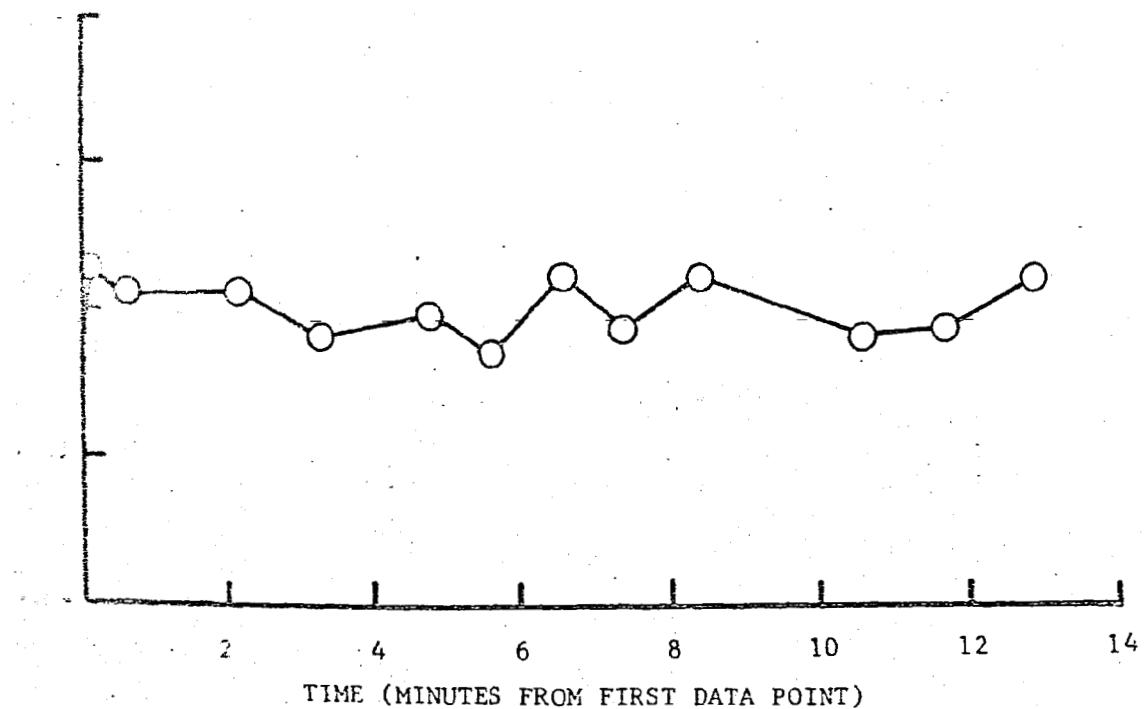
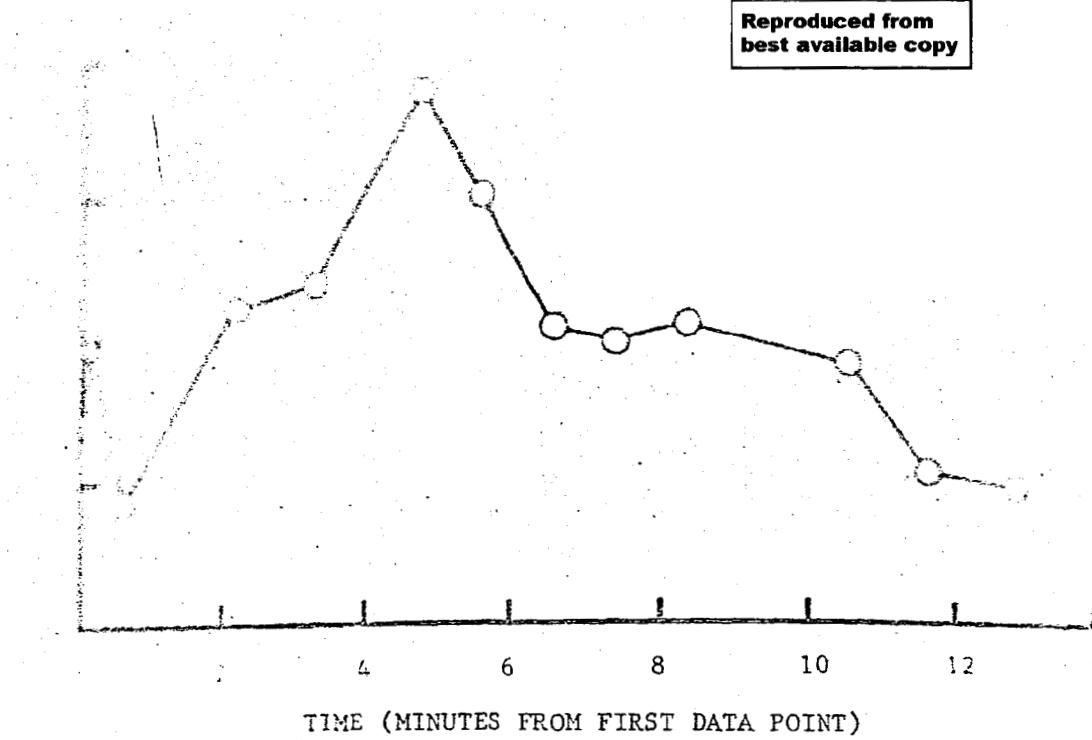


Figure 7-15 Sextant Residuals (DOI to PDI)

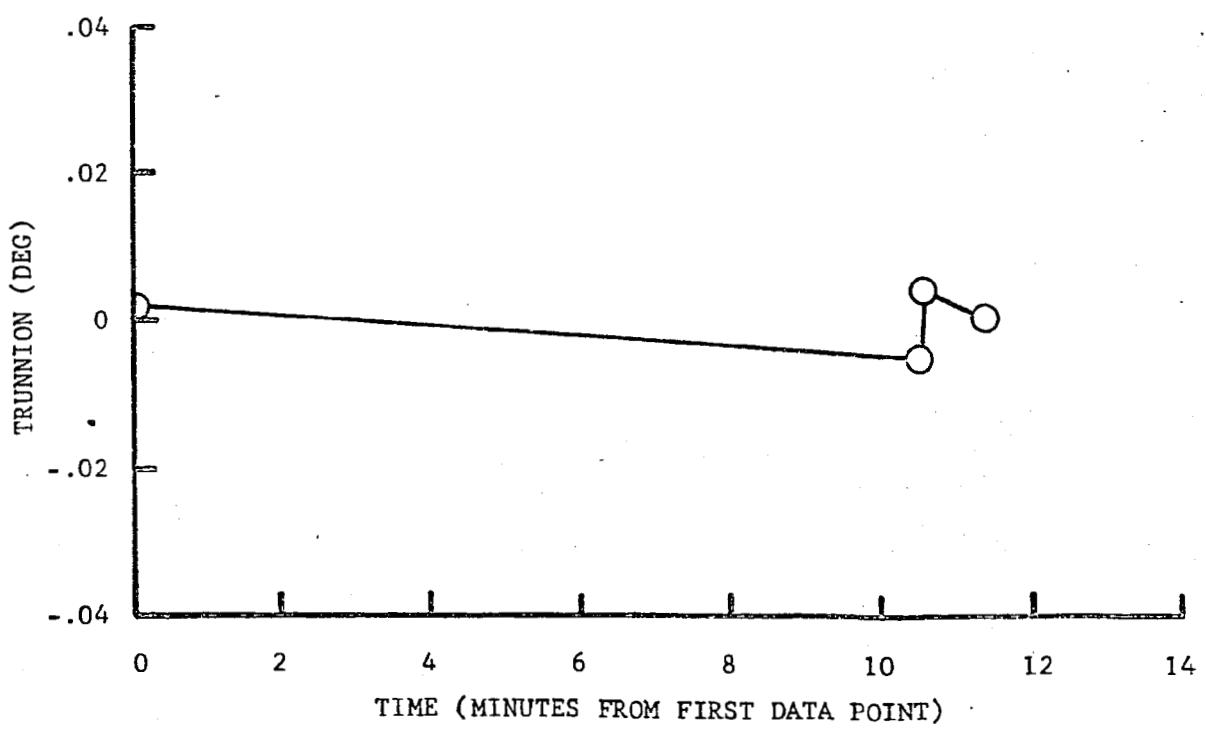
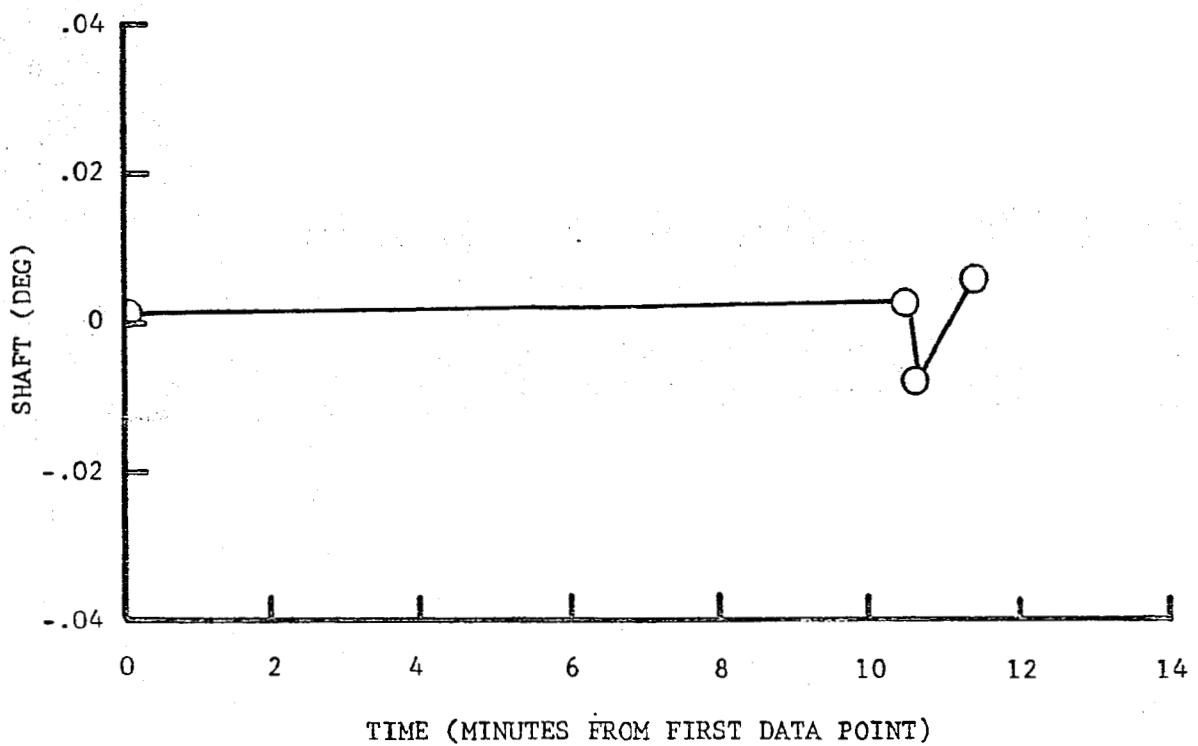


Figure 7-16 Sextant Residuals (Insertion to CSI)

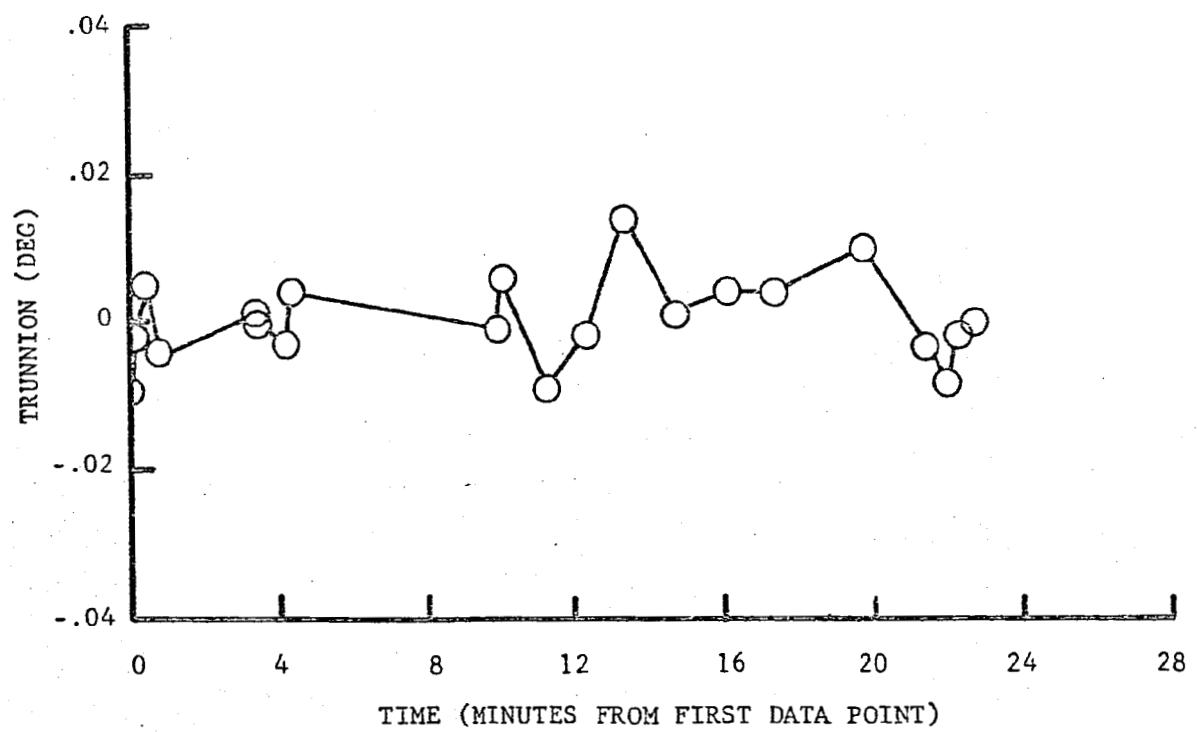
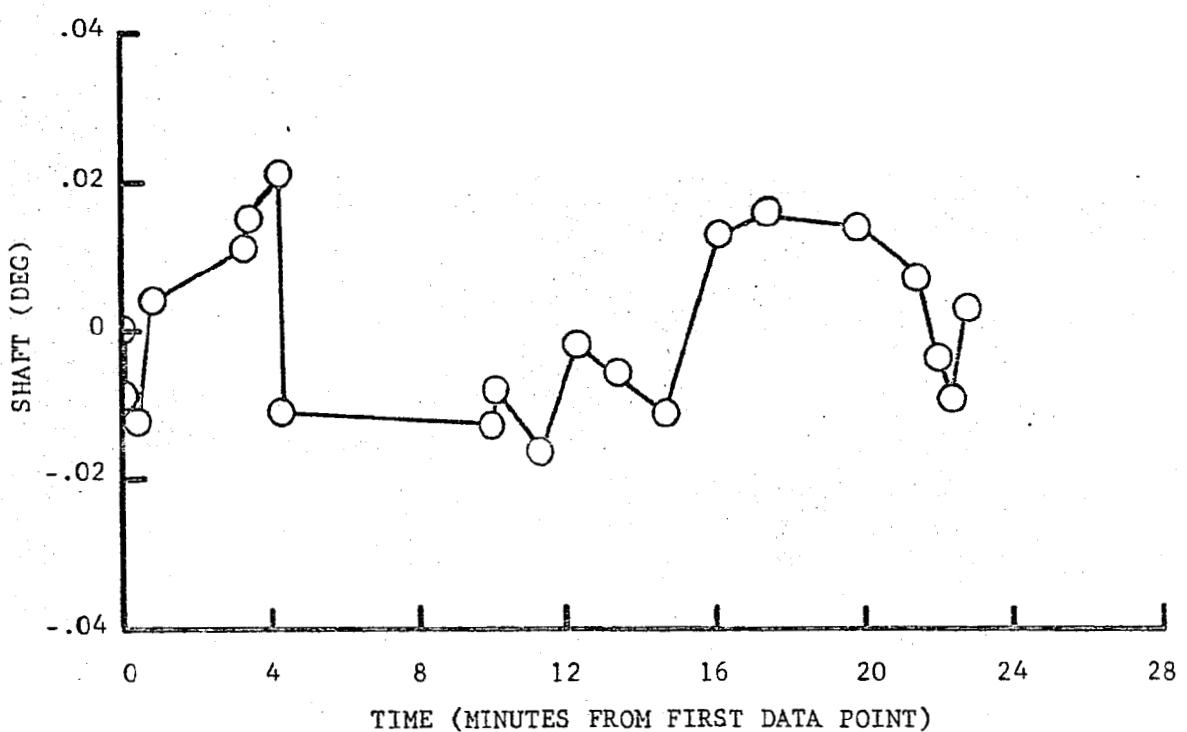


Figure 7-17 Sextant Residuals (CSI to CDH)

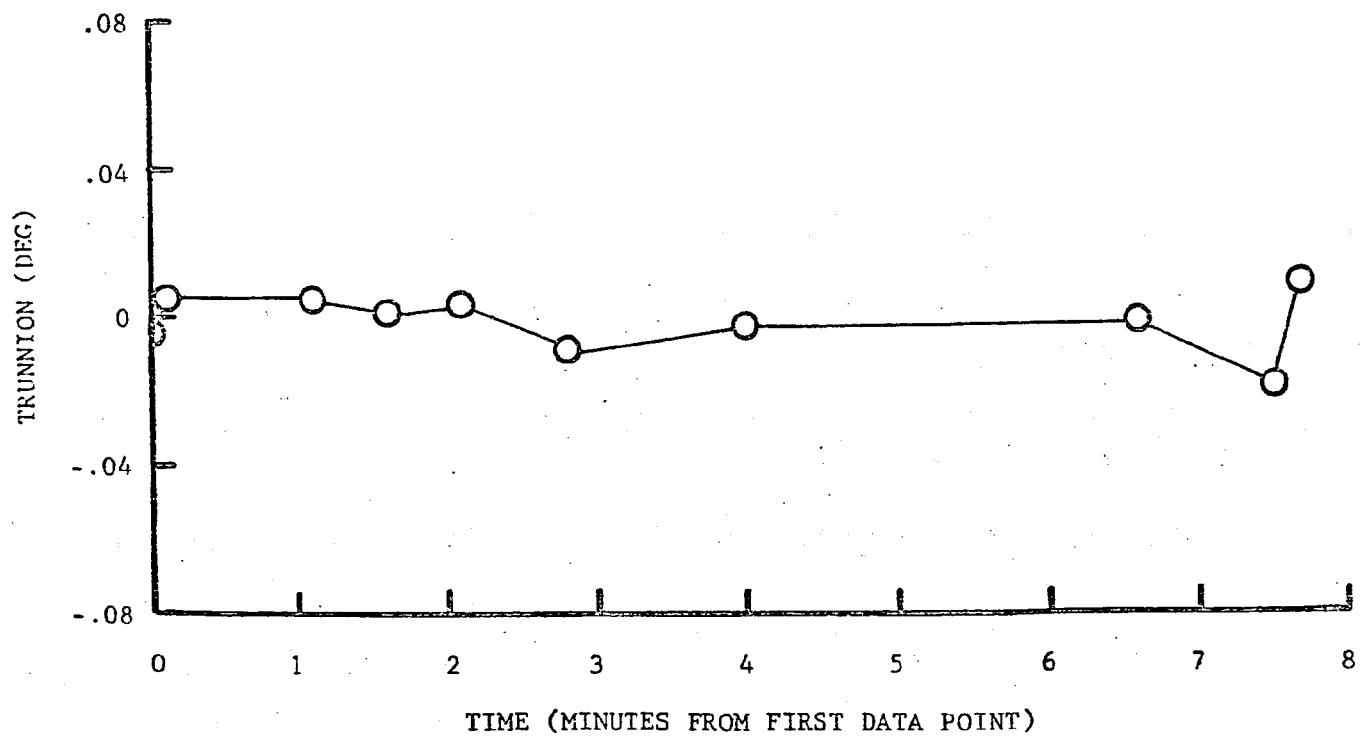
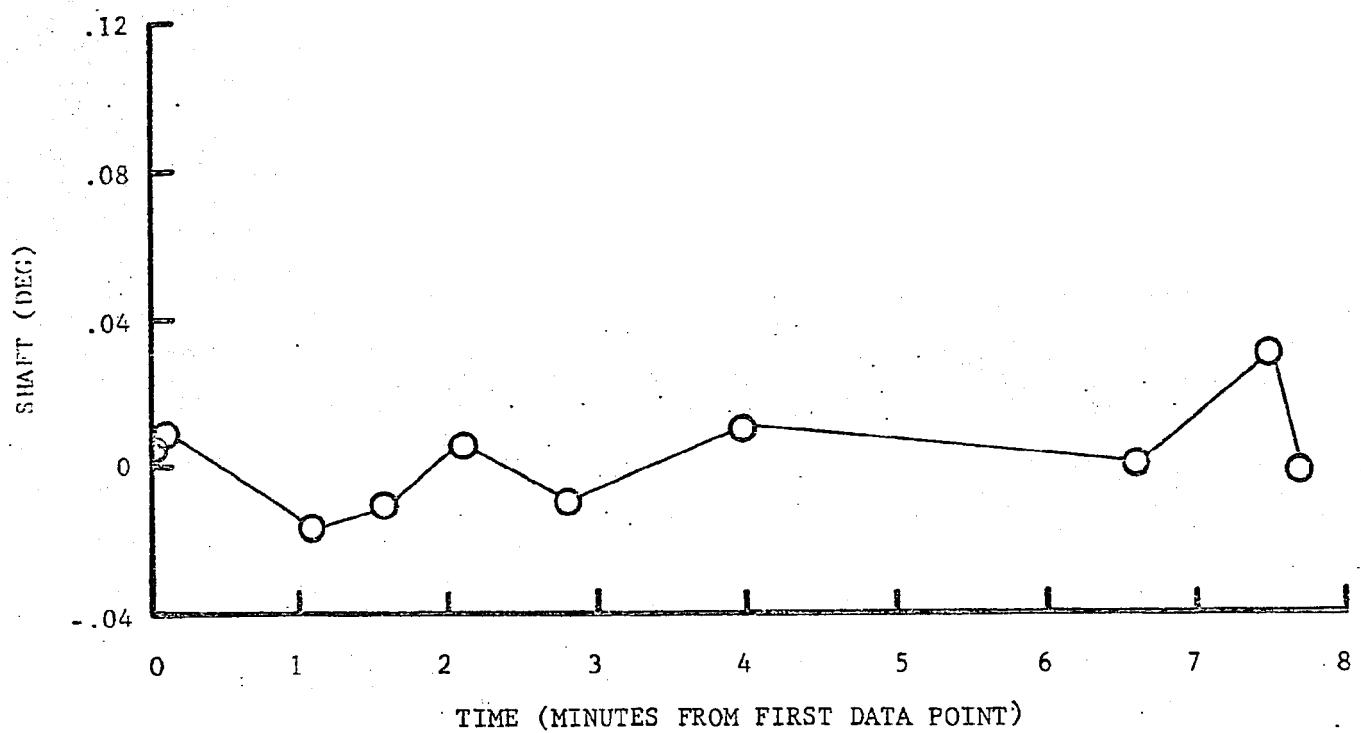


Figure 7-18 Sextant Residuals (CDH to TPI)

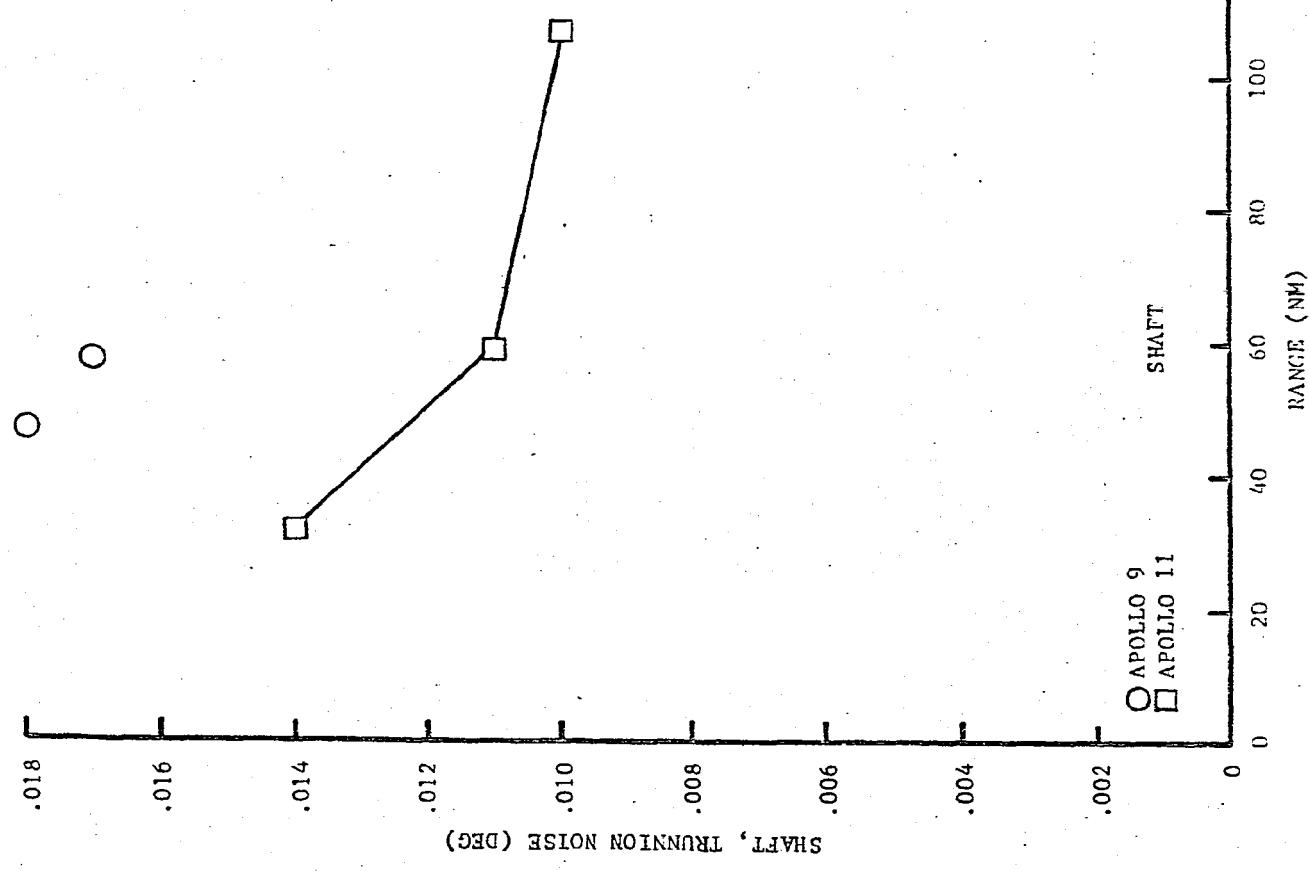


Figure 7-10. Constant Amplitude Random Noise as a Function of Range.

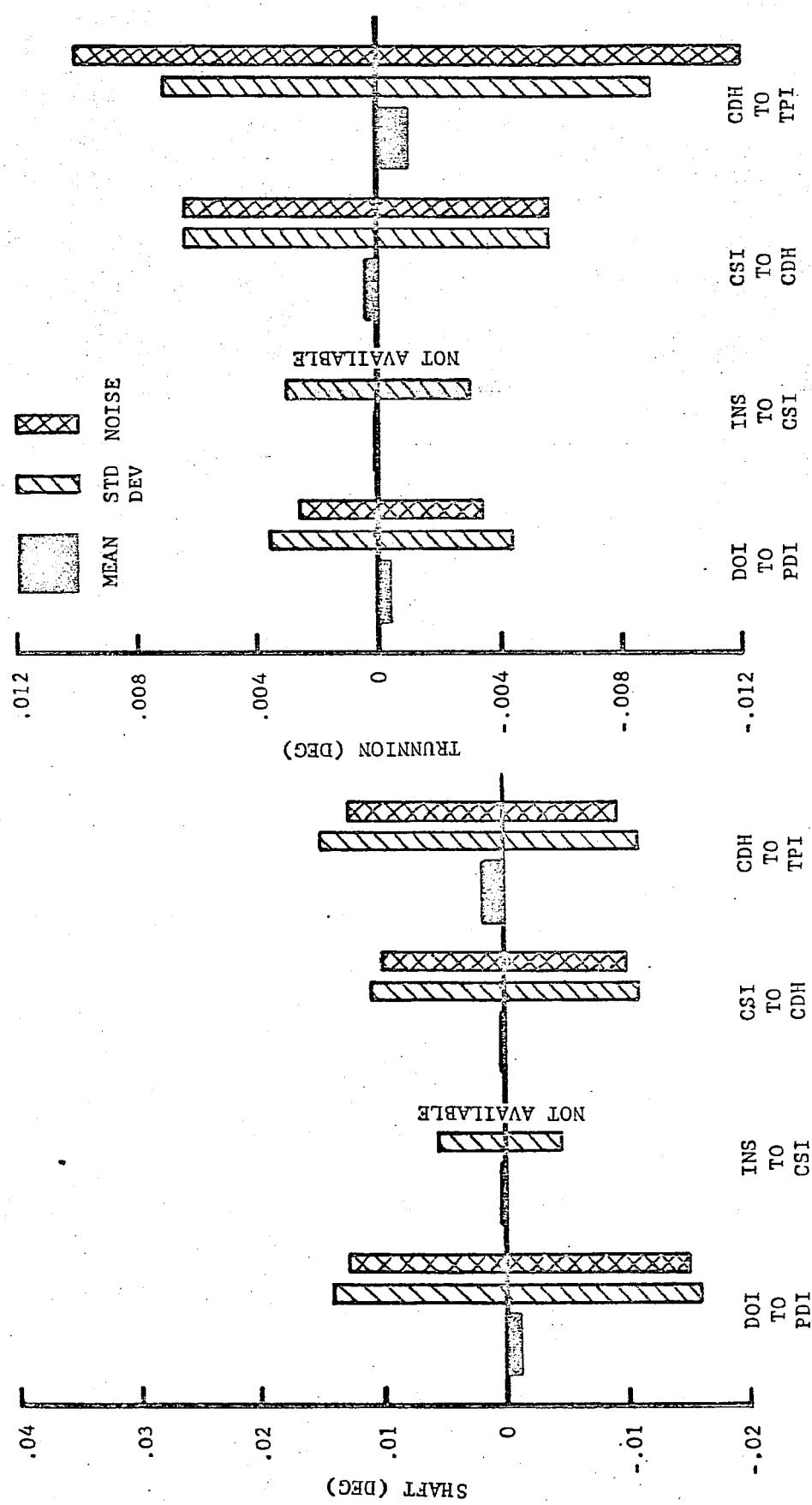


Figure 7-20 Sextant Residual Statistics

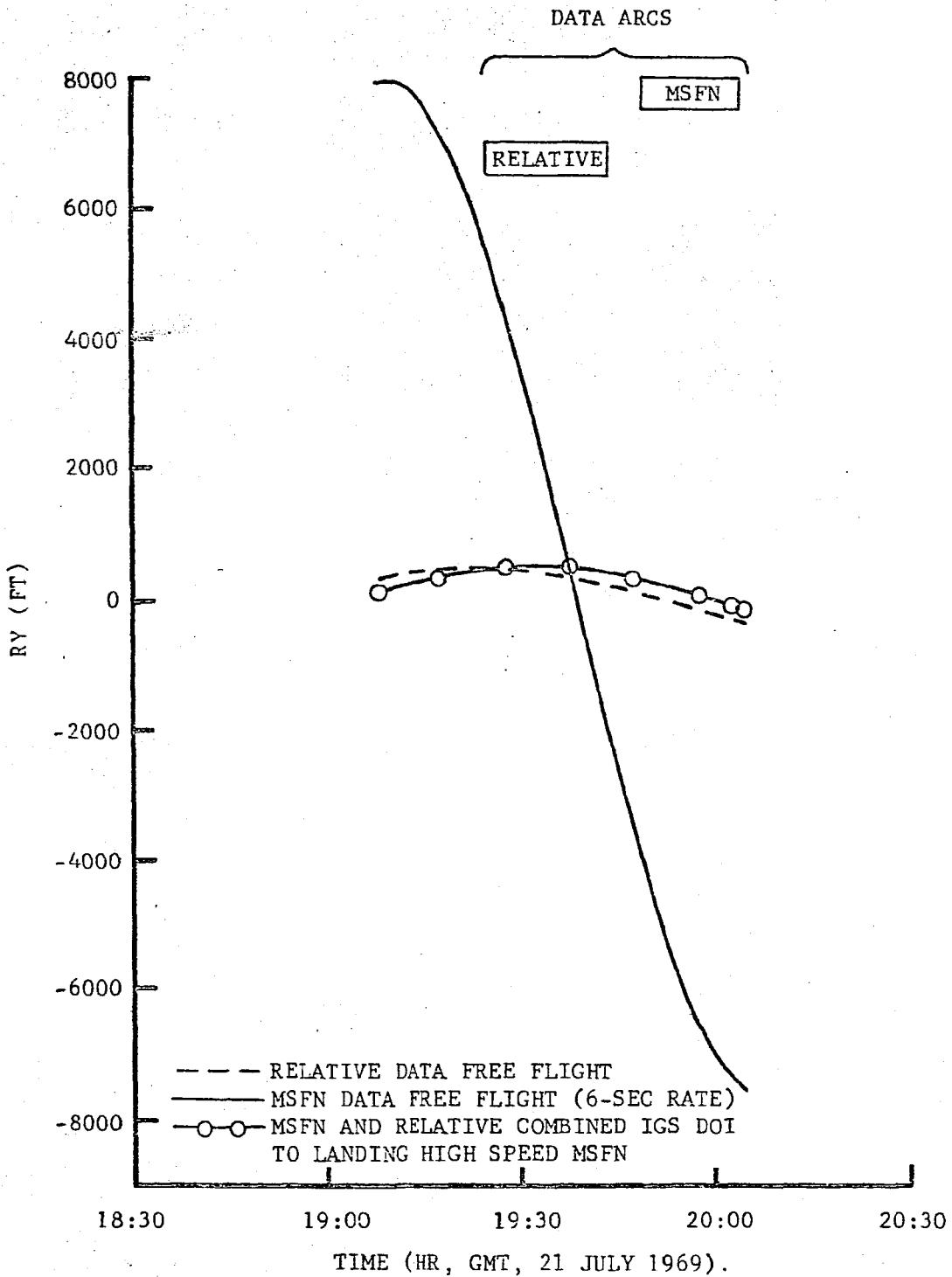
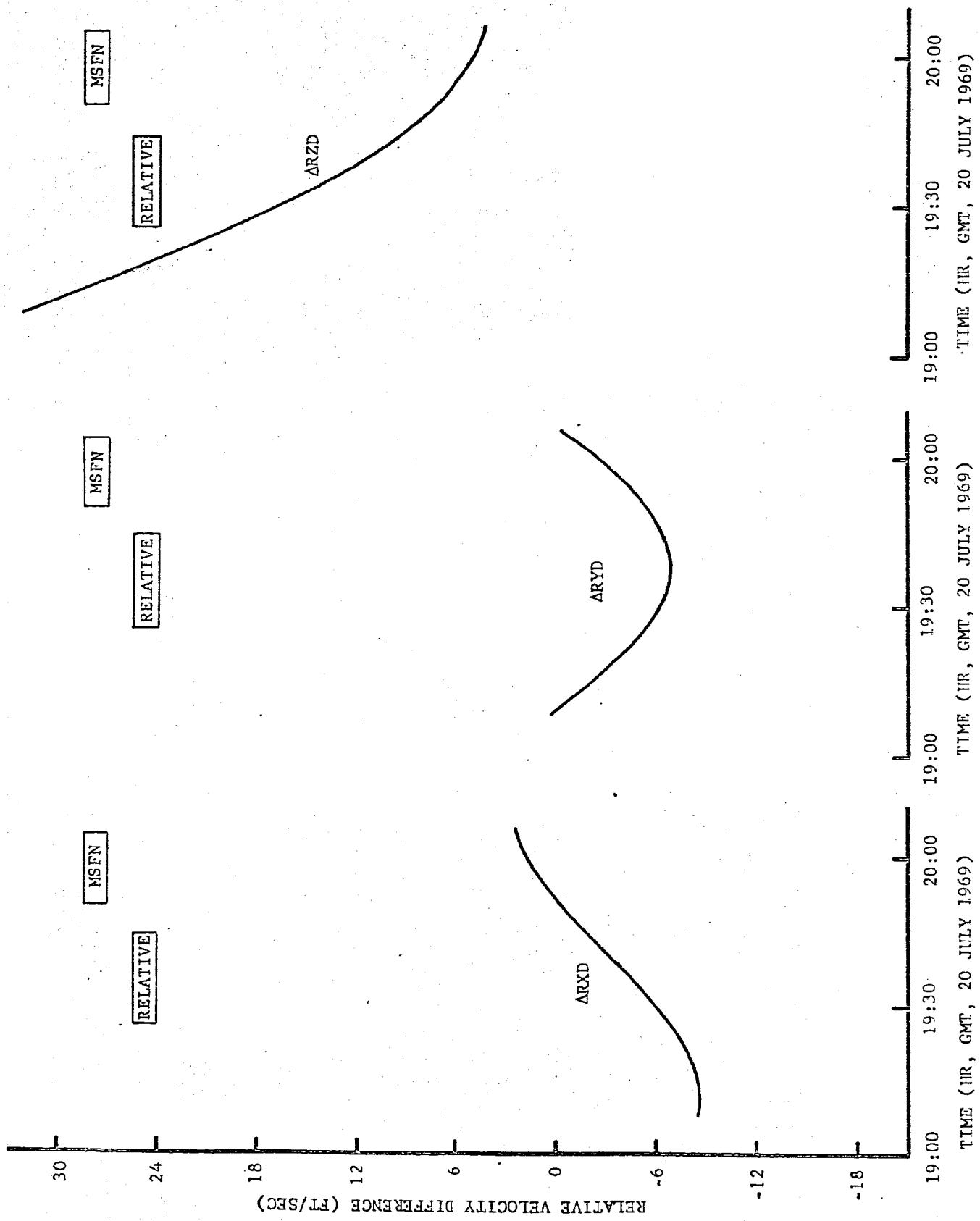


Figure 7-21 Out-of-Plane Component of LM Position Relative to CSM (DOI to PDI)



FIGURE 7-22 Differences Between Position Components of Relative Trajectories (DOI to PDI)



RELATIVE VELOCITY DIFFERENCE (FT/SEC)

Figures 7-24 and 7-25 show the differences between position and velocity components of the two relative trajectories obtained for the Insertion to CSI period. These trajectories were obtained from a MSFN (low speed) data free flight fit and an onboard data free flight fit. Note that the differences between the RX and RZ components are nominal whereas the RY component (crossrange) is large. This characteristic is expected since onboard data fits produce a much better relative trajectory in the out-of-plane sense. Figure 7-26 illustrates the better crossrange position obtained from onboard data fits.

Figure 7-27 illustrates that the trajectory obtained from onboard tracking data eliminates three to four thousand feet of relative cross-range error which the MSFN data could not. The phase differences evident in Figures 7-26 and 7-27 result primarily from differences in the determination of the right ascension of the ascending node of the orbits. The results of this phase difference are very evident in the plot of the differences between out-of-plane position components of trajectories derived from MSFN and from onboard data (Figure 7-28 ( $\Delta$ RY)).

The important feature to note in these figures is that the trajectories based on onboard tracking data eliminate a large portion of the cross-range error present in independent MSFN fits for both vehicles. It is also interesting to note that in the out-of-plane position curves shown in Figures 7-26 and 7-27, that the trajectories produced from relative data match across the CSI burn much more closely than the fits produced from MSFN data. While this agreement does depend, to some extent, on a good match between the CSM trajectories, the relative data did produce a more continuous trajectory in the out-of-plane sense from one independent fit to another.

Despite the large out-of-plane differences, it can be seen that trajectories produced from onboard tracking data are generally consistent with MSFN based fits, especially in overlapping data arcs (Figures 7-24 and 7-28). Therefore, because of better characteristics in the relative sense, trajectories produced from relative tracking data are more suitable for detailed rendezvous analysis purposes.

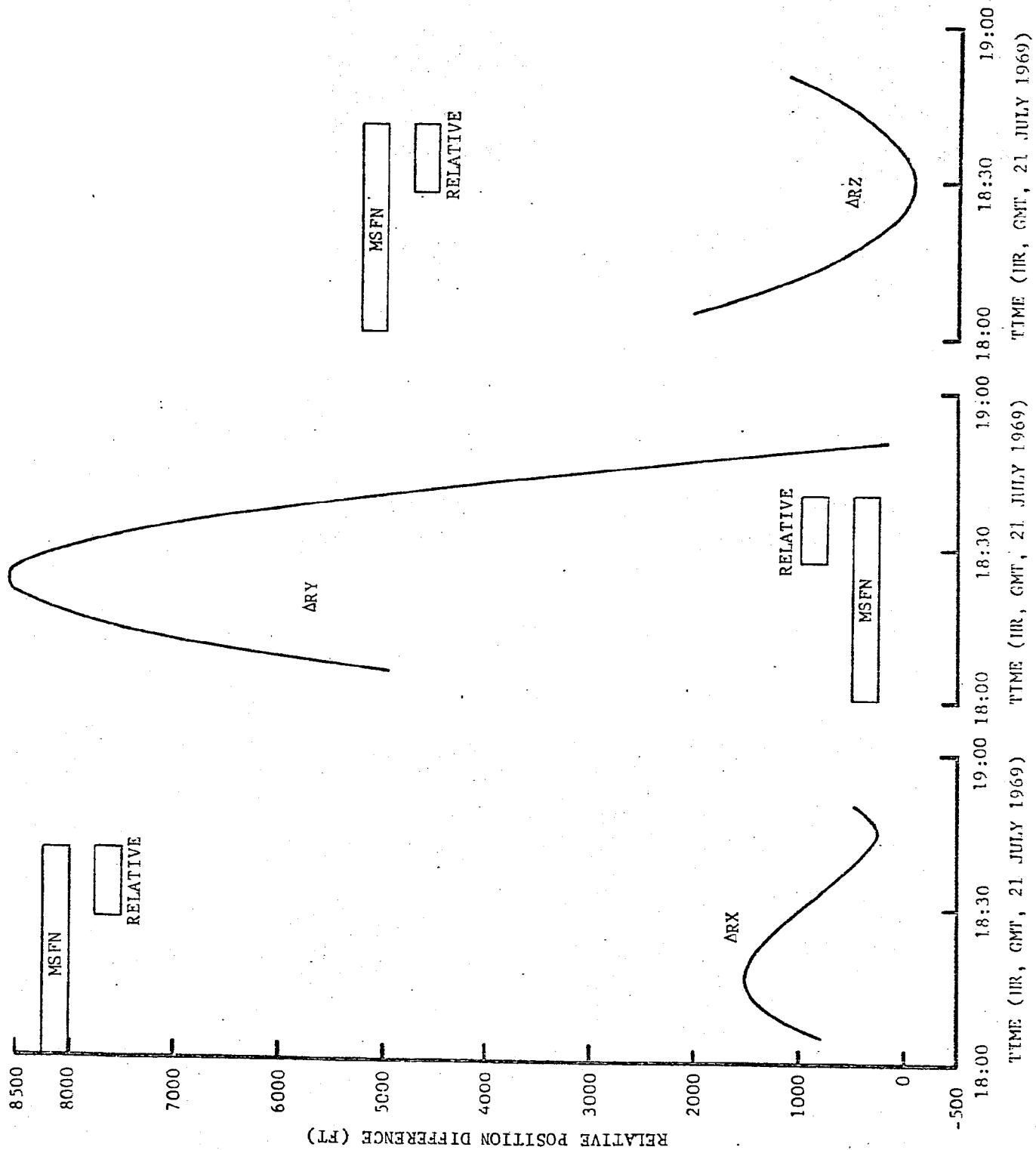


Figure 7-24 Differences Between Position Components of Relative Trajectories (Insertion to CST)

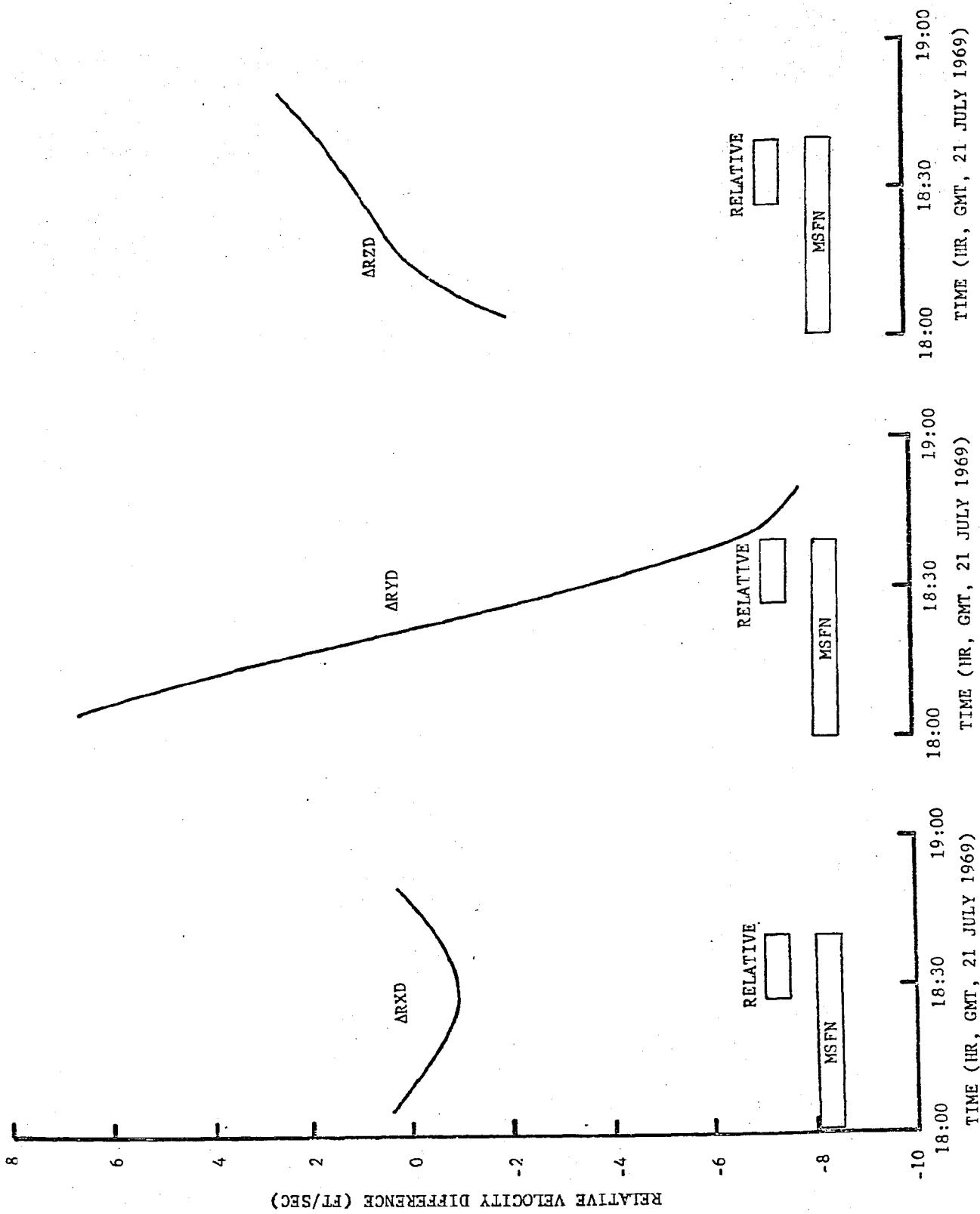


Figure 7-25 Differences Between Velocity Components of Relative Trajectories (Insertion to CSI)

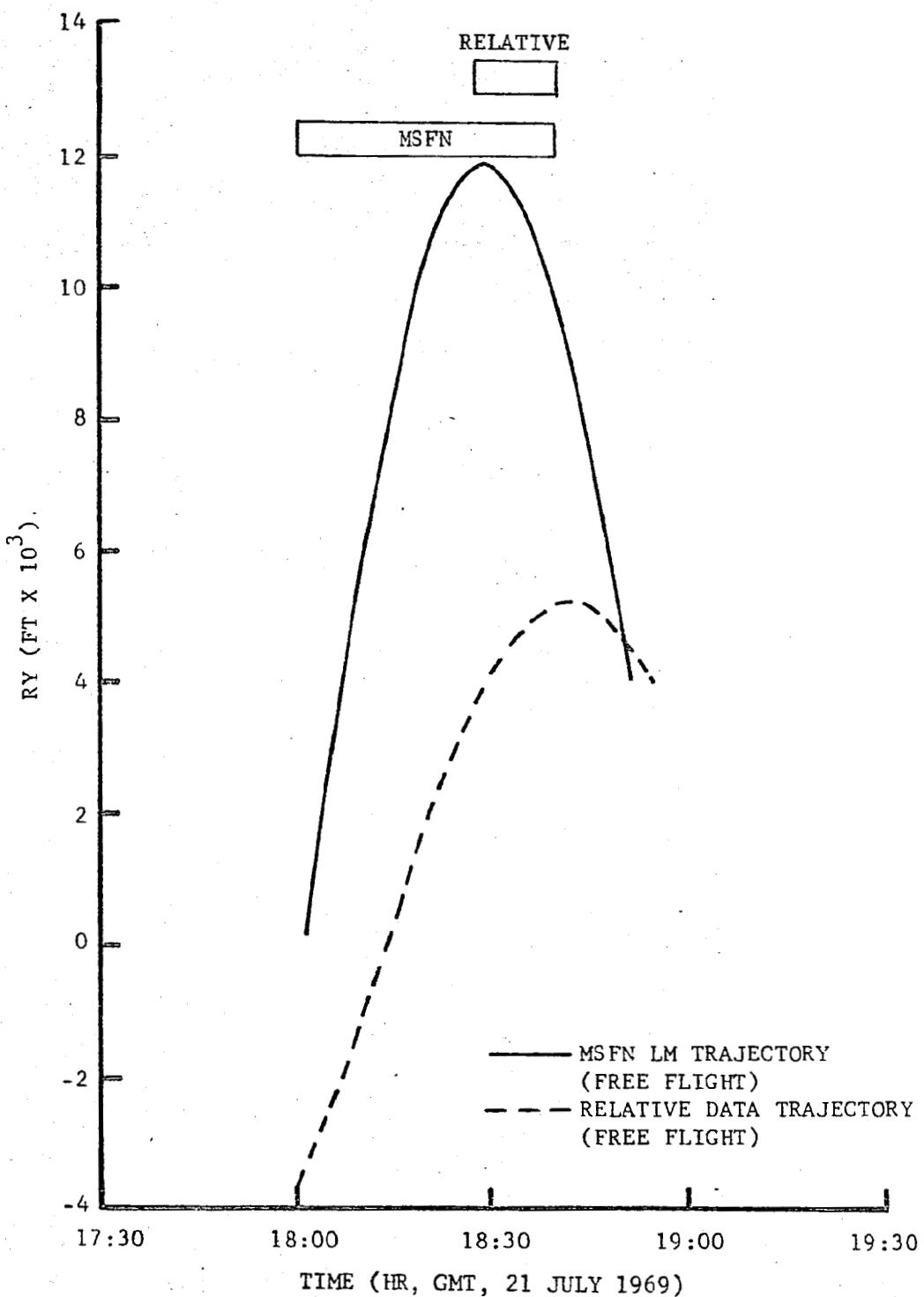


Figure 7-26 Out-of-Plane Component of LM Position Relative to CSM (Insertion to CSI)

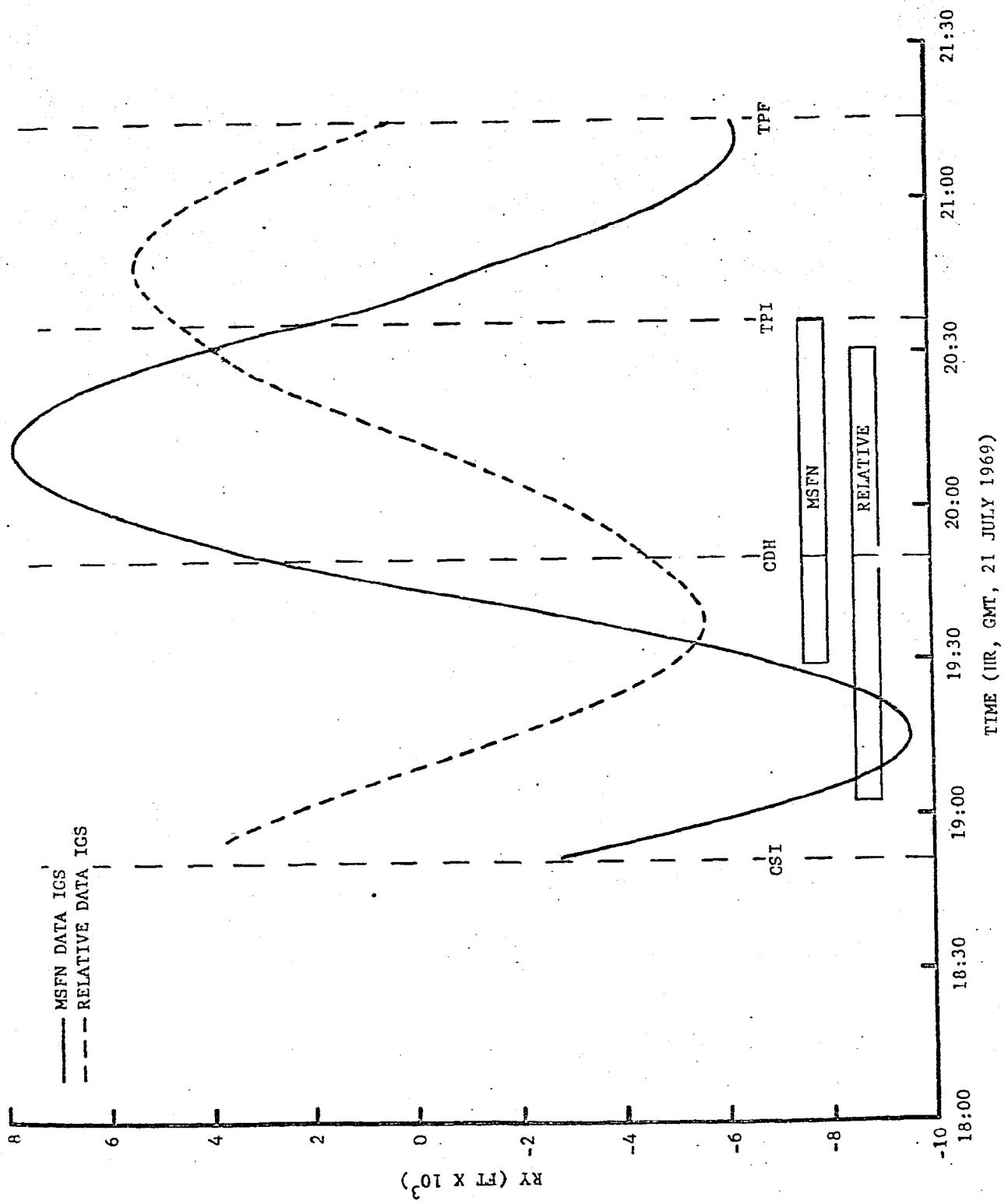


Figure 7-27 Out-of-Plane Component of LM Position Relative to CSM (CSI to TPF)

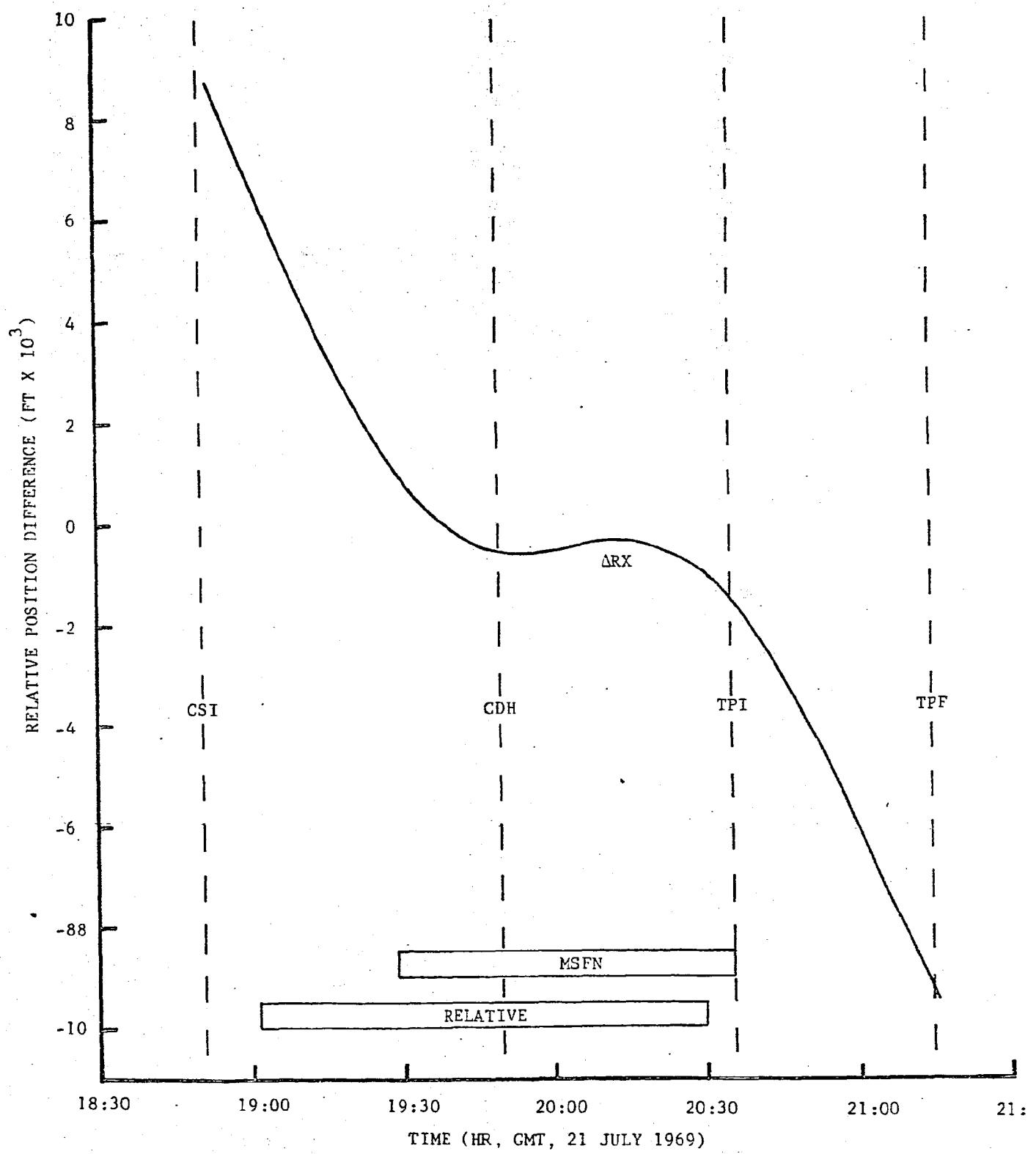


Figure 7-28 Differences Between Position Components of Relative Trajectories  
(CSI to TPF)

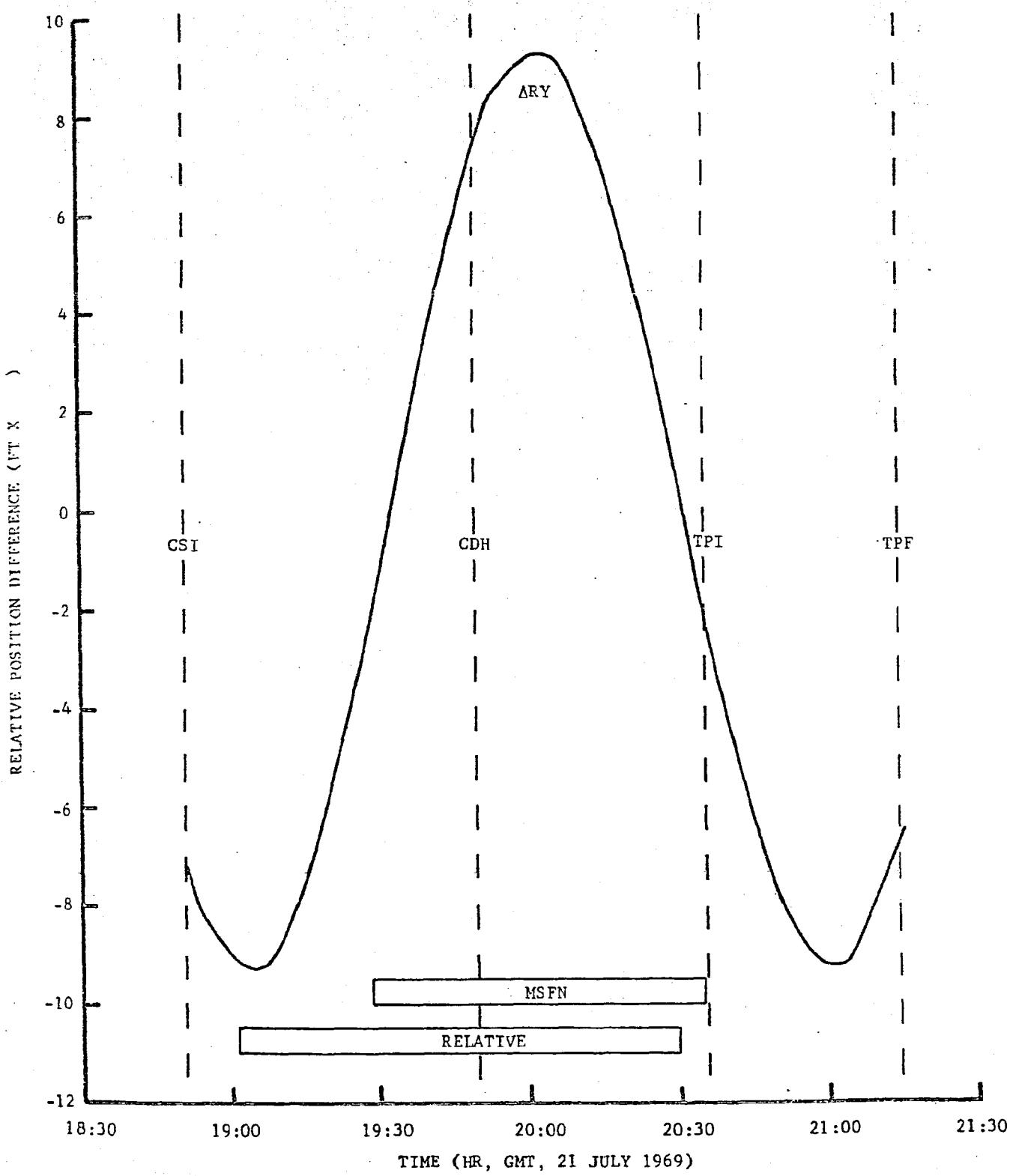


Figure 7-28 (Continued)

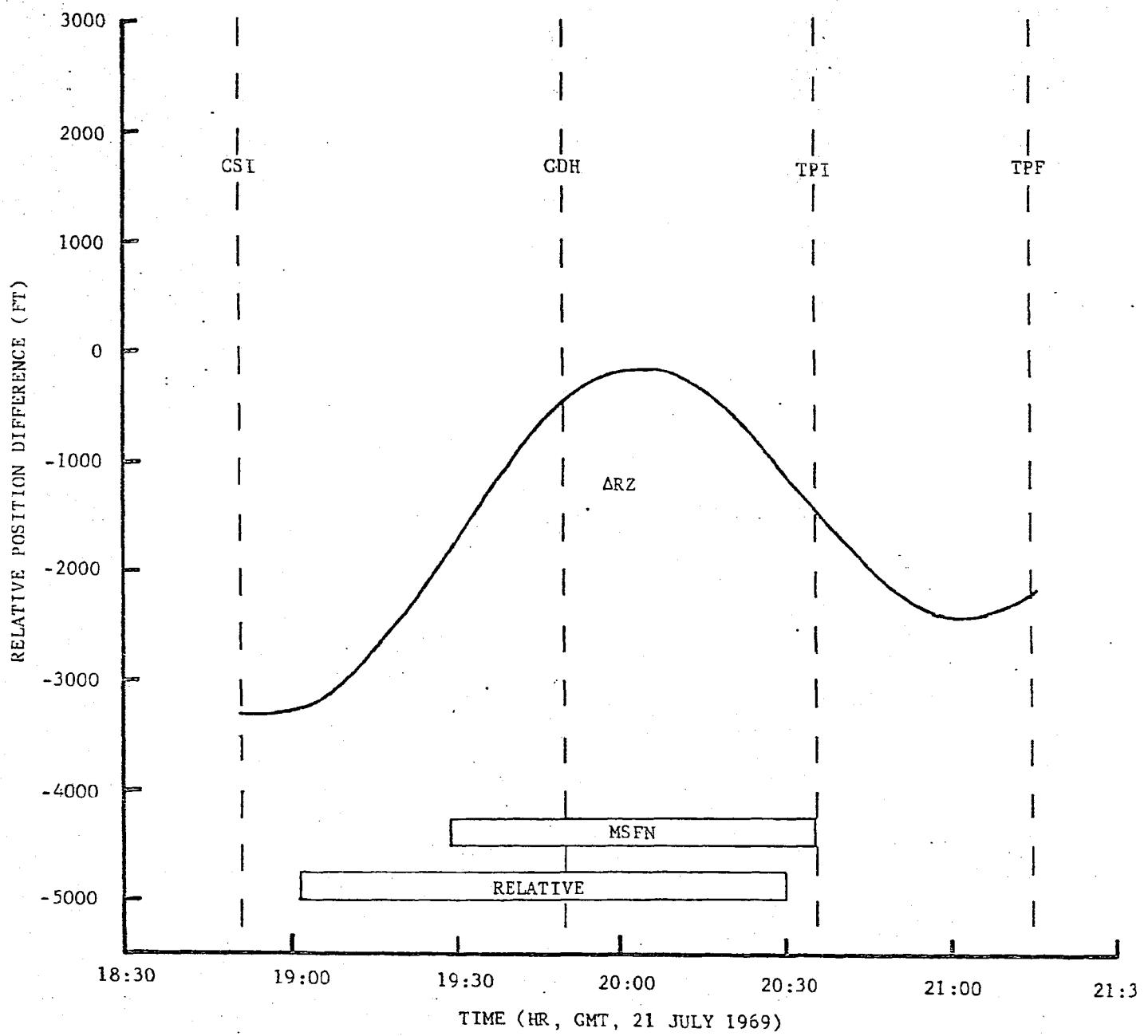


Figure 7-28 (Concluded)

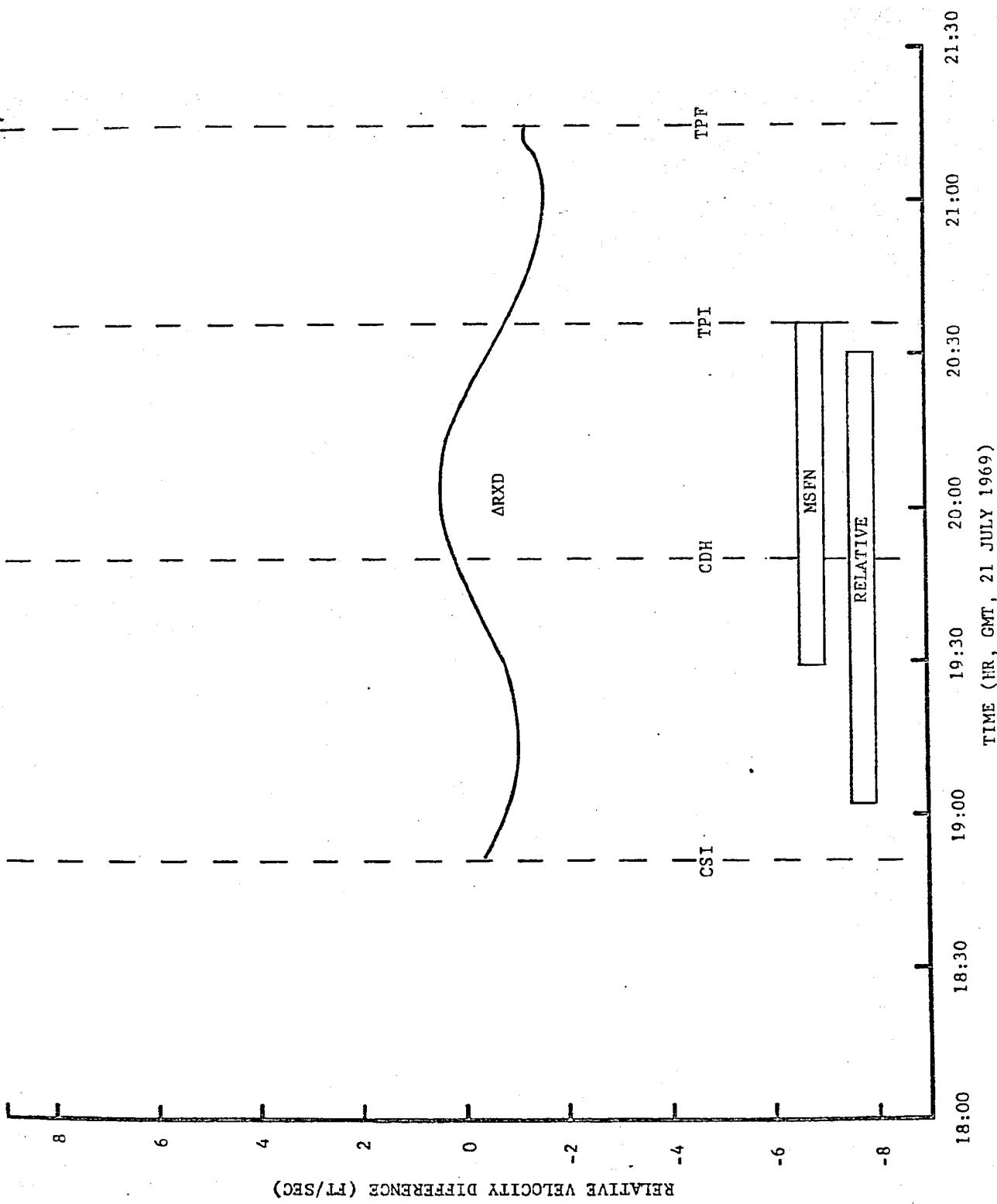
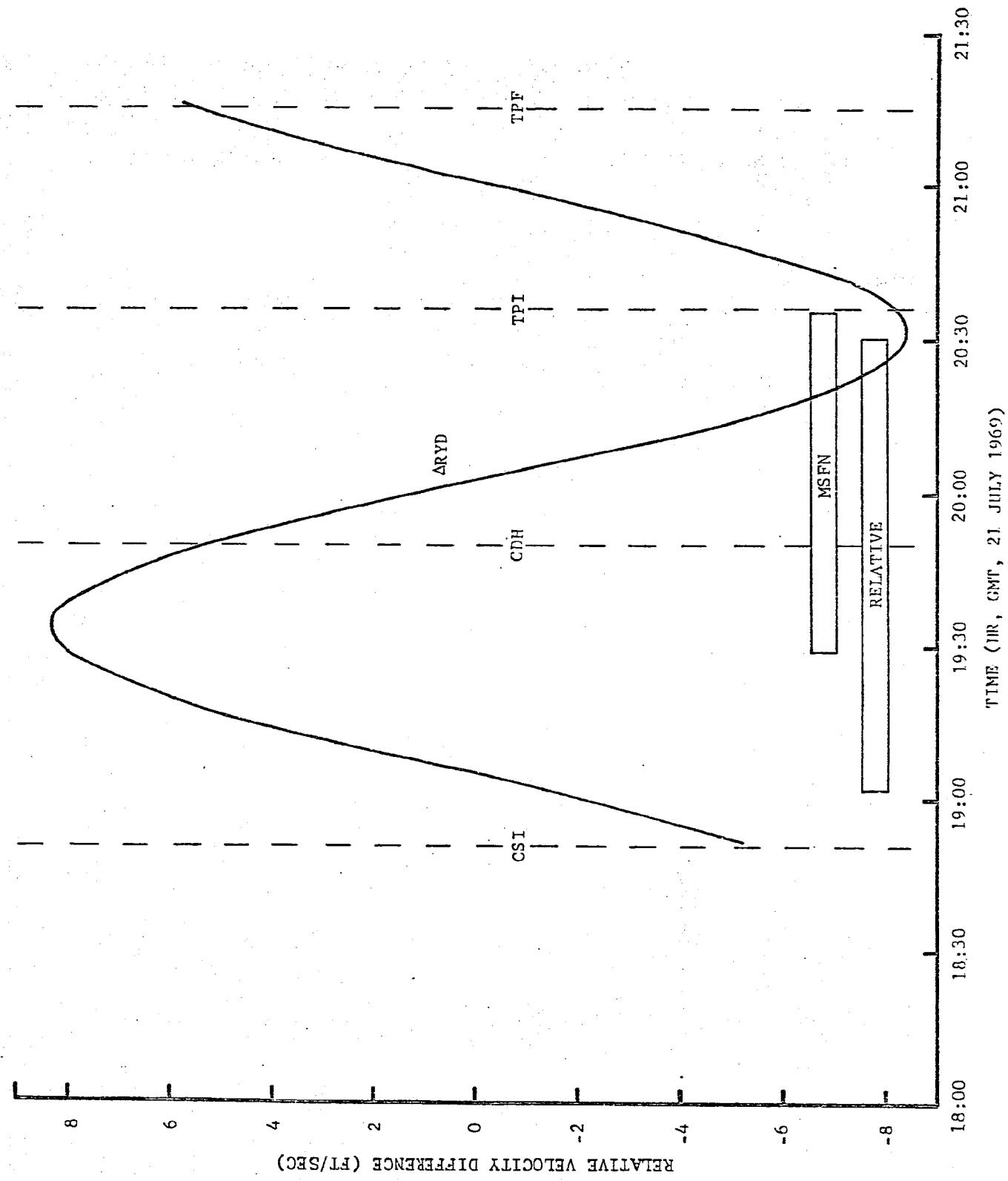


Figure 7-29 Differences Between Velocity Components of Relative Trajectories (CSI to TPF)



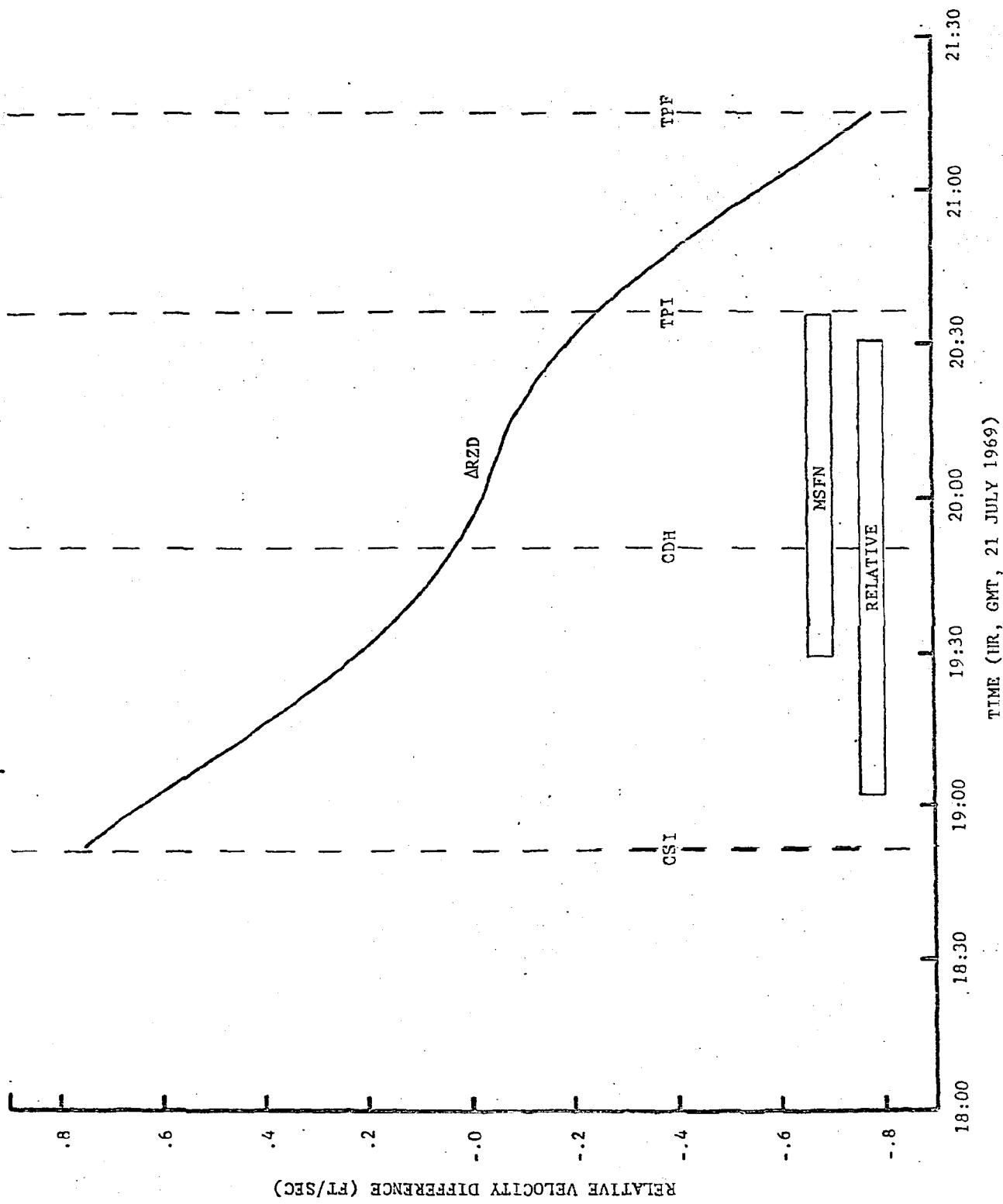


Figure 7-29 Concluded

Table 7.9 Comparison of Rendezvous Radar Noise Estimates with Specification Requirements

Free Flight Segment	Average Range (n. mi.)	Angular Noise		Range Noise	
		$3\sigma$ (deg) Est.	Spec.	$3\sigma$ (feet) Est.	Spec.
INS to CSI	140	.049	.1146	117.	2126.
CSI to CDH	107	.038	.1146	111.	1627.
CDH to TPI	59	.037	.1146	81.	890.

Table 7.10 Comparison of VHF Ranging and Sextant Noise Estimates with Specification Requirements

Free Flight Segment	Average Range (n. mi.)	Sextant Angular Noise		VHF Ranging Range Noise	
		$3\sigma$ (deg) Est.	Spec(1)	$3\sigma$ (feet) Est.	Spec.
DOI to PDI	32	.043	-	69.	180.
INS to CSI	140		NA		NA
CSI to CDH	107	.035	-	69.	180.
CDH to TPI	59	.047	-	57.	180.

(1) No specification value was available.

### Specification Comparisons

Table 7.9 compares the  $3\sigma$  values of noise estimated from the rendezvous radar residuals with specification requirements. It can be seen that the estimates were all well within specification limits. Noise estimates for the sextant and VHF ranging data are listed in Table 7.10. Although no specification value was found for the sextant, the values obtained (RSS of individual angle noise estimates) were all within acceptable limits. The VHF ranging noise estimates also compare well with specifications.

### Conclusions

The following conclusions were drawn from the analysis.

1. The onboard data was generally of good quality. The sextant data, examined for the first time, appeared to be as accurate as the rendezvous radar angular measurements.
2. Estimates of data random noise were all within specification and expected values.
3. Trajectories produced from onboard tracking data proved to be generally consistent with those produced from MSFN data. It was found that a method used in the past to demonstrate trajectory consistency was inadequate. On Apollo 10, trajectories were compared only at selected times. Because of the significantly large phase differences found to be present in relative trajectories, the values for out-of-plane position differences obtained at selected times may be misleading. The out-of-plane position components must be plotted as a function of time in order to see the total differences in the trajectories.

## 7.4 LANDING RADAR DATA ANALYSIS

The landing radar data analysis consisted of generating and evaluating landing radar residuals (difference between observed measurement and computed measurement) and mapping of the lunar surface profile and ground-track with the slant range measurement.

The landing radar data were obtained by processing the downlink telemetry data with a special purpose computer program which outputs onboard observations on punched cards in a HOPE-compatible format.

The HOPE Program was used to compute simulated landing radar observables from selected LM trajectories and from auxiliary information such as REFSMAT, gimbal angles, and radar operating mode. The LM trajectories were generated by the HOPE Program utilizing telemetered acceleration data in the IGS burn option to model the descent burn. Residuals were then formed by subtracting the computed from the actual observable value. Paragraph 7.4.2 presents statistics and selected plots of residuals obtained from various LM state vectors.

Terrain mapping data were obtained from a small, special purpose computer program designed to compute terrain altitude above a mean lunar radius as a function of latitude and longitude. The results of an attempt to correlate this terrain data with lunar contour maps are presented in Paragraph 7.4.3.

### 7.4.1 Descent Trajectories

Six different descent trajectories were examined in the landing radar data analysis. The origins of these trajectories are summarized as follows:

- (a) RTCC - This vector was obtained in the RTCC in real time.
- (b) MSFN (LS) - This vector was obtained from an IGS fit using low speed MSFN data obtained from acquisition of signal to LM touchdown (revolution 14). The doppler data were compacted to two observations per minute.
- (c) Onboard - This vector was obtained from a free flight fit using CSM sextant and VHF ranging observations. The technique required fixing the CSM trajectory as a reference and updating the LM state from onboard observations and the CSM reference trajectory.

- (d) BET #3 - The MSFN state vector described in item (b) above, was used as the basis for this trajectory. The BET #3 was obtained by correcting the MSFN low speed state with a linear error analysis program so that the resultant powered descent trajectory would impact a desired landing site with a relative velocity of zero. The landing coordinates used as reference were the MPB photographic estimate.
- (e) Lear - High speed MSFN data (ten samples per second) obtained over a 232 second data arc just prior to PDI were fit by the Lear Powered Flight Processor producing this state vector.
- (f) Onboard/MSFN (H-S) - This trajectory was obtained with the HOPE Program and used high speed MSFN doppler data which had been compacted to 30 observations/minute and from CSM sextant and VHF ranging data using the HOPE orbit determination program. The descent burn was modeled by the HOPE IGS burn option. The HOPE weighted least squares solution vector included position and velocity at epoch (which was prior to PDI), and Y platform misalignment. The tracking data interval was from DOI to LM touchdown. Figure 7-2 shows the tracking data timeline.

In order to gauge the quality of the landing radar data, it was necessary to determine that the above trajectories did accurately represent the actual descent trajectory. This quality judgement was based largely on the landing point conditions obtained from each trajectory. These landing sites obtained from each trajectory are summarized graphically in Figure 7-30. Note that both the BET #3 and the Onboard/MSFN H-S estimates are very close to the 16mm photographic estimate (accepted as the best estimate).

Since the data type being examined is a velocity measurement, it is most important that the reference trajectory be virtually free of velocity errors in the data arc. The onboard/MSFN H-S trajectory contains a large velocity error at landing where the BET #3 was constructed in such a manner that the velocities are zero at landing. Therefore, the BET #3 was chosen as the basic reference upon which to base the analysis of landing radar velocity residuals.

#### 7.4.2 Landing Radar Velocity Residuals

Table 7.12 lists the velocity residual statistics obtained from all the trajectories considered in the analysis. Note the small mean values obtained from the reference trajectory (BET #3). In the absence of a

real standard of comparison, the mean values obtained from BET #3 were reasonably small. Standard deviations indicate that  $V_{YA}$  and  $V_{ZA}$  are somewhat more erratic than  $V_{XA}$ . However, these values are still of reasonably good quality as shown by Figures 7-31 through 7-33. These figures show the BET #3 velocity residuals plotted versus time. In addition, specification limits have been plotted. Note that a few points fall outside specification.

It is difficult to isolate measurement errors from trajectory errors in this particular case. The descent trajectory is a particularly difficult one to reconstruct, and the landing radar velocity data are particularly sensitive to trajectory errors. Notice that the velocity residuals in Figures 7-31 through 7-33 tend toward zero at landing where the BET #3 velocities were constrained to zero. In contrast, the trajectory obtained from the Onboard/MSFN H-S fit is known to contain velocity errors at landing. The resultant total velocity at landing was 8.02 fps, with the primary contribution in the Z direction (North). The residual statistics show a mean value for  $V_{YA}$  of 6.966 fps. Since  $V_{YA}$  was directed roughly North, the large mean value reflects the -7.96 fps in the Z component of velocity at landing. The residuals obtained from the Onboard/MSFN H-S fit are plotted in Figures 7-34 through 7-36.

The residual statistics listed in Table 7.12 also indicate that the best trajectories do produce the best landing radar velocity residual statistics, that is, the BET #3 and the Onboard/MSFN H-S trajectories produce the smallest residual mean values. This fact, together with the sensitivity which the data has exhibited to trajectory velocities indicate that descent trajectory reconstruction activities will be aided considerably by the landing radar velocity data.\*

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\* Subsequent reconstructions using landing radar data have produced a trajectory landing at acceptable coordinates (Lat. = .649 deg, Long. = 23.490 deg) with a total relative velocity of .96 fps. A report of this reconstruction will be forthcoming under a separate cover.

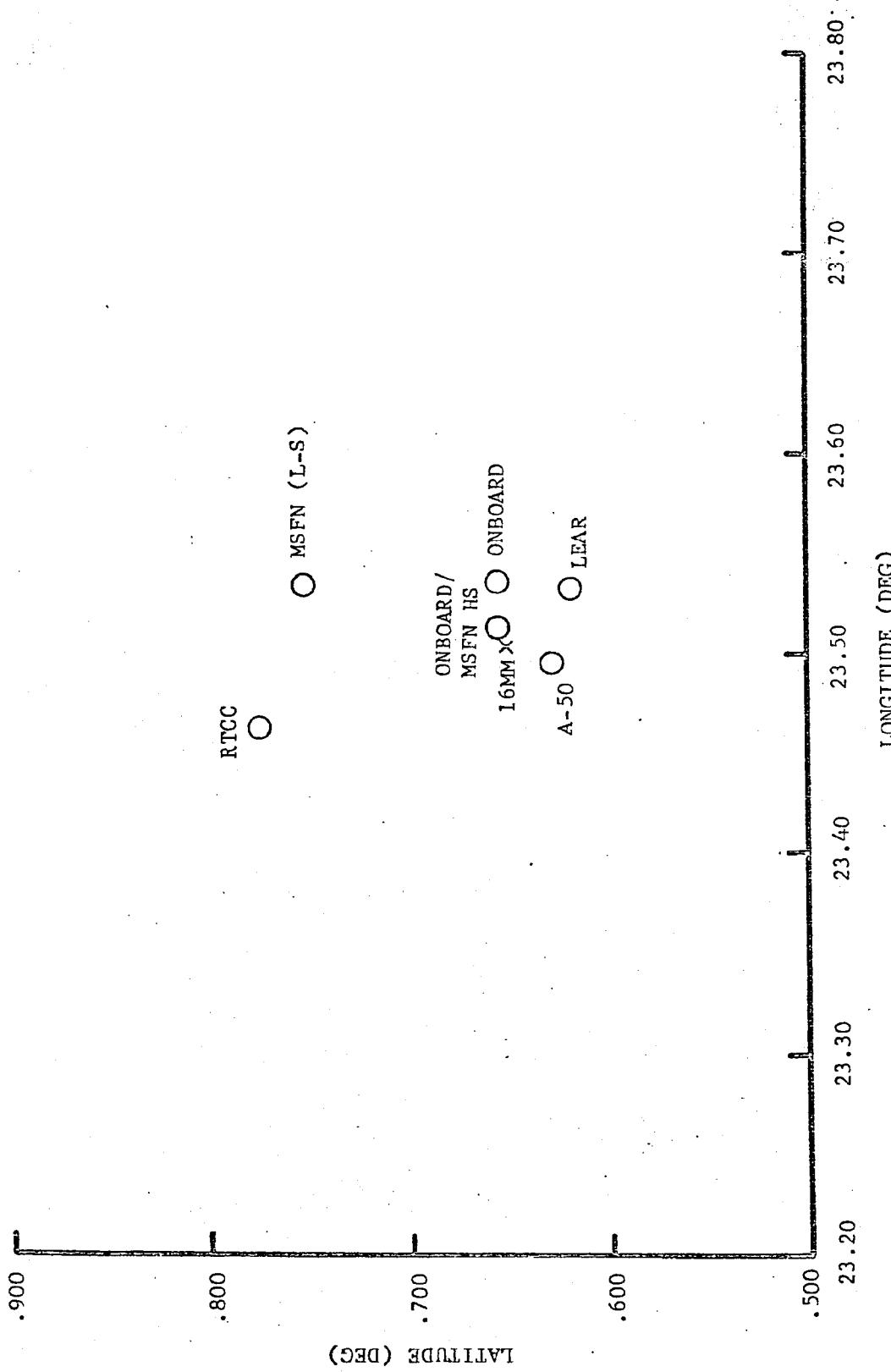


Table 7.11 LM Landing Site Coordinates

VECTOR SOURCE	LATITUDE (deg)	LONGITUDE (deg)	RADIUS (n.mi.)
RTCC	0.777	23.461	936.59
MSFN (L-S)	0.756	23.537	937.93
ONBOARD (VHF, SXT)	0.656	23.538	936.90
BET #3	0.630	23.497	937.15
LEAR	0.620	23.532	936.66
16MM	0.647	23.505	N/A
ONBOARD/MSFN H-S	0.655	23.515	937.04

Table 7.12 Landing Radar Velocity Residual Statistics

Vector Source	$V_{XA}$	$V_{YA}$	$V_{ZA}$
<u>RTCC</u>			
Mean	9.543	3.909	3.022
S.Dev.	1.532	5.455	3.918
Noise	1.172	3.891	3.446
<u>MSFN (LS)</u>			
Mean	-1.997	6.501	4.533
S.Dev.	1.758	4.081	3.486
Noise	1.120	3.281	3.661
<u>ONBOARD</u>			
Mean	2.681	6.724	4.640
S.Dev.	1.475	4.209	3.430
Noise	1.316	3.948	2.203
<u>BET #3</u>			
Mean	.857	.893	-.173
S.Dev.	1.829	4.306	3.689
Noise	1.142	4.565	2.361
<u>LEAR</u>			
Mean	4.733	5.625	4.287
S.Dev.	1.018	4.189	3.723
Noise	.718	3.932	2.340
<u>ONBOARD/MSFN (H-S)</u>			
Mean	.234	6.966	1.729
S.Dev.	1.183	3.866	2.978
Noise	.575	3.336	2.349

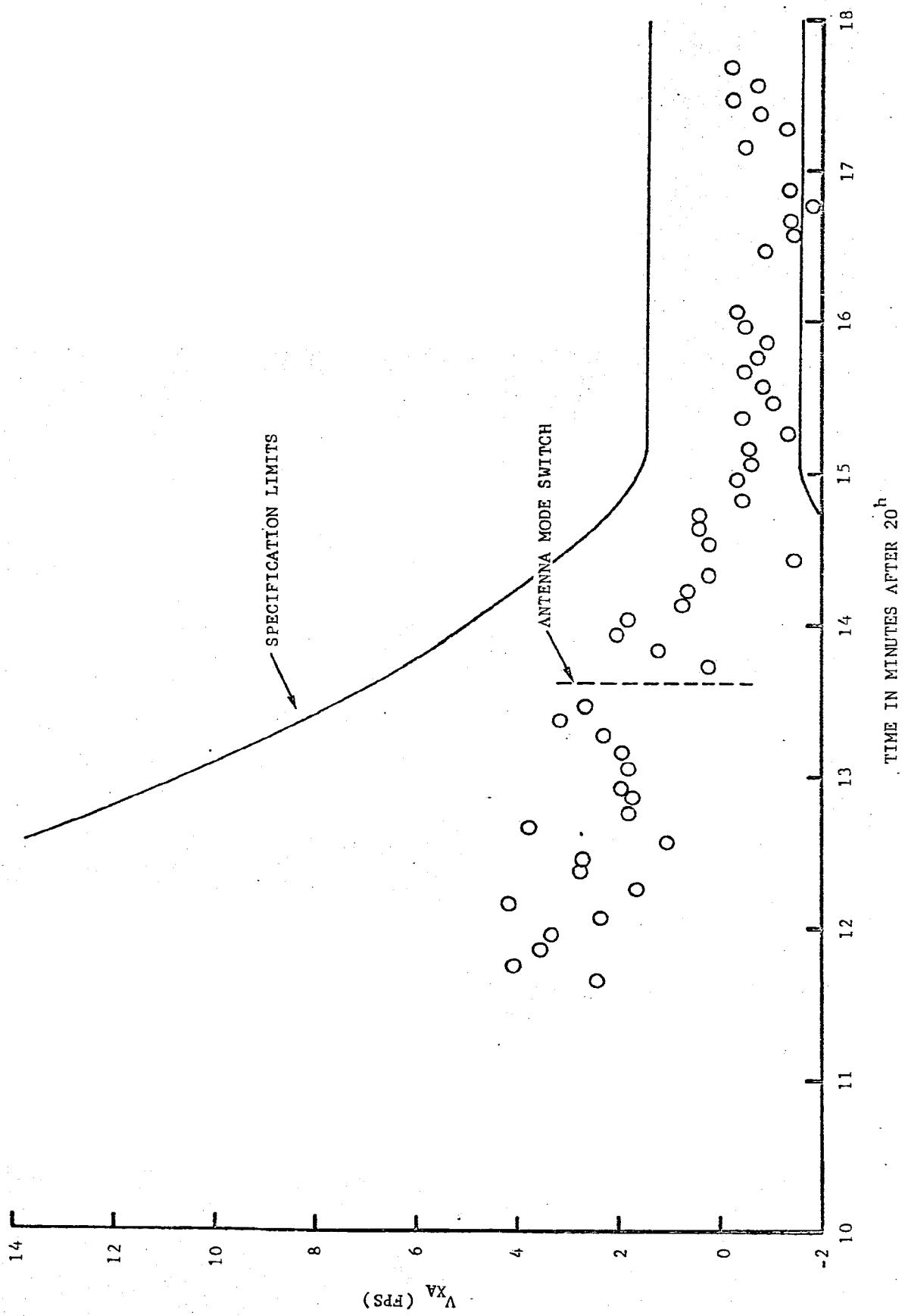


Figure 7-31. Landing Radar X-Antenna Velocity Residuals (REET #3)

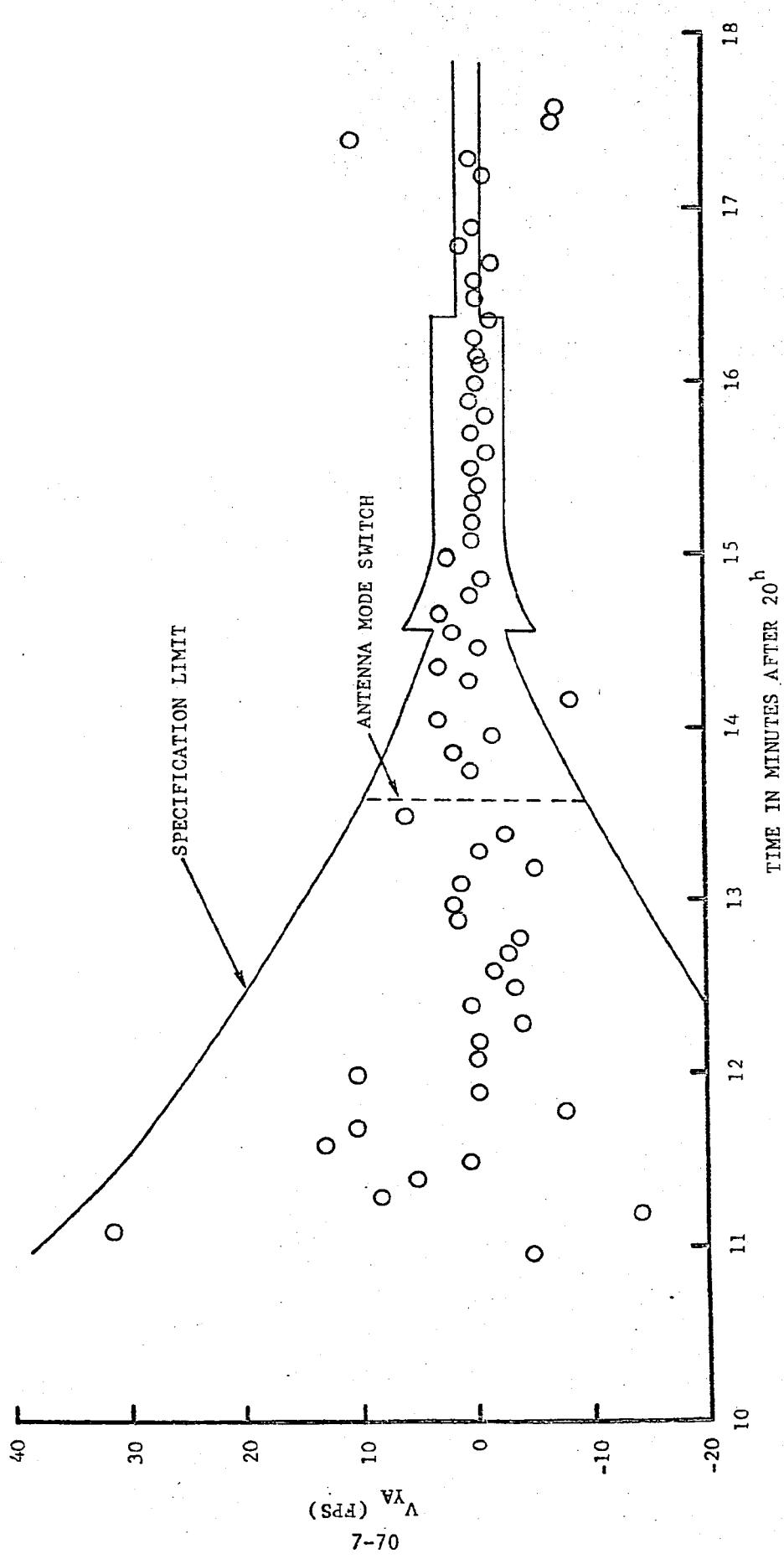
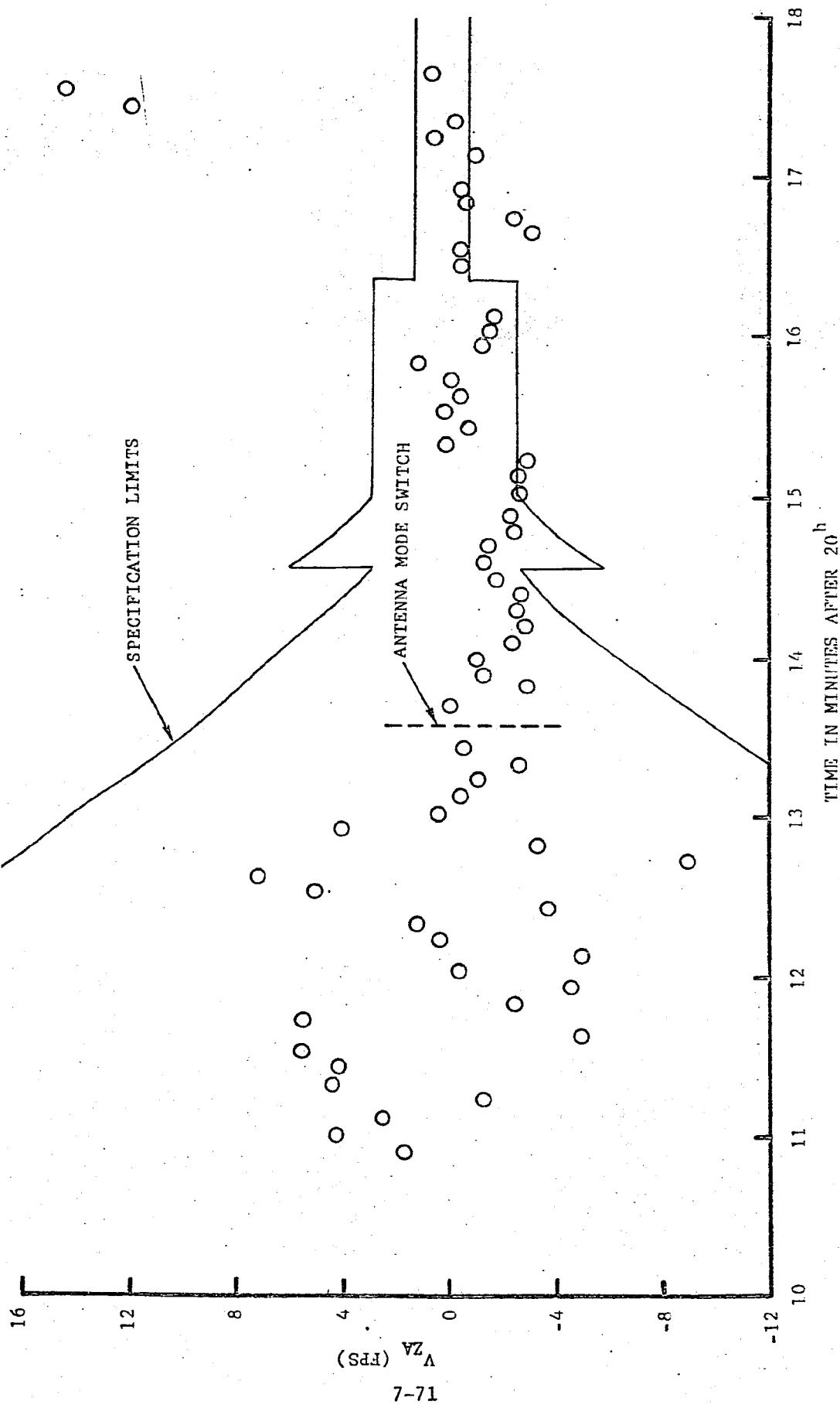


Figure 7-32 . Landing Radar Y-Antenna Velocity Residuals (BET#3)



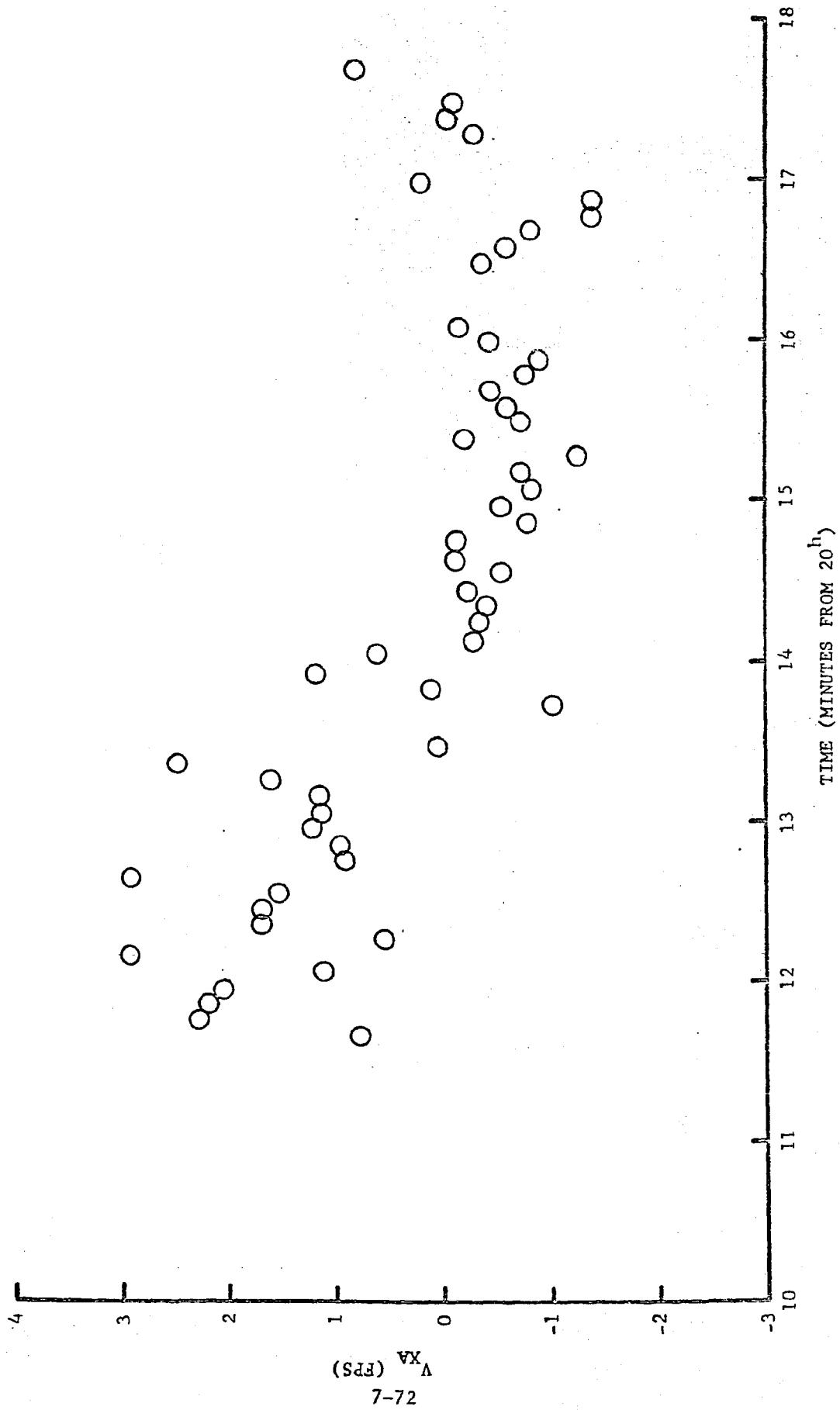


Figure 7-34 . Landing Radar X-Antenna Velocity Residuals (Onboard/MSTN H-S)

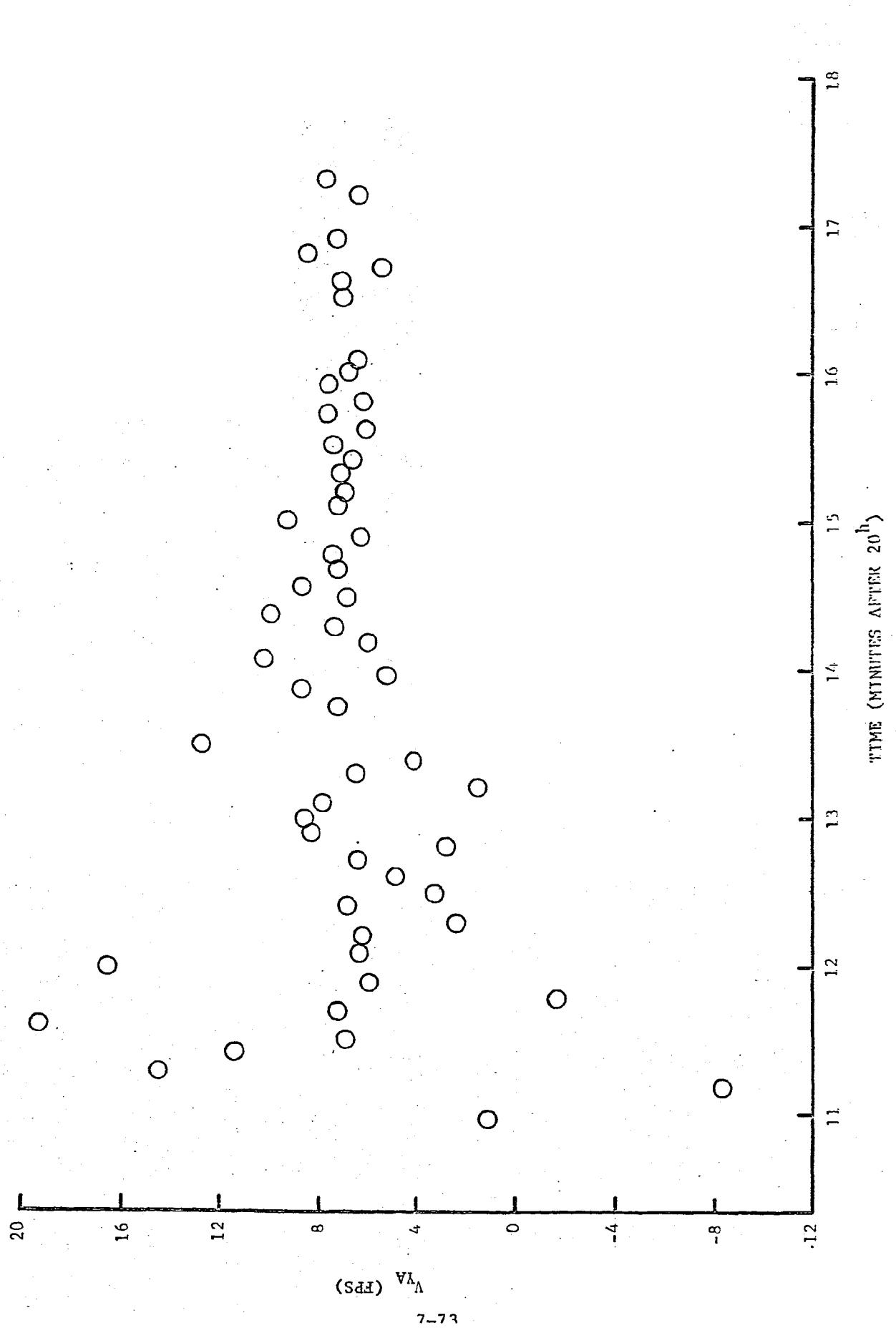
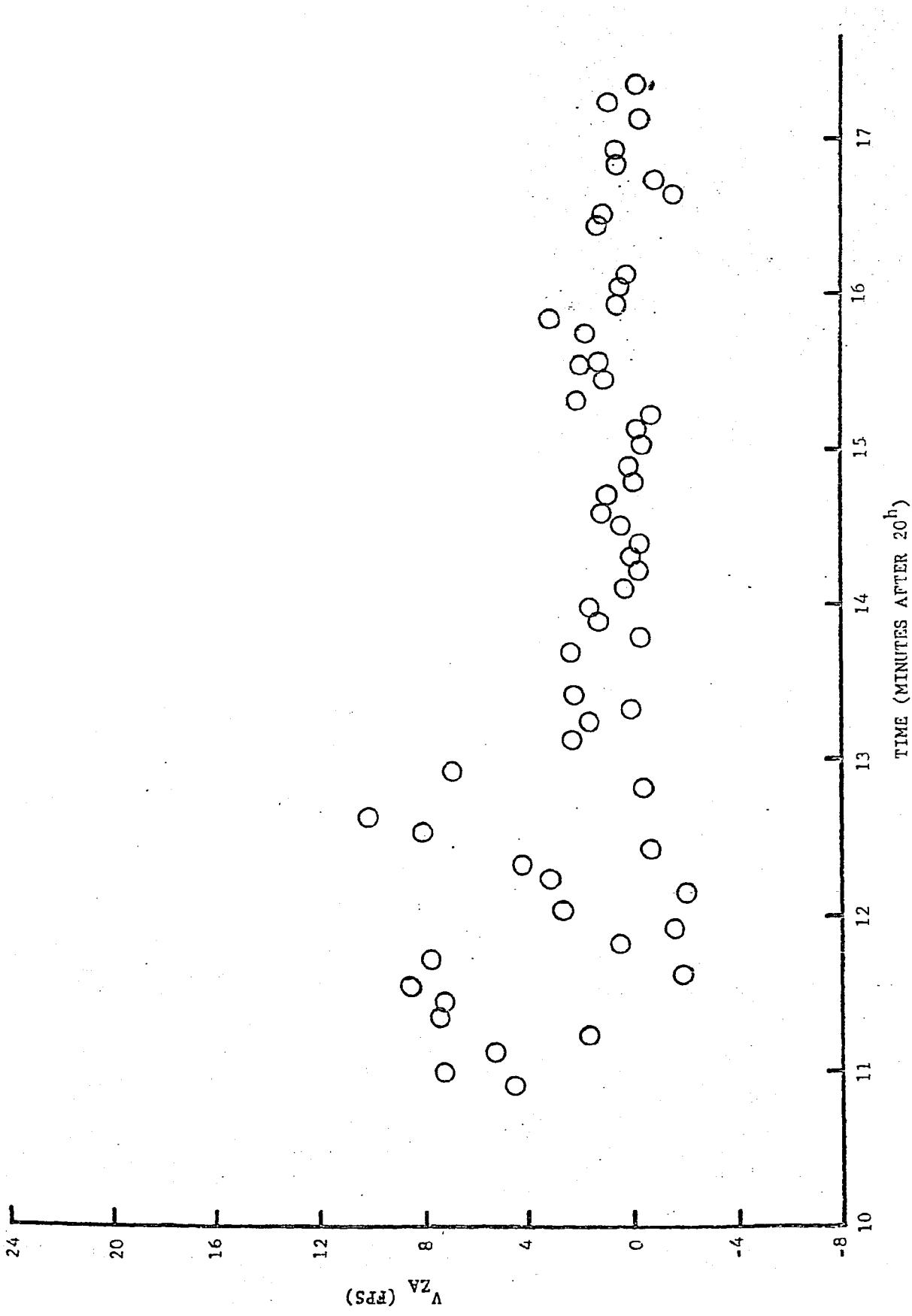


Figure 7-35. Landing Radar Y-Antenna Velocity Residuals (Onboard/MSFN H-S)



**Figure 7-36.** Landing Radar Z-Antenna Velocity Residuals. (Onboard/MSTN II-S)

#### 7.4.3 Lunar Surface Altitude Along Groundtrack

Landing Radar range residuals are used to compute an estimate of the relative altitude of the surface along the groundtrack of the piercepoint.

Surface altitude relative to the landing site is plotted versus angular range in Figure 7-37. Time ticks are indicated at the LR range read times (2-second intervals).

The ground track of the range beam piercepoint is shown in Figure 7-38. The plot is made on Lunar Maps ORB-II-6 and ORB-I-3 (scale 1: 100,000)\*. The latitude does not agree with postflight estimates of Tranquility Base coordinates. Time ticks are at LR range read times and correspond to those on the surface altitude plot. The size of the range beam on the surface is indicated by the small ellipses drawn periodically along the groundtrack.

Little quantitative information can be obtained from Figure 7-38.1 except to note that the gentle upward slope of the terrain on the approach to the landing site is in general agreement with the surface altitude plot.

On Figure 7-38.2, surface altitude variations can be correlated to several prominent features:

The 170 ft drop in altitude between the readings at 102:39:37.19 and 102:39:39.19 correspond to range beam centers at the top and bottom of a cliff.

The point at 102:39:51.19 is centered in a fairly large crater. A depression of approximately 300 ft is clearly outlined in the surface altitude plot.

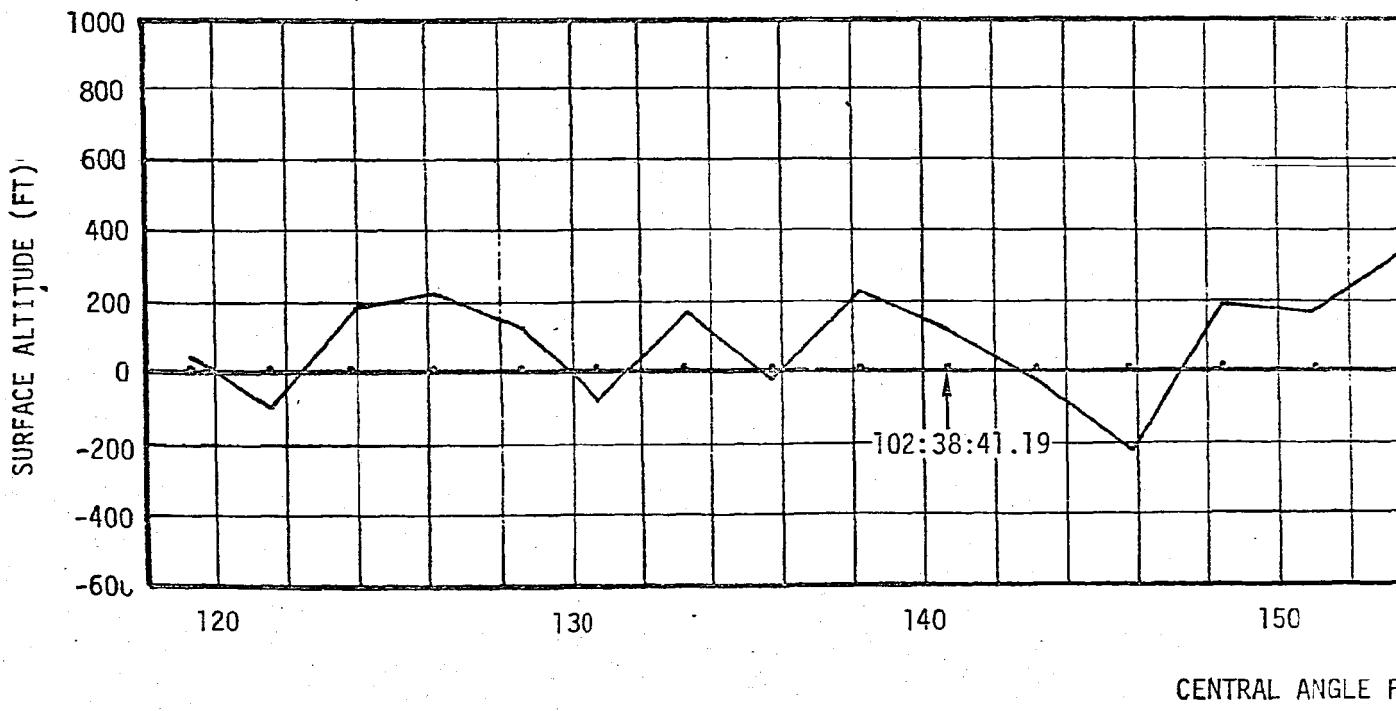
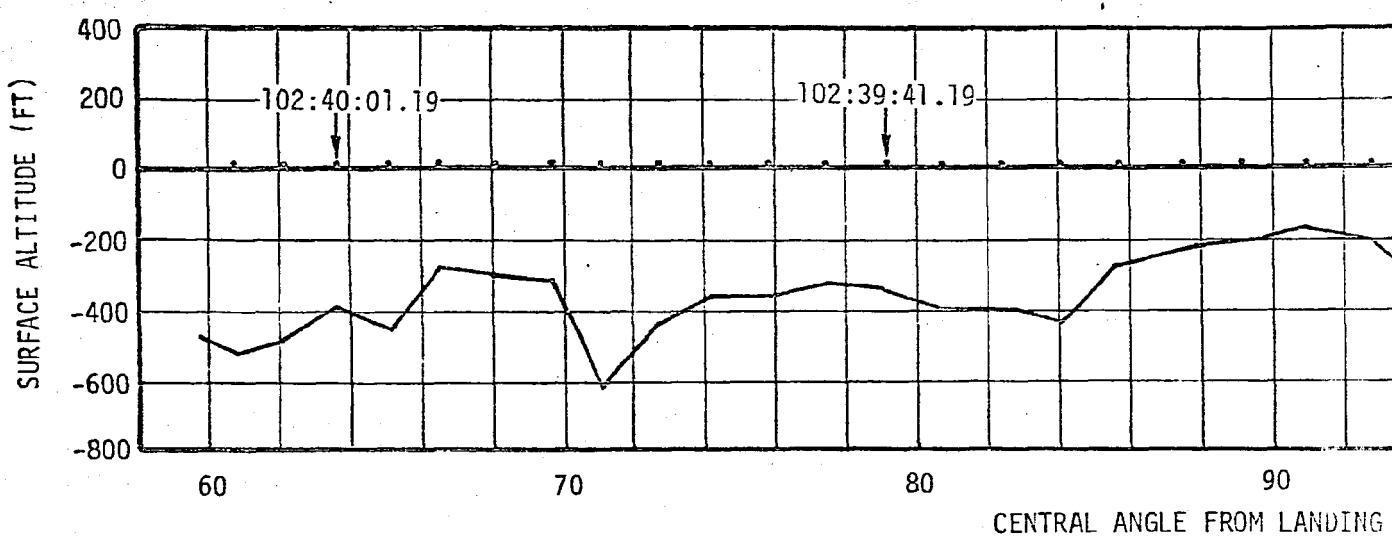
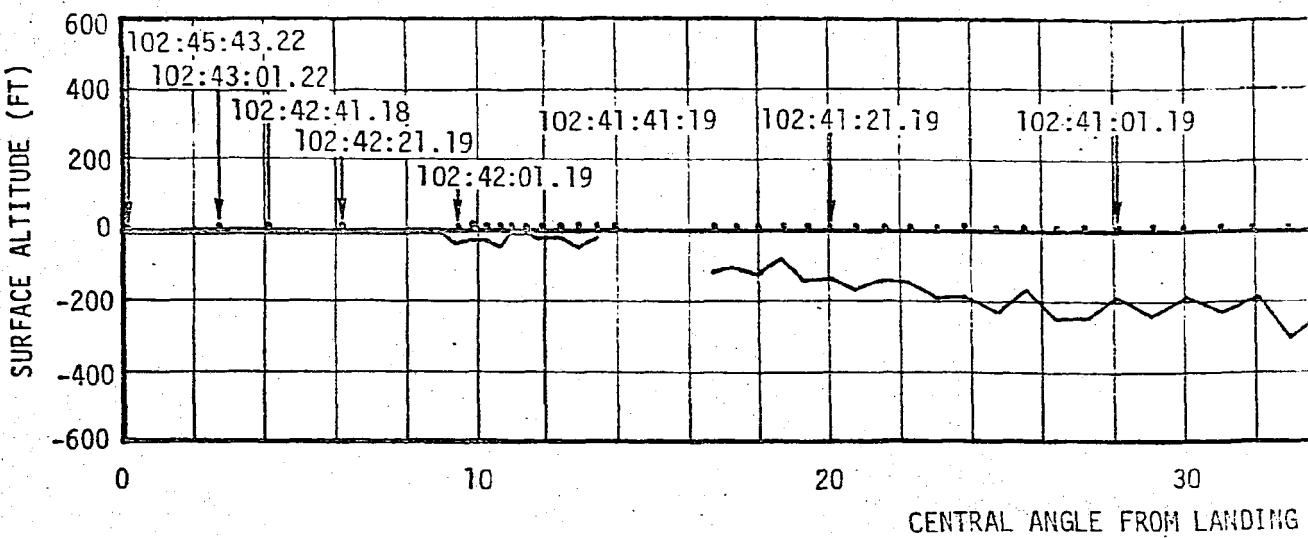
\* Map legend: Contour lines (at 50 meter intervals) are indexed by an estimate of the radius in meters with the first three digits omitted. Crater markings such as 45R (110) indicate - Height of rim above terrain = 45 meters, Crater depth (floor to rim) = 110 meters.

The point at 102:39:23.19 falls inside a crater, and a depression of approximately 200 ft is indicated.

As the range beam intersection grows in size with increasing LM altitude, surface details become increasingly difficult to resolve. The overall downward terrain slope along the ground-track in Figure 7-38.3 is in general agreement with the surface altitude plot.

The altitude of the LM above the LLS radius during LR range data coverage is shown in Figure 7-39.

The data presented in this section results from a HOPE program orbit determination which includes LR velocity in the DC fit. This option has only recently become available and the results presented here are among the first obtained using Apollo 11 data. The principal effect of including LR velocity in the fit is to produce a more accurate relative velocity profile. Surface altitude plots, derived from earlier versions of the descent trajectory, show unrealistic terrain slopes due to small inplane velocity errors.



FOLDOUT FRAME

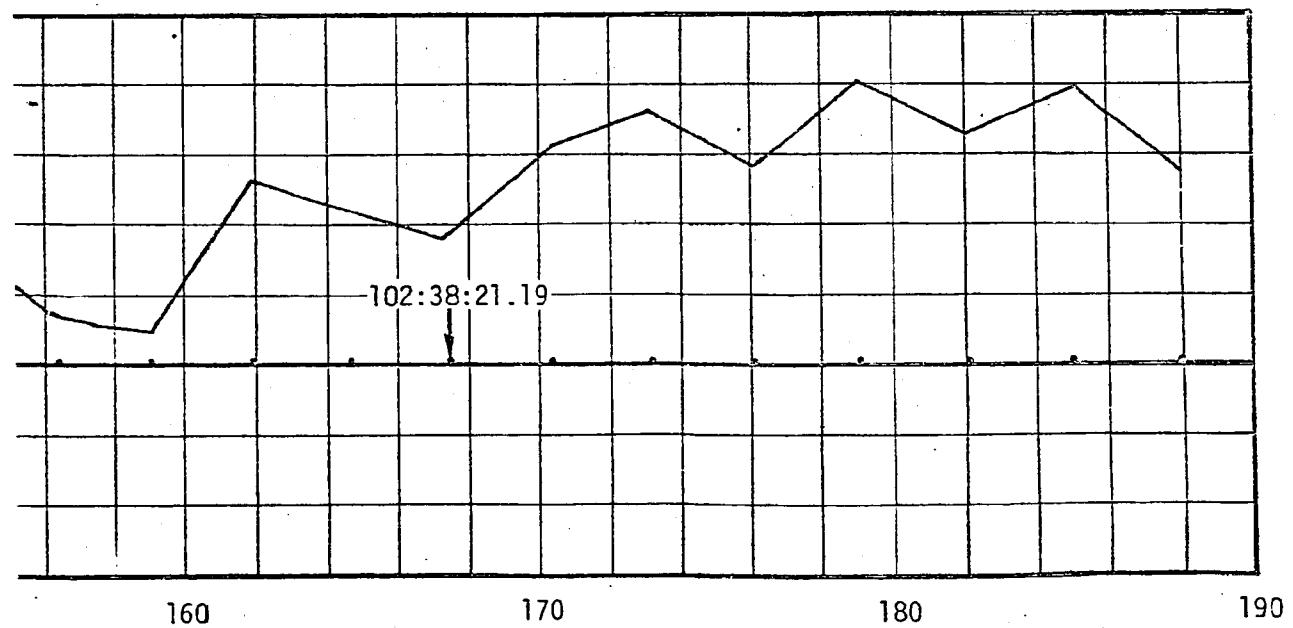
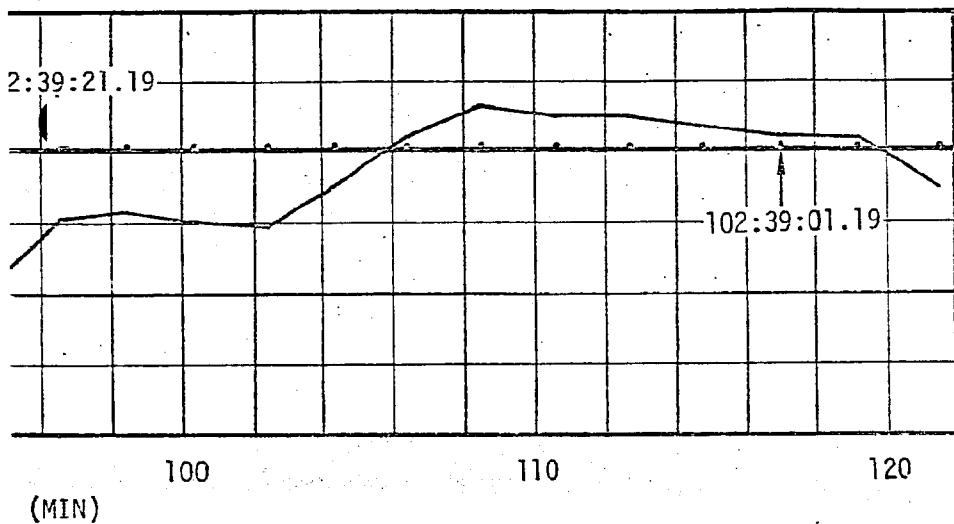
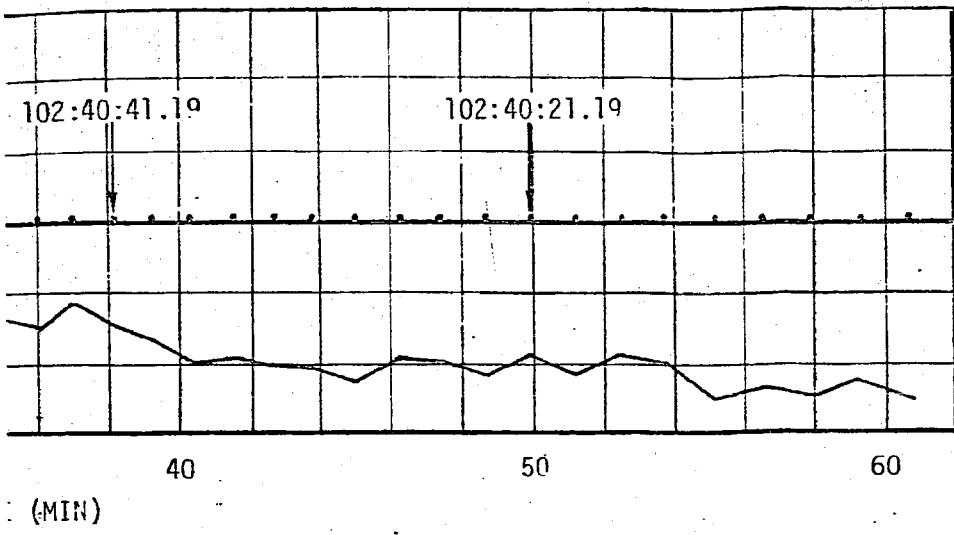


Figure 7-37 Surface Altitude Along Groundtrack.

FOLDOUT FRAME

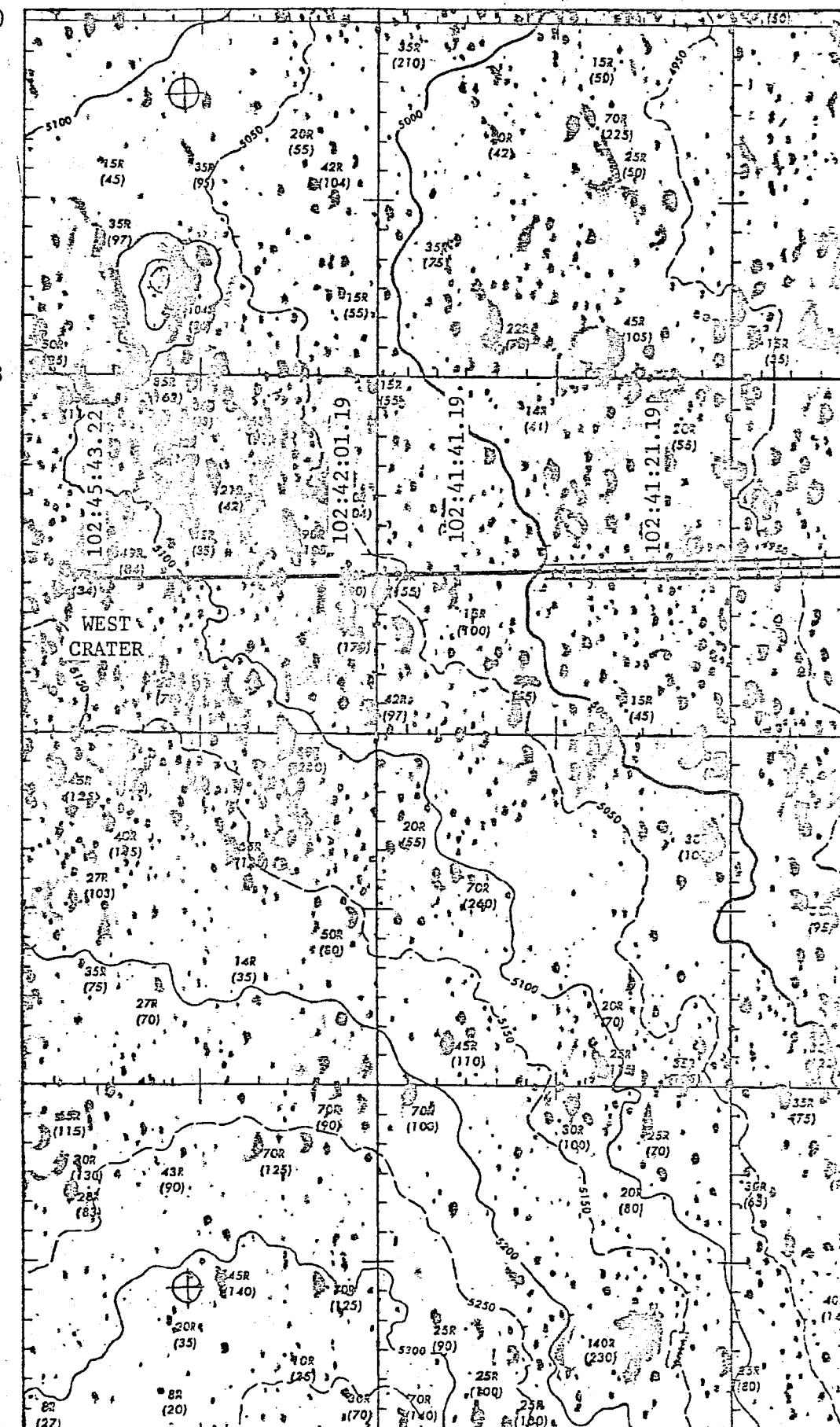
LATITUDE (DEG:MIN)

+0:36

+0:24

+0:12

+0:60



23:24

23:36

23:48

LONG

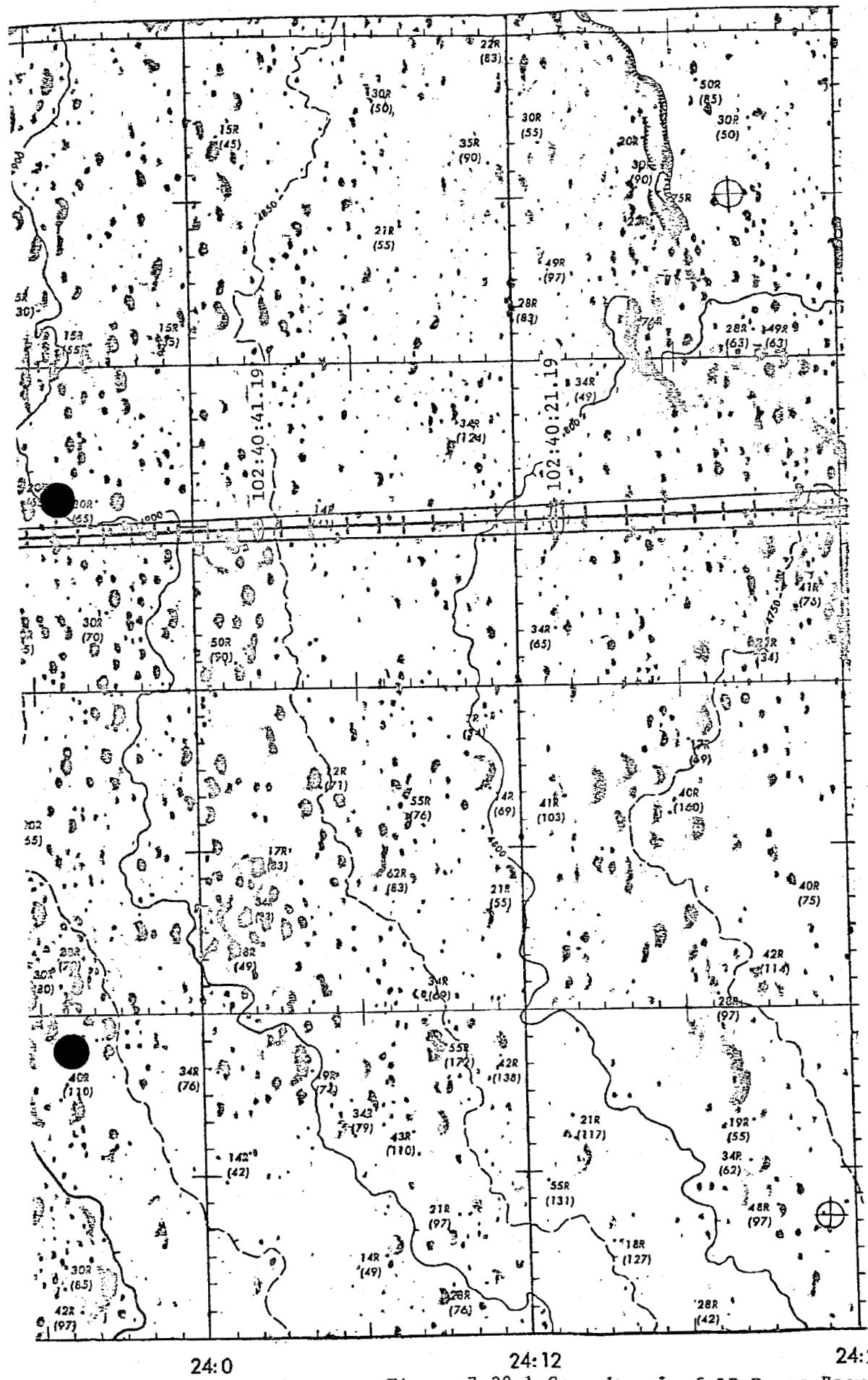


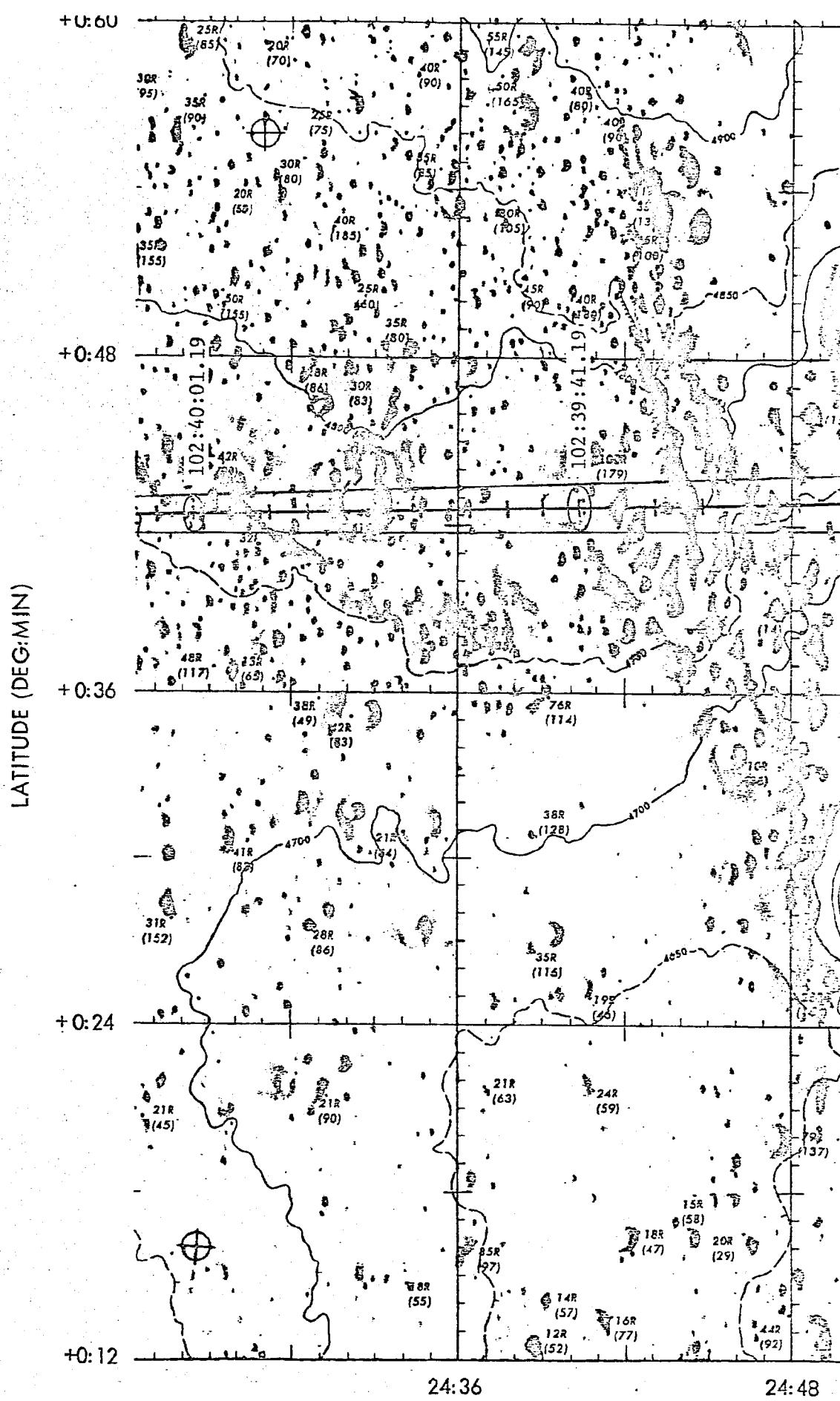
Figure 7-38.1 Groundtrack of LR Range Beam Piercelpoint

DE (DEG:MIN)

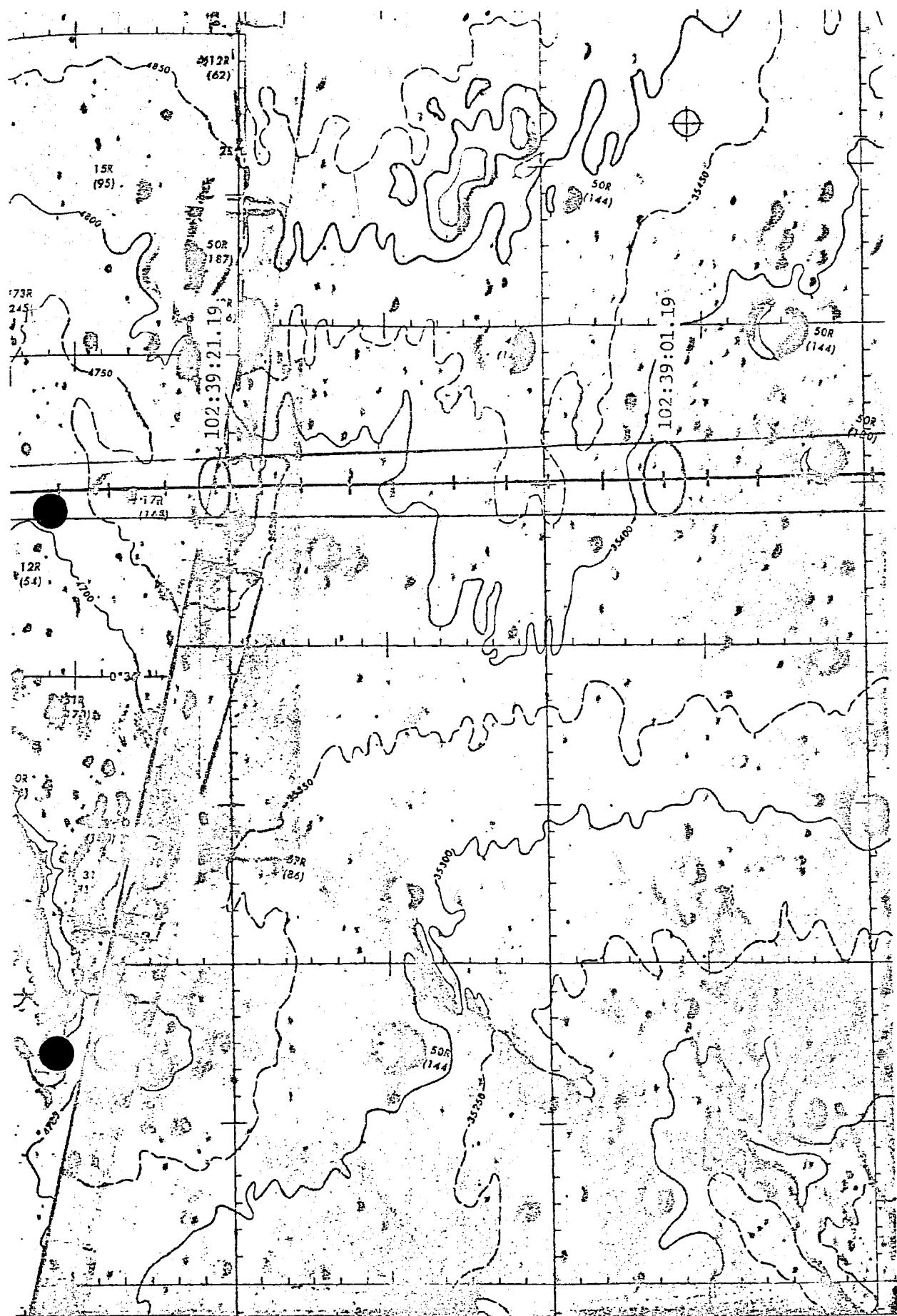
**FOLDOUT FRAME**

1

24:24



FOLDOUT FRAME



25:0  
LONGITUDE (DEG:MIN)

25:12

25:24

Figure 7-38.2

+0:60

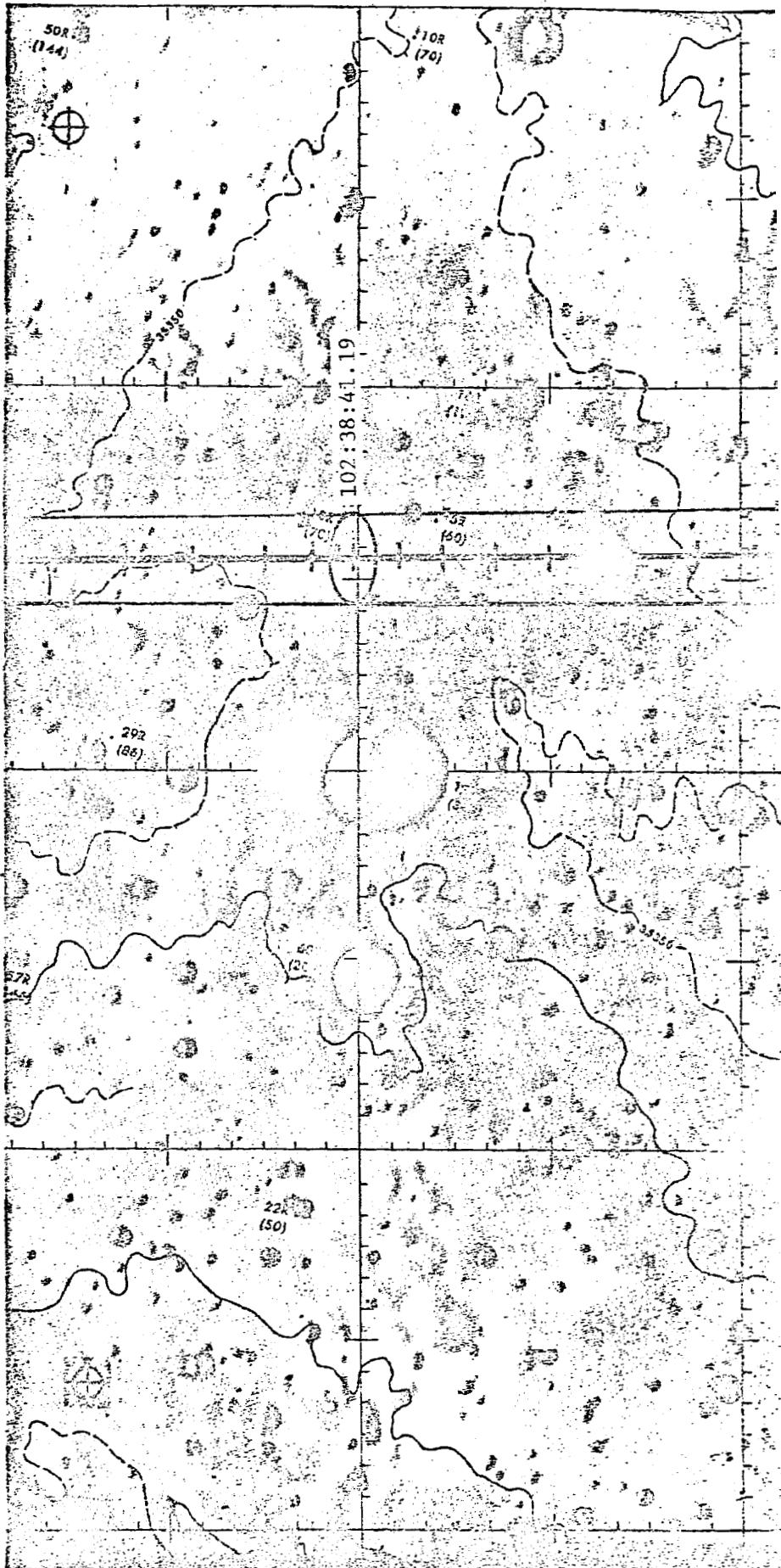
LATITUDE (DEG:MIN)

+0:48

+0:36

+0:24

+0:12



25:36

25:48

FOLDOUT FRAME



LONGITUDE (DEG:MIN)

26:0

26:12

26:24

Figure 7-38.3

7-83

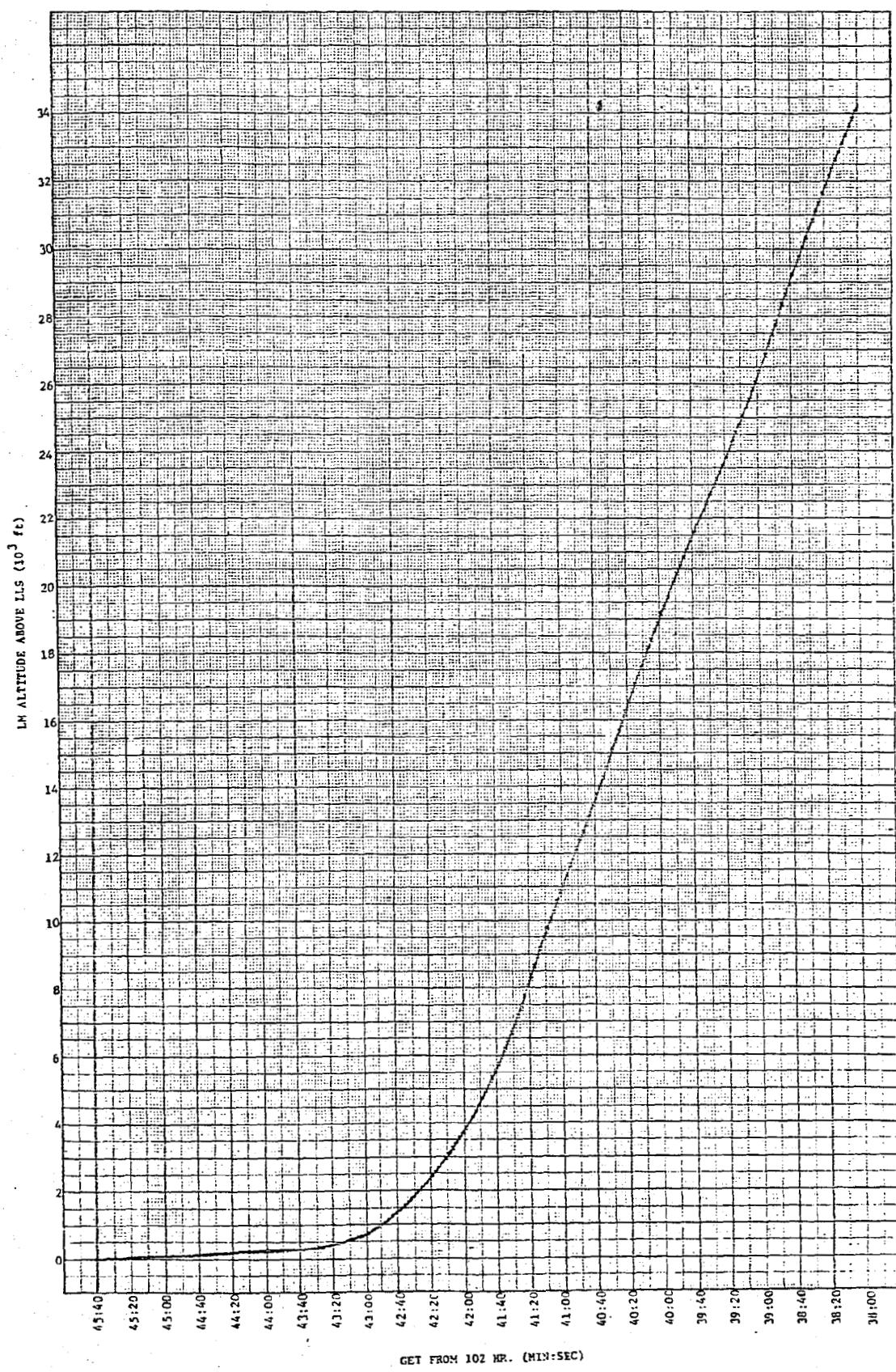


Figure 7-39 Altitude of LM During LR Range Sampling

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## APPENDIX A

### Summary of CSM, LM Vectors Used to Generate the Preliminary NAT for Apollo 11

Appendix A documents the vectors used to generate the NAT trajectory in order that the user may know the quality of the trajectory. Since most of the vectors were not based on postflight fits but rather on RTCC vectors which were then propagated, propagation errors arise which can degrade the trajectory.

In order to reduce the error, the lunar orbit propagation times were kept to a minimum. Also, the total difference in position and velocity (which is a measure of the quality of the trajectory) were calculated at a common time point for adjacent trajectory intervals and tabulated in Table A.1 (CSM) and Table A.2 (LM) for user convenience. Whenever two intervals were separated by a maneuver, the  $\Delta V$  as exhibited in Tables A.1 and A.2 represents the difference between the total velocity difference and the measured velocity of the maneuver.

Each table lists the vector ID and RTCC batch number, the source of the vector, the initial time of the vector, the propagation interval, the total differences in position and velocity of adjacent intervals, and comments relevant to a particular propagation interval. Maneuvers are listed between the appropriate free flight intervals for easy reference.

Most lunar trajectories were generated using RTCC SS2 (inclination constrained) solution vectors as opposed to SS1 (no a priori) solution vectors. Unlike the Apollo 10 SS2 vectors which were constrained to the pre-LOI1, rev 18, and rev 29 planes, the Apollo 11 SS2 vectors were constrained on a rev-to-rev basis. Each SS2 vector contained two revs of data and was constrained to the SS1 solution plane of one of these two revs (exceptions existed at maneuvers).

By using the new SS2 scheme, the Apollo 11 out-of-plane error was not allowed to accumulate as it did during the Apollo 10 mission.

It should be noted that the vectors used to generate the trajectory from insertion to TPI were based on free flight solutions utilizing MSFN data and not RTCC vectors. The quality of the vector from DOI to PDI was

questionable, but was included because no better vector was available at that time.

In general, the quality of the CSM trajectory was better than the quality of the LM trajectory during the rendezvous period.

Table A.1 Apollo 11 CSM NAT Trajectories

Vector ID	Source	Vector Time (d:h:m:s)	Time (d:h:m:s) GMT	Trajectory Interval (GMT) (d:h:m:s)	$\Delta t$ (ft)	$\Delta V$ (fps)	Comment
CDSUS61	RTCC *	16:17:31:48	16:16:22:03	16:17:49:13	346	0.6	TLI to extraction
MFLX103	RTCC	16:17:49:24	16:17:49:13	16:18:12:01	6066	0.8	Extraction to MCC2
HSK5153	RTCC	17:03:33:18	16:18:12:04:39	17:16:16:57:92	---	0.2	Evasive to MCC2
PTRX034	RTCC	17:16:21:06	17:16:17:01:47	19:04:00:00	15438	0.6	MCC2 to 19 d <sup>h</sup> 04 m <sup>s</sup>
ANX389	RTCC	19:07:46:24	19:06:00:00	19:17:27:52:38	---	---	19 d <sup>h</sup> 04 m <sup>s</sup> to LORI
PTRX040	RTCC	19:17:47:36	19:17:27:52:38	19:19:28:00	2138	8.91	Rev 1
RDXA20	RTCC	19:17:47:36	19:19:28:00	19:21:43:36	6201	3.8	Rev 2 to LORI
GAMX55	RTCC	19:22:07:24	19:21:43:53	20:01:37:00	16789	5.76	Revs. 3 and 4
GARX72	RTCC	20:02:02:12	20:01:37:00	20:03:37:00	5438	3.50	Rev 5
HAXX79	RTCC	20:04:02:48	20:03:37:00	20:05:37:00	5092	3.56	Rev 6
HAXX85	RTCC	20:05:38:46	20:05:37:00	20:07:37:00	3963	3.17	Rev 7
CROX90	RTCC	20:07:37:18	20:07:37:00	20:09:32:00	4629	6.03	Rev 8
CHX496	RTCC	20:10:01:42	20:09:32:00	20:11:32:00	4093	2.10	Rev 9
CHX501	RTCC	20:11:53:36	20:11:32:00	20:13:27:00	10114	6.10	Rev 10
MFLX507	RTCC	20:13:53:00	20:13:27:00	20:17:22:00	7597	6.39	Revs 11 and 12
ANX507	RTCC	20:15:50:10	20:17:22:00	20:18:11:58:24	5166	6.36	Rev 13 pre sep
ACMX527	RTCC	20:18:11:36	20:18:11:58:24	20:21:17:00	3666	2.36	Post sep and rev 14
HAXX535	RTCC	20:19:46:54	20:21:17:00	20:23:17:00	5126	3.48	Rev 15
CDSX522	RTCC	20:21:47:06	20:21:17:00	21:01:17:00	8472	5.12	Rev 16
GRMX550	RTCC	20:23:43:12	21:01:17:00	21:03:17:00	3921	3.15	Rev 17
GRMX555	RTCC	21:01:14:42	21:03:17:00	21:05:12:00	4023	3.07	Rev 18
CROX564	RTCC	21:03:40:48	21:05:12:00	21:07:12:00	3915	3.47	Rev 19
HAXX569	RTCC	21:05:38:06	21:17:12:00	21:09:12:00	3754	3.44	Rev 20
NBEX573	RTCC	21:07:36:18	21:09:12:00	21:11:07:00	4342	4.21	Rev 21
MADX579	RTCC	21:09:34:36	21:11:07:00	21:13:07:00	3814	3.05	Rev 22
CROX584	RTCC	21:11:33:06	21:11:33:07:00	21:15:02:00	6678	5.94	Rev 23
AGHX595	RTCC	21:15:29:12	21:15:02:00	21:18:57:00	5070	3.38	Rev 24 and 25
CHSX600	RTCC	21:17:27:30	21:18:57:00	21:20:57:00	5813	2.99	Rev 26
HAXX625	RTCC	21:21:30:00	21:20:57:00	22:00:02:07:1	4052	4.46	Docking and sep revs 27 and 28
HSXN651	RTCC	22:00:03:06	22:00:02:07:1	22:02:57:00	3065	2.05	Post sep and rev 29
CDSX657	RTCC	22:01:20:12	22:02:57:00	22:04:58:12	7604	5.00	Rev 30
ANIC695	RTCC	22:07:37:36	22:04:58:12	22:14:00:00	---	---	IEI
PNO**	RTACF	22:20:01:54:53	22:14:00:00	22:20:02:05:29	---	0.1	MCCS
PAO	RTACF	23:05:31:59:99	23:20:02:05:29	23:15:10:00	19159	0.3	CSH/LW sep
PAO	RTACF	23:15:31:59:99	23:15:30:00	24:01:30:00	20419	0.4	
PAO	RTACF	24:01:32:00	24:01:30:00	24:16:21:18	21093	4.7	Entry Interface
PAO	RTACF	24:16:35:06	25:16:21:10	24:16:35:06	---	---	

\*Real Time computer center (RTCC) on-line 1st path.

\*\*Post flight auxiliary computer facility (RTACF) check-out monitor for the Postflight Analysis Office (PAO).

Table A.2 Apollo 11 LM NAT Trajectories

Vector	Source	Vector Time (d:h:m:s) GMT	Trajectory Interval (d:h:m:s) GMT	ΔR (ft)	ΔV (fps)	Comment
MSFN FIT	TRW	20:19:08:06.6	20:17:45:38.	20:19:08:14.1	---	---
REAL TIME	MPAD	20:20:04:35.17	20:19:08:43.9	20:20:05:04.4	---	DOI to PDI
MSFN FIT	TRW	21:18:01:14.88	21:18:01:14.88	21:18:51:34.7	8400	0.7
MSFN FIT	TRW	21:19:49:46	21:18:52:21.7	21:19:49:46	8558	1.4
MSFN FIT	TRW	21:19:50:04.08	21:19:50:04.08	21:20:36:30.8	---	CDH to TPI

## APPENDIX B

### Supplementary Data

Appendix B contains supplementary information which is too detailed for the main body of the report. This information includes a summary of the radar data used in each BET fit segment, a summary of ground and on-board data weights used in HOPE, a summary of the USBS station locations, and a summary of the components used in the R2 and L1 lunar potential models.

Tables B.1 and B.2 list by vehicle statistics computed from the data used in each BET fit, the type and number of observables, and the mean and standard deviations obtained from the residuals calculated in the final iteration of the fit. The range statistics are in feet, doppler units are cycles per second, range rate units are in feet per second, and angular units are degrees.

Table B.3 lists the data weights used in the HOPE Program for ground based radar data and Table B.4 lists the data weights used in the HOPE Program for onboard data by type of observable.

Table B.5 lists the terms of the R2 lunar potential model.

Table B.6 lists the terms of the Langley 1 lunar potential mode, a modification of the R2 model.

Table B.7 lists the S-band tracking stations and their locations as used in the Apollo 11 postflight analysis. All locations are referenced to the Fischer Ellipsoid of 1960. The mean surface refractivity numbers for each station for the month of July are also listed.

Table B.1 CSM BET Ground Based Tracking Data Statistics

<u>Station</u>	<u>Data Type</u>	<u>Number of OBS</u>	<u>Mean</u>	<u><math>\sigma</math></u>
Rev 13 Segment				
MAD	2-way doppler	122	-.013	.236
MIL	3-way doppler	103	-.009	.246
ACN	3-way doppler	101	-.018	.235
Rev 14 Segment				
MAD	2-way doppler	142	.002	.186
GDS	3-way doppler	138	.009	.182
ACN	3-way doppler	63	-.004	.171
Rev 25 Segment				
MAD	2-way doppler	136	.002	.160
MIL	3-way doppler	52	.001	.165
ACN	3-way doppler	47	.007	.157
Rev 26 Segment				
MAD	2-way doppler	128	.001	.223
MIL	3-way doppler	114	.0005	.199
ACN	3-way doppler	114	.005	.188
GDS	3-way doppler	70	.006	.182

**Table B.2 LM BET Ground Based and Onboard Tracking Data Statistics**

<u>Station</u>	<u>Data Type</u>	<u>Number of OBS</u>	<u>Mean</u>	<u><math>\sigma</math></u>
Undock to DOI Segment				
RID	2-way doppler	141	-.023	.193
CYI	3-way doppler	140	-.049	.202
ACN	3-way doppler	112	-.014	.193
ANG	3-way doppler	137	.030	.219
MIL	3-way doppler	114	-.012	.189
DOI to PDI Segment				
Sextant shaft		13	-.0097	.015
Sextant trunnion		13	-.0004	.004
VHF ranging		18	-26.000	74.000
Insertion to CSI Segment				
RID	2-way doppler	74	-.022	.315
BDA	3-way doppler	69	-.019	.319
ANG	3-way doppler	72	.059	.315
ACN	3-way doppler	60	.011	.320
MIL	3-way doppler	63	.014	.316
CDH to Post-TPI Segment				
Sextant shaft		31	.030	.026
Sextant trunnion		31	..011	.023
VHF ranging		29	-394.000	222.000
Rend. radar shaft		65	-.012	.107
Rend. radar trunnion		65	-.084	.056
Rend. radar range		65	142.000	271.000
Rend. radar range rate		65	-.115	.543

Table B.3 Ground Based Radar Data Weighting

Data Type	Radar	Weighting
Range	USB: 30-ft. antenna 85-ft. antenna	600 ft.
Doppler (2-way)	USB: 30-ft. antenna 85-ft. antenna	0.1 cycle/sec.
Doppler (3-way)	USB: 30-ft. antenna 85-ft. antenna	0.1 cycle/sec.

Table B.4 Onboard Data Weighting

Data Type	Shaft	Trunnion	Range	Range Rate
Rendezvous radar	.01	.01	30.	1.
Sextant	.001	.001		
VEF ranging			30.	

Table B.5 R2 Lunar Potential Model

Term	Value
J2	$2.07108 \times 10^{-4}$
J3	$-2.1 \times 10^{-5}$
C22	$2.0716 \times 10^{-5}$
C31	$3.4 \times 10^{-5}$
All other harmonics are zero	

Table B.6 L1 Lunar Potential Model

Term	Value
J2	$2.07180 \times 10^{-4}$
J3	$-2.1 \times 10^{-5}$
C22	$2.0716 \times 10^{-5}$
C31	$3.4 \times 10^{-5}$
C33	$2.583 \times 10^{-6}$
All other harmonics are zero	

Table B.7 USRS Station Locations

Station	Antenna	Identification	Latitude*	Longitude*	Altitude*	Surface Refractivity
			(deg.)	(deg.)	(ft.)	
Antigua	30'	ANG	17.01692	298.24715	141.08	378
Ascension	30'	ACN	-7.95510	345.67330	1843.83	353
Bermuda	30'	BDA	32.35195	295.34287	68.90	377
Canary Island	30'	CYI	27.76454	344.36519	567.69	343
Honeysuckle Creek	85'	HSK	-35.58361	148.97805	3757.55	296
Carnarvon	30'	CRO	-24.90705	133.72620	82.00	325
Goldstone	85'	GDS	35.34154	243.12655	2975.066	279
Grand Bahama	30'	GMB	26.63286	281.76234	16.40	386
Guam	30'	GMM	13.31062	144.73747	416.67	373
Guaymas	30'	GYM	27.96382	249.27943	62.34	368
Hawaii	30'	HAW	22.12666	200.33528	3772.97	308
Madrid	85'	MAD	40.45514	355.83183	2551.18	299
Merritt Island	30'	MIL	28.50866	279.30738	32.81	385
Texas	30'	TEX	27.65428	262.62220	32.81	395
Honeysuckle Creek Wing	85'	NBE	-35.40111	148.98153	2199.15	296
Goldstone Wing	85'	PTR	35.38952	243.14078	3186.02	279
Madrid Wing	85'	RID	40.42843	355.75128	2524.93	299

\*All quantities are referenced to the Fischer Ellipsoid of 1960.

## APPENDIX C

### LM Rendezvous Radar Data, CSM VHF Ranging Data and CSM Sextant (Apollo 11)

The LM rendezvous radar data that was used in the analysis are listed in the two card format of the HOPE orbit determination program. The first card specifies the vehicle taking the observation, the vehicle that is being observed, the time of the observation (year (mod 1900), month, day, hour, minute, and second (GMT)), three code numbers, shaft observable, trunnion observable, range observable, and range rate observable. The second card specifies the inner, middle, and outer gimbal angles. The units are feet, degrees, and seconds.

The CSM VHF ranging data are also listed in the same format. The card format differences are the following: 1) vehicle ID's are reversed, 2) code numbers are different, 3) range is the only observable, and 4) gimbal angles are not needed to process the ranging data.

The CSM sextant data are also listed. The card format is also similar to the rendezvous radar cards.

VEH1 VEH2 YYMMDDHHMMSS.SSS XFSHAFT(DEG) TRUN(IFT) RANGE(FT) RRATE(IFPS)  
           INNER(DEC) MIDDLE(DEC) OUTER(DEC)

CSM	LEM	69	720184617.695	62	88.2641602	29.1824434	1
CSM	LEM	69	7201925	3.547114	54.6350098	4.6472168	2
						338.5437012	1
						84093.437	2
CSM	LEM	69	720192534.824	62	5163574	23.3789155	1
CSM	LEM	69	720192540.676	62	327.7551270	1.8347168	2
CSM	LEM	69	7201926	3.816114	6372070	23.3349702	1
CSM	LEM	69	720192729.605114		327.9528809	1.8457031	2
CSM	LEM	69	720192610.746	62	1.2524414	22.9257295	1
CSM	LEM	69	720192839.305114		329.1064453	1.8676758	2
CSM	LEM	69	720192746.867	62	4174805	22.0852754	1
CSM	LEM	69	720193019.016114		332.3254395	2.0214844	2
CSM	LEM	69	720192856.437	62	359.9121094	22.3022554	1
CSM	LEM	69	720193026.348	62	333.7866211	2.1643066	2
CSM	LEM	69	720193133.504114		359.7253418	22.1319673	1
CSM	LEM	69	720193112.766	62	336.0058594	2.2631836	2
CSM	LEM	69	720193212.098	62	359.5056152	22.1786592	1
CSM	LEM	69	720193234.348114		336.9177246	2.3510742	2
CSM	LEM	69	720193212.098	62	5493164	22.4670503	1
					337.7526855	2.6158691	2
						3.5156250	1

CSM	LEM	69	720193335•516114		144915•354
CSM	LEM	69	7201933 1•707 62	359•3627930	23•0026338
CSM	LEM	69	720193436•426114	338•0273437	2•6696777
CSM	LEM	69	720193538•477114		155791•600
CSM	LEM	69	7201934 1•316 62	339•1369629	167700•785
CSM	LEM	69	720193638•824114		
CSM	LEM	69	720193612•625 62	1•1206055	22•7362154
CSM	LEM	69	720193741•965114	340•9167480	2•8125000
CSM	LEM	69	720193718•957 62	341•3562012	3•1311035
CSM	LEM	69	720193850•777114		194435•693
CSM	LEM	69	720193829•965 62	2307129	22•0221040
CSM	LEM	69	720193953•195114	340•7299805	3•2958984
CSM	LEM	69	720194053•867114		4•4714355
CSM	LEM	69	720194154•324114		211023•488
CSM	LEM	69	720194254•785114		
CSM	LEM	69	720194356•004114		299127•164

## INS TO CSI

VEH1 VEH2 YYMMDDHHMMSS.SSSS XFSHAFT(DEG) TRUN(DEG) RANGE(FT) RRATE(FPS)  
 INNER(DEG) MIDDLE(DEG) OUTER(DEG)

CSM	LEM	69	721182722.246	62	359.3078613	22.7444551	1.5380859	1
LEM	CSM	69	721183052.766	11	359.9890137	1.6699219	888923.836	2
LEM	CSM	69	721183158.105	11	359.5605469	1.0437012	.1098633	2
LEM	CSM	69	72118333.746	11	359.9670410	0.0769043	876692.312	1
LEM	CSM	69	721183415.707	11	357.8906250	1.0437012	.1428223	2
LEM	CSM	69	721183523.215	11	354.1003418	0.0439453	864835.992	2
LEM	CSM	69	721183641.754	11	249.8620605	1.1096191	.2087402	2
LEM	CSM	69	721183737.504	11	354.1113281	359.3188477	854105.273	2
LEM	CSM	69	721183719.246	11	245.4125977	0.9448242	.8789063	2
LEM	CSM	69	721183749.316	62	356.2646484	355.5175781	844350.078	2
LEM	CSM	69	721183753.215	11	242.1936035	2.9113770	4.3395996	2
LEM	CSM	69	721183753.574	62	358.7145996	1.8786621	834294.719	2
CSM	LEM	69	721183749.316	62	238.6779785	357.1325684	-121.7931	2
CSM	LEM	69	721183749.316	62	0.8459473	3.82043.516	-136.8601	2
LEM	CSM	69	721183753.215	11	0.8569336	4.5483398	-118.0261	2
CSM	LEM	69	721183753.574	62	0.9667969	3.3398438	832043.516	2
CSM	LEM	69	721183842.324	62	234.4592285	3.55.4736328	-121.7931	2
CSM	LEM	69	721183842.324	62	0.8789063	2.5708008	-114.2601	2
CSM	LEM	69	721183842.324	62	0.6262207	3.829942.398	-114.2601	2
CSM	LEM	69	721183842.324	62	0.9667969	3.8562012	-114.2601	2
CSM	LEM	69	721183842.324	62	21.9534395	3.357.5939941	-114.2601	2
LEM	CSM	69	721183753.215	11	0.8569336	5.7238770	8.0.0639648	1
CSM	LEM	69	721183753.574	62	0.9667969	358.7475586	826115.359	2
CSM	LEM	69	721183842.324	62	0.8789063	21.9479463	1.6040039	2
CSM	LEM	69	721183842.324	62	0.6262207	5.7458496	8.1188965	1
CSM	LEM	69	721183842.324	62	0.9667969	21.8518159	7.3608398	1
CSM	LEM	69	721183842.324	62	0.8789063	6.0974121	818270.469	1
CSM	LEM	69	721184012.098114				812133.586	2

## CSI TO CDH

VEH1	VEH2	YYMMDDHHMMSS.SS	XFSHAFT(DEG) INNER(DEG)	MIDDLE(DEG)	RANGE(FT)	RRATE(FPS)
CSM	LEM	69 721119 217.414114			746693.828	1
CSM	LEM	69 721119 7 2.098114			731503.539	2
CSM	LEM	69 721119 8 2.566114			728283.195	1
CSM	LEM	69 721119 9 4.617114			724941.336	2
CSM	LEM	69 721119 943.887	62	1.1096191	22.5576875	1
CSM	LEM	69 721119 946.906	62	1.0656738	1.5930176	2
CSM	LEM	69 721119 10 5.555	62	259.1455078	22.6428316	1
CSM	LEM	69 72111910 9.316114		258.0139160	1.5930176	2
CSM	LEM	69 72111910 9.316114		258.0139160	22.8378389	1
CSM	LEM	69 72111910 9.316114		258.0139160	1.6259766	2
CSM	LEM	69 7211191029.414	62	1.4282227	21.2393281	1
CSM	LEM	69 7211191113.117114		258.4094238	1.6040039	2
CSM	LEM	69 7211191215.125114			714490.414	1
CSM	LEM	69 7211191258.777	62	2856445	22.6373384	2
CSM	LEM	69 7211191352.465	62	249.4555664	2.5158691	1
CSM	LEM	69 7211191357.098	62	2416992	22.6675508	2
CSM	LEM	69 7211191320.387114		249.3347168	2.5268555	1
CSM	LEM	69 7211191352.465	62	359.3298340	22.5933931	2
CSM	LEM	69 7211191357.098	62	246.7749023	3.0102539	1
CSM	LEM	69 7211191357.098	62	359.3847656	22.7691743	2
				246.3684082	3.0651855	1
					4.3505859	2

CSM	LEM	69	121191752.375114		694743.031
CSM	LEM	69	721191853.535114		690915.086
CSM	LEM	69	721191941.215 62	•6152344	22.2473238
CSM	LEM	69	721191948.887 62	229.9328613	•9997559 2.3291016
CSM	LEM	69	721191948.887 62	•4724121	22.4121187
CSM	LEM	69	7211920 8.625114	229.3945312	1.0327148 2.2961426
CSM	LEM	69	7211921 3.785 62	359.3957520	21.9946382
CSM	LEM	69	721192125.965114	226.1096191	1.1645508 1.7907715
CSM	LEM	69	7211922 3.438 62	358.4948730	22.1621797
CSM	LEM	69	721192226.598114	223.0224609	1.3842773 1.5380859
CSM	LEM	69	7211923 7.707 62	•7910156	22.8625581
CSM	LEM	69	721192424.516 62	219.1992187	1.0217285 2.6257324
CSM	LEM	69	721192545.574114	359.6594238	22.0660493
CSM	LEM	69	721192548.605 62	216.2438965	•6481934 1.3183594
CSM	LEM	69	721192548.605 62	358.6157227	22.0687959
CSM	LEM	69	7211926 9.484 62	212.1679687	•3845215 2.856445
CSM	LEM	69	721192933.285 62	359.0002441	21.8655488
CSM	LEM	69	721192935.656 11	211.3549805	•3186035 •4504395
CSM	LEM	69	721193041.336 11	358.7145996	21.8902681
CSM	LEM	69	721193052.586114	201.4892578	•1538086
CSM	LEM	69	721193052.586114	359.8461914	356.1877441 0.988770
CSM	LEM	69	721193052.586114	76.0144043	9.2724609 3.3288574
CSM	LEM	69	721193052.586114	354.1113281	2.3400879 638290.234
CSM	LEM	69	721193052.586114	78.5083008	•8789063 357.0886230
CSM	LEM	69	721193052.586114		636837.656
CSM	LEM	69	7211931 7.395 62	359.1979980	22.0193574
CSM	LEM	69	721193142.527 62	196.8200684	•0329590 2.636719
CSM	LEM	69	721193142.527 62	358.8684082	22.0578096
CSM	LEM	69	721193142.527 62	195.0952148	•0109863 0.329590

LEM	CSM	69	721193149.0117	11	359.0551758	359.9011230	632287.039	-90.4031
LEM	CSM	69	7211932 1.266	62	70.4113770	7.6574707	359.4946289	2
LEM	CSM	69	7211932 2.215114		358.6816406	22.0578096		1
LEM	CSM	69	7211932 2.215114		194.2053223	.0219727	359.9340820	2
LEM	CSM	69	7211934 4.824	11	630700.781			1
LEM	CSM	69	72119342.035	11	22.0468233			2
LEM	CSM	69	721193512.375	11	193.1066895	.0549316	359.8352051	2
LEM	CSM	69	721193617.215	11	357.05717773	357.1875000	6259983.672	-93.5421
LEM	CSM	69	7211936.617	11	67.5878906	1.3293457	2.2851563	2
LEM	CSM	69	721193736.617	11	624867.711			1
LEM	CSM	69	721193842.035	11	359.328	3518066	619605.273	-96.0531
LEM	CSM	69	721194047.637	11	61.8640137	7.3498535	.2966309	2
LEM	CSM	69	7211941 6.355	11	357.2753906	2.5378418	613076.797	-98.5651
LEM	CSM	69	721194144.145	11	62.3693848	355.5834961	357.1545410	-101.0761
LEM	CSM	69	721194144.145	11	355.4956055	4.6252441	606623.359	-104.8431
LEM	CSM	69	7211942 4.105	11	61.1718750	5.3063965	354.4299316	2
LEM	CSM	69	7211942 4.105	11	356.5393066	354.8803711	598519.039	
LEM	CSM	69	7211942 4.105	11	56.3269043	4.1308594	4.3615723	2
LEM	CSM	69	7211942 4.105	11	62307129	354.8474121	591540.312	-106.7261
LEM	CSM	69	7211942 4.105	11	49.5922852	10.7226562	4.6691895	2
LEM	CSM	69	7211942 4.105	11	353.4411621	357.3193359	577807.992	-111.7481
LEM	CSM	69	7211942 4.105	11	50.3833008	3.9111328	1.7138672	2
LEM	CSM	69	7211942 4.105	11	1.67578125	356.2536621	575706.875	-112.3761
LEM	CSM	69	7211942 4.105	11	41.2426758	9.5581055	3.5156250	2
LEM	CSM	69	72119425.125	11	64284668	.2526855	573680.797	-113.6321
LEM	CSM	69	72119425.125	11	41.6491699	4.9438477	359.2749023	2
LEM	CSM	69	72119425.125	11	356.6601562	4.3505859	571429.594	-114.2601
LEM	CSM	69	72119425.125	11	43.5168457	359.3627930	354.8583984	2
LEM	CSM	69	721194227.074	11	355.2209473	3.7792969	566551.992	-115.5151
LEM	CSM	69	721194227.074	11	43.9343262	1.7578125	355.5285645	2
LEM	CSM	69	721194246.027	11	354.0154102	3.2409668	564375.836	-116.1431
LEM	CSM	69	7211943 5.457	11	44.2199707	2.8564453	355.9130859	2
LEM	CSM	69	7211943 5.457	11	353.3203125	2.4938965	562124.633	-116.7711
LEM	CSM	69	721194324.848	11	44.0222168	2.5927734	356.6601562	-118.0261
LEM	CSM	69	721194324.848	11	357.0336914	1.5380859	559873.437	2
LEM	CSM	69	721194533	11	39.4189453	2.8454590	357.7917480	2

LEM	CSM	69	721194347	•3667	11	2•8564453	•4614258	557171•992	-118•0261
						32•5195313	•0988770	359•0332031	2
LEM	CSM	69	7211944	7•426	11	2•4279785	359•2199707	554770•719	-118•6541
						32•0141602	4•4384766	•4504395	2

## CDH TO TPI

VEH1	VEH2	YMMDDHHMMSS.SSS	XFSHAFT(DEG)	TRUN(DEG)	RANGE(FT)	RRATE(FPS)
			INNER(DEG)	MIDDLE(DEG)	OUTER(DEG)	
LEM	CSM	69 721195358.598	11 358.5058594	353.4082031	481156.477	-124.3041
LEM	CSM	69 7211955 3.687	11 7.8552246	353.7487793	6.3281250	2
LEM	CSM	69 721195535.055114	1.5380859	3.2629395	473127.199	-123.6771
LEM	CSM	69 7211956 9.316	11 1.6259766	348.9807129	356.0339355	2
LEM	CSM	69 721195717.098	11 355.4626465	355.8471680	465097.918	-123.0491
LEM	CSM	69 721195738.605114	4.6472168	356.1328125	4.0649414	2
LEM	CSM	69 721195824.957	11 354.8254395	3.9111328	448439.039	-122.4211
LEM	CSM	69 721195926.266	11 358.7475586	358.4838867	355.8361816	2
LEM	CSM	69 721195945.348114	11 350.3430176	3076172 357.9345703	5.932617 359.0441895	-122.4211
LEM	CSM	69 72120 031.117	11 359.9121094	438209.445		2
LEM	CSM	69 72120 236.715	11 347.7282715	15.1281738	433055.836	-121.7931
LEM	CSM	69 72120 318.117	11 357.7368164	357.8356934	359.6154785	2
LEM	CSM	69 72120 336.746	11 343.8171387	357.7807617	417822.719	-121.1651
LEM	CSM	69 72120 337.0605469	11 339.9060059	•0329590 7.4157715	1.9665527 359.6484375	2
LEM	CSM	69 72120 412.254	11 1.6589355	358.7915039	412870.078 410543.836	-121.1651
LEM	CSM	69 72120 348.926114	337.0605469	5.4272461	1.0766602	-120.5381
LEM	CSM	69 72120 412.254	11 1.7138672	355.8691406	406266.559	2
LEM	CSM	69 72120 335.3356934	335.3356934	4.0209961	3.9880371	2

CSM	LEM	69	72120	450.437114		401327.426	
LEM	CSM	69	72120	520.215 11	355.5834961	2.8564453	398087.199
LEM	CSM	69	72120	338.2470703	5.0207520	356.5173340	-120.5381
LEM	CSM	69	72120	357.2424316	358.3850098	389982.879	-119.9101
CSM	LEM	69	72120	333.4460449	9.8327637	•9228516	2
CSM	LEM	69	72120	655.426114		386380.180	1
CSM	LEM	69	72120	7 6.906 62	359.4506836	22.5467012	2
CSM	LEM	69	72120	93.6364746	1.0876465	1.2304688	1
CSM	LEM	69	72120	359.3408203	22.5851533		2
LEM	CSM	69	72120	93.2739258	1.1755371	1.2744141	2
LEM	CSM	69	72120	359.0659180	359.3737793	381878.559	-119.2821
CSM	LEM	69	72120	327.3706055	•7690430	•4724121	2
CSM	LEM	69	72120	756.324114		379149.602	1
CSM	LEM	69	72120	813.984 62	359.7692871	22.8350923	2
LEM	CSM	69	72120	90.1977539	1.3732910	1.8237305	1
CSM	LEM	69	72120	358.5498047	2.4499512	373999.359	-118.6541
CSM	LEM	69	72120	325.7336426	•7800293	357.4072266	2
CSM	LEM	69	72120	359.2858887	22.3791597		2
CSM	LEM	69	72120	89.1979980	1.4721680	1.5820313	1
CSM	LEM	69	72120	6.414114		370825.324	2
CSM	LEM	69	72120	917.125 62	358.7145996	21.8023775	2
LEM	CSM	69	72120	88.2751465	1.5930176	1.3183594	2
CSM	LEM	69	72120	355.8581543	3.9550781	365895.039	-118.6541
CSM	LEM	69	72120	325.2392578	1.0546875	355.8691406	2
CSM	LEM	69	72120	358.5607910	22.0330904		2
CSM	LEM	69	72120	86.2866211	1.5930176	1.1975098	1
LEM	CSM	69	721201059.355 11	358.5827637	4.0759277	357865.758	-118.0261
CSM	LEM	69	7212011 5.098 62	319.3395996	1.4392090	355.8471680	2
CSM	LEM	69	721201128.637114	•1318359	22.8433321	1.4172363	1
LEM	CSM	69	721201310.047 11	357.1655273	1.0546875	354055.246	2
LEM	CSM	69	721201310.047 11	358.9453125	342482.559	-116.7711	1
LEM	CSM	69	7033691	359.3627930	1.1206055	2	2

LEM	CSM	69	721201328•746	11	353•8366699	357•7258301	340306•398	-116•7711
CSM	LEM	69	721201339•566	62	359•7802734	22•7746675	2•3620605	2
LEM	CSM	69	721201347•437	11	354•5178223	356•2097168	338130•238	-117•3991
CSM	LEM	69	721201434•098	62	315•6152344	•3845215	3•8342285	2
CSM	LEM	69	721201436•617114		72•8723145	22•5192354	1•9555664	1
CSM	LEM	69	721201447•098	62	359•6594238	22•7499483	332059•707	1
CSM	LEM	69	721201452•555	11	357•4951172	2•7136230	1•8786621	2
LEM	CSM	69	721201816•816	11	309•6826172	357•1325684	330551•199	-116•7711
LEM	CSM	69	72120209•406	11	356•8249512	358•4838867	357•5280762	2
LEM	CSM	69	721202038•305	11	307•2436523	1•9885254	322596•957	-115•5151
LEM	CSM	69	72120178•656	11	2•0764160	359•4177246	1•5600586	-115•5151
LEM	CSM	69	72120209•406	11	298•8830566	3•8122559	9228516	2
LEM	CSM	69	721202038•305	11	354•5068359	3•9770508	306876•078	-114•8871
LEM	CSM	69	721202020	9•406	303•3984375	357•4401855	356•5173340	-114•2601
LEM	CSM	69	721202251•035	11	3186035	358•9892578	294006•719	-113•6321
LEM	CSM	69	721202424•887	11	292•5878906	358•3410645	1•3732910	2
LEM	CSM	69	721202454•957	11	256•2426758	•5383301	290695•578	-113•6321
LEM	CSM	69	721202145•957	11	295•4223633	355•3527832	•1538086	2
LEM	CSM	69	721202251•035	11	358•0554199	•1867676	283032•117	-113•6321
LEM	CSM	69	721202424•887	11	288•0944824	1•6259766	4504395	2
LEM	CSM	69	721202454•926	11	282•3706055	•0549316	265125•699	-112•3761
LEM	CSM	69	721202532•207	11	359•8681641	6•7016602	•4394531	2
LEM	CSM	69	721202513•324	11	280•5578613	3•4167480	261748•898	-111•7481
LEM	CSM	69	721202550•605	11	359•7473145	359•5056152	•8239746	2
LEM	CSM	69	721202550•605	11	279•9755859	358•0883789	259694•680	-112•3761
LEM	CSM	69	721202532•207	11	358•6486816	358•7255859	257593•559	-111•7481
LEM	CSM	69	721202513•324	11	280•2832031	357•3303223	1•9775391	2
LEM	CSM	69	721202550•605	11	356•8029785	357•6379395	255558•100	-111•7481
LEM	CSM	69	72120269•004	11	281•3049316	359•8242187	3•0432129	2
LEM	CSM	69	72120269•004	11	354•1333008	356•2536621	253513•260	-111•7481
					283•1616211	2•8674316	4•1638184	2

LEM	CSM	69	721202627.586	11	350.5078125	354.3969727	251440.279	-111.1211
					285.9741211	6.4270020	5.3063965	2
LEM	CSM	69	721202646.504	11	346.2451172	351.9360352	249329.779	-111.1211
					289.4567871	10.7666016	6.4050293	2
LEM	CSM	69	7212027 5.555	11	343.1799316	354.0563965	247209.898	-111.1211
					291.6979980	6.6467285	4.9768066	2
LEM	CSM	69	721202724.695	11	350.3430176	•4724121	245099.398	-111.1211
					283.8208008	1.8237305	359.9890137	2
LEM	CSM	69	721202743.746	11	359.8352051	•0109863	242998.279	-110.4931
					273.5266113	359.9890137	•7470703	2
LEM	CSM	69	7212028 2.785	11	3186035	357.4731445	240906.539	-110.4931
					272.2961426	358.0773926	3.2958984	2
LEM	CSM	69	721202821.785	11	359.7912598	354.8913574	238814.799	-109.8651
					272.0874023	356.7041016	5.9216309	2
LEM	CSM	69	721202840.785	11	359.3188477	356.2316895	236732.439	-110.4931
					271.7578125	359.0332031	4.6032715	2
LEM	CSM	69	721202859.797	11	358.8574219	357.6818848	234640.699	-109.8651
					271.4172363	•1757813	3.1530762	2
LEM	CSM	69	721202918.816	11	1428223	358.9892578	232548.959	-109.8651
					269.3408203	1.0546875	1.8786621	2
LEM	CSM	69	721202937.816	11	358.6816406	2526855	230466.600	-109.2371
					270.0439453	•9777832	•6042480	2

## APPENDIX D

### Apollo 11 Landing Radar Data

The LM landing radar data that was used in the analysis is listed in the two card format of the HOPE orbit determination program. The first card specifies the vehicle, the time of the observation (year (mod 1900), month, day, hour, minute, and second), three code numbers,  $V_{XA}$  measurement,  $V_{YA}$  measurement,  $V_{ZA}$  measurement, and the slant range measurement ( $\rho$ ). The second card specifies the inner, middle, and the outer gimbal angles. The units are feet and feet per second.

## LANDING RADAR OBSERVATIONS

VEHI VY(MDDHHMMSS.SSS) XFVX(FPS)  
 INNER(DEG) MIDDLE(DEG) OUTER(DEG) VY(FPS)  
 VZ(FPS) RANGE(FT)

LEM	69	72020 953.164125	77.1564941	.2746582	28.026123	43753.45r1
LEM	69	72020 955.164125	78.9147949	359.7583008	20.3796387	41897.57r1
LEM	69	72020 957.164125	78.3654785	359.9450684	12.7001953	41144.1951
LEM	69	72020 958.164125	77.9599844	.6701666	4.9329613	39329.55r1
LEM	69	72020 1.164125	77.8401211	1.2744141	1.2524414	39005.85r1
LEM	69	72020 10 3.164125	78.0468750	1.1865234	3.0541992	38671.36r1
LEM	69	72020 10 5.164125	78.1457520	.1861676	3.6694336	38520.30r1
LEM	69	72020 10 7.164125	77.9919434	358.9782715	3.9221191	38444.77r1
LEM	69	72020 10 9.164125	77.7502441	353.8793945	4.5593262	37781.1851
LEM	69	72020 1011.164125	77.2558594	359.9352051	5.2284922	37473.66r1
LEM	69	72020 1013.164125	77.9340527	.3569336	4.7680664	37295.6351
LEM	69	72020 1015.164125	77.8491211	1.2634277	3.8891602	37284.8451
LEM	69	72020 1017.164125	77.2448730	.6921387	4.2187590	36594.2851
LEM	69	72020 1019.164125	77.4645996	.5673327	5.0267520	36480.99r1
LEM	69	72020 1021.164125	77.3657227	1.3732910	4.9387793	35666.3451
LEM	69	72020 1025.164125	77.1700551	350.5758594	3.1211172	35785.0351

LEM	69 720201020.164125	76.8933175	359.34.8203	2.96663086	35161.5941
LEM	69 720201031.164125	76.1632120	•8784.063	3.186 352	34262.401
LEM	69 720201033.164125	76.7724609	•7910156	3.2849121	34867.8851
LEM	69 720201035.164125	77.1130371	359.98990137	3.26229395	34511.9141
LEM	69 720201037.164125	77.3531738	359.9346820	3.1031309	34290.6201
LEM	69 720201041.164125	75.8056641	•5493164	3.0212402	33195.4351
LEM	69 720201039.164125	74.2895508	•6811523	2.9223633	33119.9151
LEM	69 720201043.164125	75.3222656	•2307129	2.8894043	33087.5351
LEM	69 720201045.164125	76.5197754	•3878906	2.9443359	32245.9151
LEM	69 720201047.164125	74.0036062	359.6484375	2.9553223	31733.3001
LEM	69 720201049.164125	73.9163156	1.4721680	2.9553223	31560.7501
LEM	69 720201051.164125	73.4436035	•7031250	2.8344727	30860.0551
LEM	69 720201053.164125	72.6635742	359.6704102	2.7355957	31514.1201
LEM	69 720201054.164125	72.9492188	359.8022461	1.1206055	2
LEM	69 720201055.164125	72.9931641	359.8352051	1204.332	1
LEM	69 720201057.164125	73.2128906	359.8022461	358.6596680	32449.3301
LEM	69 720201059.164125	72.0373535	359.644922	359.3551758	31109.4951
LEM	69 720201058.176125	70.6640625	-94.0511999	359.2968750	29311.0351
LEM	69 72020111.246125	71.7977637	•1310359	359.3408203	1
LEM	69 720201111.164125	77.1636777	1.1216055	359.8352051	28894.8301

LEM	65 7202011 3.164125	71.1584473	.83496039	.1098633	27573.8451
LEM	65 7202011 5.164125	70.0277344	-3.76172	.2746582	26388.4001
LEM	65 7202011 6.277125	70.0048829	-46.055998		2
LEM	65 7202011 7.164125	69.0270096	359.9450684	.3735352	1
LEM	65 7202011 7.934125	68.9541406	.3076172	176.941	2
LEM	65 72020111 9.164125	68.7963867	.5712891	.4394531	27325.6751
LEM	65 72020111 1.164125	69.5324707	-0.297556	.4394531	27309.4001
LEM	65 720201111.957125	68.8203457	-04.7783955	.4394531	26921.0501
LEM	65 720201113.957125	69.5174805	359.4177246	.31986035	2
LEM	65 720201113.164125	68.3459473	359.4177246	138.975	1
LEM	65 720201113.957125	67.9174805	359.436426	.3205898	2
LEM	65 720201113.164125	68.3459473	359.4177246	26726.8301	
LEM	65 720201117.164125	67.9284668	.4284668	.2526855	2
LEM	65 720201117.164125	66.8627930	.9008789	.1318359	26273.6501
LEM	65 720201115.164125	67.9284668	.4284668	.2526855	2
LEM	65 720201117.957125	66.8627930	-59.6302952	.0540316	25836.6551
LEM	65 720201119.164125	66.4562988	.8560336		25797.1751
LEM	65 720201119.164125	65.9729004	.6011523	359.6346820	25798.8901
LEM	65 720201119.957125	66.4233398	1.0107422	359.6374512	2
LEM	65 720201123.164125	67.1044922	-81.4463987	.0540316	2
LEM	65 720201124.086125	65.6872559	.5383301	359.7602871	25317.9451
LEM	65 720201125.164125	65.6872559	.5383301	136.895	2
LEM	65 720201126.086125	65.9729004	.6011523	359.6346820	25317.9451
LEM	65 720201127.164125	67.7636719	.2526855	358.9182715	25361.8951

LEM	69 720201125.164125	68.4228516	.9887695	358.9672852	25016.6151
LFM	69 720201135.055125	67.5433453	.4064941	358.9233398	2
LEM	69 720201131.164125	66.6870117	-95.5056030	358.9892578	1
LEM	69 720201131.926125	66.5441895	359.7253418	358.9782715	2
LEM	69 720201133.164125	66.1816406	359.5275879	359.0332031	1
LEM	69 720201135.164125	67.3022461	359.6594238	359.0022441	2
LEM	69 720201135.897125	66.9177246	-73.6806000	359.0112305	1
LEM	69 720201137.164125	66.9177246	.0433453	358.9782715	2
LEM	69 720201137.895125	67.2363281	.7250977	359.0112305	2
LEM	69 720201139.164125	66.4562988	.2526955	358.9343262	1
LEM	69 720201139.897125-973.4935837	66.1486816	359.9343820	359.0441895	2
LEM	69 720201141.164125	65.6652832	359.5635469	359.0332031	1
LEM	69 720201141.397125	65.7212148	359.9340820	359.1101074	2
LEM	69 720201145.055125	65.5554190	-74.4167995	359.1540527	1
LEM	69 720201143.164125	65.3796387	1.3513184	359.1870117	2
LEM	69 720201143.965125	64.7534180	1.3732910	359.2529297	1
LEM	69 720201145.875125-912.5479889	63.2712637	.6591797	359.1979980	2
LEM	69 720201147.164125	63.5898672	.5053711	359.2309570	1
LEM	69 720201147.895125	62.9077148	.1423223	359.1760254	2
LEM	69 720201149.164125	63.5559082	-89.2343988	359.1760254	1
LEM	69 720201149.164125	64.1793213	1.1755371	359.1650391	2

LEM	69 720201143..926125	64.346023A	.1.4252227	359.6801211	920.542	1
LEM	69 720201151..164125	63.50.0766	.6811523	359.6771484	22254.3751	2
LEM	69 720201151..855125..891..4247894	63.3471680	.4064041	359.0441895	1	2
LEM	69 720201153..164125	62.5451660	359.7473145	359.2529207	21542.02351	2
LEM	69 720201153..897125	62.4572754	359.5035050	359.3627930	21252.351	2
LEM	69 720201155..164125	62.1057129	359.7692871	359.5715332	2	1
LFM	69 720201155..837125	62.0617676	359.7121094	359.7143555	611.181	1
LEM	69 720201157..164125	62.0517812	.6262237	359.9711231	2~921.81	1
LEM	69 720201157..895125-845..0567856	61.0510943	.8459473	.0549316	2	2
LEM	69 720201159..164125	61.9628906	1.5930176	.1757813	21835.4901	2
LEM	69 720201159..855125	61.2817383	-40.7231994	1.2854004	.2856445	1
LEM	69 7202012 1..164125	60.9312989	1.3942773	.3845215	21)376.9151	2
LEM	69 7202012 1..887125	60.2050781	.9947559	.4284668	905.633	1
LEM	69 7202012 3..164125	60.2329687	.9937559	.5393311	20139.5351	2
LEM	69 7202012 3..895125-791..4759903	59.9633789	.6701660	.5383301	19923.7351	2
LEM	69 7202012 5..164125	60.5346680	.6152344	.6262207	19643.1951	2
LEM	69 7202012 5..887125	60.5017090	-62.5391994	.6262207	846.517	1
LEM	69 7202012 7..164125	61.2268366	.3735352	.6481934	6591797	2
LEM	69 7202012 7..887125	61.2537656	.4724121	.6591797	10443.0751	2
LEM	69 7202012 9..164125	61..4355469	.4284669	.6152344	7	1
LEM	69 7202012 9..897125..787..2255859					

LEM	69	720201211.164125	61.3476562	• 8235746	• 6481934	16059.35 <sup>r1</sup>	2
LEM	69	720201211.895125	60.3992331	• 8789663	• 5932617	2	1
LEM	69	720201213.164125	60.7653809	-40.3655995	• 5822754	2	1
LEM	69	720201213.895125	59.8255566	1.7468262	• 5493164	2	1
LFM	69	720201213.895125	59.7436523	2.3513742	835.422 • 4943848	2	1
LFM	69	720201215.164125	58.9196777	1.3073730	• 4284668	2	1
LEM	69	720201215.957125-734.4175873	59.1833496	1.3217285	• 2856445	2	1
LEM	69	720201217.164125	58.7878418	• 0549316	17981.5351	2	1
LEM	69	720201217.937125	59.6118164	-68.5991993	• 3405762	2	1
LEM	69	720201219.164125	59.9743652	• 8020020	359.8681641	2	1
LEM	69	720201219.895125	60.6445313	1.2634277	783.587 • 359.7473145	2	1
LEM	69	720201221.164125	59.6777344	1.0107422	17522.9601	2	1
LEM	69	720201221.895125-713.8095856	59.4140625	• 5922754	359.4067303	2	1
LEM	69	720201223.164125	58.5681152	• 3625488	17103.8651	2	1
LEM	69	720201223.895125	58.4033203	-74.1743094	359.3078613	2	1
LEM	69	720201225.164125	58.2495117	• 3405762	16859.3751	2	1
LEM	69	720201225.926125	58.2385254	• 2197266	766.945 350.4726562	2	1
LEM	69	720201227.164125	58.6560059	1.0766602	16600.4151	2	1
LEM	69	720201227.895125-679.8063812	58.7219238	1.1425781	359.5385742	2	1
LEM	69	720201229.164125	59.1833496	1.9896484	16422.39 <sup>r1</sup>	2	1
LEM	69	720201229.805125	58.4912169	-49.9647999	359.5495605	2	1

LEM	69	720201231.164125	58.1945801	1.1755371	359.5166016	16023.1561
LEM	69	720201231.895125	57.4914551	.9118652	359.4726562	1
LEM	69	720201233.164125	57.5463867	.7800293	359.3957520	2
LEM	69	720201233.887125-636.2719879	57.0849609	.9228516	359.4506836	15683.2651
LEM	69	720201235.164125	57.5024414	1.0327148	359.5166016	2
LEM	69	720201235.887125	57.2827148	-46.5407996	359.5825195	1
LEM	69	720201237.164125	57.7985723	1.5161133	359.6264648	2
LEM	69	720201237.895125	57.8979492	1.9445801	359.6264649	15122.1851
LEM	69	720201239.164125	58.6120605	1.6040039	359.6594238	1
LEM	69	720201239.937125-628.5439911	58.7438965	1.6149902	359.6154785	2
LEM	69	720201241.164125	58.5351562	1.4064941	359.6154785	14474.7851
LEM	69	720201242.055125	57.9748535	-51.8736000	359.5495605	1
LEM	69	720201243.164125	56.9860840	.5603627	359.5605469	14145.6901
LEM	69	720201243.895125	56.8762207	.9887695	359.5385742	2
LEM	69	720201245.164125	56.6674805	.8459473	359.4616699	13916.5951
LEM	69	720201245.957125-591.8359909	57.5573730	.71411113	359.4177246	1
LEM	69	720201247.164125	57.9198219	-56.4791994	359.4067383	2
LEM	69	720201247.895125	58.3593750	.3295898	359.5275879	1
LEM	69	720201249.164125	56.9531250	1.2963867	359.7253418	13190.7151
LEM	69	720201249.895125	56.5026855	1.5930176	359.8681641	1
LEM	69	720201251.164125			12910.2351	2

LEM	69	720201251.0.895125-543.9455948	55.6457520	1.7248535	.000000000	2
LEM	69	720201253.164125	55.9643555	1.0107422	.0769043	1
LEM	69	720201253.937125	56.0961914	.5053711	.12516.4001	2
LEM	69	720201253.937125	56.6674905	-48.9647099	.1429223	1
LEM	69	720201255.164125	56.7553711	1.4062500	.0988770	2
LEM	69	720201255.887125	56.6784668	1.7358398	.2087402	1
LEM	69	720201257.0.875125-526.927916	56.4477539	2.6916504	.12322.1801	2
LEM	69	720201257.875125-526.927916	56.3598633	1.7578125	.3186035	1
LEM	69	720201259.1.164125	56.5686035	.7360840	.599.306	2
LEM	69	720201259.895125	56.5026855	-45.3287997	.3845215	1
LEM	69	7202013.1.164125	56.9750977	.7360840	.11968.4801	2
LEM	69	7202013.1.887125	56.7224121	1.1096191	.5163574	1
LEM	69	7202013.3.164125	56.8212891	2.0324707	.5053711	2
LEM	69	7202013.3.895125-501.8047905	56.4697266	2.2631836	.11437.4001	2
LEM	69	7202013.5.164125	57.1179199	1.7138672	.5383301	1
LEM	69	7202013.5.895125	57.0959473	-25.4519999	.555.272	2
LEM	69	7202013.7.164125	57.3815918	.4174805	.5712991	1
LEM	69	7202013.7.895125	56.7663574	.5053711	.11226.9951	2
LEM	69	7202013.9.164125	56.2280273	.1977539	.10957.2451	1
LEM	69	7202013.9.926125-469.6047897	55.7446289	.4064941	.10342.2151	2
LEM	69	7202013.9.926125-469.6047897	55.7446289	.2526855	.0996.0351	1
LEM	69	720201311.164125	55.6677246	.0109863	.1647949	2

LEM	69	720201311.895125	55.1446289	-44.8439999	.0769043	9743.3701
LEM	69	720201313.164125	56.1071777	359.9450684	359.9670410	2
LEM	69	720201314.055125	56.54666309	.2307129	359.8242187	1
LEM	69	720201315.164125	56.9421387	.1757813	359.7253418	?
LEM	69	720201315.926125-454.4063911	57.1728516	.7690430	359.6154785	1
LEM	69	720201317.164125	56.6125498	1.9116211	359.7253418	2
LEM	69	720201317.957125	56.6125488	-12.8471999	.355.9681641	1
LEM	69	720201319.895125	55.8984375	2.5598145	.0878906	2
LEM	69	720201321.895125	56.1730957	2.0104980	.438.427	1
LEM	69	720201321.164125	55.9753418	1.5490723	.2966309	2
LEM	69	720201321.895125-418.7287903	56.2390137	1.0437012	.4174805	1
LEM	69	720201323.164125	56.0522461	1.0986328	.4833984	2
LEM	69	720201323.895125	56.1950684	-26.6639998	.5932617	1
LEM	69	720201325.164125	55.9863281	1.1315918	.6701660	2
LEM	69	720201325.095125	55.8544922	.9777832	.7250977	1
LEM	69	720201327.164125	55.6347656	1.1315918	.8239746	2
LEM	69	720201327.895125-386.7863922	55.2512441	1.0656738	.8349609	1
LEM	69	720201329.895125	55.0964355	.9448242	.9118652	2
LEM	69	720201329.895125	54.6240234	-15.0287999	.9338379	1
LEM	69	720201331.164125	55.0315176	.5493164	.9448242	2
LEM	69	720201341.164125			6538.7401	

LEM	69	720201341.754125	46.3623047	1.7029809	-8893926	2
LEM	69	720201343.164125	46.3952637	2.2302246	217.567	1
LEM	69	720201343.895125~375.5877915	45.3955078	2.0544434	.8569336	2
LEM	69	720201345.7680430	45.7680430	1.5270996	.7910156	2
LEM	69	720201345.164125	45.3186035	.7360840	.7141113	1
LEM	69	720201345.937125	45.6481934	.75.9369000	.5383301	2
LEM	69	720201347.164125	44.3957520	1.1875098	5653.9601	2
LEM	69	720201347.965125	44.0112305	1.5930176	4614258	1
LEM	69	720201349.164125	43.3959961	2.4389648	3186035	2
LEM	69	720201349.937125~332.3020932	43.4399414	2.0874023	206.992	1
LEM	69	720201351.164125	44.1101074	.2746502	.2746502	2
LEM	69	720201351.926125	43.9792715	.0219727	5395.0001	1
LEM	69	720201353.164125	44.1101074	.18566895	1539.07912598	2
LEM	69	720201353.837125	43.9792715	-18.6647999	5194.5651	2
LEM	69	720201355.164125	43.3959961	1.4062500	359.7692871	2
LEM	69	720201355.926125	44.3018613	1.1096191	359.8601641	1
LEM	69	720201355.957125~375.424291692	42.4291692	1.1865234	359.9560547	2
LEM	69	720201355.164125	42.6269531	1.7797852	4979.5851	2
LEM	69	720201355.957125~296.6263962	42.6269531	1.7797852	4758.3901	2
LEM	69	720201357.957125	43.2531738	3.3619164	0.988770	1
LEM	69	720201357.957125	42.4291692	3.2629395	2526955	2
LEM	69	720201359.164125	43.0773926	-15.5136000	.3076172	1
LEM	69	720201359.945125	42.7697754	1.9676758	2636719	2
LEM	69	720201359.945125	42.7697754	359.7692871	2856445	1
LEM	69	72020141.164125	42.7697754	356.3519366	173.013	2
LEM	69	7202014359.945125	42.7697754	359.8352051	2856445	2
LEM	69	7202014359.945125	359.7505215	359.8352051	4094.0151	2

LEM	65	7202014 2.164125	39.657123	359.2743550	.4504395	1
LEM	65	7202014 3.164125	38.3245605	359.1253418	.4394531	2
LEM	69	7202014 4.026125	35.0563365	359.4646285	.5603027	1
LEM	69	7202014 5.164125	38.562117	359.3298340	.5163574	2
LEM	69	7202014 6.137125	38.2953398	359.4177246	.5483164	1
LEM	69	7202014 7.164125	37.8369141	359.3408203	.6262207	2
LEM	69	7202014 7.994125-226.0430968	36.7712402	359.9670410	.5663027	1
LEM	69	7202014 9.164125	36.1010742	359.345215	.6921387	2
LEM	69	720201410.145125	35.1123047	-19.6343899	.6811523	1
LEM	69	720201411.164125	35.4090355	.7693430	.6481934	2
LEM	69	720201412.027125	35.9044434	.3295898	.6921387	1
LEM	69	720201413.164125	36.0990979	.3295898	.5603027	2
LEM	69	720201414.164125-202.4735985	36.8811035	.0549316	.5712891	1
LEM	69	720201415.164125	36.2548828	.6042480	.5712891	2
LEM	69	720201416.047125	36.0131836	-14.7864000	.5053711	1
LEM	69	720201417.164125	35.4968262	1.3293457	.2719.0801	2
LEM	69	720201418.055125	34.5310293	1.6699219	.6701660	1
LEM	69	720201419.164125	34.7937012	2.1423340	.7250977	2
LEM	69	720201420.066125-173.6223965	33.7604863	1.9017578	.8459473	1
LEM	69	720201421.075125	-12.119909	.5423164	.6008780	2
LEM	69	720201423.164125	33.3034375	.5423164	2316.6131	2

LEM	69 720201423.984125	32.5085449	359.3188477	1.5051270	2
LEM	69 720201425.164125	32.5085449	359.5058594	1.40.243	1
LEM	69 720201426.164125-152.8855972	32.2998047	358.6706543	2.5158691	2
LEM	69 720201427.164125	32.4865723	359.5385742	3.0102539	2
LEM	69 720201428.027125	32.8820801	359.9230957	3.2209805	2
LEM	69 720201429.164125	32.4316406	-9.9383998	3.3618164	1
LEM	69 720201430.176125	32.1020508	.1428223	3.4616934	2
LEM	69 720201430.176125	30.9045410	359.4726562	128.806	1
LEM	69 720201431.164125	29.4104004	359.2523297	3.2189941	2
LEM	69 720201432.277125-125.5799980	28.9640430	359.3298340	2.7905273	1
LEM	69 720201433.164125	28.0371194	359.4836426	1749.0561	2
LEM	69 720201433.965125	27.7054102	-10.1817998	2.598145	1
LEM	69 720201435.164125	27.0854102	.0439453	2.4609375	2
LEM	69 720201435.957125	27.8723145	.3295898	2.1862703	2
LEM	69 720201435.957125	27.4328613	.4174805	1.9775391	1
LEM	69 720201437.176125	27.6416016	.7470703	1.7578125	2
LEM	69 720201437.957125-108.5783987	27.7075195	.5932617	1.5380859	1
LEM	69 720201438.176125	27.4548340	.6921387	1.1645508	2
LEM	69 720201440.055125	27.9272461	-11.3927999	1.2084961	1
LEM	69 720201441.176125	28.8171387	359.9890137	1.1975068	2
LEM	69 720201442.156125	30.7177734	.2317129	1.1975098	1
LEM	69 720201444.387125-03.2511078	27.6153909	.2307125	1.3403320	2

LEM	69	720201445.217125	25.4013906	-1.0.2956445	1.3623047	1229.0911
LEM	69	-20201446.437125	24.5214344	-1.0.9179999	1.5387859	1
LEM	69	720201447.207125	24.6972656	.3955078	1.4831543	1162.0831
LEM	69	720201448.047125	25.1417351	.8453473	1.4721680	1
LEM	69	720201450.066125	25.8947754	1.0217285	1.6479492	1093.0271
LEM	69	720201450.066125	-81.4015989			1
LEM	69	720201451.215125	26.2335316	1.1535645	1.5930176	1027.0281
LEM	69	720201452.098125	26.0925293	-9.8459473	1.5161133	2
LEM	69	720201452.098125	25.5981445	-9.9383998	1.5161133	1
LEM	69	720201453.215125	24.7302246	.7251977	1.5380856	978.6531
LEM	69	720201453.977125	24.2248535	.9777832	1.4611816	1
LEM	69	720201455.215125	23.1811523	.9997559	1.5710449	2
LEM	69	720201453.977125	24.2248535	.9777832	1.4611816	930.00981
LEM	69	720201457.215125	21.8078613	1.2034961	1.3952637	590.02131
LEM	69	720201457.824125	-60.5350993			1
LEM	69	720201459.215125	21.4892578	1.0217285	1.4282227	801.6971
LEM	69	720201459.977125	21.0278320	.8789063	1.3183594	2
LEM	69	720201515.1.215125	20.8630371	-6.0599999	1.1975098	758.5371
LEM	69	720201515.3.215125	19.8083496	.2137266	1.1206055	705.6661
LEM	69	720201515.3.215125	19.3136648	.2137266	.9228516	2
LEM	69	720201515.3.977125	-49.0423994			1
LEM	69	720201515.5.215125	18.9624323	.0878896	1.0986329	1
LEM	69	720201515.5.215125			662.5161	2

LEM	69	7202015 5.977125	18.6937395	0549316	1.3293457
LEM	69	7202015 7.215125	19.5668945	-7.7568000	1.3952637
LEM	69	7202015 7.977125	18.1054687	359.6484375	1.6918945
LEM	69	7202015 9.215125	17.9626465	359.822461	1.8237305
LEM	69	7202015 9.906125	17.6110841	359.3791504	1.9555664
LEM	69	7202015 9.9316125	17.6399994	359.8461914	2.0654297
LEM	69	720201511.215125	17.1676445	3515625	2.3291016
LEM	69	720201511.945125	17.8507912	-5.8176000	2.5693027
LEM	69	720201513.215125	16.6223145	-7250977	2.5598145
LEM	69	720201514.016125	16.5344238	96667969	2.6916504
LEM	69	720201515.215125	15.4687500	9997559	2.8125000
LEM	69	720201515.984125	12.0739746	6811523	2.9333496
LEM	69	720201517.215125	9.3383789	7031250	3.2083078
LEM	69	720201518.024125	6.3061523	-4.3631999	3.3308439
LEM	69	720201519.215125	4.9768966	-1647949	3.5156250
LEM	69	720201521.937125	5.01196289	2087402	3.6804199
LEM	69	720201521.215125	5.1086426	1647949	3.8671875
LEM	69	720201521.937125	5.5590820	0219727	3.9990234
LEM	69	720201523.215125	5.0436035	4504395	4.2187500
LEM	69	720201524.277125	-3.6363000	-39555078	4.4165039
LEM	69	720201525.215125	5.4931641	380.5191	4.5493309

LEM	<del>69</del>	720201526.437125	5.7348633	.4294668	57.729
LEM	69	720201527.215125	5.5371794	.3945215	4.7463938
LEM	69	720201528.445125	-12.1071998	.2956445	4.8669434
LEM	69	720201529.215125	5.9545858	5.0207520	367.9391
LEM	69	720201530.437125	6.0424905	.3405762	364.7021
LEM	69	720201531.437125	5.7897940	-1.9392090	3.1
LEM	69	720201532.437125	6.1293984	.2856445	2
LEM	69	720201533.215125	6.3391113	.2087402	343.1221
LEM	69	720201534.437125	6.1523439	5.1196289	2
LEM	69	720201535.215125	-9.2735999	.1098633	1
LEM	69	720201536.437125	6.4819336	5.0097656	2
LEM	69	720201537.215125	6.8334961	559.8791504	1
LEM	69	720201538.437125	7.0642090	4.9108887	2
LEM	69	720201539.215125	6.8334961	359.7912598	332.3321
LEM	69	720201540.437125	6.8334961	-3.8784000	2
LEM	69	720201541.215125	7.2619629	4.6911621	321.5421
LEM	69	720201542.445125	-9.1447998	4.6362305	2
LEM	69	720201543.215125	7.6464844	51.661	1
LEM	69	720201544.477125	7.2839355	4.5043945	2
LEM	69	720201545.215125	6.9174004	358.5278320	321.5421
LEM	69	720201546.477125	7.6464844	4.3835449	2
LEM	69	720201547.477125	-9.1447998	4.2626953	1
LEM	69	720201548.477125	7.2619629	316.1471	2
LEM	69	720201549.477125	6.9174004	358.4399414	1
LEM	69	720201550.477125	7.2839355	4.0120098	2
LEM	69	720201551.477125	6.9174004	358.6360000	312.9101
LEM	69	720201552.477125	7.2619629	3.9660645	2
LEM	69	720201553.477125	6.9174004	47.154	1
LEM	69	720201554.477125	7.2839355	3.9660645	2
LEM	69	720201555.477125	6.9174004	302.1201	1
LEM	69	720201556.477125	7.2619629	3.8891602	2
LEM	69	720201557.477125	6.9174004	1	

LEM	69	720201547.215125	11.7333984	359.0112305	3.7573242	2
LEM	69	720201548.47125	12.3266602	359.0332031	3.7243652	2
LEM	69	720201549.215125	13.6669922	359.2419434	3.6254883	2
LEM	69	720201550.437125	14.9425293	359.4726562	3.5705566	2
LEM	69	720201551.215125	14.934199	359.5605469	3.4926669	2
LEM	69	720201552.445125	15.1611329	359.6813965	3.4387267	2
LEM	69	720201553.215125	15.3629730	359.9780273	3.2958984	2
LEM	69	720201554.426125	15.3588967	-4.3631999	3.2087078	2
LEM	69	720201555.215125	15.7104492	-2.5268555	3.1091309	2
LEM	69	720201556.437125	15.7983398	3515625	2.9882813	2
LEM	69	720201557.215125	15.6225586	3735352	2.8125000	2
LEM	69	720201558.437125	15.6305859	3625488	2.7136230	2
LEM	69	720201559.215125	-9.1447998	4394531	2.5408281	2
LEM	69	720201560.215125	15.6555176	5273438	2.4061059	2
LEM	69	7202016.438125	15.5236816	-4.8480000	2.2192383	2
LEM	69	7202016.1.215125	15.4138184	.5822754	2.1093750	2
LEM	69	7202016.2.437125	15.4907227	.6591797	2.1093750	2
LEM	69	7202016.3.215125	15.4907227	.8129893	22.537	1
LEM	69	7202016.4.437125	15.4687500	.8789063	1.7468262	2
LEM	69	7202016.5.215125	-7.2127999	1.906348	1.5380859	2
LEM	69	7202016.6.496125	15.6714902	1.0107422	254.6441	2
LEM	69	7202016.7.3623047	15.7653803	-4.3631999	1.3952637	2
LEM	69	7202016.8.3623047	15.7653809	1.3623047	1.165234	2

LEM	69	7202016 7.215125	15.4737363	1.4062560	1.1755371	244.0331
LEM	69	7202016 8.496125	10.5468750	1.2414551	1.2524414	15.429
LEM	69	7202016 9.215125	9.3493652	1.2414551	1.2963867	241.6961
LEM	69	720201626.195125	5.6680453	1.0546875	2.2412109	8.321
LEM	69	720201627.215125	5.5480957	0.9558105	2.2521973	169.4031
LEM	69	720201628.484125	-6.1823999	0.9777832	0.5932617	2.3291016
LEM	69	720201629.215125	.9078789	-6.042480	2.3620605	167.2451
LEM	69	720201630.477125	359.2749623	-7272000	2.44499512	152.1391
LEM	69	720201631.215125	359.2309570	0.8459473	2.4829102	8.668
LEM	69	720201632.516125	359.7583008	2.1203613	2.6916504	143.5071
LEM	69	720201633.215125	359.4726562	2.9003906	2.7905273	2
LEM	69	720201634.477125	-4.6367999	2.9333496	2.9223633	1
LEM	69	720201635.215125	358.6047363	3.1311035	2.9333496	130.5591
LEM	69	720201636.477125	359.7583008	3.1970215	3.0541992	2
LEM	69	720201637.215125	0.0329590	.7272000	3.1691309	115.4531
LEM	69	720201638.445125	359.7143555	2.9882813	6.761	2
LEM	69	720201641.215125	359.5605469	1.9665527	3.1420898	1
LEM	69	720201641.215125	.0210727	.88899926	3.1530762	2
LEM	69	720201642.484125	-3.7352000	.6042480	3.2739258	1
LEM	69	720201643.215125	359.7912598	3.0990234	3.3178711	2
LEM	69	720201644.215125	.4614258	.4943848	0.0000000	1
LEM	69	720201645.484125	.0020020	.0020020	3.4606934	2
LEM	69	720201646.0215125	111.1371	111.1371	111.1371	2

LEM	69 720201644.477125	3.3178711	.7693437	3.5705566	2
		2.6477351	.5163574	3.7133789	6.934
LEM	69 720201645.215125	2.6696777	.3845215	3.8122559	98.1891
LEM	69 720201646.484125	-3.9927999	3.0322266	1.538086	1
LEM	69 720201647.215125	2.9663086	359.5495605	3.9770508	2
LEM	69 720201643.484125	3.4407070	358.2861328	4.1748047	84.1621
LEM	69 720201649.215125	2.9223633	356.7810059	4.1748047	2
LEM	69 720201651.477125	3.0871582	356.7810059	4.3835449	80.9251
LEM	69 720201651.215125	5.3173028	356.8798828	4.6582031	78.7671
LEM	69 720201652.445125	-1.2880000	5.0756836	356.7910022	4.8339844
LEM	69 720201653.215125	4.7680664	356.8353375	4.9548340	78.7671
LEM	69 720201654.316125	4.6142578	356.7150979	5.1525879	76.6091
LEM	69 720201655.215125	4.4934082	356.4843750	5.2954102	1
LEM	69 720201656.387125	4.1748047	356.3635254	5.4162598	2
LEM	69 720201657.215125	4.5373535	356.4074707	5.5920410	77.6881
LEM	69 7202017 7.215125	6.0534668	2.0983887	8.0310059	55.0291
LEM	69 7202017 7.048125	6.0314941	2.2631836	9.1848145	1
LEM	69 7202017 9.215125	1.4831543	1.5490723	8.8330078	57.1871
LEM	69 720201711.215125	354.0902344	-1.5456000	34.05762	56.1881
LEM	69 720201712.176125	355.5944824	54.93164	-1.9392030	2
LEM				9.2504883	1
LEM				9.6130371	2

LEM	69	720201713.215125	355.7502773	1.5490723	9.9865723	45.3181	2
LEM	69	720201714.437125	356.1437988	2.6257324	13.3710937	2	
LEM	69	720201715.215125	356.8469238	2.9003906	10.6567383	42.0811	2
LEM	69	720201716.477125	-2.4472600				1
LEM	69	720201717.4291992	357.4291992	3.3768848	11.0632324		2
LEM	69	720201717.215125	357.4051172	3.5375977	11.2719727		2
LEM	69	720201718.484125	358.2971191	3.7243652	11.6125488	34.5281	1
LEM	69	720201719.215125	358.8354492	2.9663086	11.8103027		2
LEM	69	720201720.324125	358.7915039	1.1535645	12.0849609	3.467	1
LEM	69	720201721.215125	358.6926270	1.1315918	12.3706055	28.0541	2
LEM	69	720201722.324125	-1.4168000				1
LEM	69	720201723.215125	1.1535645	1.4721680	12.7770996		2
LEM	69	720201724.395125	1.7139672	.7141113	13.1666895	28.0541	2
LEM	69	720201725.215125	2.1093750	.1428223	13.4912109		1
LEM	69	720201726.324125	2.6586914	358.8024902	13.7988281	22.6591	2
LEM	69	720201727.215125	3.1420898	357.2863770	14.1613770		2
LEM	69	720201728.316125	3.0651855	357.3413086	14.2163086	22.6591	2
LEM	69	720201730.336125	2.9016000				1
LEM	69	720201729.215125	2.9333496	357.0886230	14.2712402	11.8691	2
LEM	69	720201731.215125	3.5815430	355.5285645	14.3481445	24.8171	2
LEM	69	720201730.336125		-7.2720000		16.296	1
LEM	69	720201732.324125	4.6472168	355.9240723	14.5019531	14.7216797	2
LEM	69	720201733.215125				29.1331	

LEM	69	720201734.316125	5.5151367	356.2966211	14.9205566	2
			7.5931390			1
LEM	69	720201735.215125	5.2075195	356.4514166	14.8205566	2
					21.591	1
LEM	69	720201737.215125	4.7680664	356.5502930	14.8095703	2
				9.6962500		1
LEM	69	720201736.324125	4.3615723	358.1323242	14.9084473	2
					18.3431	1
LEM	69	720201737.215125	3.5046387	359.9230957	15.0952143	2
					1.041	1
LEM	69	720201738.348125	1.5710449	4504395	15.6225586	2
						1
LEM	69	720201739.215125	3515625	2.6337538	15.6555176	2
			5152000			1
LEM	69	720201740.387125	4.5493399	.5953711	14.0185547	2