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APOLLO 12 (MISSION H-1) SPACECRAFT DISPERSION ANALYSIS VOLUME IV DESCENT AND ASCENT DISPERSION ANALYSES PART 1 - LUNAR DESCENT

Landing Analysis Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

APOLLO 12 (MISSION H-1) SPACECRAFT DISPERSION ANALYSIS VOLUME IV - DESCENT AND ASCENT DISPERSION ANALYSES PART 1 - LUNAR DESCENT

By Gilbert L. Carman and Moises N. Montez
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PART 1 - LUNAR DESCENT

By Gilbert L. Carman and Moises N. Montez

1.0 SUMMARY

The results of the Apollo 12 (Mission H-1) dispersion analysis for the LM descent are presented in the form of statistical tables and 99 percent, 90 percent, and 50 percent landing dispersion ellipses. The study is based on a nonlinear Monte Carlo analysis, and 100 descents were run.

In summary, there were no violations of known systems or trajectory constraints. All 100 descents were successful. The 99 percent landing dispersion ellipse (3.2 n. mi. by 1.1 n. mi.) does not indicate a significant improvement from Apollo 11 because DOI execution errors that result from systems uncertainties overshadow any improvement in the orbital navigation accuracies. To determine these numbers, it was assumed that no update of the landing site vector during P63 was used and that no state vector update from the ground was incorporated post-DOI. Reduction of the accelerometer bias uncertainty and a correction to the landing site increase the probability of a pinpoint landing (i.e., a landing which occurs within a 1-km radius of the designated landing point).

A reduction in the accelerometer bias uncertainty has been confirmed since the data for this report were generated. The major effect of this reduction is a reduction in the landing dispersions (from 3.2 by 1.1 n. mi. to 1.2 by 0.7 n. mi.). The effect of this reduction on other trajectory dispersions is minimal.

2.0 INTRODUCTION

The purpose of this document is to present the technical approach assumptions and the results of the final dispersion analysis performed for the lunar descent phase of Apollo 12 (Mission H-1) as defined in reference 1. The purpose of the dispersion analysis is to assess the effects of navigation, terrain, and systems uncertainties on the probabilities for mission success and flight safety.

A nonlinear Monte Carlo analysis of the mission was performed to permit inclusion of nonlinear effects so that the resultant non-Gaussian sample statistic could be computed. The covariance matrices sampled by the Monte Carlo simulation were generated by the Mathematical Physics Branch (ref. 2). Samples from the simulation were analyzed by the TRW statistical processor (ref. 3).

3.0 ABBREVIATIONS

APS	ascent propulsion system
DAMP	descent ascent Monte Carlo program
DOI	descent orbit insertion
DPS	descent propulsion system
FTP	fixed throttle point
GAC	Grumman Aerospace Corporation
G&N	guidance and navigation
LAB	Landing Analysis Branch
LGC	LM guidance computer
LM	lunar module
LPD	landing point designator
LR	landing radar
PDI	powered descent initiation
PGNCS	primary guidance and navigation control subsystem
RCS	reaction control subsystem
t_{GO}	time to go
t_{IG}	time of ignition
ΔV	change in velocity

4.0 ANALYSIS

Dispersion data for this Monte Carlo analysis were generated by the LAB DAMP program. This study considered the effects of propulsion uncertainties, landing radar errors, terrain, and terrain slope on the lunar landing trajectory from lunar orbit. Initial systems errors for each Monte Carlo cycle were selected by a random number generator. Navigation uncertainties were incorporated into the initial state vector for each cycle by sampling a covariance matrix. Statistics were generated for the dispersion data at nine points in the trajectory. A detailed description of the major points which constituted this Monte Carlo analysis is given in subsections 4.1 through 4.3.

4.1 Descent Trajectory and Guidance

The latest descent targeting philosophy was used to generate the desired conditions used in this study; these conditions are documented in reference 1.

The simulation was initialized over the landing site one revolution prior to landing. The sequence of events was as follows.

a. Target the DOI burn.

b. Coast with an ENCKE program to t_{IG} for DOI.

c. Perform the DOI burn.

d. Coast with an ENCKE program to PDI.

e. Perform the powered descent.

All the navigation and guidance routines used in the simulation were acquired from reference 4 except for the ENCKE and the DOI targeting routine.

4.2 Error Sources

The PGNCS errors considered in this analysis were accelerometer bias, scale factor, gyro drift, and misalinement. The 3σ values for these errors were obtained from reference 5 and are listed in table I.

The terrain variation model for site 7 (ref. 6) was used with a 3σ uncertainty of $\pm 1^\circ$ in terrain slope superimposed on the terrain for ranges of less than 40 kilometers. Elevation uncertainties are computed in the following manner.

If range $<$ 40 km, use -TS *Range

If range $\geq$ 40 km, use -TS *(40 km)

where TS is the tangent of the uncertainty in the terrain slope. A positive slope is defined as one which slopes up (from the LM) toward the landing site.

The LM DPS model (Victory 7) used in this analysis is described in reference 7. It is a linear DPS engine model that uses basic acceptance test data and adjusts them to flight interface conditions. Interface conditions calculated in Victory 7 are functions of vehicle longitudinal acceleration and propellant flow rates. Engine tag values and class coefficients which were used in this analysis are documented in reference 8.

Navigation uncertainties for a position and velocity vector one revolution prior to landing were used in the form of a covariance matrix (ref. 2). These covariance matrices are listed in table II. The data presented in this table describe the uncertainty of the estimated state vector from the actual state vector. Initially, the actual state vector is assumed to be in the nominal 60-n. mi. altitude circular orbit.

Entries in the matrix are given in a UVW system which is defined as follows.

$$U = \frac{\underline{r}}{|\underline{r}|}, \text{ vertical}$$

$$V = W \times U, \text{ down range}$$

$$W = \frac{\underline{r} \times \underline{v}}{|\underline{r} \times \underline{v}|}$$

where $\underline{r}$ is the position vector and $\underline{v}$ is the inertial velocity in selenocentric coordinates.

The landing radar model used in the studies for the report was the GAC mathematical model of reference 9. This model includes terrain effects and detailed track logic based on signal to noise ratio calculations. A detailed error model is also included which introduces the following error sources into the range and velocity measurements.

a. Deterministic errors

   1. Terrain bias error

   2. Preamplifier slope error

   3. VCO drift error

   4. Dynamic lag error

   5. Doppler compensation error

b. Random bias errors

   1. Boresight misalinement error

   2. Installation misalinement error

   3. Modulation rate error

c. Random fluctuation errors

   1. Spread spectrum error

   2. Doppler compensation error

   3. Quantization error

The triaxial potential function was modified as suggested in reference 10 to obtain the R2 potential function which was used in this study.

All the parameters which are randomized during each Monte Carlo cycle are listed in table III.

4.3 Statistical Output

Covariance matrices were generated at landing and at 3 minutes prior to nominal PDI. The format for these matrices is the following.

$$\begin{bmatrix} \underset{6\times 6}{\wedge}_{AR} & & \text{(covariance terms)} \\ & \underset{6\times 6}{\wedge}_{EA} & \\ & & \underset{1\times 1}{\wedge}_{W} \end{bmatrix}$$

13×13

where $\underset{6\times 6}{\wedge}_{AR}$ describes the uncertainty of the actual about the reference

$\underset{6\times 6}{\wedge}_{EA}$ describes the uncertainty of the estimated about the actual

$\underset{1\times 1}{\wedge}_{T}$ describes the uncertainty in weight

Statistics were computed for the parameters defined in table IV at each of the following points in the descent trajectory.

a. DOI cutoff

b. PDI minus 3 minutes

c. High gate

d. Ranges of 20 000, 10 000, 5000, and 2000 feet

e. Vertical descent initiation

f. Landing

Statistics were generated only for cases which did not violate any of the following abort criteria.

a. Propellant depletion prior to lunar landing

b. Failure to achieve landing radar altitude update initiation prior to high gate

c. Lunar landing prior to the vertical descent phase

d. Violation of the 4-second APS abort boundary (altitude versus altitude rate constraint) prior to 600-foot altitude above lunar surface

5.0 DISCUSSION AND RESULTS

One hundred descents were run, and none of these violated the abort criteria defined in the preceding section. The results for the 100 successful landings are presented in the form of statistical tables and landing dispersion ellipses. This discussion includes dispersions at DOI cutoff and PDI; landing radar acquisition; throttle recovery; dispersions at high gate, glide path, and low gate; dispersions at vertical descent; pitch dispersions at landing and DPS burn time; landing dispersion ellipses, landing velocity; ΔV and propellant dispersions; and time histories with associated 3σ dispersions for selected parameters.

The summary for the statistical parameters is presented in table V while the covariance matrices which were generated in this study are presented in table VI.

5.1 Dispersions at DOI Cutoff

The DOI burn is well behaved, and the accuracy with which the burn is performed is acceptable to establish a safe perilune altitude at which the powered descent can be initiated. The dispersions in burn duration are attributed primarily to navigation uncertainty and accelerometer bias error. A 3σ variation in burn time is ± 0.6 second, and a 3σ variation in ΔV is ± 1.5 fps. A 1-fps variation in ΔV causes a variation in perilune altitude uncertainty of 0.7 n. mi. A 3σ variation in ΔV would reflect an altitude uncertainty at perilune which is well within the limit of a safe perilune for performance of a powered descent. The mean and the standard deviation in the ΔV residuals at DOI cutoff, in body coordinates, are as follows.

$$\Delta V_{x\text{-body}} = 0.09 \pm 0.04 \text{ fps}$$

$$\Delta V_{y\text{-body}} = 0.00 \pm 0.02 \text{ fps}$$

$$\Delta V_{z\text{-body}} = 0.00 \pm 0.02 \text{ fps}$$

The residuals will not be trimmed.

5.2 Dispersion at PDI

No convergence problems caused by dispersions at PDI were encountered in the ignition computations. Because of systems uncertainties, the 3σ dispersion in perilune altitude is 4800 feet. The 3σ dispersions in

vertical and horizontal velocity (at PDI minus 3 min) are ±4.5 fps and ±9.0 fps, respectively. Dispersions of this magnitude can be corrected by the G&N system and will result in a safe landing.

5.3 Landing Radar Acquisition

Landing radar acquisitions of altitude and velocity data nominally occur at altitudes of 36 000 feet and 16 700 feet, respectively. The 3σ high and low altitudes for landing radar altitude acquisition are 41 520 feet and 30 500 feet, respectively. The 3σ high and low altitudes for velocity acquisition are 18 500 feet and 14 900 feet, respectively.

5.4 Throttle Recovery

Throttle recovery nominally occurs at t_{GO} = 180 seconds (approximately 118 sec prior to high gate because target switch occurs when t_{GO} = 62 sec). A 3σ high value for t_{GO} at throttle recovery is 195 seconds, and a 3σ low value would be 165 seconds. The shutoff valve malfunction, which would reduce the t_{GO} at throttle recovery by 60 seconds, is not incorporated in these values. These statistics indicate that without a shutoff valve malfunction there will be at least a 105-second period of throttle recovery in which to meet the target conditions at high gate. A minimum throttle recovery time of 30 seconds has been shown to be adequate in previous studies.

5.5 High-gate Dispersions

Nominally, high gate occurs at an altitude of 6700 feet with a flight-path angle of -22° and a vertical velocity of -167 fps. The 3σ high values for altitude, flight-path angle, and vertical velocity are 7750 feet, -28°, and -200 fps, respectively. The 3σ low values, in the same order, are 5650 feet, -17°, and -134 fps. These dispersions do not indicate a flight safety problem at high gate.

5.6 Glide Path

The 3σ altitude dispersions at ranges of 20 000 feet, 10 000 feet, 5000 feet, and 2000 feet are ±750 feet, ±546 feet, ±450 feet, and ±369 feet, respectively. These dispersions cause the approach to be outside the desired approach corridor of reference 22 [fig. 1(a)]. The approach trajectory dips into the sun angles (visibility washout)

at a range of approximately 7000 feet and an altitude of 1500 feet. Altitude versus range for the nominal trajectory as well as the 3σ altitude dispersions are presented in figure 1(b).

5.7 Low Gate (Range of 2000 ft)

Low gate occurs nominally at an altitude of 500 feet. The approach trajectory has been designed to provide a more efficient automatic trajectory and an improved redesignation capability at low gate. The statistics presented in this section were computed at a range of 2000 feet, which is approximately the range at which low gate occurs. The nominal values for horizontal velocity, vertical velocity, and pitch are 84 fps, -18 fps, and 23°, respectively. The 3σ dispersion of these parameters are ±3.6 fps, ±9 fps, and ±0.9°, respectively. These dispersions are considered to be within the capability of the pilot to perform his takeover function.

5.8 Vertical Descent

The nominal altitude at vertical descent initiation is 100 feet (no terrain). A 3σ high altitude at vertical descent initiation is 156 feet, and a 3σ low altitude is 48 feet. These altitudes include terrain effects and are for completely automatic landings. Terminal propellant dispersions are extremely sensitive to altitude dispersions at vertical descent initiation because of the small vertical rate. For each second of time, approximately 9 pounds of propellant is expended, and altitude is reduced by only 3 feet. Therefore, altitude dispersions are 3 lb/ft.

5.9 Pitch at Landing (Landing Gear Probe Contact)

The nominal pitch (from local vertical) at landing is 0°. The 3σ low and high samples are -0.5° and 0.9°, respectively. These values were well within the 6° constraint of reference 12.

5.10 Powered Descent Burn Time

The nominal DPS burn time is 676 seconds, and there is a 99 percent probability that the time will be less than 706 seconds. The smallest sample was 642 seconds. These dispersions indicate that there is no conflict with the DPS burn time constraint, which is approximately 910 seconds.

5.11 Landing Dispersion Ellipses

The current estimate of the LM landing dispersion ellipses is based on a sample size of 100 runs and is given in table VII. The 99 percent ellipse (3.2 n. mi. by 1.1 n. mi.) does not indicate a significant improvement from Apollo 11 because DOI execution errors that result from systems uncertainties overshadow any improvement in the orbital navigation accuracies. These numbers assume that no update of the landing site vector during P63 was used and that no state vector update from the ground was incorporated post-DOI. Reduction of the accelerometer bias and a correction to the landing site increase the probability for a pinpoint landing.

The dispersion ellipses for different 3σ values for accelerometer bias as well as different navigation accuracies used with an Apollo 12 (H-1) mission timeline are presented in table VII. Also included in the table are the dispersion ellipses in which a perfect state vector update was incorporated prior to PDI. The data in table VII indicate that a reduction in the accelerometer bias increases the probability for a pinpoint landing. A state vector update prior to PDI or during P63 increases the probability even more. There is no method currently in existence that can be used to correct cross-range errors. Therefore, cross-range dispersions remain the same with or without a landing site correction. The ellipses in this case are rotated 90° primarily because of a platform misalinement which has a greater effect on the cross-range dispersions. A scatter plot of the samples and the 99 percent, 90 percent, and 50 percent dispersion ellipses are presented in figure 2(a). The dispersion ellipses for the reduced accelerometer bias 3σ uncertainty (0.2 cm/sec^2) are presented in figure 2(b).

5.12 Landing (Landing Gear Probe Contact) Velocity

Nominal horizontal and vertical velocities at landing are 0.008 fps and -3 fps, respectively. The 3σ dispersions, in the same order, are ± 0.6 fps and ± 0.6 fps. No free-fall effects are reflected in these velocity uncertainties. The 3σ velocity error ellipse is compared in figure 3 with the landing gear constraints at landing specified in reference 12.

5.13 ΔV and Propellant Summary

The ΔV and propellants are summarized in this document for an automatically guided descent only; that is, manual translation and landing site redesignation (manually input) are not considered. The ΔV and propellants required are tabulated at major event points during the descent in table VIII(a). The fuel, oxidizer, and total propellant

results are derived by use of the linear propulsion system model (ref. 7). The propellant status for the total descent is presented in table VIII(b), which includes loaded propellant, propellant consumed, and usable remaining propellant. Usable remaining propellant is, by definition, the propellant remaining at landing which can be used for ΔV. The usable remaining propellant values do not allow for system malfunctions, biases, or contingency situations (redline low-level sensor, engine valve malfunction).

5.14 Time Histories and Dispersions for Selected Parameters

Time histories as well as the 3σ dispersions for true altitude, LPD angle, pitch, vertical velocity, glide angle, and commanded thrust are plotted in figure 4. Time histories for engine parameters and their associated dispersions were not included because they would be identical to the time histories which will appear in the LM data book (ref. 14).

6.0 CONCLUSIONS

There were no violations of known systems or trajectory constraints. All 100 descents were successful. The 99 percent landing dispersion ellipse (3.2 n. mi. by 1.1 n. mi.) does not indicate a significant improvement from Apollo 11 because DOI execution errors that result from systems uncertainties overshadow any improvement in the orbital navigation accuracies. To determine these numbers it was assumed that no update of the landing site vector during P63 was used and that no state vector update from the ground was incorporated post-DOI. Reduction of the accelerometer bias uncertainty and a correction to the landing site increase the probability for a pinpoint landing.

A reduction in the accelerometer bias uncertainty has been confirmed since the data for this report were generated. The major effect of this reduction is a reduction in the landing dispersions (from 3.2 by 1.1 n. mi. to 1.2 by 0.9 n. mi.). The effect of this reduction on other trajectory dispersions is minimal.

TABLE I.- IMU ERRORS

Component	3σ error	Equivalent errors in program units
Gyro misalinement	0.057 deg	0.0009948 rad
Coasting flight gyro drift	.09 deg/hr	$.436332 \times 10^{-6}$ rad/sec
Powered flight gyro drift	.3 deg/hr	$.14544 \times 10^{-5}$ rad/sec
Accelerometer bias	.6 cm/sec^2	.019685 ft/sec^2
Accelerometer scale factor	$300/10^6$	.003

TABLE II.- COVARIANCE MATRIX OF NAVIGATION UNCERTAINTIES[a]

(a) 95 % confidence

INPUT COVARIANCE MATRIX

1,407076D+05	-2,533486D+04	2,0901800-01	1,5501240+02	-1,237820+02	4,967753D-04	0.0000000
-2,533486D+04	8,8513800+05	5,3273990+00	-8,0119659+02	-1,6991330+01	9,5562319-02	0.0000000
2,0901800-01	5,3273990+00	1.046047D+06	-4,5841160-03	-2,9048970-04	7,3334499+01	0.0000000
1,5501240+02	-8,0119659+02	-4,5841160-03	2,4603470+00	-1,0190390-01	-8,4823219-05	0.0000000
-1,2397820+02	-1,6991330+01	-2,9048970-04	-1,0190390-01	1,1107730-01	-7,1466230-07	0.0000000
4,9677530-04	9,5562319-02	7,3334499+01	-8,4823219-05	-7,1466230-07	1,7123640+00	0.0000000
0,0000000	0,0000000	0,0000000	0.0000000	0.0000000	0,0000000	5.8225999+02

(b) 55 % confidence

INPUT COVARIANCE MATRIX

1,407,040+05	-2,5289830+04	2,0890670-01	1,5497220+02	-1,2398280+02	4,9677260-04	0.0000000
-2,5289830+04	4,3045420+05	6,4432210+00	-3,9669820+02	4,2423040+00	9,5578140-02	0.0000000
2,0890670-01	6,4432210+00	1,0460470+06	-5,5767810-03	-3,4259770-04	7,3334499+01	0.0000000
1,5497220+02	-3,9669820+02	-5,5767810-03	2,1004940+00	-1,2079370-01	-8,4837289-05	0.0000000
-1,2398280+02	4,2423040+00	-3,4259770-04	-1,2079370-01	1,1008790-01	-7,1540000-07	0.0000000
4,9677260-04	9,5578140-02	7,33344990+01	-8,4837289-05	-7,1540000-07	1,7123640+00	0.0000000
0,0000000	0,0000000	0,0000000	0,0000000	0,0000000	0,0000000	5,8225999+02

[a]Format for covariance matrix

σ_{xx}	σ_{xy}	σ_{xz}	$\sigma_{x\dot{x}}$	$\sigma_{x\dot{y}}$	$\sigma_{x\dot{z}}$
	σ_{yy}	σ_{yz}	$\sigma_{y\dot{x}}$	$\sigma_{y\dot{y}}$	$\sigma_{y\dot{z}}$
		σ_{zz}	$\sigma_{z\dot{x}}$	$\sigma_{z\dot{y}}$	$\sigma_{z\dot{z}}$
			$\sigma_{\dot{x}\dot{x}}$	$\sigma_{\dot{x}\dot{y}}$	$\sigma_{\dot{x}\dot{z}}$
				$\sigma_{\dot{y}\dot{y}}$	$\sigma_{\dot{y}\dot{z}}$
					$\sigma_{\dot{z}\dot{z}}$

TABLE III.- PARAMETERS RANDOMIZED DURING EACH MONTE CARLO CYCLE

(a) IMU

Gyro misalinement
Coasting flight gyro drift
Powered flight gyro drift
Accelerometer bias
Accelerometer scale factor

(b) LR

Boresight misalinement error
Installation misalinement error
Modulation rate error
Spread spectrum error
Doppler compensation error
Quantization error

(c) Engine model and propulsion system

Thrust
Specific impulse
Mixture ratio
Pressure drop ratio across the injector
Loaded fuel
Loaded oxidizer
Dry weight of LM + APS propellant

(d) State vector

Navigated position and velocity vectors

(e) Terrain

Terrain slope

TABLE IV.- DEFINITION OF SYMBOLS

FPAG	Estimated flight-path angle, deg
FPAGT	True flight-path angle, deg
HORV	Estimated horizontal velocity, fps
HORVT	True horizontal velocity, fps
HDOT	Estimated vertical velocity, fps
VERVT	True vertical velocity, fps
PVRT	Estimated pitch from vertical, deg
PVRTT	True pitch from vertical, deg
HEST	Estimated altitude, ft
HTRU	Altitude above the local terrain, ft
RANGE	Z component of LM position vector in the guidance coordinate system, ft
HVIS	True altitude at landing sight visibility acquisition, ft
HORZ	True altitude at horizon visibility acquisition, ft
LATLM	Latitude of LM, deg
LONLM	Longitude of LM, deg
HLRA	True altitude at landing radar altitude acquisition, ft
HLRV	True altitude at landing radar velocity acquisition, ft
ELANG	Glide angle, deg
ELAS	LPD angle, navigated, deg
HPER	LM perilune altitude, ft
HAPO	LM apolune altitude, ft
ECC	Eccentricity, n.d.

TABLE IV.- DEFINITION OF SYMBOLS - Concluded

DEVMT	Total actual accumulated ΔV, fps
TFIG	Total DPS burn time, sec
BURN	Burn time at FTP (fixed throttle point), sec
TFXA	TGO at throttle down time, sec
WT	Weight deviation from nominal, lb
TTVIS	Total landing sight visibility time, sec
WPR	DPS propellant remaining, lb
WF	DPS fuel remaining, lb
WOX	DPS oxidizer remaining, lb
FC	Thrust commanded by the guidance, lb
THF	DPS thrust, lb
PIO	Oxidizer interface pressure, lb
PIF	Fuel interface pressure, lb
DWO	Oxidizer flow rate, lb/sec
DWF	Fuel flow rate, lb/sec
RE	Mixture ratio, n.d.
REE	Effective mixture ratio, n.d.
CISP	Specific impulse, sec
EISP	Effective specific impulse, sec

TABLE V.- SUMMARY OF STATISTICAL PARAMETERS

Descent orbit insertion cutoff

NOMINAL VALUES

FPAG	-1.5308590-02	HPER	5.4706625+04	HAPO	0.0000000	ECC	2.6142434-02	ELAS	-2.2532273+01	PVRT	1.0591662+02
HORV	5.2915844+03	HDOT	-1.4138336+00	RANGE	0.0000000	ELANG	8.2960120+01	HTRU	3.6245437+05	HEST	3.6340807+05
WPR	1.7840712+04	WF	6.8472948+03	WOX	1.0993416+04	DEVMT	7.3327030+01	TFIG	3.5511719+01	TFXA	0.0000000
BURN	0.0000000	HVIS	0.0000000	TTVIS	0.0000000	FC	0.0000000	VERVT	-1.5855560+00	HORVT	5.2915886+03
FPAGT	-1.7167937-02	PVRTT	1.0591672+02	LATLM	6.3923213+00	LONLM	1.7043951+02	HLRA	0.0000000	HLRV	0.0000000
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	0.0000000	PIO	2.4061340+02	PIF	2.4057164+02	DWO	0.0000000
DWF	0.0000000	RE	1.5959122+00	REE	1.6001752+00	CISP	0.0000000	EISP	0.0000000		

MEAN VALUES

FPAG	-1.5239996-02	HPER	5.4902628+04	HAPO	0.0000000	ECC	2.6126245-02	ELAS	-2.2475418+01	PVRT	1.0585901+02
HORV	5.2915679+03	HDOT	-1.4074946+00	RANGE	0.0000000	ELANG	8.2958807+01	HTRU	3.6245757+05	HEST	3.6343764+05
WPR	1.7840337+04	WF	6.8477112+03	WOX	1.0992624+04	DEVMT	7.3263810+01	TFIG	3.5469296+01	TFXA	0.0000000
BURN	0.0000000	HVIS	0.0000000	TTVIS	0.0000000	FC	0.0000000	VERVT	-1.4702046+00	HORVT	5.2916318+03
FPAGT	-1.5919136-02	PVRTT	1.0587130+02	LATLM	6.3907186+00	LONLM	1.7043297+02	HLRA	0.0000000	HLRV	0.0000000
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	0.0000000	PIO	2.4064523+02	PIF	2.4060471+02	DWO	0.0000000
DWF	0.0000000	RE	1.5959025+00	REE	1.6001753+00	CISP	0.0000000	EISP	0.0000000		

STANDARD DEVIATION

FPAG	2.1987106-04	HPER	1.6709183+03	HAPO	0.0000000	ECC	1.4450605-04	ELAS	1.2000074+00	PVRT	1.2022115+00
HORV	2.4494897+00	HDOT	2.0264407-02	RANGE	0.0000000	ELANG	4.6875000-02	HTRU	7.1554174+01	HEST	5.6068529+02
WPR	1.3856406+01	WF	5.9160798+00	WOX	1.0630146+01	DEVMT	6.0545614-01	TFIG	1.8371837-01	TFXA	0.0000000
BURN	0.0000000	HVIS	0.0000000	TTVIS	0.0000000	FC	0.0000000	VERVT	1.3499074+00	HORVT	2.5495097+00
FPAGT	1.4616607-02	PVRTT	1.1564083+00	LATLM	1.3948102-02	LONLM	1.0126157-01	HLRA	0.0000000	HLRV	0.0000000
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	0.0000000	PIO	3.1715286-01	PIF	3.2400689-01	DWO	0.0000000
DWF	0.0000000	RE	2.9851121-03	REE	3.0929832-03	CISP	0.0000000	EISP	0.0000000		

Powered descent initiation minus 3 min

NOMINAL VALUES

FPAG	-2.0748393-01	HPER	4.9803562+04	HAPO	0.0000000	ECC	2.6870723-02	ELAS	2.5036166+02	PVRT	8.2881046+01
HORV	5.5769283+03	HDOT	-2.0195694+01	RANGE	0.0000000	ELANG	9.9338533+00	HTRU	5.1225625+04	HEST	5.1248875+04
WPR	1.7840712+04	WF	6.8472948+03	WOX	1.0993416+04	DEVMT	7.3327030+01	TFIG	3.2982109+03	TFXA	0.0000000
BURN	0.0000000	HVIS	0.0000000	TTVIS	0.0000000	FC	0.0000000	VERVT	-2.0006226+01	HORVT	5.5769514+03
FPAGT	-2.0553655-01	PVRTT	8.2873368+01	LATLM	-8.4290671+00	LONLM	-1.4345466+00	HLRA	0.0000000	HLRV	0.0000000
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	0.0000000	PIO	2.4061340+02	PIF	2.4057164+02	DWO	0.0000000
DWF	0.0000000	RE	1.5959122+00	REE	1.6001752+00	CISP	0.0000000	EISP	0.0000000		

MEAN VALUES

FPAG	-2.0777720-01	HPER	4.9999491+04	HAPO	0.0000000	ECC	2.6854469-02	ELAS	2.5041158+02	PVRT	8.2946678+01
HORV	5.5769164+03	HDOT	-2.0224210+01	RANGE	0.0000000	ELANG	9.9394937+00	HTRU	5.1453290+04	HEST	5.1271075+04
WPR	1.7840337+04	WF	6.8477112+03	WOX	1.0992624+04	DEVMT	7.3263810+01	TFIG	3.2980376+03	TFXA	0.0000000
BURN	0.0000000	HVIS	0.0000000	TTVIS	0.0000000	FC	0.0000000	VERVT	-2.0146128+01	HORVT	5.5767813+03
FPAGT	-2.0698200-01	PVRTT	8.2934942+01	LATLM	-8.4313072+00	LONLM	-1.4245521+00	HLRA	0.0000000	HLRV	0.0000000
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	0.0000000	PIO	2.4064523+02	PIF	2.4060471+02	DWO	0.0000000
DWF	0.0000000	RE	1.5959025+00	REE	1.6001753+00	CISP	0.0000000	EISP	0.0000000		

STANDARD DEVIATION

FPAG	2.0769897-03	HPER	1.6733583+03	HAPO	0.0000000	ECC	1.4523430-04	ELAS	1.2390142+00	PVRT	1.2583462+00
HORV	2.2360680+00	HDOT	2.0175885-01	RANGE	0.0000000	ELANG	3.9330137-02	HTRU	1.7805707+03	HEST	1.7816846+02
WPR	1.3856406+01	WF	5.9160798+00	WOX	1.0630146+01	DEVMT	6.0545614-01	TFIG	1.1180340+00	TFXA	0.0000000
BURN	0.0000000	HVIS	0.0000000	TTVIS	0.0000000	FC	0.0000000	VERVT	1.6165646+00	HORVT	3.0413812+00
FPAGT	1.6633956-02	PVRTT	1.2712308+00	LATLM	1.9433348-02	LONLM	8.4470186-02	HLRA	0.0000000	HLRV	0.0000000
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	0.0000000	PIO	3.1715286-01	PIF	3.2400689-01	DWO	0.0000000
DWF	0.0000000	RE	2.9851121-03	REE	3.0929832-03	CISP	0.0000000	EISP	0.0000000		

TABLE V - SUMMARY OF STATISTICAL PARAMETERS - Continued

High gate

NOMINAL VALUES

FPAG	-2.0941182+01	HPER	-5.6784975+06	HAPO	0.0000000	ECC	9.9416371-01	ELAS	7.5645180+01	PVRT	5.9698998+01
HORV	4.3569817+02	HDOT	-1.6673588+02	RANGE	2.3824884+04	ELANG	1.5714779+01	HTRU	6.7385143+03	HEST	6.7533257+03
WPR	3.6209597+03	WF	1.3606557+03	WOX	2.2603034+03	DEVMT	5.5001451+03	TFIG	5.0600000+02	TFXA	1.8066028+02
BURN	3.5800000+02	HVIS	0.0000000	TTVIS	0.0000000	FC	5.9950690+03	VERVT	-1.6683920+02	HORVT	4.3568916+02
FPAGT	-2.0953427+01	PVRTT	5.9698256+01	LATLM	-3.0021345+00	LONLM	-2.3218641+01	HLRA	3.6116537+04	HLRV	1.6760927+04
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	5.9995120+03	PIO	2.3626515+02	PIF	2.3633367+02	DWO	1.2191180+01
DWF	7.6878839+00	RE	1.5857653+00	REE	1.5918522+00	CISP	3.0180053+02	EISP	3.0155487+02		

MEAN VALUES

FPAG	-2.1233711+01	HPER	-5.6782564+06	HAPO	0.0000000	ECC	9.9408028-01	ELAS	7.5924982+01	PVRT	5.9723646+01
HORV	4.3773077+02	HDOT	-1.7015122+02	RANGE	2.3947464+04	ELANG	1.5976961+01	HTRU	6.9123569+03	HEST	6.9082093+03
WPR	3.6339014+03	WF	1.3660782+03	WOX	2.2678217+03	DEVMT	5.4961532+03	TFIG	5.0626000+02	TFXA	1.8149857+02
BURN	3.5766000+02	HVIS	0.0000000	TTVIS	0.0000000	FC	6.0340342+03	VERVT	-1.7104546+02	HORVT	4.3864021+02
FPAGT	-2.1296801+01	PVRTT	5.9733251+01	LATLM	-3.0011920+00	LONLM	-2.3216273+01	HLRA	3.5976625+04	HLRV	1.6948947+04
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	6.0380671+03	PIO	2.3629257+02	PIF	2.3636350+02	DWO	1.2258824+01
DWF	7.7317015+00	RE	1.5855633+00	REE	1.5917942+00	CISP	3.0203498+02	EISP	3.0162808+02		

STANDARD DEVIATION

FPAG	1.2452853+00	HPER	2.9412161+03	HAPO	0.0000000	ECC	5.2504426-04	ELAS	1.0007626+00	PVRT	9.8981631-01
HORV	4.9868969+00	HDOT	1.0795846+01	RANGE	2.4675494+02	ELANG	6.5777121-01	HTRU	3.2994696+02	HEST	3.1733342+02
WPR	4.8900409+01	WF	1.9320488+01	WOX	3.3083228+01	DEVMT	9.1515025+00	TFIG	1.4875788+00	TFXA	5.3461252+00
BURN	3.9299282+00	HVIS	0.0000000	TTVIS	0.0000000	FC	1.4258506+02	VERVT	1.0764060+01	HORVT	5.0303764+00
FPAGT	1.2749524+00	PVRTT	1.0448762+00	LATLM	2.1027298-02	LONLM	6.4423525-02	HLRA	1.7685474+03	HLRV	6.7362006+02
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	1.4479813+02	PIO	3.8017265-01	PIF	3.8527587-01	DWO	2.6496716-01
DWF	1.7387064+01	RE	4.6802464+03	REE	4.1360044-03	CISP	1.3360974+00	EISP	1.1771755+00		

Range to go = 20 000 ft

NOMINAL VALUES

FPAG	-1.9486473+01	HPER	-5.6823977+06	HAPO	0.0000000	ECC	9.9552210-01	ELAS	4.5018617+01	PVRT	2.9971334+01
HORV	3.8350018+02	HDOT	-1.3570266+02	RANGE	1.9736730+04	ELANG	1.4848904+01	HTRU	5.3110632+03	HEST	5.2668992+03
WPR	3.4268739+03	WF	1.2856173+03	WOX	2.1412560+03	DEVMT	5.5993863+03	TFIG	5.1600000+02	TFXA	1.8066028+02
BURN	3.5800000+02	HVIS	6.4291670+03	TTVIS	8.0000000+00	FC	5.5991935+03	VERVT	-1.3579627+02	HORVT	3.8346151+02
FPAGT	-1.9500720+01	PVRTT	2.9978586+01	LATLM	-2.9915536+00	LONLM	-2.3258330+01	HLRA	3.6116537+04	HLRV	1.6760927+04
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	5.6035852+03	PIO	2.3719180+02	PIF	2.3726915+02	DWO	1.1438750+01
DWF	7.2045296+00	RE	1.5877164+00	REE	1.5917810+00	CISP	3.0056863+02	EISP	3.0151782+02		

MEAN VALUES

FPAG	-1.9707316+01	HPER	-5.6823781+06	HAPO	0.0000000	ECC	9.9551567-01	ELAS	4.5143056+01	PVRT	2.9962437+01
HORV	3.8287730+02	HDOT	-1.3719021+02	RANGE	1.9646681+04	ELANG	1.4985335+01	HTRU	5.3039457+03	HEST	5.2935615+03
WPR	3.4292969+03	WF	1.2869675+03	WOX	2.1423279+03	DEVMT	5.6008345+03	TFIG	5.1675999+02	TFXA	1.8149857+02
BURN	3.5766000+02	HVIS	6.5706101+03	TTVIS	8.4399999+00	FC	5.6257922+03	VERVT	-1.3796721+02	HORVT	3.8368857+02
FPAGT	-1.9772990+01	PVRTT	2.9972104+01	LATLM	-2.9899663+00	LONLM	-2.3258093+01	HLRA	3.5976625+04	HLRV	1.6948947+04
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	5.6304111+03	PIO	2.3717385+02	PIF	2.3725264+02	DWO	1.1485604+01
DWF	7.2349151+00	RE	1.5875560+00	REE	1.5917174+00	CISP	3.0075373+02	EISP	3.0159134+02		

STANDARD DEVIATION

FPAG	1.1012646+00	HPER	2.8043395+03	HAPO	0.0000000	ECC	5.1790047-04	ELAS	6.5611047-01	PVRT	9.1043283-01
HORV	3.2439848+00	HDOT	8.2175616+00	RANGE	2.2966062+02	ELANG	5.7099100-01	HTRU	2.4984945+02	HEST	2.2136226+02
WPR	4.8960443+01	WF	1.9639724+01	WOX	3.2942184+01	DEVMT	8.4113019+00	TFIG	1.5712256+00	TFXA	5.3461252+00
BURN	3.9299282+00	HVIS	3.0351936+02	TTVIS	9.6249734-01	FC	1.1377939+02	VERVT	8.2838144+00	HORVT	3.6755633+00
FPAGT	1.1363764+00	PVRTT	9.5777633-01	LATLM	2.1123455-02	LONLM	6.4126777-02	HLRA	1.7685474+03	HLRV	6.7362006+02
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	1.1728491+02	PIO	4.5069391-01	PIF	4.5714809-01	DWO	2.1615809-01
DWF	1.4234650-01	RE	4.6738744-03	REE	4.1647271+03	CISP	1.2739886+00	EISP	1.1784192+00		

TABLE V. - SUMMARY OF STATISTICAL PARAMETERS - Continued

Range to go = 10 000 ft

NOMINAL VALUES

FPAG	-1.4416463+01	HPER	-5.6902892+06	HAPO	0.0000000	ECC	9.9828001-01	ELAS	4.2586700+01	PVRT	2.9633542+01
HORV	2.4325069+02	HDOT	-6.2530672+01	RANGE	9.7749811+03	ELANG	1.2854854+01	HTRU	2.2404087+03	HEST	2.2391044+03
WPR	2.8844980+03	WF	1.0762404+03	WOX	1.8082570+03	DEVMT	5.8803499+03	TFIG	5.4800000+02	TFXA	1.8066028+02
BURN	3.5800000+02	HVIS	6.4291670+03	TTVIS	4.0000000+01	FC	4.5165341+03	VERVT	-6.2549973+01	HORVT	2.4322731+02
FPAGT	-1.4422055+01	PVRTT	2.9640784+01	LATLM	-2.9657425+00	LONLM	-2.3355128+01	HLRA	3.6116537+04	HLRV	1.6760927+04
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	4.5174916+03	PIO	2.3958917+02	PIF	2.3968044+02	DWO	9.3140206+00
DWF	5.8449227+00	RE	1.5935233+00	REE	1.5917327+00	CISP	2.9800835+02	EISP	3.0130685+02		

MEAN VALUES

FPAG	-1.4691748+01	HPER	-5.6902204+06	HAPO	0.0000000	ECC	9.9825621-01	ELAS	4.2674915+01	PVRT	2.9580621+01
HORV	2.4421394+02	HDOT	-6.4045299+01	RANGE	9.8087977+03	ELANG	1.3001396+01	HTRU	2.2848915+03	HEST	2.2795437+03
WPR	2.8911851+03	WF	1.0792195+03	WOX	1.8119640+03	DEVMT	5.8797800+03	TFIG	5.4834000+02	TFXA	1.8149857+02
BURN	3.5766000+02	HVIS	6.5706101+03	TTVIS	4.0020000+01	FC	4.5471720+03	VERVT	-6.4090090+01	HORVT	2.4476571+02
FPAGT	-1.4671300+01	PVRTT	2.9590444+01	LATLM	-2.9642887+00	LONLM	-2.3353875+01	HLRA	3.5976625+04	HLRV	1.6948947+04
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	4.5485871+03	PIO	2.3955708+02	PIF	2.3964970+02	DWO	9.3722156+00
DWF	5.8822482+00	RE	1.5933213+00	REE	1.5916647+00	CISP	2.9817941+02	EISP	3.0138664+02		

STANDARD DEVIATION

FPAG	7.2168167-01	HPER	3.1974390+03	HAPO	0.0000000	ECC	5.7903033-04	ELAS	1.1878533+00	PVRT	6.0247495-01
HORV	2.4314829+00	HDOT	3.4199213+00	RANGE	1.1063001+02	ELANG	8.8031246-01	HTRU	1.8240820+02	HEST	1.6845456+02
WPR	4.7187127+01	WF	1.9268660+01	WOX	3.1933035+01	DEVMT	7.7781746+00	TFIG	1.5000000+00	TFXA	5.3461252+00
BURN	3.9299282+00	HVIS	3.0351936+02	TTVIS	5.2877410-01	FC	5.5691112+01	VERVT	3.3554665+00	HORVT	2.6800405+00
FPAGT	7.3263278-01	PVRTT	6.5880270-01	LATLM	2.1389840-02	LONLM	6.4304991-02	HLRA	1.7685474+03	HLRV	6.7362006+02
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	5.8025856+01	PIO	3.3365870-01	PIF	3.3729739-01	DWO	1.0934884-01
DWF	7.1822171-02	RE	4.6418831-03	REE	4.1683035-03	CISP	1.1813161+00	EISP	1.1763456+00		

Range to go = 5 000 ft

NOMINAL VALUES

FPAG	-1.1456019+01	HPER	-5.6934563+06	HAPO	0.0000000	ECC	9.9939022-01	ELAS	4.0416686+01	PVRT	2.7369879+01
HORV	1.5075495+02	HDOT	-3.0550947+01	RANGE	4.6946915+03	ELANG	1.2999584+01	HTRU	1.1024264+03	HEST	1.0857971+03
WPR	2.5167462+03	WF	9.3453446+02	WOX	1.5822111+03	DEVMT	6.0744095+03	TFIG	5.7400000+02	TFXA	1.8066028+02
BURN	3.5800000+02	HVIS	6.4291670+03	TTVIS	6.6000000+01	FC	3.8320990+03	VERVT	-3.0577596+01	HORVT	1.5071387+02
FPAGT	-1.1468788+01	PVRTT	2.7377112+01	LATLM	-2.9525668+00	LONLM	-2.3404546+01	HLRA	3.6116537+04	HLRV	1.6760927+04
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	3.8309992+03	PIO	2.4056019+02	PIF	2.4064990+02	DWO	7.9416227+00
DWF	4.9717352+00	RE	1.5973543+00	REE	1.5918138+00	CISP	2.9666948+02	EISP	3.0109546+02		

MEAN VALUES

FPAG	-1.2069889+01	HPER	-5.6933680+06	HAPO	0.0000000	ECC	9.9935951-01	ELAS	4.1057131+01	PVRT	2.7529131+01
HORV	1.5367826+02	HDOT	-3.2875855+01	RANGE	4.8224597+03	ELANG	1.3483445+01	HTRU	1.1677505+03	HEST	1.1594499+03
WPR	2.5328838+03	WF	9.4114751+02	WOX	1.5917345+03	DEVMT	6.0688882+03	TFIG	5.7360000+02	TFXA	1.8149857+02
BURN	3.5766000+02	HVIS	6.5706101+03	TTVIS	6.5280000+01	FC	3.8703210+03	VERVT	-3.2835408+01	HORVT	1.5405531+02
FPAGT	-1.2029760+01	PVRTT	2.7539045+01	LATLM	-2.9513650+00	LONLM	-2.3402501+01	HLRA	3.5976625+04	HLRV	1.6948947+04
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	3.8696355+03	PIO	2.4055788+02	PIF	2.4064894+02	DWO	8.0150328+00
DWF	5.0183603+00	RE	1.5971434+00	REE	1.5917428+00	CISP	2.9690366+02	EISP	3.0118203+02		

STANDARD DEVIATION

FPAG	1.0354004+00	HPER	2.8506953+03	HAPO	0.0000000	ECC	4.6482990-04	ELAS	1.8549958+00	PVRT	4.2298573-01
HORV	2.1798975+00	HDOT	2.9826924+00	RANGE	1.0549052+02	ELANG	1.5967087+00	HTRU	1.5058122+02	HEST	1.4529808+02
WPR	4.9956856+01	WF	2.0768629+01	WOX	3.3158709+01	DEVMT	9.0000000+00	TFIG	1.6250000+00	TFXA	5.3461252+00
BURN	3.9299282+00	HVIS	3.0351936+02	TTVIS	1.0008236+00	FC	3.9785361+01	VERVT	2.5487076+00	HORVT	2.6800860+00
FPAGT	8.8918361-01	PVRTT	4.7256746-01	LATLM	2.1484375-02	LONLM	6.4541842-02	HLRA	1.7685474+03	HLRV	6.7362006+02
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	4.2638011+01	PIO	3.3874192-01	PIF	3.2997987-01	DWO	7.9017122-02
DWF	4.9318823-02	RE	2.9449067-03	REE	4.1432038-03	CISP	1.8736975+00	EISP	1.8862658+00		

TABLE V. - SUMMARY OF STATISTICAL PARAMETERS - Continued

Range to go = 2 000 ft

NOMINAL VALUES

FPAG	-1.2323558+01	HPER	-5.6947456+06	HAPO	0.0000000	ECC	9.9984267-01	ELAS	4.1318802+01	PVRT	2.3363805+01
HORV	8.3749114+01	HDOT	-1.8296336+01	RANGE	1.9165020+03	ELANG	1.7935719+01	HTRU	6.1689375+02	HEST	6.2076298+02
WPR	2.2263724+03	WF	8.2279978+02	WOX	1.4035719+03	DEVMT	6.2299287+03	TFIG	5.9800000+02	TFXA	1.8066028+02
BURN	3.5800000+02	HVIS	6.4291670+03	TTVIS	9.0000000+01	FC	3.3721880+03	VERVT	-1.8345626+01	HORVT	8.3673345+01
FPAGT	-1.2366583+01	PVRTT	2.3371023+01	LATLM	-2.9453618+00	LONLM	-2.3431575+01	HLRA	3.6116537+04	HLRV	1.6760927+04
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	3.3692799+03	PIO	2.4108980+02	PIF	2.4117478+02	DWO	7.0067791+00
DWF	4.3789758+03	RE	1.6000954+00	REE	1.5919410+00	CISP	2.9592064+02	EISP	3.0089680+02		

MEAN VALUES

FPAG	-1.2052817+01	HPER	-5.6947341+06	HAPO	0.0000000	ECC	9.9983888-01	ELAS	4.0231040+01	PVRT	2.3130405+01
HORV	8.4213890+01	HDOT	-1.8011885+01	RANGE	1.9280074+03	ELANG	1.7082480+01	HTRU	6.0233608+02	HEST	5.9472211+02
WPR	2.2299680+03	WF	8.2457300+02	WOX	1.4053932+03	DEVMT	6.2312332+03	TFIG	5.9825999+02	TFXA	1.8149857+02
BURN	3.5766000+02	HVIS	6.5706101+03	TTVIS	8.9940000+01	FC	3.4078058+03	VERVT	-1.7801854+01	HORVT	8.4449565+01
FPAGT	-1.1886729+01	PVRTT	2.3140399+01	LATLM	-2.9439353+00	LONLM	-2.3430762+01	HLRA	3.5976625+04	HLRV	1.6948947+04
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	3.4054877+03	PIO	2.4106685+02	PIF	2.4115384+02	DWO	7.0763230+00
DWF	4.4230237+00	RE	1.5998880+00	REE	1.5918706+00	CISP	2.9615238+02	EISP	3.0098001+02		

STANDARD DEVIATION

FPAG	2.2876176+00	HPER	2.6106980+03	HAPO	0.0000000	ECC	5.3904790-04	ELAS	3.2897722+00	PVRT	3.6372201-01
HORV	9.0799939-01	HDOT	3.5195535+00	RANGE	3.1323414+01	ELANG	3.1087204+00	HTRU	1.2339645+02	HEST	1.1459908+02
WPR	4.8443911+01	WF	1.9862221+01	WOX	3.2745228+01	DEVMT	7.9686887+00	TFIG	1.4895469+00	TFXA	5.3461252+00
BURN	3.9299282+00	HVIS	3.0351936+02	TTVIS	3.4125515-01	FC	5.4677463+01	VERVT	3.1042598+00	HORVT	1.3473788+00
FPAGT	1.9946943+00	PVRTT	3.6542755-01	LATLM	2.1567444-02	LONLM	6.4541842-02	HLRA	1.7685474+03	HLRV	6.7362006+02
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	5.5091969+01	PIO	3.2625958-01	PIF	3.3071891-01	DWO	1.1526540+01
DWF	7.2407351-02	RE	2.9650776-03	REE	4.1143309-03	CISP	1.8548395+00	EISP	1.2066709+00		

Vertical descent initiation

NOMINAL VALUES

FPAG	-3.4754613+01	HPER	-5.6951839+06	HAPO	0.0000000	ECC	9.9999658-01	ELAS	7.3694072+01	PVRT	7.3940725+00
HORV	5.3567140+00	HDOT	-3.7167238+00	RANGE	4.4389218+01	ELANG	6.6299549+01	HTRU	1.0256737+02	HEST	1.0121773+02
WPR	1.6904496+03	WF	6.1678073+02	WOX	1.0736682+03	DEVMT	6.5231778+03	TFIG	6.4800000+02	TFXA	1.8066028+02
BURN	3.5800000+02	HVIS	6.4291670+03	TTVIS	1.3000000+02	FC	2.9152533+03	VERVT	-3.7781125+00	HORVT	5.2083862+00
FPAGT	-3.5956762+01	PVRTT	7.4012403+00	LATLM	-2.9405195+00	LONLM	-2.3449735+01	HLRA	3.6116537+04	HLRV	1.6760927+04
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	2.9106117+03	PIO	2.4139483+02	PIF	2.4148035+02	DWO	6.0716221+00
DWF	3.7877421+00	RE	1.6029661+00	REE	1.5922465+00	CISP	2.9521291+02	EISP	3.0049842+02		

MEAN VALUES

FPAG	-3.2503690+01	HPER	-5.6951826+06	HAPO	0.0000000	ECC	9.9999637-01	ELAS	7.3616596+01	PVRT	7.4409325+00
HORV	5.3683183+00	HDOT	-3.6553151+00	RANGE	4.4537285+01	ELANG	6.6175589+01	HTRU	1.0430284+02	HEST	1.0140803+02
WPR	1.6939423+03	WF	6.1851488+02	WOX	1.0754257+03	DEVMT	6.5247631+03	TFIG	6.4834000+02	TFXA	1.8149857+02
BURN	3.5766000+02	HVIS	6.5706101+03	TTVIS	1.3032000+02	FC	2.9108903+03	VERVT	-3.4518660+00	HORVT	5.7524552+00
FPAGT	-3.0339851+01	PVRTT	7.4508530+00	LATLM	-2.9392398+00	LONLM	-2.3449215+01	HLRA	3.5976625+04	HLRV	1.6948947+04
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	2.9066079+03	PIO	2.4145193+02	PIF	2.4153733+02	DWO	6.0599173+00
DWF	3.7803886+00	RE	1.6030131+00	REE	1.5921789+00	CISP	2.9538721+02	EISP	3.0058449+02		

STANDARD DEVIATION

FPAG	1.1480281+01	HPER	2.6106980+03	HAPO	0.0000000	ECC	5.3904790-04	ELAS	1.8177792+00	PVRT	3.6991293-01
HORV	2.9730194+01	HDOT	1.8106554+00	RANGE	2.2641732+00	ELANG	1.7514991+00	HTRU	1.4720948+01	HEST	8.6748587+00
WPR	5.0033114+01	WF	2.0545205+01	WOX	3.3691152+01	DEVMT	7.5828754+00	TFIG	1.5000000+00	TFXA	5.3461252+00
BURN	3.9299282+00	HVIS	3.0351936+02	TTVIS	3.3790123+00	FC	1.2126830+02	VERVT	1.6949351+00	HORVT	1.2660817+00
FPAGT	1.0927141+01	PVRTT	3.7175234-01	LATLM	2.1760039-02	LONLM	6.4600919-02	HLRA	1.7685474+03	HLRV	6.7362006+02
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	1.2070108+02	PIO	3.3729739-01	PIF	3.3946189-01	DWO	2.5309082-01
DWF	1.5934137-01	RE	3.0247831-03	REE	4.0779524-03	CISP	1.8418953+00	EISP	1.2366474+00		

TABLE V. - SUMMARY OF STATISTICAL PARAMETERS - Concluded

Landing (probe contact)

NOMINAL VALUES

FPAG	-8.8170060+01	HPER	-5.6951719+06	HAPO	0.0000000	ECC	9.9999238-01	ELAS	6.0414444+01	PVRT	1.6974246-01
HORV	9.4747324-02	HDOT	-2.9655517+00	RANGE	7.6110553+00	ELANG	6.0244581+01	HTRU	1.3271654+01	HEST	1.3343326+01
WPR	1.4215359+03	WF	5.1349092+02	WOX	9.0804427+02	DEVMT	6.6735784+03	TFIG	6.7600000+02	TFXA	1.8066028+02
BURN	3.5800000+02	HVIS	6.4291670+03	TTVIS	1.3000000+02	FC	2.7995158+03	VERVT	-3.0675406+00	HORVT	8.3429677-02
FPAGI	-8.8442084+01	PVRTI	1.7680041-01	LATLM	-2.9404369+00	LONLM	-2.3450051+01	HLRA	3.6116537+04	HLRV	1.6760927+04
HORZ	3.6245437+05	RESVG	8.3370611-02	THF	2.7929470+03	PIO	2.4159702+02	PIF	2.4167979+02	DWO	5.8323653+00
DWF	3.6367124+00	RE	1.6037466+00	REE	1.5924270+00	CISP	2.9495449+02	EISP	3.0028698+02		

MEAN VALUES

FPAG	-8.5752172+01	HPER	-5.6951706+06	HAPO	0.0000000	ECC	9.9999218-01	ELAS	5.2205338+01	PVRT	1.7580040-01
HORV	7.8766852-02	HDOT	-2.9541672+00	RANGE	7.5485133+00	ELANG	5.2074092+01	HTRU	1.2046466+01	HEST	1.0615884+01
WPR	1.3709138+03	WF	4.9444265+02	WOX	8.7446946+02	DEVMT	6.7060234+03	TFIG	6.8212000+02	TFXA	1.8149857+02
BURN	3.5766000+02	HVIS	6.5706101+03	TTVIS	1.3096000+02	FC	2.7894441+03	VERVT	-2.7416656+00	HORVT	9.1560362-01
FPAGI	-5.4397409+01	PVRTI	1.6713420-01	LATLM	-2.9392749+00	LONLM	-2.3449685+01	HLRA	3.5976625+04	HLRV	1.6748947+04
HORZ	3.6245757+05	RESVG	9.2365096-02	THF	2.7829759+03	PIO	2.4162672+02	PIF	2.4171062+02	DWO	5.8089825+00
DWF	3.6219749+00	RE	1.6038176+00	REE	1.5923982+00	CISP	2.9509575+02	EISP	3.0033187+02		

STANDARD DEVIATION

FPAG	1.5208201+01	HPER	2.7572044+03	HAPO	0.0000000	ECC	5.0330879-04	ELAS	1.1032304+01	PVRT	1.7478577-01
HORV	9.3028788-02	HDOT	7.5965798-02	RANGE	6.6630266-01	ELANG	1.0880638+01	HTRU	2.4343127+00	HEST	4.4243524+00
WPR	1.1540892+02	WF	4.5589241+01	WOX	7.1740472+01	DEVMT	5.9418011+01	TFIG	1.1130685+01	TFXA	5.3461252+00
BURN	3.9299282+00	HVIS	3.0351936+02	TTVIS	3.7892799+00	FC	1.7078861+01	VERVT	1.3968685-01	HORVT	2.1878169-01
FPAGI	1.5403943+01	PVRTI	1.6575149-01	LATLM	2.2016016-02	LONLM	6.4541842-02	HLRA	1.7685474+03	HLRV	6.7362006+02
HORZ	7.1554174+01	RESVG	3.7038714-02	THF	1.8381376+01	PIO	3.2400689-01	PIF	3.1715286-01	DWO	9.0647764-02
DWF	2.5059819-02	RE	2.9801161-03	REE	4.0264703-03	CISP	1.8516779+00	EISP	1.2527314+00		

TABLE VI - COVARIANCE MATRICES

(a) Powered descent initiation minus 3 min

3.1673049+06	-1.2061524+07	-8.9850609+03	1.0313026+04	-2.2886843+03	6.6289970+01	-3.3903353+06
-1.2061524+07	7.3872555+07	1.4862947+04	-5.8781028+04	8.8860824+03	-1.2309412+02	1.2419903+07
-8.9850609+03	1.4862947+04	3.2249068+03	-1.5777566+01	6.2702526+00	-2.2985938+01	1.0659712+04
1.0313026+04	-5.8781028+04	-1.5777566+01	4.7200006+01	-7.5711884+00	1.2577474+01	-1.0696687+04
-2.2886843+03	8.8860824+03	6.2702526+00	-7.5711884+00	1.6550311+00	-4.6340727-02	2.4472487+03
6.6289970+01	-1.2309412+02	-2.2985938+01	1.2577474+01	-4.6340727-02	1.6389293-01	-7.8157419+01
-3.3903353+06	1.2419903+07	1.0659712+04	-1.0696687+04	2.4472487+03	-7.8157419+01	3.6451051+06
6.7751270+06	-2.2258358+07	-4.3134474+04	1.9595803+04	-4.8896338+03	3.0731394+02	-7.5082091+06
1.2797005+05	-1.9029474+05	-2.5527272+03	2.0897877+02	-8.9444458+01	1.9206046+01	-1.4330650+05
-5.3402692+03	1.0190572+04	4.2265385+01	-1.0312668+01	3.8114346+00	-2.9835271-01	6.0750444+03
2.5376855+03	-9.8191660+03	-7.3382897+00	8.3713944+00	-1.8345686+00	5.4249784-02	-2.7140993+03
6.2940544+01	-7.4464709+02	1.7666935+01	5.5701523-01	-4.7415302-02	-1.2481929-01	-4.6580473+01
0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

6.7751270+06	1.2797005+05	-5.3402692+03	2.5376855+03	6.2940544+01	0.0000000
-2.2258358+07	-1.9029474+05	1.0190572+04	-9.8191660+03	-7.4464709+02	0.0000000
-4.3134474+04	-2.5527272+03	4.2265385+01	-7.3382897+00	1.7666935+01	0.0000000
1.9595803+04	2.0897877+02	-1.0312668+01	8.3713944+00	5.5701523-01	0.0000000
-4.8896338+03	-8.9444458+01	3.8114346+00	-1.8345686+00	-4.7415302-02	0.0000000
3.0731394+02	-1.9206046+01	-2.9835271-01	5.4249784-02	-1.2481929-01	0.0000000
-7.5082091+06	-1.4330650+05	6.0750444+03	-2.7140993+03	-4.6580473+01	0.0000000
2.2987025+07	2.1568941+05	-2.0219619+04	5.3485446+03	-4.5555975+02	0.0000000
2.1568941+05	1.0843896+06	-2.3513888+02	1.0742817+02	-5.8999754+02	0.0000000
-2.0219619+04	-2.3513888+02	1.9698978+01	-4.1667496+00	5.6885887-01	0.0000000
5.3485446+03	1.0742817+02	-4.1667496+00	2.0400325+00	5.0978950-02	0.0000000
-4.5555975+02	-5.8999754+02	5.6885887-01	5.0978950-02	2.0093644+00	0.0000000
0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000

(b) Landing

8.9401294+03	4.0214718+05	-1.0083222+05	-1.2097859+01	8.6492727+00	-1.1516702+00	-8.8730659+03
4.0214718+05	3.9267974+07	-9.2973420+06	-1.3411112+03	-3.6956773+02	6.3481602+01	-3.9622443+05
-1.0083222+05	-9.2973420+06	4.7320261+06	1.9858105+02	3.8236894+02	1.5695294+03	9.8686791+04
-1.2097859+01	-1.3411112+03	1.9858105+02	3.6349326-01	-3.3748975-01	-7.7699443-02	1.0686285+01
8.6492727+00	-3.6956773+02	3.8236894+02	-3.3748975-01	1.7117478+00	2.4129552-01	-7.0454865+00
-1.1516702+00	6.3481602+01	1.5695294+03	-7.7699443-02	2.4129552-01	3.8811944+00	1.5804325+00
-8.8730659+03	-3.9622443+05	9.8686791+04	1.0686285+01	-7.0454865+00	1.5804325+00	8.8257081+03
-4.0329169+05	-3.9439116+07	9.3088287+06	1.4202701+03	2.8849388+02	-8.0859516+01	3.9697603+05
1.0082805+05	9.2967747+06	-4.7318451+06	-1.9839669+02	-3.8256238+02	-1.5695157+03	-9.8683830+04
1.3684417+01	1.4038240+03	-2.1431258+02	-3.6824370-01	3.4607133-01	9.2635043-02	-1.2123991+01
-9.7567078+00	2.2194289+02	-3.5006725+02	3.6781936-01	-1.7461673+00	-2.6515092-01	7.8614663+00
1.4497831+00	-2.5037333+01	-1.5790583+03	6.9881402-02	-2.3230732-01	-3.8759568+00	-1.8026898+00
-7.6410599+01	-1.1380413+04	7.6854475+02	5.2425870+00	-5.3695262+00	-1.1619752+00	-5.0335608+01

-4.0329169+05	1.0082805+05	1.3684417+01	-9.7567078+00	1.4497831+00	-7.6410599+01
-3.9439116+07	9.2967747+06	1.4038240+03	2.2194289+02	-2.5037333+01	-1.1380413+04
9.3088287+06	-4.7318451+06	-2.1431258+02	-3.5006725+02	-1.5790583+03	7.6854475+02
1.4202701+03	-1.9839669+02	-3.6824370-01	3.6781936-01	6.9881402-02	5.2425870+00
2.8849388+02	-3.8256238+02	3.4607133-01	-1.7461673+00	-2.3230732-01	-5.3695262+00
-8.0859516+01	-1.5695157+03	9.2635043-02	-2.6515092-01	-3.8759568+00	-1.1619752+00
3.9697603+05	-9.8683830+04	-1.2123991+01	7.8614663+00	-1.8026898+00	5.0335608+01
3.9638618+07	-9.3081982+06	-1.4839243+03	-1.3203040+02	4.0127117+01	1.3258336+04
-9.3081982+06	4.7316639+06	2.1412162+02	3.5028944+02	1.5790370+03	-7.6437164+02
-1.4839243+03	2.1412162+02	3.7876774-01	-3.7920640-01	-8.4080655-02	-5.3058452+00
-1.3203040+02	3.5028944+02	-3.7920640-01	1.7887020+00	2.5408946-01	5.9572344+00
4.0127117+01	1.5790370+03	-8.4080655-02	2.5408946-01	3.8712511+00	1.0098373+00
1.3258336+04	-7.6437164+02	-5.3058452+00	5.9572344+00	1.0098373+00	1.2433774+02

TABLE VII.- CURRENT ESTIMATE OF LM LANDING DISPERSION ELLIPSE

Accelerometer bias (3σ) cm/sec^2	Percent ellipse	Down-range semimajor axis, n. mi.	Cross-range semiminor axis, n. mi.
95% confidence navigation uncertainties			
0.6	99	3.2	1.1
.6	90	2.3	.8
.6	50	1.2	.4
.2	99	1.2	.7
.1	99	.95	.7
0	99	.9	.7
55% confidence navigation uncertainties			
.6	99	3.0	1.2
.2	99	1.2	.8
No navigation uncertainties (perfect update prior to PDI)			
.6	99	.5	.7
.2	99	.24	.54
.1	99	.18	.48

TABLE VIII.- ΔV AND PROPELLANT SUMMARY

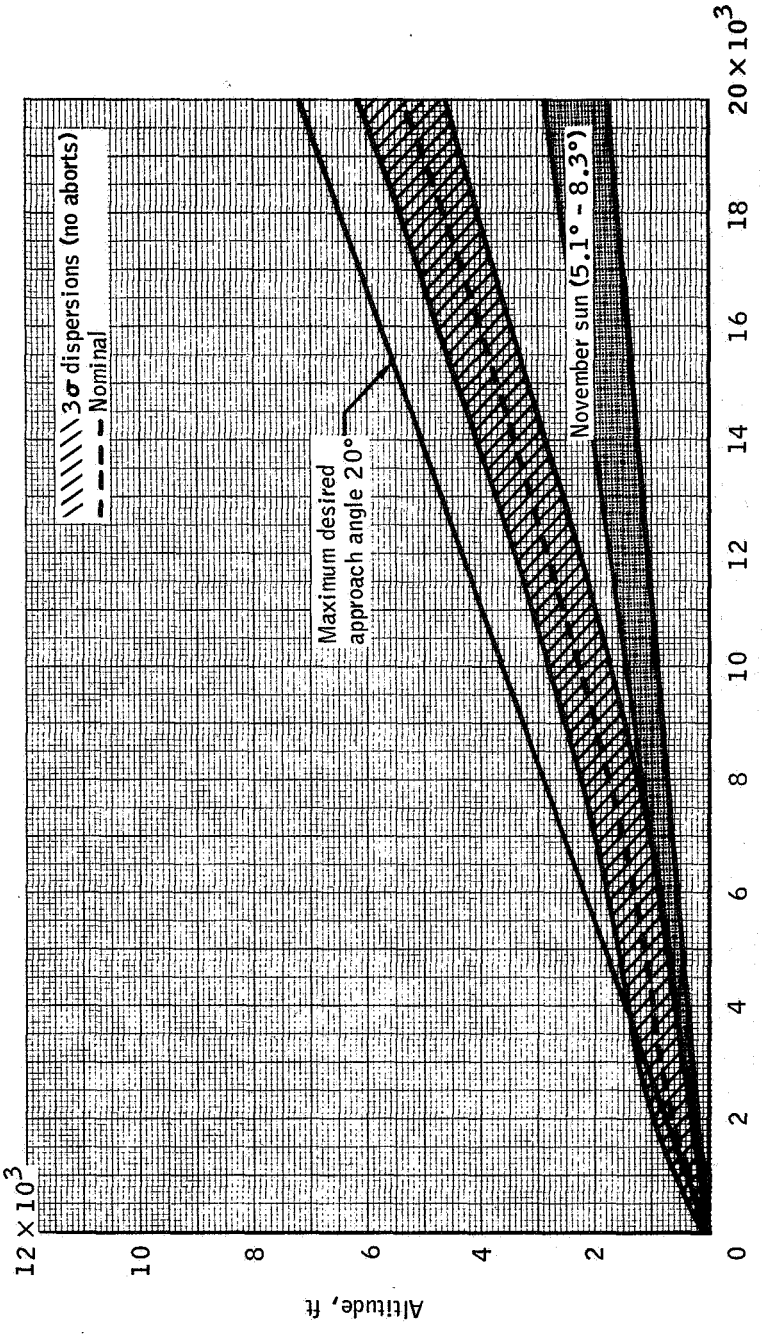
(a) Major event points[a]

Event	ΔV, fps	Propellant, lb	Oxidizer, lb	Fuel, lb
DOI	71.8 ± 0.5	251 ± 3	155 ± 2	96 ± 1
Braking (high gate)	5500 ± 9	14 471.0 ± 43	8989 ± 29	5582 ± 16
Approach (low gate)	6278.0 ± 8	16 854.0 ± 46	10 359.0 ± 32	6154.0 ± 18
Landing	6674.0 ± 58	16 670.9 ± 114	10 241.0 ± 72	6429.9 ± 44

(b) Total descent

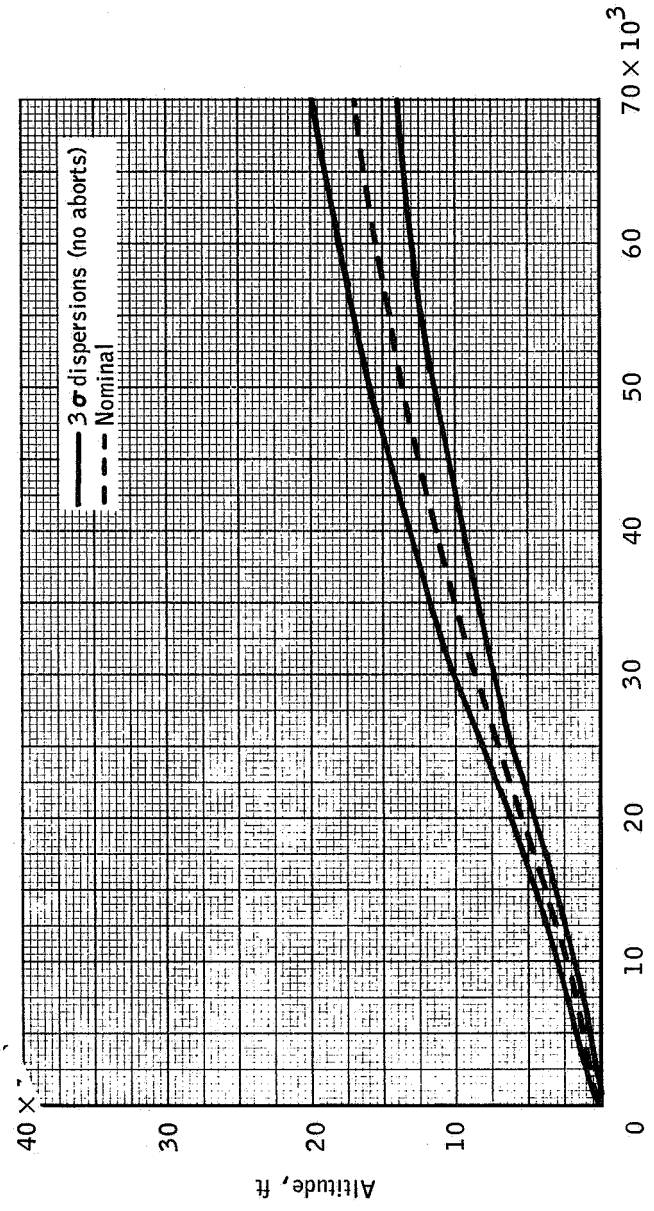
Item	Propellant, lb	Oxidizer, lb	Fuel, lb
Loaded (tank)	18 091.9	11 148.0 ± 10	6943.9 ± 6.3
Required	16 670.5	10 241.1 ± 72	6428.6 ± 45
Usable remaining	1290.4 ± 115	794.7 ± 71	495.7 ± 44

[a]All uncertainties presented are 1σ.



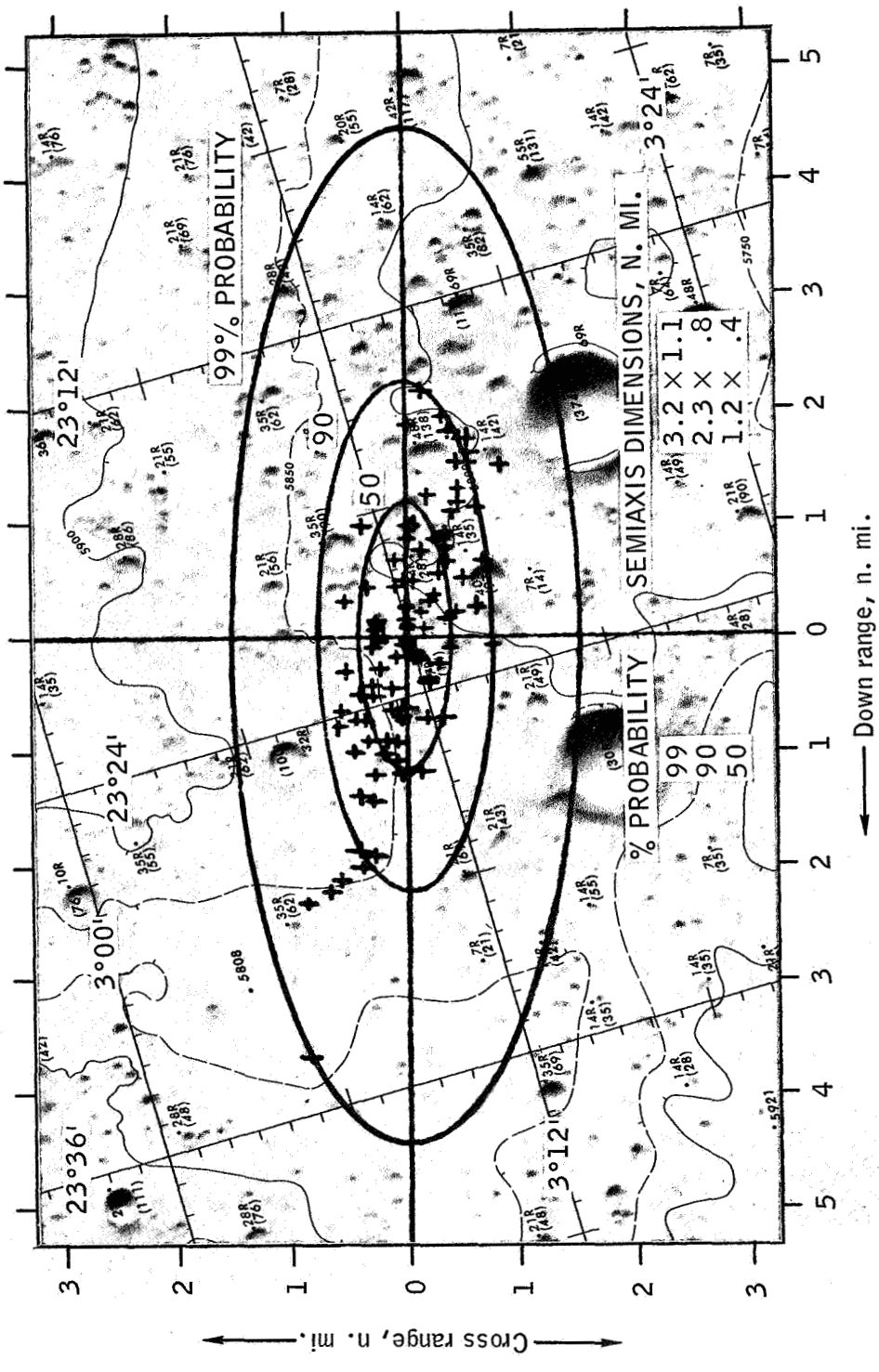
(a) Range 20 000 feet to 0.

Figure 1.- Altitude dispersion corridor.



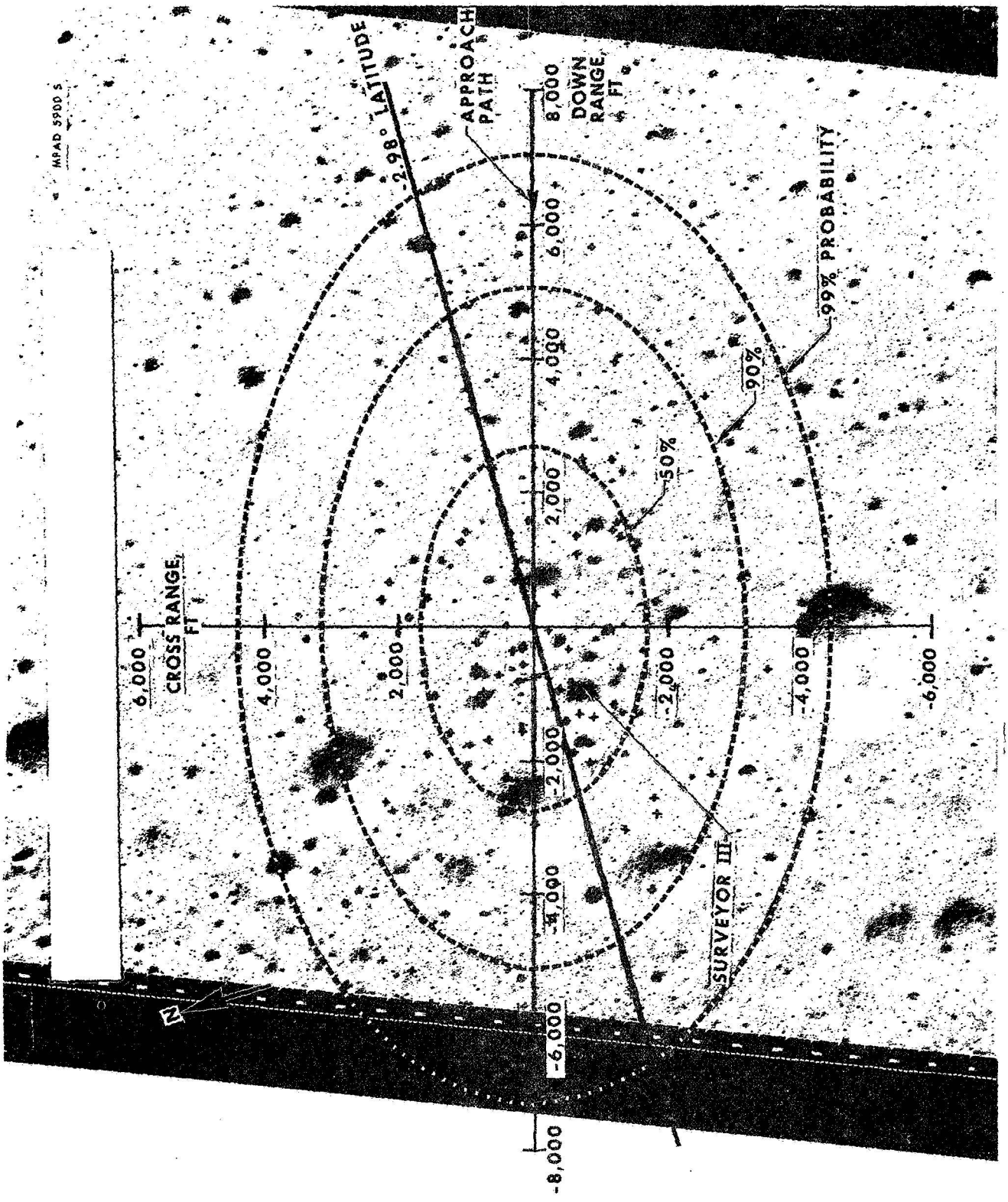
(b) Range 70 000 feet to 0.

Figure 1.- Concluded.



(a) 0.6 cm/sec^2 accelerometer bias uncertainty.

Figure 2.- Predicted landing dispersions for site 7.



(b) 0.2 cm/sec^2 accelerometer bias uncertainty.

Figure 2.- Concluded.

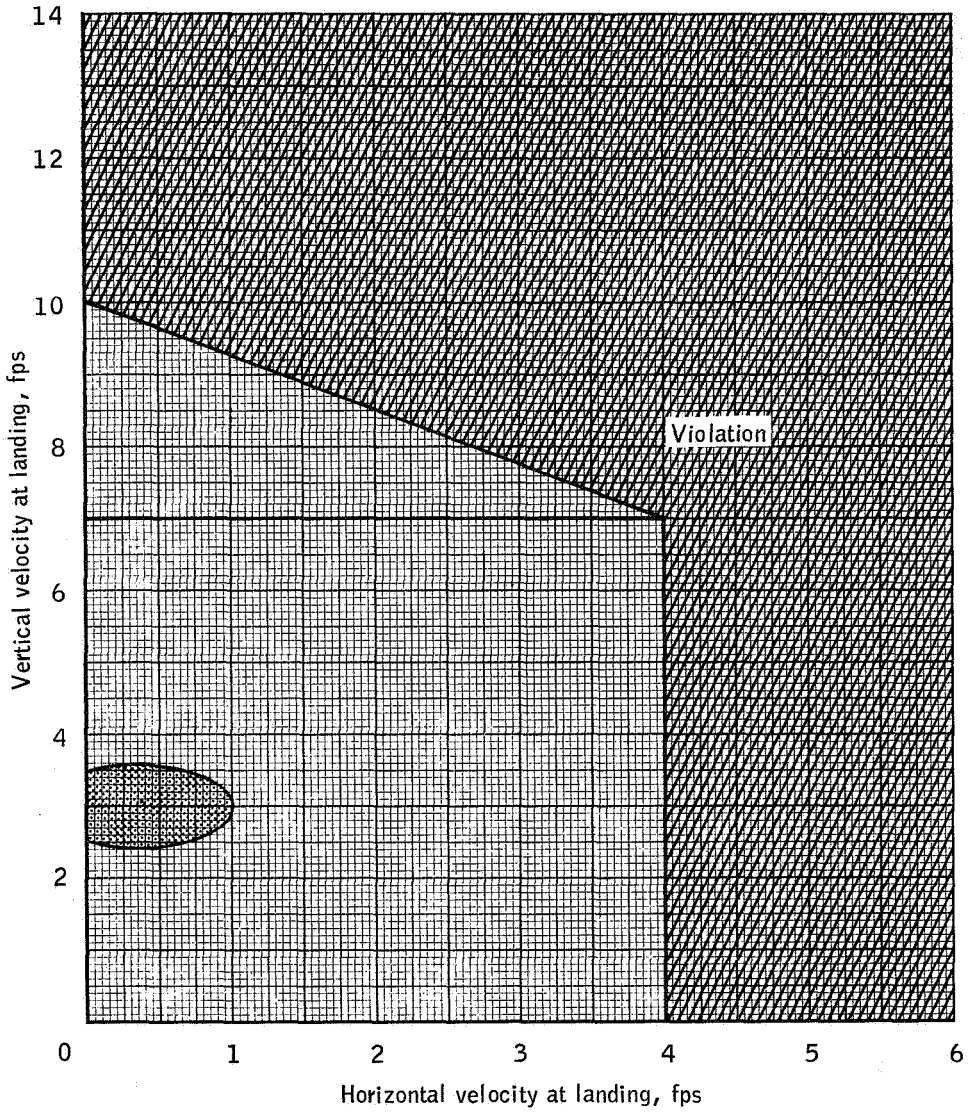
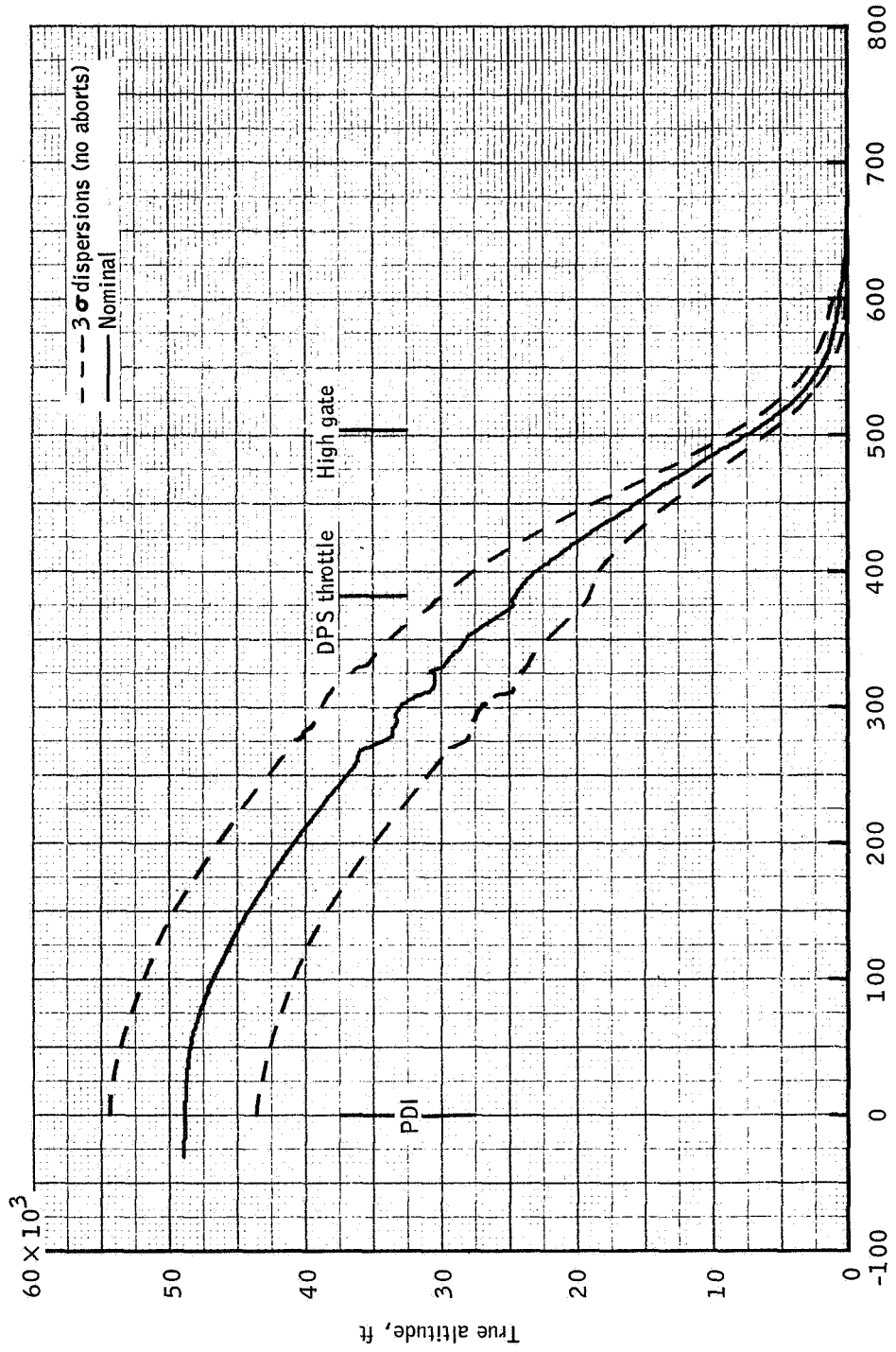
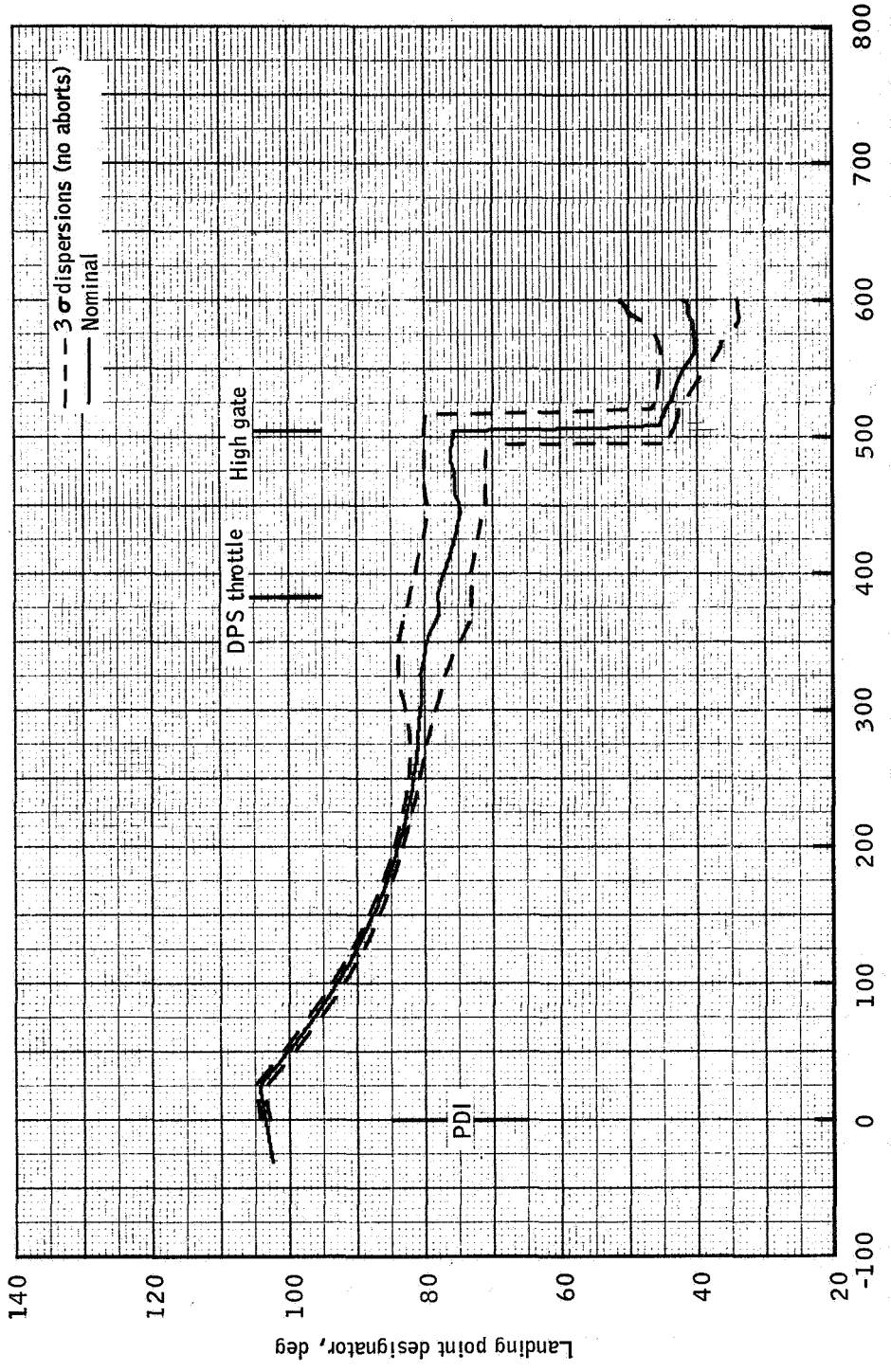


Figure 3.- Landing gear constraints at landing and three-sigma velocity error ellipse at probe contact.



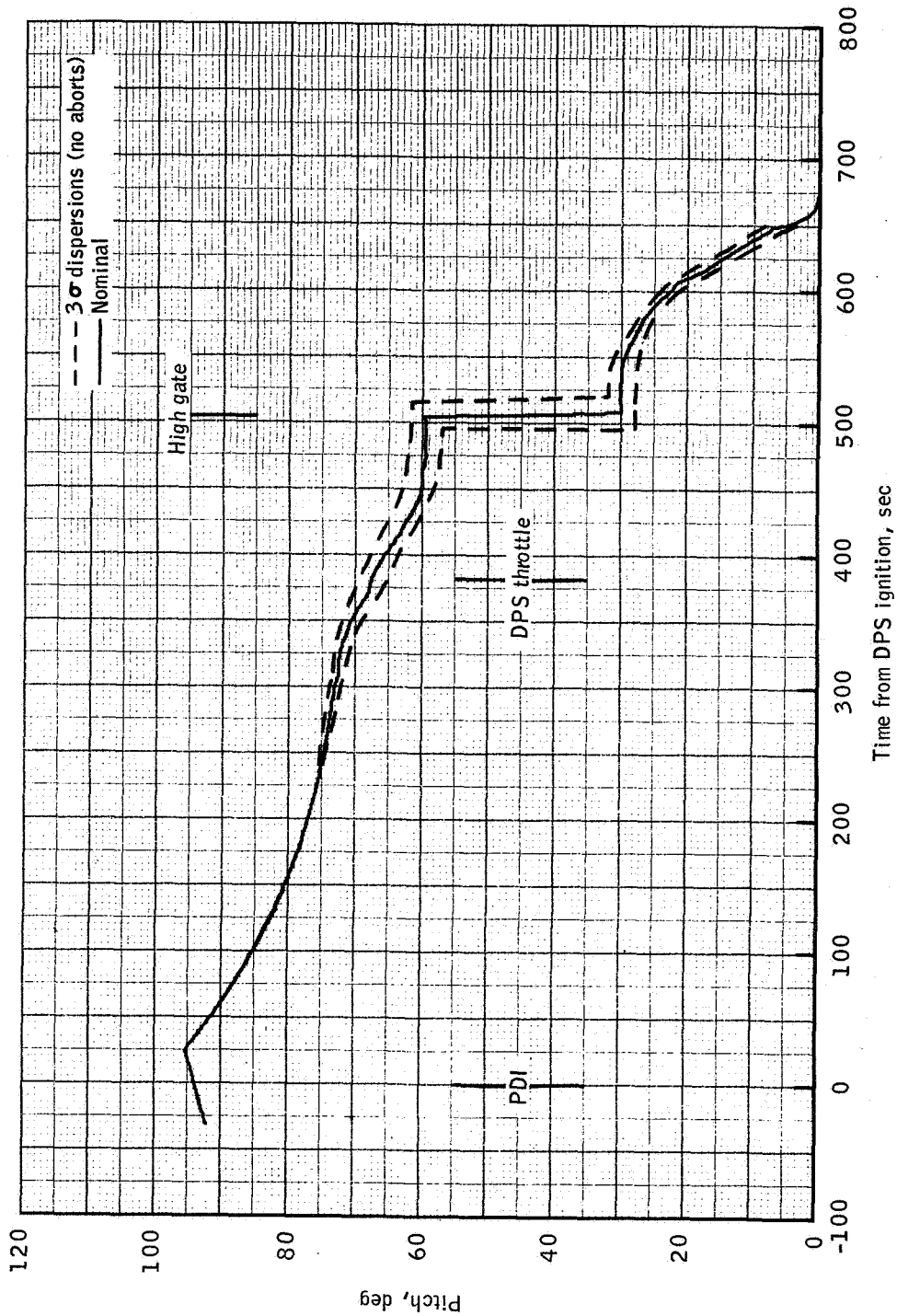
(a) True altitude.

Figure 4.- Time histories of selected parameters.



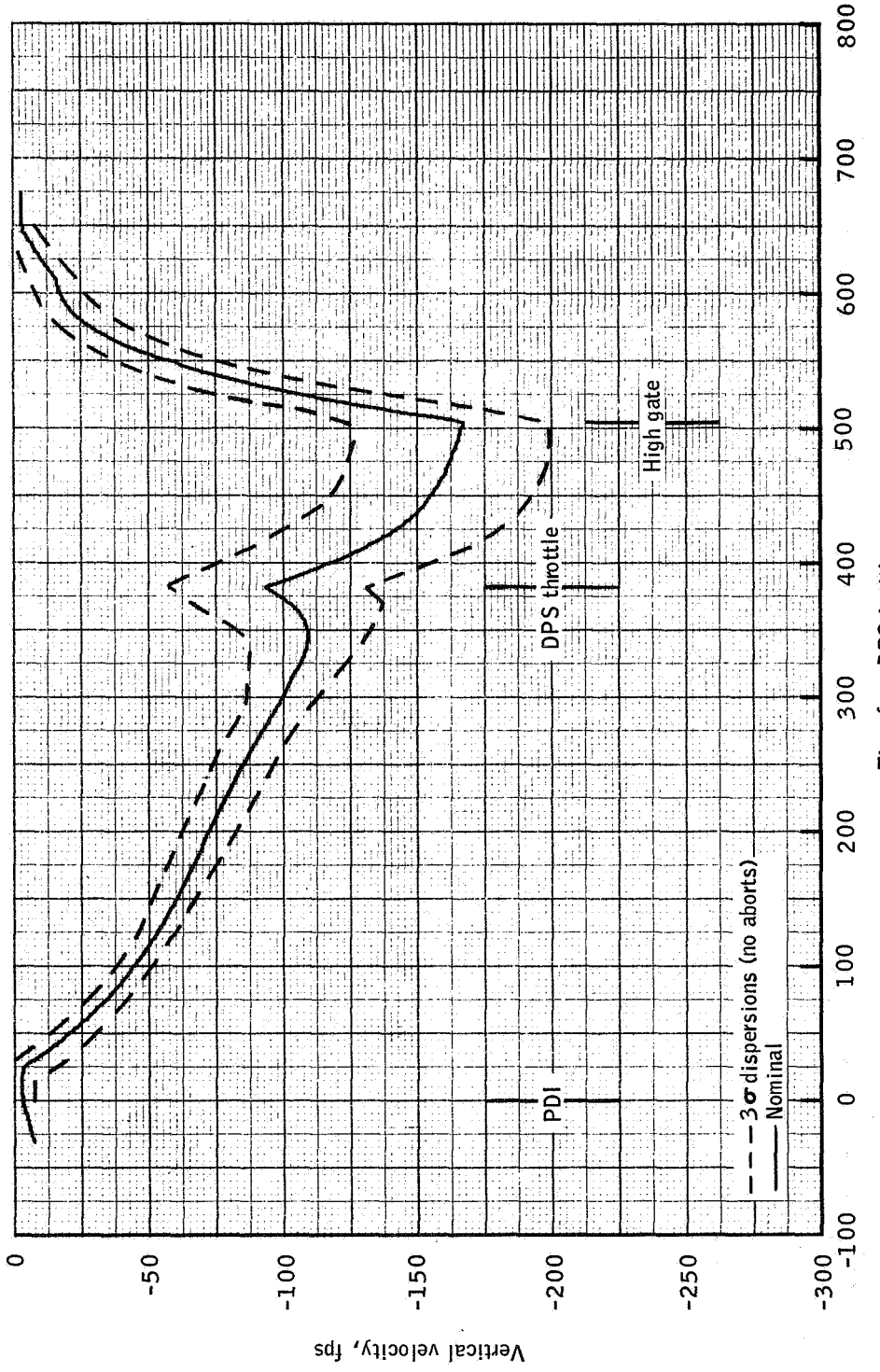
(b) Landing point designator.

Figure 4.- Continued.



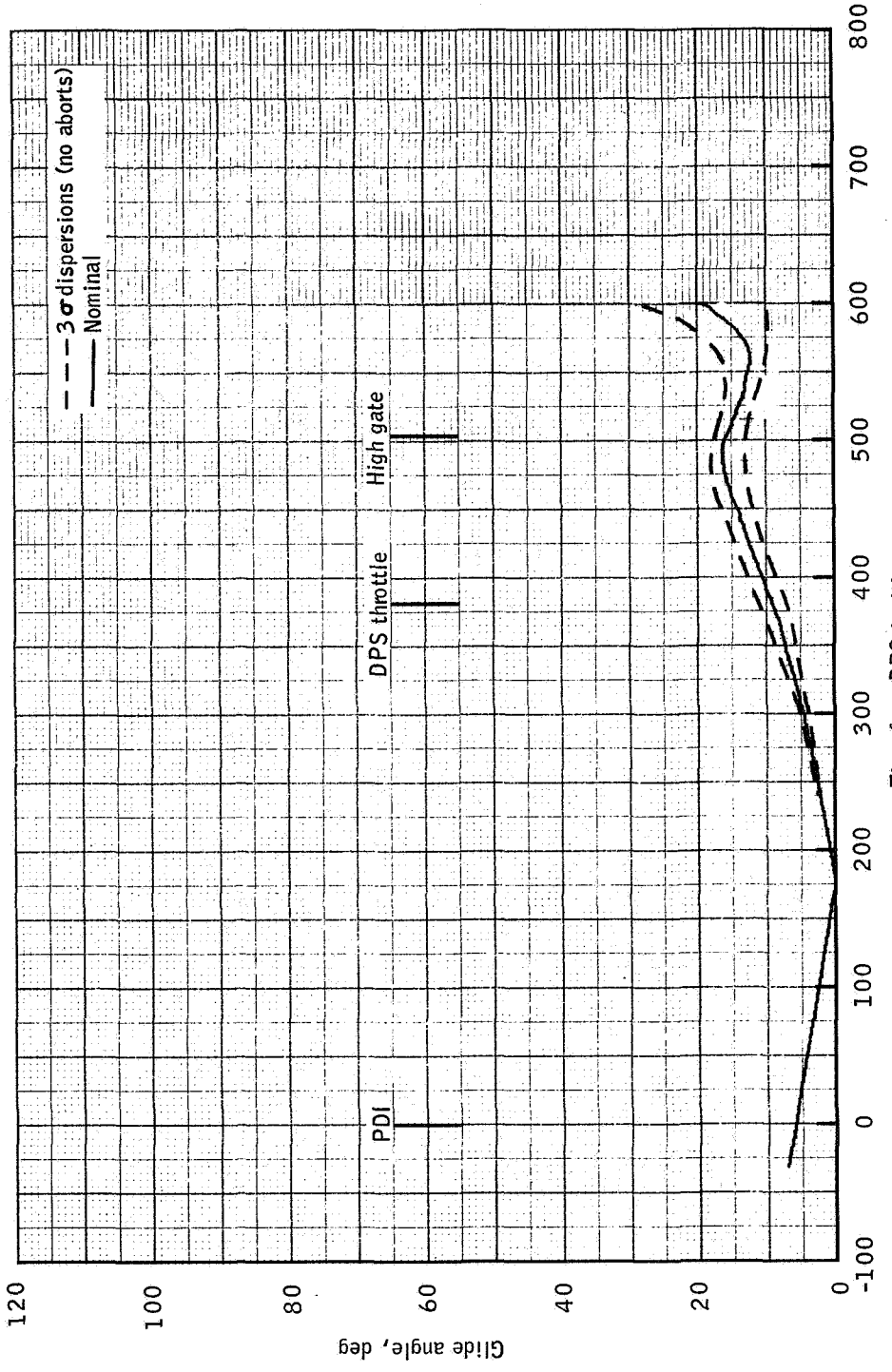
(c) Pitch.

Figure 4.- Continued.



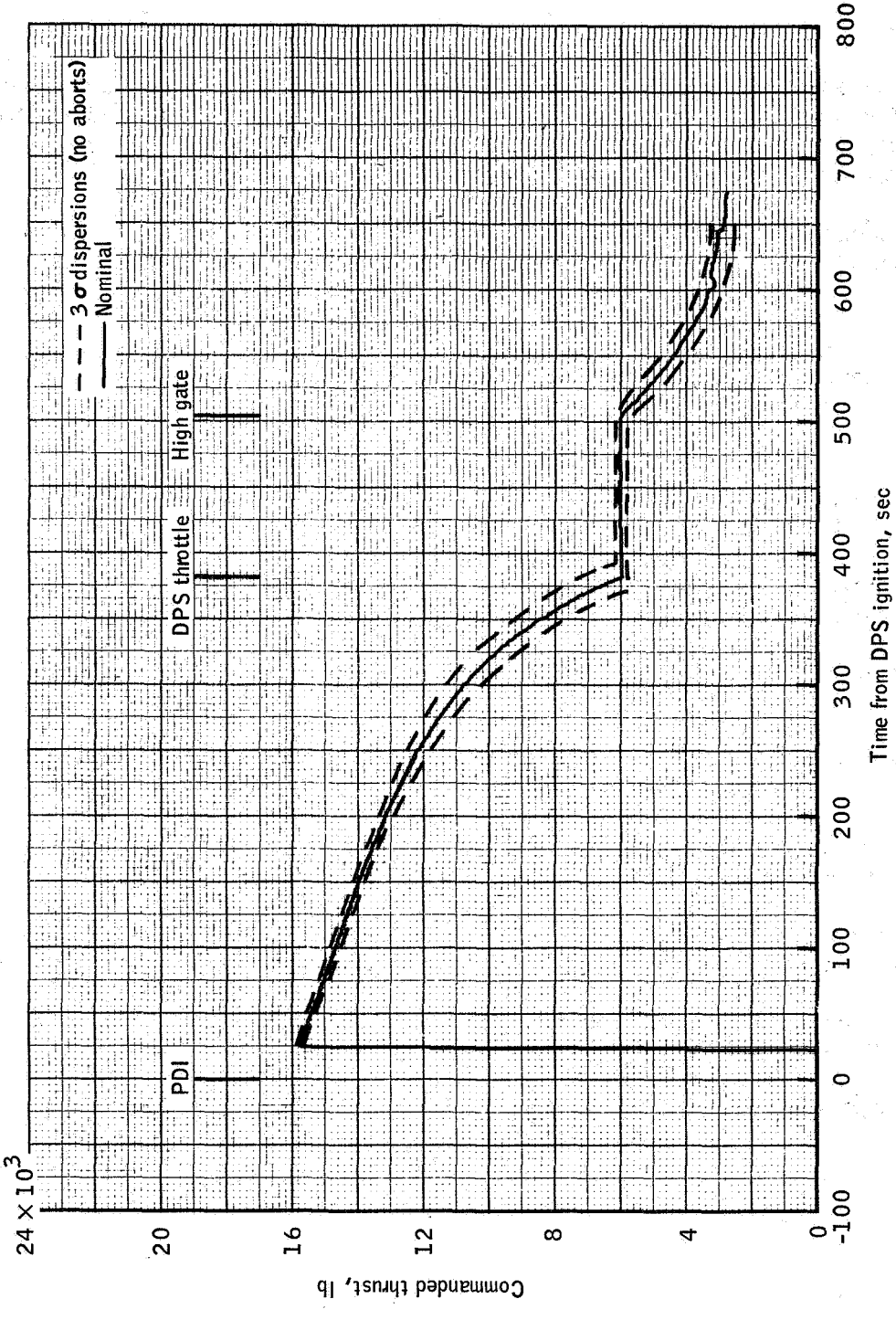
(d) Vertical velocity.

Figure 4.- Continued.



(e) Glide angle.

Figure 4.- Continued.



(f) Commanded thrust.

Figure 4.- Concluded.

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