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LM POWERED ASCENT TRAJECTORY FOR THE APOLLO LUNAR LANDING MISSION

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PROJECT APOLLO

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FIGURES

LM POWERED ASCENT TRAJECTORY FOR THE APOLLO LUNAR LANDING MISSION

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SUMMARY

This document presents the LM powered ascent trajectory for the lunar landing mission. The LM ascent utilizes a two-phase guided trajectory to achieve an orbit characterized by a periapsis altitude of 60 000 ft and an apoapsis altitude of 30 n. mi. The total characteristic velocity expended during the ascent to nominal orbit insertion is 6012 fps. The nominal ascent trajectory duration is 412.7 seconds.

INTRODUCTION

The last official publication containing the nominal lunar ascent trajectory was the "AS-504A Preliminary Spacecraft Reference Trajectory" (ref. 1), published July 1, 1966. Since that time, there have been updates in LM weights and engine performance data (ref. 2), and refinements to and better definition of the onboard ascent guidance equations (refs. 3 and 4).

An unscheduled document (ref. 5), whose purpose was to describe the data format planned for use in reference trajectory documentation, was published February 16, 1968. It should be emphasized, however, that this reference was not intended to be an official trajectory document and, hence, did not reflect recent data and guidance equation changes.

The purposes of this report are to present the revised LM powered ascent trajectory incorporating the latest available data along with the latest guidance equations and to serve as an interim ascent trajectory reference until the scheduled reference trajectory document is published. Data describing the trajectory is defined in the text and is presented in tabular and graphical form.

DEFINITION OF THE LM POWERED ASCENT TRAJECTORY

Operational Phases

The LM powered ascent trajectory assumes an in-plane launch into a 60 000-ft (9.88-n. mi.) by 30-n. mi. orbit about the moon. The ascent consists of two operational phases, a vertical rise phase (approximately 10-seconds duration) and a near-optimum guidance phase. The purpose of the vertical rise phase is to obtain sufficient altitude for terrain clearance prior to pitch over to the ascent guidance attitude. This phase terminates on the first computing interval after achieving a vertical ascent rate of 50 fps. The near-optimum guidance phase is designed to insert the LM into the desired nominal lunar orbit, which allows for completion of LM-CSM rendezvous in about 3 hours. Rendezvous maneuvers are performed using the LM reaction control system (RCS). The LM-CSM phase angle at insertion is 15.91° in this simulation.

Guidance and Targeting

The primary guidance and navigation control system (PGNCS) is used to guide the LM into a preselected orbit. The ascent guidance uses a fixed-thrust linear guidance concept (refs. 3 and 4) to control the powered ascent to specific insertion conditions. The desired orbital conditions at insertion are an altitude of 60 000 ft above the lunar launch site and an inertial velocity magnitude of 5510 fps. The PGNCS guidance has position control in the lateral and radial directions until the time to go (T_{go}) becomes less than 10 seconds. After T_{go} reaches 10 seconds, position control is eliminated, but velocity control is maintained. When T_{go} reaches 4 seconds, the PGNCS initializes a special timer to command engine shutdown.

The time-to-go equation, included in the ascent guidance, contains a parameter which is referred to as the T_{go} constant (K_T). A change in the value of this constant is reflected by a change in the shape of the altitude and altitude-rate profiles and a change in the characteristic velocity required to achieve nominal insertion conditions. After considerable study (refs. 6 and 7), it was determined that K_T should be assigned a value of 0.5. The official source for guidance constants (ref. 4) now reflects this value for K_T; and is, therefore, used here.

POWERED ASCENT SIMULATION DATA

Weight and Performance Data

The weight and performance data used to generate this trajectory were obtained from reference 2. Table I gives a brief summary of these data. The thrust used in simulating the ascent burn is the effective thrust considering +X axis RCS thrusting for center-of-gravity control. The RCS interconnect is used during ascent for center-of-gravity control; thus, an average ascent burn specific impulse (I_{sp}) is used. The ascent ΔV budget of 6060 fps, which is now under configuration control, is a result of a study documented in reference 8. This ΔV budget is confirmed by reference 2 and was adhered to in designing of this trajectory.

Trajectory Data

The conditions achieved after a nominal ascent to insertion are listed in table II. Time histories of trajectory parameters defining the LM ascent are presented in figure 1. It should be noted that the oscillations in the LM thrust angle [fig. 1(f)] reflect the attitude damping by the ascent guidance. The digital autopilot (DAP) was not included in this simulation. Since the DAP affects attitude response, its inclusion in the simulation would change the attitude damping characteristics. This area will be explored further when hybrid simulation capabilities are completed. Figure 2 shows the altitude rate with respect to altitude. Figure 3 shows the inertial flight-path angle as a function of inertial velocity. Time histories of the relative LM-CSM parameters are given in figure 4. The X and Z relative range plots [figs. 4(f) and (g)] are referenced to a curvilinear coordinate system whose origin is at the CSM. The fact that the X relative range is negative and the Z relative range is positive means that the LM is behind and below the CSM. Figure 5 presents Z relative range as a function of X relative range. Figure 6 shows the LM-CSM range rate versus range.

CONCLUDING REMARKS

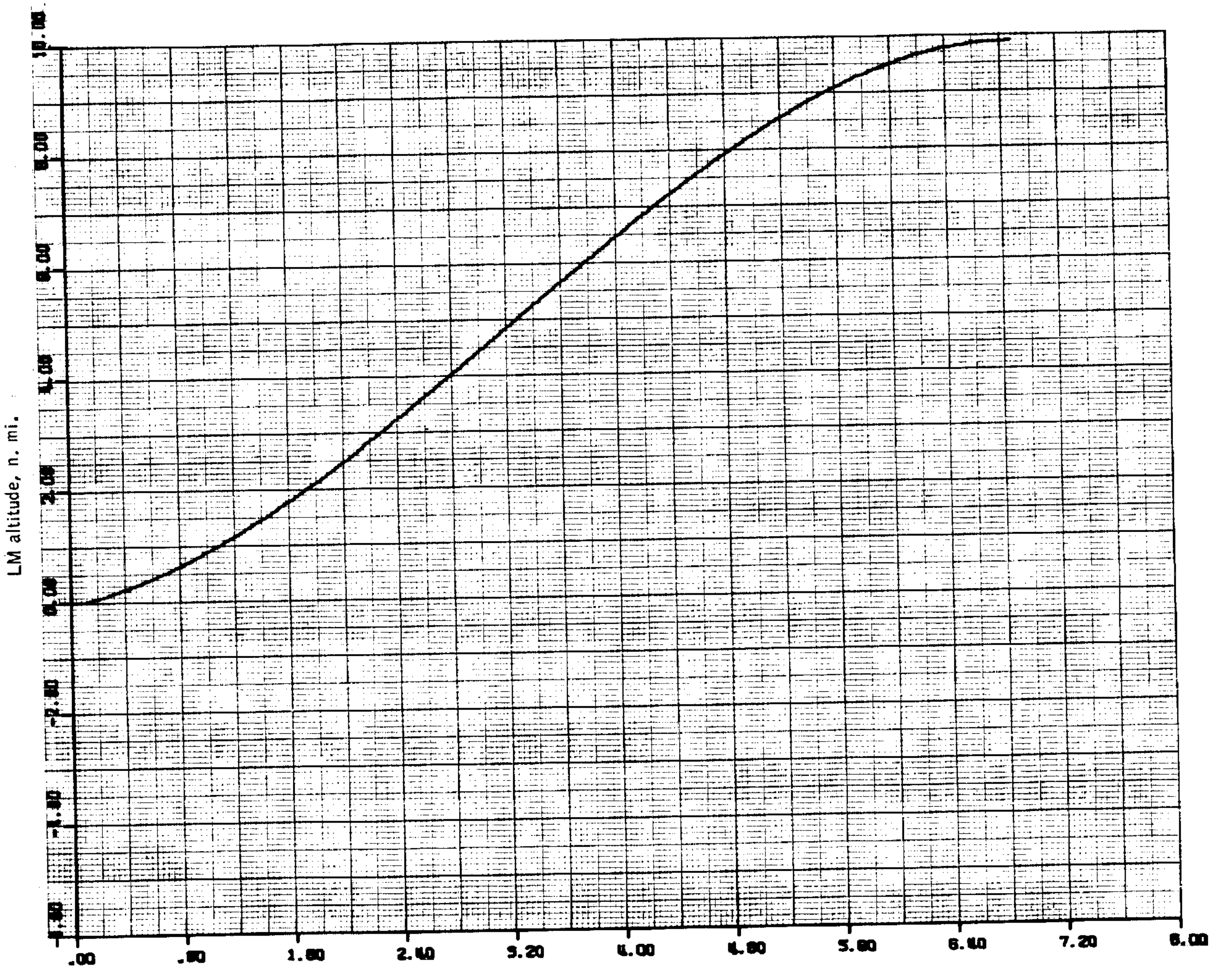
The LM powered ascent trajectory for the lunar landing mission has been redesigned as a result of recent changes in LM weights and performance data. These data changes also necessitated a reduction in the CSM lunar parking orbit altitude from 80 to 60 n. mi. As far as the LM powered ascent is concerned, this altitude change affected only the time sequencing of the LM-CSM rendezvous; and, is reflected in the relative motion plots. This trajectory should be used in engineering simulations as the nominal LM ascent trajectory for the Apollo lunar landing mission until it is superseded by the reference trajectory document.

TABLE I.- LM POWERED ASCENT WEIGHT AND PERFORMANCE DATA

Total weight at lunar lift-off, lb	10 729.0
APS propellant (for $\Delta V = 6060$ fps), lb	4 962.0
APS and RCS effective thrust, lb	3 627.0
APS and RCS average I_{sp}, sec	303.4

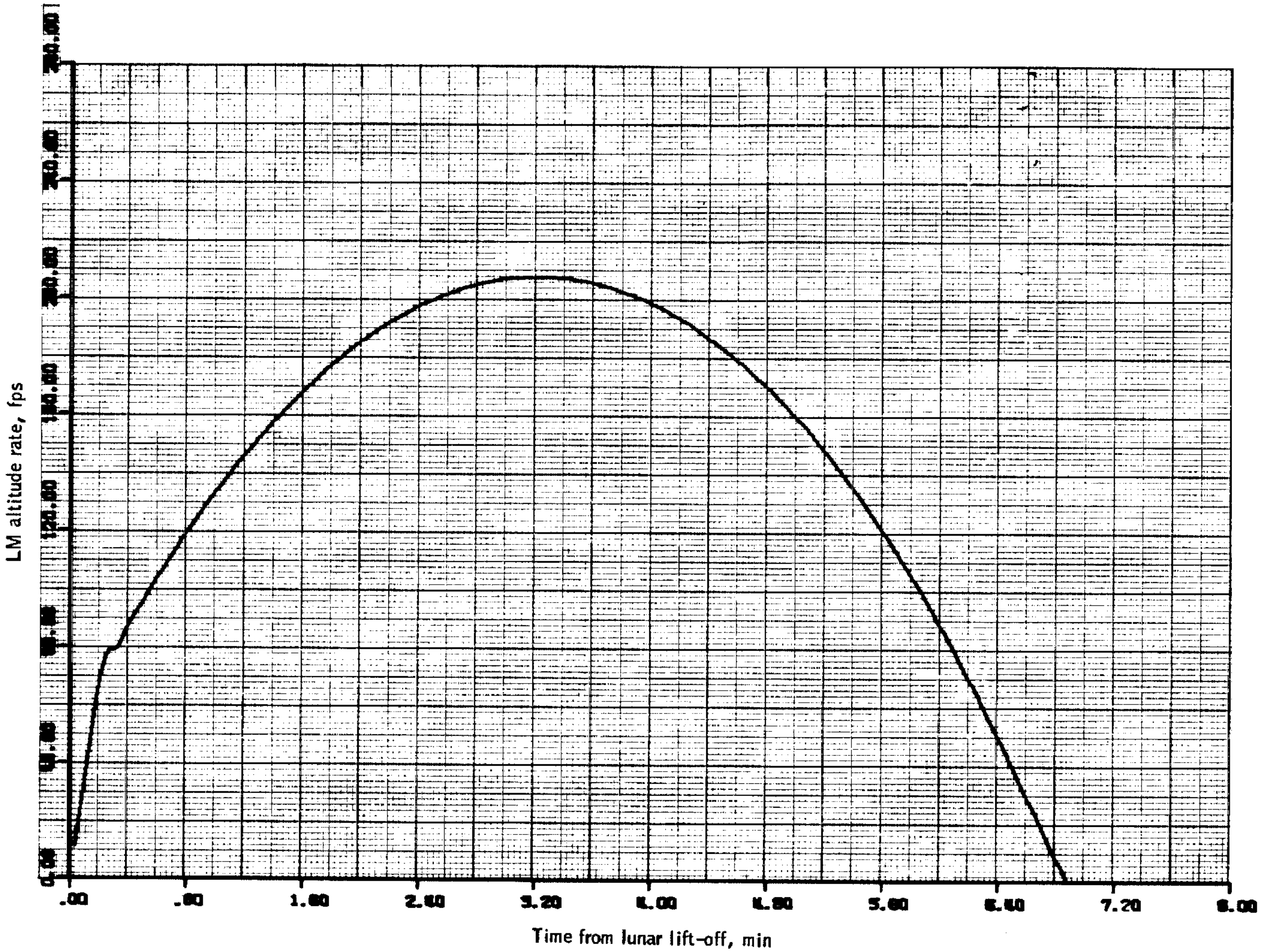
TABLE II.- LM POWERED ASCENT INSERTION CONDITIONS

Burn time, sec	412.686
Burn arc, deg	9.47
Thrust angle (pitch), deg.	-5.44
Insertion phase angle, deg	15.91
Insertion velocity, fps.	5510.0
Insertion altitude, ft	60 000.0
Delta V, fps	6011.74
Propellant used, lb.	4933.44
Insertion weight, lb	5795.56



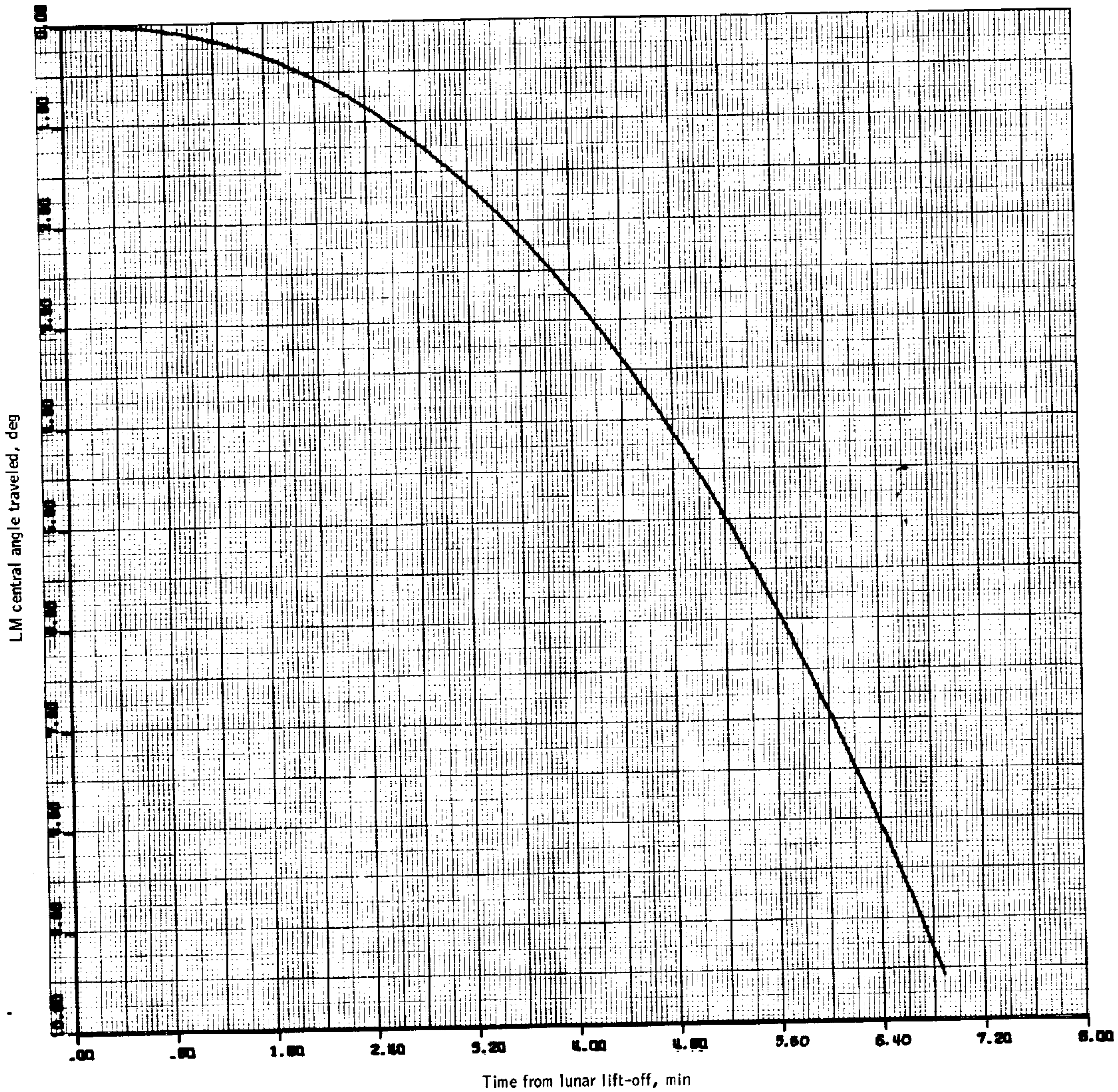
(a) LM altitude.

Figure 1.- Time histories of LM trajectory parameters during powered ascent.



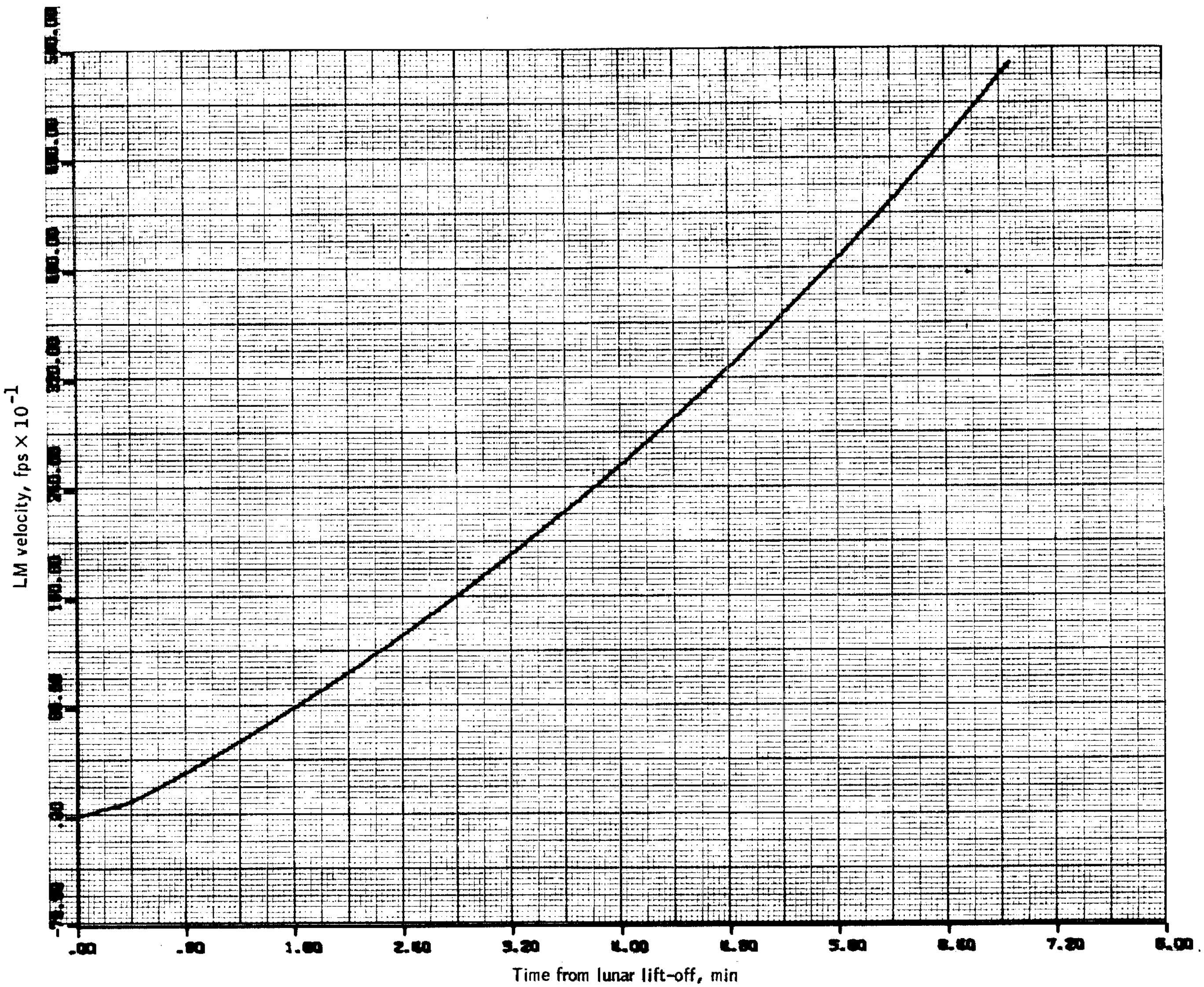
(b) LM altitude rate.

Figure 1.- Continued.



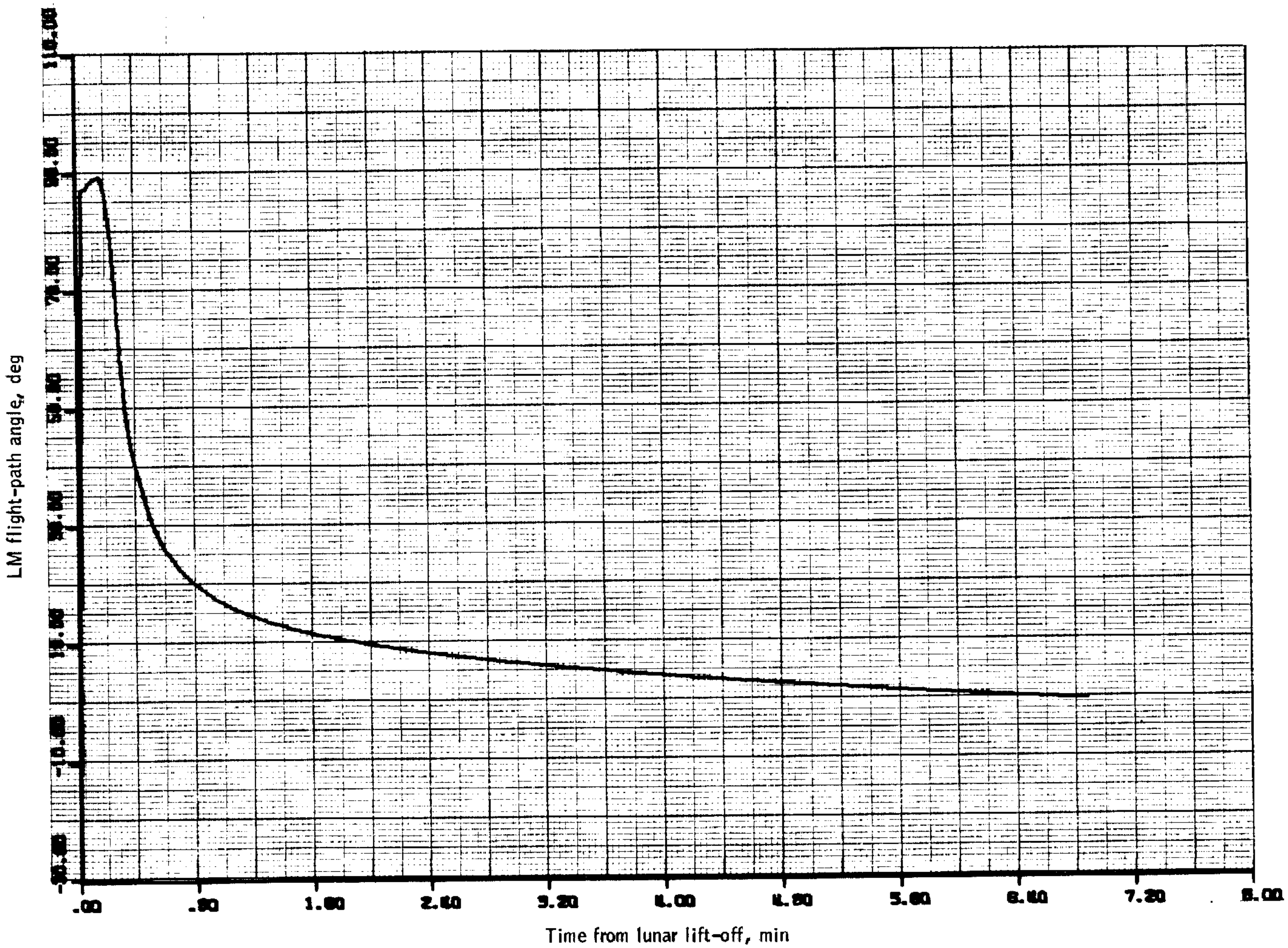
(c) LM central angle traveled.

Figure 1.- Continued.



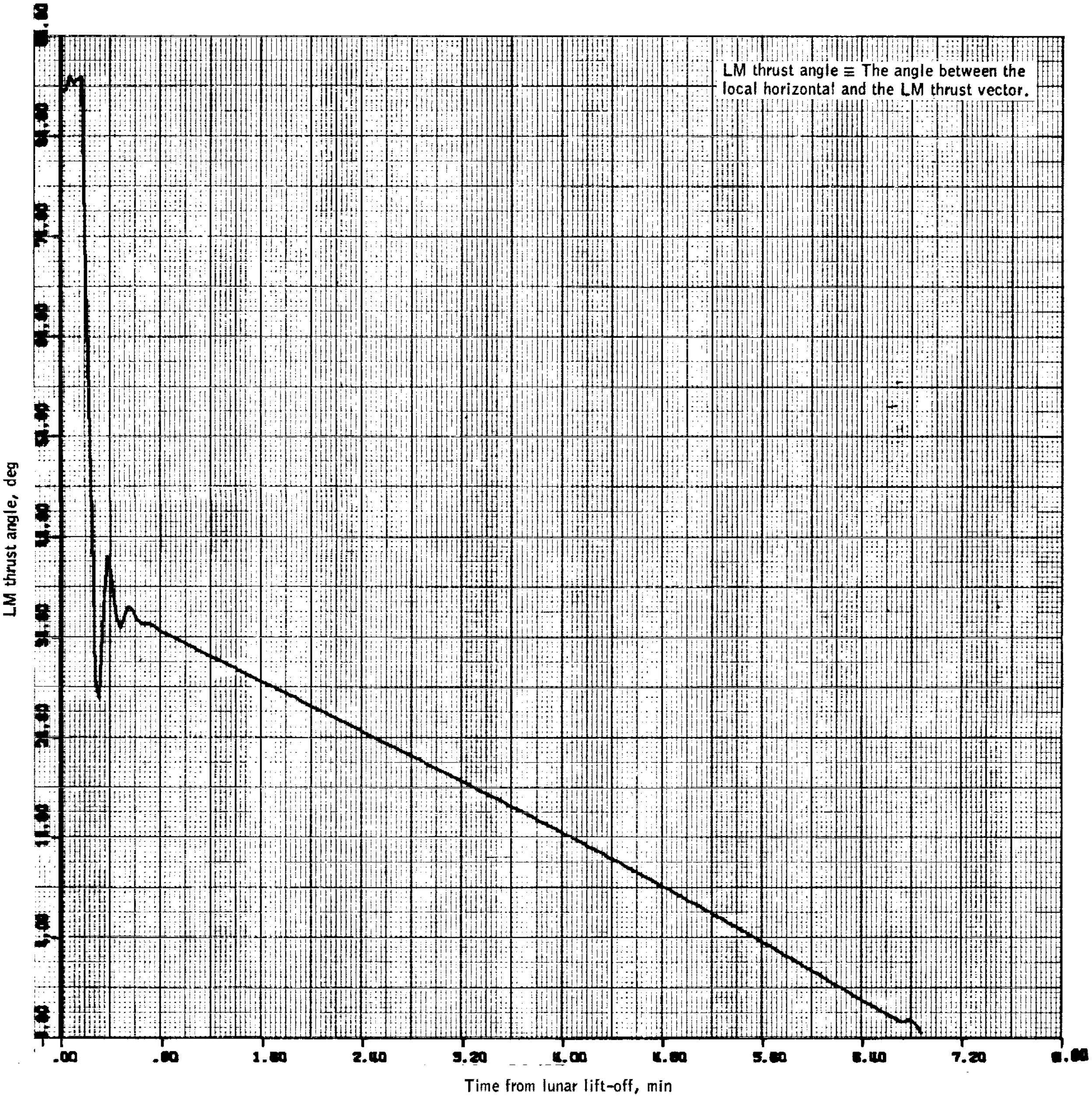
(d) LM velocity.

Figure 1.- Continued.



(e) LM flight-path angle.

Figure 1.- Continued.



(f) LM thrust angle (pitch).

Figure 1.- Concluded.

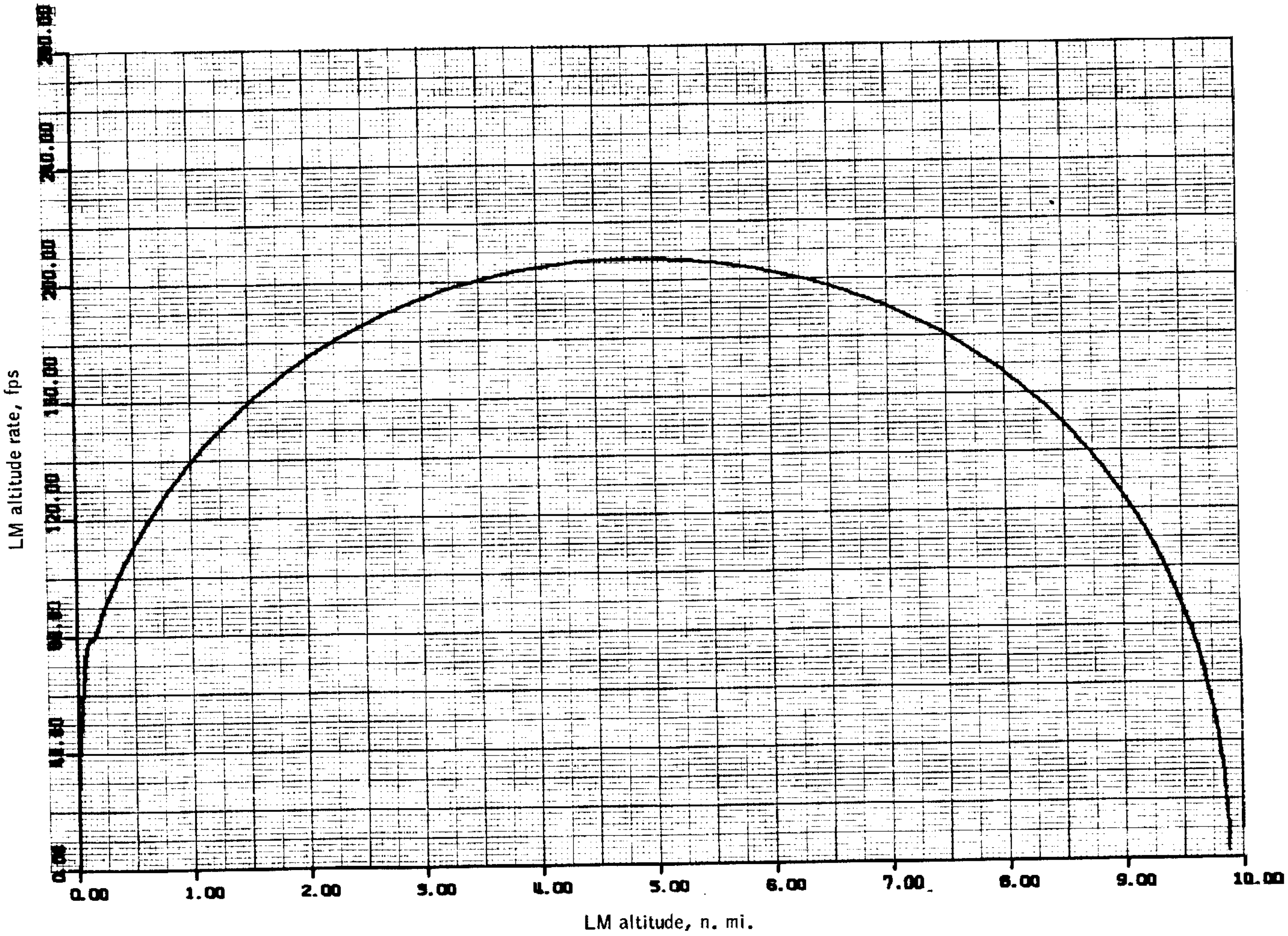


Figure 2.- LM altitude rate versus altitude during powered ascent.

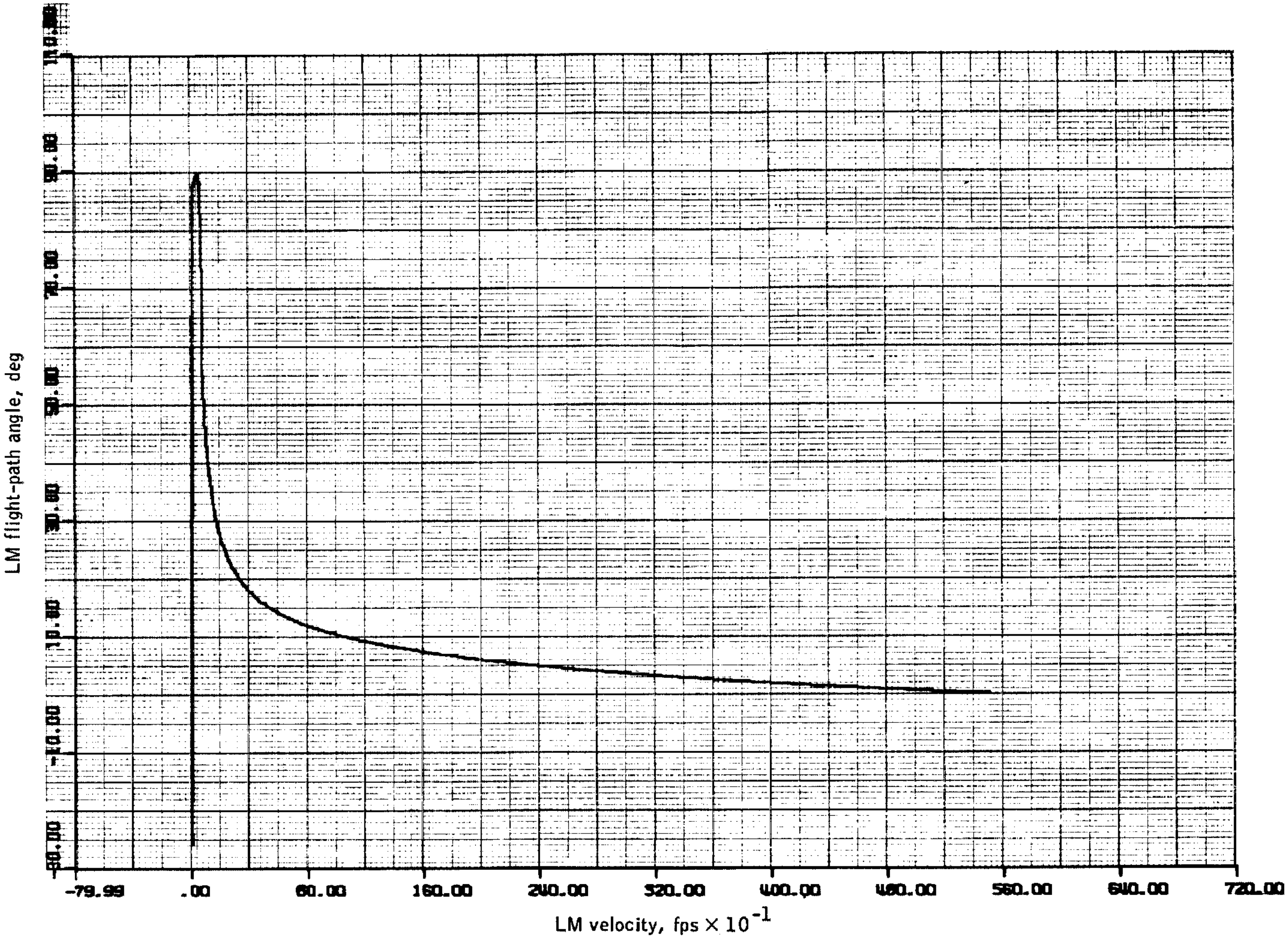
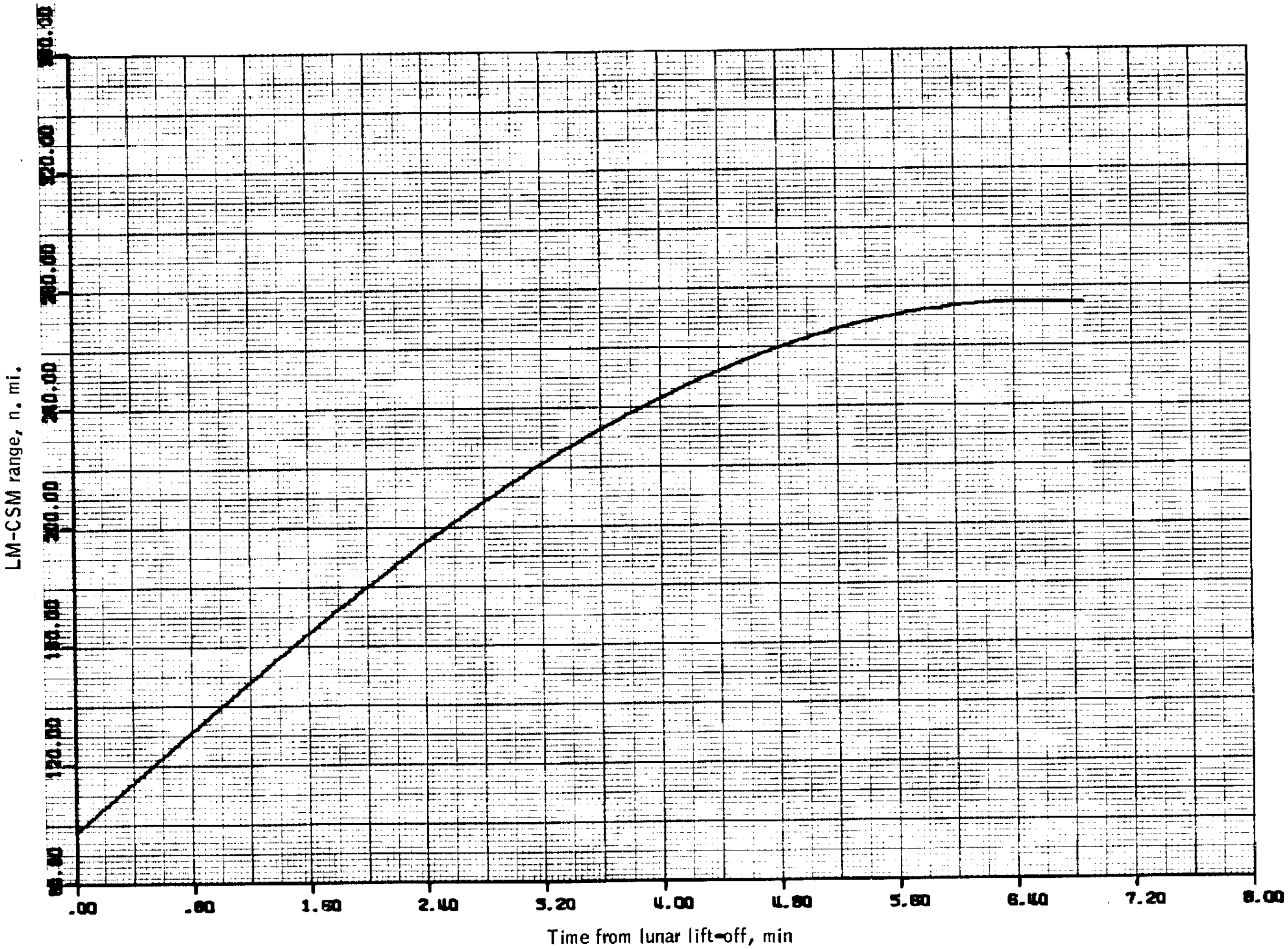
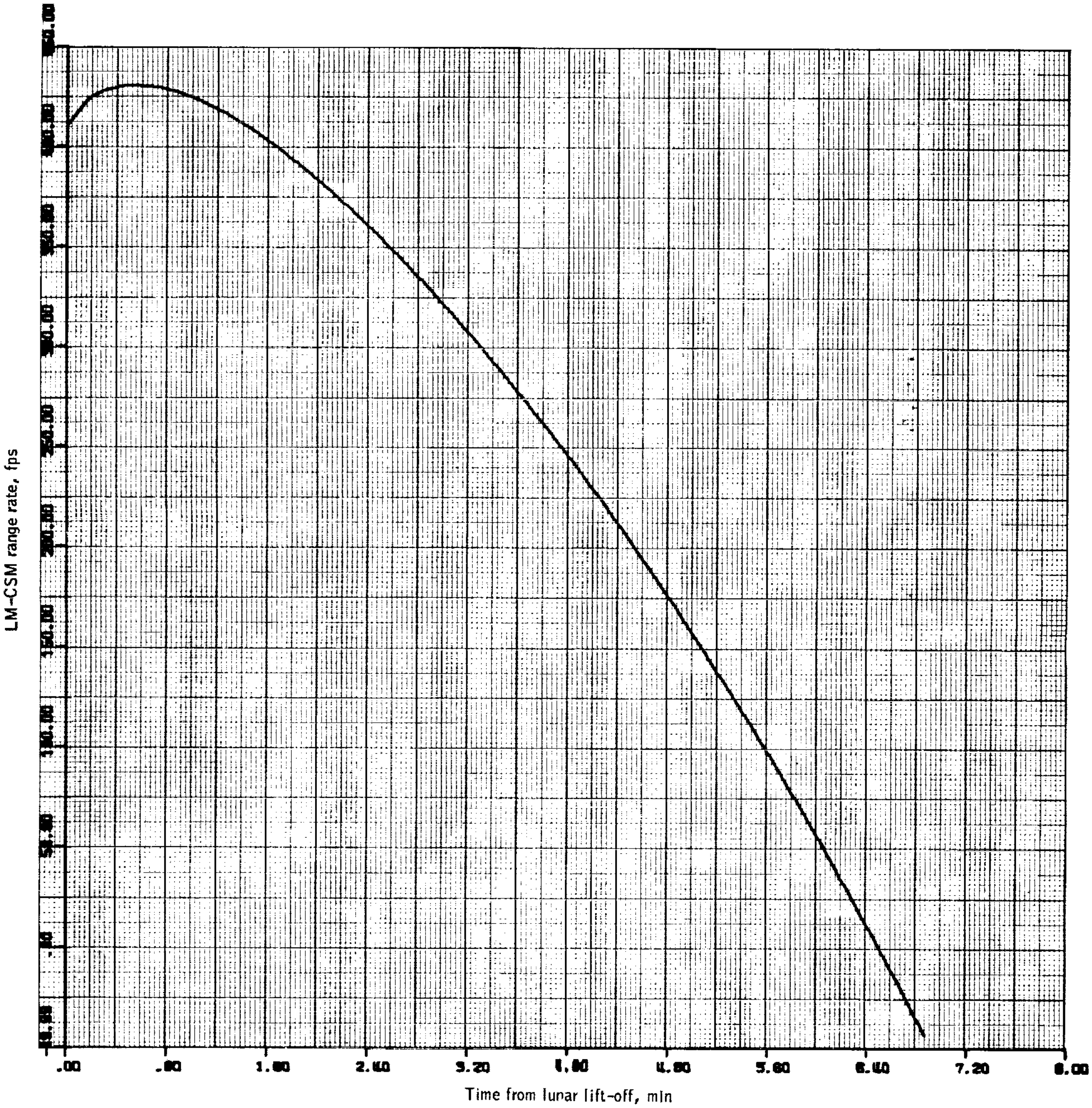


Figure 3.- LM flight-path angle versus inertial velocity during powered ascent.



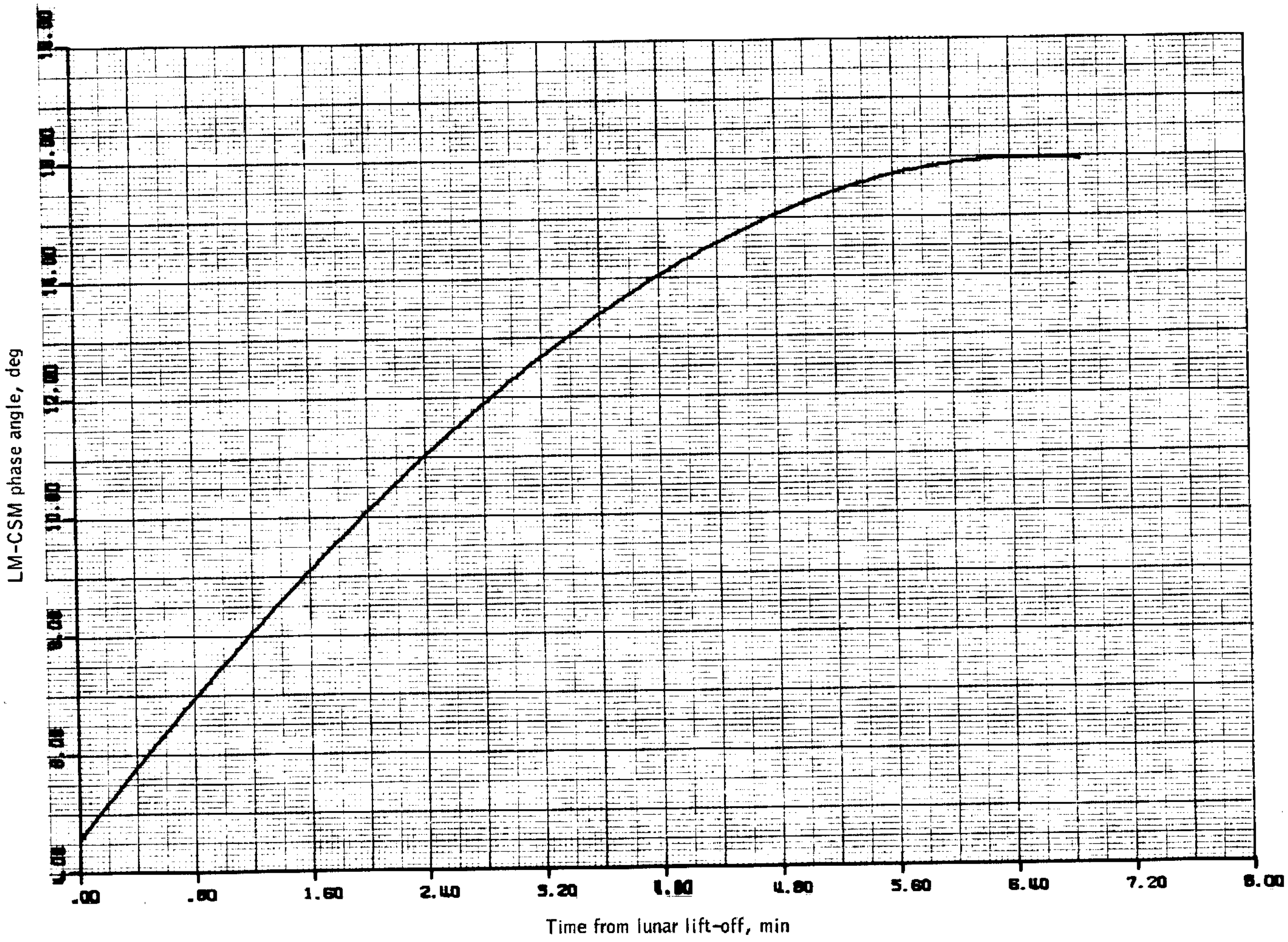
(a) LM-CSM range.

Figure 4. - Time histories of relative LM-CSM parameters during powered ascent.



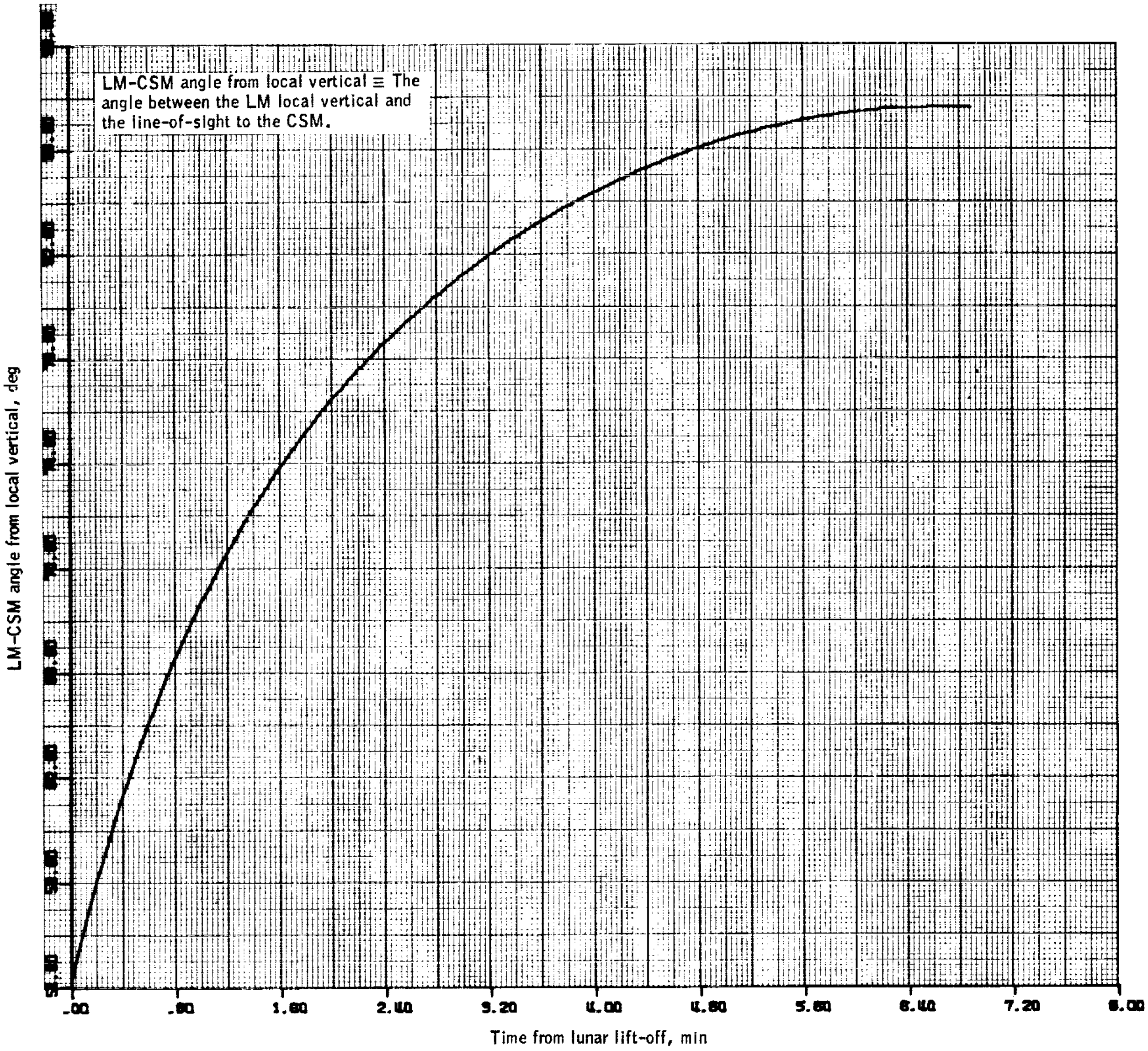
(b) LM-CSM range rate.

Figure 4.- Continued.



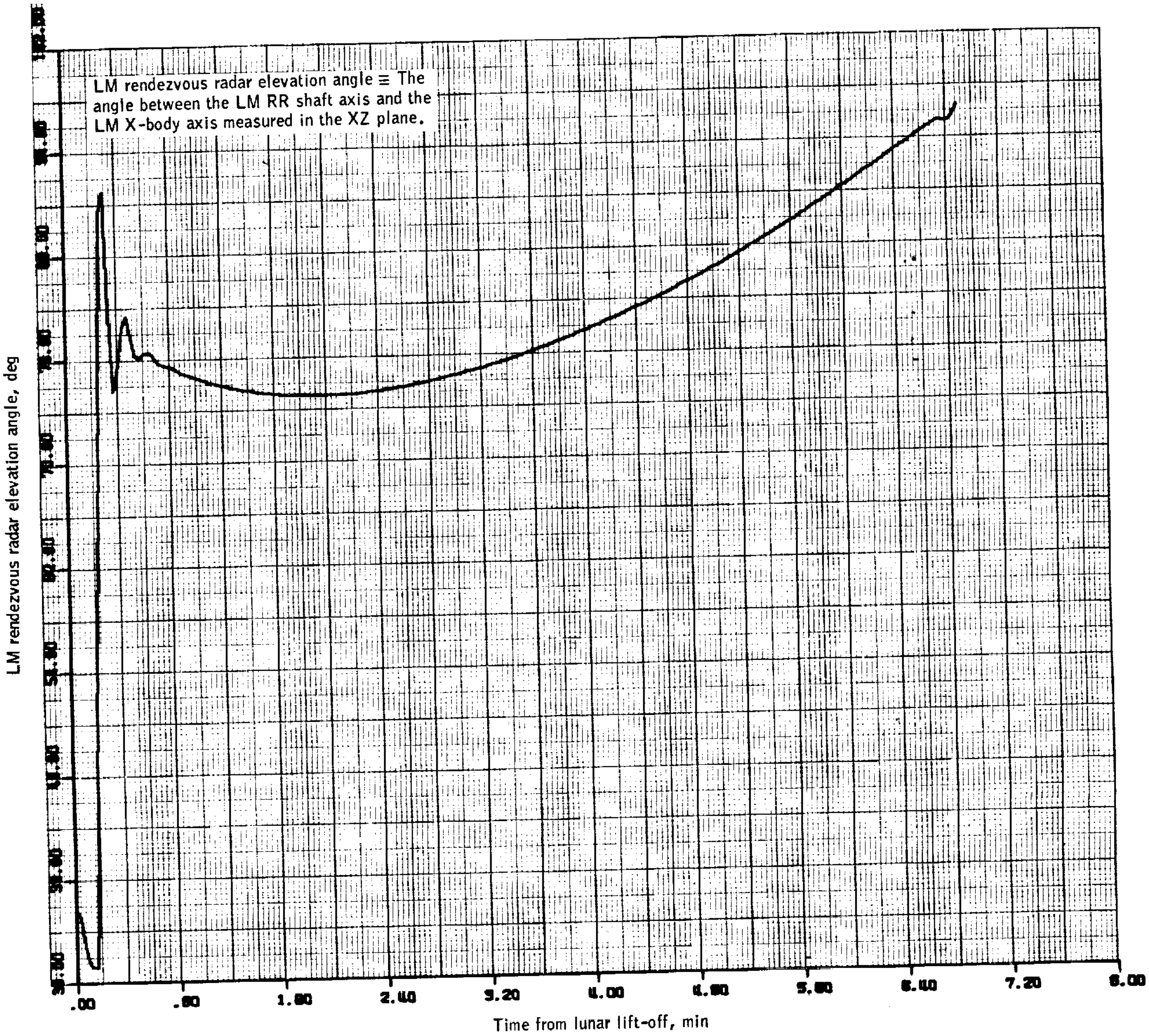
(c) LM-CSM phase angle.

Figure 4.- Continued.



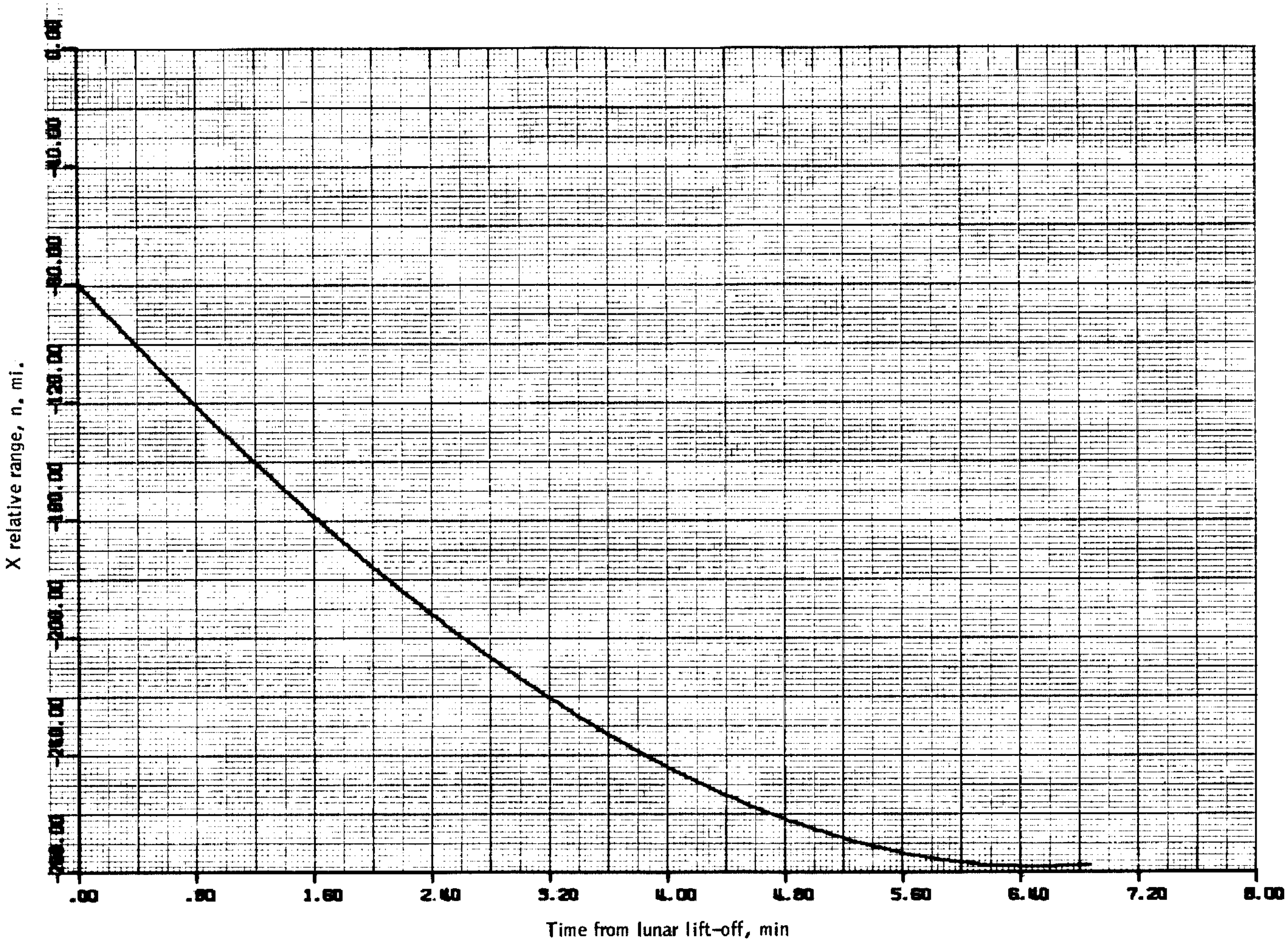
(d) LM-CSM angle from local vertical.

Figure 4.- Continued.



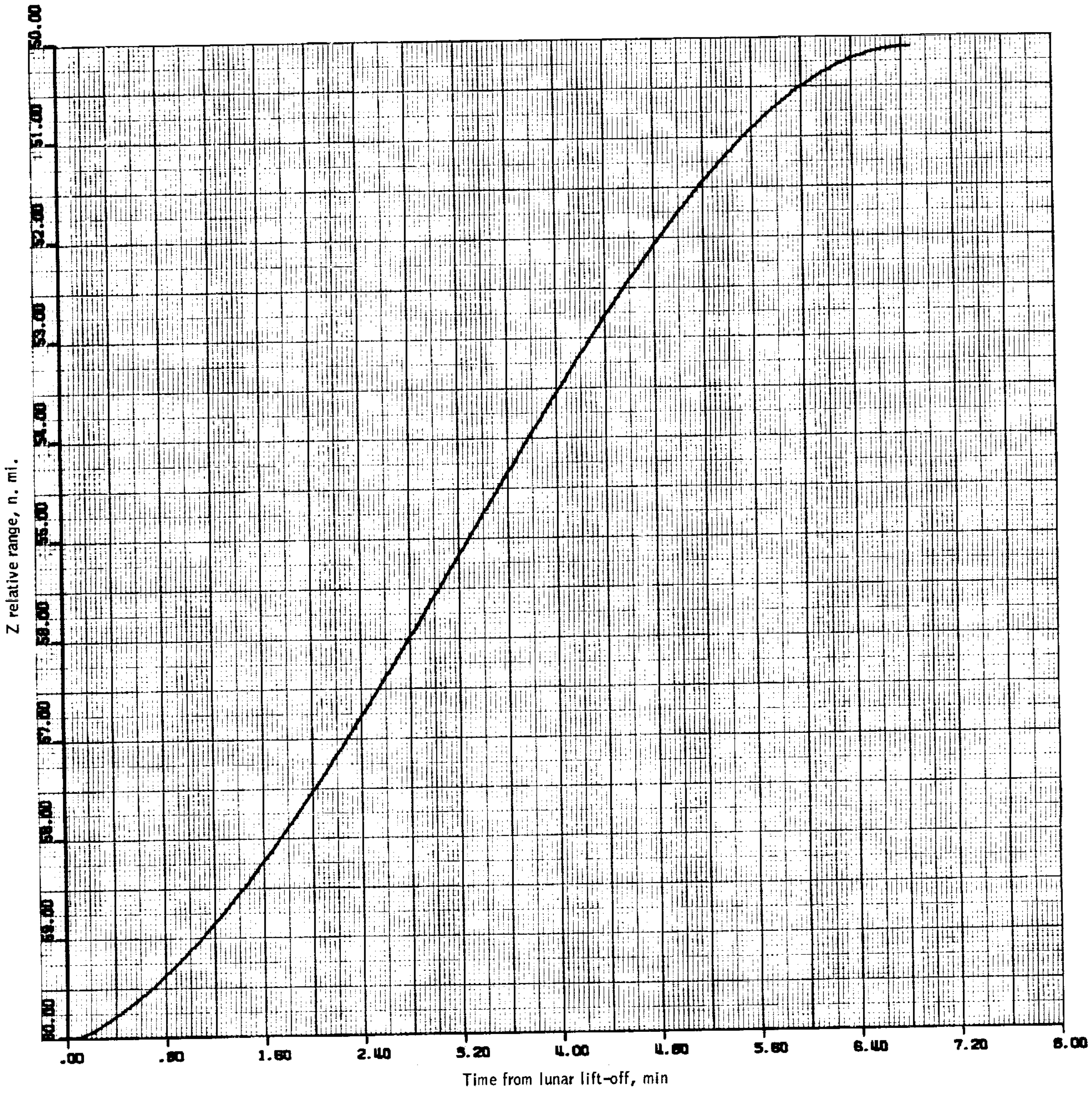
(e) LM rendezvous radar elevation angle.

Figure 4.- Continued.



(f) X relative range (CSM referenced).

Figure 4.- Continued.



(g) Z relative range (CSM referenced).

Figure 4.- Concluded.

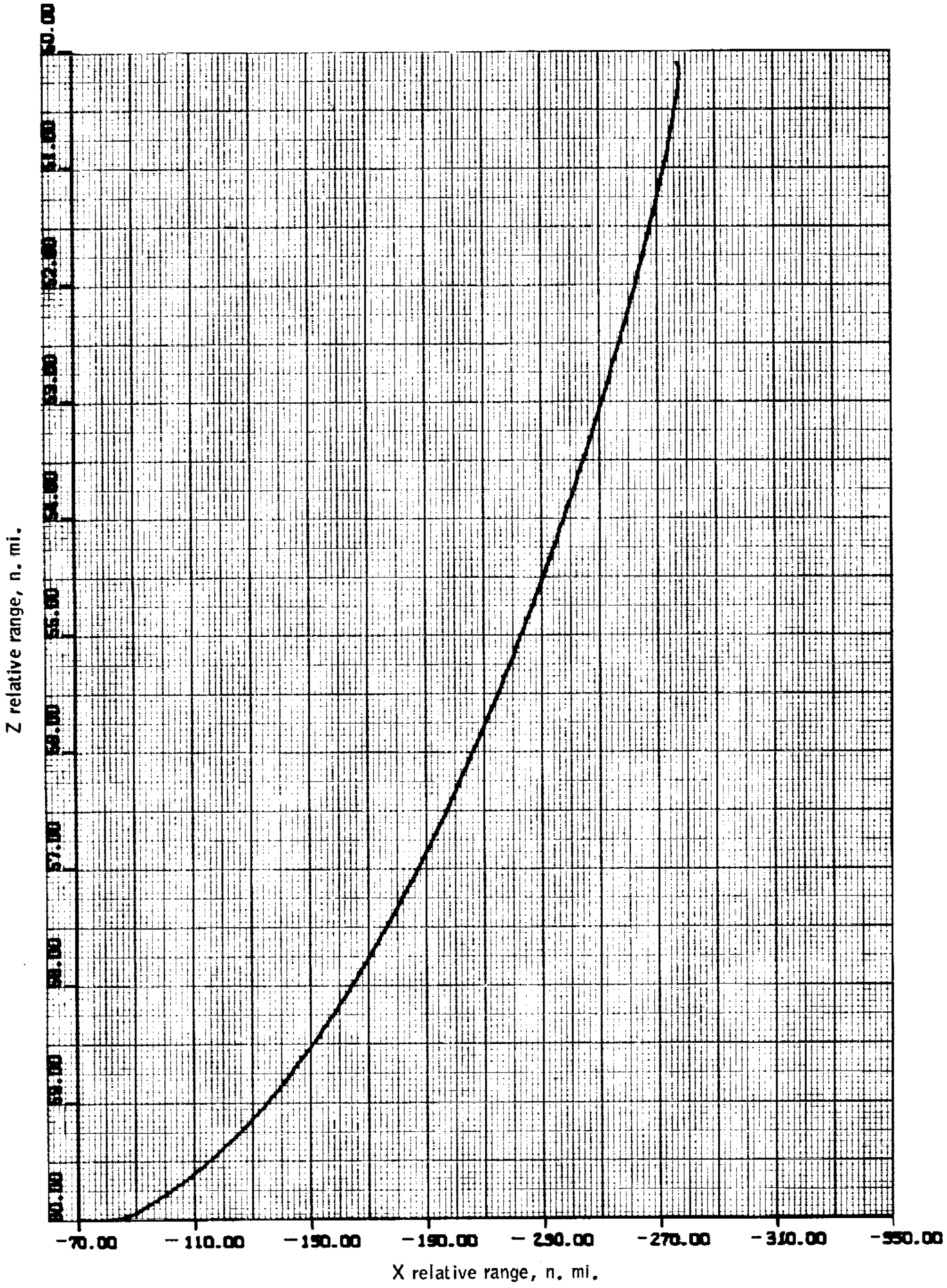


Figure 5.- Z relative range versus X relative range during powered ascent (CSM referenced).

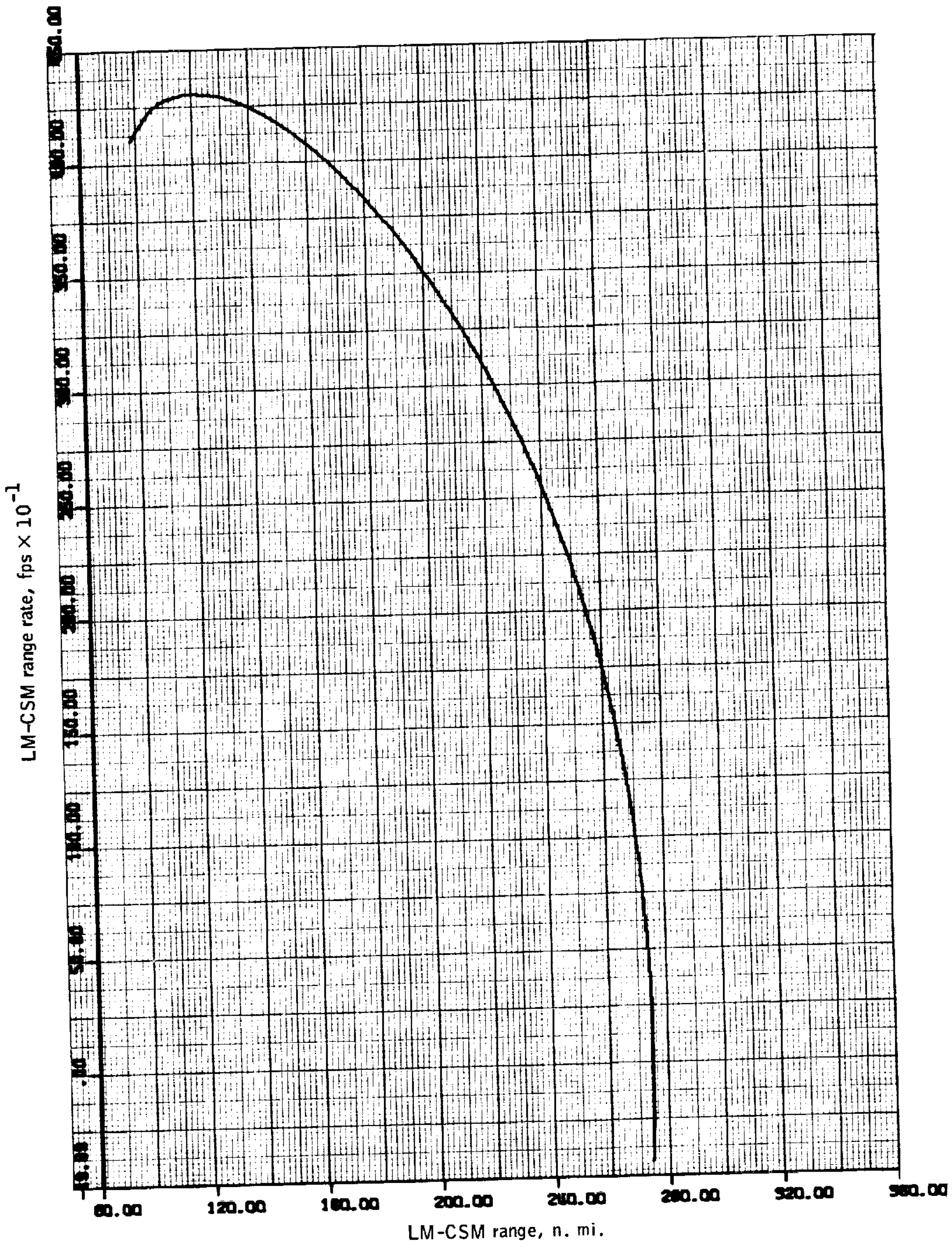


Figure 6.- LM-CSM range rate versus range during powered ascent.

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