256

NO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. CF-R-69-20

APRIL 29, 1969

APOLLO MISSION F PERFORMANCE ANALYSIS OF RENDEZVOUS CHARTS

Flight Procedures Branch

FLIGHT CREW SUPPORT DIVISION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

MSC INTERNAL NOTE MSC-CF-R-69-20

APOLLO MISSION F
PERFORMANCE ANALYSIS
OF RENDEZVOUS CHARTS

PREPARED BY: Robert K. Buell
Robert K. Buell
Orbital Procedures Section

John E. Hutchins
John E. Hutchins
Orbital Procedures Section

APPROVED BY: Milton C. Contella
Milton C. Contella
Chief, Orbital Procedures Section

Paul C Kramer
Paul C. Kramer
Chief, Flight Procedures Branch

for Paul C Kramer
James W. Bilodeau
Assistant Chief for Crew Integration

Warren J. North
Chief, Flight Crew Support Division

April 29, 1969

TABLE OF CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

AGS	Abort Guidance System
CDH	Constant Differential Height
CES	Control Electronic System
CSI	Concentric Sequence Initiation
CSM	Command and Service Module
LM	Lunar Module
LOS	Line-of-Sight Between LM and CSM
MC1	First Mid-Course Correction
MC2	Second Mid-Course Correction
TPI	Terminal Phase Initialization
TPF	Terminal Phase Finalization
ΔT	Change in Time
ΔV	Change in Velocity
σ	Standard Deviation
CSI ΔV_H	Horizontal Component of CSI Solution
CDH ΔV_V	Vertical Component of CDH Solution
CDH ΔV_H	Horizontal Component of CDH Solution
TPI ΔV_{LOS}	Along Line-of-Sight Component of TPI Solution
TPI ΔV_N	Normal to Line-of-Sight Component of TPI Solution
MC1 ΔV_{LOS}	Along Line-of-Sight Component of MC1 Solution
MC1 ΔV_N	Along Line-of-Sight Component of MC2 Solution
MC2 ΔV_N	Normal to Line-of-Sight Component of MC2 Solution
CSI $\Delta\Delta V_H$	Error in Horizontal Component of CSI Solution
CDH $\Delta\Delta V_V$	Error in Vertical Component of CDH Solution
CDH $\Delta\Delta V_H$	Error in Horizontal Component of CDH Solution
TPI $\Delta\Delta V_{LOS}$	Error in Along Line-of-Sight Component of TPI Solution
TPI $\Delta\Delta V_N$	Error in Normal to Line-of-Sight Component of TPI Solution
MC1 $\Delta\Delta V_{LOS}$	Error in Along Line-of-Sight Component of MC1 Solution
MC1 $\Delta\Delta V_N$	Error in Normal to Line-of-Sight Component of MC1 Solution
MC2 $\Delta\Delta V_{LOS}$	Error in Along Line-of-Sight Component of MC2 Solution
MC2 $\Delta\Delta V_N$	Error in Normal to Line-of-Sight Component of MC2 Solution

LIST OF TABLES

LIST OF FIGURES

APOLLO MISSION F
PERFORMANCE ANALYSIS
OF RENDEZVOUS CHARTS

1.0 Summary

A digital analysis of the F Mission backup rendezvous charts has been performed to verify their ability to predict CSI, CDH, TPI, and midcourse corrections in the presence of system and application errors and trajectory dispersions. Procedures for data acquisition were as defined in the current LM Rendezvous Procedures Document (Reference 1). The charts simulated were those from the LM 4 onboard data package. The mission situation simulated represented the PNGS inoperative, rendezvous radar information available from the tapemeter, attitude data from the AGS and control by the CES. The study showed that the standard deviation of the arrival time at TPI was 4.45 minutes. The mean ΔT from TPI to intercept with braking and line-of-sight control was 45.9 minutes with a standard deviation of 1.0 minutes. If no braking or line-of-sight control was executed after the second midcourse correction, the mean miss distance would have been 0.27 NM with a standard deviation of .41 NM. The mean total translational ΔV required after insertion was 150.5 ft/sec with a standard deviation of 21.0 ft/sec.

2.0 Discussion

This analysis was performed to determine the ability of the charts to predict all maneuvers after insertion required to complete the LM-active F mission rendezvous. One hundred independent sets of initial conditions (IC's) were selected by adding random errors to the 6 components of the nominal relative state vector between the LM and CSM. Forty percent of the relative error was incorporated into the inertial state vector of the CSM, while the remaining sixty percent of the relative error was incorporated into the inertial state vector of the LM.

The 100 cases were run including system and execution errors with braking and line-of-sight (LOS) control. The runs were repeated omitting braking and LOS control to obtain miss distances. The results of the 100 Monte Carlo runs were processed to obtain statistical data for the parameters of interest.

The first 50 cases were also run without system or application errors to establish the theoretical chart capabilities.

2.1 Study Rules

The following ground rules consistent with F Mission procedures and planning were used in this study:

1. CSI occurs 51 min 01 sec after insertion.
2. CDH occurs 58 min 01 sec after CSI.
3. TPI was assumed to occur 9 min after the elevation angle of 19.40 degrees was reached.
4. The first midcourse correction (MC1) occurred 15 minutes after TPI and the second midcourse correction (MC2) occurred at 30 minutes after TPI.
5. CSI and CDH were burned in local vertical coordinates using impulsive thrust.
6. TPI, MC1, MC2, braking, and LOS control were executed along and normal to the line-of-sight using finite thrust, burning each component individually.
7. 130 degrees of CSM orbit travel between TPI and TPF.
8. No out-of-plane corrections were made prior to LOS control during the braking phase.

2.2 Digital Program

In the analysis, functions describing the backup rendezvous charts were programmed into a digital routine which integrated the equations of motion of two particles about a triaxial lunar gravity model. These functions allowed simulation of the procedures for using the backup rendezvous charts by incorporating elevation angle (AGS address 304), range, and range rate from the tapemeter at the times called for by the backup data sequence. System errors were included in the data taken at each point and an appropriate error of application was included in each maneuver.

The runs included effects of both bias and random errors as defined in Section 2.5. Bias errors were selected by the program at the beginning of each run and held constant for that run. Random errors were selected at each point where data were taken.

2.3 Charts

The charts modeled in the study were those which will be carried on the F Mission, and are shown in Figures 1-6. The data sequence was obtained from Reference 1 and is summarized on the relative motion plot of the nominal trajectory from CSI-30 min to TPF (Figure 7).

2.3.1 CSI

The CSI chart solution is based on a third order Maclaurin's expansion of four variables for the delta V at CSI (range rate at 30, 20, and 10 minutes prior to CSI and range 10 minutes prior to CSI). The coefficients are determined by the simultaneous solution of several expansions, each representing a dispersed trajectory prior to CSI.

2.3.2 CDH

The CDH chart solution is based on a second order Maclaurin's expansion of three variables for the delta V at CDH (range rate at 36, 23, and 10 minutes prior to CDH). The coefficients are determined by the simultaneous solution of several expansions, each representing a dispersed trajectory prior to CDH.

2.3.3 TPI and MCC

The TPI charts solve for the relative position and velocity at TPI resolved into normal and along the line-of-sight (LOS) coordinates. The measured relative conditions are differenced from the required conditions for intercept in 130 degrees of orbit travel. Information required for the TPI charts is the

elevation angle at 9 and 5 minutes prior to TPI and range and range rate at 5 minutes before TPI. In a similar manner, the MCC charts maintain the time of TPF consistent with the TPI maneuver. Data are taken for the midcourses at 9 and 13 minutes after TPI for MC1 and at 24 and 28 minutes after TPI for MC2. The same measurement sequence as used at TPI is used for both midcourse corrections.

2.4 Initial Conditions

The initial conditions were generated by perturbing the nominal state vectors of the LM and CSM with errors supplied by a relative covariance matrix. Forty percent of the relative error was applied to the state vector of the CSM, while the remaining sixty percent of the relative error was applied to the state vector of the LM.

The nominal vectors relative to the LM orbital plane were derived from Reference 2 and are summarized as follows:

Table 2-1
Initial Conditions
CSI-33 min.
(103 hrs 0 min 46 sec)

LM Altitude	131859.3 feet
CSM Altitude	349583.7 feet
LM Total Velocity	5458.4 ft/sec
CSM Total Velocity	5350.0 ft/sec
LM Flight Path Angle	.935 deg
CSM Flight Path Angle	.002 deg
In Plane Central Angle	11.869 deg
LM Latitude	0.0 deg
Out of Plane Distance	0.0 feet
Out of Plane Velocity	0.0 ft/sec
Heading Angle (relative to equator)	0.0 deg

The covariance matrix used for initialization of the Monte Carlo runs is as follows:

Table 2-2
Covariance Matrix

254189300.	812877.2	44433410.	-53475.3	-424.228	214069.
812877.2	180909.9	271115.	-81.066	-2.29299	644.7976
44433410.	271115.	10541620.	-6910.21	-113.378	36791.17
-53475.3	-81.066	-6910.21	13.45366	.05168073	-45.6078
-424.228	-2.29299	-113.378	.05168073	.009133634	-.343047
214069.	644.7969	36791.17	-45.6078	-.343047	181.2414

It has since been learned that this matrix, obtained from Reference 3, reflects trajectory dispersions approximately 4 times greater than those which can be expected in the actual mission.

2.5 Errors in Sensors and Execution

The 1σ errors in sensor and maneuver executions were:

1. System Errors

   A. Noise

      1. Range — .333%

      2. Range Rate — .333 ft/sec

   B. Biases and Drifts (constant for a given run)

      1. Initial Pitch Bias — .1 deg (assumes calibrated COAS)

      2. Pitch Drift Rate — .18 deg/hr

2. Execution Errors

   A. Reading Tapemeter

      1. Range Rate — .25 ft/sec

      2. Range

         a. Outer Scale — 2400 ft

         b. Middle Scale — 100 ft

   B. Application of Burns — .25 ft/sec (per axis)

   C. Time Measurements — .5 sec

   D. Elevation Angle (Error in pointing Z-axis at target) — .12 deg

2.6 Braking Schedule and LOS Angular Rate Deadbands

The braking schedule used in this simulation consisted of five gates and a lower limit on the range rate. The first gate was at 13500 feet. At this point only LOS control was executed because the allowed range rate was 80 ft/sec. The second gate was at 6000 ft with an allowed range rate of 30 ft/sec. The nominal range rate at this range was 32 ft/sec. The remaining gates were 20 ft/sec at 3000 ft, 10 ft/sec at 1500 ft and 5 ft/sec at 500 ft. The lower range rate limit consisted of a straight line connecting 20 ft/sec at 13500 ft and 0 ft/sec at intercept.

Both the upper and lower range rate limits are shown in Figure 8. LOS control procedures were simulated by sampling inertial drift of the LOS inplane and normal to the orbit plane every 15 seconds beginning at a range of 13500 ft. When the LOS rates exceeded .3 mr/sec at a sampling time, thrust was applied in the appropriate axis in increments of 1 second until the LOS rate was reduced below the threshold. The 15 seconds were allowed to elapse before sampling again.

3.0 Results

Several sets of Monte Carlo runs were made to obtain statistical data for determination of the effects of errors, trajectory dispersions, and braking on the size of maneuvers, arrival time at TPI, and total translational ΔV. The sets of runs are identified in the following table:

Table 3-1
Run Summary

Set	Number of Runs	Errors in Maneuver Solutions	Maneuvers Applied	LOS Control and Braking
A	100	Yes	With Errors	Yes
		No		
B	100	Yes	With Errors	No
C	50	No	No Errors	No
D	50	No	No Errors	Yes

Solutions for the maneuvers in Set A were obtained with errors. In addition, conic solutions were obtained for each maneuver except CSI. These were used to establish nominal ΔV values, which were used as a basis to compute the $\Delta\,\Delta V$ values in Table 3-3. In the case of CSI, a chart solution with no sensor and reading errors was used for this purpose. All solutions which were actually applied in Set A, however, were arrived at using sensor and reading errors. The runs for Set B

were identical to Set A, but with braking and LOS control omitted to establish miss distance.

Sets C and D were run to establish baseline data for chart performance. It was felt that a reduced number of runs would suffice to obtain statistically meaningful results since only initial conditions were varied. Examination of significant parameters such as maneuver solution and miss distances revealed nearly normal statistical distributions, confirming the adequacy of 50 runs for those sets. The runs for Sets C and D were made with the same initial conditions as the first 50 runs of Set A.

3.1 Maneuver Values

The nominal solution, along with the average, mean, and standard deviation for each maneuver in Set A and Set D are shown in Table 3-2 on Page 3-4. The data given for Set A are the solutions with errors. The average, mean, and standard deviation for the difference between the error solution and the theoretical solution computed for each maneuver in Set A are shown in Table 3-3 on Page 3-5.

It can be noted from the data in Table 3-3 that the chart solutions with errors progressively decrease in accuracy from CSI to CDH to TPI. The trend then reverses with MCC1 more accurate than TPI and MCC2 more accurate than MCC1.

In addition, it should also be noted that the value listed for the nominal CSI solution in Table 3-2 differs from the current value for CSI ΔV. This is explained by the fact that the reference trajectory from which the IC's were derived represented a 58 NM circular orbit, due to a smaller DOI burn than is currently being used. The difference between the DOI burn and the current value, is approximately the same as the difference between the CSI burn and its current value.

Table 3-2

Magnitude of Maneuvers

Maneuvers	Nominal Solution ft/sec	Average SET D ft/sec	Average SET A ft/sec	Mean SET D ft/sec	Mean SET A ft/sec	Standard Deviation SET D ft/sec	Standard Deviation SET A ft/sec
CSI ΔV_H	47.41	46.34	47.07	46.34	47.07	4.62	5.05
CDH ΔV_V	- 3.90	7.15	7.60	- 1.35	- 2.58	8.36	8.93
CDH ΔV_H	1.92	6.50	6.97	.25	1.46	7.89	8.56
TPI ΔV_{LOS}	24.48	25.08	24.76	25.08	24.76	3.26	4.33
TPI ΔV_N	- .37	1.00	2.74	.64	.54	1.33	3.47
MCC1 ΔV_{LOS}	1.01	1.91	4.75	.75	.15	2.36	6.06
MCC1 ΔV_N	.28	3.20	4.19	3.20	3.07	1.93	4.58
MCC2 ΔV_{LOS}	3.59	4.67	7.55	4.67	5.75	2.51	7.74
MCC2 ΔV_N	- 2.06	.93	2.39	- .76	- .95	.69	2.87

The term Average refers to the mean of the absolute values of the data.

The term Mean refers to the value obtained by dividing the arithmetic sum of a set of values by the number of values in the set.

Table 3-3

Differences Between Chart Solutions With and Without Errors and Conic Solutions

Maneuver	Average		Mean		Standard Deviation	
	Set D ft/sec	Set A ft/sec	Set D ft/sec	Set A ft/sec	Set D ft/sec	Set A ft/sec
*CSI $\Delta\Delta V_H$	0.0	.77	0.0	- .02	0.0	.95
CDH $\Delta\Delta V_V$	1.11	1.54	1.11	1.05	1.21	1.83
CDH $\Delta\Delta V_H$	.25	.46	- .25	- .33	.34	.60
TPI $\Delta\Delta V_{LOS}$	1.34	2.40	-1.04	- .76	1.45	3.02
TPI $\Delta\Delta V_N$	.37	2.41	- .29	- .44	.54	3.12
MCC1 $\Delta\Delta V_{LOS}$	1.59	2.65	-1.59	-1.83	.91	2.80
MCC1 $\Delta\Delta V_N$	1.34	2.16	1.34	1.47	.37	2.26
MCC2 $\Delta\Delta V_{LOS}$	.84	1.48	- .82	- .97	.59	1.48
MCC2 $\Delta\Delta V_N$	.50	1.29	.50	.85	.16	1.77

The data in Table 3-3 listed under Set D represents the theoretical error inherent in the charts, while the data listed under Set A represents the total expected error, including theoretical error, system errors, and execution errors.

*The value for CSI $\Delta\Delta V$ represents the difference between CSI ΔV computed with sensor and reading errors, and the value for CSI ΔV computed without sensor and reading errors.

3.2 Miss Distance

The miss distances were established by Sets B and C. The average in plane miss distance at the point of closest approach for the 50 cases without errors (Set C) was 494 feet, and for the 100 cases with errors (Set B) was 1664 feet.

The average, mean, and standard deviation of the components of the miss distance in a local vertical coordinate system with X along the radius vector of the LM, Z along the angular momentum vector of the LM, and Y completing the right-handed system were as follows:

Table 3-4

Coordinates at Closest Approach

Axis	Average		Mean		Standard Deviation	
	SET B Feet	SET C Feet	SET B Feet	SET C Feet	SET B Feet	SET C Feet
X	939	194	-329	122	1488	208
Y	1374	454	102	392	1952	256
Z	301	251	51	17	411	307

3.3 Δ V Used

The mean total translation ΔV used in the 50 cases without errors (Set D) was 136.3 ft/sec with a standard deviation of 15.0 ft/sec while the mean for the 100 cases with errors (Set A) was 150.5 ft/sec with a standard deviation of 21.0 ft/sec.

The minimum and maximum ΔV cases without errors required 120.5 ft/sec and 180.1 ft/sec, respectively, while with errors minimum and maximum ΔV cases required 120.2 ft/sec and 230.4 ft/sec. Figure 9 shows the distribution of total ΔV.

A breakdown of how the ΔV was used is shown in the following table:

Table 3-5

Translation ΔV

Maneuver	ΔV (Set D) Average Without Errors ft/sec	ΔV (Set A) Average With Errors ft/sec
CSI	46.3	47.1
CDH	13.6	14.6
TPI	26.1	27.5
MCC1	5.1	8.9
MCC2	5.6	9.9
Braking and LOS Control	39.7	42.6

3.4 Arrival Time at TPI

The mean arrival time at TPI for the 50 cases without errors (Set D) was 23 seconds later than nominal with a standard deviation of 31 seconds, while the mean for the 100 cases with errors (Set A) was 21 seconds late with a standard deviation of 4 minutes and 27 seconds.

Figure 10 shows the distribution of arrival time at TPI over intervals of two minutes for the 100 cases with errors.

3.5 Δ T from TPI to TPF

The mean Δ T from TPI to close approach without braking for the 50 cases in Set C was 2586 seconds with a standard deviation of 9 seconds while the mean Δ T of transfer without braking for the 100 cases in Set B was 2584 seconds with a standard deviation of 44 seconds.

The mean Δ T from TPI to intercept with braking and LOS control for the 50 cases in Set D was 2747 seconds with a standard deviation of 32 seconds while the mean Δ T of transfer with braking for the 100 cases in Set A was 2756 seconds with a standard deviation of 59 seconds. The nominal case required 2737 seconds with braking and LOS control.

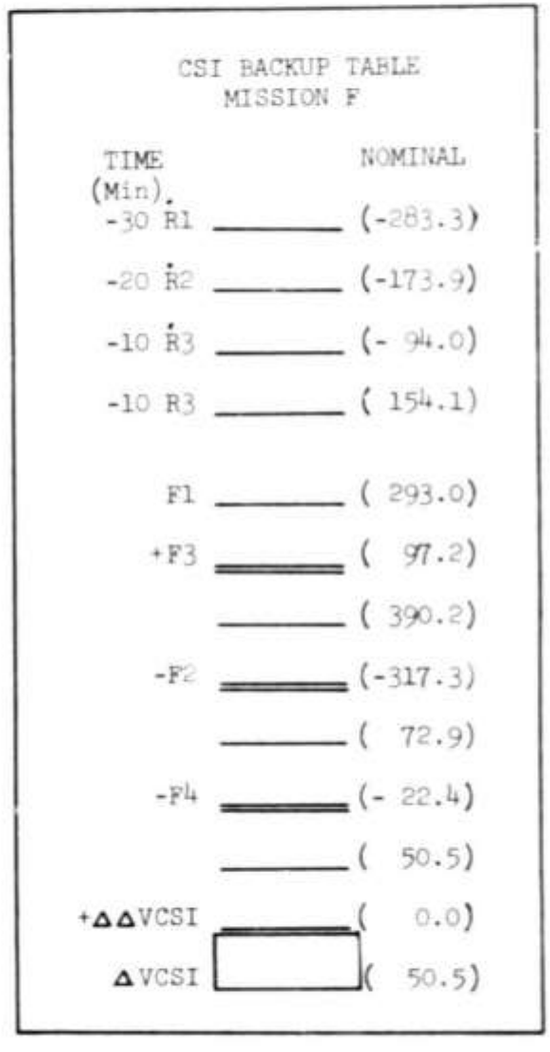
Figure 11 shows the distribution of the Δ T transfer with braking for the 100 cases with errors.

4.0 References

1. LM Rendezvous Procedures F Mission, Flight Crew Support Division, dated March 17, 1969.
2. Apollo Mission F Spacecraft Operational Trajectory, Volume 1, Mission Profile, dated March 26, 1969.
3. Relative Covariance Matricies of the Actual Post Insertion and CDH State Vectors for Apollo 10, Mission Planning and Analysis Division, Memorandum No. 69-FM62-63, dated April 3, 1969.

$\dot{\Delta}_1$	Δ_1	$\dot{\Delta}_2$	Δ_2	$\dot{\Delta}_3$	Δ_3	Δ_4
-240.0	247.3	-140.0	254.7	-70.0	72.4	120.0	15.2
-241.0	248.4	-141.0	255.6	-71.0	73.4	121.0	15.5
-242.0	249.4	-142.0	257.4	-72.0	74.4	122.0	15.7
-243.0	250.5	-143.0	260.2	-73.0	75.5	123.0	15.9
-244.0	251.5	-144.0	262.1	-74.0	76.5	124.0	16.1
-245.0	252.5	-145.0	263.9	-75.0	77.5	125.0	16.3
-246.0	253.6	-146.0	265.7	-76.0	78.6	126.0	16.5
-247.0	254.6	-147.0	267.6	-77.0	79.6	127.0	16.7
-248.0	255.7	-148.0	269.4	-78.0	80.6	128.0	16.9
-249.0	256.7	-149.0	271.3	-79.0	81.7	129.0	17.1
-250.0	257.8	-150.0	273.1	-80.0	82.7	130.0	17.3
-251.0	258.8	-151.0	274.9	-81.0	83.7	131.0	17.5
-252.0	259.9	-152.0	276.8	-82.0	84.8	132.0	17.7
-253.0	260.9	-153.0	278.6	-83.0	85.8	133.0	17.9
-254.0	262.0	-154.0	280.4	-84.0	86.9	134.0	18.1
-255.0	263.0	-155.0	282.3	-85.0	87.9	135.0	18.4
-256.0	264.1	-156.0	284.1	-86.0	88.9	136.0	18.6
-257.0	265.1	-157.0	286.0	-87.0	90.0	137.0	18.8
-258.0	266.2	-158.0	287.8	-88.0	91.0	138.0	19.0
-259.0	267.2	-159.0	289.7	-89.0	92.0	139.0	19.2
-260.0	268.3	-160.0	291.5	-90.0	93.1	140.0	19.4
-261.0	269.3	-161.0	293.4	-91.0	94.1	141.0	19.6
-262.0	270.4	-162.0	295.2	-92.0	95.2	142.0	19.8
-263.0	271.4	-163.0	297.0	-93.0	96.2	143.0	20.0
-264.0	272.5	-164.0	298.9	-94.0	97.2	144.0	20.2
-265.0	273.5	-165.0	300.7	-95.0	98.3	145.0	20.5
-266.0	274.6	-166.0	302.6	-96.0	99.3	146.0	20.7
-267.0	275.7	-167.0	304.4	-97.0	100.4	147.0	20.9
-268.0	276.7	-168.0	306.3	-98.0	101.4	148.0	21.1
-269.0	277.8	-169.0	308.1	-99.0	102.4	149.0	21.3
-270.0	278.8	-170.0	310.0	-100.0	103.5	150.0	21.5
-271.0	279.9	-171.0	311.9	-101.0	104.5	151.0	21.7
-272.0	281.0	-172.0	313.7	-102.0	105.6	152.0	21.9
-273.0	282.0	-173.0	315.6	-103.0	106.6	153.0	22.1
-274.0	283.1	-174.0	317.4	-104.0	107.7	154.0	22.4
-275.0	284.2	-175.0	319.3	-105.0	108.7	155.0	22.6
-276.0	285.2	-176.0	321.1	-106.0	109.7	156.0	22.8
-277.0	286.3	-177.0	323.0	-107.0	110.8	157.0	23.0
-278.0	287.4	-178.0	324.9	-108.0	111.8	158.0	23.2
-279.0	288.4	-179.0	326.7	-109.0	112.9	159.0	23.4
-280.0	289.5	-180.0	328.6	-110.0	113.9	160.0	23.6
-281.0	290.6	-181.0	330.4	-111.0	115.0	161.0	23.8

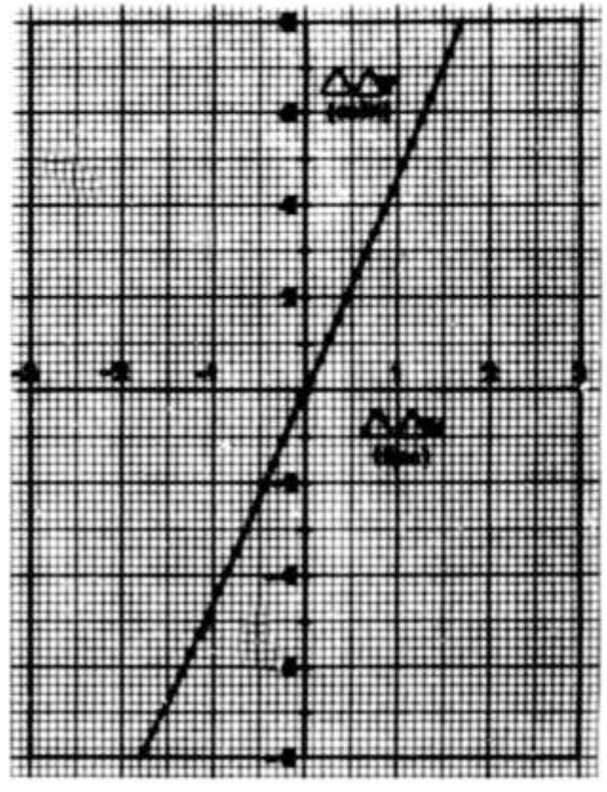
FIGURE 1



Prepared by FPrB/OPS

MISSION APOLLO 10, APRIL 11, 1969

$\dot{R}1$	F1	$\dot{R}2$	F2	$\dot{R}3$	F3	R3	F4
-282.0	291.6	-182.0	332.3	-112.0	116.1	162.0	24.0
-283.0	292.7	-183.0	334.2	-113.0	117.0	163.0	24.2
-284.0	293.8	-184.0	336.0	-114.0	118.1	164.0	24.5
-285.0	294.8	-185.0	337.9	-115.0	119.1	165.0	24.7
-286.0	295.9	-186.0	339.8	-116.0	120.2	166.0	24.9
-287.0	297.0	-187.0	341.6	-117.0	121.2	167.0	25.1
-288.0	298.1	-188.0	343.5	-118.0	122.3	168.0	25.3
-289.0	299.2	-189.0	345.4	-119.0	123.3	169.0	25.5
-290.0	300.2	-190.0	347.2	-120.0	124.4	170.0	25.7
-291.0	301.3	-191.0	349.1	-121.0	125.4	171.0	25.9
-292.0	302.4	-192.0	351.0	-122.0	126.5	172.0	26.1
-293.0	303.5	-193.0	352.9	-123.0	127.5	173.0	26.3
-294.0	304.6	-194.0	354.7	-124.0	128.6	174.0	26.5
-295.0	305.6	-195.0	356.6	-125.0	129.6	175.0	26.7
-296.0	306.7	-196.0	358.5	-126.0	130.7	176.0	26.9
-297.0	307.8	-197.0	360.4	-127.0	131.7	177.0	27.1
-298.0	308.9	-198.0	362.2	-128.0	132.8	178.0	27.3
-299.0	310.0	-199.0	364.1	-129.0	133.8	179.0	27.5
-300.0	311.1	-200.0	366.0	-130.0	134.9	180.0	27.7
-301.0	312.2	-201.0	367.9	-131.0	135.9	181.0	27.9
-302.0	313.2	-202.0	369.8	-132.0	137.0	182.0	28.1
-303.0	314.3	-203.0	371.6	-133.0	138.0	183.0	28.3
-304.0	315.4	-204.0	373.5	-134.0	139.1	184.0	28.5
-305.0	316.5	-205.0	375.4	-135.0	140.1	185.0	28.7
-306.0	317.6	-206.0	377.3	-136.0	141.2	186.0	28.9
-307.0	318.7	-207.0	379.2	-137.0	142.2	187.0	29.1
-308.0	319.8	-208.0	381.1	-138.0	143.3	188.0	29.3
-309.0	320.9	-209.0	383.0	-139.0	144.3	189.0	29.5
-310.0	322.0	-210.0	384.9	-140.0	145.4	190.0	29.7
-311.0	323.1	-211.0	386.8	-141.0	146.4	191.0	29.9
-312.0	324.2	-212.0	388.7	-142.0	147.5	192.0	30.1
-313.0	325.3	-213.0	390.5	-143.0	148.5	193.0	30.3
-314.0	326.4	-214.0	392.4	-144.0	149.6	194.0	30.5
-315.0	327.5	-215.0	394.3	-145.0	150.7	195.0	30.7
-316.0	328.6	-216.0	396.2	-146.0	151.7	196.0	30.9
-317.0	329.7	-217.0	398.1	-147.0	152.8	197.0	31.0
-318.0	330.8	-218.0	400.0	-148.0	153.8	198.0	31.2
-319.0	331.9	-219.0	401.9	-149.0	154.9	199.0	31.4
-320.0	333.0	-220.0	403.8	-150.0	155.9	200.0	31.6
-321.0	334.1	-221.0	405.7	-151.0	157.0	201.0	31.8
-322.0	335.3	-222.0	407.7	-152.0	158.1	202.0	32.0
-323.0	336.4	-223.0	409.6	-153.0	159.1	203.0	32.2



TIG TPI ___:___:___

- TIG CSI ___:___:___

ΔT ___:___:___

- NOMΔT -1:35:21

ΔΔT ___:___

ΔΔVCSI

Prepared by FPrB/OPS

MISSION APOLLO 10, APRIL 11, 1969

RDOT	X1	Z1	X2	Z2	X3	Z3
-75.	29.7	52.6	30.6	132.0	.9	79.2
-76.	30.1	53.4	31.0	133.9	.9	80.3
-77.	30.5	54.3	31.3	135.9	.9	81.5
-78.	30.8	55.1	31.7	137.9	.9	82.6
-79.	31.2	55.9	32.1	139.9	.9	83.8
-80.	31.6	56.8	32.5	141.8	.9	84.9
-81.	32.0	57.6	32.8	143.8	.9	86.1
-82.	32.4	58.4	33.2	145.8	.9	87.2
-83.	32.7	59.3	33.6	147.8	.8	88.4
-84.	33.1	60.1	33.9	149.8	.8	89.6
-85.	33.5	61.0	34.3	151.8	.8	90.7
-86.	33.9	61.8	34.7	153.8	.8	91.9
-87.	34.2	62.7	35.0	155.9	.8	93.1
-88.	34.6	63.5	35.4	157.9	.8	94.2
-89.	35.0	64.4	35.8	159.9	.8	95.4
-90.	35.4	65.3	36.1	161.9	.8	96.6
-91.	35.7	66.1	36.5	164.0	.8	97.8
-92.	36.1	67.0	36.9	166.0	.8	98.9
-93.	36.5	67.9	37.2	168.1	.7	100.1
-94.	36.9	68.8	37.6	170.1	.7	101.3
-95.	37.2	69.6	38.0	172.2	.7	102.5
-96.	37.6	70.5	38.3	174.2	.7	103.7
-97.	38.0	71.4	38.7	176.3	.7	104.9
-98.	38.3	72.3	39.0	178.4	.7	106.1
-99.	38.7	73.2	39.4	180.5	.6	107.3
-100.	39.1	74.1	39.8	182.6	.6	108.5
-101.	39.5	75.0	40.1	184.7	.6	109.7
-102.	39.8	75.9	40.5	186.7	.6	110.9
-103.	40.2	76.8	40.8	188.9	.6	112.1
-104.	40.6	77.7	41.2	191.0	.6	113.3
-105.	40.9	78.6	41.5	193.1	.5	114.5
-106.	41.3	79.5	41.9	195.2	.5	115.7
-107.	41.7	80.4	42.2	197.3	.5	116.9
-108.	42.0	81.4	42.6	199.4	.5	118.2
-109.	42.4	82.3	42.9	201.6	.5	119.4
-110	42.8	83.2	43.3	203.7	.4	120.6
-111.	43.1	84.2	43.6	205.9	.4	121.8
-112.	43.5	85.1	44.0	208.0	.4	123.0
-113.	43.9	86.0	44.3	210.2	.4	124.3
-114.	44.2	87.0	44.7	212.3	.4	125.5
-115.	44.6	87.9	45.0	214.5	.3	126.7
-116.	45.0	88.9	45.4	216.7	.3	128.0
-117.	45.3	89.8	45.7	218.8	.3	129.2

CDH BACKUP TABLE
MISSION F

TIME (MIN)		NOMINAL
-36	$\dot{R}1$	(-122.21)
-23	$\dot{R}2$	(-122.68)
-10	$\dot{R}3$	(-122.87)

ΔVX:	X1	(47.2)	
	+X3	(0.1)	
		(47.3)	
	-X2	(-47.7)	
	ΔVX	(- 0.4)	FPS

ΔVZ:	Z2	(231.3)	
	-Z1	(-94.8)	
		(136.5)	
	-Z3	(-136.5)	
	ΔVZ	(0.0)	

MISSION APOLLO 10, APRIL 11, 1969

PREPARED BY FPRB/OPS

FIGURE 2

RDOT	X1	Z1	X2	Z2	X3	Z3
-118.	45.7	90.8	46.1	221.0	.3	130.5
-119.	46.1	91.7	46.4	223.2	.2	131.7
-120	46.4	92.7	46.7	225.4	.2	132.9
-121.	46.8	93.6	47.1	227.6	.2	134.2
-122.	47.1	94.6	47.4	229.8	.2	135.4
-123.	47.5	95.6	47.8	232.0	.1	136.7
-124.	47.9	96.5	48.1	234.2	.1	137.9
-125.	48.2	97.5	48.4	236.4	.1	139.2
-126.	48.6	98.5	48.8	238.6	.0	140.5
-127.	48.9	99.5	49.1	240.9	.0	141.7
-128.	49.3	100.5	49.5	243.1	-.0	143.0
-129.	49.7	101.5	49.8	245.3	-.0	144.3
-130.	50.0	102.4	50.1	247.6	-.1	145.5
-131.	50.4	103.4	50.5	249.8	-.1	146.8
-132.	50.7	104.4	50.8	252.1	-.1	148.1
-133.	51.1	105.4	51.1	254.4	-.2	149.3
-134.	51.5	106.4	51.4	256.6	-.2	150.6
-135.	51.8	107.4	51.8	258.9	-.2	151.9
-136.	52.2	108.5	52.1	261.2	-.3	153.2
-137.	52.5	109.5	52.4	263.4	-.3	154.5
-138.	52.9	110.5	52.8	265.7	-.3	155.8
-139.	53.2	111.5	53.1	268.0	-.4	157.0
-140.	53.6	112.5	53.4	270.3	-.4	158.3
-141.	53.9	113.6	53.7	272.6	-.4	159.6
-142.	54.3	114.6	54.1	274.9	-.5	160.9
-143.	54.6	115.6	54.4	277.2	-.5	162.2
-144.	55.0	116.6	54.7	279.6	-.5	163.5
-145.	55.3	117.7	55.0	281.9	-.6	164.8
-146.	55.7	118.7	55.3	284.2	-.6	166.1
-147.	56.1	119.8	55.7	286.5	-.7	167.4
-148.	56.4	120.8	56.0	288.9	-.7	168.8
-149.	56.8	121.9	56.3	291.2	-.7	170.1
-150.	57.1	122.9	56.6	293.6	-.8	171.4
-151.	57.5	124.0	56.9	295.9	-.8	172.7
-152.	57.8	125.0	57.3	298.3	-.9	174.0
-153.	58.2	126.1	57.6	300.7	-.9	175.3
-154.	58.5	127.2	57.9	303.0	-.9	176.7
-155.	58.8	128.2	58.2	305.4	-1.0	178.0
-156.	59.2	129.3	58.5	307.8	-1.0	179.3
-157.	59.5	130.4	58.8	310.2	-1.1	180.7
-158.	59.9	131.5	59.1	312.6	-1.1	182.0
-159.	60.2	132.6	59.4	315.0	-1.2	183.3

"F" MISSION

TERMINAL PHASE INITIATION

10-28-68
FP/B/OPS

$\dot{R}_{REQ}$ _____ 136.9

Θ_{-5} _____ 22.24 R_{-5} _____ 38.18 $\dot{R}_{-5}$ _____ 112.3

Θ_{-9} _____ 19.54 $\Delta\dot{R}$ _____ 24.6

$\Delta\Theta$ _____ 2.70

	PNGS (N59)	GND	CHARTS	ΔT
$\dot{F}/A$				
$\dot{R}/L$				
$\dot{D}/U$				

+X JET +Z JET

UP

ΔV_N

DOWN

PGNS (N81)

ΔVXL _____

ΔVYL _____

ΔVZL _____

R_{-5}

Θ_{-5}

$\dot{R}_{REQ}$

$\Delta\Theta$

FIGURE 3

MISSION APOLLO 10, APRIL 11, 1969

"F" MISSION

FIRST MIDCOURSE CORRECTION

10-28-68
FPRB/OPS

$\dot{R}_{REQ}$ ——— 104.5

Θ_{13} ——— 43.28 R_{13} ——— 17.23 $\dot{R}_{13}$ ——— 104.5

Θ_{9} ——— 37.24 $\Delta\dot{R}$ ——— 0.0

$\Delta\Theta$ ——— 6.04

	PNGS (N59)	GND	CHARTS	ΔT
F/A				
R/L				
D/U				

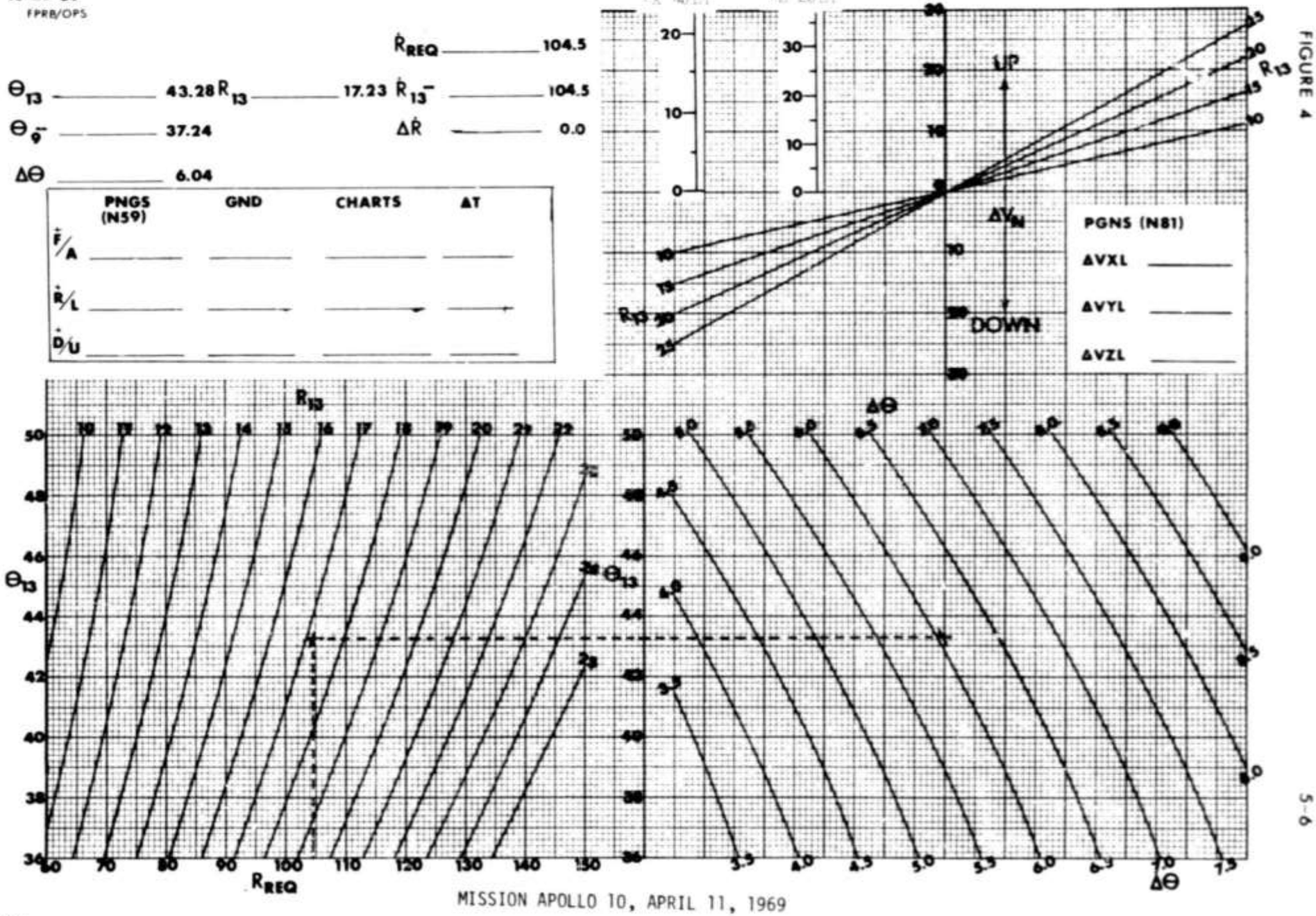


FIGURE 4

MISSION APOLLO 10, APRIL 11, 1969

"F" MISSION

SECOND MIDCOURSE CORRECTION

10-28-68
FPRB/OPS

$\dot{R}_{REQ}$ ____ 52.4

Θ_{28} ____ 77.41 R_{28} ____ 34.3 $\dot{R}_{2\overline{8}}$ ____ 52.4

$\Theta_{\overline{24}}$ ____ 66.22 $\Delta\dot{R}$ ____ 0.0

$\Delta\Theta$ ____ 11.19

	PNGS (N59)	GND	CHARTS	AT
$\dot{F}/A$				
$\dot{R}/L$				
$\dot{D}/U$				

+X JET +Z JET

UP

DOWN

ΔV_N

PGNS (N81)

ΔVXL ____

ΔVYL ____

ΔVZL ____

R_{28}

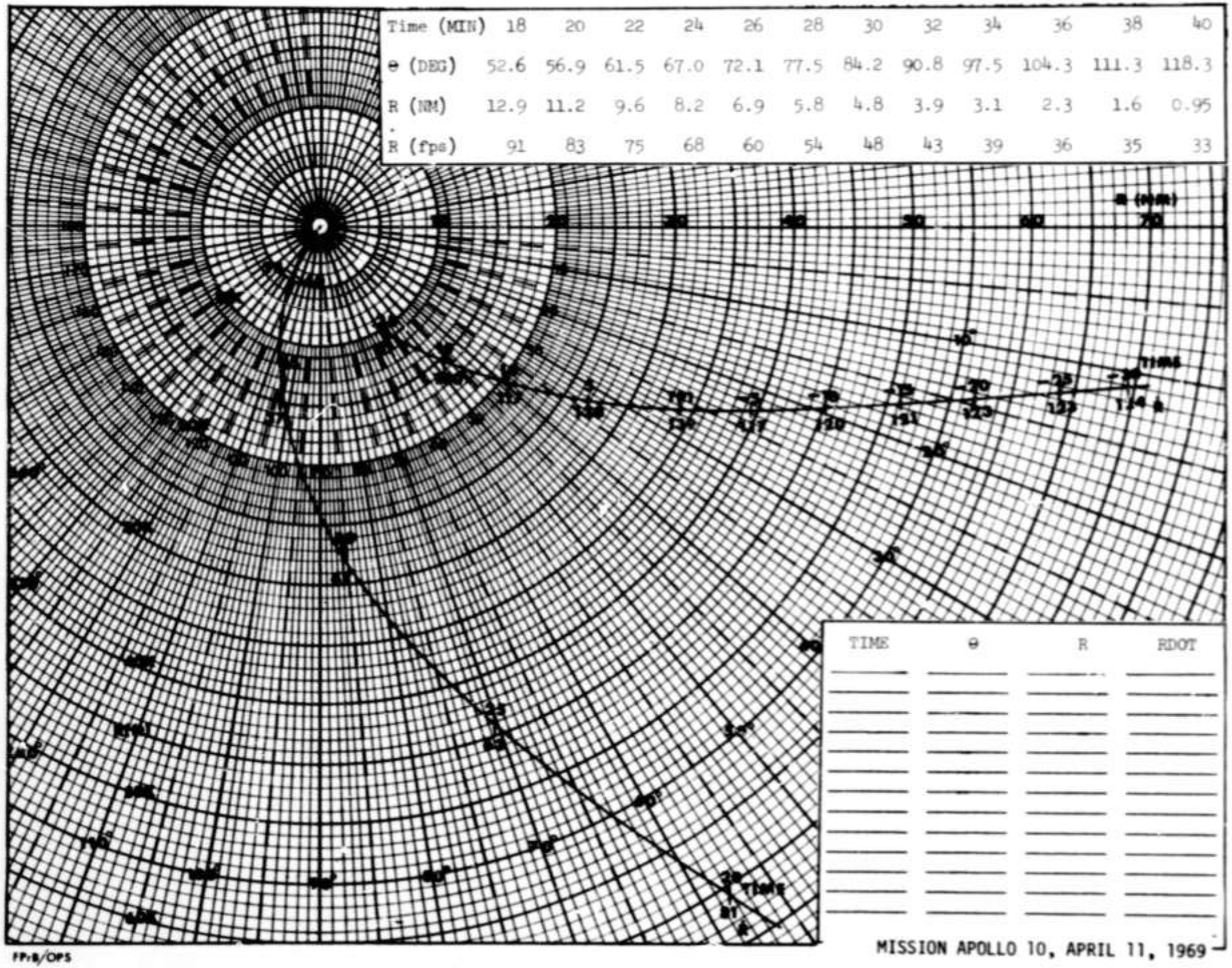
Θ_{28}

$\Delta\Theta$

$\dot{R}_{REQ}$

FIGURE 5

F MISSION-RELATIVE REFERENCE TRAJECTORY



Time (MIN)	18	20	22	24	26	28	30	32	34	36	38	40
θ (DEG)	52.6	56.9	61.5	67.0	72.1	77.5	84.2	90.8	97.5	104.3	111.3	118.3
R (NM)	12.9	11.2	9.6	8.2	6.9	5.8	4.8	3.9	3.1	2.3	1.6	0.95
Ṙ (fps)	91	83	75	68	60	54	48	43	39	36	35	33

TIME	θ	R	RDOT

FP-8/OPS

MISSION APOLLO 10, APRIL 11, 1969

FIGURE 6

CSM CENTERED RELATIVE MOTION PLOT

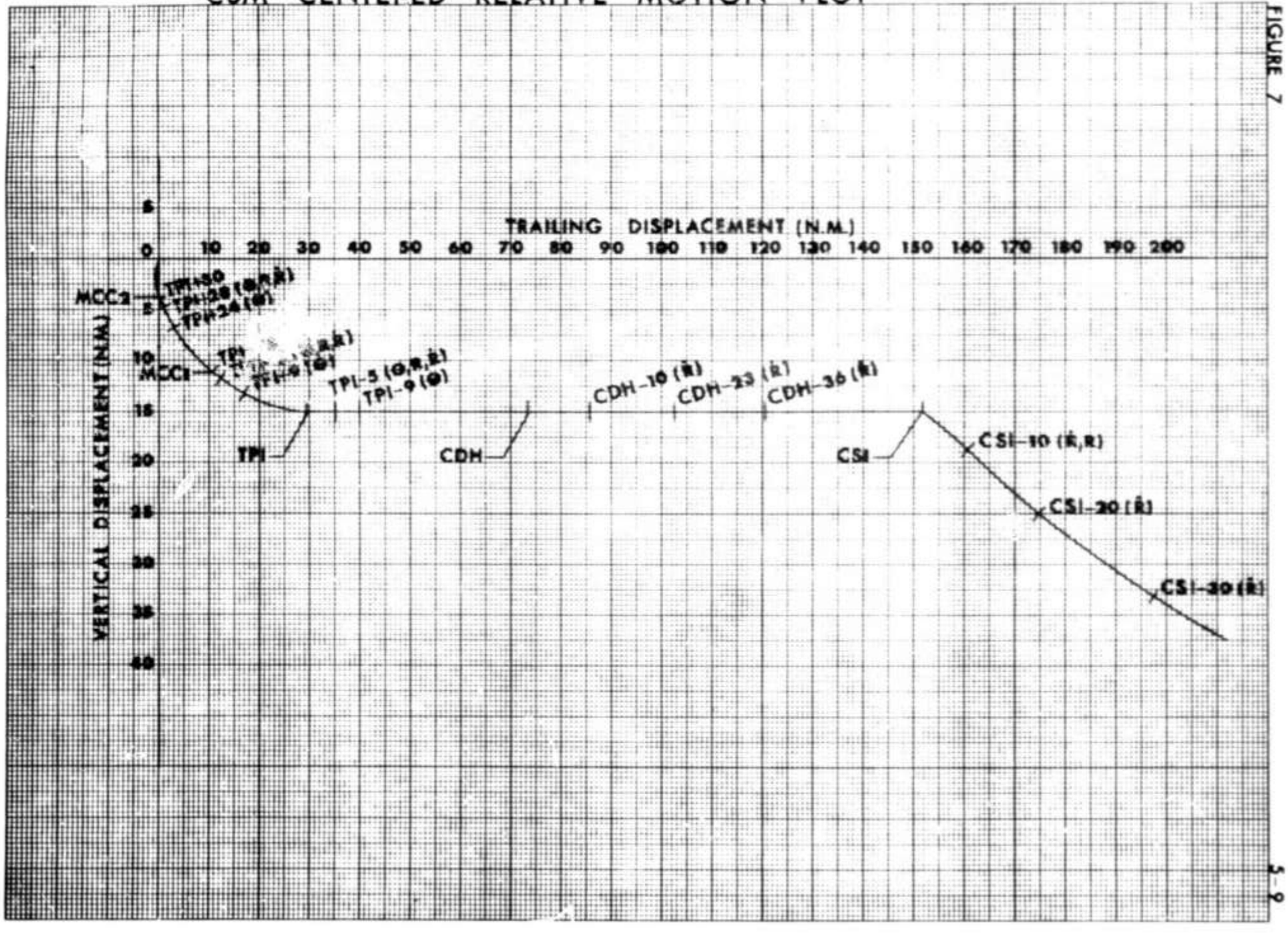


FIGURE 7

BRAKING SCHEDULE

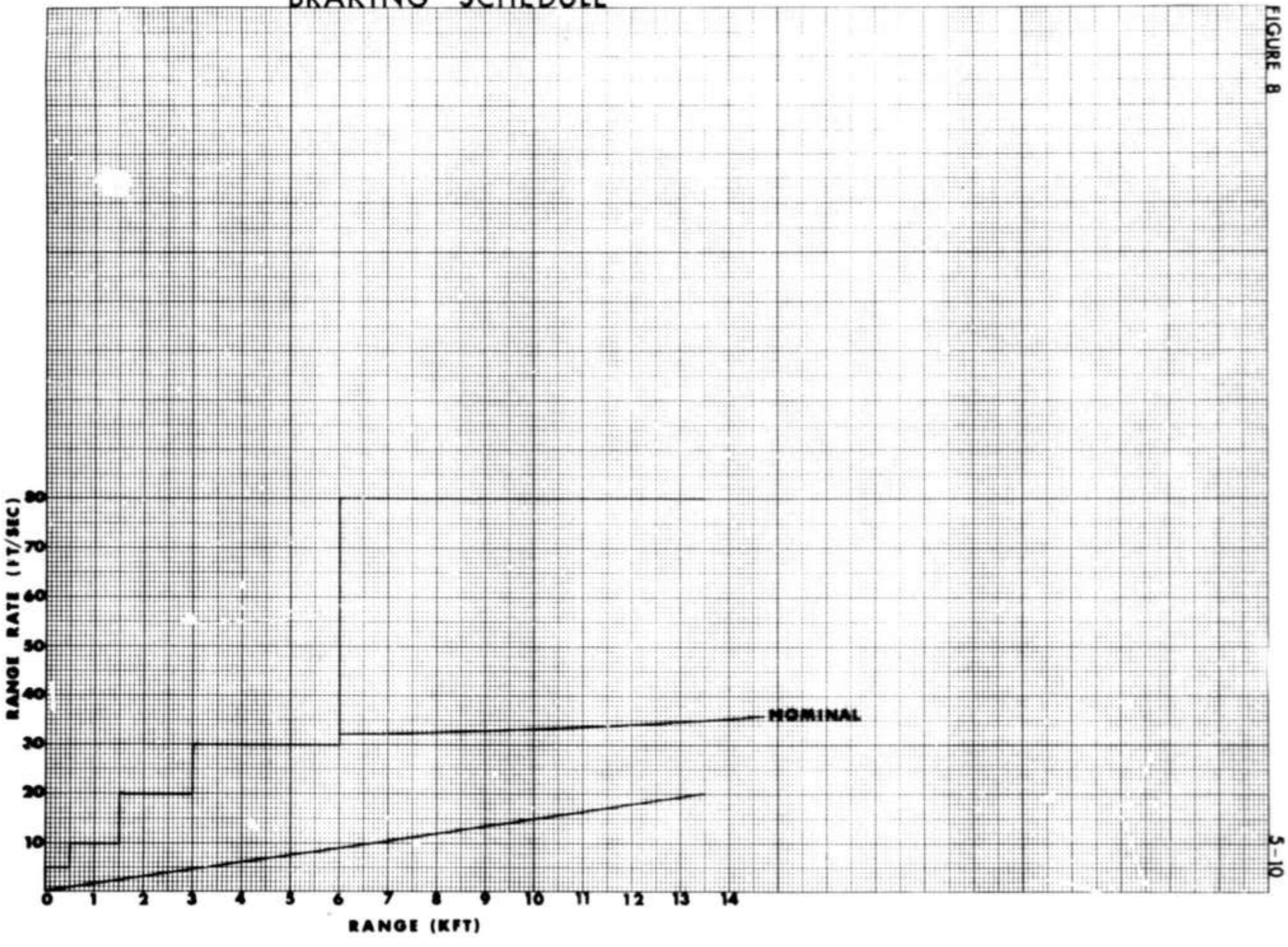


FIGURE 8

FIGURE 9

TOTAL ΔV

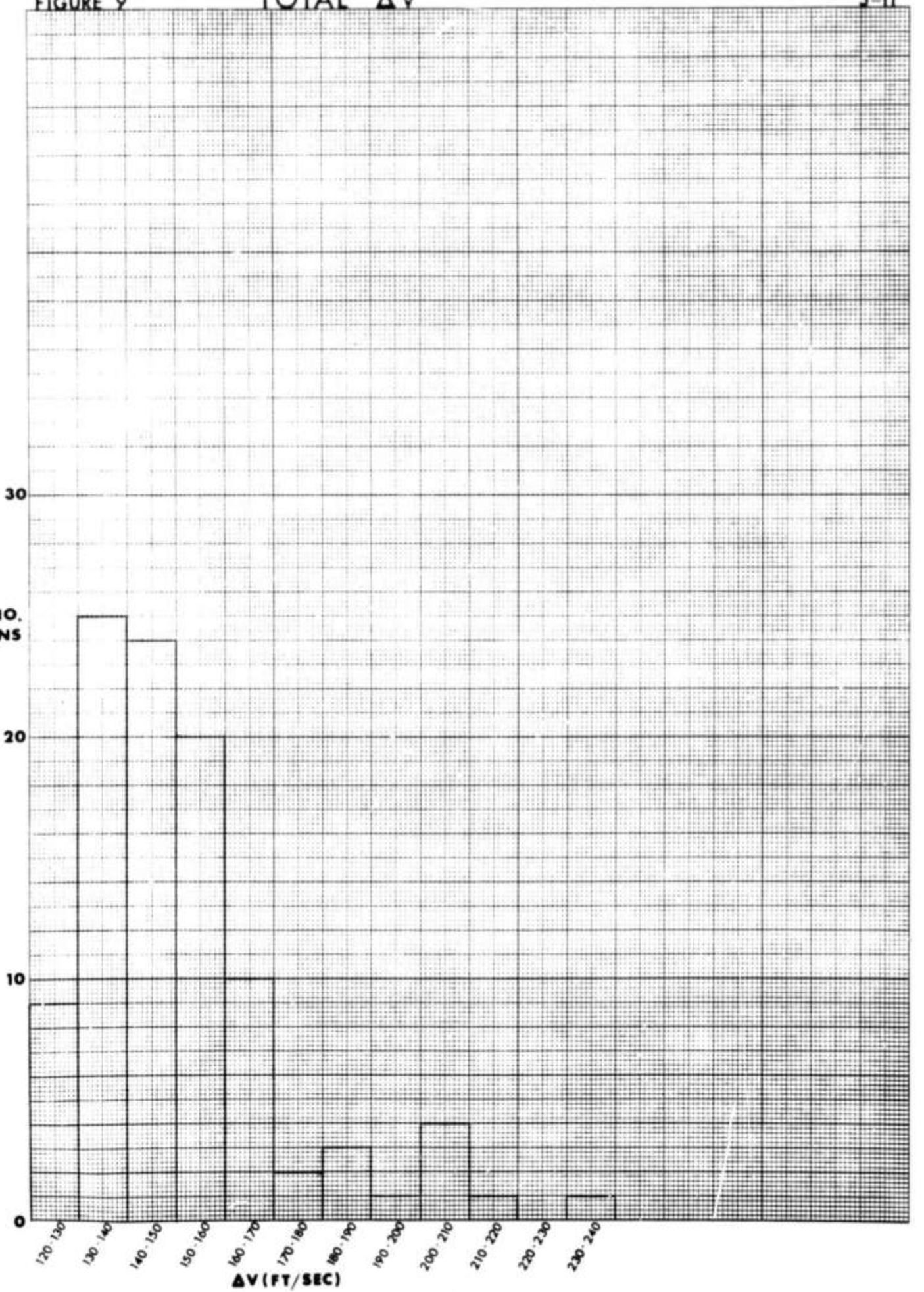


FIGURE 10 TIME OF TPI

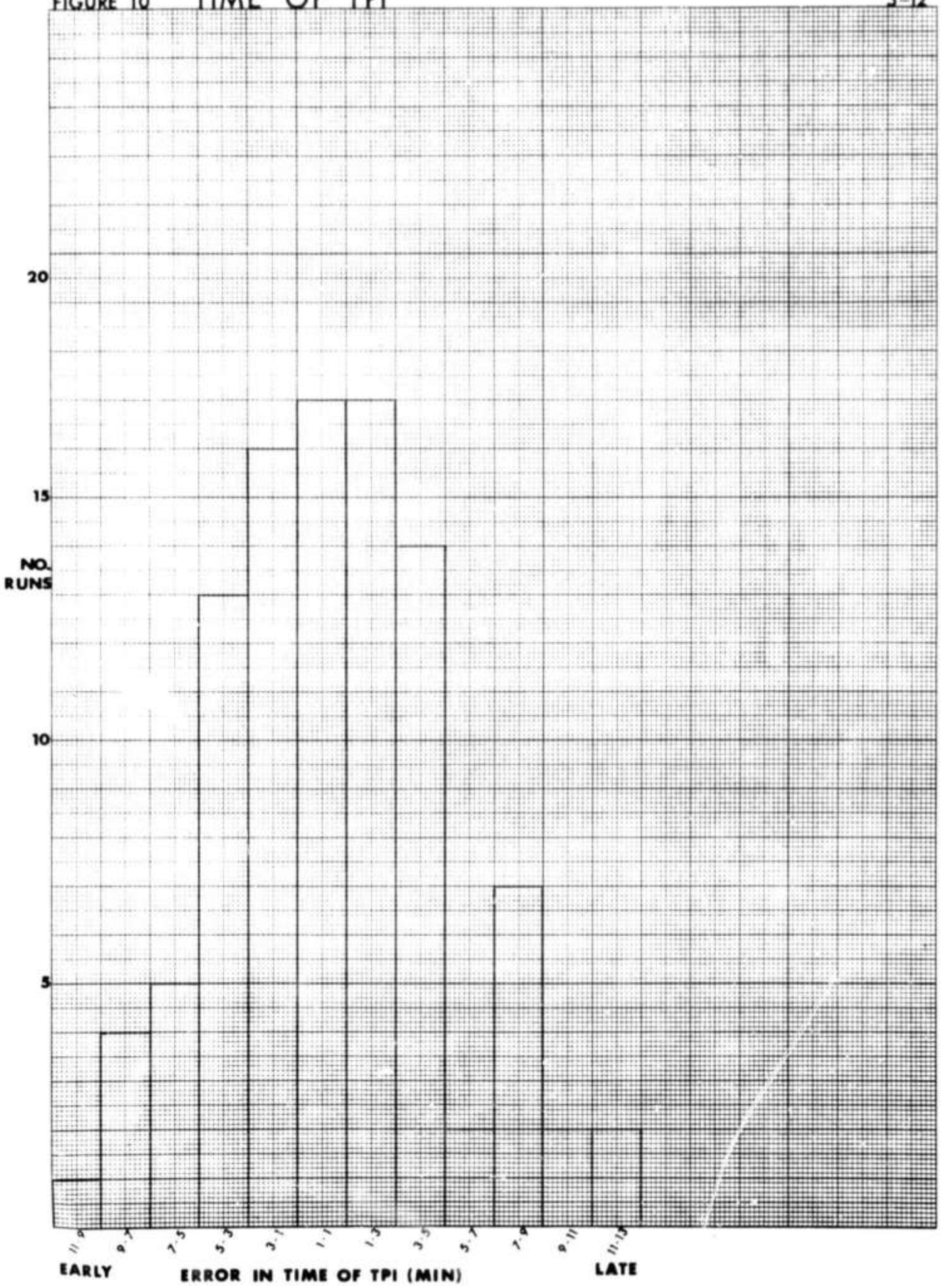


FIGURE 11 ΔT FROM TPI TO TPF