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OPERATIONAL ABORT PLAN FOR THE APOLLO 9 MISSION VOLUME II CONTINGENCY DEORBIT

Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

OPERATIONAL ABORT PLAN FOR THE APOLLO 9 MISSION
VOLUME II - CONTINGENCY DEORBIT

By Mission Support Section, Flight Analysis Branch

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HOUSTON, TEXAS

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CONTENTS

TABLES

FIGURES

OPERATIONAL ABORT PLAN FOR THE APOLLO 9 MISSION

VOLUME II - CONTINGENCY DEORBIT

By Mission Support Section, Flight Analysis Branch

1.0 SUMMARY

The Apollo 9 preflight nominal and contingency deorbit and reentry data are based on the Apollo 9 spacecraft operational trajectory. These data are designed not only as a contingency deorbit study, but also as a tool for flight control and flight dynamics SSR personnel use in simulation support and mission control. In addition to data for the mass properties, data are presented for GO - NO-GO area and general reentry studies for the nominal reentry into the prime Atlantic recovery area, 151-1.

Volume I of this document gives the abort data for the launch phase.

INTRODUCTION

The nominal mission plan for Apollo 9 (Mission D) is for an earth orbital mission of up to 10-days duration. An LM-active rendezvous exercise with the CSM is scheduled to begin at the end of the fourth day. Two large LM burns are scheduled, DPS-1 and APS burn-to-depletion, along with eight SPS burns. The nominal deorbit burn, SPS-8, will be performed at approximately 238 hours g.e.t.

The prime backup deorbit procedure is an SM RCS burn, and this procedure will remain prime until the RCS redline has been violated. A combination of maneuvers known as the hybrid deorbit will be employed as the secondary backup deorbit procedure. The hybrid deorbit consists of an SM RCS burn followed by a CM/SM separation and a CM RCS burn. This maneuver sequence is performed about apogee so that an optimum effective ΔV is achieved and a 40-n. mi. vacuum perigee can be obtained from the available propellants. Although not presented in this report, there also exists one other deorbit procedure, which is for the CSM failing to separate from the S-IVB prior to a contingency reentry. Under this condition the S-IVB LOX dump will be used to lower the perigee of the orbit to an altitude such that the CM RCS can be used to insure atmospheric capture. This procedure is being developed and will be documented in a revision to this document.

The trajectory data presented in this report were computed using the RTACF's programs and processors which will be used to support the Apollo 9 mission. Note that all GO - NO-GO reentry data are based on a lift-vector-up to 0.2g and a GNCS reentry targeted for the 55° contour line. The hybrid and SM RCS reentry data are based on a lift-vector-down to 1.0g and a GNCS reentry targeted for the 55° contour line.

Abort data for the launch phase are published in reference 1.

3.0 ABBREVIATIONS

BBO	begin blackout
BOM	beginning of mission
C_D	drag coefficient
C_L	lift coefficient
CM	command module
CSM	command and service modules
c.g.	center of gravity
EBO	end blackout
EOM	end of mission
g	acceleration of gravity
g.e.t.	ground elapsed time
GNCS	guidance, navigation, and control subsystem
I_{XX}	moment of inertia about the spacecraft roll axis
I_{YY}	moment of inertia about the spacecraft pitch axis
I_{ZZ}	moment of inertia about the spacecraft yaw axis
RCS	reaction control system
RTACF	Real-Time Auxiliary Computing Facility
RTCC	Real-Time Computer Complex
SM	service module
SPS	service propulsion system

SSR	Staff Support Room
TPI	terminal phase initiation
ΔV	delta velocity
Δt	delta time
ΔV_t	total delta velocity along X-body axis

4.0 INPUT DATA

4.1 Mass Properties

The mass properties values of c.g.'s, moments of inertia, and pitch and yaw trim angles as a function of weight for the CSM configuration used in the report are presented in table I. This table was generated from the CSM launch configuration provided in reference 2 and reflects usage of SPS fuel and oxidizer only. This table relates the SPS thrust vector to the spacecraft body coordinate system, and it should be noted that the pitch and yaw trim angles in the table do not reflect the SPS electronic null bias. Table II lists the predicted nominal BOM and EOM trim aerodynamic coefficients used. The nominal EOM coefficients were computed from the CM c.g. at entry as provided in reference 2. This c.g. reflects full water tanks and all nominal equipment changes made by the flight crew during the mission. The BOM coefficients reflect the CM launch configuration and the loss of CM RCS propellant required to orient the CM to entry attitude and the LM docking ring. Both sets of coefficients were used in this report to depict more accurately the actual entry profile.

Besides the nominal aerodynamics, those resulting from hybrid burns are shown. These were computed based on a CM RCS propellant consumption estimate of 150.4 lb for 80 fps, which was furnished by the Reentry Studies Section, Landing Analysis Branch, MPAD. This estimate was based on the CM configuration provided in reference 2. These data are provided and were used in generating this report because, following a CM RCS deorbit burn, CM lifting capability is significantly different from the nominal.

4.2 State Vectors and Spacecraft Weights

All state vectors and spacecraft weights used for deorbit computations were taken from the operational trajectory (refs. 3 and 4) and the Marshall launch vehicle operational trajectory (ref. 5).

4.3 Constants

Earth and trajectory constants were obtained from the ANWG technical report no. 1.3 (ref. 6). CSM orbital and engine constants were obtained from the CSM/LM spacecraft operational data book (ref. 7).

The spacecraft orbital constants are

CSM orbital reference area, ft^2	129.4
CM reentry reference area, ft^2	129.4
Orbital drag, C_D	2.0
K-factor	1.0

The engine parameters are

Thrust, lb	
SM RCS	393.1
SPS	
0 to 200 sec of burn	20 824.0
Burn time greater than 200 sec . .	21 107.0
Specific impulse, sec	
SM RCS	276.0
SPS	
0 to 200 sec of burn	312.5
Burn time greater than 200 sec . .	312.6

5.0 RESULTS

The data computed and its purpose and uses are discussed in four sections: reentry sequence of events for GO - NO-GO areas, SPS deorbits, SM RCS or hybrid deorbits, and general deorbit data. Data for the reentry sequence of events are required for a general review of the conditions and results of possible reentries following SPS burns, SM RCS burns, and the hybrid deorbit into the various GO - NO-GO areas and backup entry areas. The general studies give information which is useful to flight controllers and flight dynamics SSR personnel in performing their functions during simulations and mission control.

5.1 Reentry Sequence of Events for GO - NO-GO Areas

The planned burns to be performed during the flight are listed in table III. The last orbital maneuver performed prior to each GO - NO-GO deorbit is shown on each reentry sequence of events table.

The GO - NO-GO areas are those reentry areas which would place the CM splash in either the Pacific or Atlantic areas where recovery forces are stationed. An opportunity to reenter into each of these areas occurs approximately once each day as the ground track passes through the recovery forces. The geodetic latitude and longitude of the GO - NO-GO areas, as designated by the Flight Operations Directorate, are listed in table IV.

The reentry sequence of events for these areas are listed in tables V through XVI.

Table IV presents the reentry sequence of events for area 2-1. The CSM/S-IVB separation procedure used in computing this reentry was a 5-second SM RCS burn in the retrograde horizon monitor attitude. The separation is begun 20 minutes prior to the deorbit burn and places the CSM below and behind the S-IVB at retrofire. The horizon monitor attitude mentioned here is the nominal deorbit attitude and is attained by aligning a mark on the CM window with the earth horizon. (A schematic of the resulting attitude is shown on figure 5.)

5.2 Nominal and Contingency SPS Deorbits

5.2.1 Nominal EOM reentry.- The nominal reentry sequence of events for landing area 151-1 is presented in table XVII. This sequence is based on performing all maneuvers listed in table XVI. Note that this report reflects a different ΔV for the deorbit than that of the operational trajectory. This difference is caused by aligning the X-body axis 31.7°

below the line of sight to the horizon, as opposed to aligning the thrust vector as given in the operational trajectory.

Data for the new EOM target point, 67° W longitude, will be documented in a revision to this document.

5.2.2 Relative motion.- Figure 1 shows the relative displacement between the S-IVB and the CSM following separation prior to deorbit for area 2-1, but does not include the CSM deorbit burn and reentry. This reflects the same separation sequence discussed in section 5.1. Figure 2 shows the relative motion between the SM and CM for the nominal 151-1 reentry. The CM/SM separation occurs with the CSM yawed 45° to the south and a 90-second SM RCS burn applied.

5.2.3 SPS underburns.- A plot of ΔV_t versus resulting height of perigee is included (fig. 3) to show resulting perigee altitude for early SPS terminations. This plot is based on the nominal 151-1 deorbit and is used by determining the total SPS ΔV from the flight crew readout of residual ΔV from the ΔV counter. This plot would then provide the resulting perigee altitude.

5.2.4 Percent of footprint.- Figure 4 presents the percentage of footprint remaining from various true anomalies for the nominal EOM orbit. It indicates the sensitivity of the landing point to dispersions in the deorbit burn pitch attitude. The pitch attitude was chosen as the variable to be computed because the ΔV is read into the CM computer and into the ΔV counter and is therefore thought to be less subject to error, whereas the manual method of attaining the horizon monitor deorbit attitude will more likely result in pitch dispersions. Figure 4 shows that the likelihood of attaining the target is greatest when the deorbit burn occurs at a true anomaly of from 260° to 50°. This plot in no way reflects a time-of-free-fall restriction, which may occur following a deorbit burn near perigee.

5.2.5 Depression angles.- A plot of horizon depression angle for various altitudes is presented in figure 5. This depression angle is defined as that angle measured from the local horizontal axis to the line of sight to the earth horizon. (Note the schematic on figure 5.) The plot also includes spacecraft longitudinal axis and SPS thrust vector depression angles. Among its many uses is that of predicting horizon lighting conditions and deorbit attitudes. The longitudinal axis is 31.7° below the line of sight, and the SPS thrust vector is 3° below the longitudinal axis.

5.3 SM RCS and Hybrid Deorbits

5.3.1 Backup EOM reentry.- The reentry sequence of events for the two backup deorbit procedures, SM RCS and hybrid, are listed in tables XVIII and XIX, respectively. These reentries are both into landing area 152-1. Since sufficient SM RCS fuel will be available for deorbit at this time during the mission, the hybrid deorbit is shown only for general information and for comparison to the SM RCS deorbit. The 152-1 hybrid deorbit is performed by a 20 fps SM RCS burn followed 1 minute later by an 80 fps CM RCS burn. The attitude for this deorbit procedure is inertial such that at the center of the hybrid burn arc the thrust opposes the velocity vector.

5.3.2 Apogee - deorbit minimum delta velocity.- Figure 6 presents the impulsive ΔV to be applied at apogee from various orbits to achieve a 40-n. mi. perigee altitude and the transfer angle (delta longitude) from deorbit to landing. The transfer angle results from a lift-vector-down to 1g and a ballistic reentry profile. This plot is to be used in real time to determine the minimum ΔV required to deorbit the spacecraft and to determine the amount of apsidal rotation required of the orbit shaping maneuver to place the 151-1 landing point in the Western Atlantic recovery area.

The plot covers all the orbital possibilities for an apogee deorbit in the Apollo 9 mission.

5.3.3 Apogee deorbits.- Table XX is a tabulation of apogee deorbits for the first day of flight. These were calculated assuming a burn of 130-fps with the SM RCS thrusters and are included to indicate those times during the initial part of the mission when land impacts can occur.

The tabulation begins with the fifth apogee because the insertion orbit is near-circular, and the burn could be performed at any point in orbit with equal results.

5.3.4 Restricted region.- Figure 7, 8, 9, 10, and 11 depict 40-n. mi. perigee limits for deorbits from various orbits for impulsive ΔV's of 100, 125, 150, 175, and 200 fps, respectively. It is readily seen that only those true anomalies where the 40-n. mi. altitude perigee capability exists are safe for deorbit burns. Any deorbits outside these limits would not result in CM capture and reentry.

5.4 General Deorbit Data

Figures 12 and 13 are plots of incremental velocity capability versus burn time and fuel used by SM RCS and SPS burns for several spacecraft weights. The 750-second specification limit for SM RCS burns is indicated on figure 12.

CONCLUDING REMARKS

If contingencies should occur during the flight, the primary objective is to continue the mission whenever possible. This document presents data for the nominal EOM reentry; in addition, adequate information is included to plan a contingency deorbit. The data is representative of values that will occur in the Apollo 9 mission. However, the mass properties and reentry areas will change. This document will be revised to show additional information and changes to the EOM reentry areas.

TABLE I.- MASS PROPERTIES

[Center of gravity, moments of inertia, and trim angles versus total weight]

WEIGHT LBS.	X INCHES	Y INCHES	Z INCHES	IXX SLUG-FT2	IYY SLUG-FT2	IZZ SLUG-FT2	PITCH TRIM DEG.	YAW TRIM DEG.
23200.00	990.52	-3.34	7.75	13148.85	34564.12	33181.77	-2.82	-1.21
25400.00	977.62	-2.08	7.21	14324.99	44285.04	44006.02	-2.86	-0.83
27600.00	967.85	-1.03	6.76	15483.95	50954.70	51767.18	-2.87	-0.44
29800.00	960.48	-0.13	6.37	16629.53	55463.15	57357.93	-2.87	-0.06
32000.00	954.98	0.65	6.04	17764.49	58398.11	61367.89	-2.84	0.30
34200.00	951.02	1.32	5.75	18890.88	60193.35	64232.24	-2.79	0.64
36400.00	948.30	1.92	5.49	20010.26	61216.30	66319.47	-2.73	0.95
38600.00	946.63	2.44	5.27	21123.82	61705.13	67868.58	-2.66	1.23
40800.00	945.80	2.91	5.06	22232.50	61928.48	69148.86	-2.58	1.48
43000.00	945.71	3.33	4.88	23337.06	62046.98	70321.46	-2.49	1.70
45200.00	946.28	3.71	4.72	24438.10	62185.29	71511.43	-2.39	1.88
47400.00	944.55	3.85	4.82	25556.39	65224.35	74685.60	-2.48	1.98
49600.00	940.58	3.83	5.10	26699.60	69965.69	78430.85	-2.72	2.04
51800.00	937.65	3.82	5.35	27841.31	73242.47	80813.01	-2.93	2.09
54000.00	935.62	3.80	5.58	28981.72	75487.29	82114.52	-3.12	2.12
56200.00	934.39	3.78	5.80	30120.98	77044.07	82729.15	-3.28	2.14
58400.00	933.87	3.77	5.99	31259.20	78246.63	82990.53	-3.41	2.14
60600.00	933.97	3.76	6.18	32396.52	79362.93	83166.56	-3.51	2.14
62800.00	934.65	3.75	6.35	33533.01	80635.63	83499.82	-3.58	2.11
65000.00	935.18	3.73	6.50	34668.77	82197.83	84123.30	-3.65	2.10

TABLE II.- TRIM AERODYNAMICS COEFFICIENTS

(a) Beginning of mission

[X_{cg} = 1041.89 in.; Y_{cg} = -0.50 in.; Z_{cg} = 5.36 in.]

Weight = 12 875.00

MACH NO.	ALPHA	CL	CD	CL/CD
0.20	171.50	0.21536	0.82941	0.25965
0.40	168.67	0.21216	0.85805	0.24726
0.70	166.29	0.24207	0.99447	0.24341
0.90	163.63	0.29288	1.07901	0.27144
1.10	157.60	0.44964	1.20032	0.37460
1.20	157.52	0.44147	1.18546	0.37241
1.35	156.34	0.51851	1.30424	0.39756
1.65	155.40	0.52026	1.29268	0.40247
2.00	155.46	0.50901	1.31295	0.38769
2.40	156.08	0.48115	1.28445	0.37459
3.00	156.48	0.45379	1.26353	0.35914
4.00	158.16	0.41728	1.25135	0.33346
10.00	158.69	0.40571	1.26264	0.32132
29.50	162.08	0.35937	1.32727	0.27076

TABLE II.- TRIM AERODYNAMICS COEFFICIENTS - Continued

(b) End of mission

[X_{cg} = 1041.70 in.; Y_{cg} = -0.40 in.; Z_{cg} = 5.60 in.]

Weight = 12 984.00

MACH NO.	ALPHA	CL	CD	CL/CD
0.20	171.24	0.22304	0.82777	0.26945
0.40	168.13	0.22350	0.85644	0.26096
0.70	165.58	0.24990	0.99132	0.25196
0.90	162.88	0.30375	1.07417	0.28278
1.10	156.47	0.46840	1.18822	0.39421
1.20	156.54	0.45665	1.17325	0.38921
1.35	155.36	0.53743	1.29452	0.41516
1.65	154.50	0.53290	1.28155	0.41583
2.00	154.48	0.51978	1.29686	0.40080
2.40	155.08	0.49296	1.26782	0.38882
3.00	155.47	0.46546	1.24434	0.37406
4.00	157.31	0.42785	1.23638	0.34605
10.00	157.90	0.41564	1.24688	0.33335
29.50	161.25	0.37137	1.31171	0.28312

TABLE II.- TRIM AERODYNAMIC COEFFICIENTS - Continued

(c) Beginning of mission CMRCS = 80 fps

[X_{cg} = 1042.12 in.; Y_{cg} = -0.45 in.; Z_{cg} = 4.75 in.]

Weight = 12 724.60

MACH NO.	ALPHA	CL	CD	CL/CD
0.20	172.16	0.19591	0.83328	0.23510
0.40	170.17	0.18177	0.86145	0.21101
0.70	168.20	0.22074	0.99864	0.22104
0.90	165.63	0.26321	1.08904	0.24169
1.10	160.91	0.39156	1.23234	0.31773
1.20	160.44	0.39508	1.21989	0.32387
1.35	159.04	0.46498	1.32609	0.35064
1.65	158.11	0.47870	1.32688	0.36077
2.00	158.29	0.47205	1.34860	0.35003
2.40	158.71	0.44460	1.32248	0.33619
3.00	159.33	0.41545	1.31013	0.31711
4.00	160.47	0.38575	1.29051	0.29891
10.00	160.92	0.37595	1.30554	0.28796
29.50	164.42	0.32348	1.36843	0.23639

TABLE II.- TRIM AERODYNAMIC COEFFICIENTS - Concluded

(d) End of mission CMRCS = 80 fps

[X_{cg} = 1041.92 in.; Y_{cg} = -0.35 in.; Z_{cg} = 5.0 in.

Weight = 12 833.6]

MACH NO.	ALPHA	CL	CD	CL/CD
0.20	171.88	0.20391	0.83174	0.24516
0.40	169.55	0.19410	0.86023	0.22564
0.70	167.45	0.22933	0.99738	0.22993
0.90	164.83	0.27512	1.08556	0.25344
1.10	159.70	0.41325	1.22113	0.33842
1.20	159.28	0.41407	1.20666	0.34315
1.35	157.98	0.48611	1.31815	0.36878
1.65	157.05	0.49569	1.31361	0.37735
2.00	157.21	0.48722	1.33640	0.36458
2.40	157.72	0.45919	1.30885	0.35084
3.00	158.23	0.43116	1.29320	0.33340
4.00	159.58	0.39826	1.27575	0.31218
10.00	160.04	0.38804	1.28872	0.30110
25.50	163.51	0.33791	1.35288	0.24977

TABLE III.- NOMINAL MISSION MANEUVERS

Event	g.e.t. of initiation, hr:min:sec	Time to next event, hr:min:sec	Propulsion system	Burn time, sec	Ullage time, sec	Total ΔV fps	Guidance mode	Resulting h_a/h_p, n. mi.	Tracking stations
Launch[a]	00:00:00.0	00:11:35.3	--	--	--	--	--	--	ETR
Insertion	00:11:35.3	02:22:24.7	--	--	--	--	--	--	ETR, VAN
S-IVB to separation attitude	02:34:00.0	00:09:00.0	APS	--	--	--	--	--	None
CSM separation	02:43:00.0	01:25:57.0	SM RCS	--	--	--	--	--	--
LM extraction	04:08:57.0	01:52:43.0	SM RCS	3.0	--	0.4	--	112/109	None
SPS-1 (docked)	06:01:40.0	16:10:20.0	SPS	5.0	0	36.8	GNCS ext. ΔV	131/113	HAW
SPS-2 (docked)	22:12:00.0	03:06:30.0	SPS	110.4	0	849.4	GNCS ext. ΔV	191/113	BDA
SPS-3 (docked)	25:18:30.0	03:09:30.0	SPS	277.6	0	2548.1	GNCS ext. ΔV	271/115	MIL, BDA
SPS-4 (docked)	28:28:00.0	11:32:00.0	SPS	28.0	[b]20	299.8	GNCS ext. ΔV	271/115	TEX
LM systems evaluation	40:00:00.0	09:43:00.0	--	--	--	--	--	--	--
DPS burn (docked)	49:43:00.0	04:43:16.0	DPS	364.0	[b]10	1698.3	PGNCS - ext. ΔV	270/115	MIL, BDA
SPS-5 (docked)	54:26:16.0	17:13:44.0	SPS	41.5	[b]20	550.5	GNCS ext. ΔV	133/133	GYM
EVA	71:40:00.0	21:25:45.0	--	--	--	--	--	--	--
Mini-football	93:05:45.0	00:44:18.6	SM RCS	10.9	--	5.0	--	131/130	None
Phasing	93:50:03.6	01:51:44.4	DPS	25.2	[b]7	85.0	AGS - ext. ΔV	144/118	MER
Insertion	95:41:48.0	00:40:12.0	DPS - 10%	24.8	[b]7	39.9	PGNCS - ext. ΔV	143/141	GYM
CSI	96:22:00.0	00:44:27.8	LM RCS	30.6	0	37.8	PGNCS - ext. ΔV	139/120	TAN
CDH	97:06:27.8	00:53:02.0	APS	3.1	4	37.9	PGNCS - ext. ΔV	120/118	RED
TPI	97:59:20.6	02:26:30.2	LM RCS	17.6	0	21.8	PGNCS - Lambert	132/119	TAN
APS long duration burn	100:26:00.0	21:33:00.0	APS	360.0	3	5246.7	PGNCS - ext. ΔV	3258/131	TEX, MIL
SPS-6 (solo)	121:59:00.0	47:48:00.0	SPS	2.4	[b]20	62.7	GNCS - ext. ΔV	129/95	CRO
SPS-7 (solo)	169:47:00.0	68:23:00.0	SPS	6.2	[b]20	155.7	GNCS - ext. ΔV	210/93	MIL
SPS-8 (deorbit)	238:10:00.0	00:15:29.5	SPS	12.3	[b]20	313.4	GNCS - ext. ΔV	208/-29	HAW, RED
Entry (400 000 ft)	238:25:29.5	00:09:39.2	--	--	--	--	--	--	--
Chute deployment	238:35:28.7	--	--	--	--	--	--	--	--

[a]Launch is assumed to occur at 1600 G.m.t. on February 20, 1969.

[b]Two-jet ullage.

TABLE IV.- GEODETIC LATITUDE AND LONGITUDE

OF THE GO - NO-GO AREAS

Revolution - area	Latitude, deg:min	Longitude, deg:min
2-1	32:41 N	69:35 W
6-4	29:38 N	160:05 W
19-1	26:38 N	70:00 W
33-1	30:55 N	67:45 W
48-1	29:32 N	68:14 W
63-1	28:09 N	68:00 W
78-1	27:39 N	70:40 W
93-1	26:42 N	69:30 W
108-1	26:20 N	69:30 W
122-1	30:10 N	66:00 W
137-1	28:02 N	66:03 W
[a]151-1	30:37 N	58:59 W

[a]Nominal operational trajectory EOM area.

TABLE V.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 2-1 (69:35 W)

INCLUDING S-IVB/CSM SEPARATION

[Orbit = 99/103 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	487.3
Burn time, sec	41.6
Thrust pitch, deg	-48.9
True anomaly, deg	359
Altitude, n. mi.	101
Weight, lb	59 106
Pitch trim, deg	-1.29
Yaw trim, deg	3.09

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	01:26:07	00:00	--	17:02 N	131:02 W	25 585	-.00056
400 000 ft	01:33:24	07:17	--	28:40 N	103:06 W	25 528	-1.412
300 000 ft	01:36:00	09:53	--	31:11 N	91:41 W	--	--
0.2g	01:37:04	10:56	--	31:53 N	86:54 W	--	--
BBO	01:36:00	09:53	--	31:11 N	99:44 W	--	--
EBO	01:41:11	15:04	--	32:43 N	71:32 W	--	--
23 500 ft	01:44:29	18:22	--	32:40 N	69:35 W	--	--
Minimum lift	01:41:43	15:36	--	32:42 N	75:38 W	--	--
Maximum lift	01:47:08	21:01	--	32:12 N	62:39 W	--	--

TABLE VI.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 6-4 (160:05 W) BEFORE SPS-1

[Orbit = 108/110 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	471.4
Burn time, sec	40.2
Thrust pitch, deg	-49.4
True anomaly, deg	319
Altitude, n. mi.	109
Weight, lb	59 106
Pitch trim, deg	-1.29
Yaw trim, deg	3.09

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	08:51:26	00:00	--	23:44 N	129:41 E	25 550	-.022
400 000 ft	09:00:11	08:45	--	32:30 N	166:46 E	25 571	-1.458
300 000 ft	09:02:40	11:14	--	32:39 N	178:20 E	--	--
0.2g	09:03:42	12:15	--	32:21 N	176:52 W	--	--
BBO	09:02:39	11:13	--	32:39 N	178:18 E	--	--
EBO	09:07:49	16:23	--	30:05 N	161:51 W	--	--
23 500 ft	09:11:07	19:40	--	29:40 N	160:05 W	--	--
Minimum lift	09:08:21	16:55	--	30:53 N	165:48 W	--	--
Maximum lift	09:13:46	22:20	--	27:55 N	153:37 W	--	--

TABLE VII.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 6-4 (160:05 W) INCLUDING SPS-1

[Orbit = 111/128 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	492.3
Burn time, sec	41.7
Thrust pitch, deg	-49.5
True anomaly, deg	330
Altitude, n. mi.	110
Weight, lb	58 769
Pitch trim, deg	-1.27
Yaw trim, deg	3.09

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	08:52:32	00:00	--	24:14 N	130:42 E	25 578	-.099
400 000 ft	09:01:01	08:29	--	32:31 N	166:52 E	25 596	-1.487
300 000 ft	09:03:28	10:56	--	32:38 N	178:17 E	--	--
0.2g	09:04:29	11:57	--	32:21 N	176:56 W	--	--
BBO	09:03:27	10:55	--	32:38 N	178:14 E	--	--
EBO	09:08:37	16:05	--	30:04 N	161:57 W	--	--
23 500 ft	09:11:55	19:23	--	29:38 N	160:05 W	--	--
Minimum lift	09:09:09	16:37	--	30:52 N	165:51 W	--	--
Maximum lift	09:14:36	22:04	--	27:51 N	153:35 W	--	--

TABLE VIII.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 19-1 (70:00 W) INCLUDING SPS-3

[Orbit = 112/268 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	737.6
Burn time, sec	33.7
Thrust pitch, deg	-48.9
True anomaly, deg	356
Altitude, n. mi.	111
Weight, lb	32 750
Pitch trim, deg	-.67
Yaw trim, deg	1.37

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	28:20:17	00:00	CAL	31:23 N	135:09 W	25 813	-.078
400 000 ft	28:27:38	07:22	--	33:42 N	101:18 W	25 684	-1.575
300 000 ft	28:29:57	09:40	--	32:15 N	90:31 W	--	--
0.2g	28:30:57	10:40	--	31:18 N	86:01 W	--	--
BBO	28:29:56	09:39	--	32:16 N	90:38 W	--	--
EBO	28:35:11	14:54	--	26:53 N	71:29 W	--	--
23 500 ft	28:38:26	18:09	--	26:18 N	70:00 W	--	--
Minimum lift	28:35:37	15:20	--	28:19 N	75:27 W	--	--
Maximum lift	28:41:09	20:52	--	23:40 N	63:54 W	--	--

TABLE IX.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 33-1 (67:45 W) INCLUDING DPS-1

[Orbit = 113/267 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	639.6
Burn time, sec	27.6
Thrust pitch, deg	-49.2
True anomaly, deg	339
Altitude, n. mi.	115
Weight, lb	30 847
Pitch trim, deg	-.70
Yaw trim, deg	1.06

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	51:08:46	00:00	CAL	26:47 N	132:18 W	25 782	-.445
400 000 ft	51:15:58	07:12	--	33:37 N	100:51 W	25 745	-1.655
300 000 ft	51:18:14	09:28	--	33:49 N	90:03 W	--	--
0.2g	51:19:14	10:28	--	33:35 N	85:18 W	--	--
BBO	51:18:12	09:26	--	33:50 N	90:11 W	--	--
EBO	51:23:30	14:44	--	31:16 N	69:26 W	--	--
23 500 ft	51:26:46	18:00	--	30:52 N	67:45 W	--	--
Minimum lift	51:23:56	15:10	--	32:09 N	73:50 W	--	--
Maximum lift	51:29:31	20:45	--	28:59 N	60:54 W	--	--

TABLE X.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 48-1 (68:14 W) INCLUDING SPS-5

[Orbit = 129/130 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	472.8
Burn time, sec	18.5
Thrust pitch, deg	-50.1
True anomaly, deg	310
Altitude, n. mi.	129
Weight, lb	28 036
Pitch trim, deg	-.72
Yaw trim, deg	.58

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	74:55:20	00:00	RED	21:04 N	148:58 W	25 482	-.037
400 000 ft	75:06:49	11:29	--	33:28 N	100:50 W	25 644	-1.557
300 000 ft	75:09:10	13:50	--	33:14 N	89:45 W	--	--
0.2g	75:10:10	14:50	--	32:48 N	85:02 W	--	--
BBO	75:09:09	13:49	--	33:14 N	89:48 W	--	--
EBO	75:14:21	19:01	--	29:59 N	69:52 W	--	--
23 500 ft	75:17:37	22:17	--	29:33 N	68:14 W	--	--
Minimum lift	75:14:50	19:30	--	30:58 N	73:58 W	--	--
Maximum lift	75:20:18	24:58	--	27:32 N	61:45 W	--	--

TABLE XI.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 63-1 (68:00 W) INCLUDING SPS-5 - BEFORE MINIBALL

[Orbit = 129/129 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	471.5
Burn time, sec	18.4
Thrust pitch, deg	-50.0
True anomaly, deg	307
Altitude, n. mi.	128
Weight, lb	28 036
Pitch trim, deg	-.72
Yaw trim, deg	.58

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	98:41:24	00:00	RED	23:14 N	148:54 W	25 484	-.037
400 000 ft	98:52:48	11:24	--	33:30 N	100:03 W	25 641	-1.549
300 000 ft	98:55:09	13:45	--	32:45 N	89:01 W	--	--
0.2g	98:56:09	14:45	--	32:06 N	84:24 W	--	--
BBO	98:55:08	13:44	--	32:45 N	89:06 W	--	--
EBO	99:00:20	18:55	--	28:39 N	69:34 W	--	--
23 500 ft	99:03:35	22:11	--	28:09 N	68:00 W	--	--
Minimum lift	99:00:48	19:24	--	29:48 N	73:35 W	--	--
Maximum lift	99:06:17	24:53	--	25:54 N	61:43 W	--	--

TABLE XII.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 78-1 (70:40 W) INCLUDING SPS-6

[Orbit = 93/127 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	468.1
Burn time, sec	18.2
Thrust pitch, deg	-48.3
True anomaly, deg	307
Altitude, n. mi.	100
Weight, lb	27 847
Pitch trim, deg	-.72
Yaw trim, deg	.55

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	122:30:39	00:00	CAL	30:25 N	132:24 W	25 617	-.237
400 000 ft	122:37:07	06:28	--	33:28 N	103:07 W	25 570	-1.443
300 000 ft	122:39:35	08:56	--	32:31 N	91:34 W	--	--
0.2g	122:40:37	09:58	--	31:47 N	86:51 W	--	--
BBO	122:39:35	08:55	--	32:32 N	91:36 W	--	--
EBO	122:44:44	14:05	--	28:12 N	72:22 W	--	--
23 500 ft	122:48:02	17:23	--	27:38 N	70:42 W	--	--
Minimum lift	122:45:16	14:37	--	29:20 N	76:10 W	--	--
Maxi[illegible] lift	122:5[illegible]	20:02	--	[illegible]1 N	64:35 W	--	--

TABLE XIII.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 93-1 (69:30 W) INCLUDING SPS-6

[Orbit = 92/124 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	457.0
Burn time, sec	17.7
Thrust pitch, deg	-48.3
True anomaly, deg	299
Altitude, n. mi.	100
Weight, lb	27 847
Pitch trim, deg	-.72
Yaw trim, deg	.55

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	146:03:58	00:00	CAL	31:03 N	131:05 W	25 608	-.247
400 000 ft	146:10:27	06:29	--	33:20 N	101:29 W	25 568	-1.440
300 000 ft	146:12:55	08:57	--	32:05 N	90:02 W	--	--
0.2g	146:13:57	09:59	--	31:13 N	85:23 W	--	--
BBO	146:12:55	08:57	--	32:05 N	90:05 W	--	--
EBO	146:18:04	14:07	--	27:17 N	71:08 W	--	--
23 500 ft	146:21:22	17:24	--	26:41 N	69:30 W	--	--
Minimum lift	146:18:35	14:37	--	28:31 N	74:52 W	--	--
Maximum lift	146:24:01	20:03	--	24:17 N	63:30 W	--	--

TABLE XIV.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 108-1 (69:30 W) INCLUDING SPS-6

[Orbit = 90/120 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	446.0
Burn time, sec	17.3
Thrust pitch, deg	-48.3
True anomaly, deg	289
Altitude, n. mi.	100
Weight, lb	27 847
Pitch trim, deg	-.72
Yaw trim, deg	.55

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	169:35:17	00:00	CAL	31:15 N	131:17 W	25 597	-.250
400 000 ft	169:41:51	06:34	--	33:15 N	101:18 W	25 566	-1.436
300 000 ft	169:44:19	09:02	--	31:52 N	89:53 W	--	--
0.2g	169:45:21	10:04	--	30:58 N	85:16 W	--	--
BBO	169:44:19	09:02	--	31:52 N	89:56 W	--	--
EBO	169:49:28	14:11	--	26:53 N	71:06 W	--	--
23 500 ft	169:52:45	17:28	--	26:17 N	69:30 W	--	--
Minimum lift	169:49:59	14:42	--	28:09 N	74:49 W	--	--
Maximum lift	169:55:25	20:08	--	23:50 N	63:33 W	--	--

TABLE XV.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 122-1 (66:00 W) INCLUDING SPS-7

[Orbit = 90/205 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	332.2
Burn time, sec	12.6
Thrust pitch, deg	-51.4
True anomaly, deg	266
Altitude, n. mi.	153
Weight, lb	27 417
Pitch trim, deg	-.72
Yaw trim, deg	.47

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	191:54:10	00:00	RED	20:15 N	146:09 W	25 380	-.931
400 000 ft	192:05:42	11:32	--	33:24 N	98:10 W	25 807	-1.751
300 000 ft	192:07:52	13:42	--	33:23 N	87:54 W	--	--
0.2g	192:08:50	14:40	--	33:04 N	83:21 W	--	--
BBO	192:07:50	13:40	--	33:23 N	88:03 W	--	--
EBO	192:13:06	18:56	--	30:31 N	67:37 W	--	--
23 500 ft	192:16:21	22:11	--	30:07 N	66:00 W	--	--
Minimum lift	192:13:31	19:21	--	31:28 N	72:02 W	--	--
Maximum lift	192:19:07	24:57	--	28:07 N	59:09 W	--	--

TABLE XVI.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 137-1 (66:03 W) INCLUDING SPS-7

[Orbit = 89/202 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	321.7
Burn time, sec	12.2
Thrust pitch, deg	-51.6
True anomaly, deg	260
Altitude, n. mi.	157
Weight, lb	27 417
Pitch trim, deg	-.72
Yaw trim, deg	.47

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity fps	Inertial flight-path angle, deg
Retrofire	215:50:28	00:00	RED	22:02 N	149:36 W	25 339	-.899
400 000 ft	216:02:45	12:17	--	33:28 N	97:22 W	25 809	-1.749
300 000 ft	216:04:54	14:26	--	32:44 N	87:14 W	--	--
0.2g	216:05:51	15:23	--	32:08 N	82:48 W	--	--
BBO	216:04:51	14:23	--	32:46 N	87:23 W	--	--
EBO	216:10:04	19:36	--	28:40 N	67:48 W	--	--
23 500 ft	216:13:22	22:54	--	28:07 N	66:03 W	--	--
Minimum lift	216:10:31	20:03	--	29:49 N	71:50 W	--	--
Maximum lift	216:16:07	25:39	--	25:45 N	59:30 W	--	--

TABLE XVII.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 151-1 (58:59 W) INCLUDING SPS-7

[Orbit = 88/200 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	320.6
Burn time, sec	12.1
Thrust pitch, deg	-52.8
True anomaly, deg	230
Altitude, n. mi.	182
Weight, lb	27 417
Pitch trim, deg	-.72
Yaw trim, deg	.47

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	238:10:00	00:00	RED	12:11 N	150:47 W	25 166	-.669
400 000 ft	238:25:27	15:27	--	33:21 N	90:11 W	25 809	-1.857
300 000 ft	238:27:29	17:29	--	33:27 N	80:31 W	--	--
0.2g	238:28:23	18:23	--	33:14 N	76:13 W	--	--
BBO	238:27:27	17:27	--	33:27 N	80:40 W	--	--
EBO	238:32:37	22:37	--	31:01 N	60:40 W	--	--
23 500 ft	238:35:55	25:55	--	30:37 N	58:57 W	--	--
Minimum lift	238:32:58	22:58	--	31:53 N	65:10 W	--	--
Maximum lift	238:38:48	28:48	--	28:39 N	51:43 W	--	--

BLE XVIII.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 152-1 (59:09 W) USING SM RCS BURN INCLUDING 151-1 ULLAGE BURN

[Orbit = 86/200 n. mi.]

(a) Retrofire burn quantities

Total delta velocity, fps	100
Burn time, sec	215.4
Thrust pitch, deg	6.9
True anomaly, deg	148
Altitude, n. mi.	191
Weight, lb	27 402

(b) Sequence of events

Event	Ground elapsed time g.e.t., hr:min:sec	Elapsed time since retrofire min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire	239:20:00	--	--	26:28 S	123:30 E	25 091	.47
400 000 ft	239:57:31	37:31	--	33:19 N	100:34 W	25 891	-1.05
300 000 ft	240:01:23	41:23	--	30:49 N	82:35 W	--	--
1.0g	240:04:25	44:26	--	27:03 N	69:33 W	--	--
BBO	240:03:37	43:38	--	28:09 N	72:49 W	--	--
EBO	240:06:27	46:27	--	24:22 N	62:42 W	--	--
23 500 ft	240:10:53	50:53	--	22:46 N	59:07 W	--	--
Minimum lift	240:09:18	49:18	--	22:57 N	59:30 W	--	--
Maximum lift	240:17:35	57:35	--	12:31 N	40:43 W	--	--

TABLE XIX.- DETAILED REENTRY SEQUENCE OF EVENTS FOR LANDING AREA 152-1 (59:09 W) USING THE HYBRID BURN INCLUDING 151-1 ULLAGE BURN

[Orbit = 86/200 n. mi.]

(a) Burn quantities

	SM burn	CM burn
Total delta velocity, fps	20	80
Burn time, sec	43.2	112
Thrust pitch, deg	7.0	-70.7
True anomaly, deg	152	161
Altitude, n. mi.	192.8	195
Weight, lb	27 402	12 984

(b) Sequence of events

Event	Ground elapsed time, g.e.t., hr:min:sec	Elapsed time since retrofire, min:sec	Tracking at retrofire, station	Geodetic latitude, deg:min	Longitude, deg:min	Inertial velocity, fps	Inertial flight-path angle, deg
Retrofire[a]	239:21:05	--	--	24:50 S	127:38 E	25 077	.41
400 000 ft	239:57:52	36:47	--	33:13 N	99:03 W	25 891	-1.06
300 000 ft	240:01:37	40:32	--	30:37 N	81:43 W	--	--
1.0g	240:04:41	43:36	--	26:42 N	68:35 W	--	--
BBO	240:03:54	42:49	--	27:48 N	71:46 W	--	--
EBO	240:06:40	45:34	--	24:05 N	62:02 W	--	--
23 500 ft	240:10:39	49:33	--	22:47 N	59:09 W	--	--
Minimum lift	240:09:24	48:19	--	22:47 N	59:09 W	--	--
Maximum lift	240:15:41	54:36	--	15:19 N	45:15 W	--	--

TABLE XX.- SM RCS APOGEE DEORBITS FOR THE FIRST DAY

Apogee number	Retrofire time, g.e.t. hr:min:sec	Landing time, g.e.t. hr:min:sec	Latitude of impact, deg:min	Longitude of impact, deg:min	Land landing
5	06:41:04	07:35:54	28:39 N	16:50 E	YES
6	08:09:54	09:04:43	28:47 N	05:20 W	YES
7	09:38:44	10:33:32	28:57 N	27:26 W	NO
8	11:07:34	12:02:23	29:08 N	49:29 W	NO
9	12:36:24	13:31:14	29:19 N	71:27 W	NO
10	14:05:14	15:00:05	29:29 N	93:25 W	YES
11	15:34:04	16:28:55	29:39 N	115:27 W	YES
12	17:02:53	17:57:44	29:47 N	137:32 W	NO
13	18:31:43	19:26:33	29:55 N	159:40 W	NO
14	20:00:33	20:55:21	30:03 N	178:12 E	NO
15	21:29:22	22:24:10	30:11 N	156:07 E	NO
16	22:58:12	23:53:00	30:19 N	134:06 E	NO
17	22:54:56	23:51:28	27:28 N	122:59 E	NO
18	24:24:55	25:21:28	27:43 N	100:46 E	YES
19	25:54:54	26:51:28	27:58 N	78:32 E	YES
20	27:24:53	28:21:28	28:12 N	56:14 E	YES

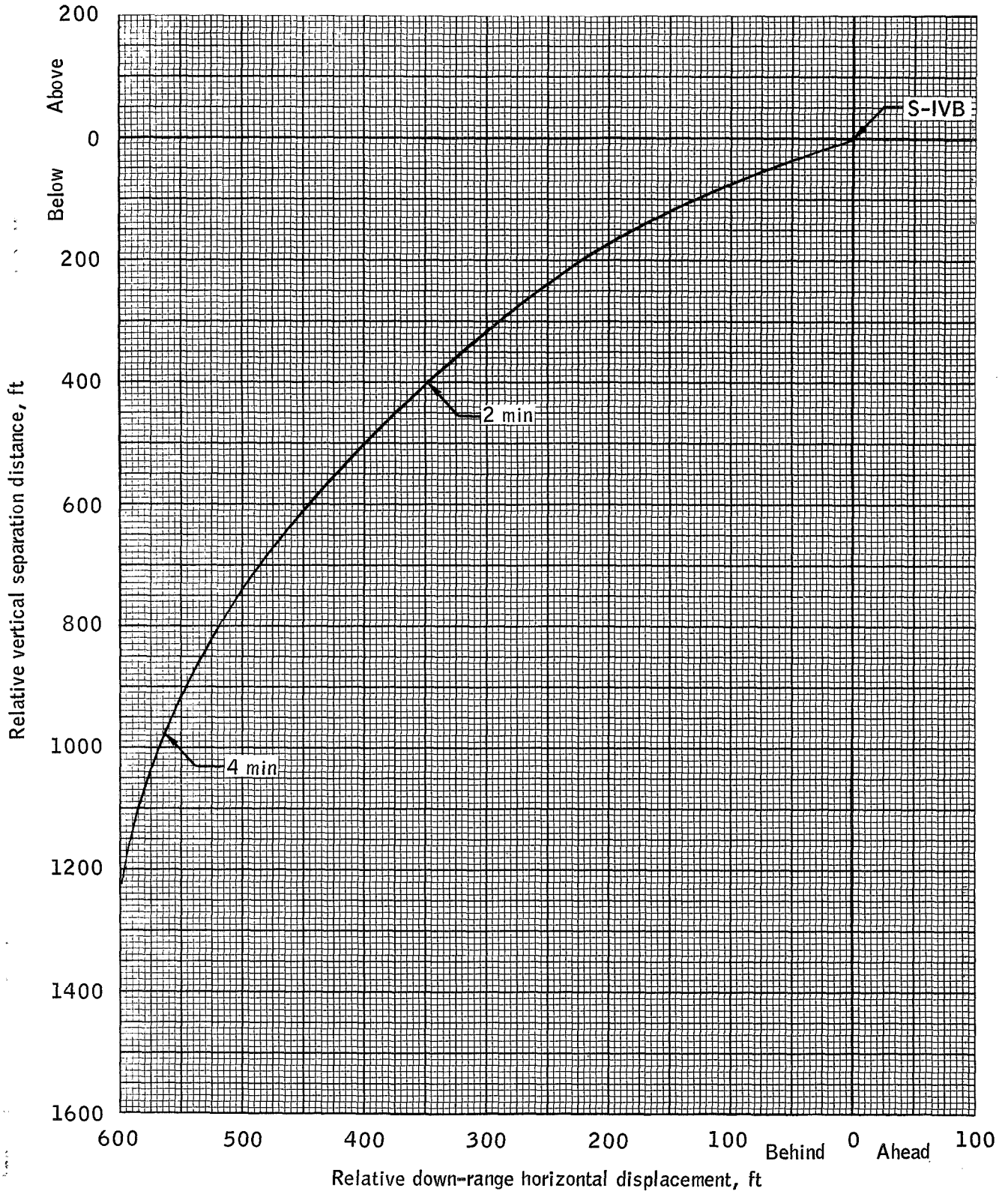

Figure 1.- CSM/S-IVB relative motion for area 2-1 separation sequence.

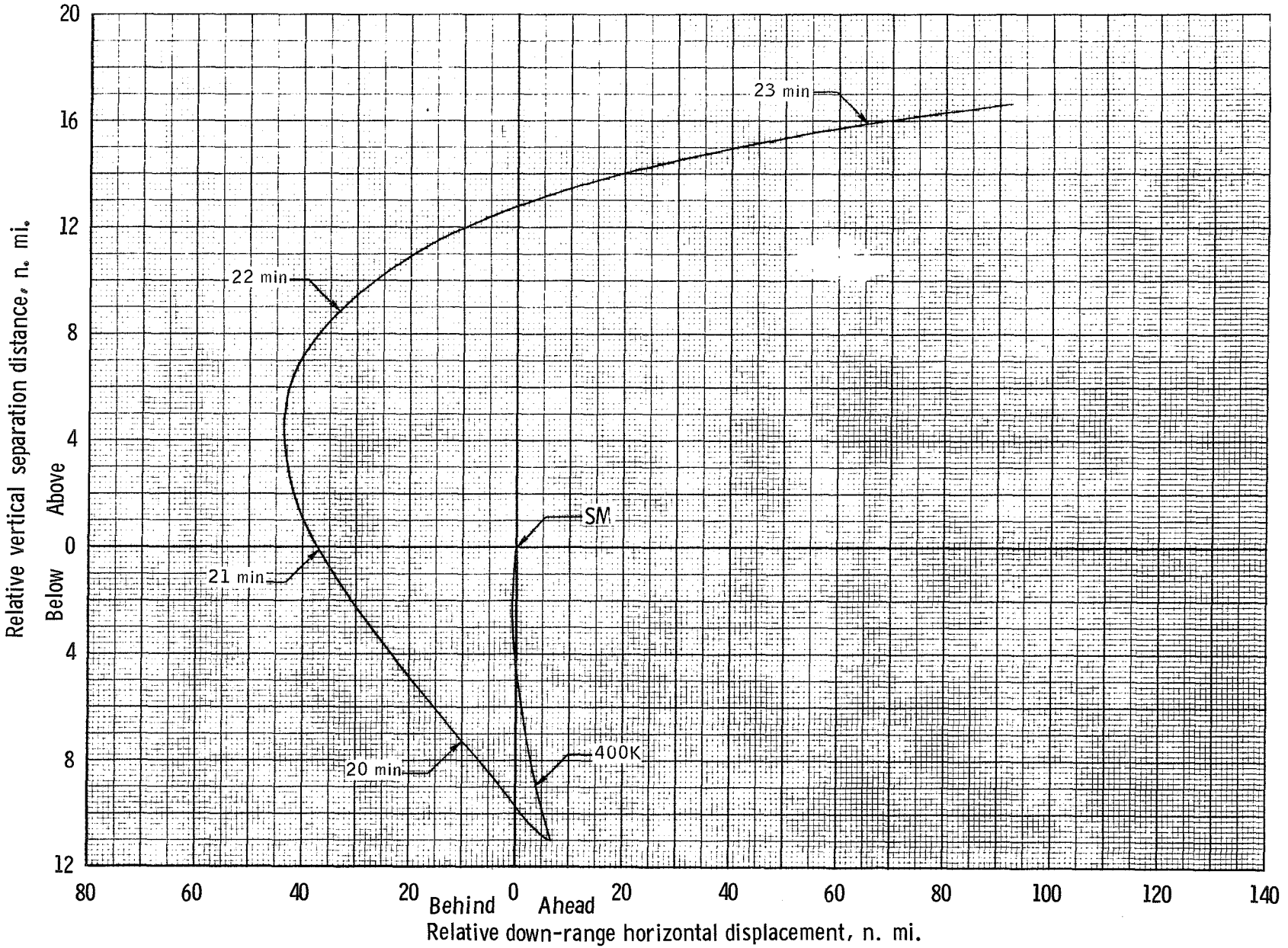

Figure 2.- CM/SM relative motion for area 151-1 with separation burn of 90 seconds.

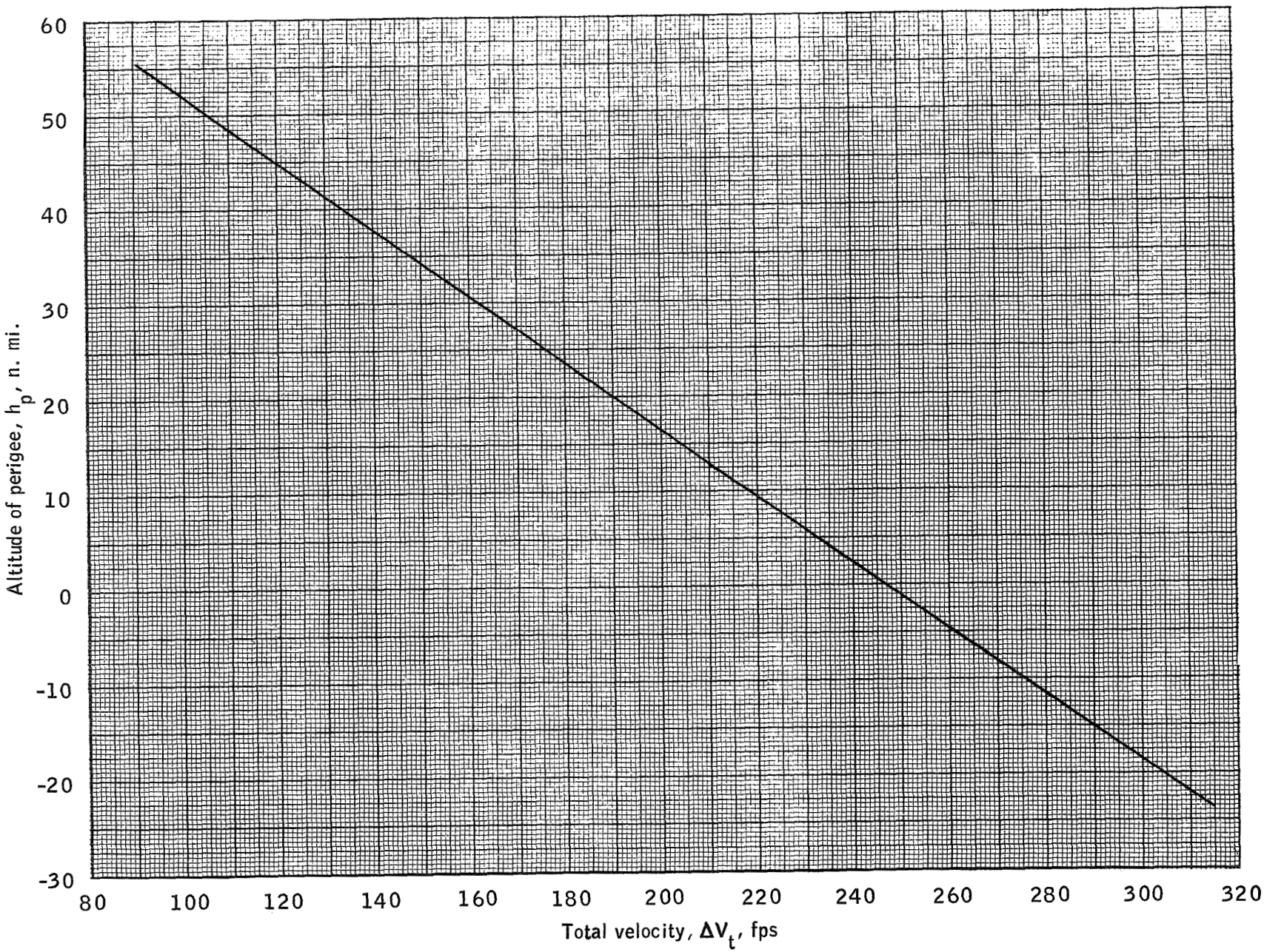

Figure 3.- Total velocity along X-body axis versus resulting perigee for area 151-1.

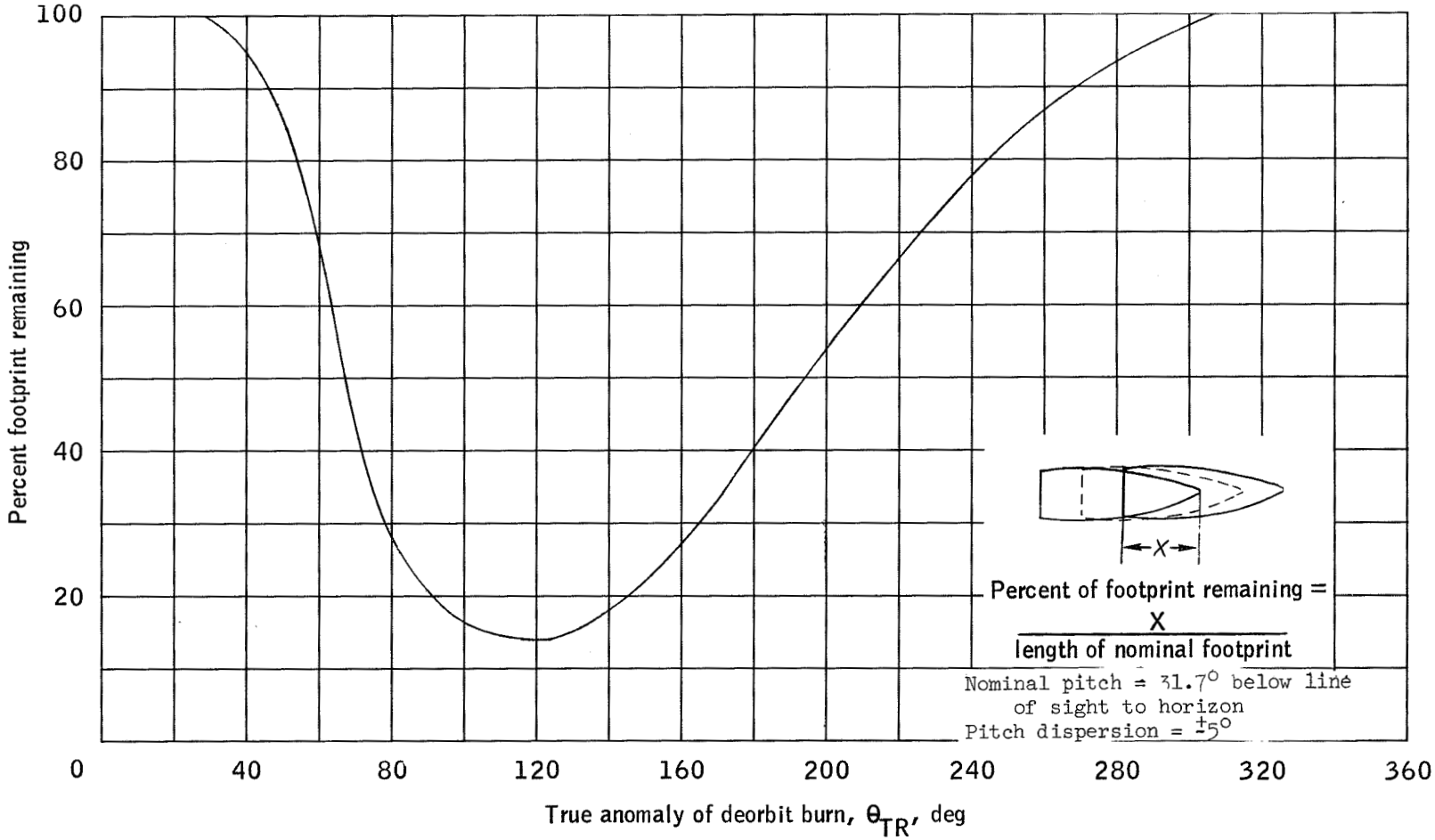

Figure 4.- Percent of footprint remaining versus true anomaly of deorbit burn from a 200/88-nautical mile orbit.

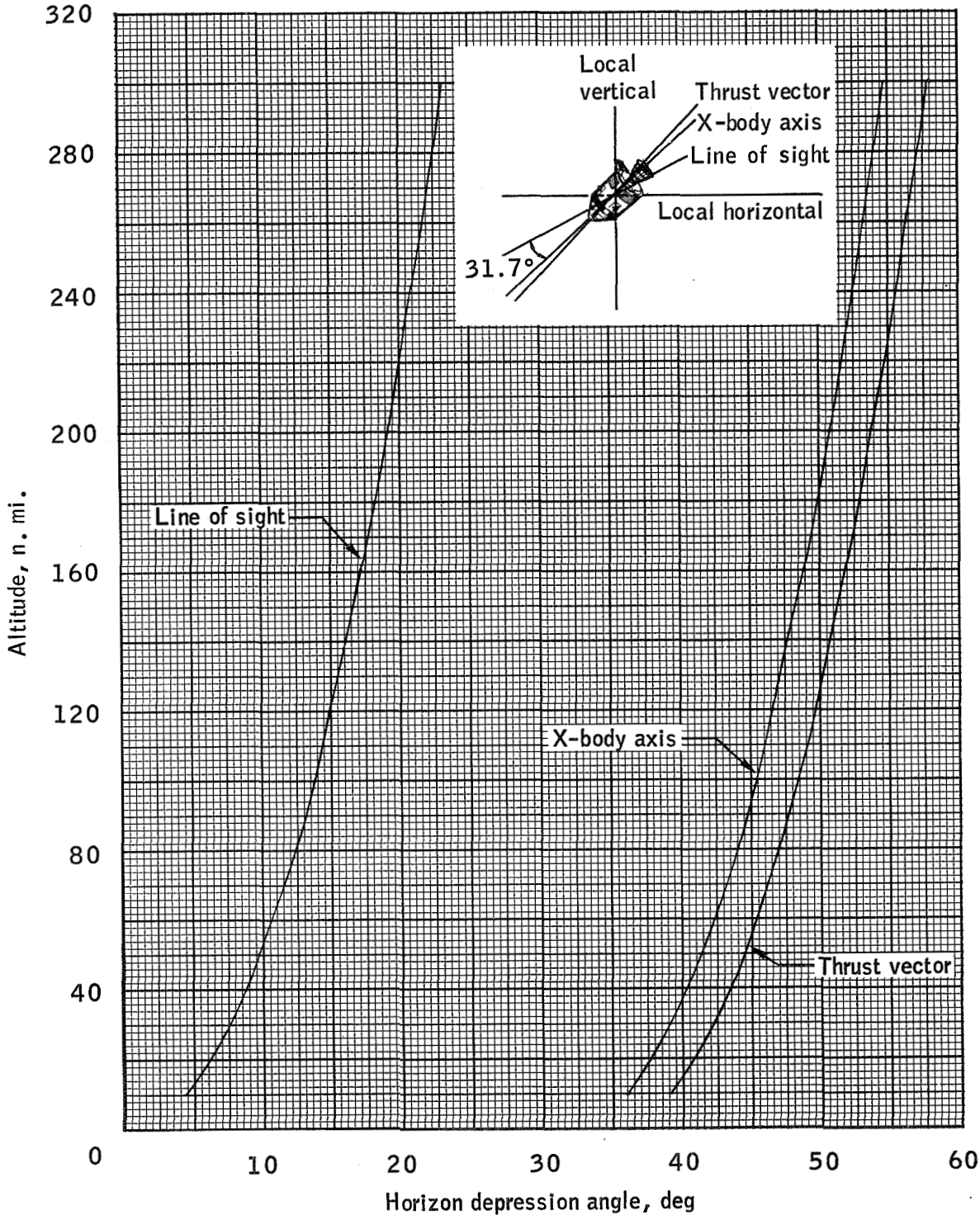

Figure 5.- Horizon depression angle versus altitude of spacecraft.

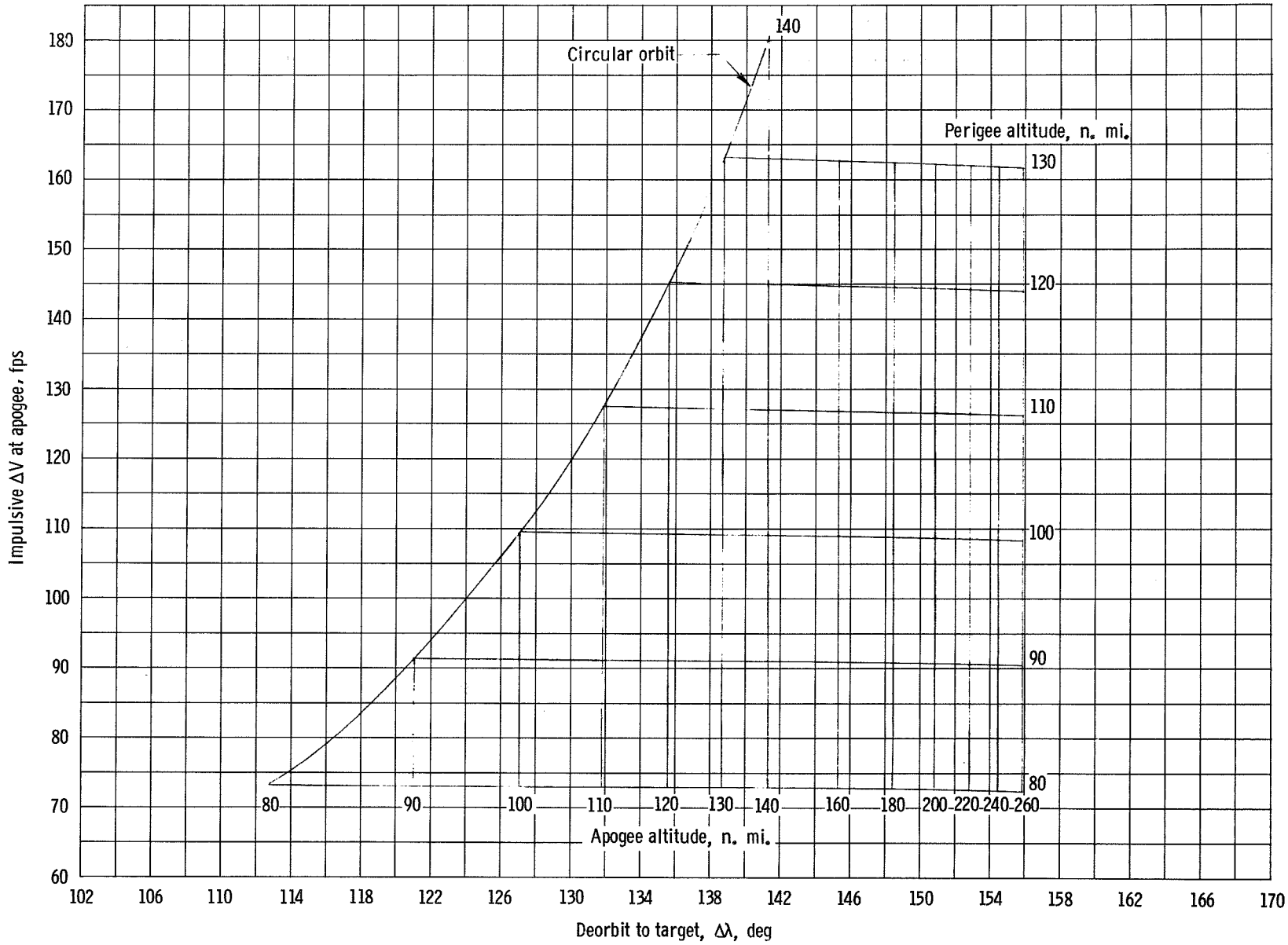

Figure 6. - Apogee ΔV and earth referenced angle from deorbit to target versus apogee altitude and perigee altitude for h_p = 40-nautical mile transfer orbit.

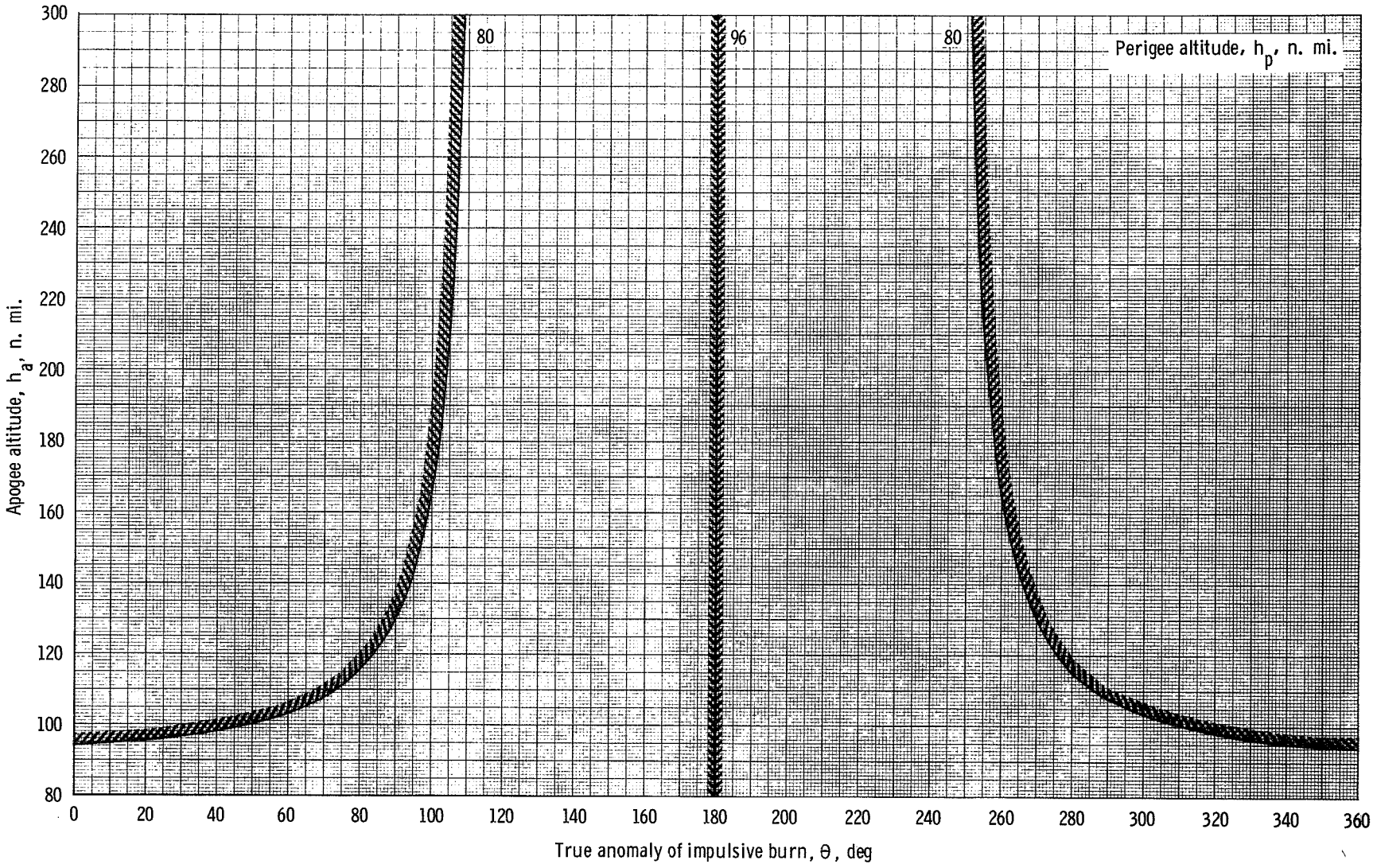

Figure 7. - True anomaly of impulsive burn as a function of apogee and perigee altitudes depicting 40-nautical mile perigee limits for a ΔV of 100 fps.

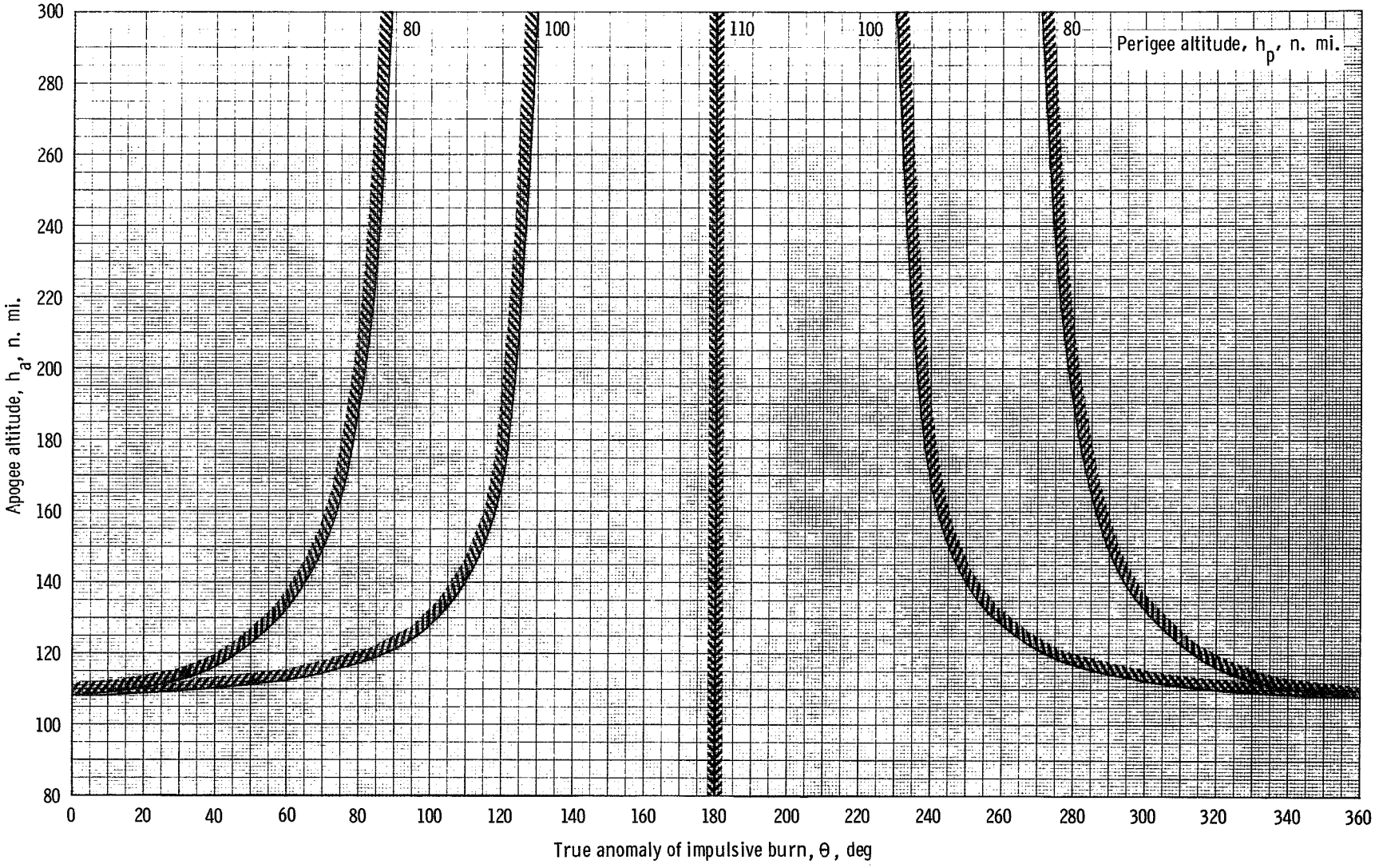

Figure 8. - True anomaly of impulsive burn as a function of apogee and perigee altitudes depicting 40-nautical mile perigee limits for a ΔV of 125 fps.

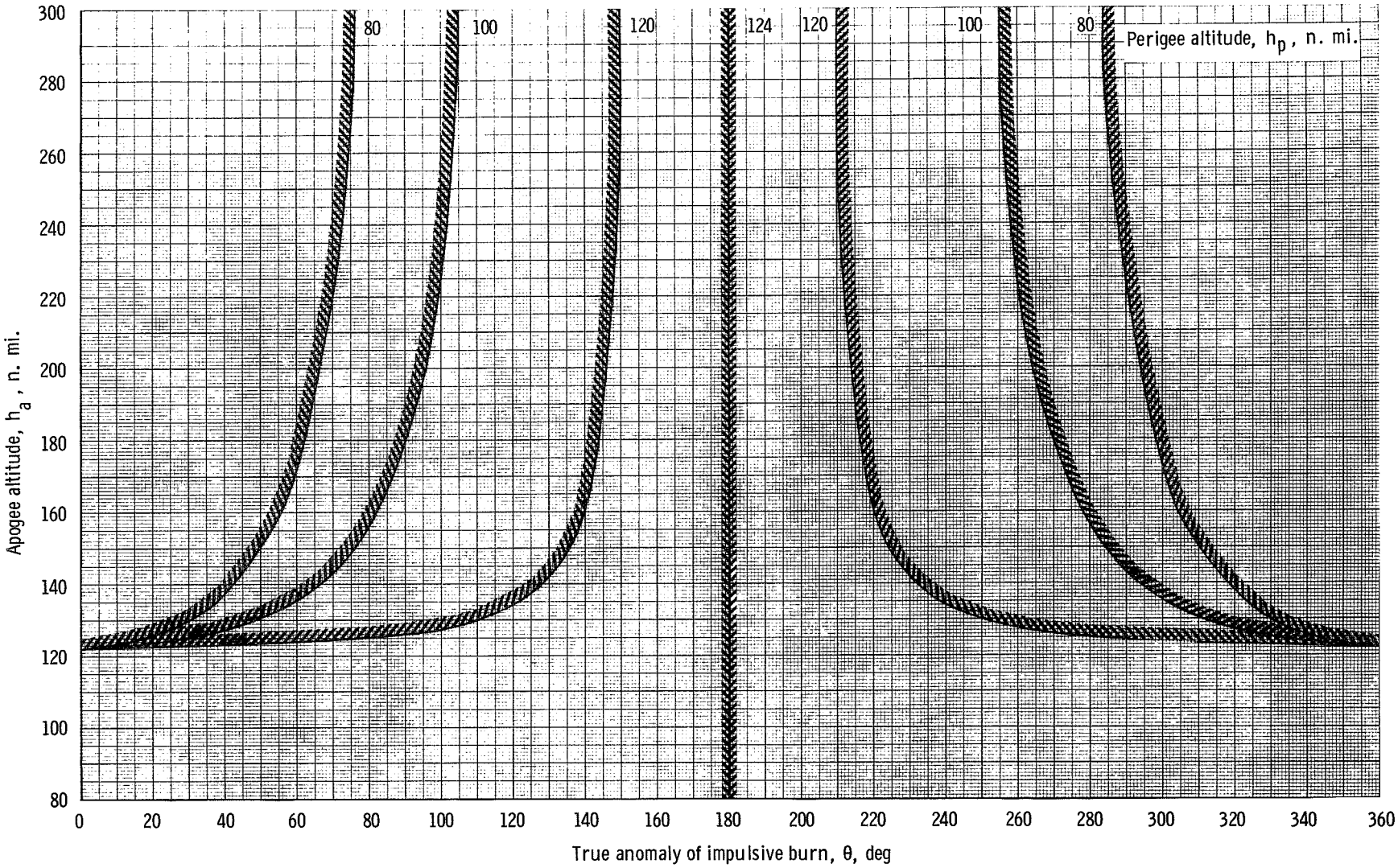

Figure 9.- True anomaly of impulsive burn as a function of apogee and perigee altitudes depicting 40-nautical mile perigee limits for a ΔV of 150 fps.

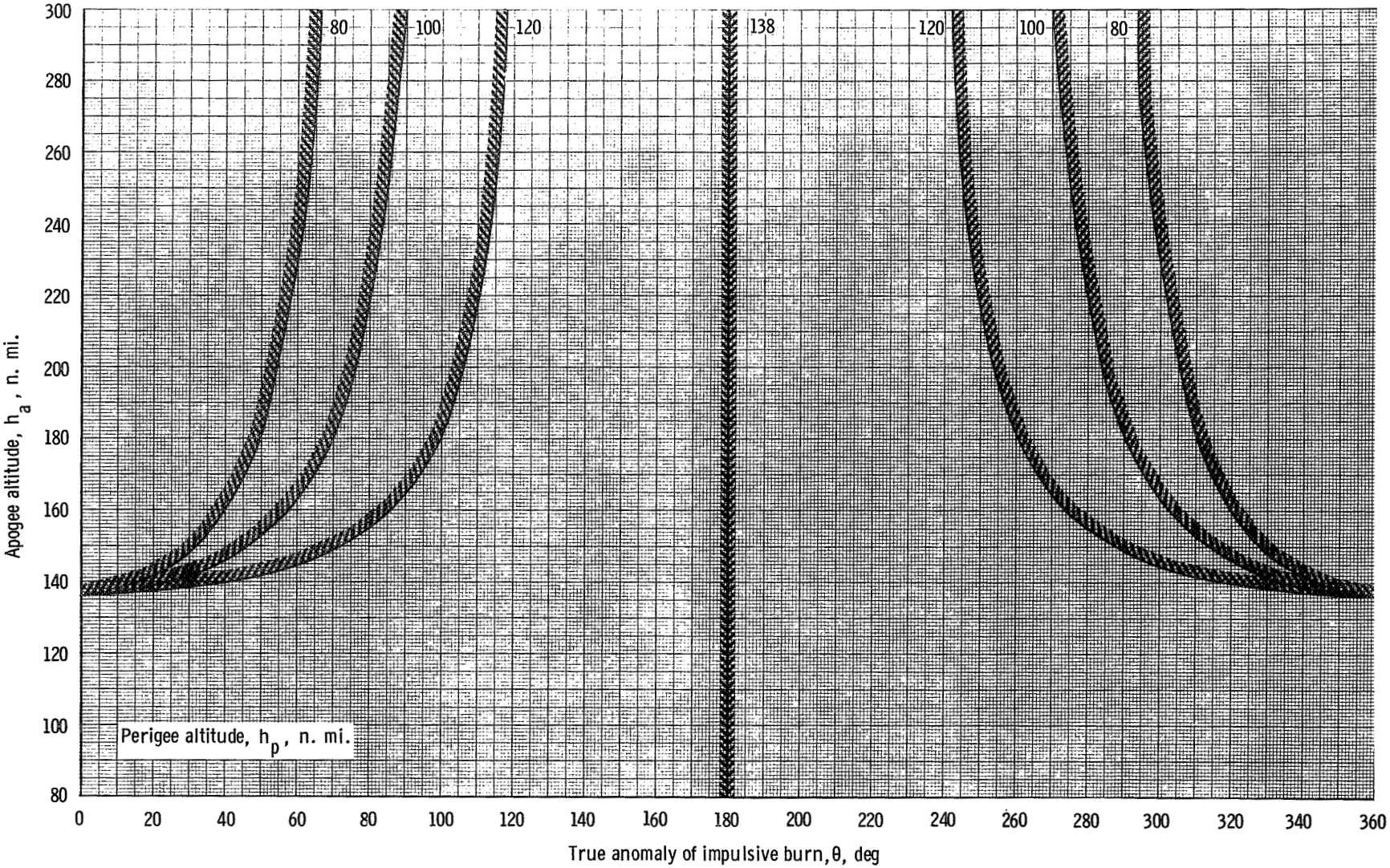

Figure10. - True anomaly of impulsive burn as a function of apogee and perigee altitudes depicting 40-nautical mile perigee limits for a ΔV of 175 fps.

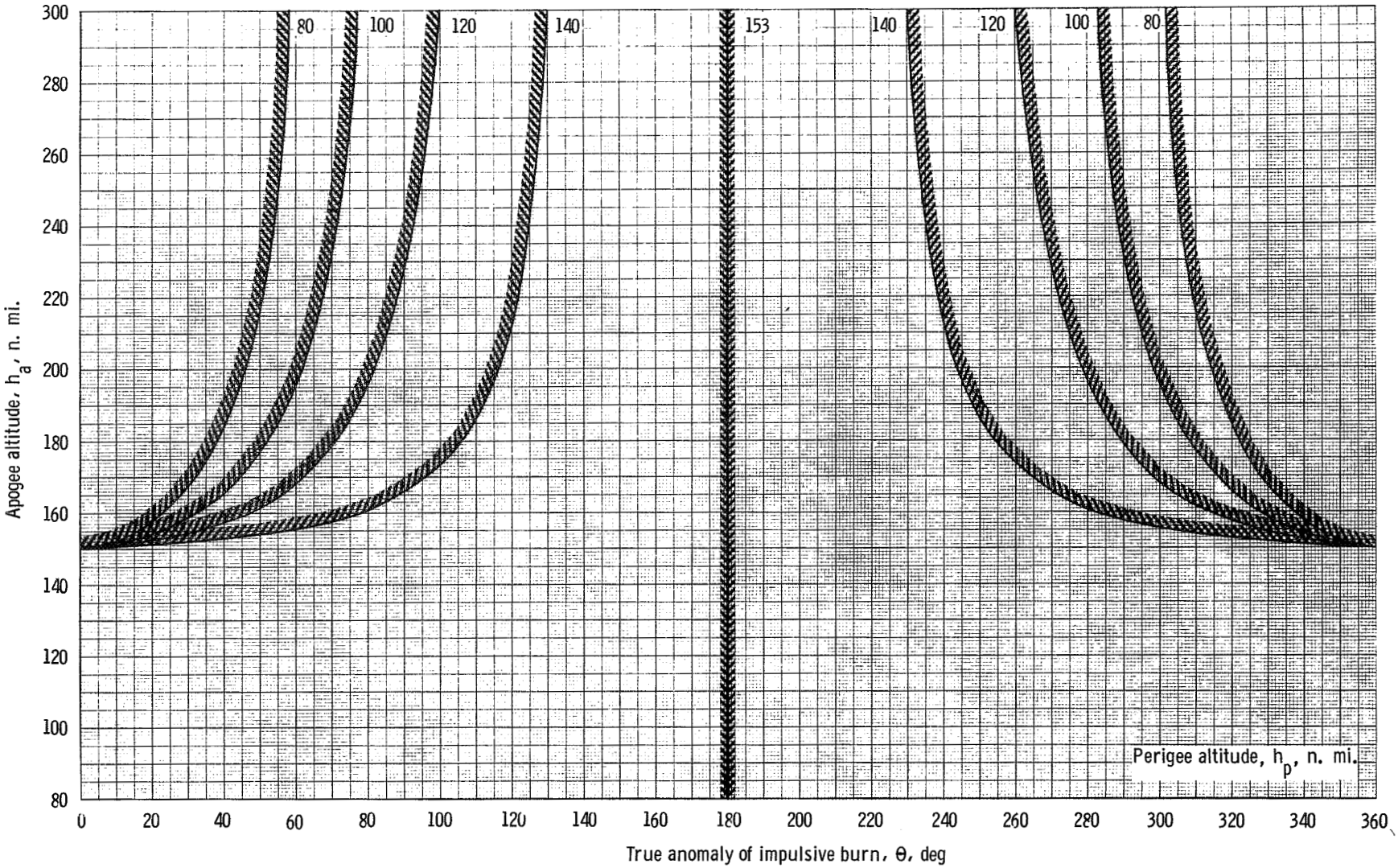

Figure 11. - True anomaly of impulsive burn as a function of apogee and perigee altitudes depicting 40-nautical mile perigee limits for a ΔV of 200 fps.

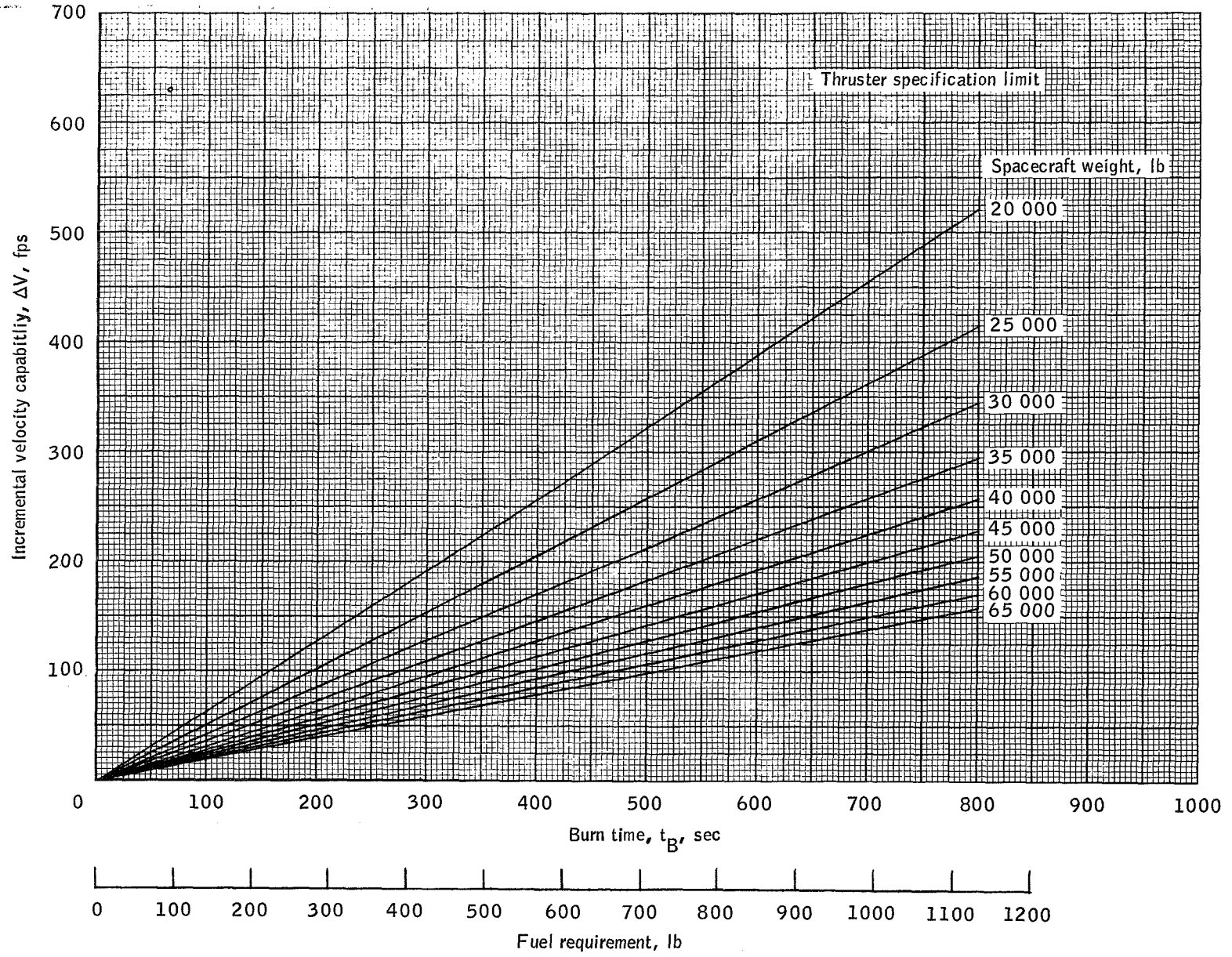

Figure 12.- Incremental velocity capability of the SM RCS versus burn time and spacecraft weight.

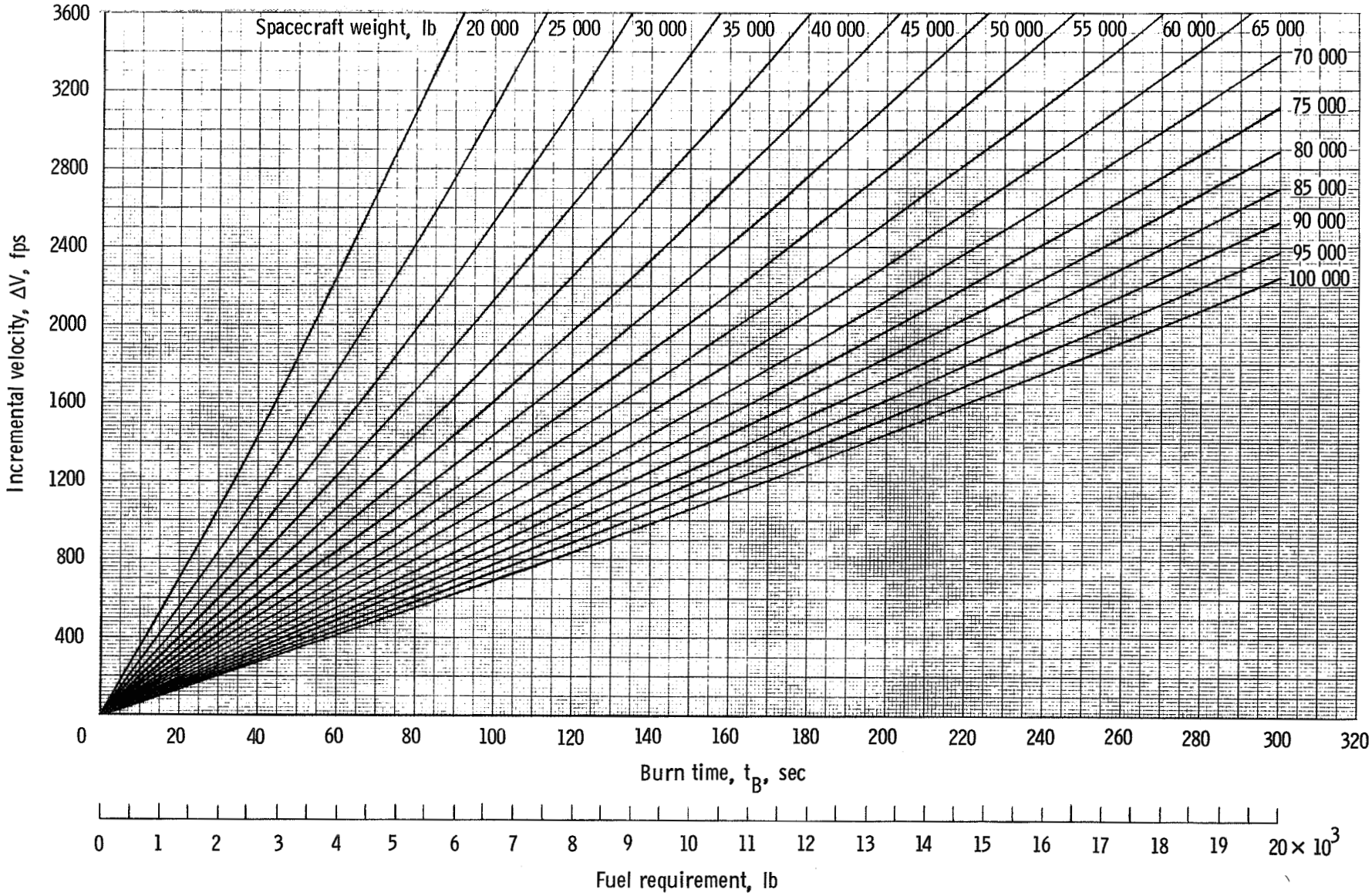

Figure 13.- Incremental velocity capability of the SPS versus burn time and spacecraft weight.

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