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November 25, 1966

COMMUNICATION BLACKOUT REGIONS FOR LUNAR RETURNS USING THE AS-504 REENTRY GUIDANCE LOGIC

By John Burton
Mission Analysis Branch

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MISSION PLANNING AND ANALYSIS DIVISION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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HOUSTON, TEXAS

Approved: M. P. Frank III, Chief
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Mission Planning and Analysis Division

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COMMUNICATION BLACKOUT REGIONS FOR LUNAR RETURNS

USING THE AS-504 REENTRY GUIDANCE LOGIC

By John Burton

SUMMARY

A preliminary study was made of communication blackout regions as a function of reentry flight-path angle, reentry range to target, and lift-to-drag ratio (L/D) for the nominal lunar-return reentry velocity of the AS-504 mission. This study was made not only to define the nominal blackout regions, but also to define the effect of non-nominal conditions on the blackout regions. Results are presented in velocity-versus-altitude plots which show VHF-band, S-band, and C-band blackout regions. Time histories of altitude and altitude-range profiles are also presented to provide an easy trajectory reference for the velocity and altitude data.

INTRODUCTION

The nominal AS-504 mission has a reentry inertial velocity of 36 070 fps and inertial flight-path angle of -6.25°. To establish preliminary reentry and recovery procedures, it is necessary to define the communication blackout regions for non-nominal entry conditions. In this study the flight-path angle, range to target, and L/D are varied, but the AS-504 nominal entry velocity is constant.

It should be noted that the data resulting from this study and presented in this note depend on the guidance logic used and will change if changes are incorporated into the AS-504 reentry guidance logic. In fact, since the guidance logic is still in a state of change, it can be expected that the data will have to be updated. However, basic trends can be seen from these data, and these trends should not change greatly.

The data obtained from this preliminary study are presented in this internal note in order to make the information available now. A more thorough presentation will be made later and will include the

effect of atmospheric deviation on communication blackout regions. This presentation will also include a study made at a L/D of 0.3 and cross plots of maximum altitude, blackout exit altitude, delta time of acquisition during skip phase, position at blackout relative to 400 000 ft altitude interface versus entry flight-path angle, L/D, and range.

ANALYSIS AND RESULTS

The trajectories presented were calculated using the present modified version of the reentry guidance logic as defined in reference 1. Reentry flight-path angles were chosen to be near the overshoot and undershoot boundaries and in the middle of the reentry corridor. Target ranges from 400 000 ft were 1500, 2000, and 2500 n. mi. All cases were run for L/D's of 0.34, 0.39, and 0.44. In all cases the velocity was held at the nominal AS-504 reentry velocity of 36 070 fps.

Figures 1 through 27 present, for all L/D's, velocity versus altitude, altitude versus range, and altitude versus time from reentry for various combinations of target ranges and flight-path angles. The velocity versus altitude plots (fig. 1, 4, 7, ..., 25) show VHF-band, S-band, and C-band blackout regions. The altitude versus range and altitude versus time from reentry plots (the remaining plots) provide an easy trajectory reference for the velocity and altitude data.

Data used to define the VHF-band, S-band, and C-band communication blackout curves were obtained from reference 2. Using this data for the nominal AS-504 inertial reentry velocity of 36 070 fps, communication blackout for the C-band, S-band, and VHF-band frequencies will occur at the altitudes of 295 000 ft, 308 000 ft, and 332 000 ft, respectively. This is true for all the trajectories investigated; however, the elapsed time from 400 000 ft to communication blackout varied depending on the entry inertial flight-path angle, such that the steeper the flight-path angle, the earlier the blackout altitude was reached. Range to target had no effect on elapsed time to blackout altitude since the guidance logic will fly the same trajectory to 0.05 g or about 300 000 ft altitude, at which point blackout altitudes have essentially been reached. There were no effects on elapsed time to blackout due to L/D changes since the aerodynamic forces are essentially negligible above an altitude of 300 000 ft. Table I shows the communication blackout altitudes and elapsed time from 400 000 ft to blackout for the cases investigated.

After entry into the communication blackout region the spacecraft might be required to gain altitude in order to reach a long target. Because of this gain in altitude or so called "skip phase" the spacecraft is able to exit the blackout region. In a few cases the C-band and/or S-band frequency was reacquired early in the trajectory and was maintained for the rest of the flight; however, in most cases where there was a skipout of the communication blackout region the blackout region was reentered. Table II presents elapsed times and altitudes of exit and reentry of the communication blackout regions for those trajectories that had a noticeable gain in altitude. Elapsed times and altitudes are summarized for final acquisition of communications in table III. Total acquisition time for those cases that had a skip phase are presented in table IV.

CONCLUDING REMARKS

Two basic trends were observed in this study. One is that for a steep reentry flight-path angle, the guidance logic will steer to a higher peak altitude than for the case of the nominal reentry flight-path angle. The guidance logic will also steer the spacecraft to a higher peak altitude for the case of a long range to target. Thus, for a steep reentry flight-path angle and/or long range to target a higher peak altitude will be reached which could result in communication acquisition during the skip phase of the reentry.

A second trend is that for a steeper reentry flight-path angle the blackout region will be entered earlier than for the nominal reentry flight-path angle.

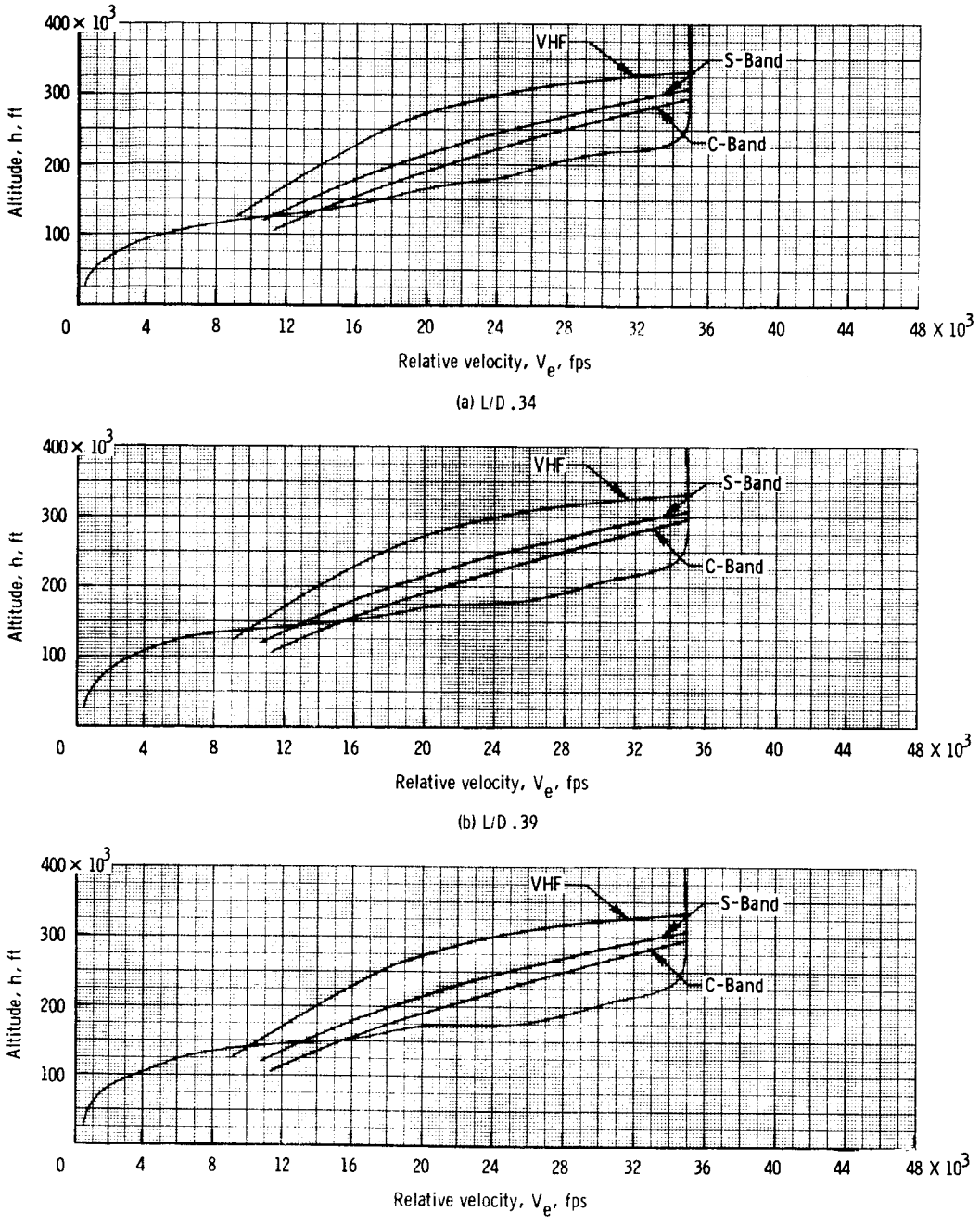
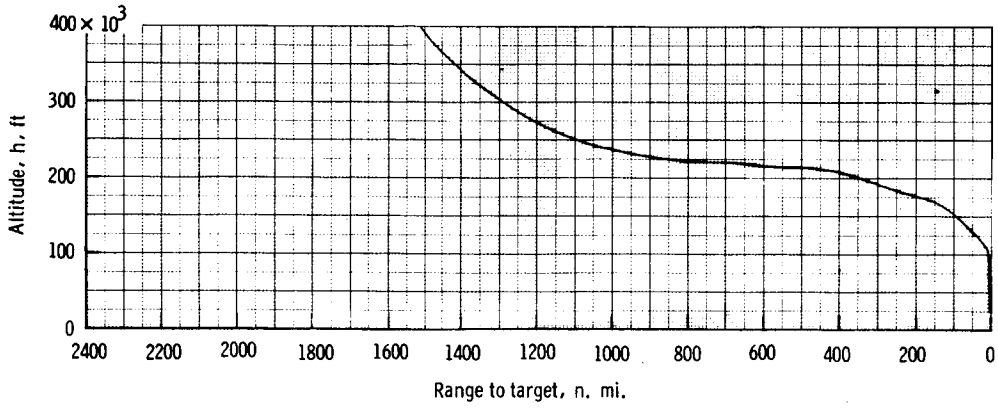


Figure 1.- Communications blackout region for lunar returns with entry range of 1500 nautical miles and a flight-path angle of -5.0 degrees.



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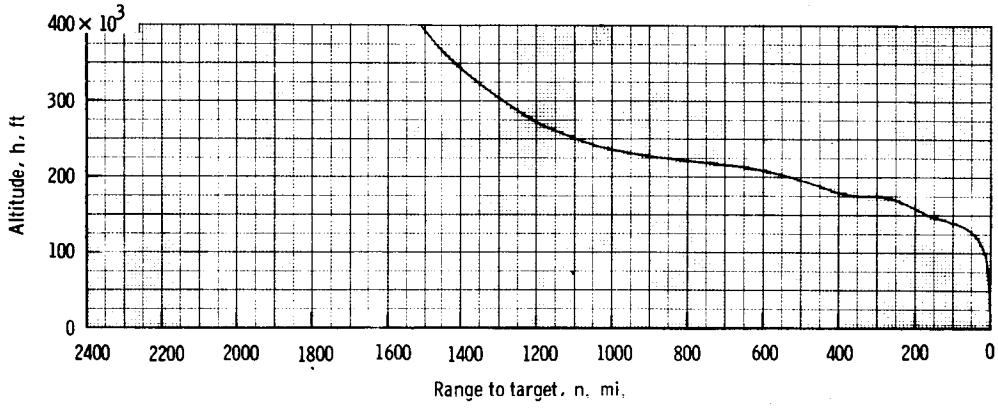
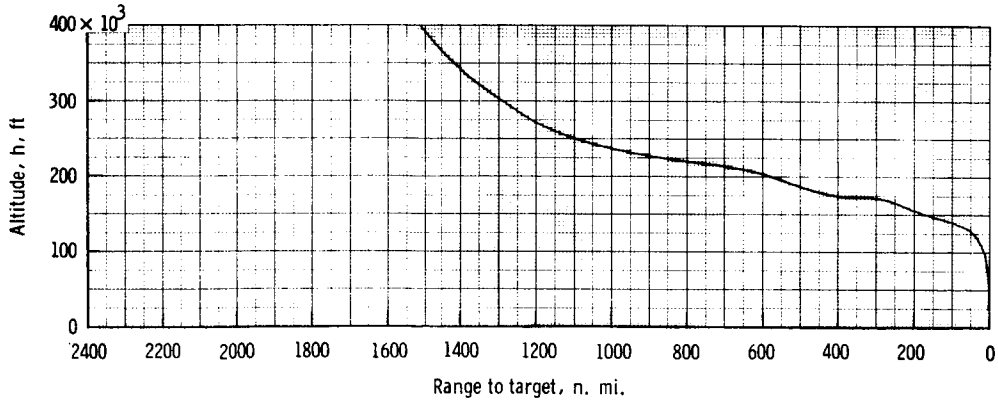
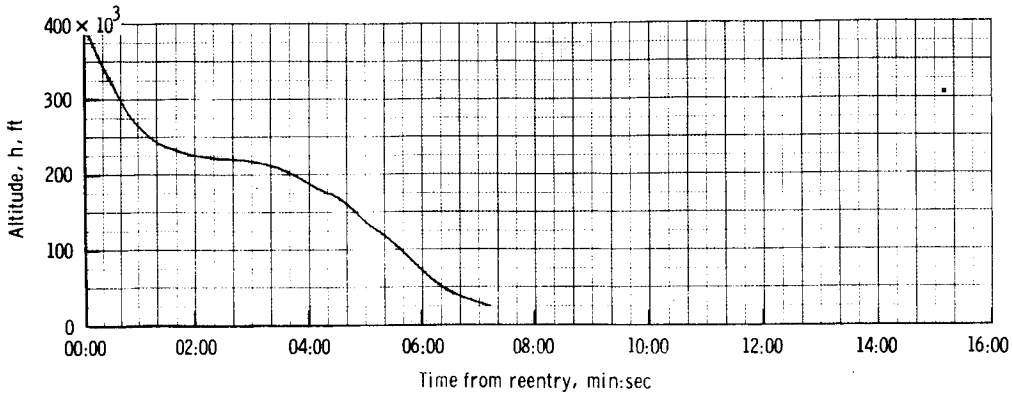


(b) L/D .39

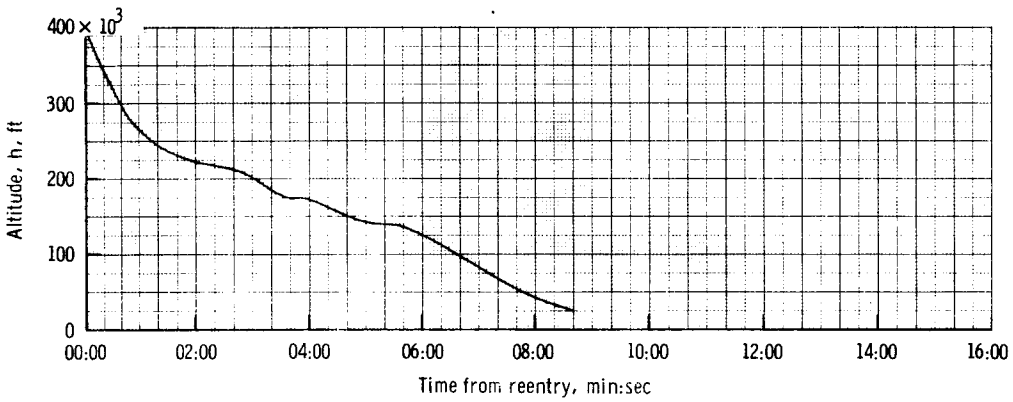


(c) L/D .44

Figure 2. - Altitude versus range with a range of 1500 nautical miles and a flight-path angle of -5.0 degrees.



(a) L/D .34



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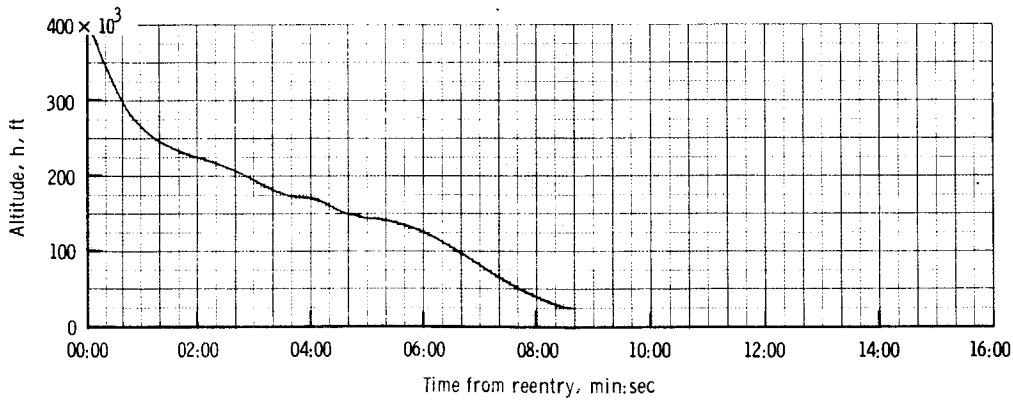
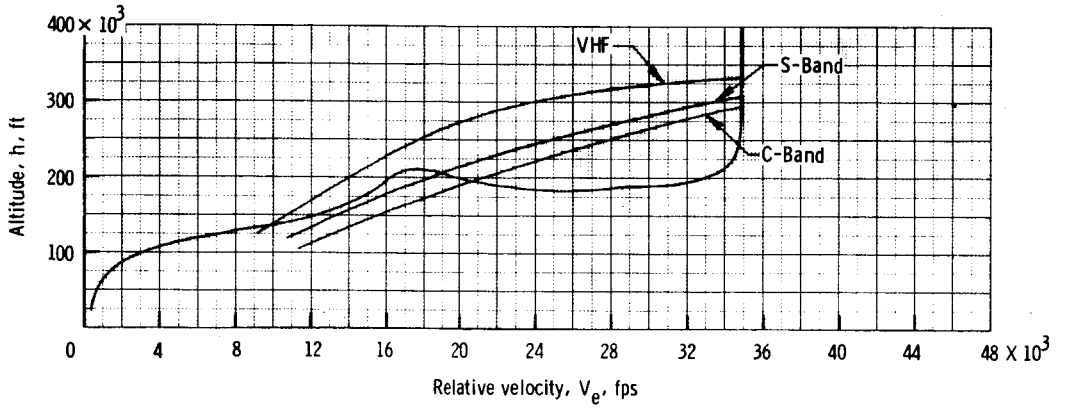


(c) L/D .44

Figure 3. - Altitude versus time from reentry with reentry range of 1500 nautical miles and a flight-path angle of -5.0 degrees.



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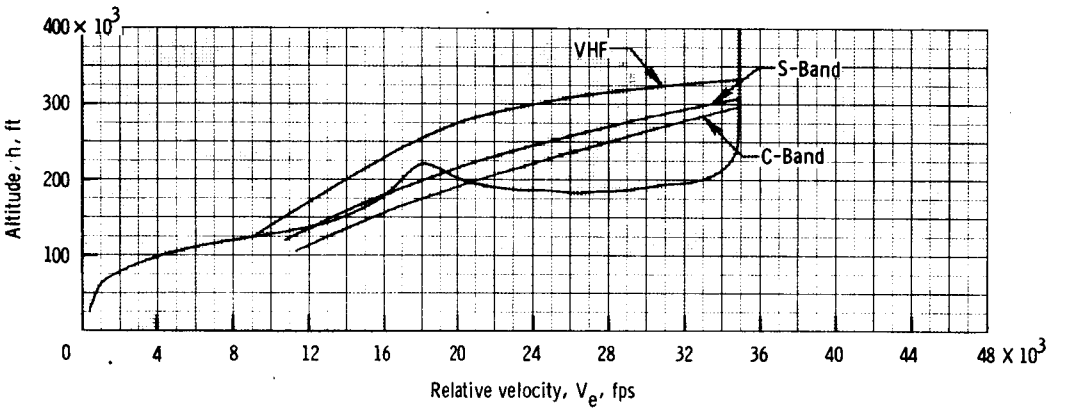

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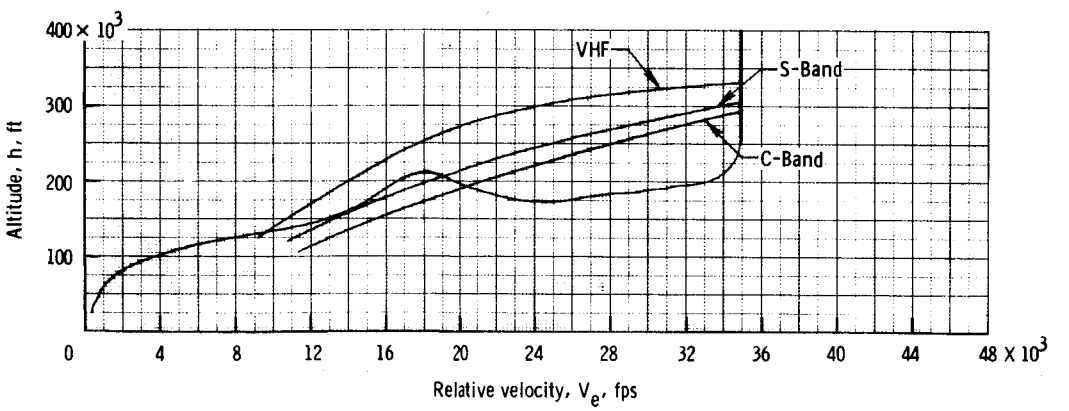
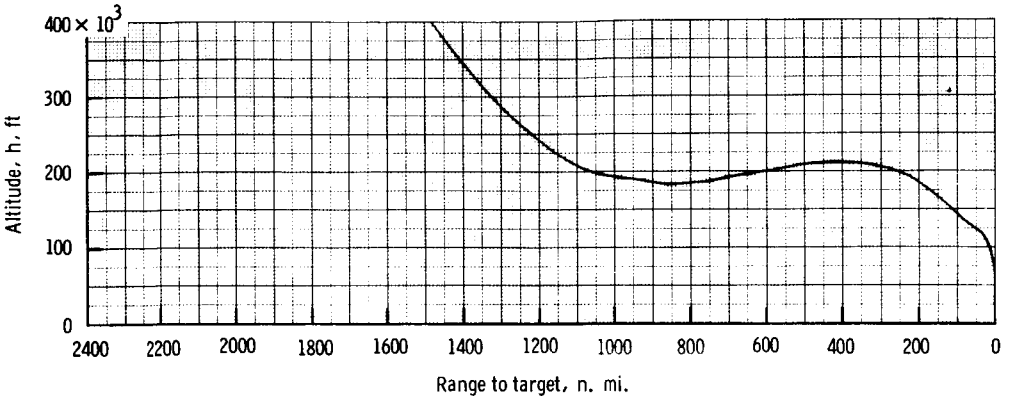
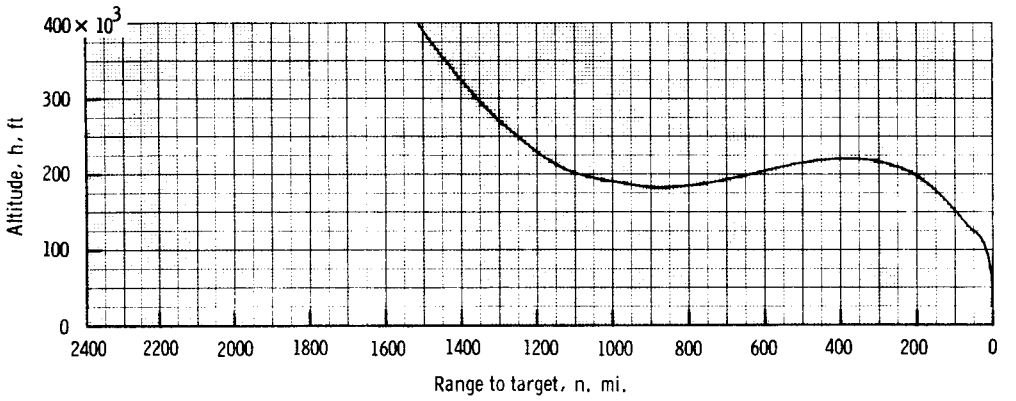


(c) L/D .44

Figure 4. - Communications blackout region for lunar returns with entry range of 1500 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34



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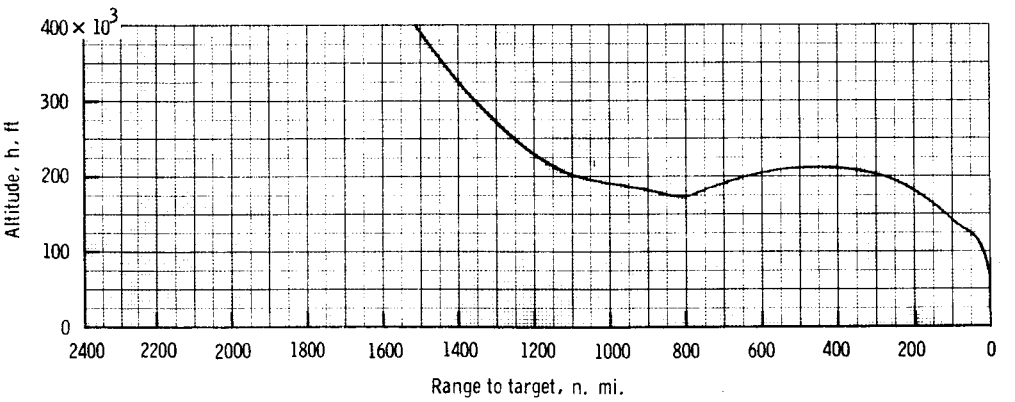
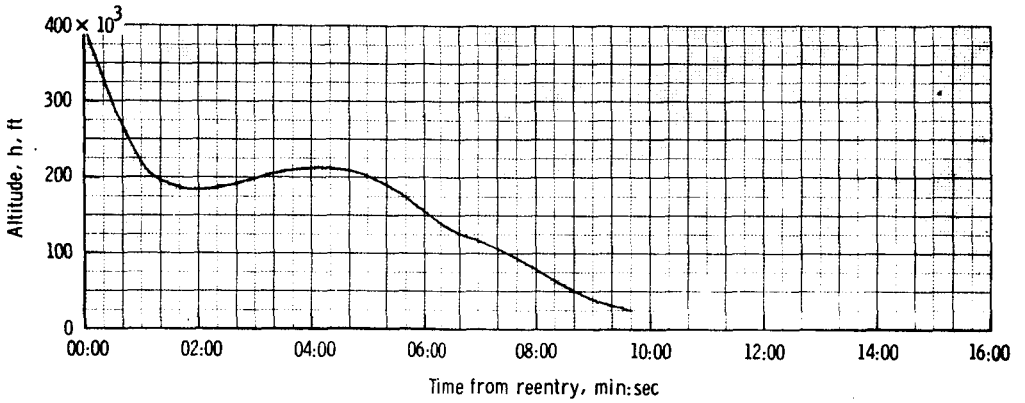
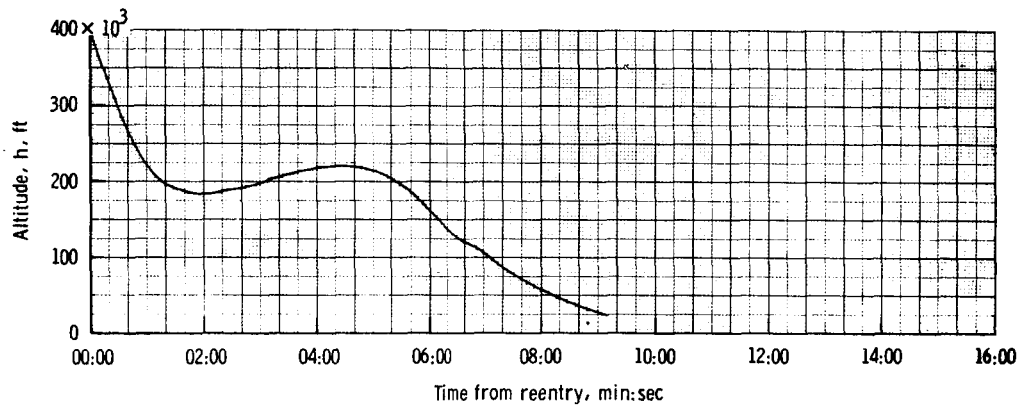


(c) L/D .44

Figure 5.- Altitude versus range with a range of 1500 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34



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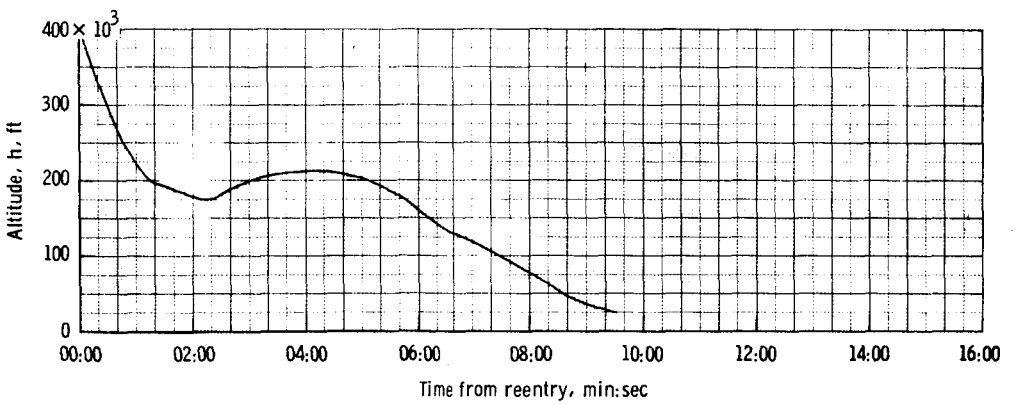
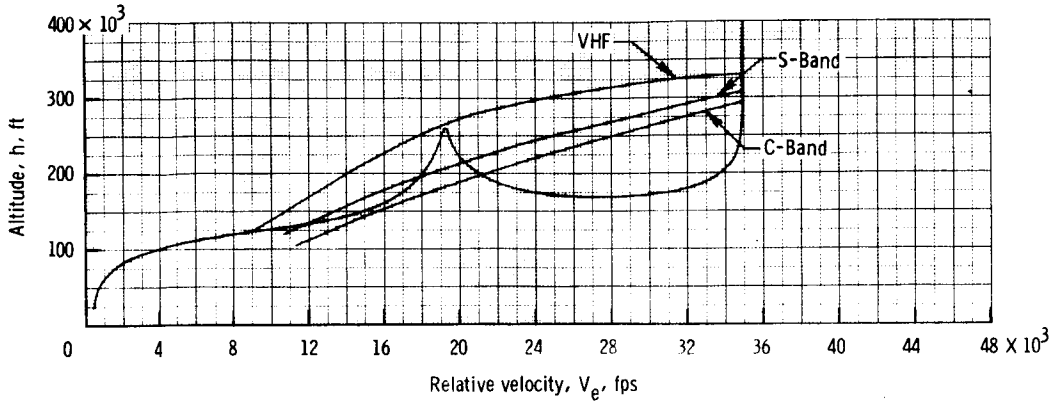
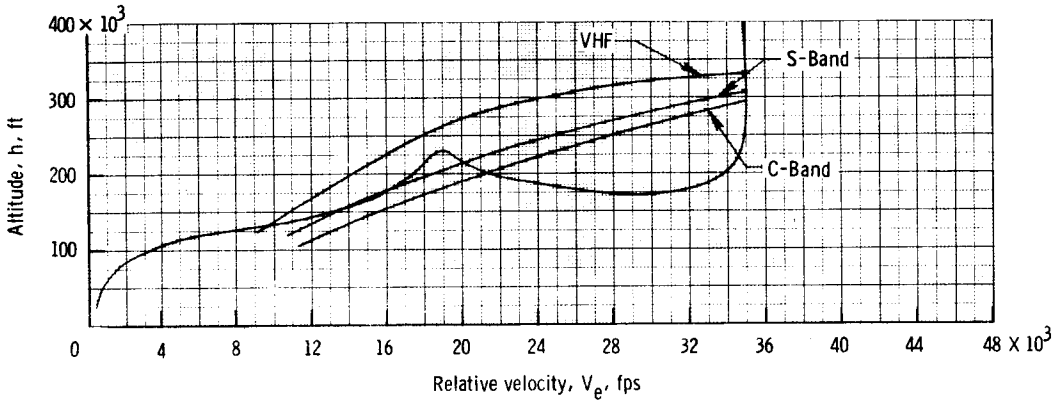


(c) L/D .44

Figure 6. - Altitude versus time from reentry with reentry range of 1500 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34



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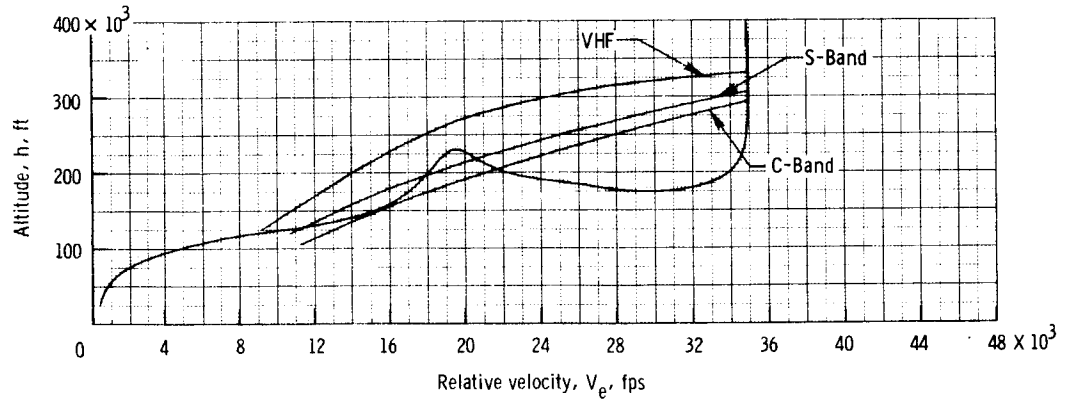

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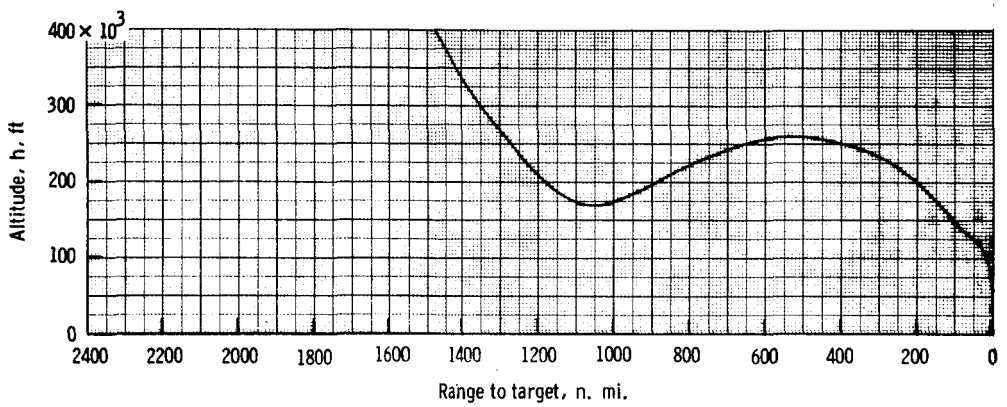
Figure 7. - Communications blackout region for lunar returns with entry range of 1500 nautical miles and a flight-path angle of -7.34 degrees.



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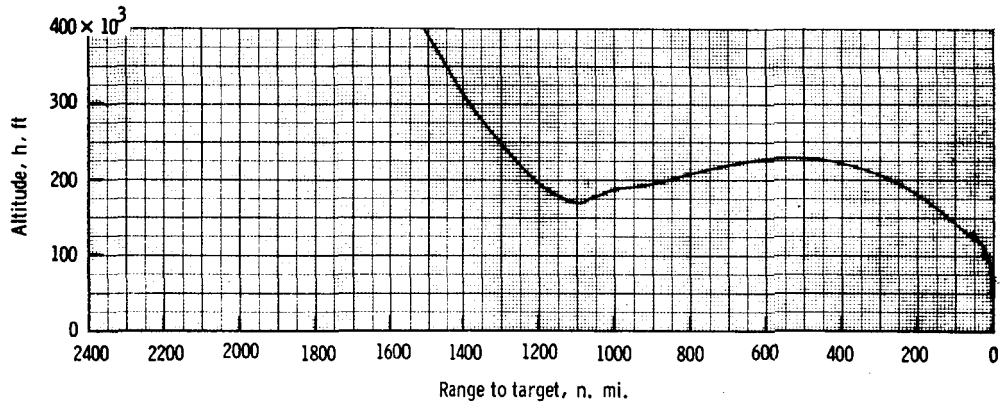

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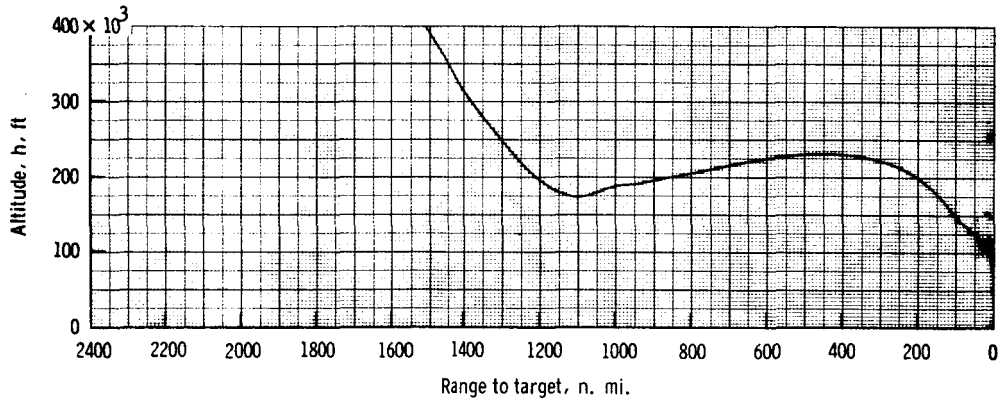

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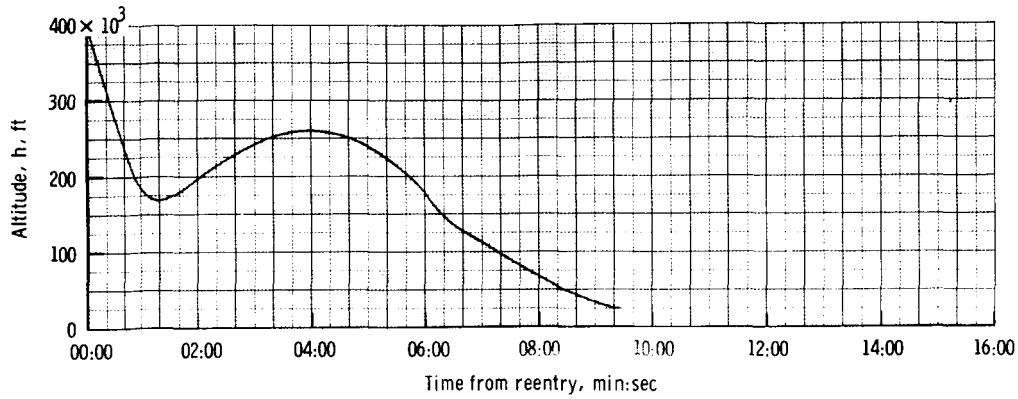
Figure 8. - Altitude versus range with a range of 1500 nautical miles and a flight-path angle of -7.34 degrees.



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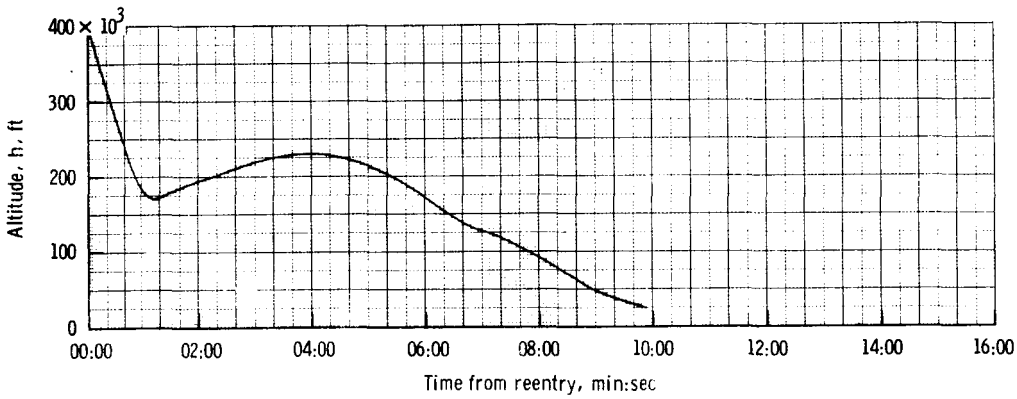

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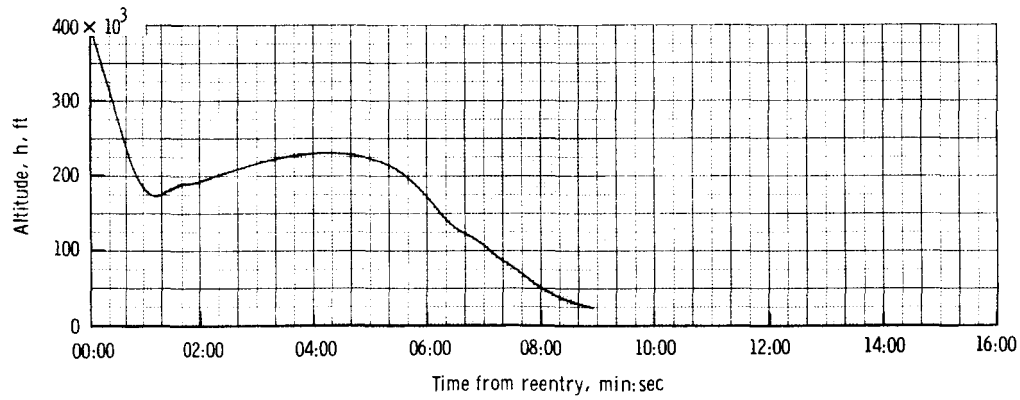

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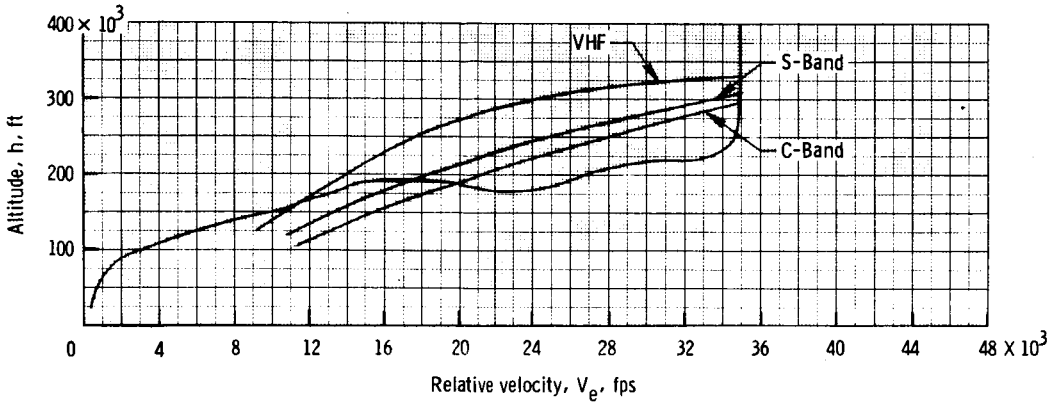
Figure 9.- Altitude versus time from reentry with reentry range of 1500 nautical miles and a flight-path angle of -7.34 degrees.



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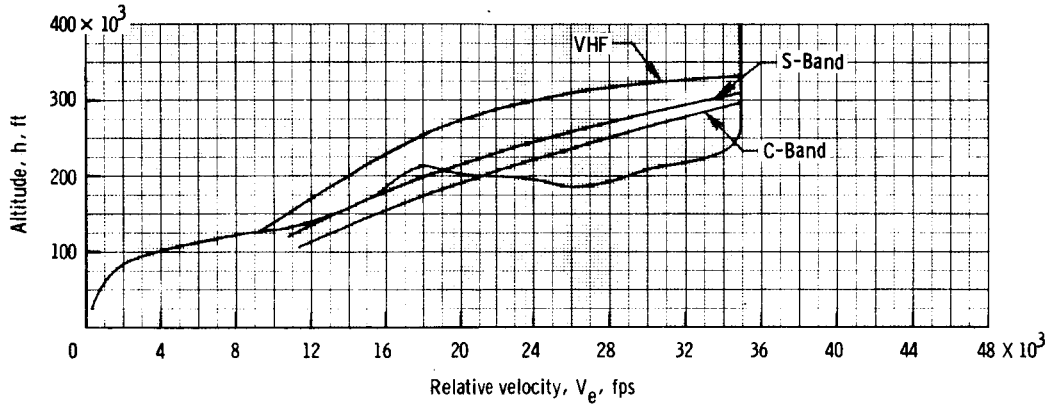

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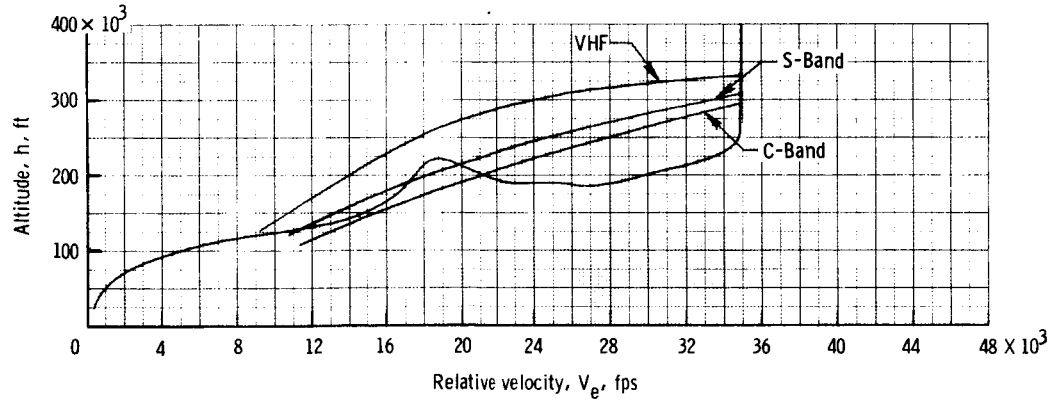
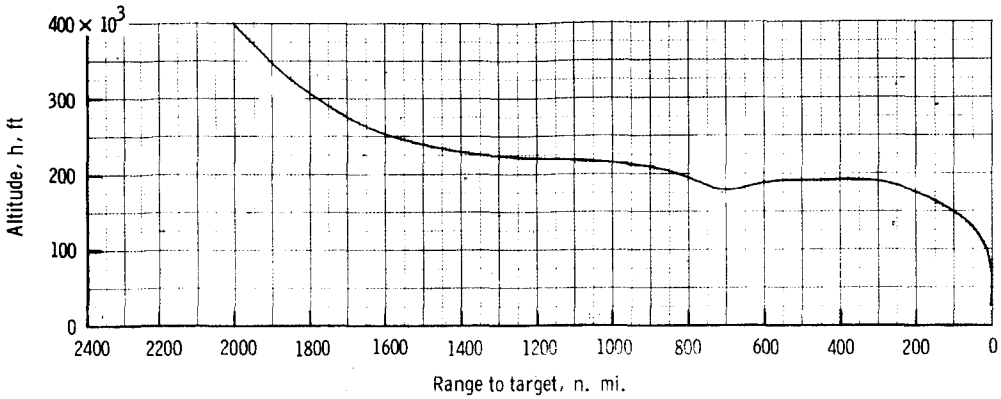


(c) L/D .44

Figure 10. - Communications blackout region for lunar returns with entry range of 2000 nautical miles and a flight-path angle of -5.0 degrees.



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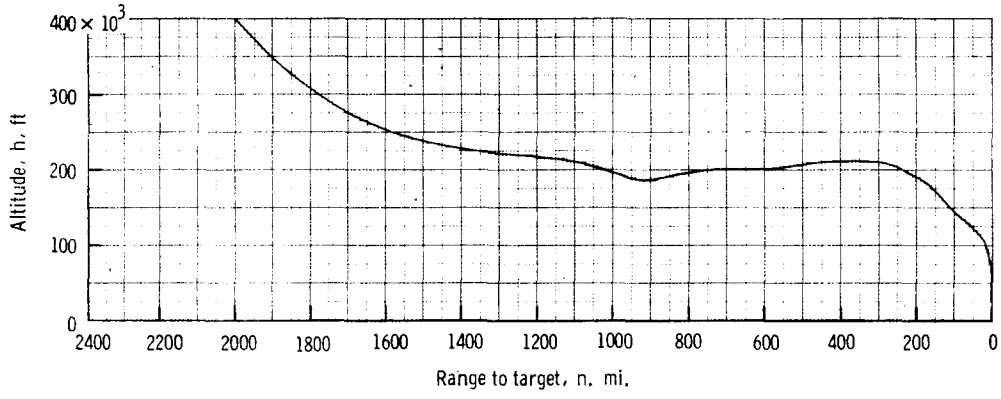

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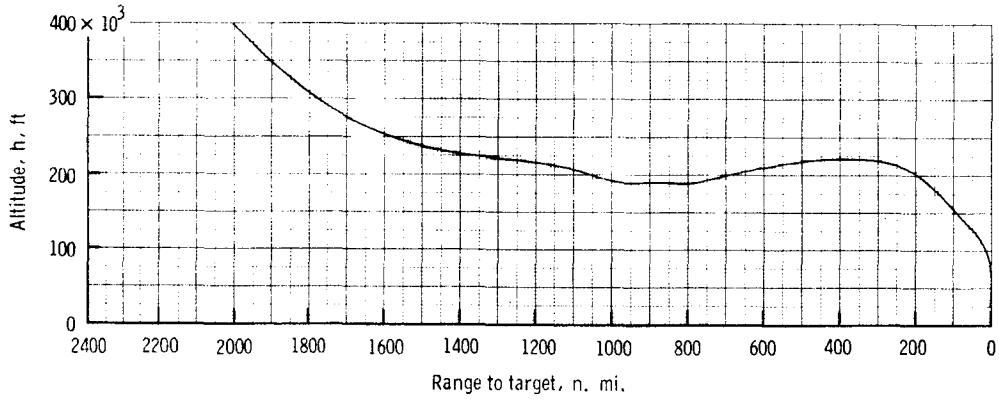
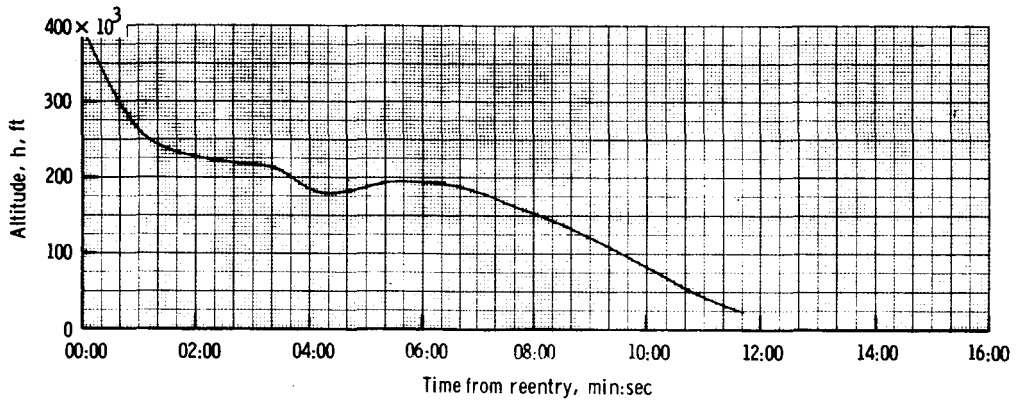


(c) L/D .44

Figure 11. - Altitude versus range with a range of 2000 nautical miles and a flight-path angle of -5.0 degrees.



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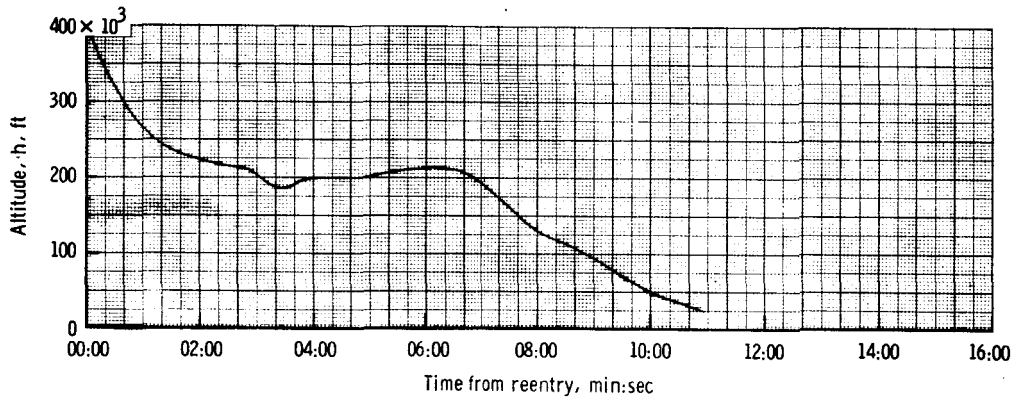

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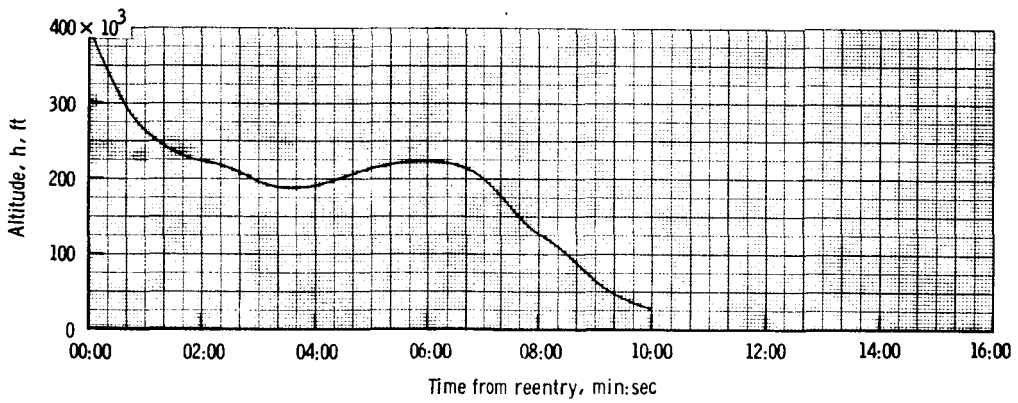
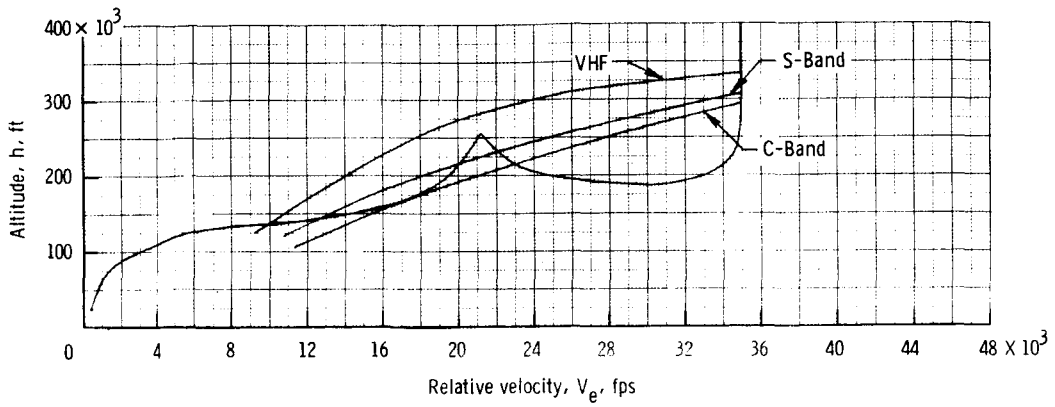
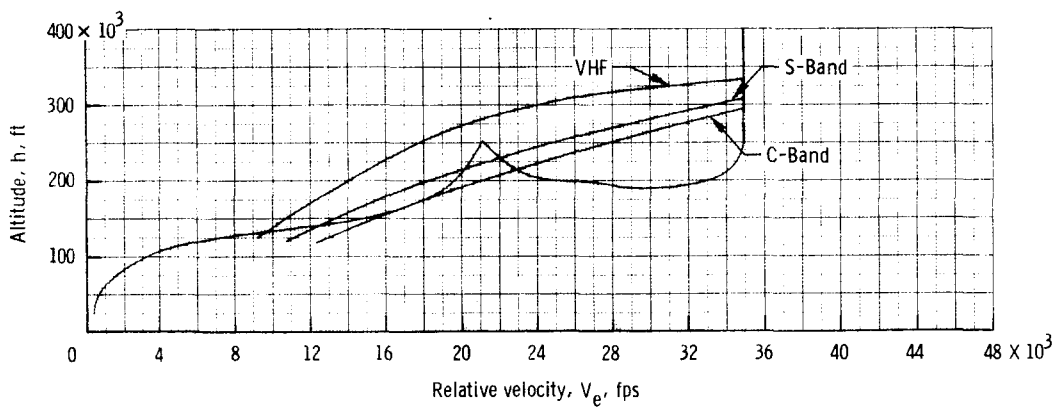


(c) L/D .44

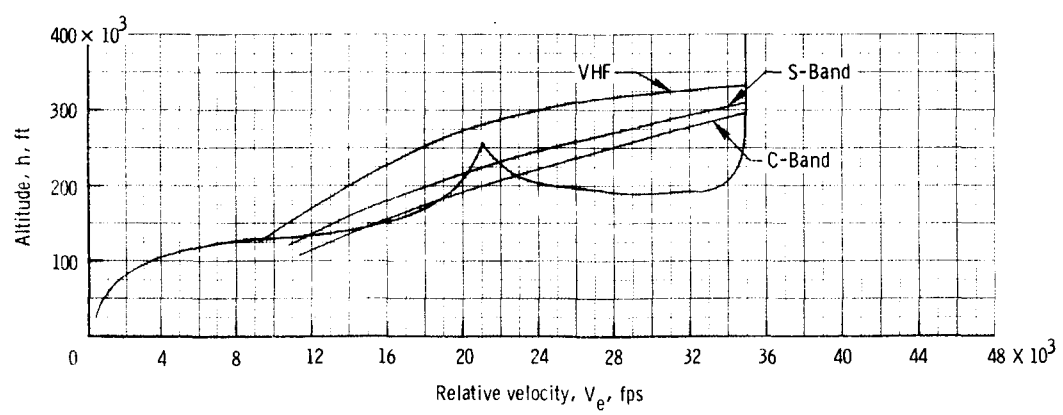
Figure 12. - Altitude versus time from reentry with reentry range of 2000 nautical miles and a flight-path angle of -5.0 degrees.



(a) L/D .34

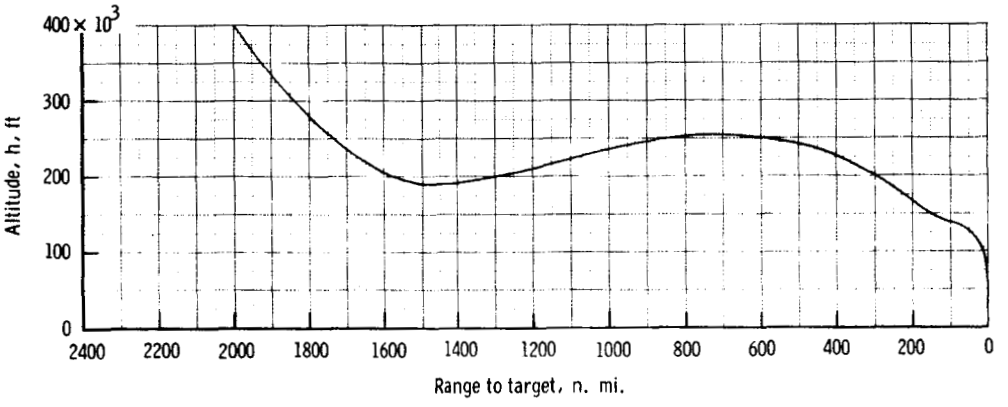


(b) L/D .39

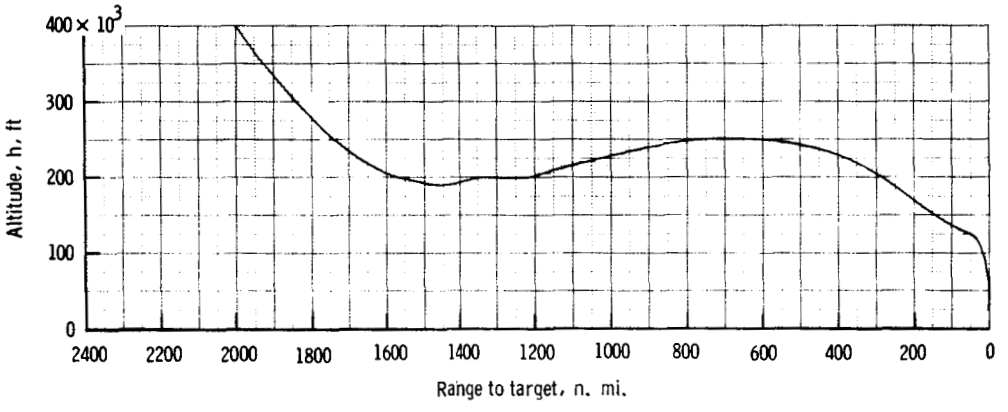


(c) L/D .44

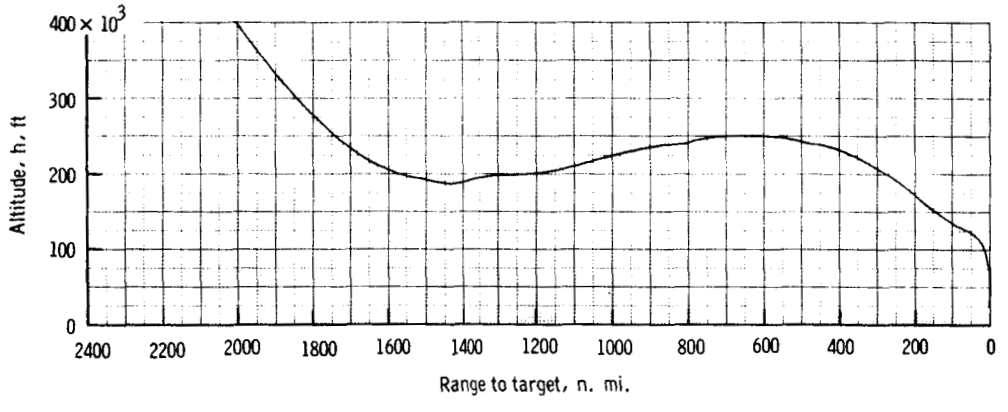
Figure 13. - Communications blackout region for lunar returns with entry range of 2000 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34

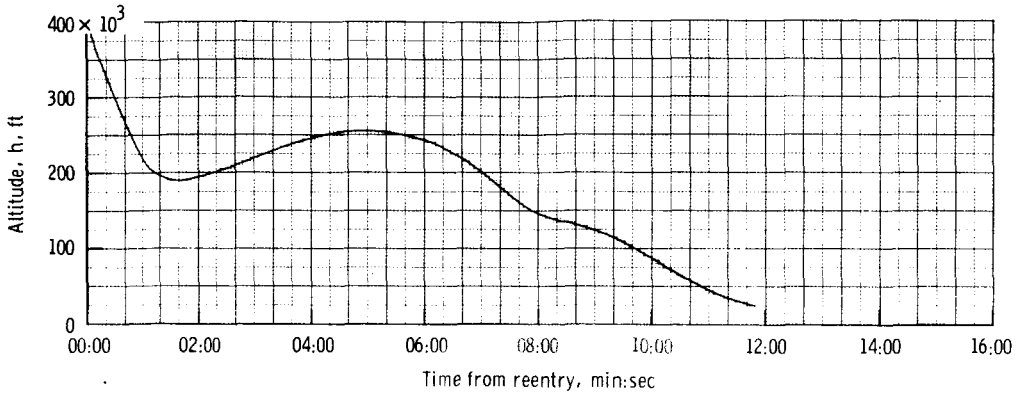


(b) L/D .39

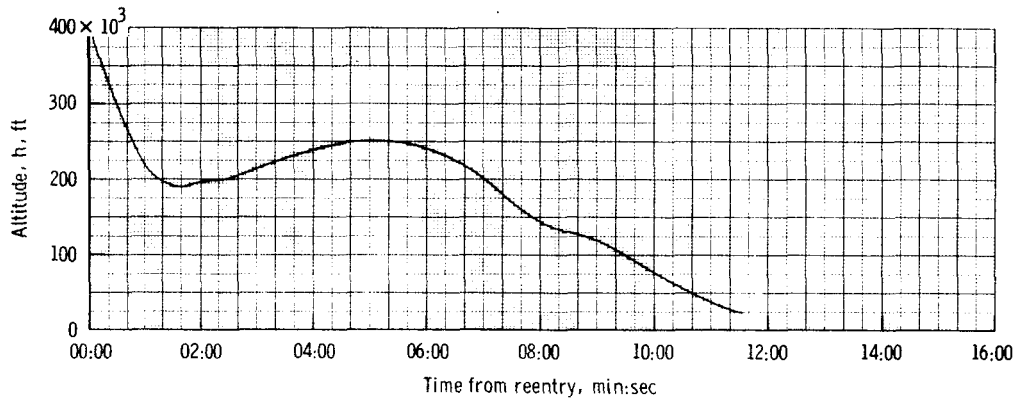


(c) L/D .44

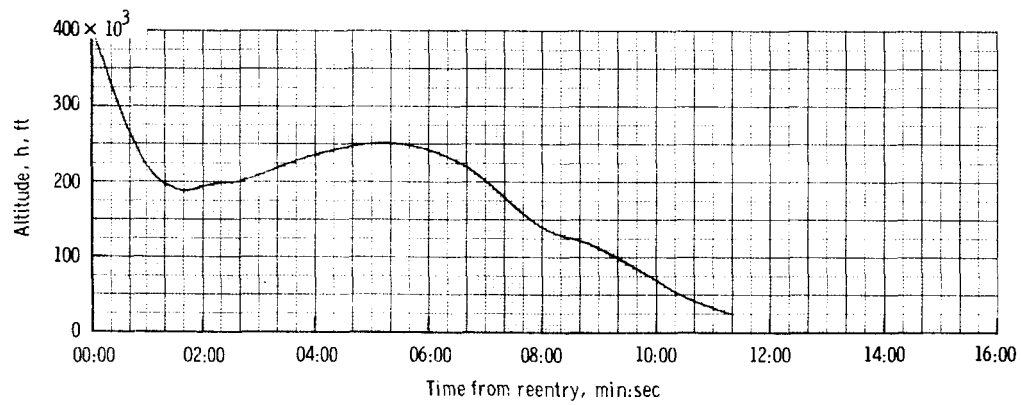
Figure 14.- Altitude versus range with a range of 2000 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34

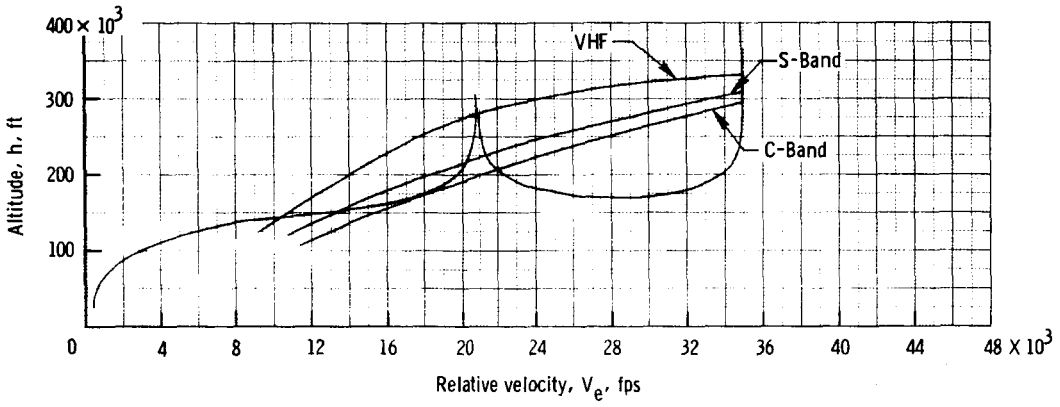


(b) L/D .39

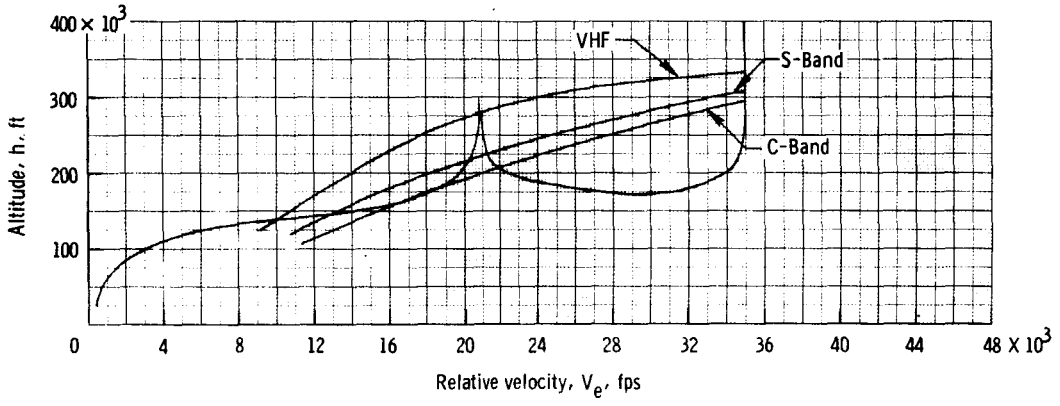


(c) L/D .44

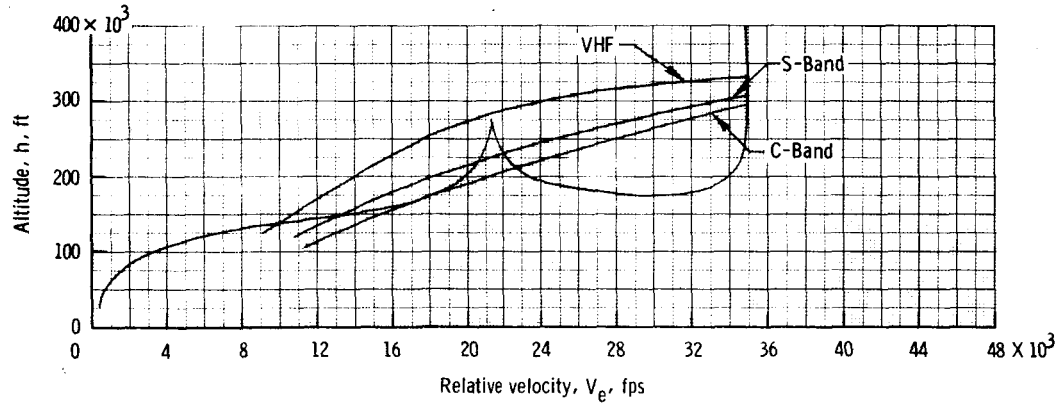
Figure 15. - Altitude versus time from reentry with reentry range of 2000 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34

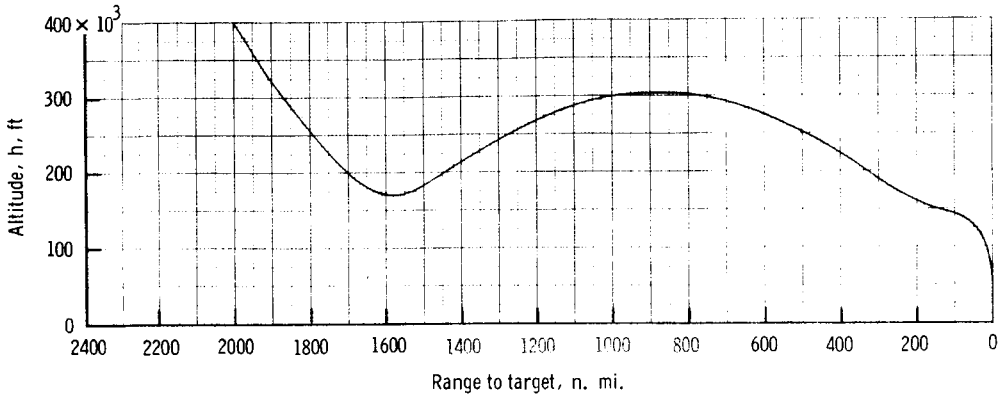


(b) L/D .39

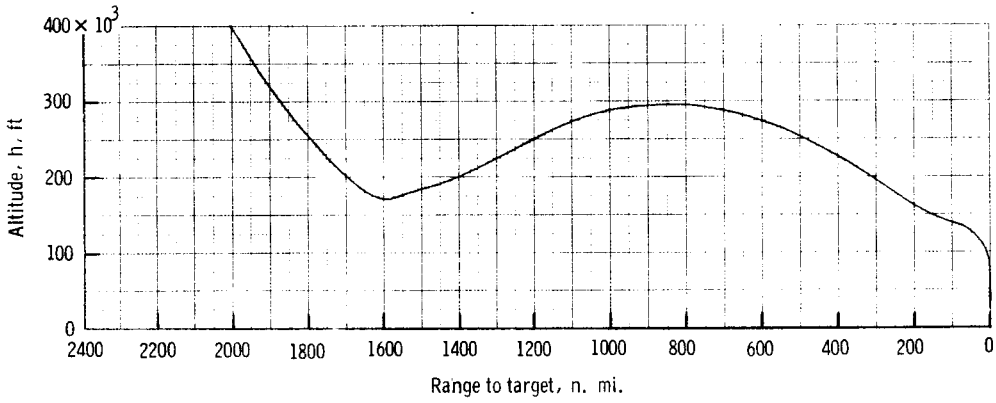


(c) L/D .44

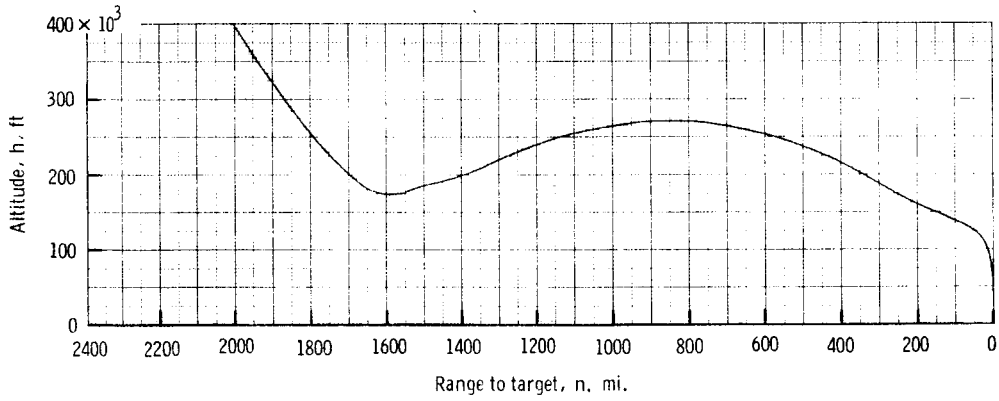
Figure 16. - Communications blackout region for lunar returns with entry range of 2000 nautical miles and a flight-path angle of -7.34 degrees.



(a) L/D .34

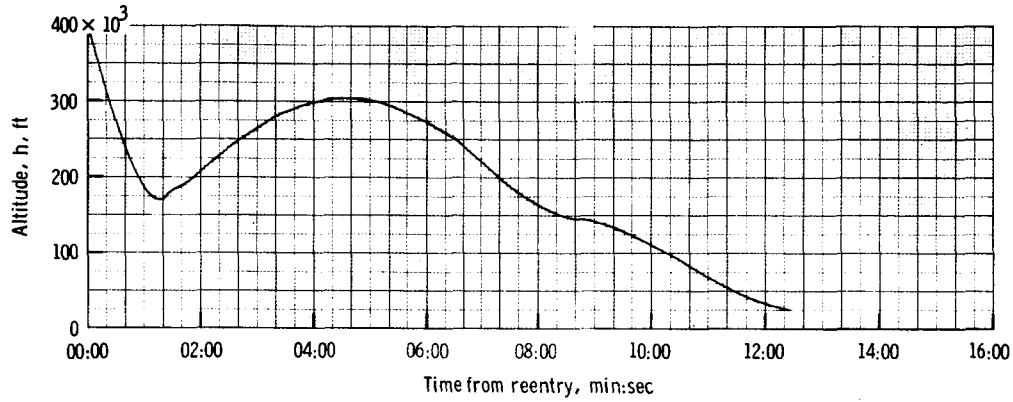


(b) L/D .39

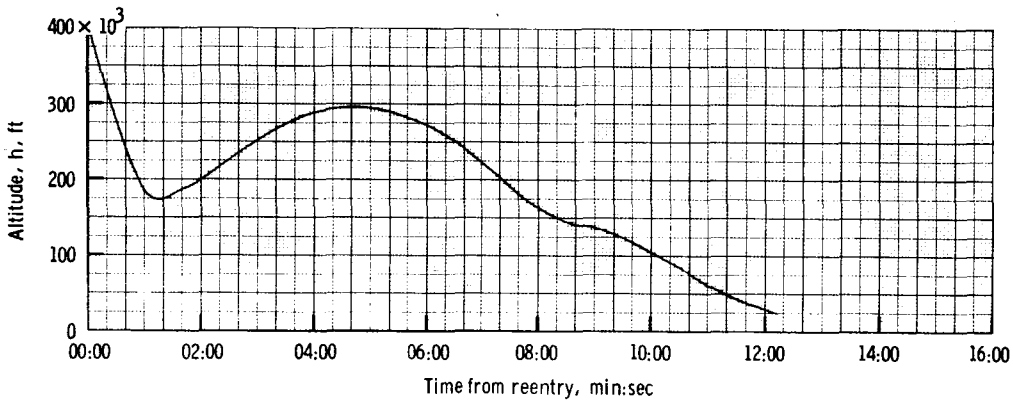


(c) L/D .44

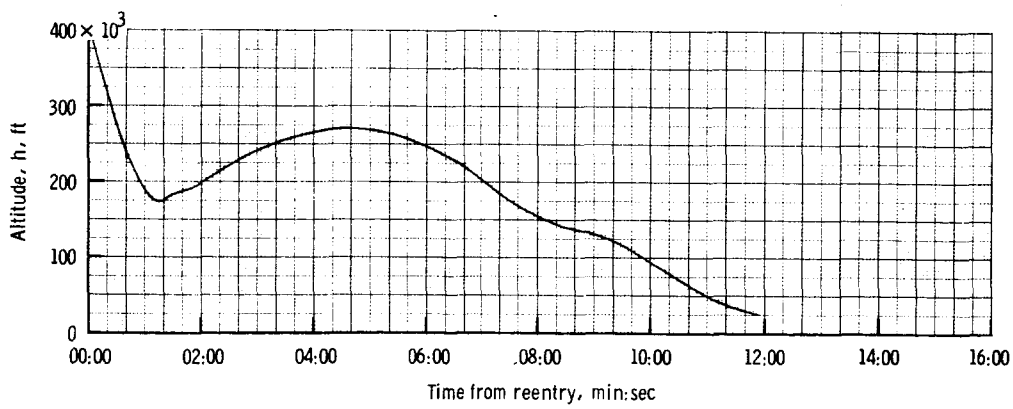
Figure 17. - Altitude versus range with a range of 2000 nautical miles and a flight-path angle of -7.34 degrees.



(a) L/D .34

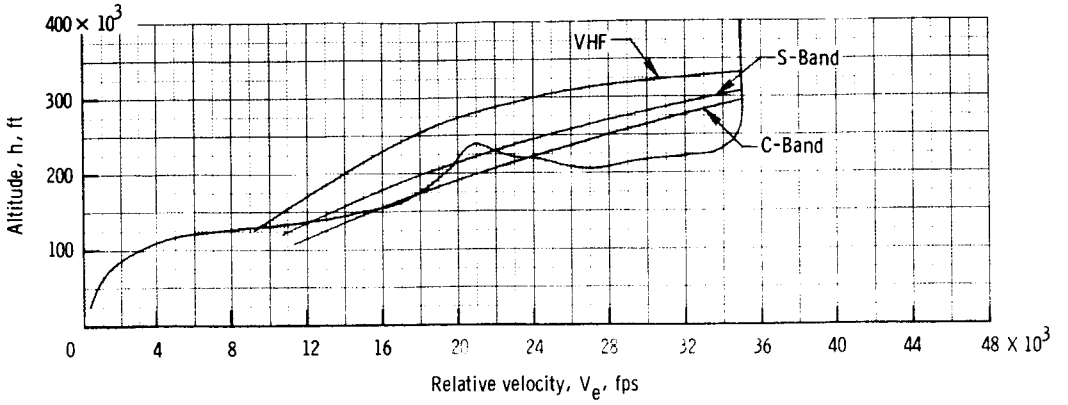


(b) L/D .39

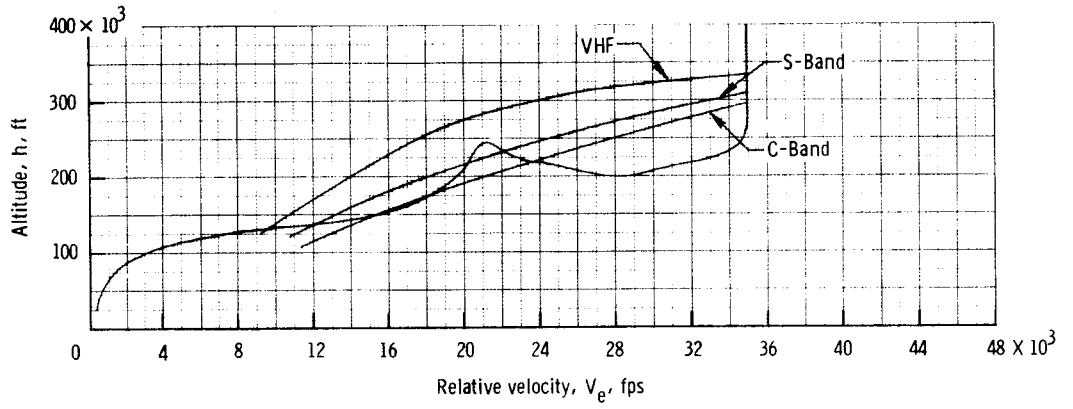


(c) L/D .44

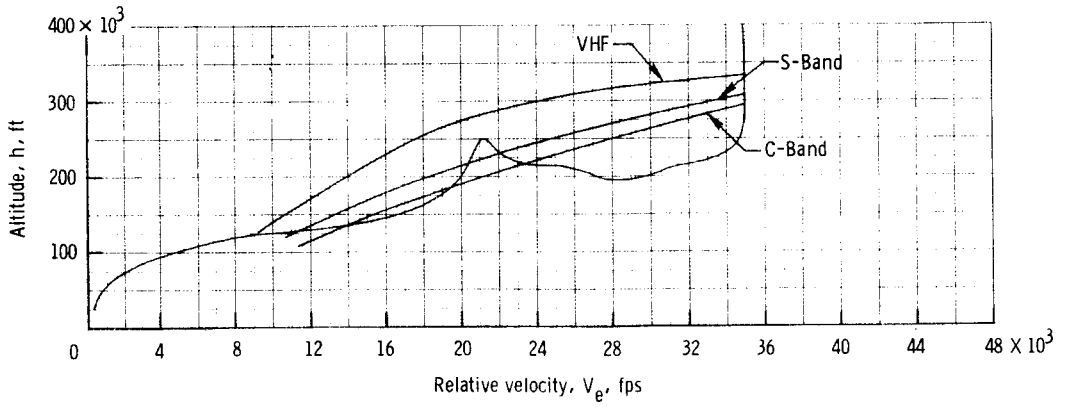
Figure 18. - Altitude versus time from reentry with reentry range of 2000 nautical miles and a flight-path angle of -7.34 degrees.



(a) L/D .34

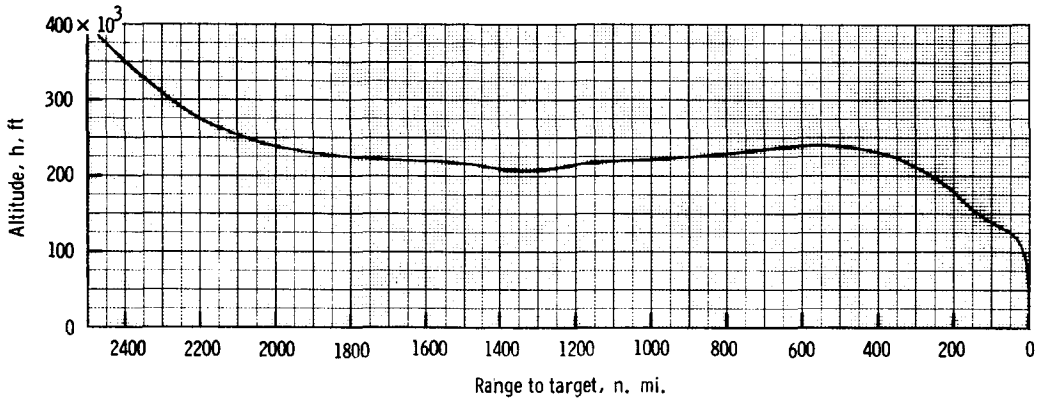


(b) L/D .39

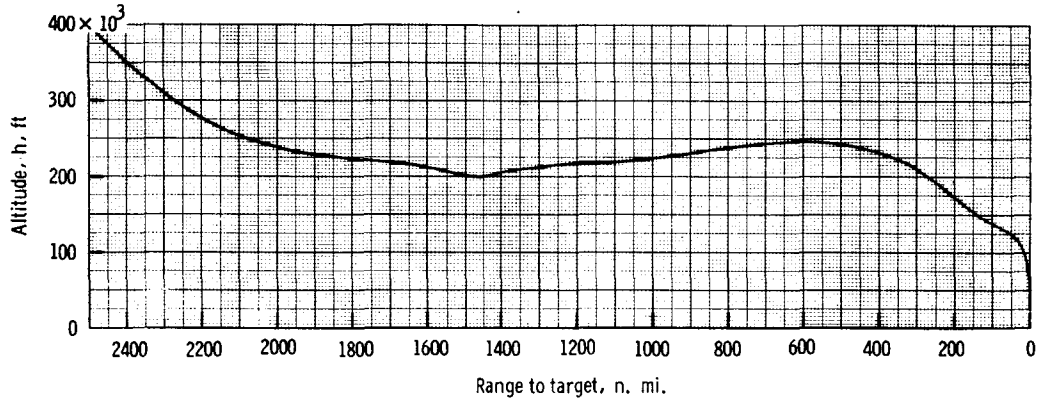


(c) L/D .44

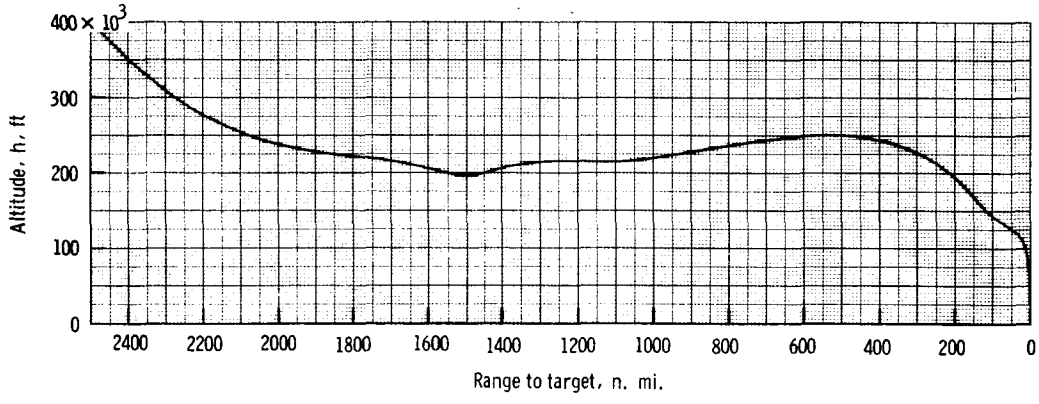
Figure 19. - Communications blackout region for lunar returns with entry range of 2500 nautical miles and a flight-path angle of -5.0 degrees.



(a) L/D .34

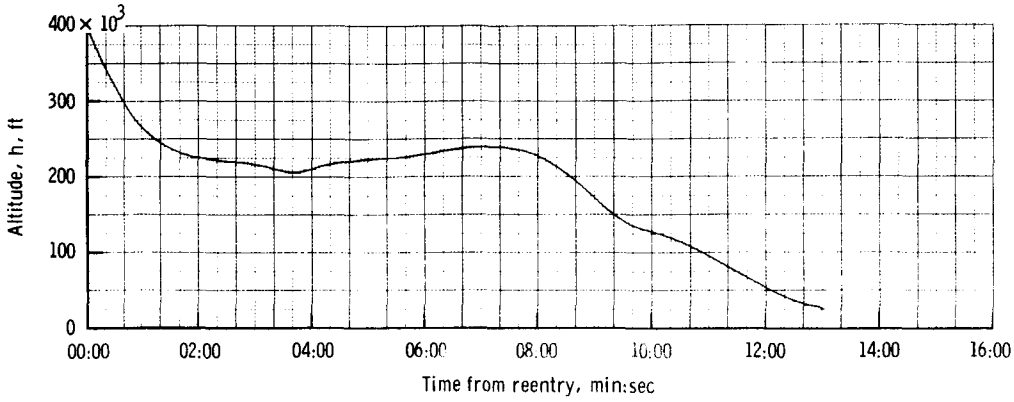


(b) L/D .39

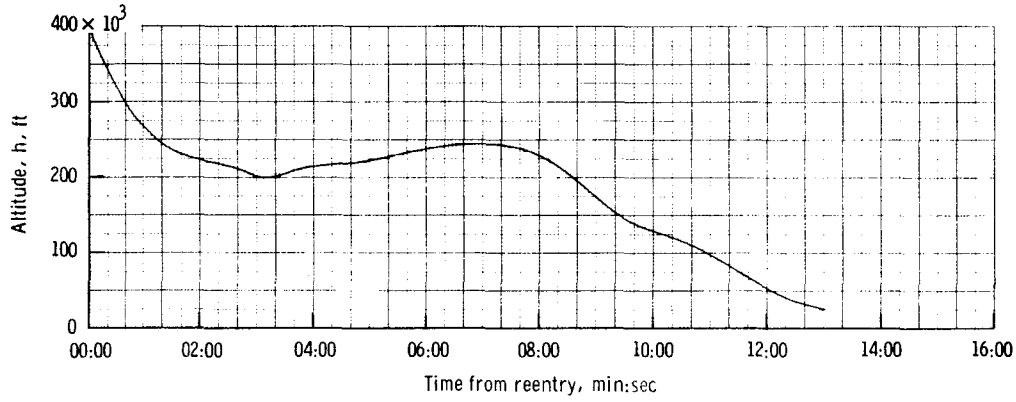


(c) L/D .44

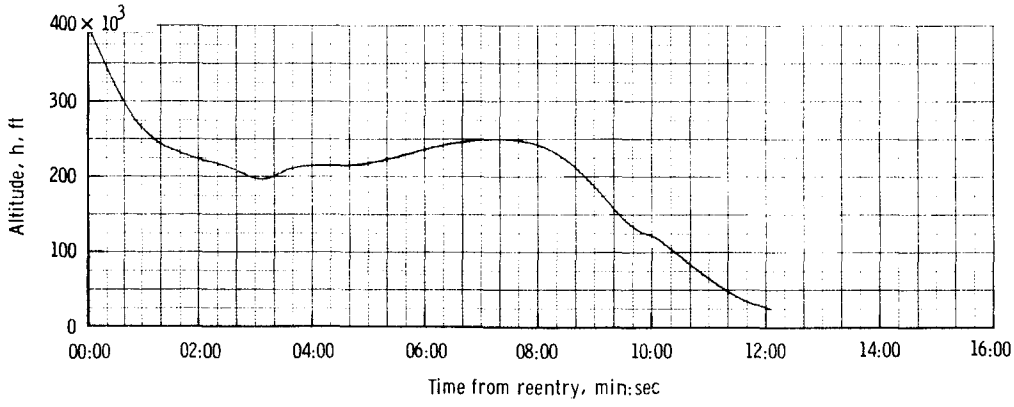
Figure 20. - Altitude versus range with a range of 2500 nautical miles and a flight-path angle of -5.0 degrees.



(a) L/D .34

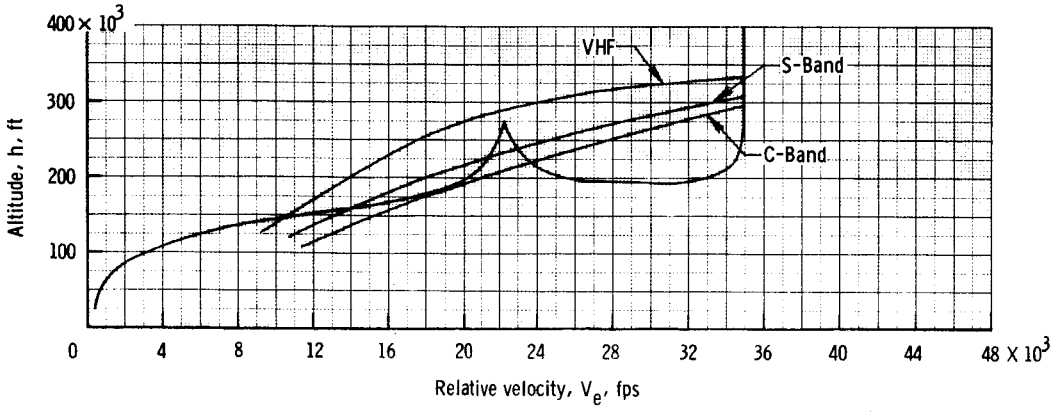


(b) L/D .39

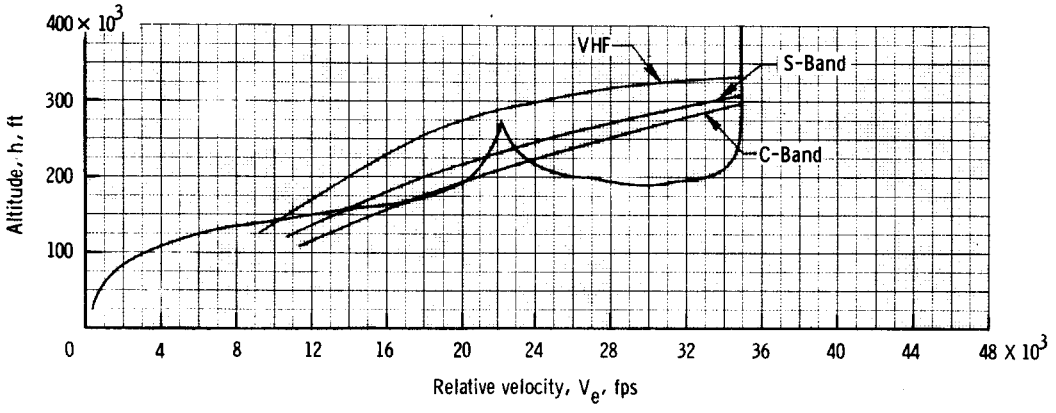


(c) L/D .44

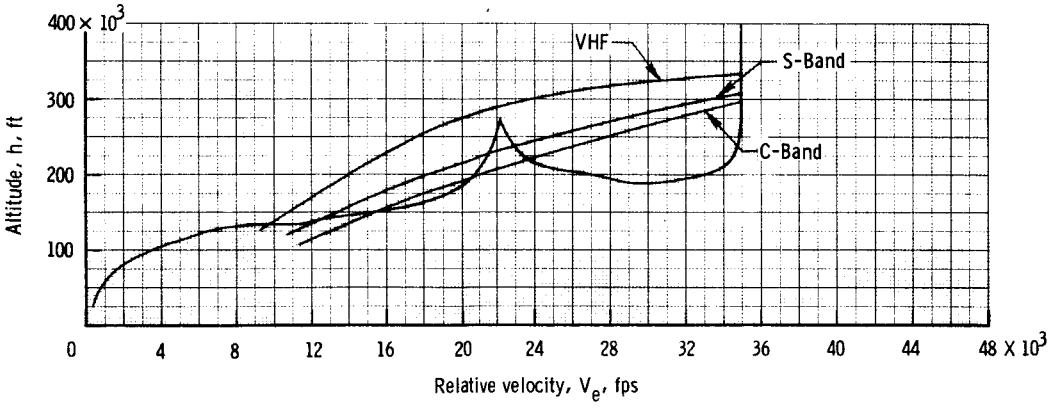
Figure 21. - Altitude versus time from reentry with reentry range of 2500 nautical miles and a flight-path angle of -5.0 degrees.



(a) L/D .34

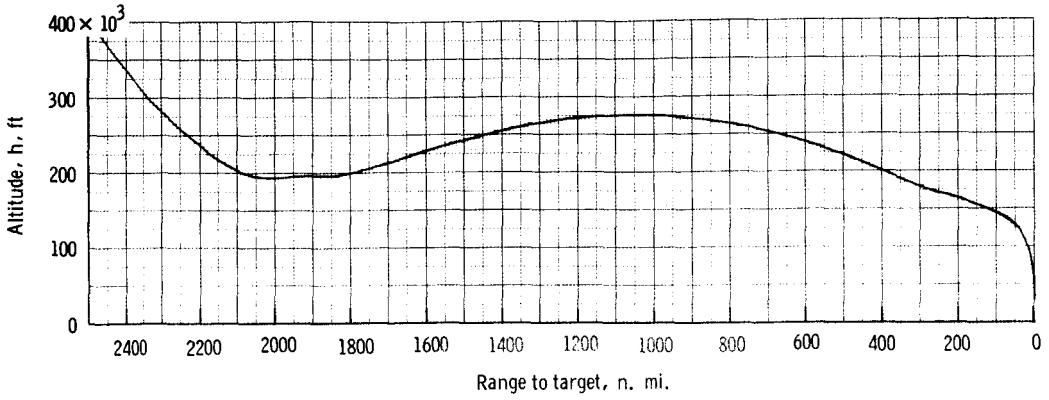


(b) L/D .39

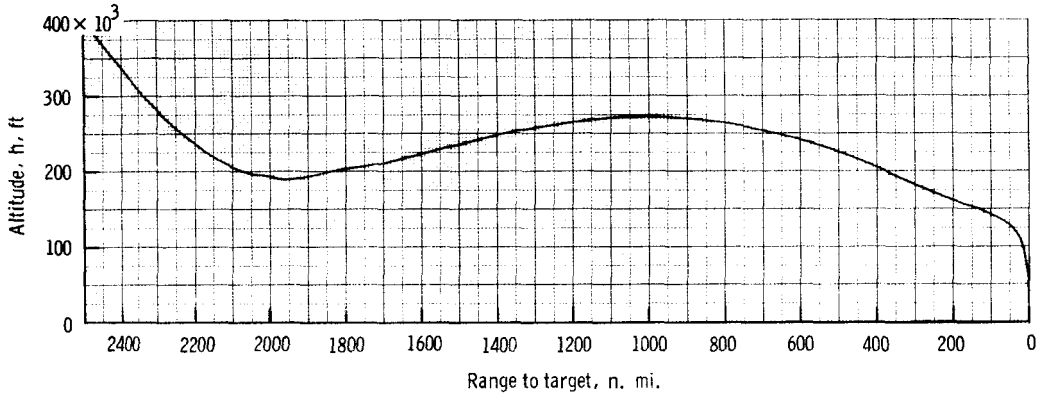


(c) L/D .44

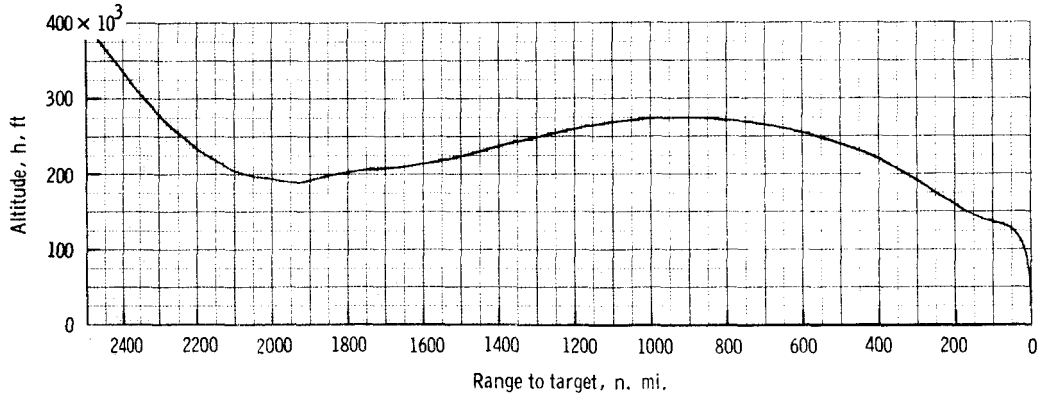
Figure 22. - Communications blackout region for lunar returns with entry range of 2500 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34

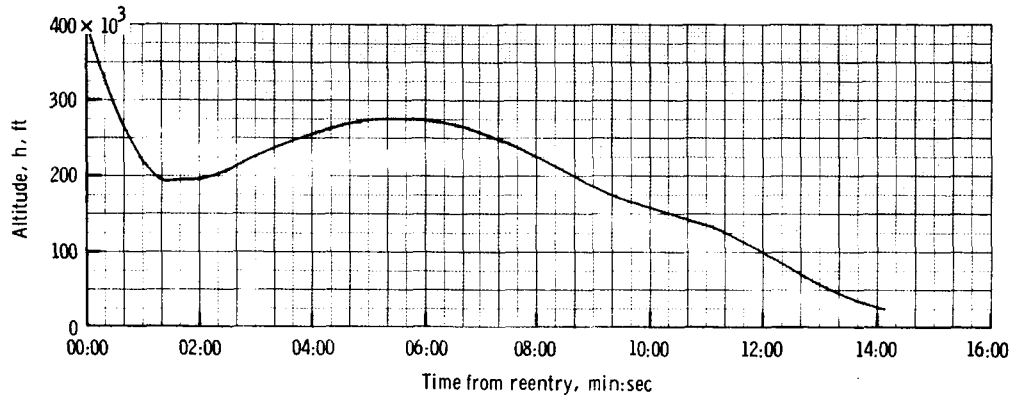


(b) L/D .39

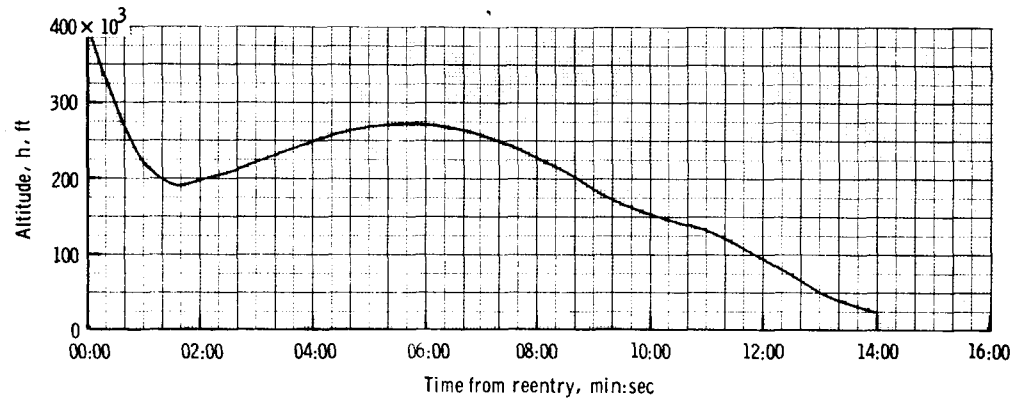


(c) L/D .44

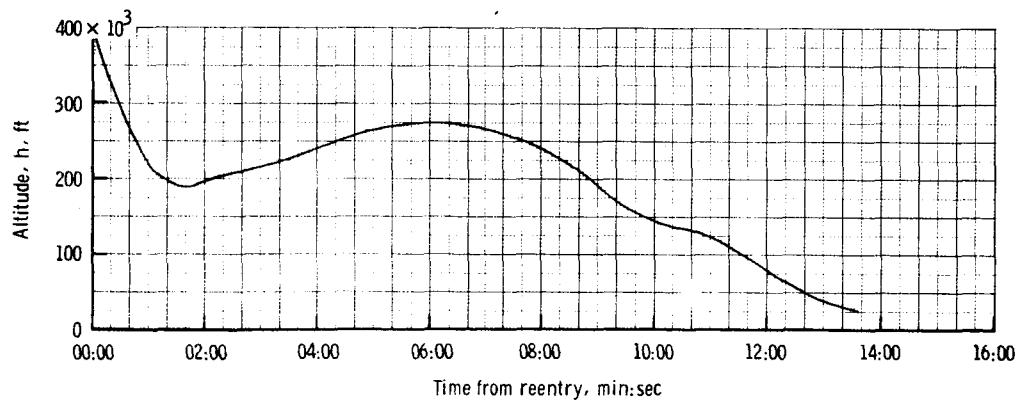
Figure 23. - Altitude versus range with a range of 2500 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34

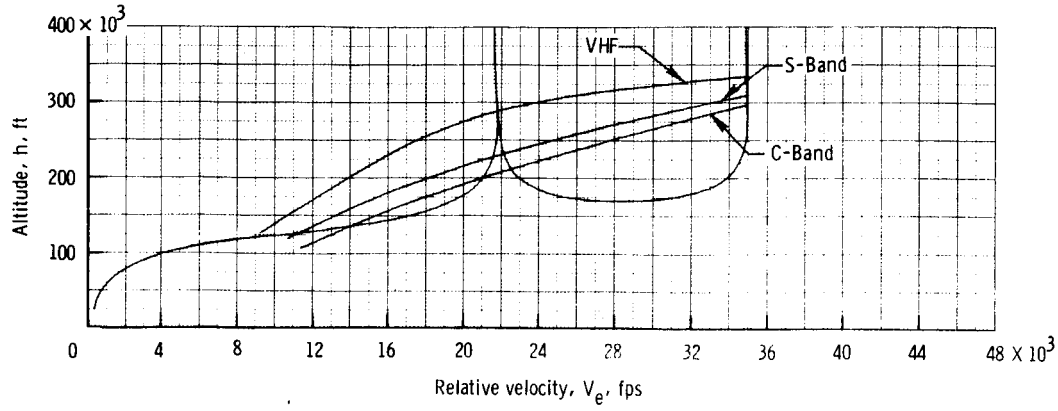


(b) L/D .39

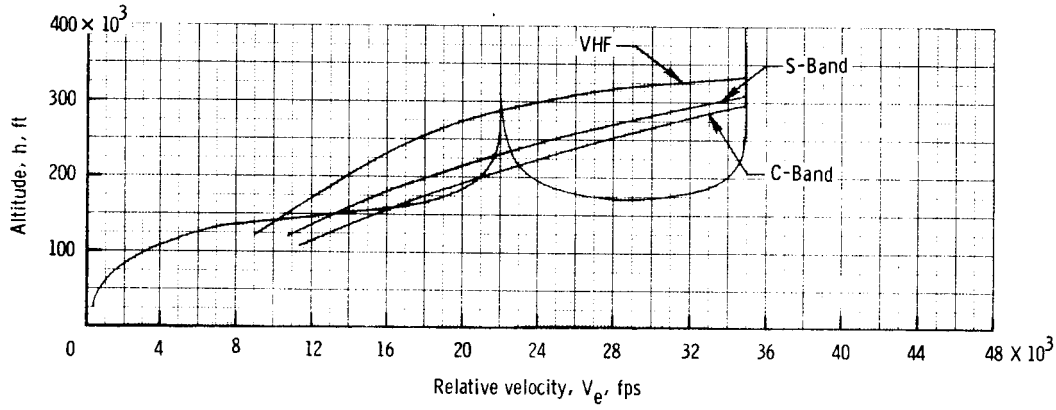


(c) L/D .44

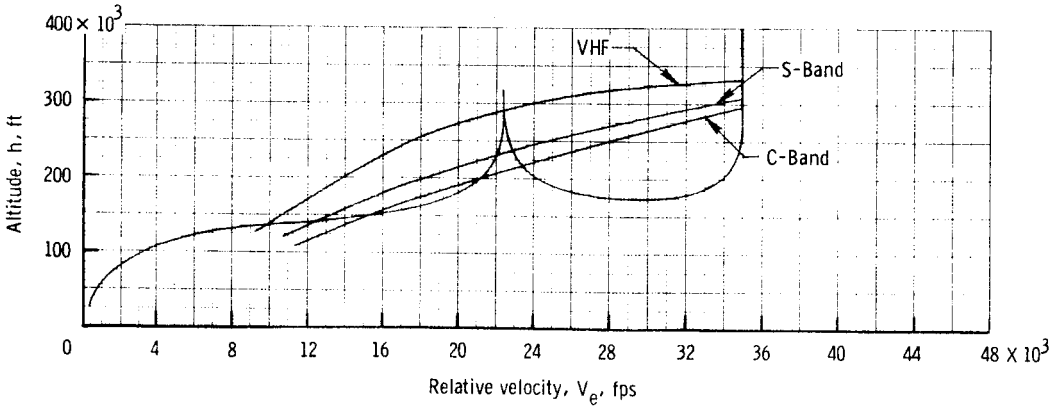
Figure 24. - Altitude versus time from reentry with reentry range of 2500 nautical miles and a flight-path angle of -6.25 degrees.



(a) L/D .34

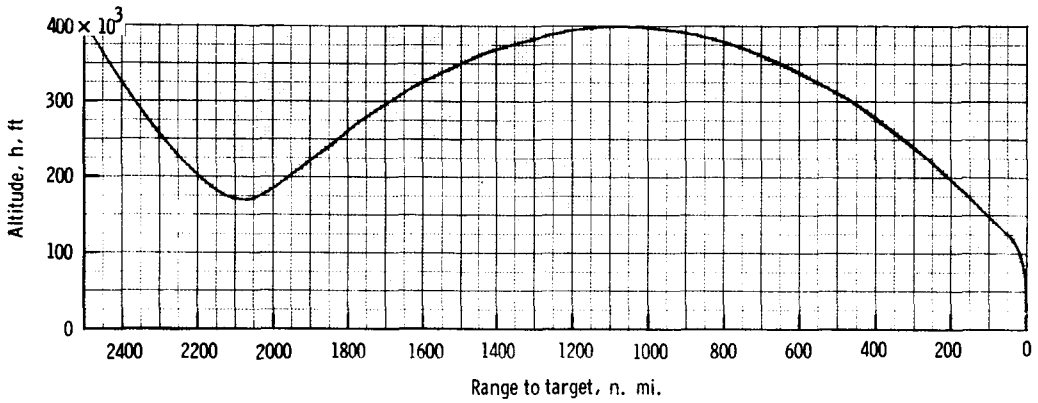


(b) L/D .39

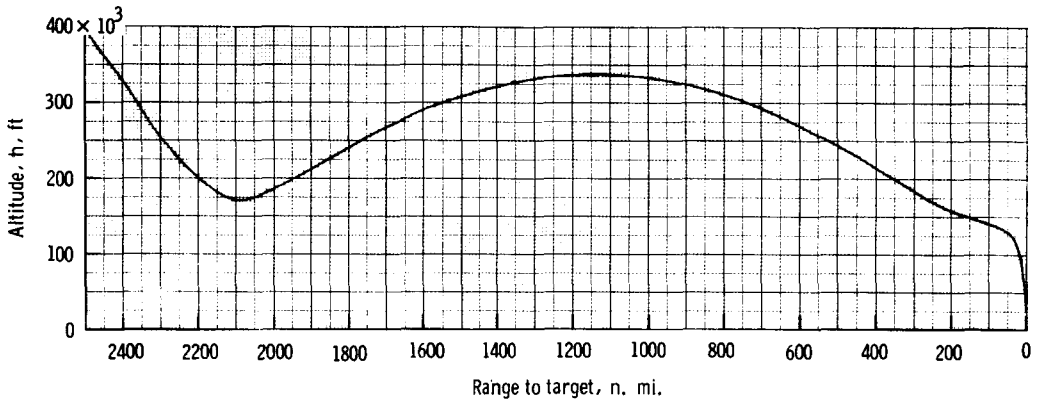


(c) L/D .44

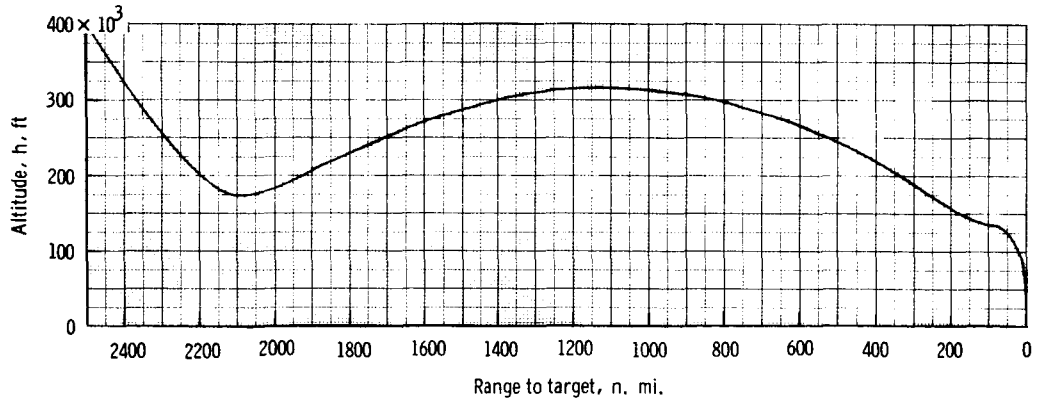
Figure 25. - Communications blackout region for lunar returns with entry range of 2500 nautical miles and a flight-path angle of -7.34 degrees.



(a) L/D .34

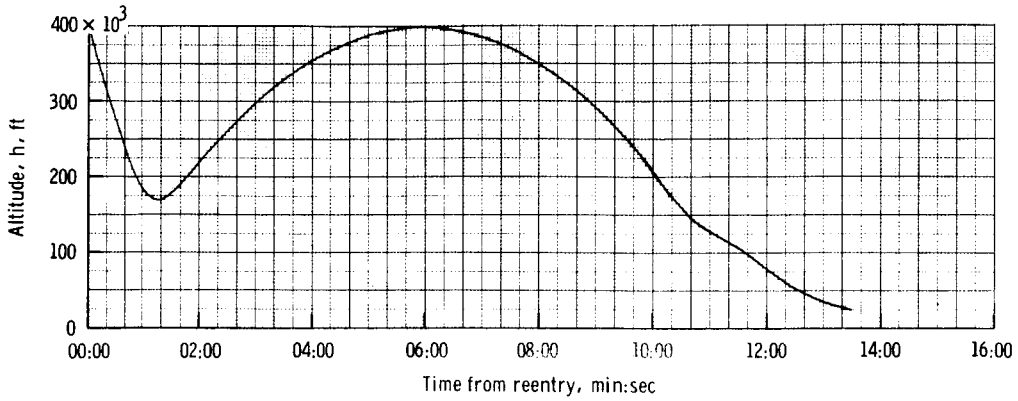


(b) L/D .39

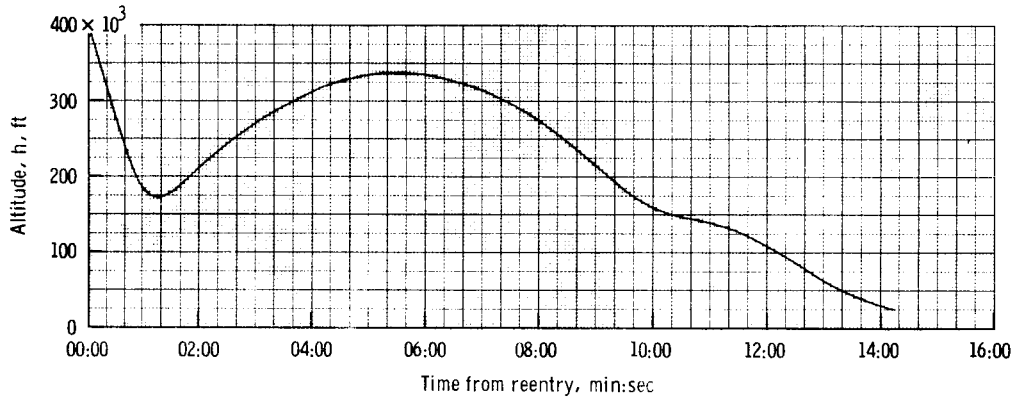


(c) L/D .44

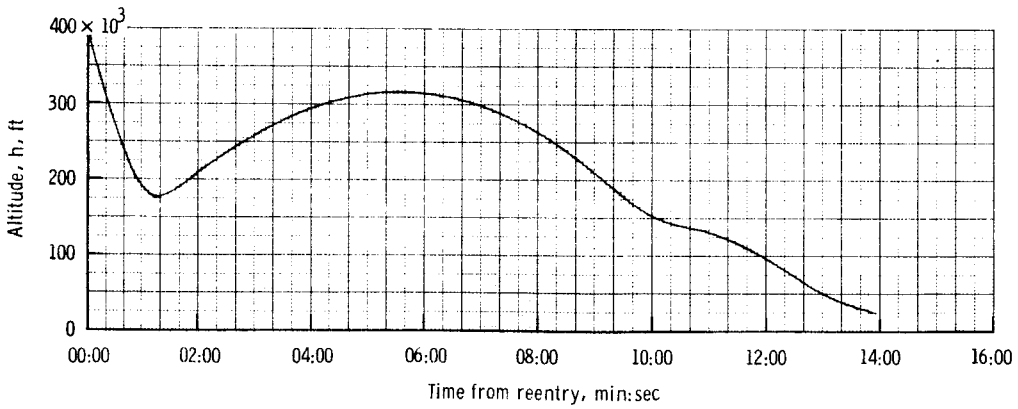
Figure 26. - Altitude versus range with a range of 2500 nautical miles and a flight-path angle of -7.34 degrees.



(a) L/D .34



(b) L/D .39



(c) L/D .44

Figure 27. - Altitude versus time from reentry with reentry range of 2500 nautical miles and a flight-path angle of -7.34 degrees.

TABLE I.--INITIAL BLACKOUT TIMES AND ALTITUDES

Entry flight-path angle, deg	C-band blackout		S-band blackout		VHF blackout	
	Time from 400 000 ft, sec	Altitude, ft	Time from 400 000 ft, sec	Altitude, ft	Time from 400 000 ft, sec	Altitude, ft
-5.0	42	295 000	35	308 000	24	332 000
-6.25	31	295 000	26	308 000	20	332 000
-7.34	25	295 000	22	308 000	16	332 000

TABLE II.--ACQUISITION TIMES AND ALTITUDE DURING SKIP PHASE

Entry flight-path angle, deg	Range, n. mi.	Lift/drag, n. d.	Acquisition		Loss	
			Time from 400 000 ft, min:sec	Altitude, ft	Time from 400 000 ft, min:sec	Altitude, ft
a. C-band						
-6.25	2000	.44	3:14	214 000	7:18	182 000
-7.34	2000	.39	2:08	207 000	7:42	180 000
-5.00	2500	.34	4:36	220 000	9:00	172 000
-5.00	2500	.39	4:48	220 000	8:58	176 000
-5.00	2500	.44	4:52	217 000	9:02	187 000
-6.25	2500	.39	3:00	222 000	8:52	193 000
-6.25	2500	.44	3:12	220 000	8:56	196 000
-7.34	2500	.34	1:55	212 000	10:04	200 000
-7.34	2500	.39	2:08	215 000	9:16	198 000
-7.34	2500	.44	2:08	217 000	9:10	200 000
b. S-band						
-6.25	1500	.39	3:30	210 000	5:45	180 000
-7.34	1500	.34	2:22	215 000	5:48	195 000
-7.34	1500	.39	2:48	215 000	5:50	180 000
-7.34	1500	.44	3:08	219 000	5:42	196 000
-5.00	2000	.44	5:05	215 000	7:09	191 000

TABLE II.--ACQUISITION TIMES AND ALTITUDE DURING SKIP PHASE - Concluded

Entry flight-path angle, deg	Range, n. mi.	Lift/drag, n. d.	Acquisition		Loss	
			Time from 400 000 ft, min:sec	Altitude, ft	Time from 400 000 ft, min:sec	Altitude, ft
b. S-band - Concluded						
-6.25	2000	.34	3:25	232 000	6:44	215 000
-6.25	2000	.39	3:37	231 000	6:43	216 000
-6.25	2000	.44	3:46	231 000	6:40	218 000
-7.34	2000	.34	2:16	225 000	7:05	215 000
-7.34	2000	.39	2:29	225 000	7:07	216 000
-7.34	2000	.44	2:44	232 000	6:42	218 000
-5.00	2500	.34	5:56	229 000	8:13	218 000
-5.00	2500	.39	5:40	233 000	8:16	218 000
-5.00	2500	.44	5:44	231 000	8:33	218 000
-6.25	2500	.34	3:24	239 000	7:56	228 000
-6.25	2500	.39	3:36	238 000	8:00	227 000
-6.25	2500	.44	3:56	238 000	8:20	228 000
-7.34	2500	.34	2:09	232 000	9:48	227 000
-7.34	2500	.39	2:20	234 000	8:48	228 000
-7.34	2500	.44	2:30	237 000	8:39	231 000
c. VHF-band						
-7.34	2500	.34	2:52	288 000	9:03	288 000
-7.34	2500	.39	3:23	288 000	7:42	288 000
-7.34	2500	.44	3:52	291 000	7:16	291 000

TABLE III.- FINAL ACQUISITION OF COMMUNICATIONS

Entry flight-path angle, deg	Range, n. mi.	Lift/drag, n. d.	C-band final acquisition		S-band final acquisition		VHF final acquisition	
			Time from 400 000 ft, min:sec	Altitude, ft	Time from 400 000 ft, min:sec	Altitude, ft	Time from 400 000 ft, min:sec	Altitude, ft
-5.00	1 500	.34	5:00	135 000	5:16	125 000	5:20	118 000
-5.00	1 500	.39	4:40	150 000	4:52	145 000	5:36	138 000
-5.00	1 500	.44	4:36	152 000	4:52	147 000	5:20	142 000
-6.25	1 500	.34	2:48	195 000	3:20	205 000	6:26	135 000
-6.25	1 500	.39	2:54	196 000	6:18	140 000	6:34	125 000
-6.25	1 500	.44	2:48	194 000	3:16	206 000	6:34	132 000
-7.34	1 500	.34	5:45	198 000	6:35	132 000	6:44	124 000
-7.34	1 500	.39	5:23	201 000	6:20	155 000	6:50	132 000
-7.34	1 500	.44	5:32	205 000	6:31	129 000	6:44	120 000
-5.00	2 000	.34	5:04	189 000	5:18	193 000	5:36	164 000
-5.00	2 000	.39	4:48	200 000	5:28	208 000	8:05	126 000
-5.00	2 000	.44	4:25	200 000	7:56	130 000	8:08	120 000
-6.25	2 000	.34	2:52	215 000	8:05	144 000	8:43	135 000
-6.25	2 000	.39	3:00	214 000	8:07	141 000	8:23	133 000
-6.25	2 000	.44	7:54	145 000	8:12	133 000	8:18	130 000
-7.34	2 000	.34	1:58	206 000	8:24	151 000	8:48	145 000
-7.34	2 000	.39	8:04	161 000	8:29	145 000	8:48	140 000
-7.34	2 000	.44	2:17	212 000	8:11	148 000	8:36	138 000
-5.00	2 500	.34	9:16	154 000	9:32	133 000	9:54	130 000
-5.00	2 500	.39	9:24	150 000	9:42	138 000	9:56	131 000
-5.00	2 500	.44	9:38	136 000	9:46	128 000	9:56	124 000
-6.25	2 500	.34	2:50	220 000	9:56	160 000	10:26	148 000
-6.25	2 500	.39	9:36	168 000	9:52	158 000	10:32	143 000
-6.25	2 500	.44	9:48	151 000	10:10	140 000	10:28	136 000
-7.34	2 500	.34	10:54	137 000	11:00	127 000	11:08	122 000
-7.34	2 500	.39	10:00	160 000	10:20	150 000	10:50	142 000
-7.34	2 500	.44	10:04	151 000	10:26	141 000	10:44	136 000

TABLE IV.--COMMUNICATION DURATION DURING SKIP PHASE

Entry flight-path angle, deg	Range, n. mi.	Lift/drag, n. d.	C-band communication duration, min:sec	S-band communication duration, min:sec	VHF communication duration, min:sec
-5.00	1500	.34	(a)	(a)	(a)
-5.00	1500	.39	(a)	(a)	(a)
-5.00	1500	.44	(a)	(a)	(a)
-6.25	1500	.34	(b)	(b)	(a)
-6.25	1500	.39	(b)	2:15	(a)
-6.25	1500	.44	(b)	(b)	(a)
-7.34	1500	.34	(b)	3:26	(a)
-7.34	1500	.39	(b)	3:02	(a)
-7.34	1500	.44	(b)	2:34	(a)
-5.00	2000	.34	(b)	(b)	(a)
-5.00	2000	.39	(b)	(b)	(a)
-5.00	2000	.44	(b)	2:04	(a)
-6.25	2000	.34	(b)	3:19	(a)
-6.25	2000	.39	(b)	3:06	(a)
-6.25	2000	.44	4:04	2:54	(a)
-7.34	2000	.34	(b)	4:49	(a)
-7.34	2000	.39	5:34	4:38	(a)
-7.34	2000	.44	(b)	3:58	(a)
-5.00	2500	.34	4:24	2:17	(a)
-5.00	2500	.39	4:10	2:36	(a)
-5.00	2500	.44	4:10	2:49	(a)
-6.25	2500	.34	(b)	4:32	(a)
-6.25	2500	.39	5:52	4:24	(a)
-6.25	2500	.44	5:44	4:24	(a)
-7.34	2500	.34	8:09	7:39	6:11
-7.34	2500	.39	7:08	6:28	4:19
-7.34	2500	.44	7:02	6:09	3:24

(a) The spacecraft does not leave the blackout region during the skip phase of this trajectory.

(b) In this case, the spacecraft leaves the blackout region during the skip phase and does not reenter the blackout region during the second entry phase.

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1. Morth, Raymond: Apollo Guidance and Navigation, MIT document R-532, January, 1966.

2. Lehnert, Richard; and Rosenbaum, Bernard: Plasma Effect on Apollo Reentry Communication, TN-2732, January, 1964.