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PROJECT APOLLO

LM POWERED DESCENT TRAJECTORY FOR THE APOLLO LUNAR LANDING MISSION

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SUMMARY AND INTRODUCTION

This report presents the LM powered descent trajectory for the Apollo lunar landing mission. This trajectory incorporates the revised weights and mission performance definition prescribed by the Apollo Spacecraft Program Office on December 12, 1967 and supersedes reference 1. These revisions did not require any major changes in the descent trajectory shaping or design concept.

Until recently lunar landing mission planning assumed a lunar parking orbit altitude of 80 n. mi. (ref. 1). A revised ΔV budget (ref. 2), resulting from updated weights and performance data (ref. 3), showed that the lunar parking orbit altitude should be reduced to 60 n. mi. This report reflects the 60-n. mi. orbit altitude and other significant changes including (1) an increase in the descent propulsion system (DPS) throttleable region, (2) an increase in the duration of landing radar updating during the braking phase, and (3) the deletion of the pitch transition guidance logic and associated targets at high gate and at initiation of vertical descent.

MISSION DESIGN CHANGES

Several changes have been made to the lunar landing mission design and LM hardware since the publication of reference 1. These changes, incorporated in this document, caused only minor perturbations in the design of the descent trajectory. The changes include the following:

1. The LM separation weight was increased to 33 055 lb (ref. 3). This was caused by an increase in the LM structural weight (as opposed to an increase in propellant loading) and was the basic reason for the majority of the other changes.

2. The CSM lunar parking orbit altitude was reduced from 80 to 60 n. mi. (refs. 2 and 3). The 20-n. mi. altitude change resulted in a 25-fps reduction in velocity at powered descent initiation, allowing a comparable savings in required ΔV.

3. The LM onboard software was simplified by deleting the pitch transition guidance logic and associated targets at high gate and at initiation of vertical descent (ref. 4).

4. The upper limit of the DPS throttleable region was raised from 60 to 65 percent of maximum rated thrust (refs. 4 and 7). This permitted the throttle recovery point to be increased from 52 to 57 percent. Since the DPS specific impulse (I_{sp}) is higher at 57 than at 52 percent thrust, this change allows more efficient engine operation, thereby conserving descent propellant.

5. Based on engine test data the predicted effective I_{sp} was increased by 3 seconds (refs. 3 and 6). This results in a decreased propellant usage rate during descent.

6. The high gate target pitch attitude was changed from 65° to 69°. This target attitude change caused an increase in the guidance time to go (from 145 to 180 seconds at 25 000-ft altitude) to high gate. As a result, there was an increase in the duration of landing radar updating during the braking phase. This is beneficial because the additional updating minimizes pitch attitude transients which occur upon initiation of landing radar updating.

DEFINITION OF THE POWERED DESCENT MANEUVER

Operational Phases

The LM powered descent maneuver is initiated near pericynthion of a 50 000-ft by 60-n. mi. (formerly 50 000-ft by 80-n. mi.) descent transfer orbit. The powered descent consists of three operational phases - braking, final approach, and landing. The braking phase, initiated at a preselected surface range from the landing site near pericynthion, is designed to efficiently reduce orbital velocity and terminates at a 9000-ft altitude, or high gate. The final approach phase, beginning at high gate, is designed to allow for pilot visual (out-the-window) assessment of the landing area and for abort safety. This phase terminates at a position called low gate, at approximately 500-ft altitude. The landing phase, beginning at low gate, is designed to allow the crew to visually assess the landing area and to provide compatibility for pilot takeover from automatic control. This phase includes a slow vertical descent (at about 3 fps) from approximately 65 ft and terminates at touchdown on the lunar surface.

Guidance and Targeting

The automatic guidance logic is based on quadratic acceleration, except for linear acceleration guidance during the last 20 seconds of the braking phase and the last 10 seconds of the final approach phase. During the braking phase, the guidance is targeted to the high gate state vector (position, velocity, and acceleration). The final approach is targeted to the state vector at the start of the vertical descent. A velocity-nulling technique maintains a constant descent rate for the vertical descent. The linear acceleration guidance phases previously used during transition from braking to final approach and final approach to vertical descent have been removed from the logic (see ref. 4).

CHARACTERISTICS OF THE POWERED DESCENT TRAJECTORY

The revised descent trajectory is based on the LM systems and spacecraft characteristics defined in references 3 and 5, except that the DPS thrust-I_{sp} profile has been updated by reference 6. Guidance and target parameters are given in table I. The braking phase targets were chosen to provide the proper altitude-time profile for landing radar updating. The ΔV and propellant requirements for LM descent are tabulated in table II. These requirements satisfy the budgeted allowances of reference 2.

Time histories of the trajectory characteristics, thrust profile, and guidance commands for the entire descent are given in figure 1. The look (visibility) angle [fig. 1(g)] is defined as the included angle between the vehicle longitudinal axis and the line of sight to the landing site. Figure 2 shows the variation of altitude with surface range to the landing site. Figure 3 shows the altitude-altitude rate profile for the descent trajectory. A comparison of these figures with similar ones in reference 1 reveals no significant differences.

Figures 4, 5, and 6 present the same parameters as figures 1, 2, and 3, respectively, for the final approach and landing phases only of the powered descent.

The landing phase parameters and constraints are presented as a function of surface range to the landing site in figure 7. As the landing phase plots indicate, the constraints are not violated in the area where range to go (hence, altitude) is critical.

CONCLUDING REMARKS

The LM powered descent trajectory for the lunar landing mission has been redesigned as a result of recent data changes. This report presents the revised trajectory and supersedes reference 1. The trajectory presented herein satisfies the known operational constraints and, in addition, increases the duration of landing radar updating during the braking phase.

It should be emphasized that there are no major changes in the descent trajectory shaping or design concept. The minor changes reflected in the trajectory are favorable, except for the increased structural weight.

It is anticipated that the trajectory design and guidance targeting documented here will be included in the forthcoming reference trajectory document for the lunar landing mission to be published by the Mission Planning and Analysis Division.

TABLE I.- GUIDANCE TARGET VECTORS FOR THE LM POWERED DESCENT

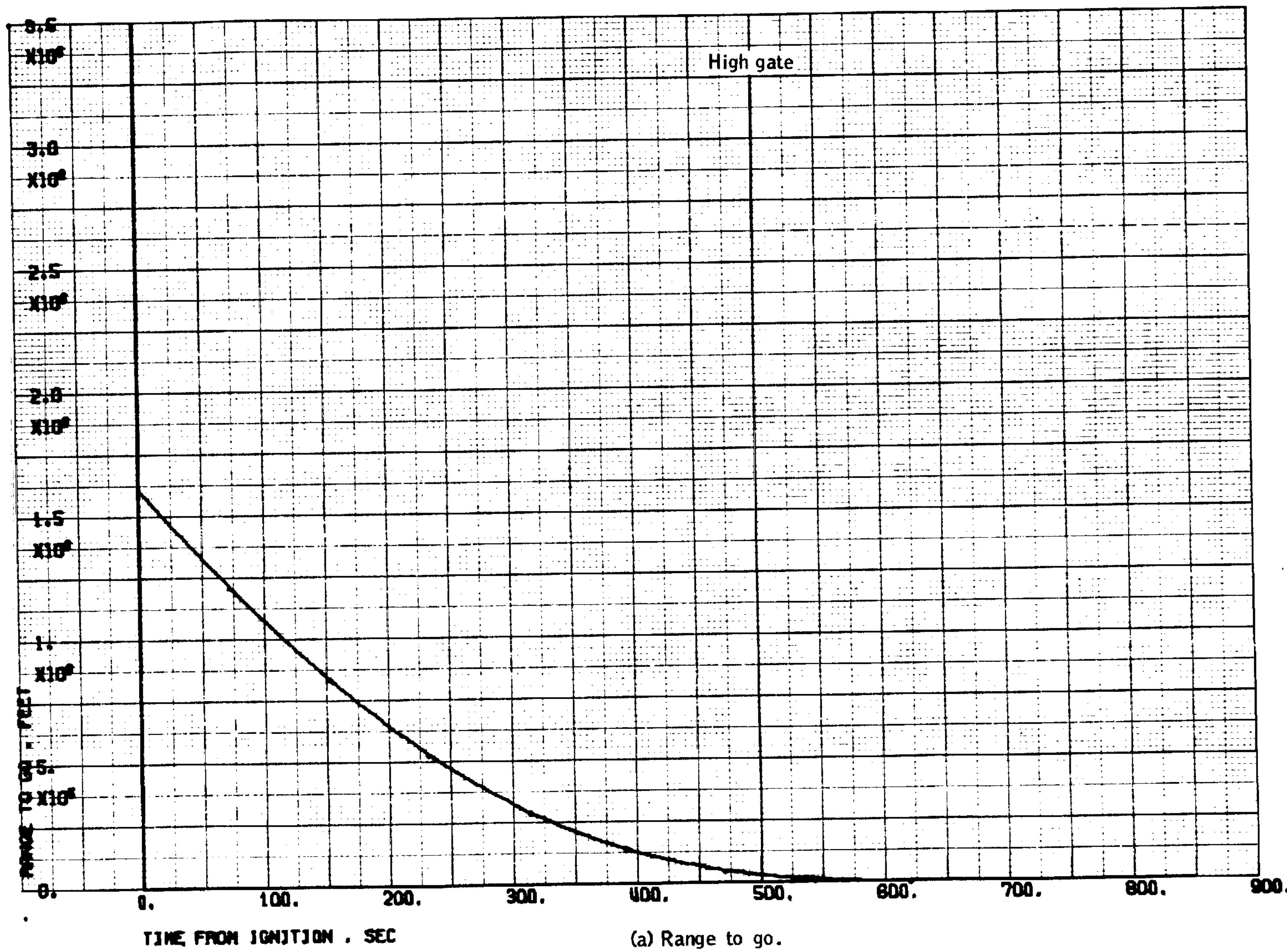
Aim conditions (G-frame[a])	Descent phases				
	Ignition	Ullage	Trim	Braking	Final approach and landing
Position:					
X, ft				9 592	77.13
Y, ft				0	0
Z, ft	-1 432 029			-33 084	-1.733
Velocity:					
X, fps				-158.8	-3.1
Y, fps				0	0
Z, fps				563.7	1.3
Acceleration:					
X, ft/sec^2				-1.696	0.05
Y, ft/sec^2				0	0
Z, ft/sec^2				-9.453	-0.65
Jerk:					
Z, ft/sec^3				-0.011885	0.034336
Nominal time for phase, sec		7.5	26	467	161

[a]The origin of the G-frame coordinate system is at the current landing site; the positive X axis is from the center of the moon to the current landing site; the positive Y axis is normal to the trajectory plane at the time of arrival at the aim point; and the Z axis completes the right-hand system.

TABLE II.- ΔV AND PROPELLANT REQUIRED FOR THE NOMINAL LM POWERED DESCENT

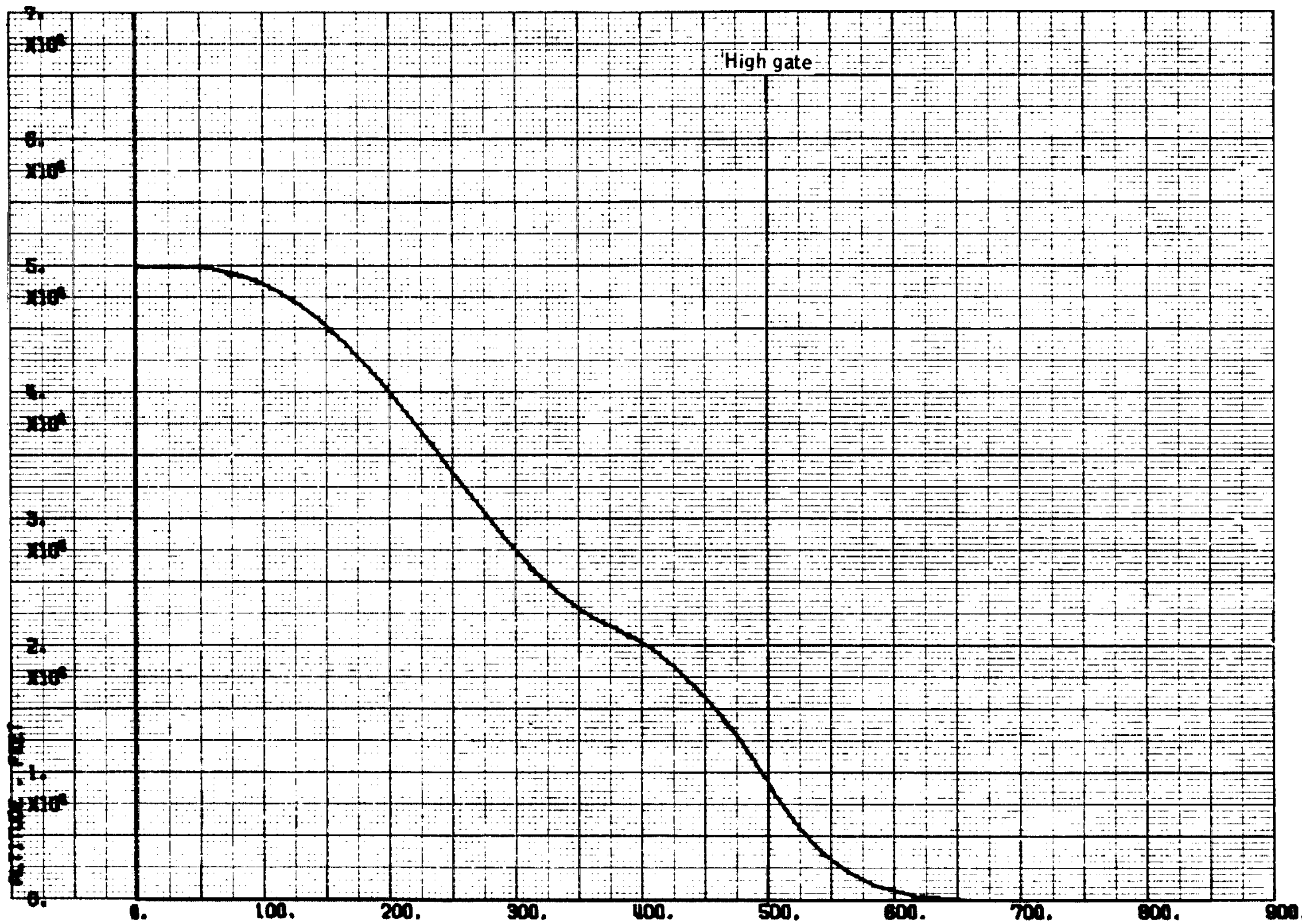
[Based on 33 055-lb LM weight at separation]

ΔV, fps:	
Braking phase	5 237
Final approach phase	863
Landing phase	387
Vertical descent	88
Total	6 575
Propellant, lb:	
Braking phase	13 666
Final approach phase	1 556
Landing phase	703
Vertical descent	155
Total	16 082



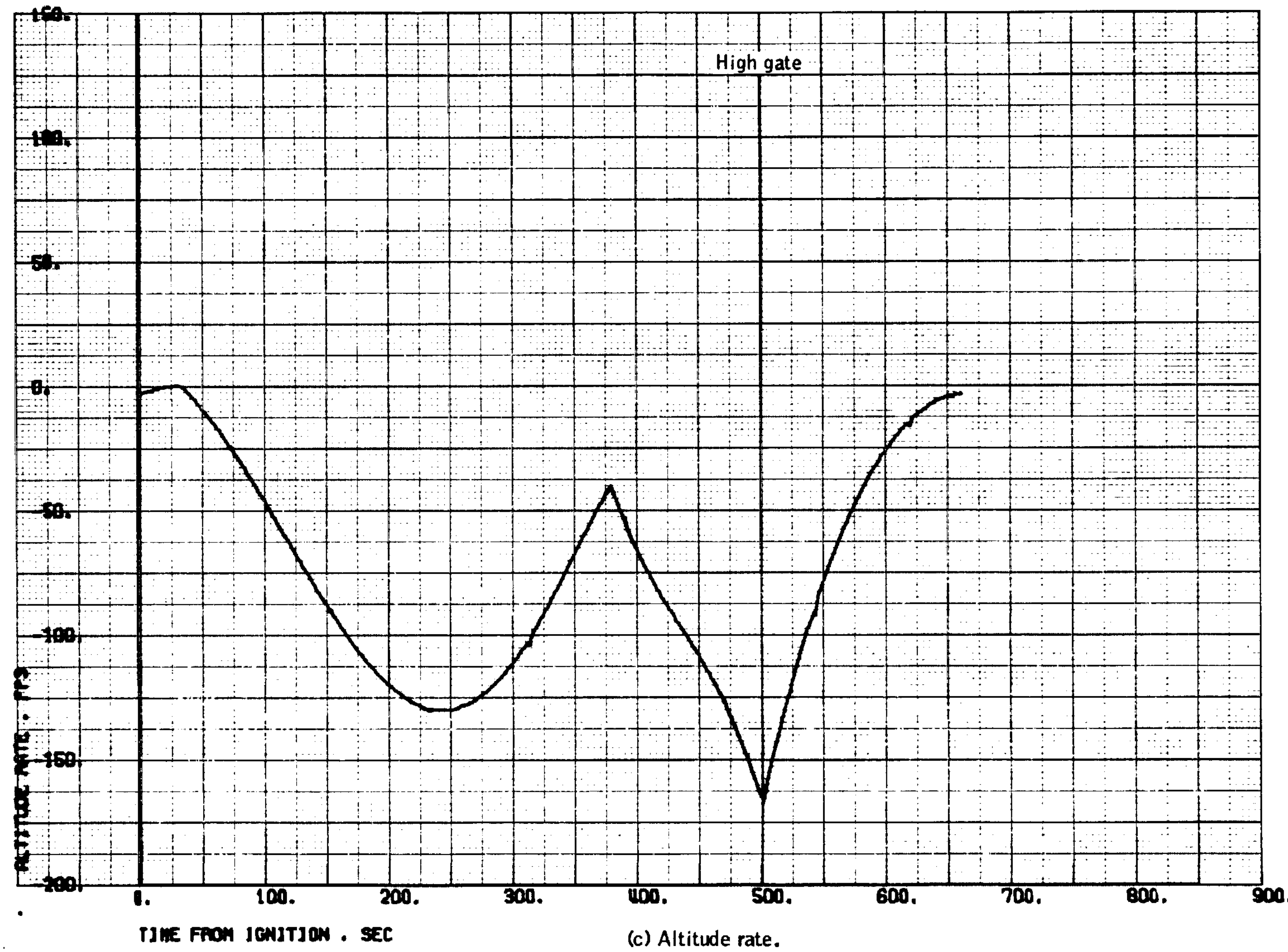
(a) Range to go.

Figure 1.- Time histories of LM powered descent trajectory parameters.



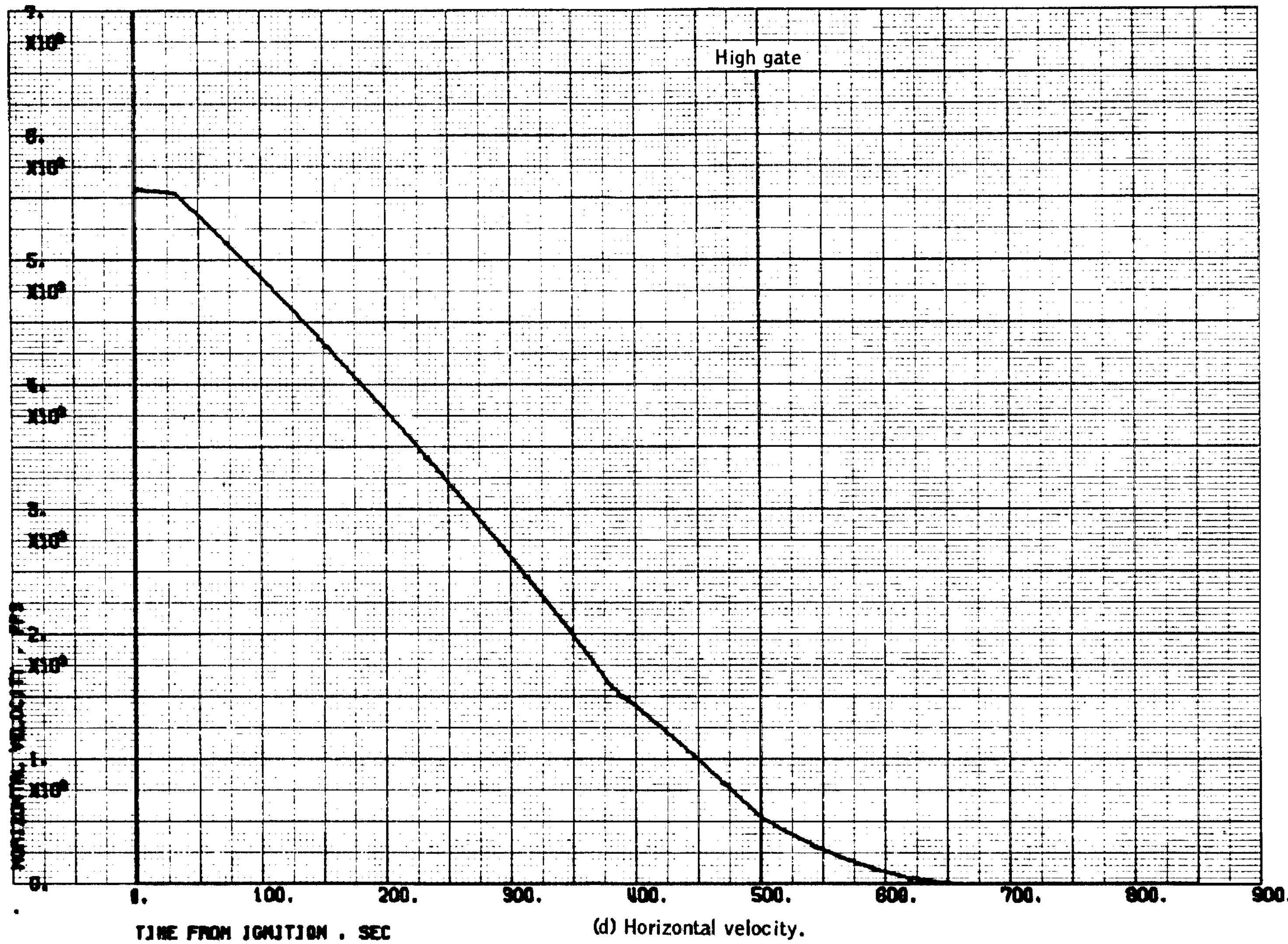
(b) Altitude.

Figure 1.- Continued.



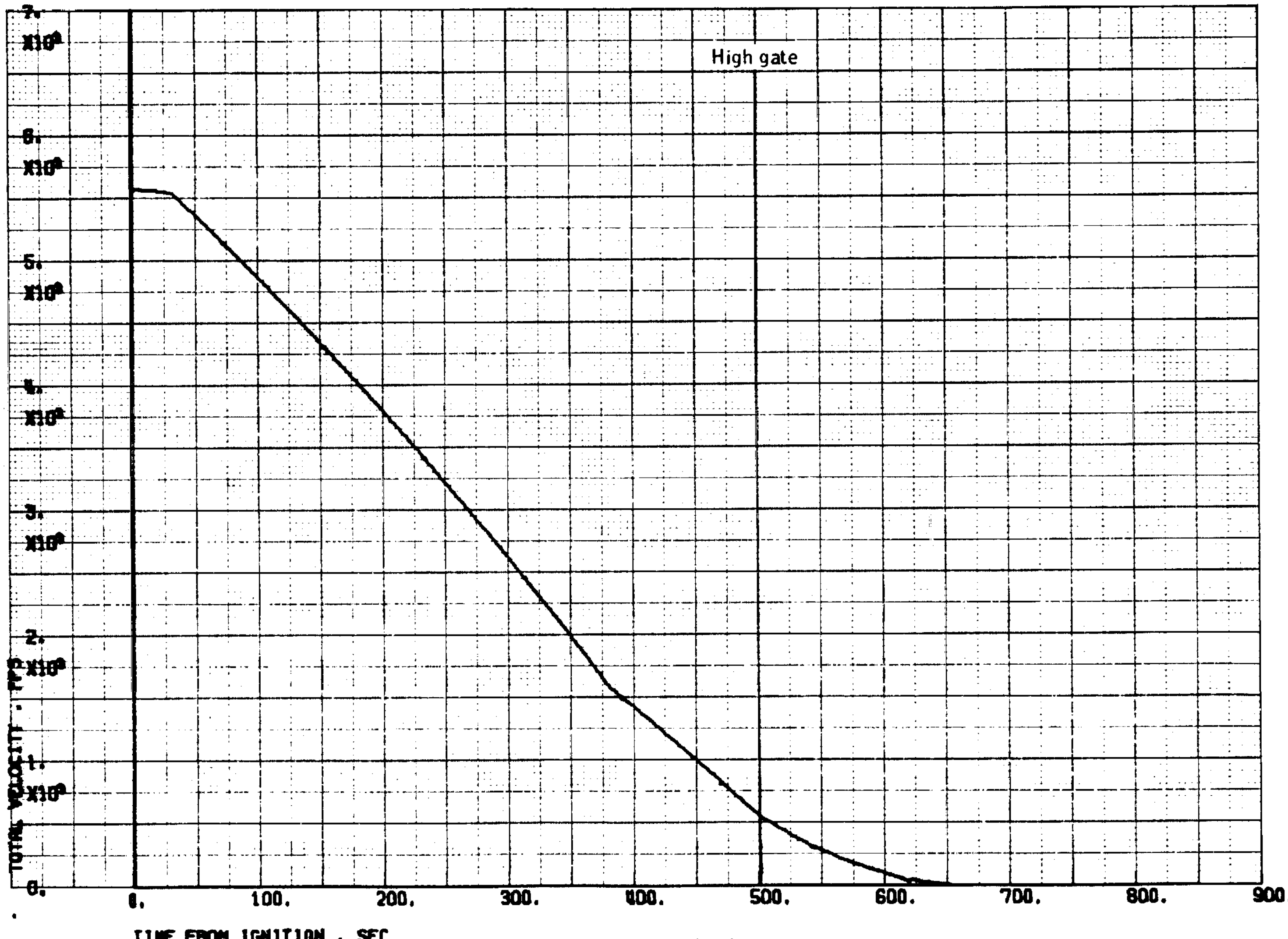
(c) Altitude rate.

Figure 1.- Continued.



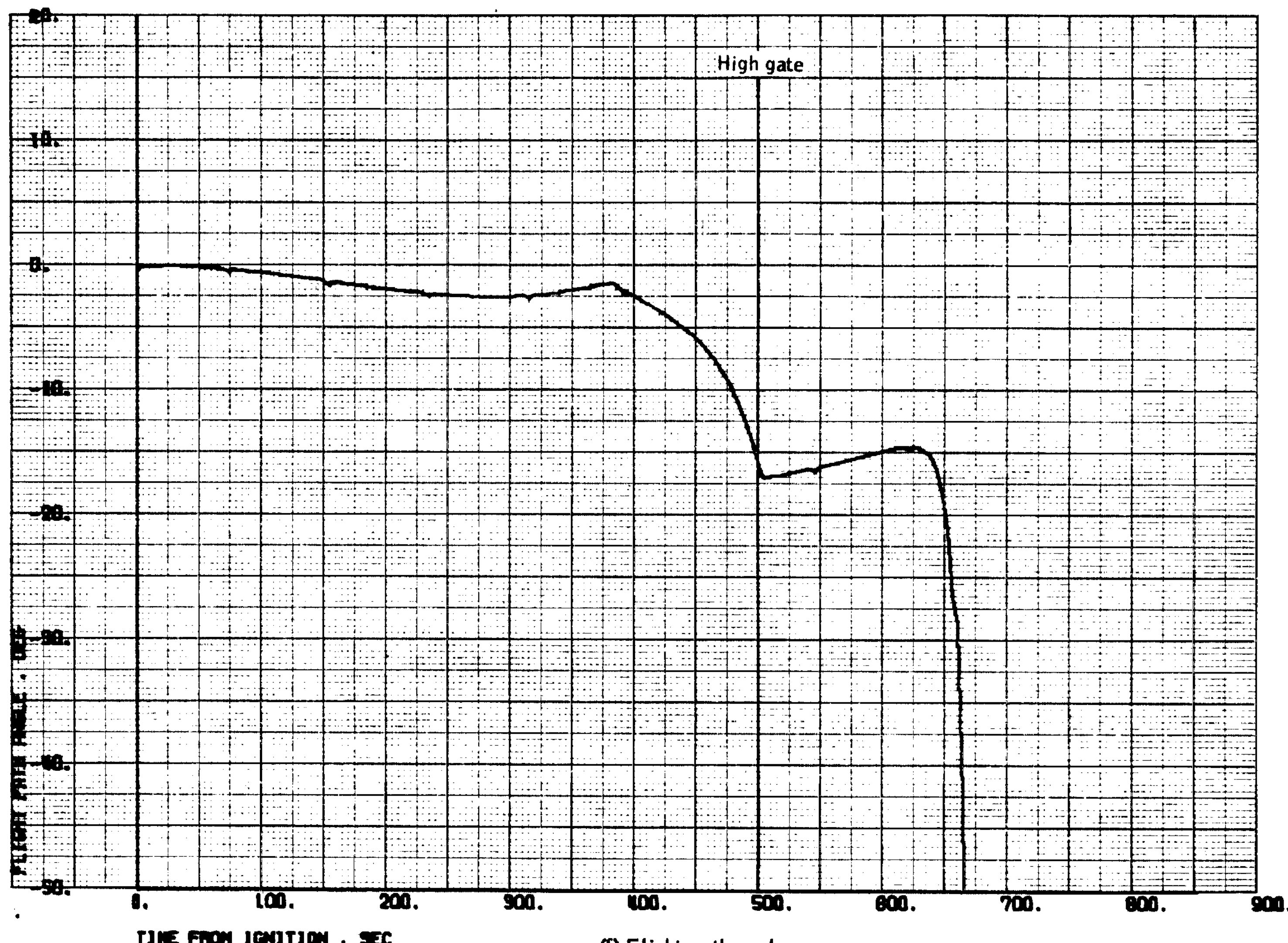
(d) Horizontal velocity.

Figure 1.- Continued.



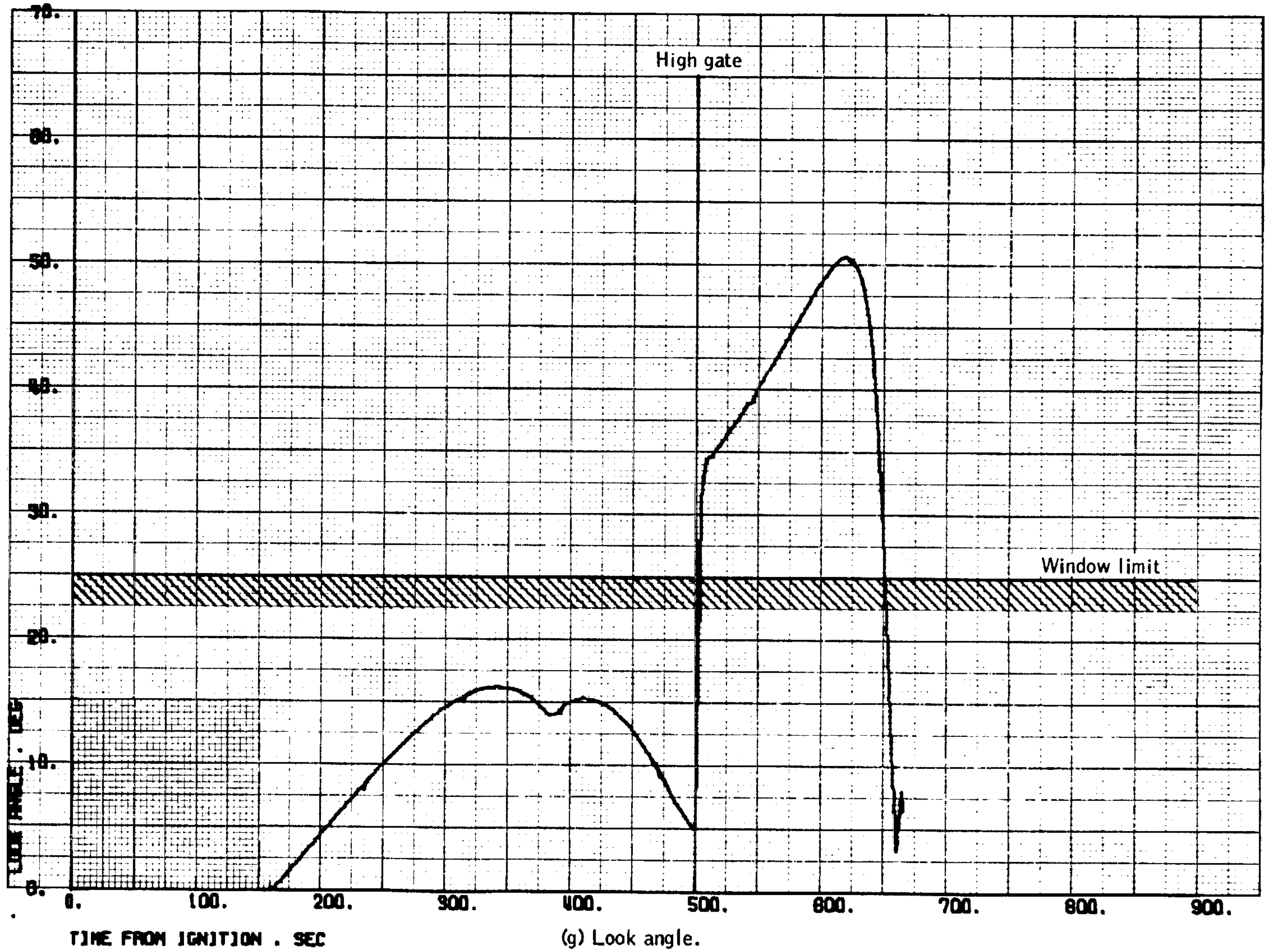
(e) Total velocity.

Figure 1.- Continued.



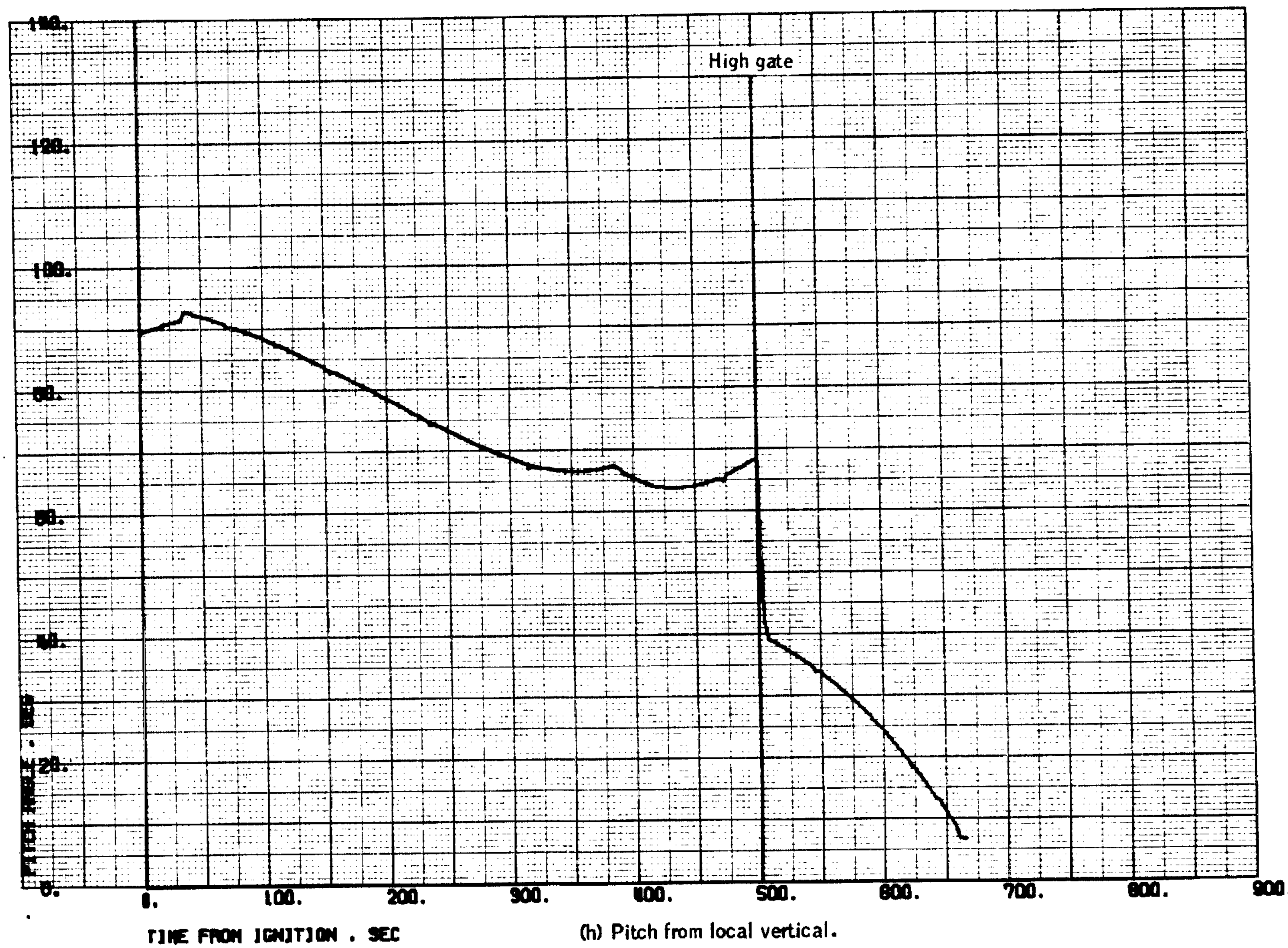
(f) Flight-path angle.

Figure 1.- Continued.



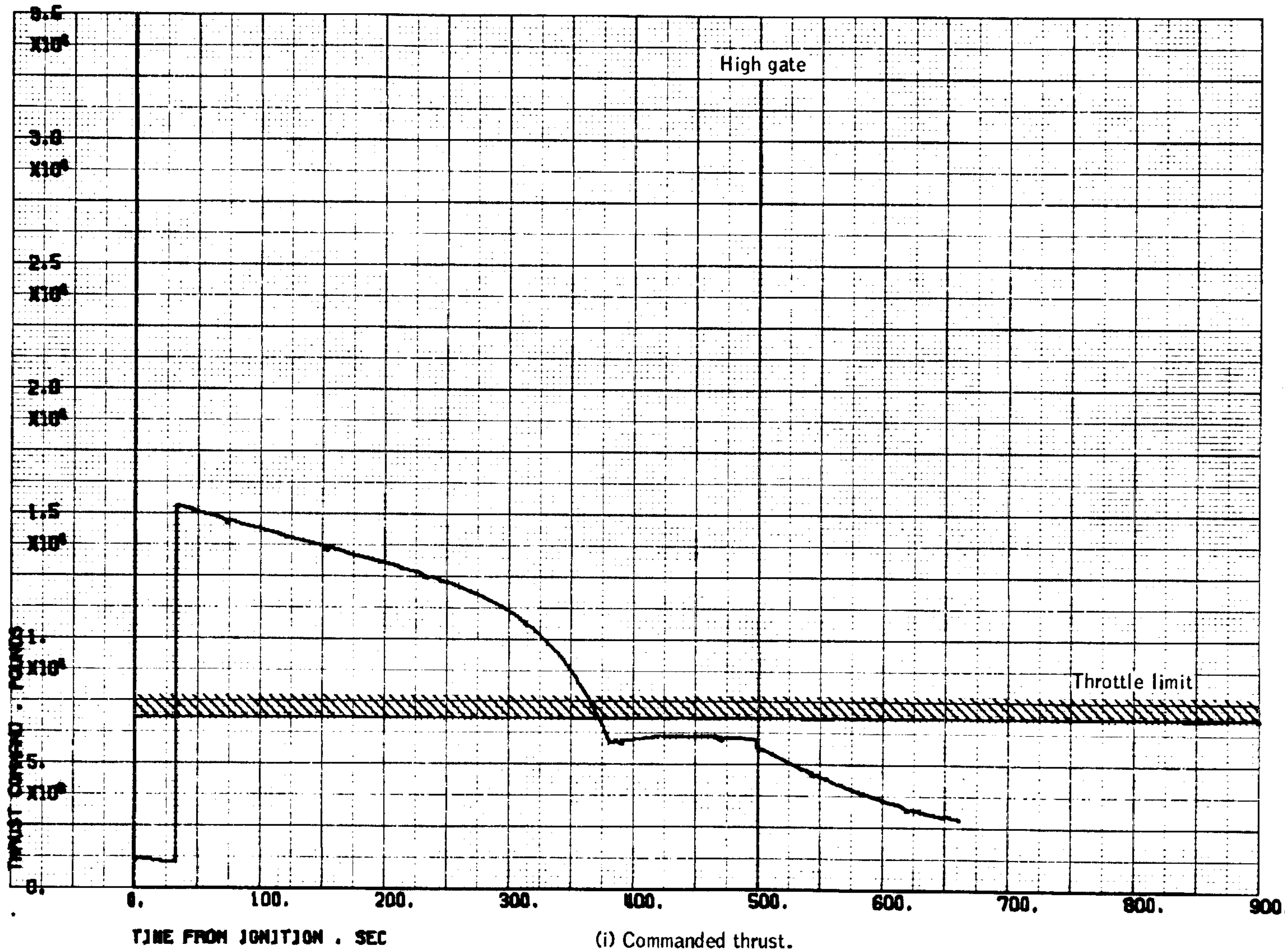
(g) Look angle.

Figure 1.- Continued.



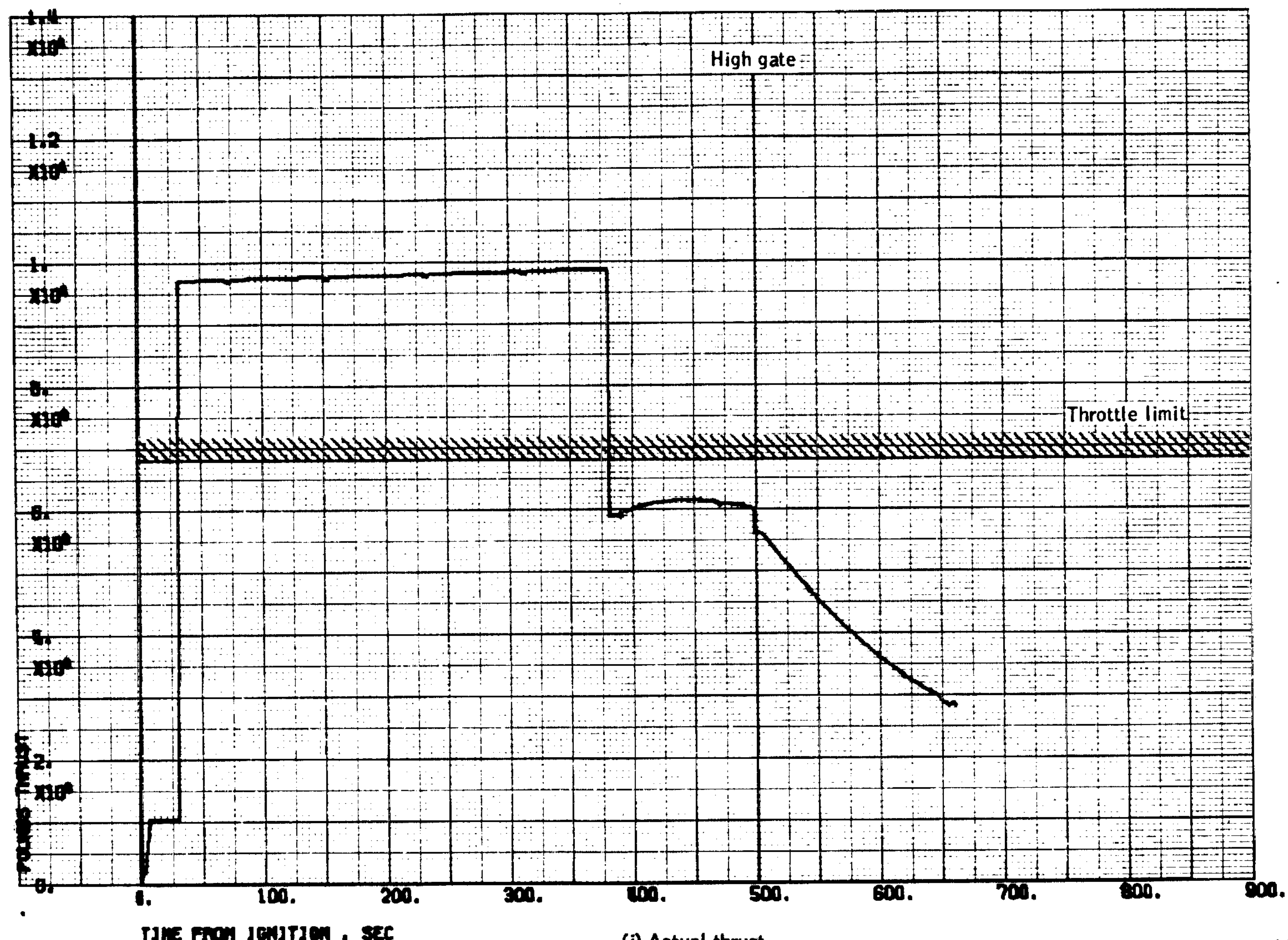
(h) Pitch from local vertical.

Figure 1.- Continued.



(i) Commanded thrust.

Figure 1.- Continued.



(j) Actual thrust.

Figure 1.- Concluded.

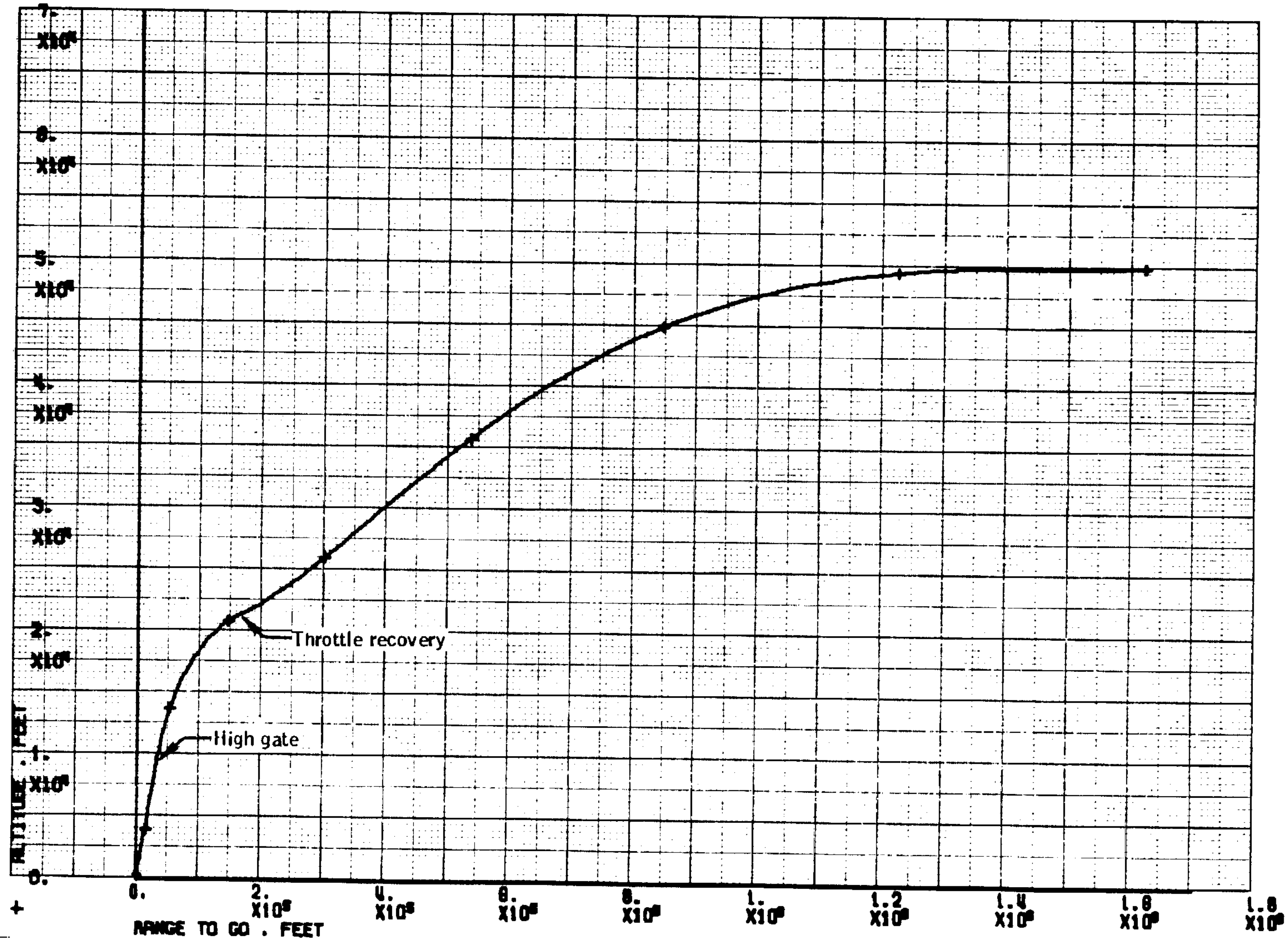


Figure 2.- Altitude-range profile for LM lunar descent trajectory.

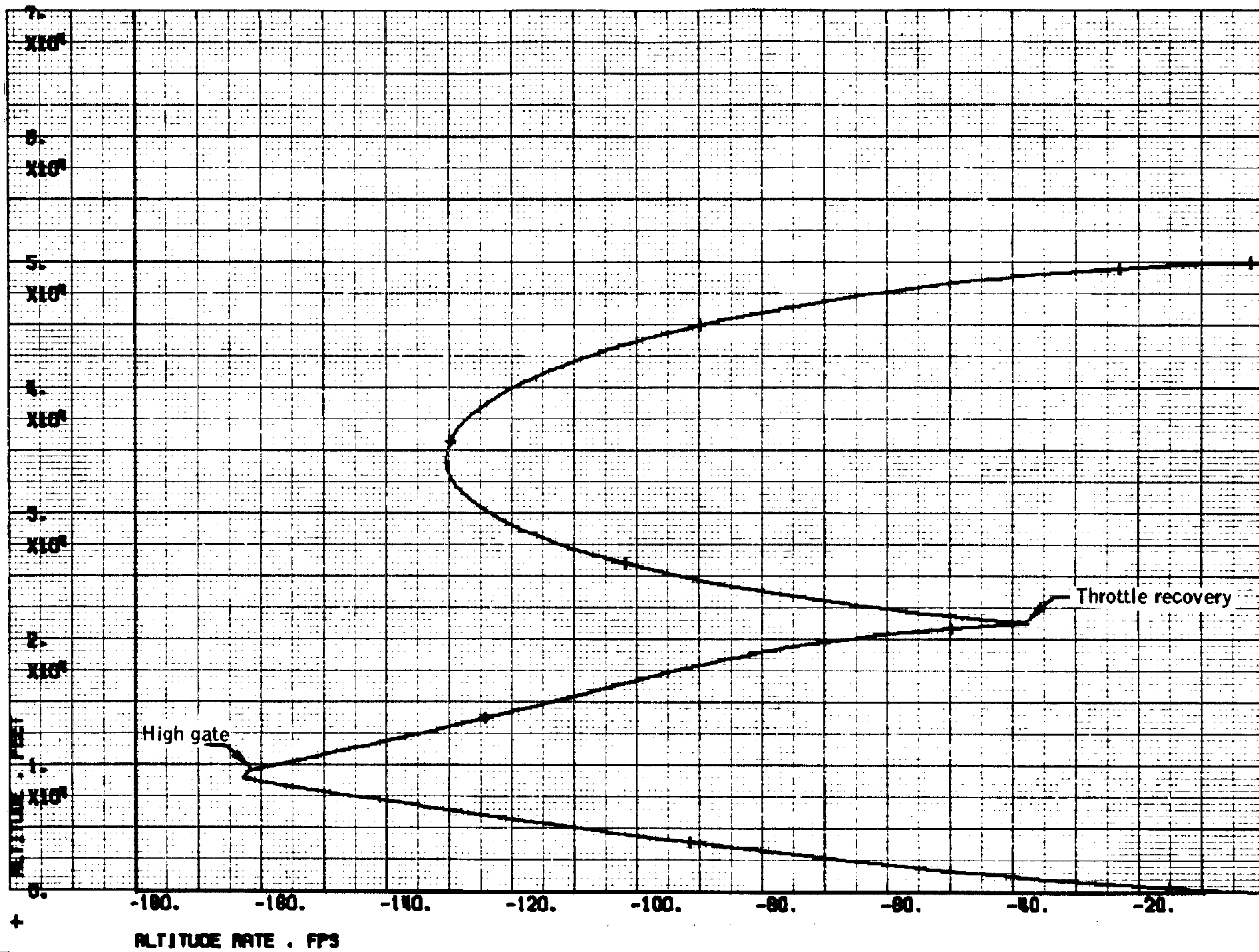
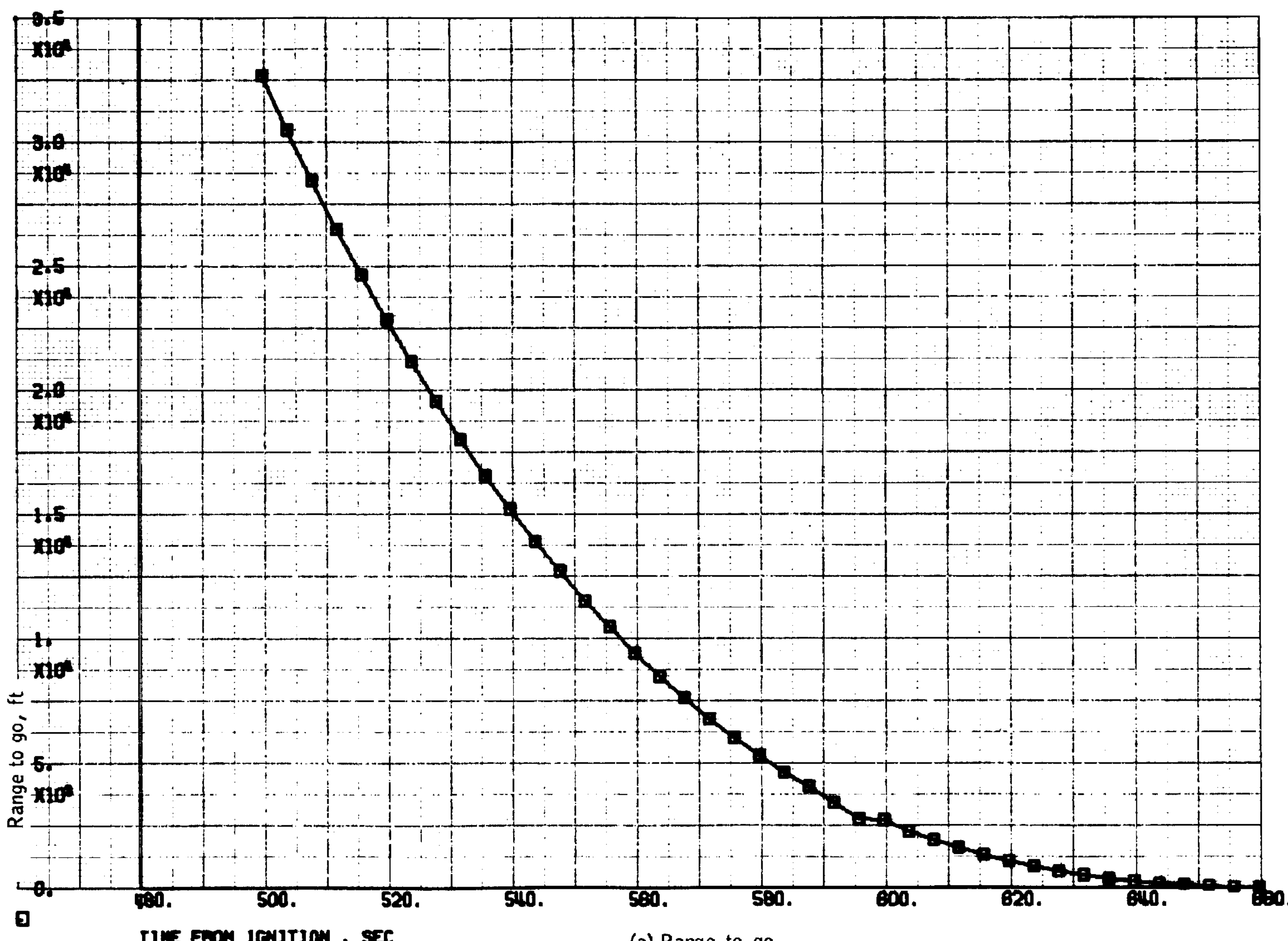
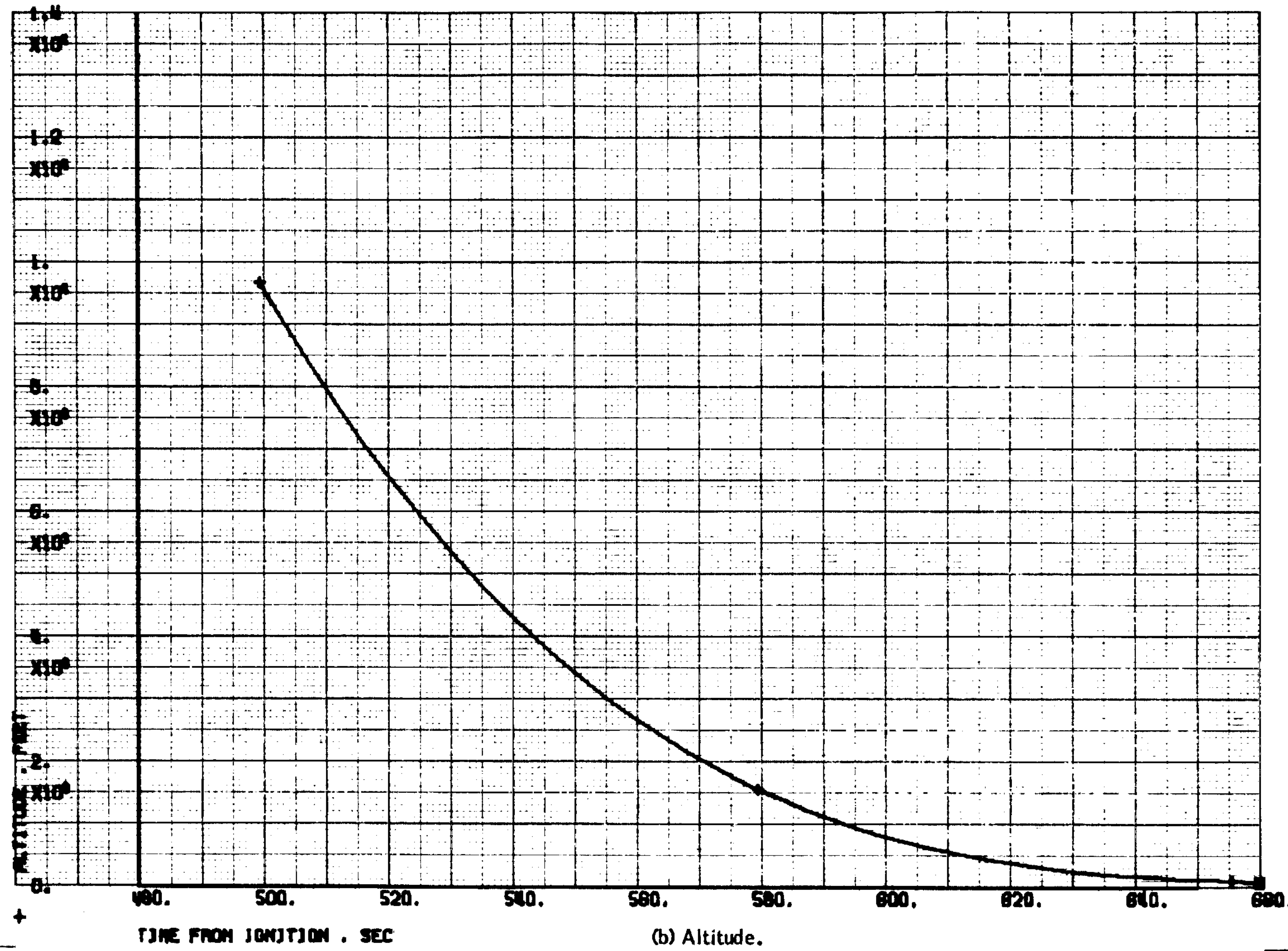


Figure 3.- Altitude-altitude rate profile for LM lunar descent trajectory.



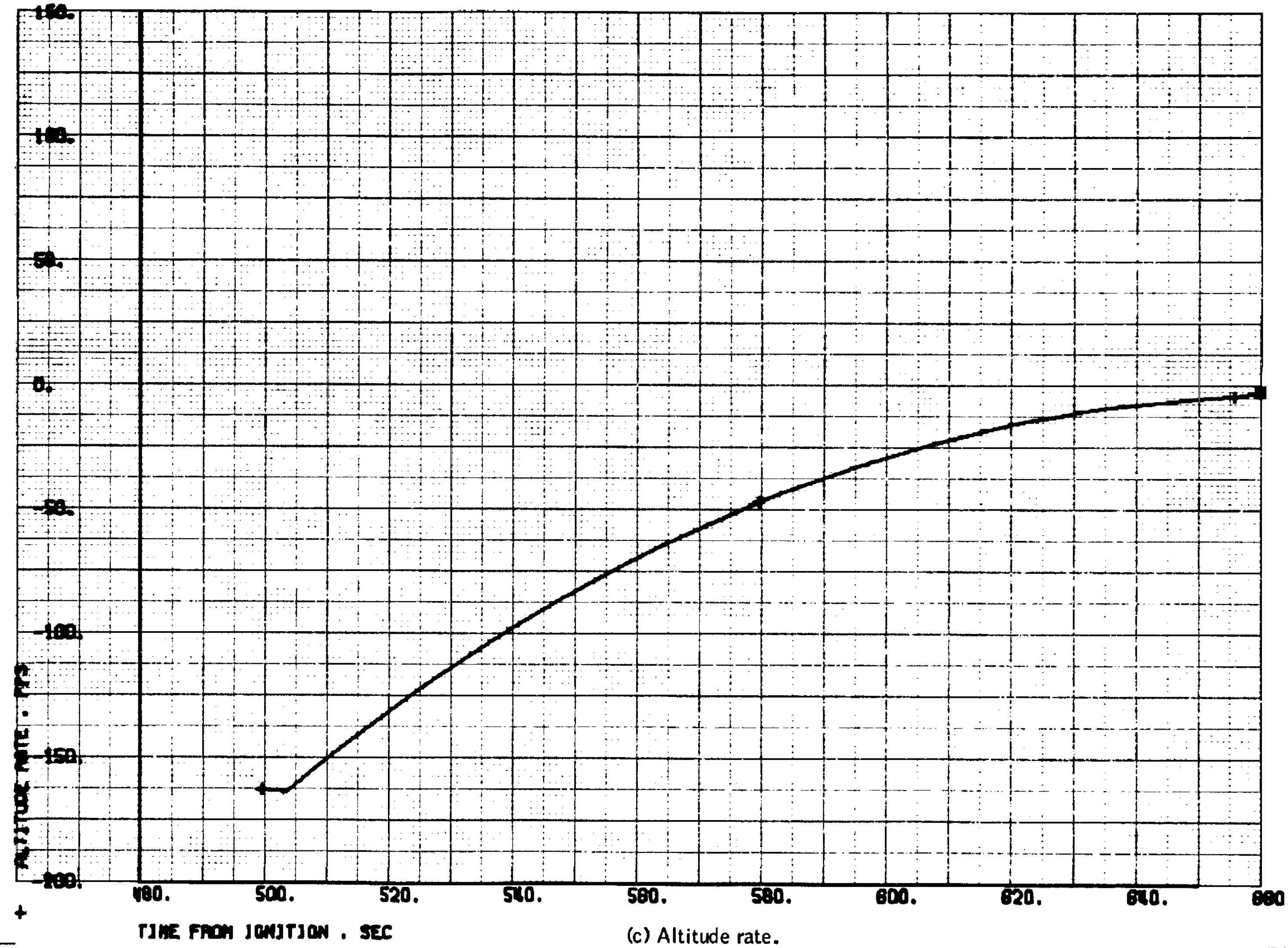
(a) Range to go.

Figure 4.- Time histories of trajectory parameters during final approach and landing phases.



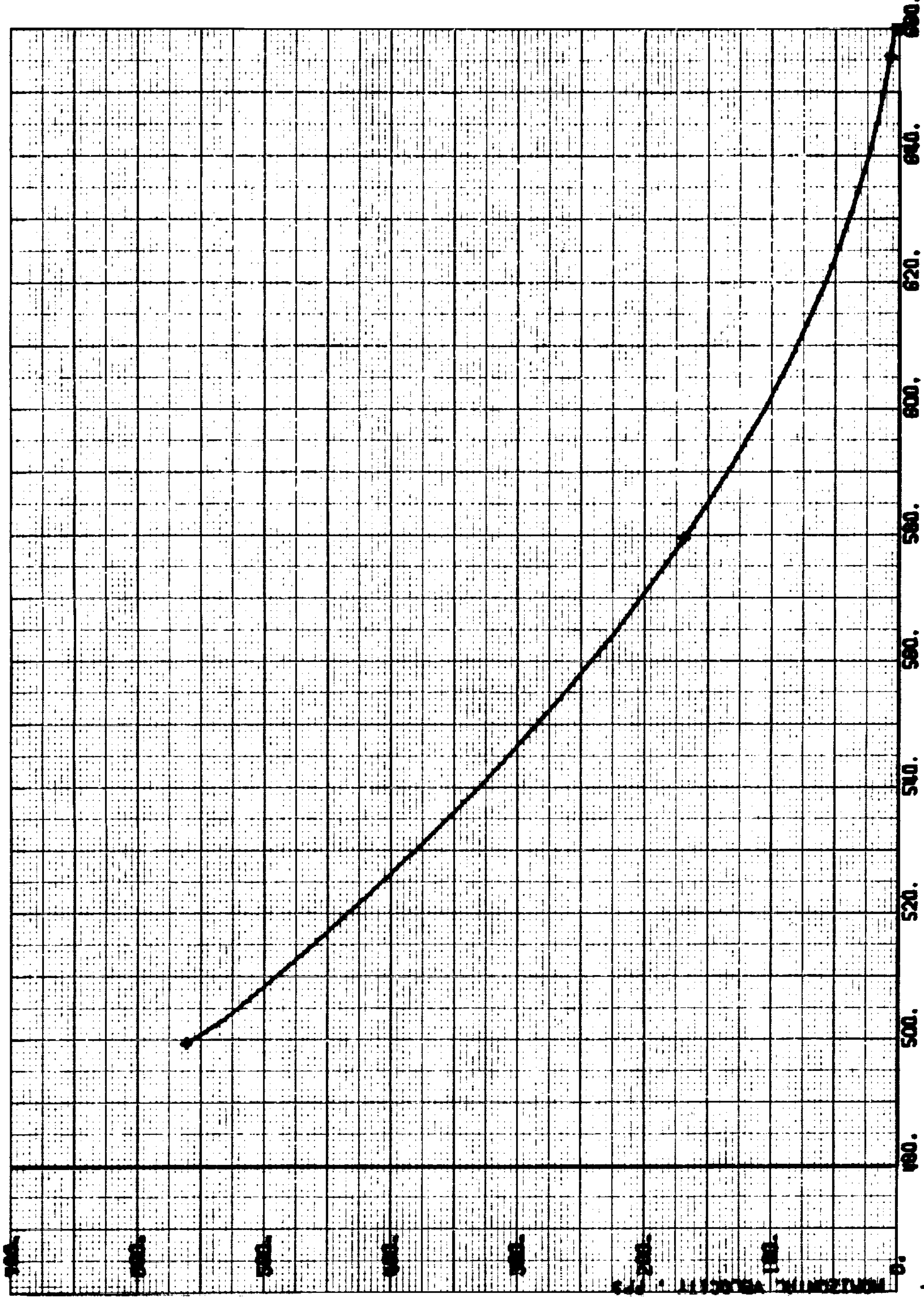
(b) Altitude.

Figure 4.- Continued.



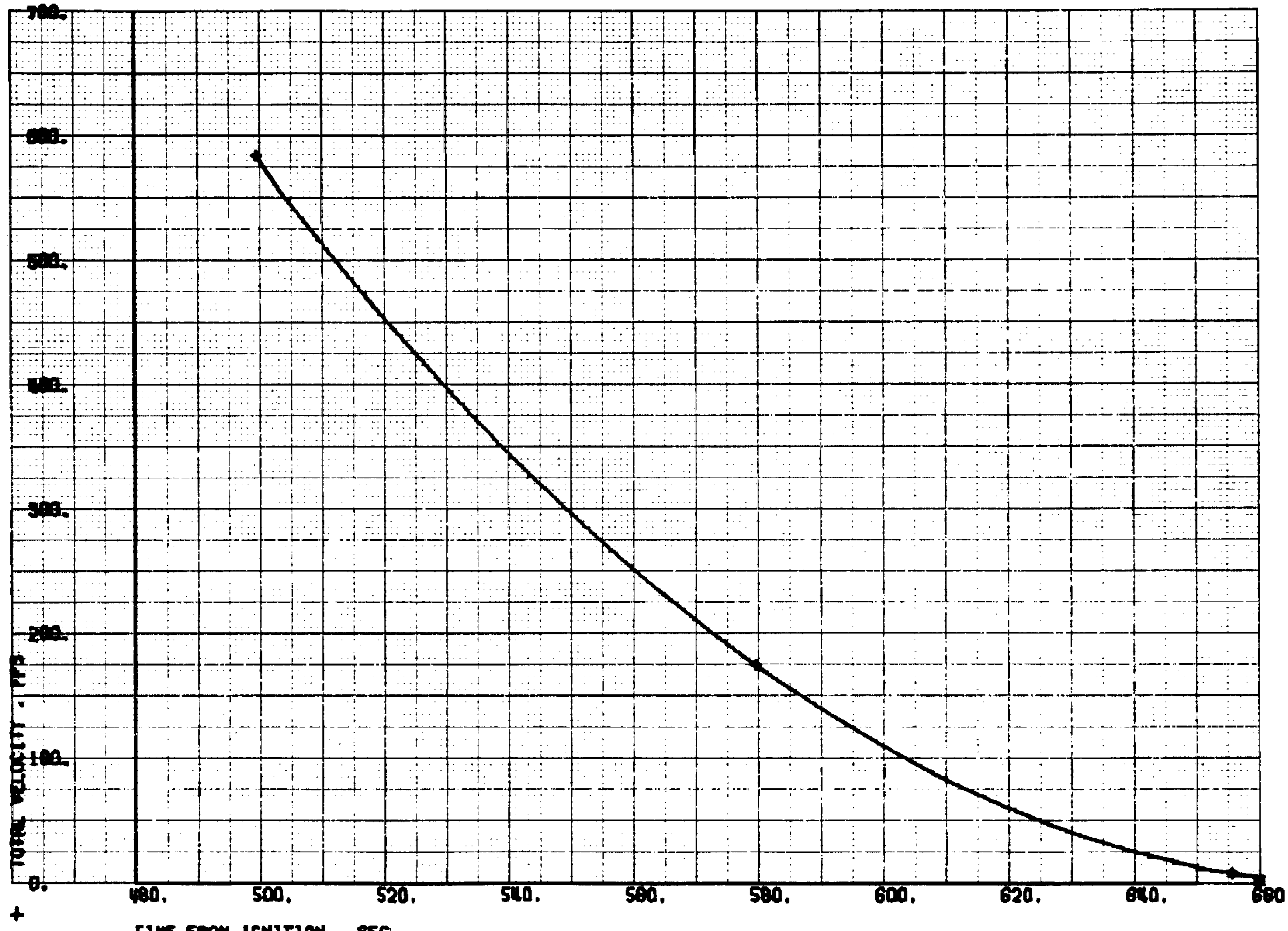
(c) Altitude rate.

Figure 4.- Continued.



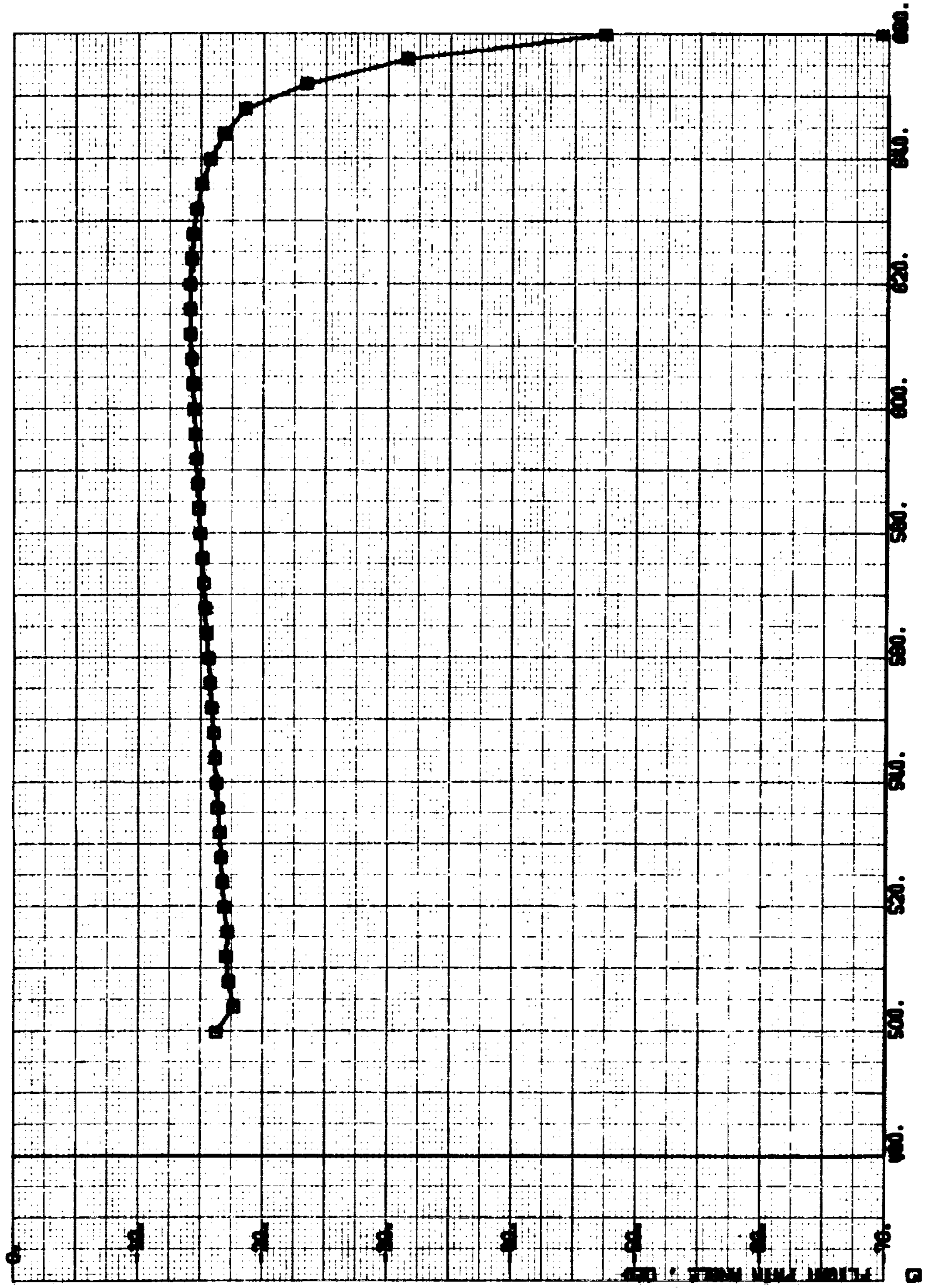
(d) Horizontal velocity.

Figure 4.- Continued.



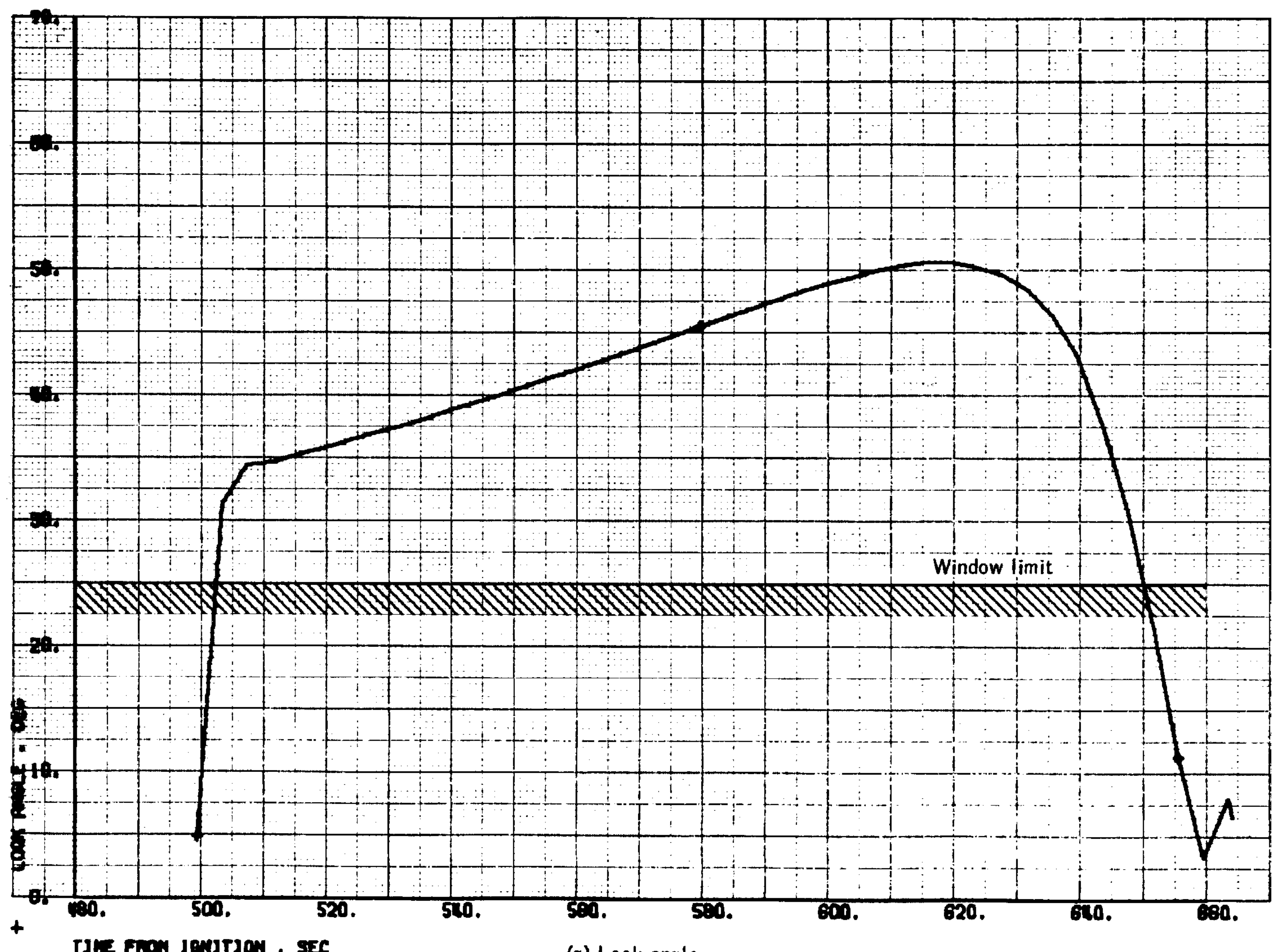
(e) Total velocity.

Figure 4.- Continued.



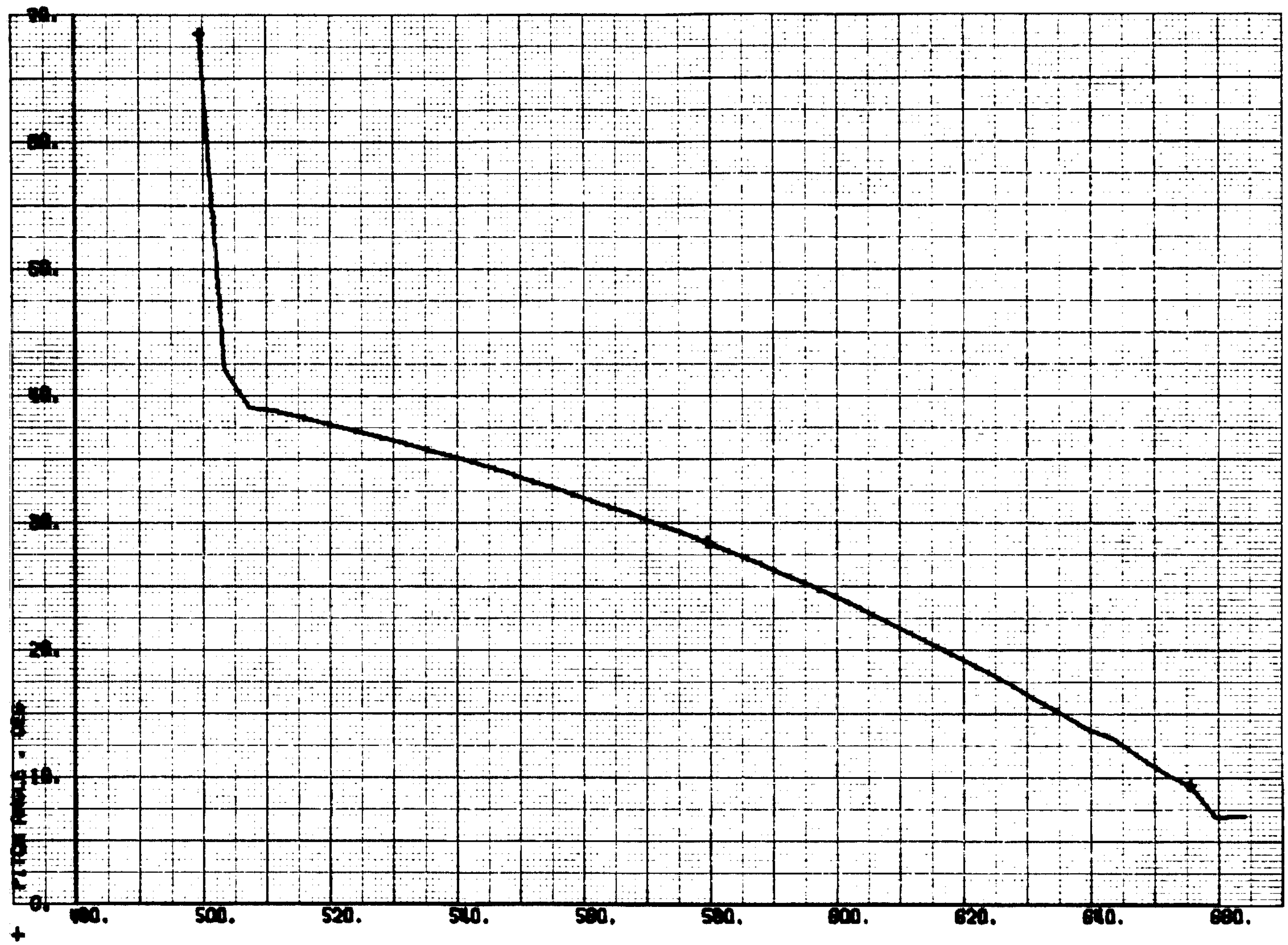
(f) Flight-path angle.

Figure 4.- Continued.



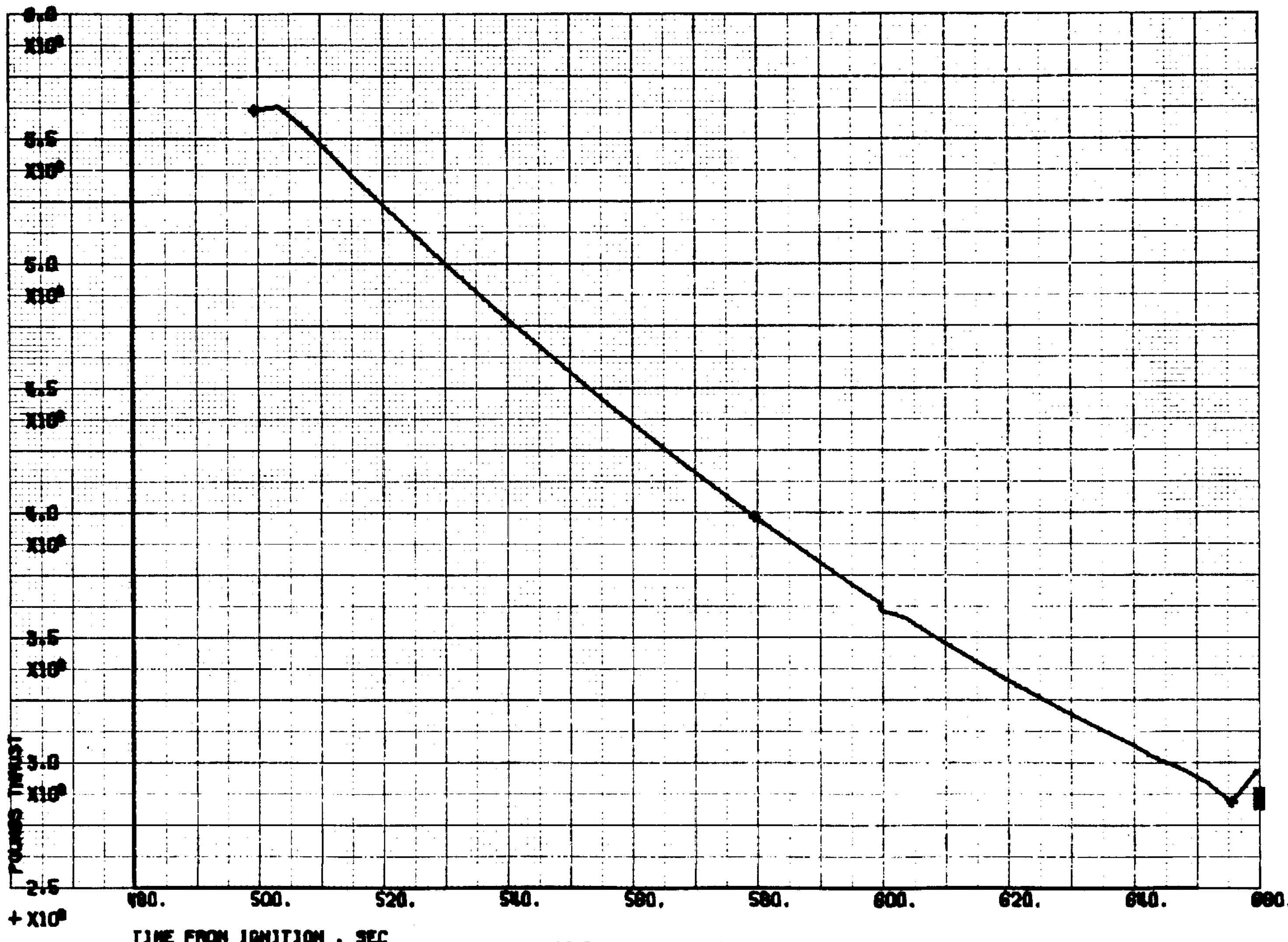
(g) Look angle.

Figure 4.- Continued.



(h) Pitch from local vertical.

Figure 4.- Continued.



(i) Commanded and actual thrust.

Figure 4.- Concluded.

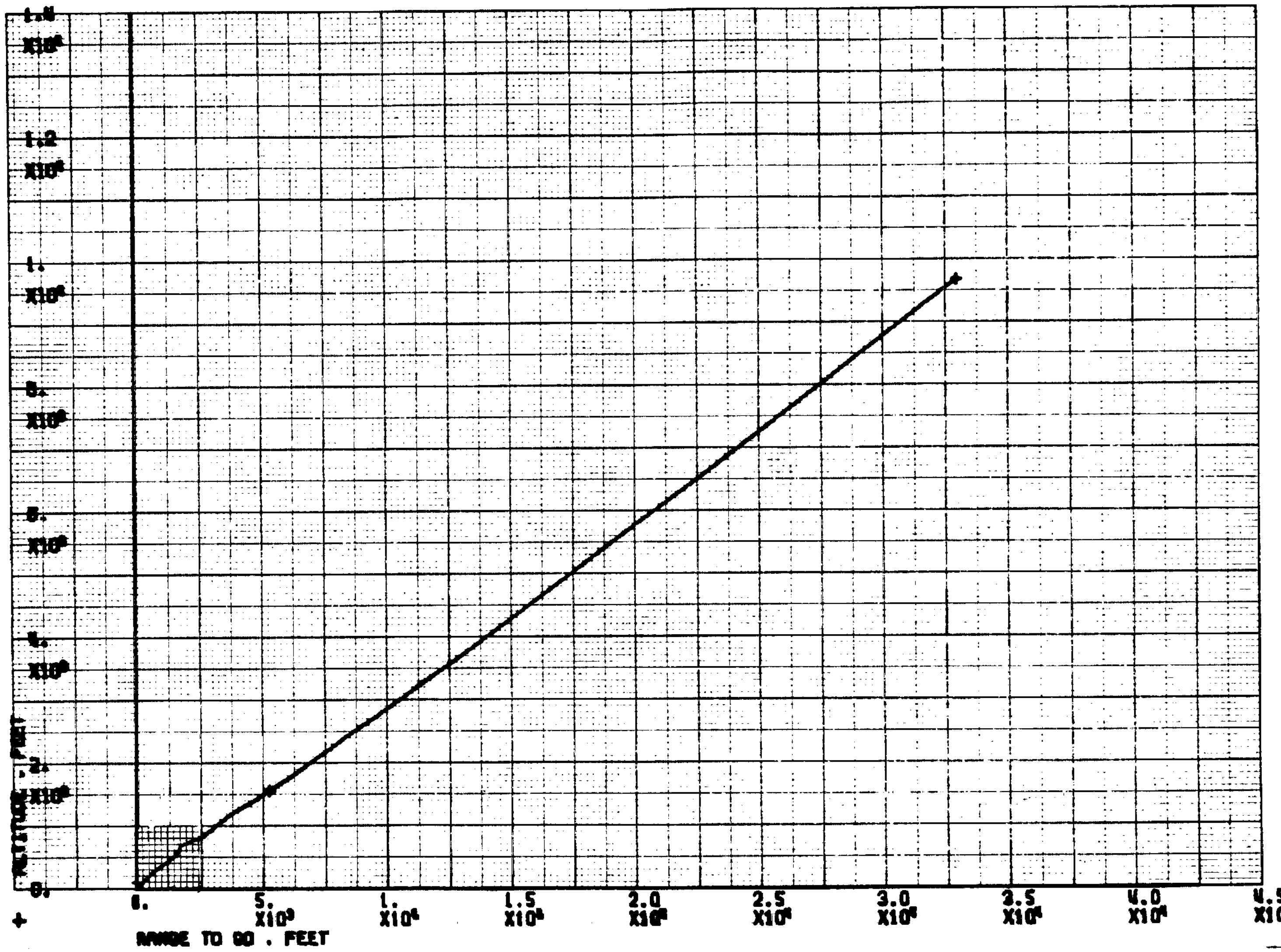


Figure 5.- Altitude-range profile for LM lunar descent trajectory.

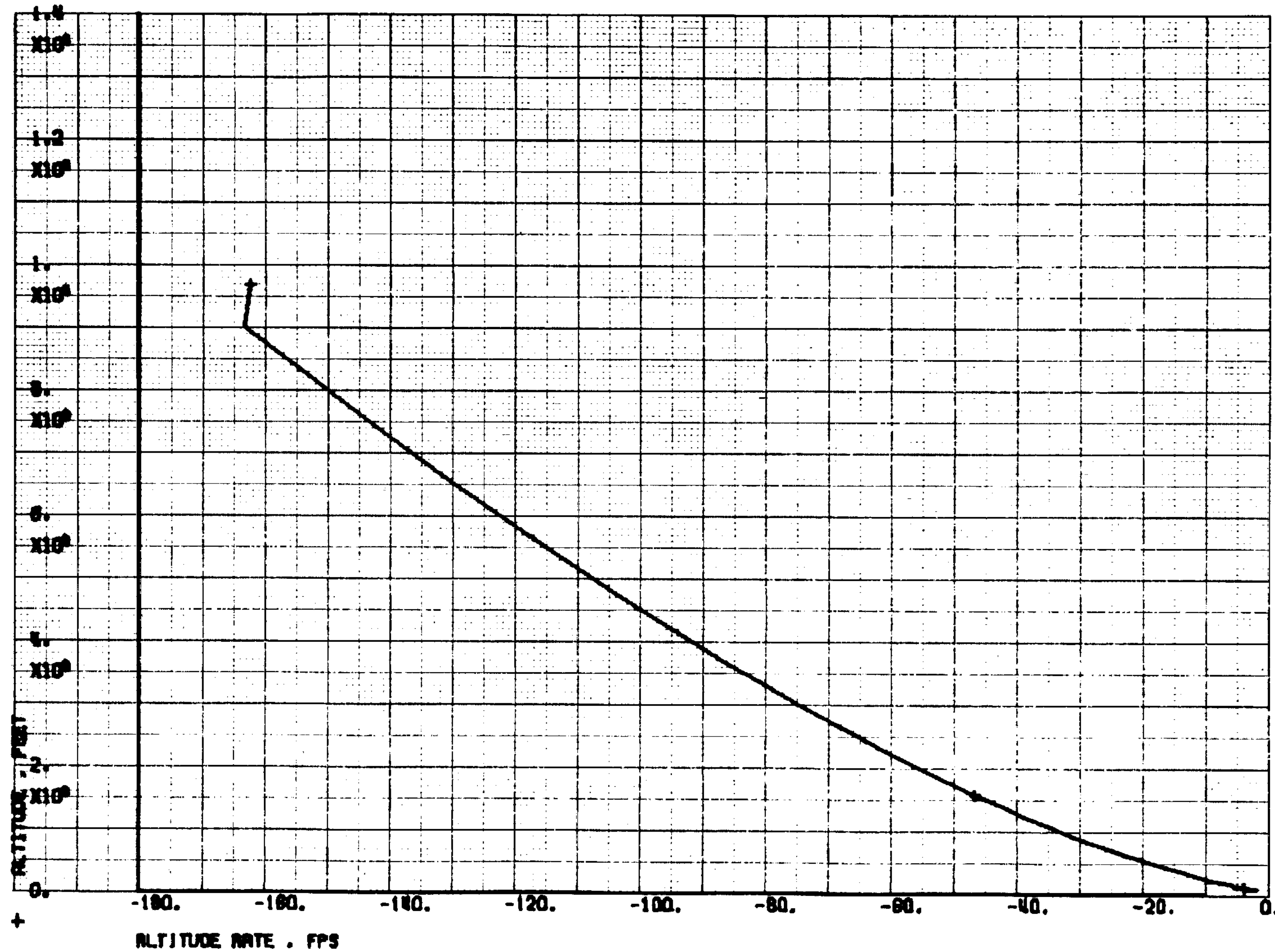
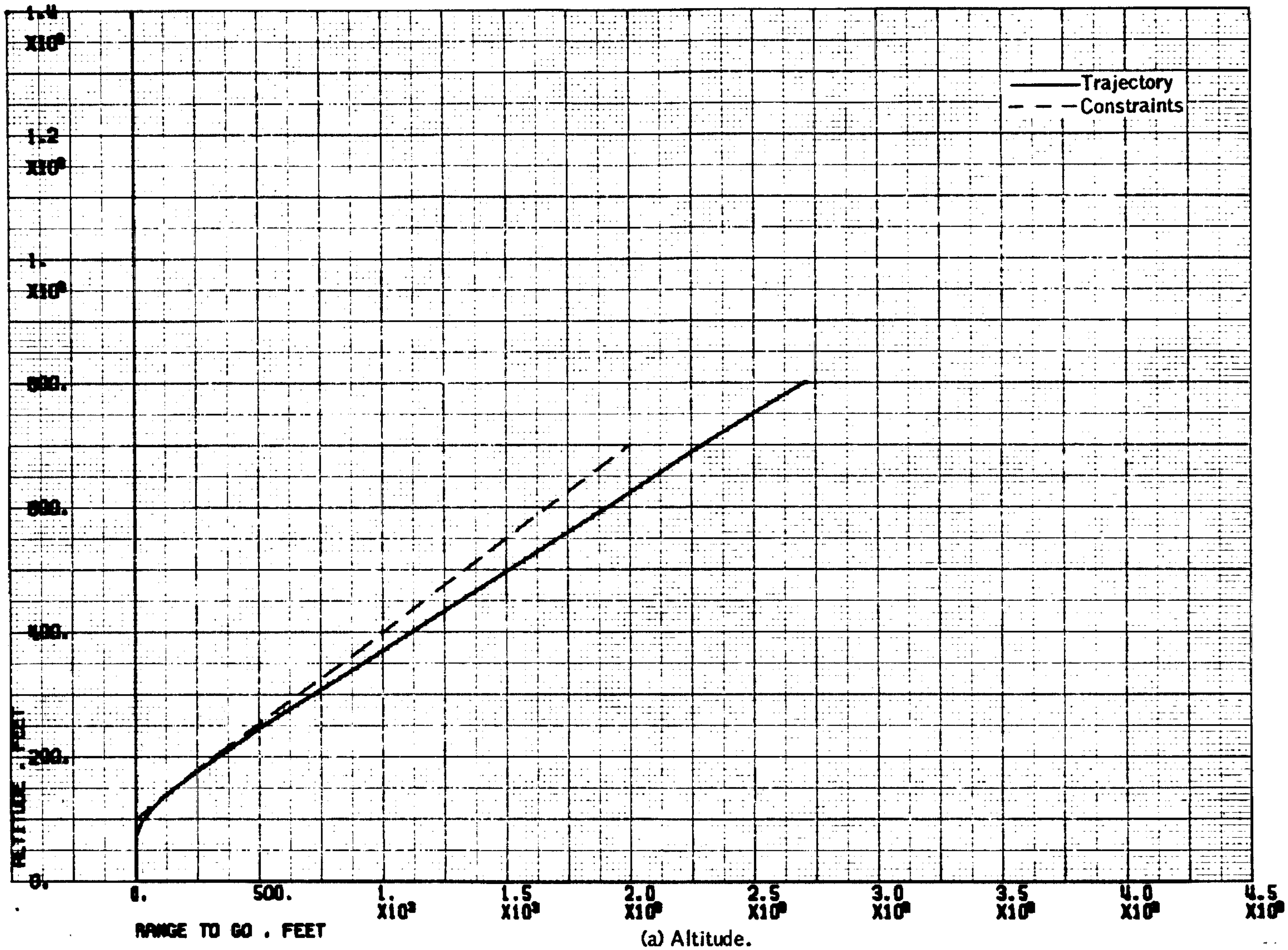
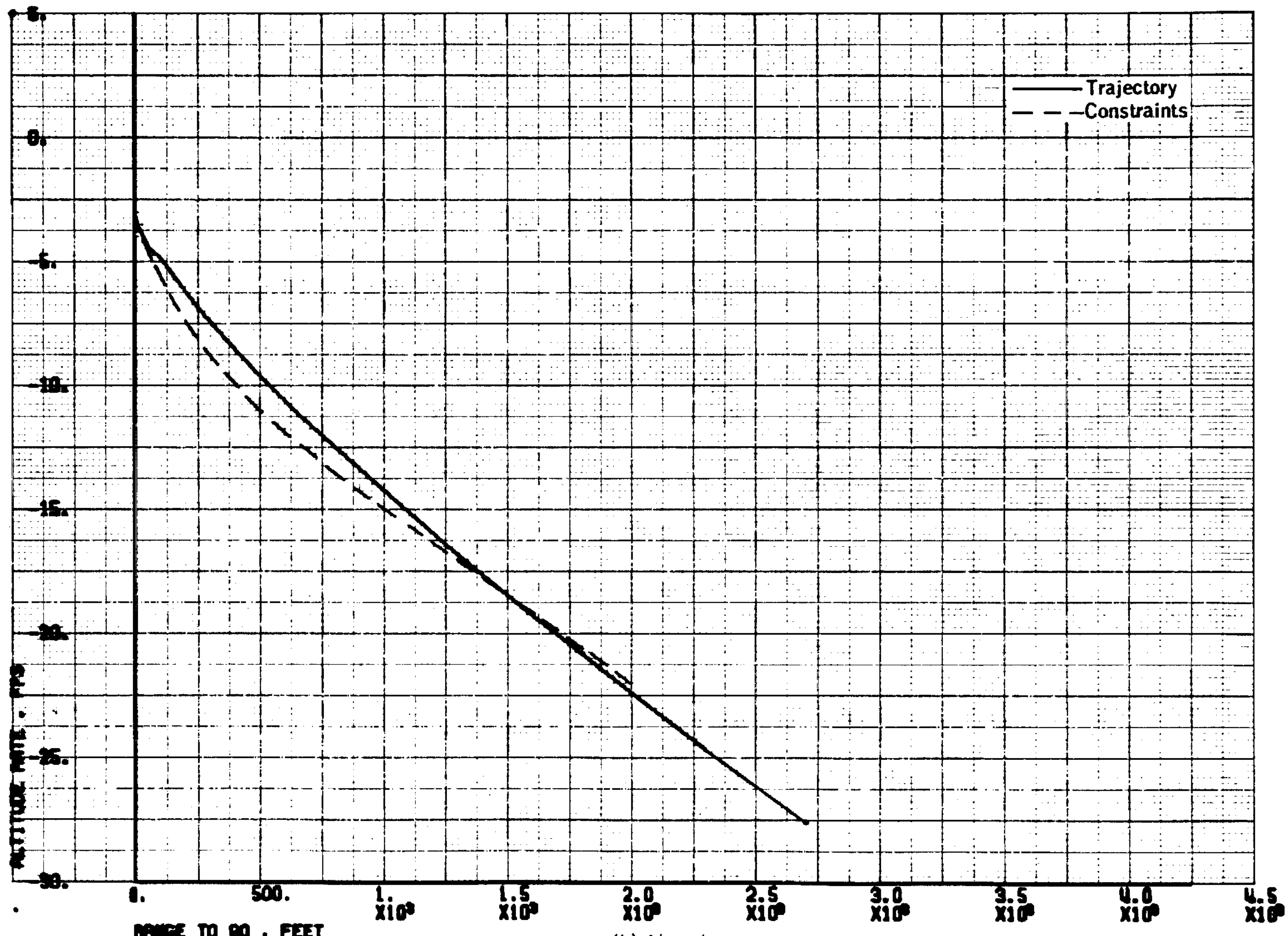


Figure 6.- Altitude-altitude rate profile for final approach and landing phases.



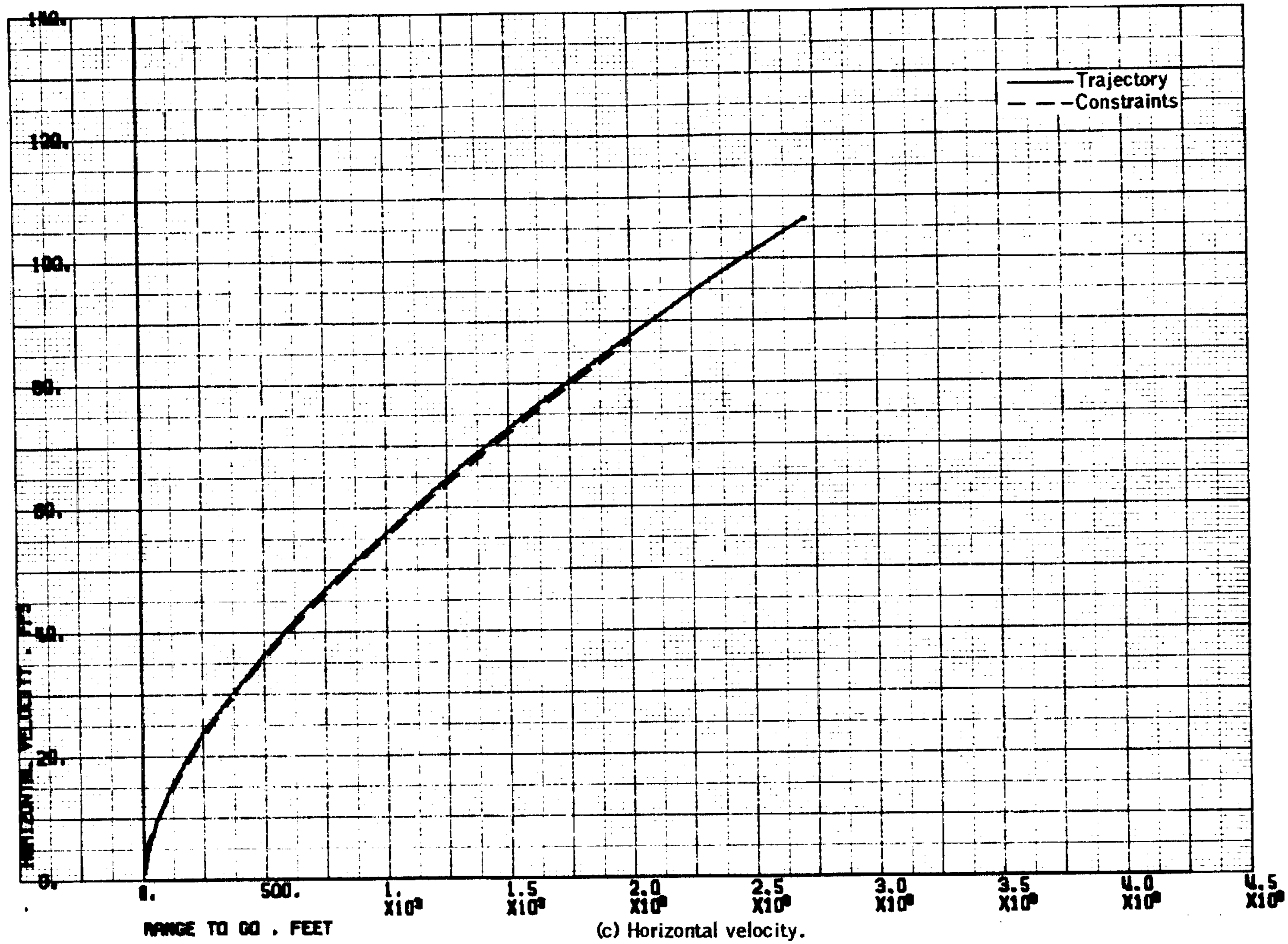
(a) Altitude.

Figure 7.- Landing phase trajectory characteristics as a function of range to the landing site.



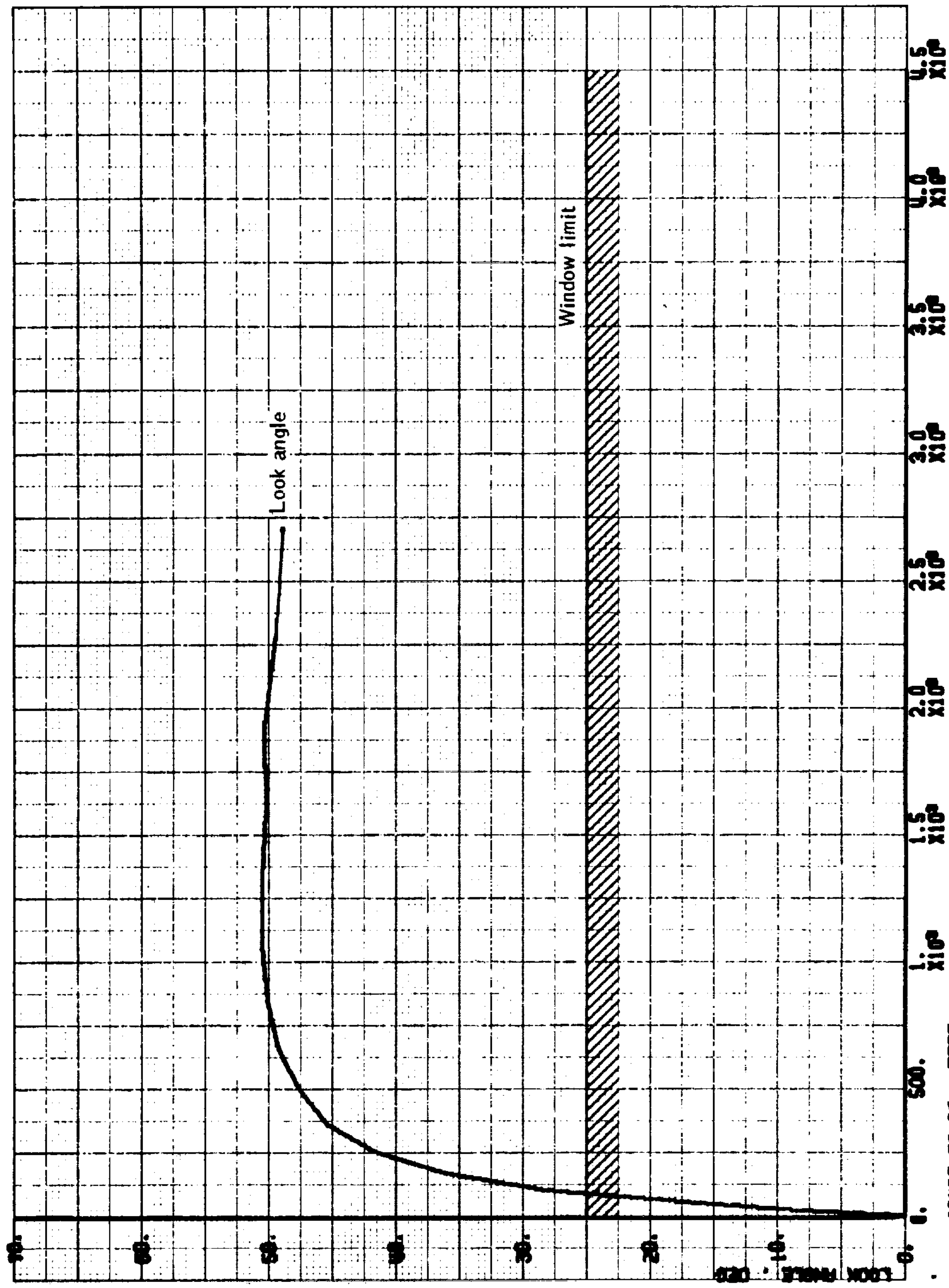
(b) Altitude rate.

Figure 7.- Continued.



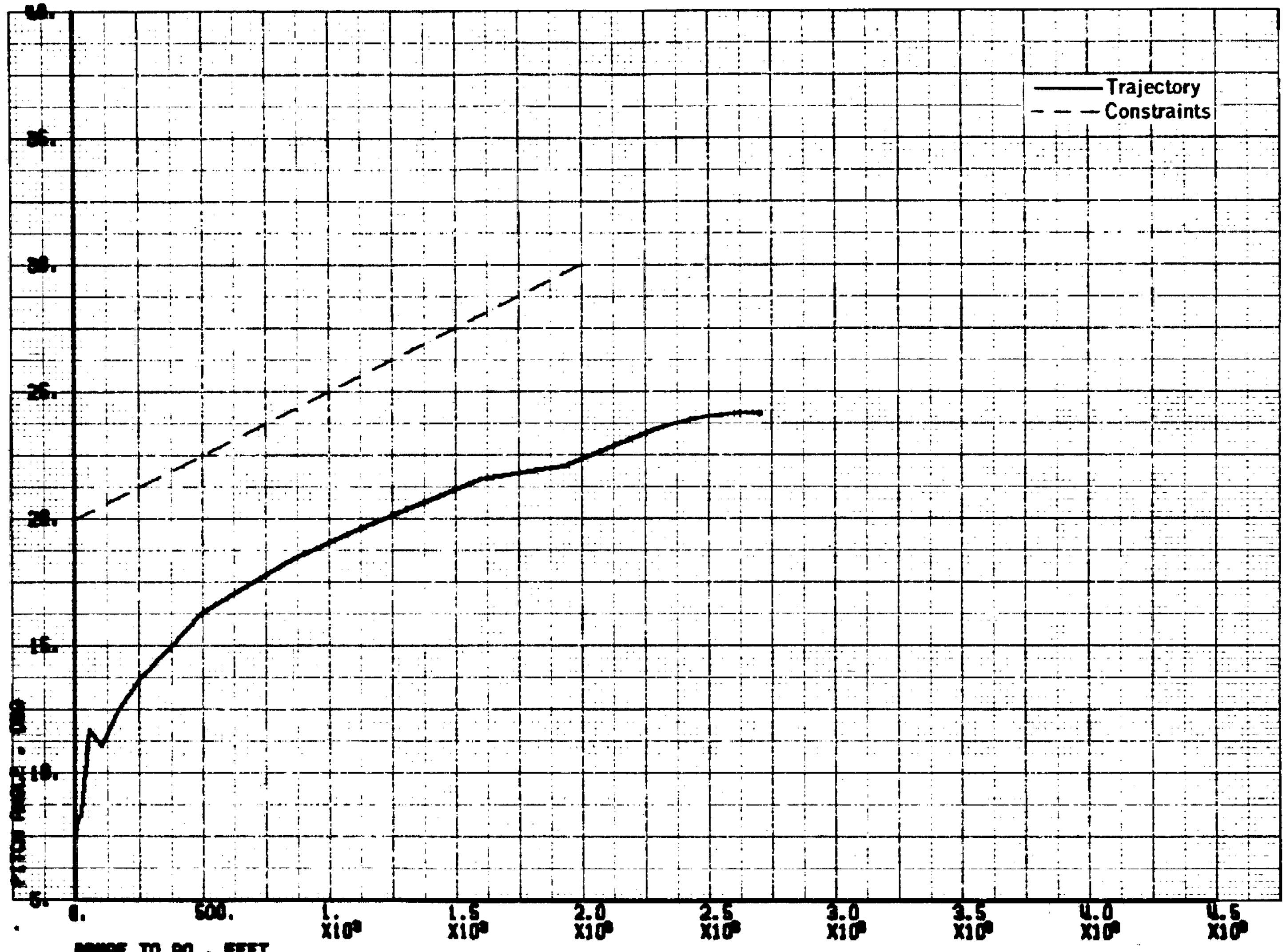
(c) Horizontal velocity.

Figure 7.- Continued.



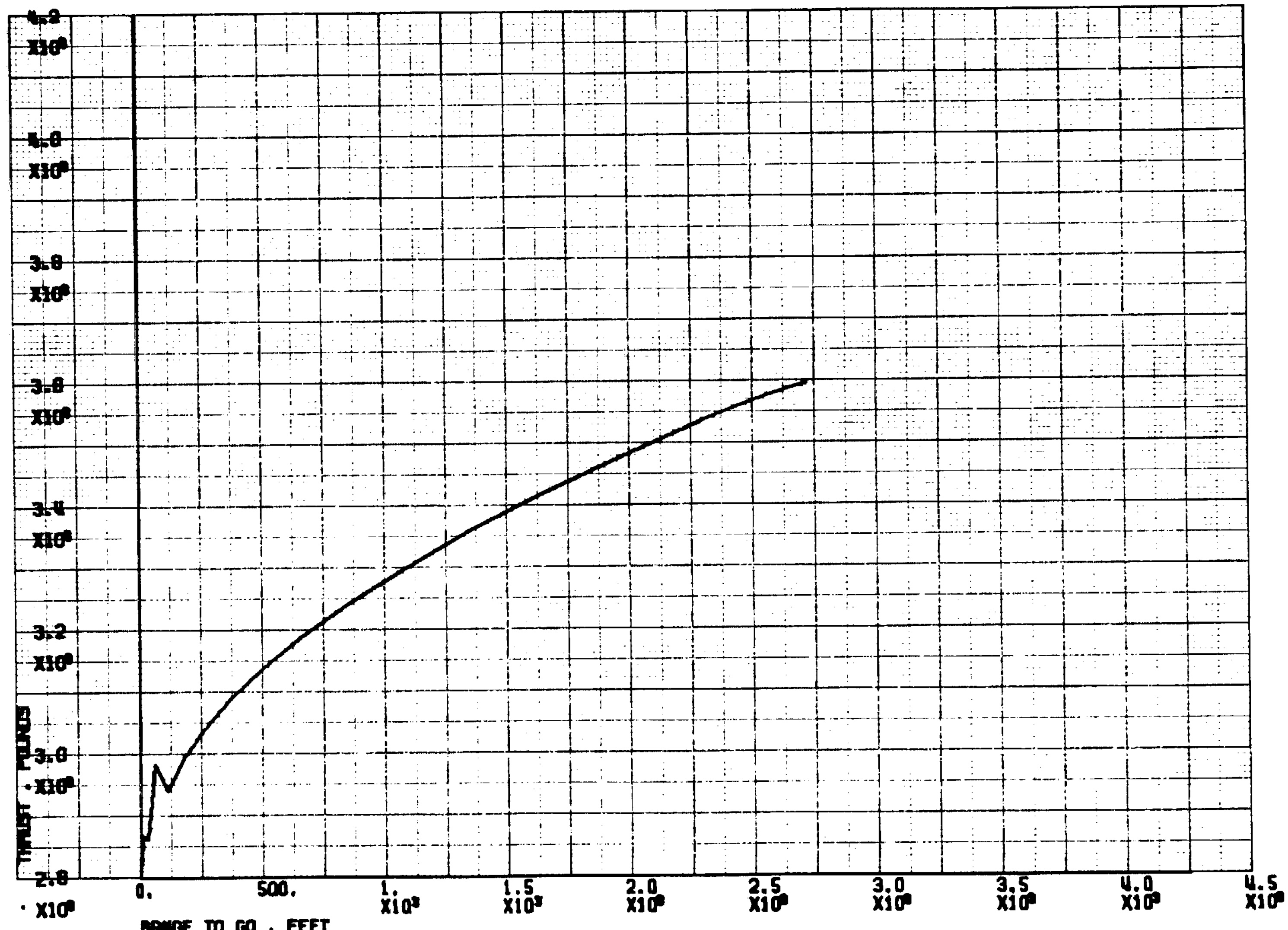
(d) Look angle.

Figure 7.- Continued.



(e) Pitch from local vertical.

Figure 7.- Continued.



(f) Commanded and actual thrust.

Figure 7.- Concluded.

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