JUN 6 1968

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27

5010-107

Armstrong

UNITED STATES GOVERNMENT

Memorandum

NASA - Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See list below

DATE: 19 MAR. 1968
File No. 68-FM13-148

FROM : FM13/Chief, Mission Planning Support Office

SUBJECT: Apollo Mission E (AS-504/CSM 104/LM-4) Spacecraft Reference Trajectory

1. The attached document presents the Spacecraft Reference Trajectory for the "E" mission. The document consists of four volumes to be published separately. They are:

Volume I--Nominal Trajectory
Volume II--Trajectory Listing
Volume III--Radar Data (combined with Volume I)
Volume IV--Consumables Analysis

2. The four volumes have been distributed according to the attached list. Any questions or comments pertaining to the document or its distribution should be referred to this office.

R. P. Parten

APPROVED BY:

John P. Mayer, Chief
Mission Planning and Analysis Division

Enclosures

Addressees:
(See attached list)

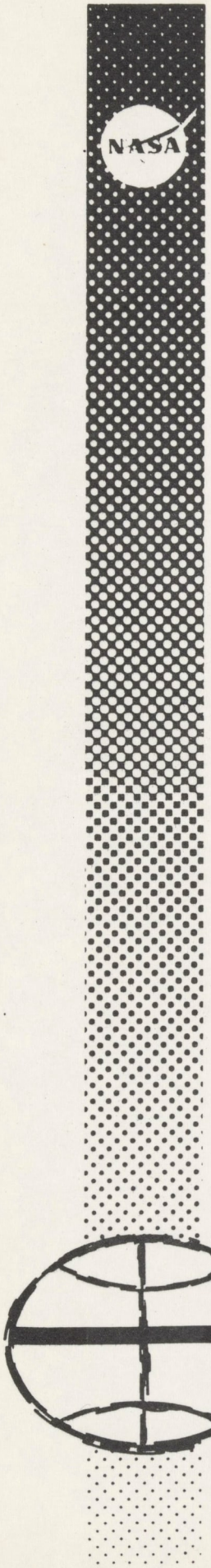
FM13:DReed:pj

Apollo Mission "E" (AS-504/CSM 104/LM-4) Spacecraft Reference Trajectory

	Volume I	Volume II	Volume III	Volume IV
Distribution:				
AC Electronics/F. Weber	3	1	1	1
Bellcomm/V. Mummert	5	5	5	5
GAEC/H. R. Grossman (KSC)	2			
GAEC/R. L. Pratt	24	3	3	5
GAEC/RASPO	1			1
GE/W. C. Schaffer	1	1	1	
GSFC/T. Roberts	2			
GSFC/Dr. F. O. Vonbun/550	5	1	1	3
GSFC/A. G. Tucker/821	10	10	10	
PSK/W. J. Kapryan	2			2
IBM Houston/J. Bednarcyk	6	1	2	3
IBM Houston/R. Kirchoff	1	1	1	
IBM Houston/Library	1	1	1	1
IBM Maryland/G. K. Tomlin	1	1	1	1
Link Group/R. W. Borland	1	1	1	
Link Group/G. Saccone	1	1	1	1
Lockheed Houston/S. Hasara	1	1	1	
KSC/Dr. A. H. Knothe, EX-SCI				1
KSC/TS-TSM-1, A. H. Moore	8	3	3	4
KSC/Flight Safety Staff, NC-1	1	1	1	1
KSC/H. Smith/HS	1			
KSC/N. Vaughn/HY	1	1	1	1
MIT/J. Dahlen	5	2	2	3
MSFC/I-I/IB-E/D. Germany	1			1
MSFC/I-MO-R/A. McNair	2	1	1	2
MSFC/I-V-E/R. Barraza	1			1
MSFC/I-VE/T. J. McCullough	1			1
MSFC/R-AERO-DA/E. Deaton	1	1	1	1
MSFC/R-AERO-DA/T. Telfer	1			
MSFC/R-AERO-DAP/J. Cremin	1			1
MSFC/R-AERO-F/C. Hagood	1			1
MSFC/R-AERO-F/L. Stone	1			1
MSFC/R-AERO-FM/O. Hardage	1			1
MSFC/R-AERO-P/H. Ledford	2		3	2
MSFC/R-AERO-P/L. McNair	1			1
MSFC/R-ASTR-F/H. Hosenthien	1			1
MSFC/R-ASTR-IR/O. Ely	1			1
MSFC/R-ASTR-N/F. Moore	1			1
MSFC/R-ASTR-NG/W. Chubb	1			1
MSFC/R-ASTR-NG/S. Seltzer	5			5
MSFC/R-ASTR-S/J. Mack	1			1

Distribution:	Volume I	Volume II	Volume III	Volume IV
NR/RASPO	1	1	1	1
NR/W. L. Steinwachs	20	6	4	6
NASA Daytona/A. S. Lyman	1	1	1	
NASA Hqs/MAO-4/Aller	2	2	2	2
NASA Hqs/MO/Stephenson	1	1	1	
NASA Hqs/MAO-3/F. E. Stout	2	2	2	
NASA Hqs/MO/Abernethy	2	2	2	2
NASA Hqs/MAS-4/Hickey	1	1	1	1
GE/Kelly	1	1	1	1
TRW/B. J. Gordon	5	1	1	5
TRW/L. Wilcox	1			1
TRW/R. L. Stamm	1			1
TRW/H. Tash	3	2	1	1
TRW/Library	1	1	1	1
AB/G. S. Trimble	1			
AR/F. J. Bailey	1			1
BM6/Technical Library	2	2	2	2
CA/D. K. Slayton	2			2
CB/A. B. Shepard	5			5
CF/W. J. North	22	22	22	11
CF/McDonnell/C. Jacobsen	2			
CF33/R. Jones	1	1	1	1
DA/C. A. Berry	1			1
DA/D. O. Coons	1			1
DB/L. F. Dietlein	1			1
DC32/S. E. Martin	1			
EA/M. A. Faget	1			1
EB/P. H. Vavra	6	1	6	1
ED/E. H. Brock	1			1
ED3/M. T. Cunningham	1			1
ED3/S. M. Keathly	1			1
EE/G. Bills	1			1
EE/R. W. Sawyer	5			1
EG/R. A. Gardiner	10	2		2
EG21/M. Kayton	1	1	1	1
EG25/J. Hanaway	1			1
EG27/R. W. Simpson	1	1	1	
EP/J. G. Thibodeau	2	1	1	1
EP2/C. H. Lambert	2			
ES12/Project Support Office	1			1
ET/W. E. Stoney	4			1
ET25/B. Redd				1
TD/J. W. Small	1			1
EX3/B. G. Jackson	5	1		1
FA/C. C. Kraft, Jr.	1	1	1	1
FA/S. A. Sjoberg	1	1	1	1
FA/R. G. Rose	1	1	1	1
FA/C. C. Critzos	1	1	1	1

Distribution:	Volume I	Volume II	Volume III	Volume IV
FC/J. D. Hodge	23	8	2	20
FC6/H. G. Miller	7	2	2	3
FL/J. B. Hammack	5	2	2	2
FM/J. P. Mayer	1	1	1	1
FM/H. W. Tindall, Jr.	1	1	1	1
FM/C. R. Huss	1	1	1	1
FM/M. V. Jenkins	1	1	1	1
FM2/F. Bennett	2	1	1	1
FM3/C. Hicks	4	3	1	4
FM4/J. McPherson	2	2	1	1
FM5/M. P. Frank	3	2	2	3
FM6/E. Lineberry	2	1	1	1
FM7/M. D. Cassetti	2	1	1	1
FM7/J. O'Loughlin	1	1	1	1
FM8/J. Funk	1	1	1	1
FM12/E. B. Patterson	25	10	7	50
FM13/R. P. Parten	3	1	1	3
FM13/D. J. Incerto	2	1	1	1
FM13/M. A. Goodwin	1	1	1	1
FS/L. Dunseith	21	19	22	5
HE03/R. P. Rudd	1	1	1	1
HR01/J. Pittman (TBC)	1	1	1	1
KA/R. F. Thompson	2	2	2	2
KM/W. B. Evans	1	1	1	1
PA/C. H. Bollender	1			1
PA/G. M. Low	1			1
CFK/R. D. McCafferty	16	2	2	12
PD/O. E. Maynard	4	4	4	4
PD/R. J. Ward	1			1
PD/L. Jenkins				1
PD/R. V. Battey	1			1
PD7/D. Segna	15			15
PE/O. G. Morris	2			1
PF/R. W. Lanzkron	3			2
PK/A. Mardell	1	1	1	1
PR/W. M. Bland	3			3
ZR2/E. W. Ivy	2	2	2	2
Pratt & Whitney Aircraft/ G. Alexander	1			
DDMS-N, Patrick AFB, Fla.	1	1	1	1
AFETR/ETOOP-2, Patrick AFB Fla.	3	3	3	3



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC INTERNAL NOTE NO. 68-FM-126

May 29, 1968

APOLLO MISSION E (AS-504/CSM-104/LM-4) SPACECRAFT REFERENCE TRAJECTORY VOLUME IV-CONSUMABLES ANALYSIS

By Arnold J. Loyd, Martin L. Alexander, Richard C. Wadle, Harry Kolkhorst, Richard M. Swalin, and Sam A. Kamen,

Guidance and Performance Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MSC INTERNAL NOTE NO 68-FM-126

PROJECT APOLLO

APOLLO MISSION E (AS-504/CSM-104/LM-4) SPACECRAFT REFERENCE TRAJECTORY VOLUME IV - CONSUMABLES ANALYSIS

By Arnold J. Loyd, Martin L. Alexander, Richard C. Wadle, Harry Kolkhorst, Richard M. Swalin, and Sam A. Kamen
Guidance and Performance Branch

May 29, 1968

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: Marlowe D. Cassetti
Marlowe D. Cassetti, Chief
Guidance and Performance Branch

Approved: for Carl R Huss
John P. Mayer, Chief
Mission Planning and Analysis Division

CONTENTS

TABLES

FIGURES

APOLLO MISSION E (AS-504/CSM-104/LM-4)

SPACECRAFT REFERENCE TRAJECTORY

VOLUME IV - CONSUMABLES ANALYSIS

By Arnold J. Loyd, Martin L. Alexander, Richard C. Wadle,
Harry Kolkhorst, Richard M. Swalin, and Sam A. Kamen

SUMMARY

The consumables analyses for Mission E indicate that adequate margins exist for all consumables except ascent water. The data used in the RCS, EPS, and ECS analyses were assumed accurate to ±10 percent. The SM RCS required 63 percent of its available propellant. The SPS required 95 percent of its available propellant. The LM RCS used 80 percent of the available propellant. Corresponding figures for the lunar module ascent and descent propulsion system are 3 and 94 percent, respectively.

The CSM used 85 percent of the available O_2 and 84 percent of the available H_2 to support the necessary EPS and the ECS. The LM descent stage EPS required 78.5 percent of the available ampere-hours. The ascent battery energy was depleted after LM jettison. The descent stage used 75 percent of the available water and 16 percent of the available oxygen. The ascent stage used all of the available water and 51 percent of the available oxygen. The analyses indicate that 72 lb of ascent water would be required to complete the mission. It is recommended that no ascent water be off-loaded.

In addition to the consumables analyses, this note presents a time history of the mass properties.

INTRODUCTION

Detailed consumables analyses were performed on the Mission E RCS, SPS, APS, DPS, EPS, and ECS. A time history of the spacecraft mass properties was also calculated. The principal sources of data were the mission modular data books (refs. 1 and 2). These data, used in the RCS, EPS, and ECS analyses, were assumed accurate to within ±10 percent.

The analyses were based on the reference trajectory (refs. 3 and 4) and the rough draft reference flight plan (ref. 5). The operational procedures described in this study are not intended to define mission rules or crew procedures, but are merely an attempt to establish an estimate of the consumables requirements. The analyses did not consider venting.

Support for the ECS and EPS analyses was obtained from TRW Systems Group. Additional support was obtained from North American Rockwell, Grumman Aircraft and Engineering Corporation, Flight Crew Support Division, Flight Control Division, Apollo Spacecraft Program Office, and Instrumentation and Electronic Systems Division.

SYMBOLS

AGS	abort guidance subsystem
APS	ascent propulsion subsystem
CDH	constant differential height
CDR	commander
c.g.	center of gravity
CM	command module
CO_2	carbon dioxide
CSI	coelliptical sequence initiation
CSM	command and service modules
DOF	degrees of freedom
DOI	descent orbit insertion
DTO	detail test objection
ECS	environmental control subsystem
EPS	electrical power subsystem
FMES	full mission engineering simulation
GAEC	Grumman Aircraft Engineering Corporation

H_2	hydrogen
g.e.t.	ground elapsed time
IMU	inertial measurement unit
LIOH	lithium hydroxide
LM	lunar module
LMP	LM pilot
LOI	lunar orbit insertion
MCC	midcourse correction
MPD	main powered descent
MTVC	manual thrust vector control
O_2	oxygen
PGNCS	primary guidance and navigation control subsystem
RCS	reaction control system
RSS	root-sum-square
SLA	spacecraft LM adapter
SM	service module
SPS	service propulsion system
T&D	transposition and docking
TEI	transearth injection
TPF	terminal phase finalization
TPI	terminal phase initiation

PROPULSION SUBSYSTEMS ANALYSES AND RESULTS

CM RCS

Following is the propellant summary of the CM RCS for Mission E:

Loaded, lb.	267.6
Residual, lb.	21.6
Available for mission planning, lb.	246.0
Used, lb.	27.8
Available at mission end, lb.	218.2

The amount of propellant loaded was taken from reference 6, and the amount of propellant used was taken from reference 7.

SM RCS

The amount of SM RCS propellant available for mission planning has been calculated and the details are given in table I. As shown in the table, 1222 lb are available for mission planning.

The detailed mission timeline and the corresponding SM RCS propellant usage is given in table II. This SM RCS budget includes added detail obtained from the rough draft of the Mission E reference flight plan (ref. 5). The graph of the SM RCS propellant budget is shown in figure 1.

The following items may have an impact on the nominal SM RCS propellant budget presented here:

1. Changes to the mission timeline.

2. Added details in the flight plan or changes in the flight plan.

3. Impact of DTO's or flight plan details on SM RCS usage.

4. Final definition of and simulation data for the navigation sightings.

5. Simulation data for the CSM-active rendezvous.

6. Simulation data or updated data sources for other phases of the mission.

SPS

For Mission E, the payload authorized for the AS-504 launch vehicle is 100 000 lb. This report gives the propellant margin for the mission, based on a loading of 39 784 lb. (See ref. 6.)

Table III presents the nominal SPS propellant usage for the mission. The usage for the steady state portion of each burn was taken from reference 4. Build-up and shutdown transients were taken from reference 8, while the nonpropulsive start losses were taken from reference 9.

The propellant margin of 1901 lb is about 5 percent of the usable propellant and includes all propellant remaining for dispersions, inflight flexibility, contingencies, and operational reserve.

LM RCS

The amount of LM RCS propellant available for mission planning has been calculated, and the details are given in table IV. As shown in the table, 507 lb are available for mission planning.

The detailed mission timeline and the corresponding LM RCS propellant usage is given in table V. This LM RCS budget includes added detail obtained from the rough draft of the Mission E reference flight plan (ref. 5). The graph of the LM RCS propellant budget is shown in figure 2.

The following items may have an impact on the nominal LM RCS propellant budget presented here:

1. Changes to the mission timeline.

2. Added details in the flight plan or changes in the flight plan.

3. Impact of DTO's or flight plan details on LM RCS usage.

4. Simulation data for the LM-active rendezvous.

5. Simulation data or updated data sources for other phases of the mission.

APS

Table VI presents the nominal APS propellant usage for the mission. The usage for the steady state portion of each burn was taken from reference 4. Build-up and shutdown transients were taken from reference 8.

The duty cycle for the APS engine uses less than 3 percent of the usable propellant.

DPS

Table VII presents the nominal DPS propellant usage for the mission. The usage for the steady state portion of each burn was taken from reference 4. Build-up and shutdown transients were taken from reference 10.

The propellant margin of 1103 lb is about 6 percent of the usable propellant and includes all propellant remaining for dispersions, inflight flexibility, contingencies, and operational reserve.

CSM EPS ANALYSIS AND RESULTS

The analysis of the CM EPS is based on the electrical power requirements given in reference 4. The timeline used is that of references 3 and 5. The assumptions, conditions, and constraints used for this analysis are as follows:

1. EPS hydrogen consumption rate = $.00257 \times I_{FC}$ (lb/hr), as given in reference 12.

2. EPS oxygen consumption rate = 7.936 × hydrogen consumption rate (lb/hr).

3. Cryogenic quantities loaded were as follows: 56.0 lb of H_2 and 640.0 lb of O_2.

4. The system was assumed to operate with two inverters.

5. Thirteen fuel cell purges were assumed.

6. Component power requirements were taken from reference 1.

7. Equipment was turned on and off as specified in reference 1.

8. Prelaunch: Fuel cell requirements for prelaunch are shown in table IX.

9. There was no H_2 or O_2 venting.

10. The launch window was assumed to be a maximum of 2 hours.

11. Entry and postlanding batteries: Three batteries were considered in supplying the total spacecraft power requirement for entry, parachute descent, stabilization period at impact, and postlanding. A battery capacity of 40 A-h was assumed with 120 A-h available prior to the SPS deorbit.

12. Battery charges: A 1.5-hour operation of battery charges was considered as required to furnish 1 A-h to the batteries. Two batteries were considered in parallel with the fuel cells during ascent and gimbal operation at each SPS burn.

The fuel cell H_2 requirements were 46.5 lb. The fuel cell oxygen requirements are 360.77 lb. The hydrogen remaining is shown in figure 3 as a function of time. The oxygen remaining is shown in figure 4 as a function of time (for EPS and ECS requirements).

A cryogenic summary is provided in table X. It includes the electrical power generation, fuel cell purges, and the environmental control subsystem usages for both prelaunch and flight. The battery requirements for entry and postlanding are shown in table XI.

The results of the CSM EPS analysis show that 85 percent of the available oxygen and 84 percent of the available hydrogen was used during the mission. The margin would support additional orbits for the simulated TLI burn.

CSM ECS ANALYSIS AND RESULTS

This analysis is based on the following considerations:

1. Urine water loss was 0.11 lb/hr/man.

2. Food water was 0.125 lb/hr.

3. Desired cabin temperature of 75° F was assumed.

4. Evaporator efficiency was 95 percent. (The efficiency is the ability of the evaporator to evaporate the water dumped into the system without losing any water through droplets carried off by the steam.)

5. Metabolic O_2 rate was 0.0766 lb/hr/man.

6. Waste management O_2 rate was 0.051 lb/hr for three men.

7. Cabin O_2 leakage rate was 0.2 lb/hr.

8. O_2 purge rate of the water tanks was 0.056 lb/hr.

9. Water generated during prelaunch was transferred to the potable tank. The water tank quantities at lift-off were 25 lb potable and 10 lb waste.

10. Three complete pressurizations of the LM were assumed.

11. The tunnel was pressurized at transposition and docking.

12. A total of 8.7 lb of O_2 was purged through the waste management system during the first 8 hours of the mission to create a near oxygen atmosphere in the cabin.

13. The average heat produced by LIOH and CO_2 reacting was 1305 Btu per pound of CO_2 absorbed.

14. Metabolic heat load for the crew was 1401 Btu/hr.

15. No venting of oxygen or hydrogen was assumed.

The ECS oxygen requirements are shown in table X. The total ECS oxygen used was 170.18 lb. The total water produced by the fuel cells prelaunch and during the flight was 405.6 lb. The water evaporated was approximately 14 lb, and approximately 250 lb of water was dumped overboard. Assuming 1 lb/man/day use in food, and 2.64 lb/man/day micturition, 27.89 lb of water was used for food and 73.6 lb in urine dump. The potable and waste water tanks were full from 45 hours g.e.t. to separation, as shown in figure 5.

The results of the CSM ECS analysis show a satisfactory margin of consumables exist to perform the mission.

LM EPS ANALYSIS AND RESULTS

This analysis is based on the electrical power requirements given in reference 2. The timeline used is that of references 3 and 5. The assumptions, conditions, and constraints for this analysis are as follows:

1. Energy available from descent batteries is 1600 A-h and from the ascent batteries is 592 A-h.

2. The 60° F battery curves are used.

3. During prelaunch the descent batteries are put on the line 30 minutes before lift-off.

4. The ascent batteries are paralleled with the descent batteries during the docked DPS burn and just prior to staging.

5. The CDR and LMP buses are not crosstied during main propulsion burns.

6. The RCS heaters are on 100 percent duty cycle for 1 hour during the two checkouts, on 25 percent duty cycle while unstaged and on 18.3 percent duty cycle when staged.

7. The rendezvous equipment is turned on just prior to the first undocked DPS burn and remains on until the completion of station keeping.

8. The tracking light is turned on at the completion of the first undocked DPS burn and remains on until the completion of station keeping.

9. The ascent stage is set for PGNCS operation at the end of the mission.

The ascent energy remaining is 212.6 A-h, which is equivalent to $5^{h}41^{m}00^{s}$ of normal electrical equipment operation in the PGNCS mode at 37.4 A after jettisoning the LM at $96^{h}55^{m}00^{s}$. The descent energy remaining is 344.7 A-h. A summary of the LM descent and ascent stage EPS requirements is shown in table XIII. The descent battery charge status remaining is shown in figure 6 for portions of the mission during which LM descent stage batteries are used. The charge status remaining in the ascent batteries is shown in figure 7. The total source current, ac-dc power profiles, and LMP and commander bus voltages are shown in figures 8, 9, and 10, respectively. All quantities in the figures are shown as a function of ground elapsed time from launch.

The results of the LM EPS analysis shows a satisfactory margin of consumable to perform the mission.

LM ECS ANALYSIS AND RESULTS

This analysis is based on the following considerations:

1. Metabolic O_2 rate was 0.086 lb/hr/man.

2. Cabin O_2 leakage rate was 0.2 lb/hr.

3. The average heat produced by the LIOH-CO_2 reaction was 1305 Btu per pound of CO_2 absorbed.

4. The structural heat load was 1000 Btu/hr.

5. The metabolic heat load for the crew was 522 Btu/hr/man.

6. No repressurization from LM O_2 tanks. Repressurization to replace leakage while the LM was unoccupied was provided from the CSM.

7. The sublimator was dried out each time the LM was deactivated, requiring 4.46 lb of water.

8. Initial tank quantities of usable water and O_2 were

Water	Descent tank, lb	310.2
	Ascent tanks, lb	79.5
Oxygen	Descent tank, lb	47.1
	Ascent tanks, lb	4.3

The total ascent water requirement was 72 lb, which includes the time required for ascent battery energy depletion. The requirement leaves an ascent water margin of -12.6 lb. If the ascent tanks were loaded full, the margin would be 10 percent of the usable water.

The LM produced an oxygen requirement of 9.2 lb (7.0 from the descent tank and 2.2 from the ascent tanks). The LM descent and ascent O_2 consumption is shown in figure 11. The total water evaporated was 216.0 lb. Assuming 2.64 lb/man/day micturition rate and 1.0 lb/man/day water added to food gave a total water usage of 219.3 lb (159.9 from the descent tank and 59.4 from the ascent tanks). Usable water remaining in the descent tank, usable water quantity remaining in the ascent tanks, and water evaporated are shown in figures 12, 13, and 14, respectively. Due to the assumption of a high structural heat load, the water boiled during an actual flight may be less than that calculated in this analysis.

The results of the LM ECS analysis show that satisfactory margins exist for all consumables involved but ascent water.

MASS PROPERTIES ANALYSIS AND RESULTS

The mass properties curves were generated for five vehicle configurations. In the generation of the curves, it was assumed that the uncertainties in the actual inert weights would negate consumables usages for mass properties calculations. In addition, a time history of spacecraft weight was generated (fig. 15). This weight profile considered nominal inert weights, main propellants, RCS propellants, and ECS usages.

The five spacecraft configurations considered were as follows. The corresponding mass properties are presented in figures 16 through 20.

1. A CSM in which the SPS propellant is used.

2. An unstaged LM in which the DPS propellant is used.

3. A staged LM (ascent stage) in which the APS propellant is used.

4. A series of docked CSM/LM configurations in which the SPS is thrusting, given in the Apollo (CSM) coordinate system.

5. A series of docked CSM/LM configurations in which the DPS is thrusting, given in the LM coordinate system.

The X, Y, and Z center-of-gravity accuracy is as follows: ±0.5, ±0.2, and ±0.2 inches, respectively, for CSM mass properties; ±0.6, ±0.2, and ±0.2 inches, respectively, for an unstaged LM; ±0.5, ±0.5, and ±0.5 inches, respectively, for an ascent LM; and ±0.7, ±0.2, and ±0.2 inches, respectively, for docked CSM/LM configurations. The moment and product of inertia data are accurate to ±10 percent (ref. 6).

In table XIV the inert component mass properties and the associated 3σ dispersions are shown. In the calculation of dispersions for vehicle mass properties, it was assumed that knowledge of the location of the propellants was exact, all rotations and translations of modules were exact, and the only propellant uncertainty was in the amount loaded; that is, the main propellants were used in a 1.6:1 ratio; the propellants were distributed regularly from the top or bottom of the tanks, as required for the docked burn under consideration; and the propellant remained level in all the DPS tanks.

All the mass properties studies considered depletion of main propellants only. The following data and assumptions were used in generating the mass properties profiles.

A. CSM (fig. 16)

1. The CSM was manned by three crewmen.

2. The phasing maneuver used 252 lb of SPS propellant.

3. The concentric maneuver used 137 lb of SPS propellant.

4. The transearth injection burn used 1965 lb of SPS propellant.

5. The deorbit burn used 790 lb of SPS propellant.

6. The CM was assumed constant throughout the profile.

B. Unstaged LM (fig. 17)

1. The LM was manned by two crewmen.

2. The phasing maneuver used 139 lb of DPS propellant.

3. The first CDH burn used 70 lb of DPS propellant.

C. Staged LM (fig. 18)

1. The ascent stage was manned by two crewmen.

2. The second CSI burn used 34 lb of SPS propellant.

3. The second CDH burn used 34 lb of SPS propellant

D. Docked CSM/LM configuration with the DPS thrusting (fig. 19)

1. The SPS propellants were shifted to the top of their respective tanks.

2. The ascent stage was manned by two crewmen.

3. The CM was manned by one crewman.

4. The landing gear was deployed.

5. The DOI burn used 278 lb of DPS propellant.

6. The MPD burn used 15 937 lb of DPS propellant.

E. Docked CSM/LM configuration with the SPS thrusting (fig. 20)

1. The APS and DPS propellants were shifted to the top of the tanks.

2. The CM was manned by three crewmen.

3. The MCC burn used 346 lb of SPS propellant.

4. The LOI burn used 29 548 lb of SPS propellant.

5. The circularization burn used 3786 lb of SPS propellant.

6. The trim burn used 175 lb of SPS propellant.

CONCLUSIONS

Satisfactory consumables margins are found to exist in all subsystems for the nominal E mission except for the LM ascent water. Enough LM ascent water would be available if the LM ascent water tank were fully loaded. Therefore, it is recommended that no LM ascent water be off-loaded.

TABLE I.- SM RCS PROPELLANT AVAILABLE FOR MISSION PLANNING

Maximum loaded propellant, lb	1362
Unusable propellant:	
Loading and temperature dispersions, lb	30
Trapped and unexpelled, lb	28
Minimum deliverable propellant, lb	1304
Mixture ratio and gaging allowance	82
Total available propellant for mission planning, lb	1222

TABLE II.- SM RCS PROPELLANT BUDGET

(a) Detailed weight

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
	Prelaunch check	Fire each jet 1.0 sec	5.9
01:25:00	RCS thruster check		
01:55:00	Align IMU	S-IVB control	-
03:16:52	TLI	S-IVB burn	-
	Transposition and docking		
	Separate at 1 fps	CSM weight = 63 445 lb	7.8
	Pitch 4 deg/sec to face booster (180°)	Attitude maneuver propellant usage increased for angles > 50°; manual maneuver.	13.5
03:45:00	Null 1 fps		7.8
03:45:05	Roll 2 deg/sec (60°)	Manual maneuver	2.1
03:45:35	Translate CSM back to S-IVB at 1 fps		7.8
	Null closing rate for docking		7.8
	Index and dock	Langley studies (1966 3σ value)	26.0
04:31:15	LM - extraction	Fire 4 jets 10 seconds	14.7
04:33:25		Roll CSM/LM 60° at 2 deg/sec to heads-up attitude (manual maneuver).	2.5
		CSM/LM weight = 96 188 lb	
		Pitch CSM/LM 0.5 deg/sec to local horizontal, heads-down attitude (180°). (Automatic maneuver.)	8.1
		Maintain orbital rate	

TABLE II.- SM RCS PROPELLANT BUDGET - Continued

(a) Detailed weight - Continued

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
06:10:00	IMU realign (P52)	3 axis automatic at 0.2 deg/sec. (Fine align.)	3.3
	MCC burn		
	Orient for MCC burn	3 axis automatic maneuver at 0.2 deg/sec	3.3
7:31:34	MCC burn	ΔV = 34 fps, Δt = 5 sec	1.1
		RCS consumption for cutoff transient	
	Orient for PTC		3.3
	PTC	Roll at 0.3 deg/sec, hold attitude pitch and yaw ≈ 1 hour	.3
08:55:00	Realign IMU	3 axis automatic maneuver at 0.2 deg/sec	3.3
09:44:58	Third apogee navigation sightings	Allocate propellant. Actual requirements to await final definition of navigation sighting procedures and simulation data.	25.0
≈11:50:00	Realign IMU		3.3
12:34:52	Fourth apogee navigation sightings	See note for third apogee navigation sightings	25.0
	Orient for LOI burn	3 axis automatic maneuver at 0.5 deg/sec. Rate specified in timeline.	7.9
14:32:21	LOI burn	Cutoff transient. ΔV = 3724 fps, Δt = 464 sec	1.1
16:32:30		Passive thermal control; 1 hour	3.6
≈27:20:00	IMU alignment for circularization burn	3 axis manual maneuver at 0.2 deg/sec. (Orientation determination.)	3.7
≈28:55:00	IMU fine align	3 axis automatic maneuver at 0.2 deg/sec	2.4

TABLE II.- SM RCS PROPELLANT BUDGET - Continued

(a) Detailed weight - Continued

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
	Orient for burn	3 axis automatic maneuver at 0.2 deg/sec. CSM/LM weight = 66 326 lb	2.4
	Ullage	Fire 2 jets 28 sec	20.1
30:12:23	Circularization burn (SPS)	Shutdown transient. Δt = 59 sec, ΔV = 595 fps, RCS propellant estimated, MTVC last 15 seconds of burn.	1.1
41:10:00	IMU align	3 axis manual maneuver at 0.2 deg/sec. (Orientation determination.)	3.7
43:22:00	LM S-band cutoff	Orient and hold attitude 1/4 hour	2.4
44:02:00	IMU realign	3 axis automatic maneuver at 0.2 deg/sec	2.4
≈45:12:00	Docked LM IMU align	3 axis manual maneuver at 0.2 deg/sec	3.7
		Hold minimum deadband 10 min	.1
46:41:40	DPS DOI burn		
47:53:00	DPS MPD burn		
	SPS trim burn	CSM/LM weight = 46 344 lb	
	Realign IMU (P52)	Fine align (3 axis automatic maneuver at 0.2 deg/sec	1.5
	Orient for burn	3 axis maneuver at 0.2 deg/sec	1.5
	Ullage	Fire 2 jets 28 sec	20.1
≈51:32:00	Burn	SPS shutdown transient. Δt = 2, ΔV = 37 fps	1.1
	RCS postburn trim	Orient at 0.2 deg/sec, 5 fps ΔV. This burn trimmed to optimize orbit for rendezvous. Propellant allocated for maneuvers.	29.5

TABLE II.- SM RCS PROPELLANT BUDGET - Continued

(a) Detailed weight - Continued

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
63:35:00	Orient IMU	3 axis manual maneuver	2.1
65:45:00	LM S-band cutoff	Orient and hold attitude ≃ 1/4 hour	1.6
66:25:00	IMU realign	3 axis automatic maneuver	1.5
67:40:00	Docked LM IMU coarse alignment	3 axis manual maneuver at 0.2 deg/sec	2.1
		Hold minimum deadband 10 min	.1
68:15:00	LM S-band cutoff		1.6
	Orient to undocking attitude		1.5
	UNDOCK		
68:50:00	Inspect LM landing gear	Allocation; major portion of the activity required for the inspection is LM activity	2.0
	CSM/LM separation burn		
	Orient	3 axis automatic maneuver	1.5
	Translate 1 fps		5.6
	Null ΔV		5.6
69:25:00	Realign IMU	P52	1.5
	CSM activity during LM active rendezvous and docking	7 manual maneuvers and 7 1/2 hours wide deadband hold. (Limit cycle.)	7.0
77:50:00	Docking transient	Allocation current weight = 40 100 lb (Docked CSM and ascent stage)	2.0
91:55:00	IMU orient	Manual maneuver	1.5
94:22:00	LM S-band activation		1.4
94:55:00	IMU realign		1.2

TABLE II.- SM RCS PROPELLANT BUDGET - Continued

(a) Detailed weight - Continued

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
95:20:00	Docked LM IMU align (coarse)	3 axis manual maneuver at 0.2 deg/sec	1.5
96:22:00	IMU realign		1.2
	CSM/LM separation		1.2
	Orient for separation		
	Translate	+ X = 1 fps. CSM weight = 29 765 lb	3.6
	Null ΔV		3.6
	CSM active rendezvous		
97:16:58	SPS phasing maneuver	Orient, .2 deg/sec automatic maneuver	.7
		19 sec 2 jet ullage	14.0
		Cutoff transient	1.1
98:27:59	SPS coelliptic maneuver	Orient	.7
		19 sec 2 jet ullage	14.0
		Cutoff transient	1.1
99:36:24	TPI	Orient	.7
		ΔV = 16.6 fps; RCS burn	59.0
	TPF	Orient	.7
		RCS burn; total TPF ΔV = 20.9 fps; allow 2.4 × theoretical TPF ΔV = 50 fps	180.0
	Attitude maneuvers during CSM active flyby		55.0

TABLE II.- SM RCS PROPELLANT BUDGET - Continued

(a) Detailed weight - Concluded

Time, hr:min:sec: g.e.t.	Event	Comment	Approximate amount of propellant, lb
	RCS phasing maneuver	Orient	.7
100:22:59		ΔV = 2 fps for separation	7.2
		RCS phasing maneuver for permanent separation	
	Align IMU		1.0
144:32:00	TEI		
	Orient		.3
	Ullage	Fire 2 jets 19 sec	14.0
	Shutdown transient		1.1
	Align IMU		1.0
	Transearth MCC with RCS	ΔV = 10 fps, Δt = 21 sec	33.6
	DTO - 20.60	Allow for IMU alignment	1.0
		Lunar landing site determination	
	Align IMU	Spacecraft weight = 27 250 lb	1.0
	Deorbit		
	Orient		.3
	Ullage	Fire 2 jets 19 sec	14.0
237:45:54	Fire SPS		1.1
	Separate and spin stabilize		30.0
		Total usage	764.4

TABLE II.- SM RCS PROPELLANT BUDGET - Concluded

(b) Summary

Propellant available for mission planning	1222.0
Nominal usage	764.4
Margin	457.6

TABLE III.- SPS PROPELLANT BUDGET

Propellant loaded[a], lb	39 784.3
Unusable[a], lb	884.4
Nonpropulsive start losses (14.4 lb per start), lb	115.2
Steady state burns, lb	36 536.1
Start-up and shutdown transients (43.4 lb per start), lb	347.2
Propellant margin, lb	1 901.4

TABLE IV.- LM RCS PROPELLANT AVAILABLE FOR MISSION PLANNING

Maximum loaded propellant, lb	638
Unusable propellant	
Loading and temperature dispersions, lb	10
Trapped and unexpelled, lb	40
Minimum deliverable propellant, lb	588
Mixture ratio uncertainty, lb	17
Gaging accuracy, lb	64
Total available propellant for mission planning, lb	507

[a]Reference 6.

TABLE V.- LM RCS PROPELLANT BUDGET

(a) Detailed budget

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
45:05:00	RCS hot fire	Test primary coils; fire each jet 1 sec.	5.9
		Test secondary coils; follow procedure in ref. 11. (Procedure for E mission LM RCS checkout is awaiting final definition).	17.6
	Determine IMU orientation	CSM activity	--
	Fine align IMU	Simultaneous rotational maneuver, PGNCS at 0.5 deg/sec (docked).	7.3
		Switch max to min deadband; propellant requirement is taken as half that of a simultaneous rotational maneuver.	3.7
	Orient to burn attitude	Simultaneous rotational maneuvers, PGNCS at 0.5 deg/sec (docked).	7.3
	Ullage (4 jets) for first DPS burn	Time to settle descent prop: 7.5 sec Overlap: 0.5 sec Total ullage: 8.0 sec	11.8
	RCS control	Control during burn estimated from Grumman FMES test (LM-1 undocked). No data available for docked burn.	4.0
	Max deadband hold	5° deadband	.2
	Realign IMU	Simultaneous rotational maneuver; PGNCS at 0.5 deg/sec (docked).	7.3
	Switch max to min deadband		3.7
	Orient for burn	Docked maneuver at 0.5 deg/sec	7.3

TABLE V.- LM RCS PROPELLANT BUDGET - Continued

(a) Detailed budget - Continued

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
	Ullage	Time to settle DPS propellants: 7.5 sec Overlap: 0.5 sec	11.8
		After APS propellants are settled, allow 5 sec to actuate interconnect. RCS control for DPS burn will come from APS tanks through the interconnect.	
47:53:00	Second DPS burn	RCS control. Allow 2.0 lb for moment control out of RCS tanks, balance from APS tanks. Uses 37 lb of APS propellant through the interconnect. (From Grumman FMES test for LM-1; no data available for docked DPS burns.)	2.0
	Checkout LM RCS (hot firing)	Test primary coils, fire each jet 1 sec.	5.9
		Test secondary coils, fire each jet 1 sec. (Procedure for E mission LM RCS checkout awaiting final definition).	5.9
67:50:00	Fine align IMU (P52)	Simultaneous rotational maneuver, PGNCS at 0.5 deg/sec (docked).	3.7
	CSM/LM undock	CSM activity	
		Weight ≈ 16 580 lb	
≈68:47:00 - 69:11:00	Inspect LM landing gear	Reorient; yaw for inspection, station keep	10.0
	Monitor CSM separation burn	Orient at 0.5 deg/sec and hold wide deadband	0.6
	LM-active rendezvous		
69:22:00	Fine align IMU	PGNCS orientation at 0.5 deg/sec	0.4
70:00:00	Rendezvous radar navigation program	Orientation maneuver	0.4

TABLE V.- LM RCS PROPELLANT BUDGET - Continued

(a) Detailed budget - Continued

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
	Orient to burn attitude	AGS controlled DPS burn Δt = 31 sec.	.4
		ΔV = 79.4	
70:40:45	Ullage for initial DPS separation burn	Time to settle APS propellant: 3.5 sec.	12.5
		Open interconnect at 8.5 sec into ullage. Total ullage required 17 sec. Uses 12.5 lb APS propellant through interconnect.	
		RCS control (last 10 sec of burn and shutdown transient). Uses 2 lb of APS propellant through the interconnect.	2.0
	Post-burn trim with RCS	Orientation + 2 fps trim	4.2
71:16:30	CSI 1		
	Nominal ΔV = 0 fps	Allow for orientation maneuver + 5 fps of ΔV	10.0
73:22:37	CDH 1	AGS controlled DPS burn Δt = 12 sec ΔV = 40.9	19.1
		Uses 14.5 lb of APS propellant through the interconnect.	
	Simulated TPI	Set-up for TPI which, nominally, is not to be executed.	1.0
75:34:40	CSI 2		
	Orient to burn attitude	Orient at .5 deg/sec	.4

TABLE V.- LM RCS PROPELLANT BUDGET - Continued

(a) Detailed budget - Continued

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
	Ullage	Ullage required: 3.5 sec Overlap : 0.5 sec Total ullage : 4.0 sec	5.9
	APS burn	Ullage drops descent stage	
		Weight ≈ 10 462 lb	
		Δt = 2.7 sec (steady state) ΔV = 33.6 fps	
	RCS control during burn	Burn under PGNCS control	1.8
		.5 lb/sec of RCS, based on burnout c.g. of Y = 0 in. Z = 3.8 in., cant angle = 2.5°	
		Δt = 2.7 sec (steady state) ΔV = 33.8 fps	3.5
	Shutdown transient and post burn trim		
76:20:19	CDH 2	APS burn under PGNCS control	11.6
77:02:17	TPI		
	Orient		.4
	RCS + X burn	ΔV = 21.6 fps, PGNCS control	25.2
		Weight ≈ 10 400 lb	
77:31:17	TPF		
	Orient	PGNCS control	.4

TABLE V.- LM RCS PROPELLANT BUDGET - Continued

(a) Detailed budget - Concluded

Time, hr:min:sec g.e.t.	Event	Comment	Approximate amount of propellant, lb
	RCS + Z burn	ΔV = 27.8 fps, PGNCS control. Take 2 × theoretical TPF for operational ΔV. ΔV operational = 55.6 fps.	90.0
	Coast to station keeping		
	Track CSM during rendezvous		
	7 orientation maneuvers plus attitude hold	5° deadband attitude hold for 7 hours	10.0
	IMU alignments	Allocate propellant for maneuvers for possible IMU aligns or other activity to be specified in a detailed flight plan.	3.0
	Attitude maneuvers during rendezvous	Scaled down by the average ratio of moments of inertia from G&C simulations (CSM active rendezvous with 3 fps error at TPI). Should be updated when more LM active rendezvous simulation date becomes available.	34.0
77:50:00	Docking	Scaled up for mass properties of full ascent stage from 6-DOF simulations referenced in MMDB. This is "mean" propellant requirement.	52.5
	Attitude hold for CSM flyby	Hold max deadband through completion of CSM flyby.	10.0
		Total Usage	415.0

TABLE V.- LM RCS PROPELLANT BUDGET - Concluded

(b) Summary

Available for mission planning	507.0
Nominal usage through docking	405.0
Margin after docking	102.0
Margin at end of LM activity	92.0

TABLE VI.- APS PROPELLANT BUDGET

Propellant loaded	5184.7
Less unusable[a]	140.6
Nonpropulsive start losses[a] (included in unusable)	--
Steady state burns	61.6
Start-up and shutdown transients	2.1
Usage through APS-RCS interconnect	66.0
Margin	4914.4

[a]See table VIII

TABLE VII.- DPS PROPELLANT USAGE

Propellant loaded[a], lb	17 979.5
Unusable[b], lb	469.4
Nonpropulsive start losses[b] (Two starts, other two included in unusable), lb	17.2
Steady state burns, lb	16 314.6
Start-up and shutdown transients, lb	75.3
Margin, lb	1 103.0

[a] Reference 6.

[b] See table VIII.

TABLE VIII.- UNUSABLE PROPELLANT FOR LM MAIN PROPULSION SYSTEMS[a]

	Ascent		Descent	
	Fuel, lb	Oxidizer, lb	Fuel, lb	Oxidizer, lb
System Variables				
Off-Nominal Operation[b]				
Regulator (±3 psi)	0	0	3.0	2.0
Check valves (±0.5 psi.)	15.0	23.0	27.0	40.0
Compatibility squib (±1/4 psi, Asc; ±0.5 Desc.)	4.0	6.0	14.0	20.0
Bulk temp. (±13.5°F Asc; ±7°F Desc.)	6.0	13.5	11.0	11.0
P.U. temp. (±10.5°F Asc; ±6°F Desc.)	8.0	12.0	20.0	27.0
P.M. temp. (±5°F Desc.)	0	0	9.0	10.0
Engine-interface match (O/F ±.015)	18.0	29.0	63.0	100.0
Engine repeatibility (±.012 Asc; ±014 Desc.)	13.0	21.5	55.0	88.0
Thrust vector/c.g. cone (±1°)	0	0	36.0	57.0
Loading accuracy (±0.5%)	9.6	15.0	32.0	53.0
Isp-repeatibility (using 3 σ values)	0	0	0	0
Mission repeatibility	0	0	0	0
PM-efficiency - (100%)	0	0	0	0
Leak detection (0.8% Asc.) (N/A Desc.)	16	25.5	0	0
RSS quantities	34.4	55.4	104.2	163.6
Malfunctions[b]				
Engine valve pair	0	37.0	0	200.0
Propellant filter cldg.	11.0	18.0	10	24.0
Check valve	22.0	35.0	42	60.0
Comp. squib failure	15.0	23.0	0	0
RSS quantities[c]	28.8	58.7	21.6	105.1
Bias	-18.3	-71.3	-20.8	-166.8
Sum of off-nominal, malfunctions and bias	44.9	42.8	105.0	101.9
Trapped Propellant				
Drain lines	-	-	-	-
Fill lines	0.2	0.8	0.1	0.2

[a]This table is an excerpt from GAEC Report No. LDP-490-3, Contract No. NAS 9-1100, dated 6-30-67. Originally Table XIV "Unusable Propellant," page 2.7 of said document.

[b]Effect of single variations prior to RSS

[c]100% of Ascent and 50% of Descent RSS quantity for malfunctions is included.

TABLE VIII.- UNUSABLE PROPELLANT FOR LM MAIN PROPULSION SYSTEMS[a] - Concluded

	Ascent		Descent	
	Fuel, lb	Oxidizer, lb	Fuel, lb	Oxidizer, lb
Balance lines	-	-	7.1	11.1
Branch lines	-	-	5.6	11.1
Engine (to SOV)	0.2	0.3	6.4	12.3
Isolation squib by pass and misc.	0.2	0.1	0.7	0.7
Interconnect to RCS	1.5	2.4	-	-
Total	2.1	3.6	19.9	35.4
Residuals in Tank				
Tank wetting	1.0	1.0	2.0	2.0
Propellant vapor	1.0	13.8	2.5	19.0
Unporting prevention	7.1	11.3	10.7	16.0
"0" G cans	1.6	2.6	5.2	8.6
Thrust vector deviation from vehicle centerline	0.4	0.6	43.0	12.0
Total	11.1	29.3	63.4	57.6
Lost Propellant				
Start transient (2 cycles) Desc./Asc.	0.1	0.1	2.0	2.6
Shutdown transient (2 cycles) Desc./Asc.	1.6	1.8	5.8	6.8
Total	1.7	1.9	7.8	9.4
Contingency for c.g. system operation and loading accuracy	1.2	2.0	0	69.0
Total	61.0	79.6	196.1	273.3
Total fuel and oxidizer	140.6		469.4	

[a]This table is an excerpt from GAEC Report No. LDP-490-3, Contract No. NAS 9-1100, dated 6-30-67. Originally Table XIV "Unusable Propellant," page 2.7 of said document.

[b]Effect of single variations prior to RSS

[c]100% of Ascent and 50% of Descent RSS quantity for malfunctions is included.

TABLE IX.- PRELAUNCH CSM FUEL CELL REQUIREMENTS AND PROCEDURES

(a) Requirements

Time, hr	Fuel cell current, A	H_2 required, lb	O_2 required, lb
T-29 to T-24	18	.23	
T-24 to T-23	60	.154	
T-23 to T-13	60	1.540	12.22
T-13 to T-3	18	.46	3.65
T-3 to T = 0	100	.771	6.12
T = 0 to T + 2	100	.514	4.08
Total		3.67	26.07

(b) Procedures

Time	Event
T-29 hours	Complete loading H_2 and switch to internal H_2 for fuel cell requirements.
T-25 hours	Complete loading O_2 and switch to internal O_2 for fuel cell requirements.
T + 2 hours	Lift-off after maximum launch window.

TABLE X.- CSM CRYOGENICS SUMMARY

	O_2, lb	H_2, lb
Loaded	640.0	56.0
Residual	13.0	.6
Available for mission	627.0	55.4
Fuel cell requirements for flight and prelaunch (power and purge)	360.8	46.5
ECS requirements	170.1	
Available at end of mission	96.1	8.9

TABLE XI.- CM BATTERY REQUIREMENTS FOR ENTRY AND POSTLANDING

Available battery, A-h	120.00
Used for SPS deorbit and for entry to touchdown, A-h	41.09
Used for two uprightings, A-h	8.40
Used for 48 hours postlanding, A-h	63.43
Total required, A-h	112.92
Remaining, A-h	7.08

TABLE XII.- CSM ECS OXYGEN REQUIREMENTS

Metabolic, lb	51.32
Waste management, lb	12.15
Cabin leakage, lb	47.66
Water tank purge, lb	13.35
Pressurizations, lb	45.70
Total, lb	170.18

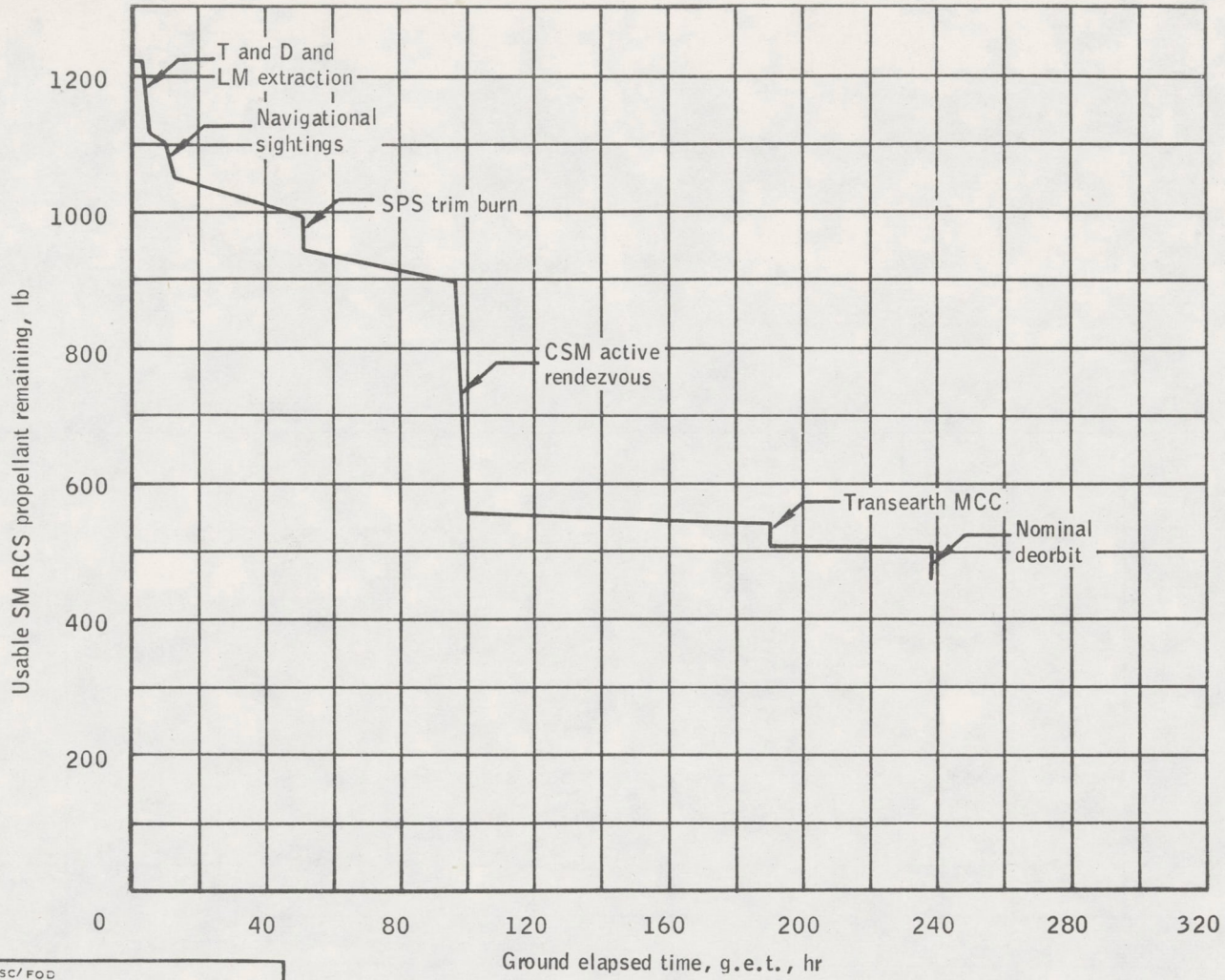
TABLE XIII.- LM DESCENT AND ASCENT STAGE EPS REQUIREMENTS

Phase	Time hr:min:sec	Descent			Ascent		
		Remaining, A-h	Used, A-h	Percent	Remaining, A-h	Used, A-h	Percent
	-00:30:00	1600.0			592.0		
Prelaunch - T&D			17.4	1.1		0.0	0.0
	04:25:00	1582.6			592.0		
	42:00:00						
Docked burns			472.6	29.5		9.2	1.5
	49:49:00	1110.0			582.8		
	64:28:00						
Rendezvous - staging			765.3	47.9		2.3	.4
	75:34:40	344.7			580.5		
Staging - crew IVT			0.0	0.0		254.4	42.9
	79:55:00	344.7			326.1		
	94:00:00						
Post jettison setup			0.0	0.0		66.5	11.2
	94:40:00						
Totals		344.7		78.5	259.4		56.0

TABLE XIV.- MISSION E INITIAL VEHICLE CONDITIONS

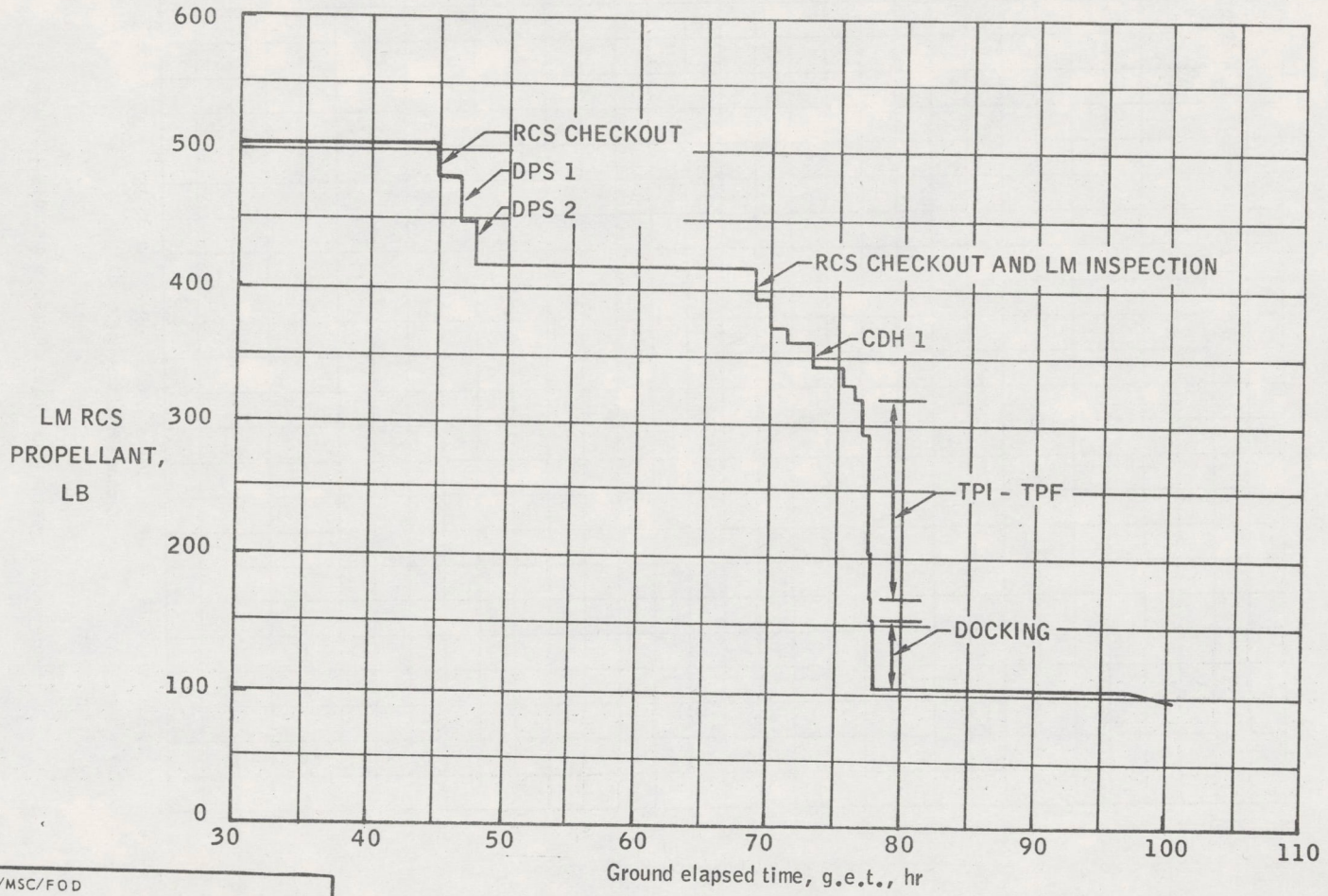
Component	Weight, lb	Center of gravity, in.			Moment of inertia, slug-ft^2			Product of inertia, slug-ft^2		
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}
Command module	12972 ±100	1042.9 ±1.0	-0.5 ±0.5	5.3 ±0.5	6040	5568	5060	52.9	-428.7	10.3
Service module	10800 ±100	918.3 ±1.0	-6.0 ±0.5	10.2 ±0.5	7342	13577	13097	-117.7	310.9	-249.9
SLA ring	91	837.1	-0.3	1.9	113	58	55	0	0	0
Ascent stage[a]	4762 ±50	257.0 ±1.0	0.4 ±0.9	1.3 ±1.0	2725	2602	1533	55.6	79.1	14.8
Descent stage[a]	4356 ±50	152.2 ±1.0	-2.2 ±0.9	-3.4 ±0.9	3905	2464	2635	62.1	42.9	249.1
CSM docked with unmanned ascent stage after 2nd CDH burn	40127	1017.6	0.0	4.6	23211	141836	142351	-845.5	-2478.9	1169.3

[a]Mass properties in LM coordinates.



NASA/MSC/FOD
MISSION PLANNING AND ANALYSIS DIVISION
BRANCH GAPB DATE 5-1-68
BY CSD PLOT NO. 194

Figure 1.- Mission E reference trajectory RCS propellant budget.



NASA/MSC/FOD
MISSION PLANNING AND ANALYSIS DIVISION
BRANCH GPB DATE 4-11-68
BY LOYD PLOT NO. 187

Figure 2.- LM RCS propellant profile for Mission E.

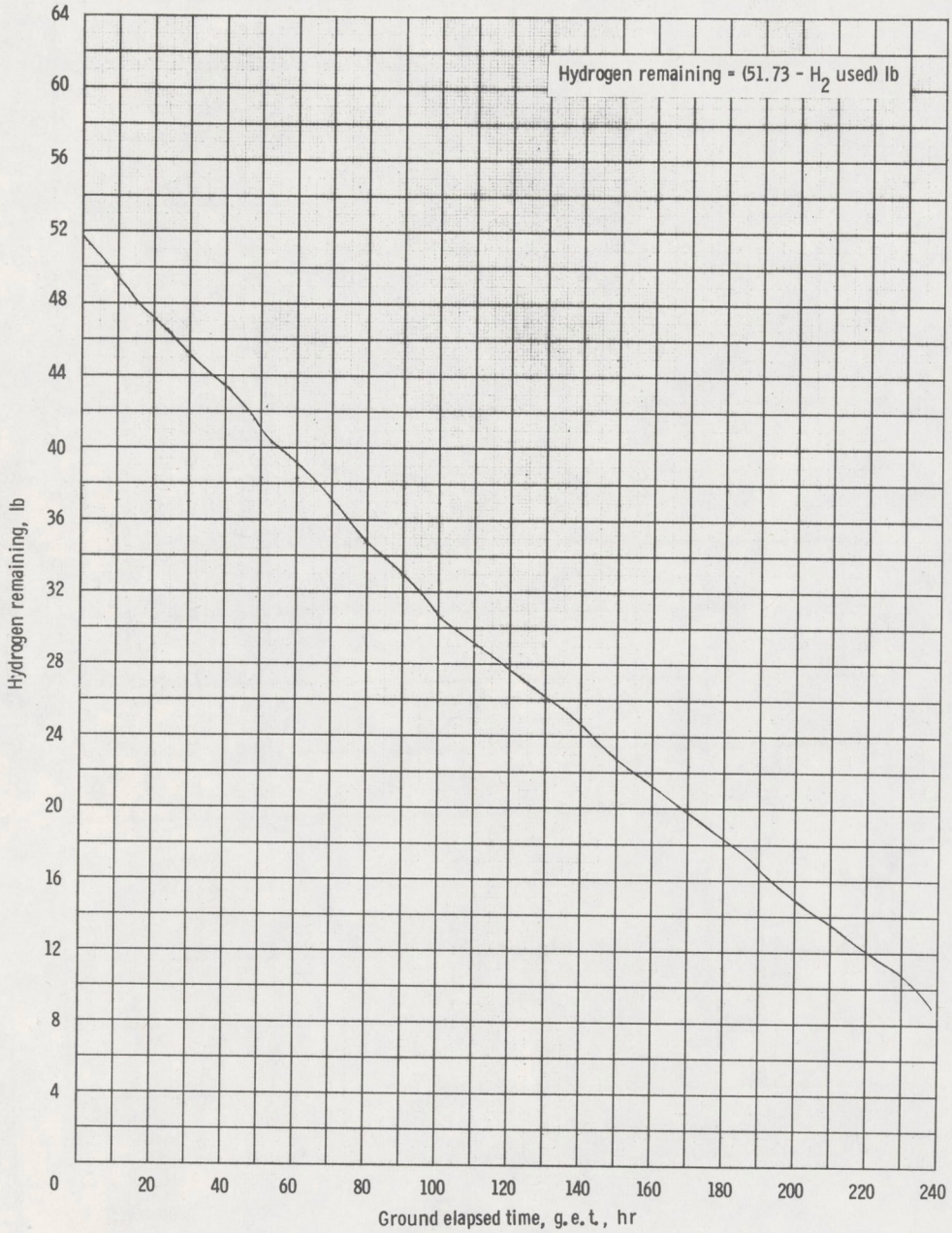


Figure 3.- CSM hydrogen remaining as a function of ground elapsed time.

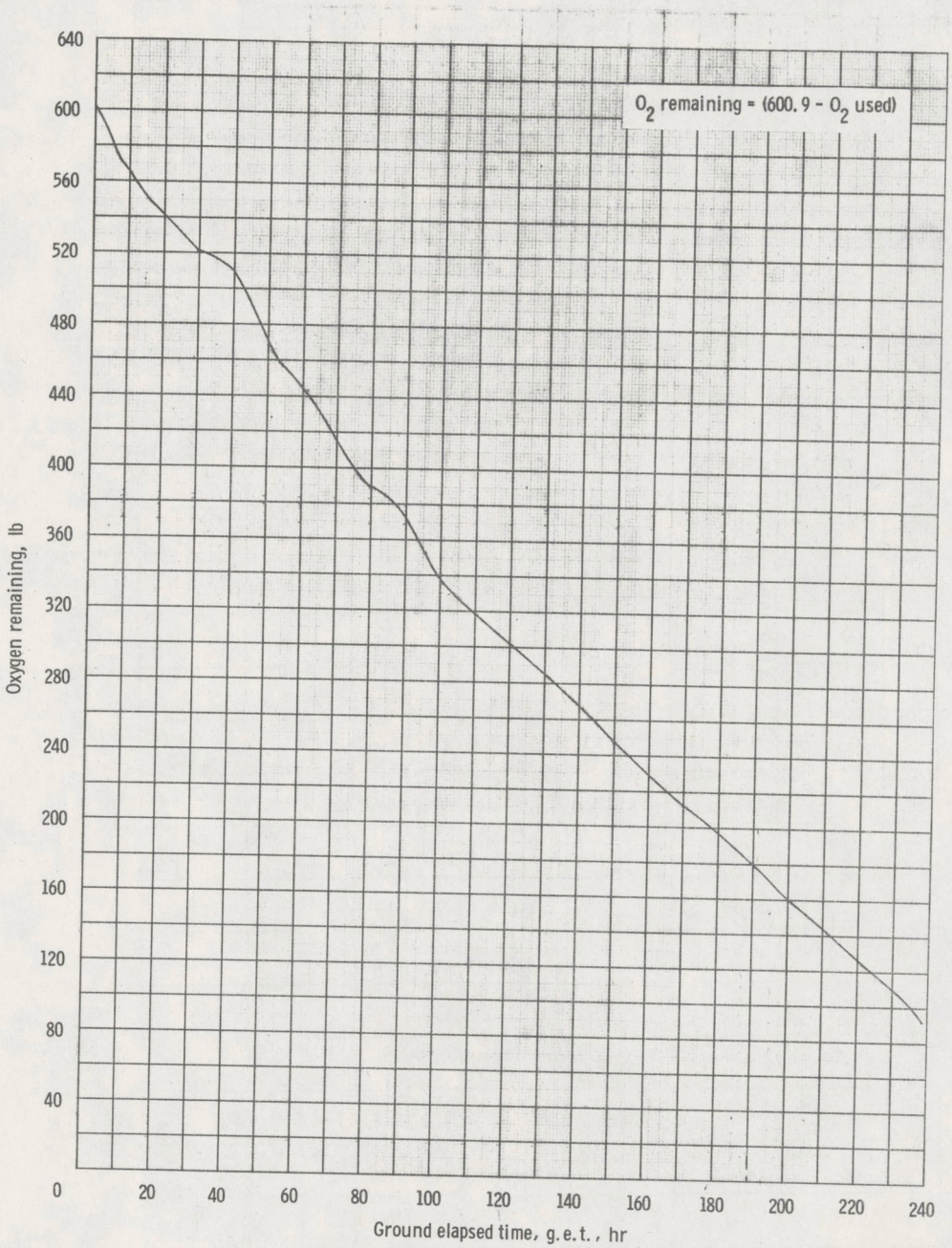


Figure 4. - CSM oxygen remaining as a function of ground elapsed time.

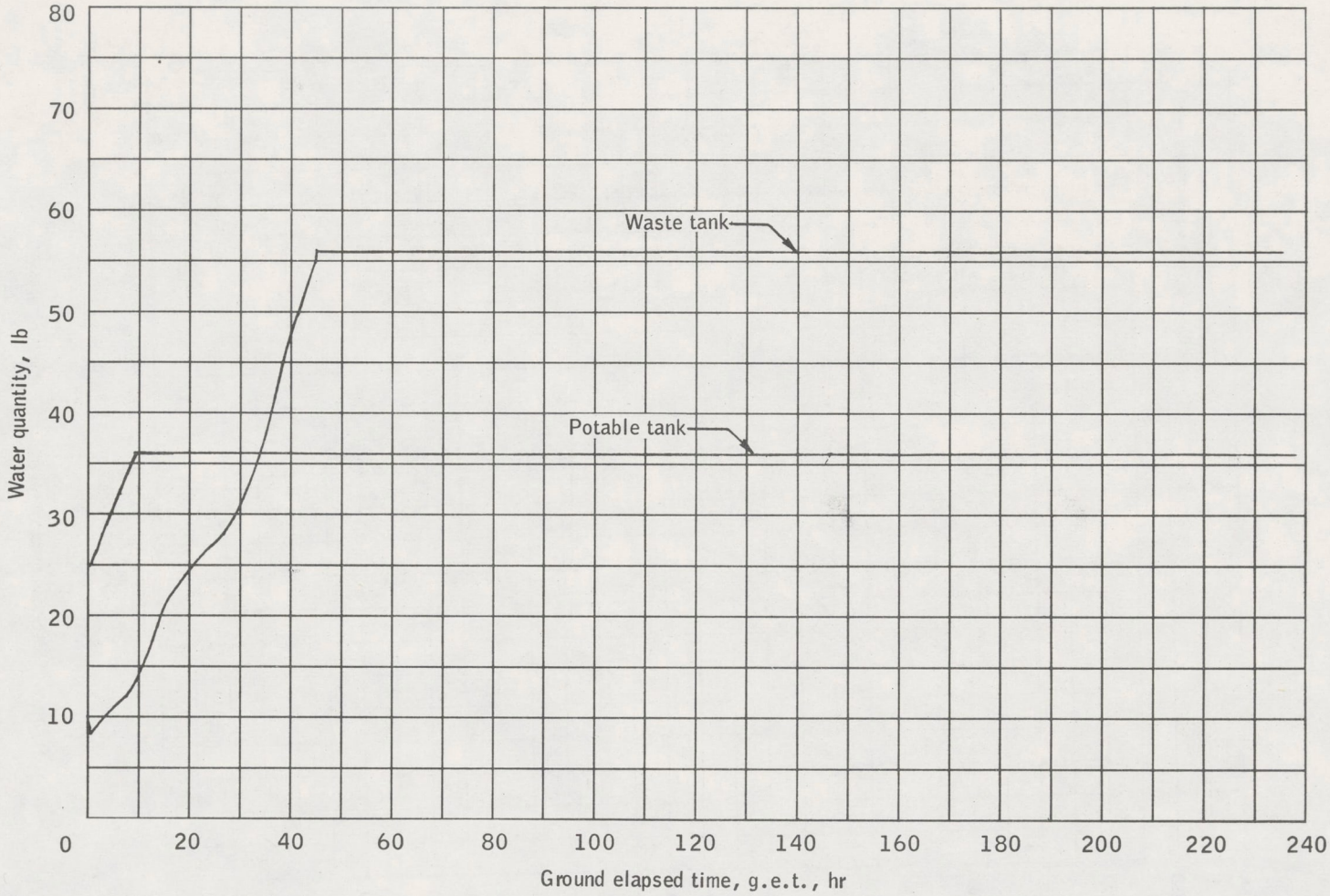
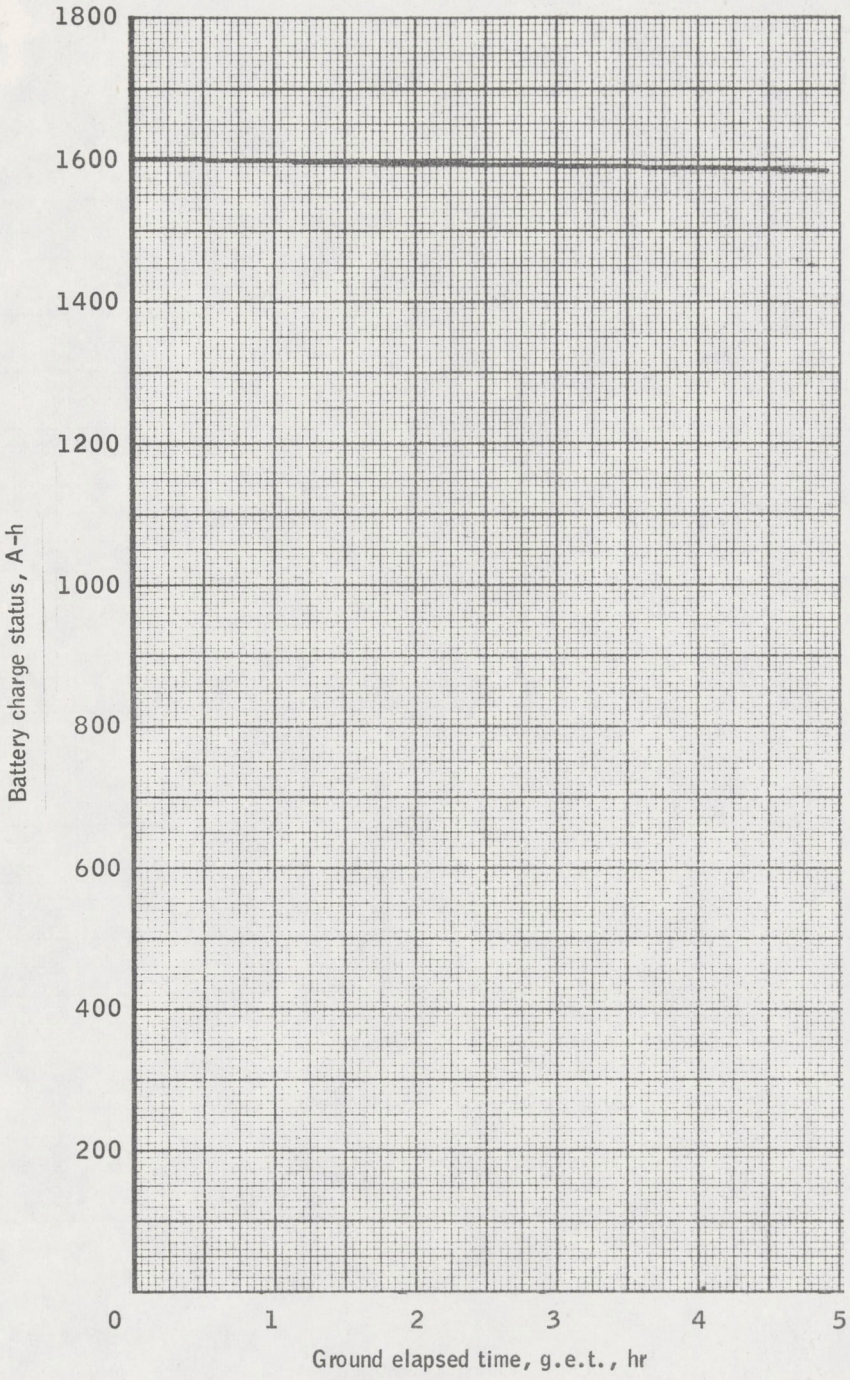
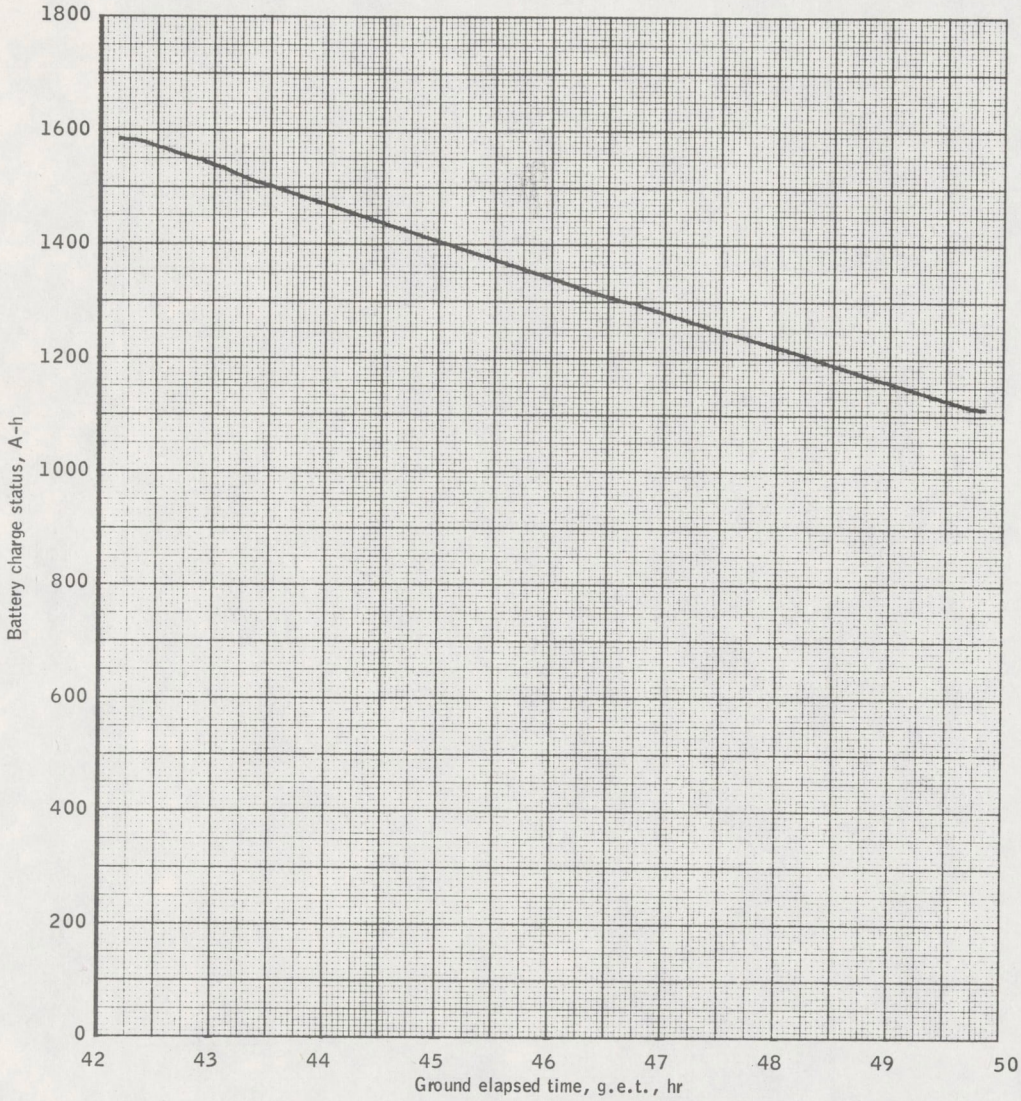


Figure 5. -CSM water available for the E mission.



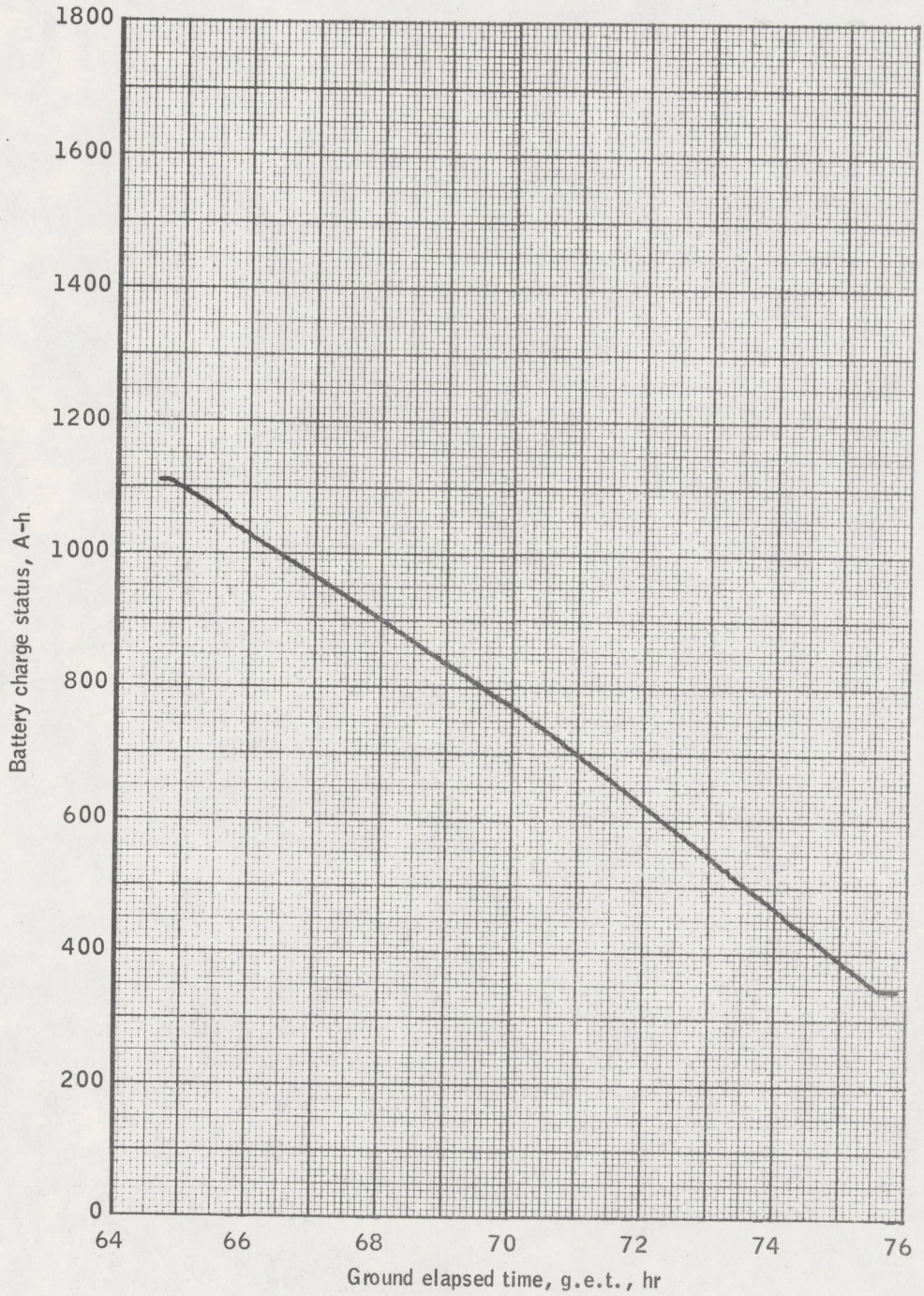
(a) 0 to 5 hours.

Figure 6. -LM descent battery charge status.



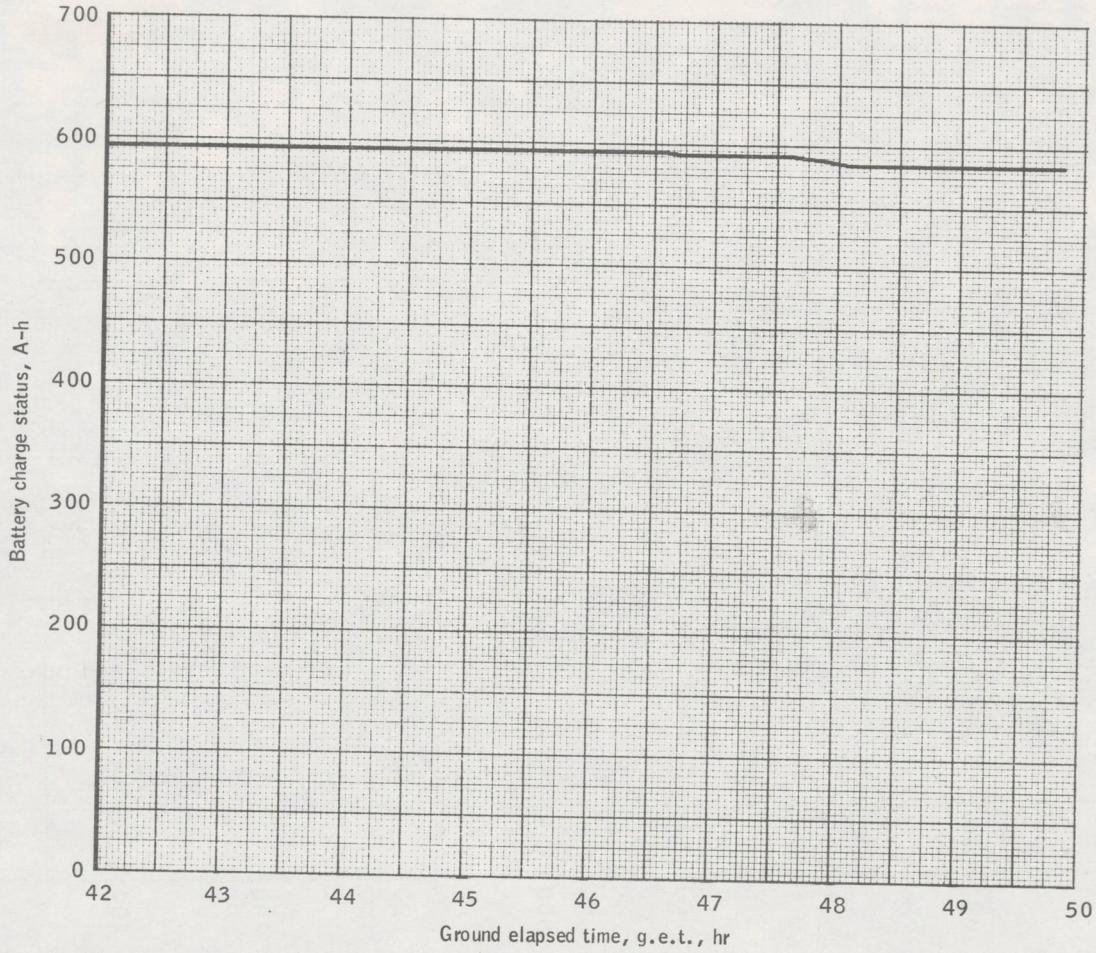
(b) 42 to 50 hours.

Figure 6.- Continued.



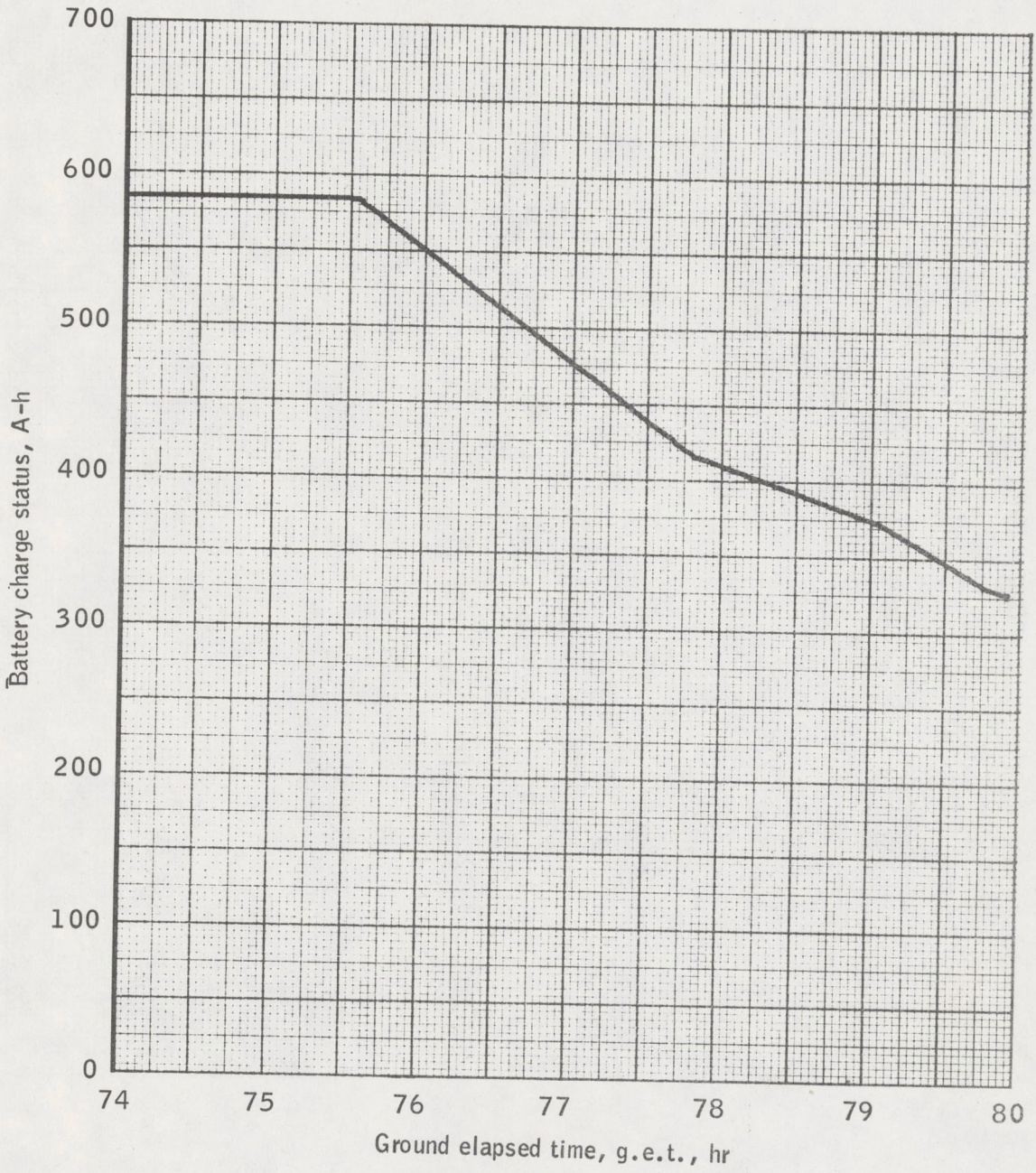
(c) 64 to 76 hours.

Figure 6.- Concluded.



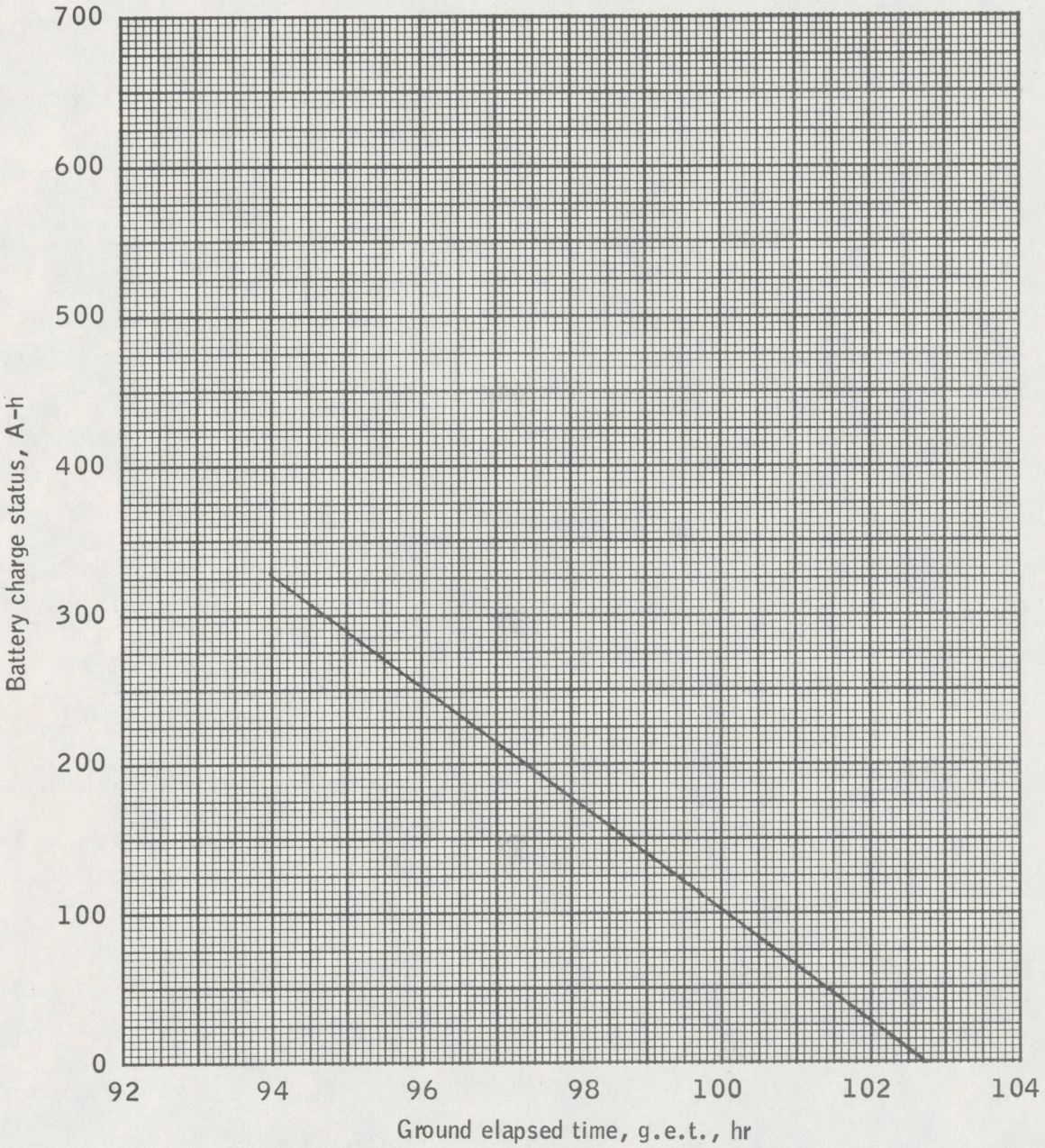
(a) 42 to 50 hours.

Figure 7. -LM ascent battery charge status.



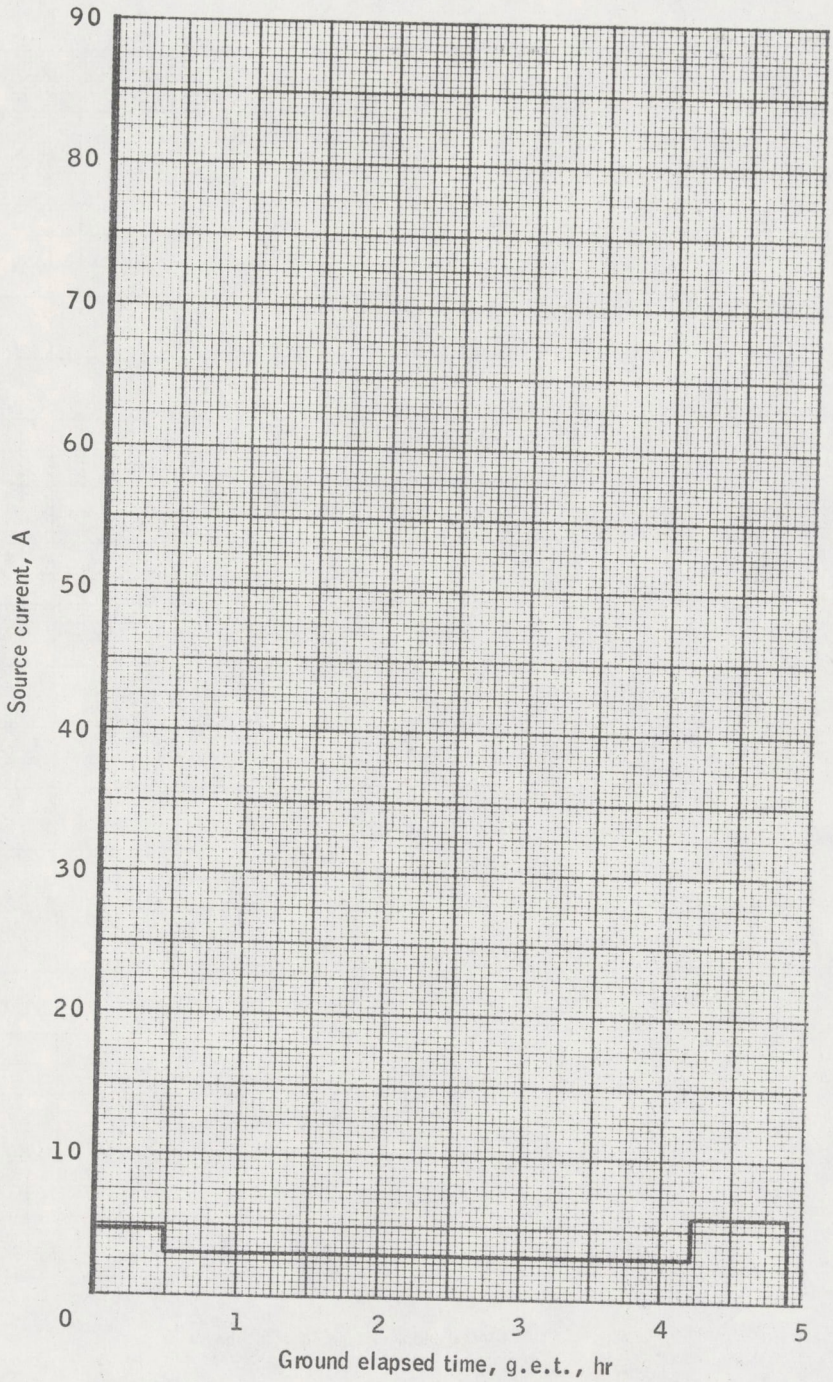
(b) 74 to 80 hours.

Figure 7.- Continued.



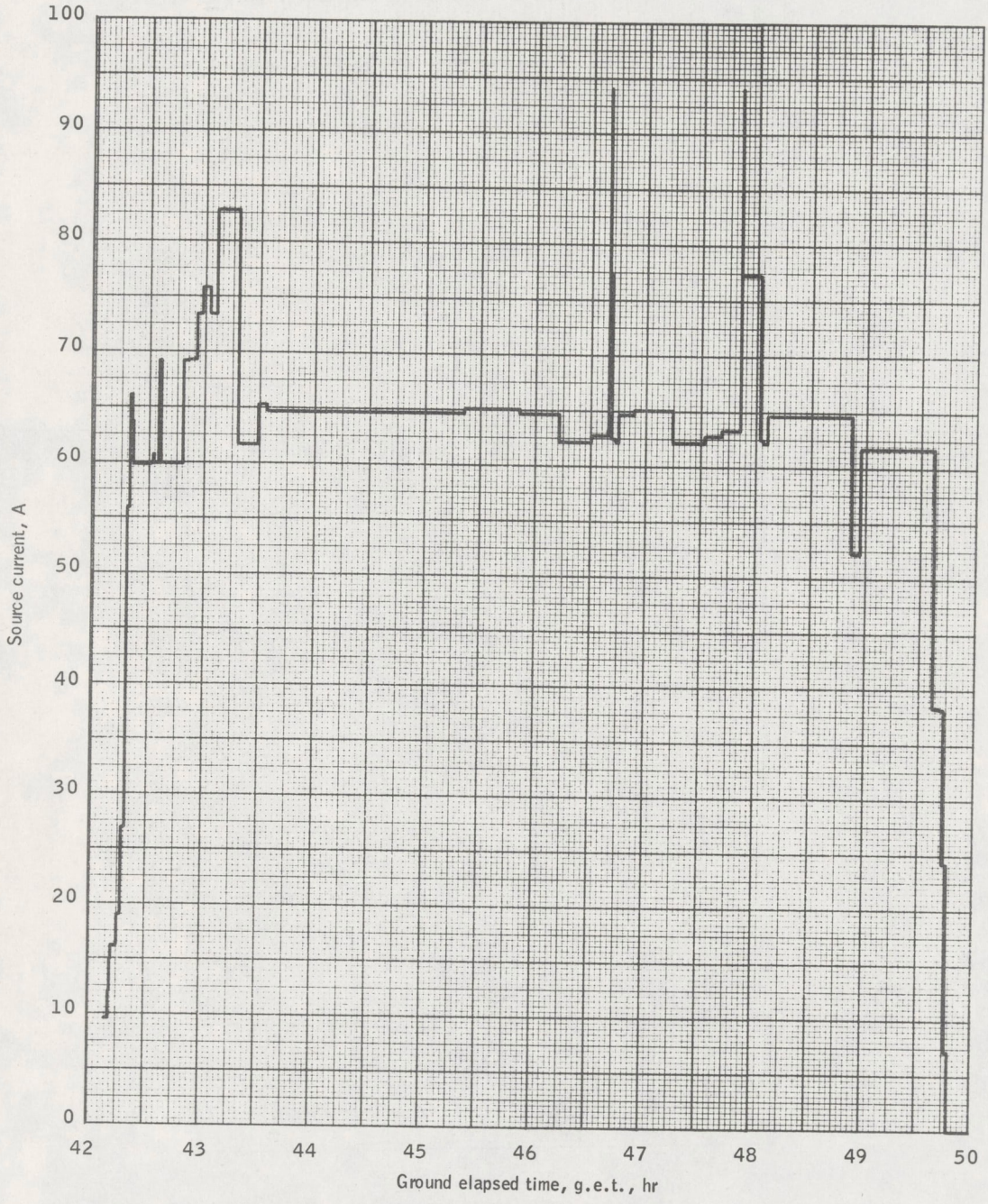
(c) 92 to 104 hours.

Figure 7.- Concluded.



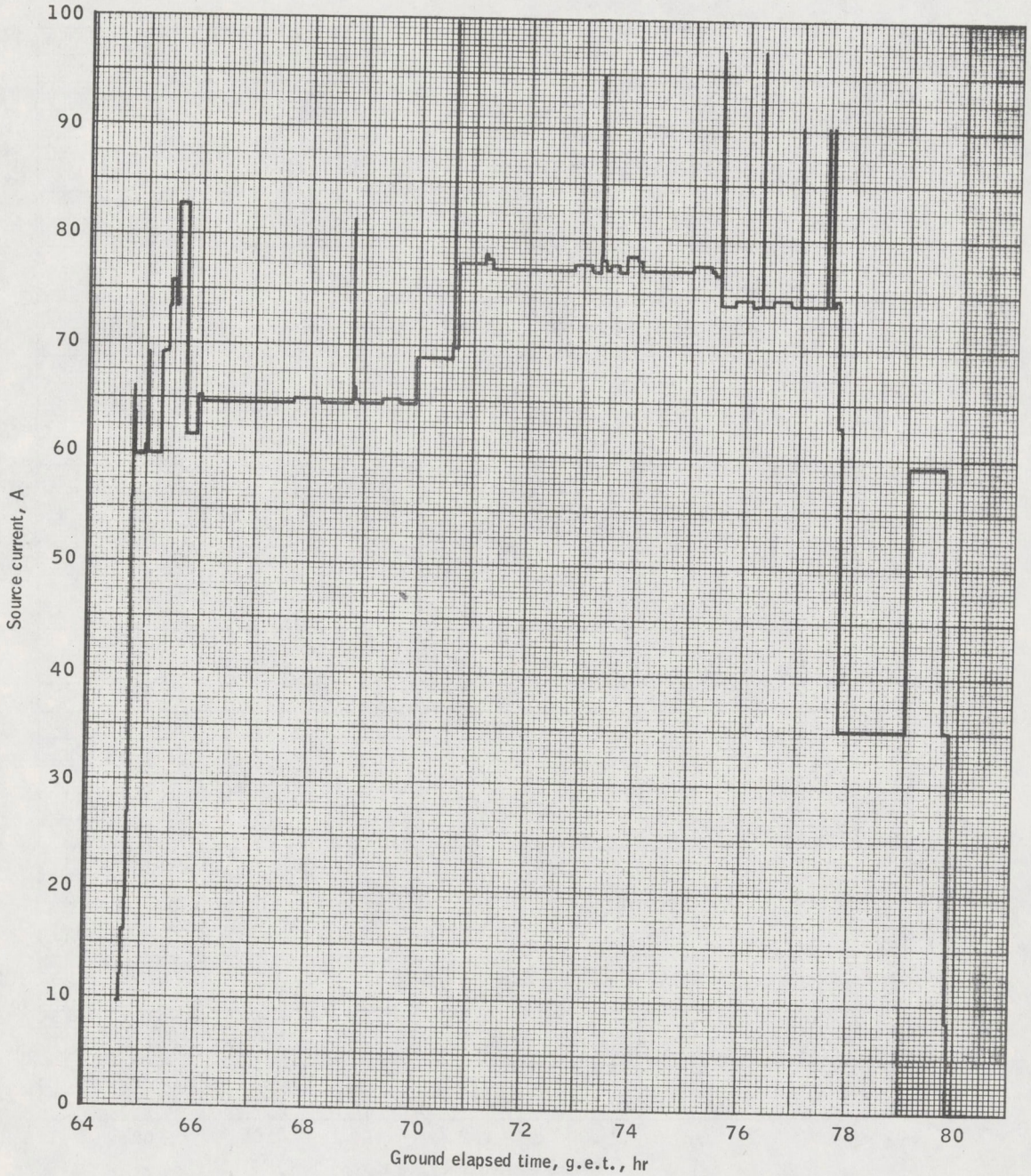
(a) 0 to 5 hours.

Figure 8. -LM source current.



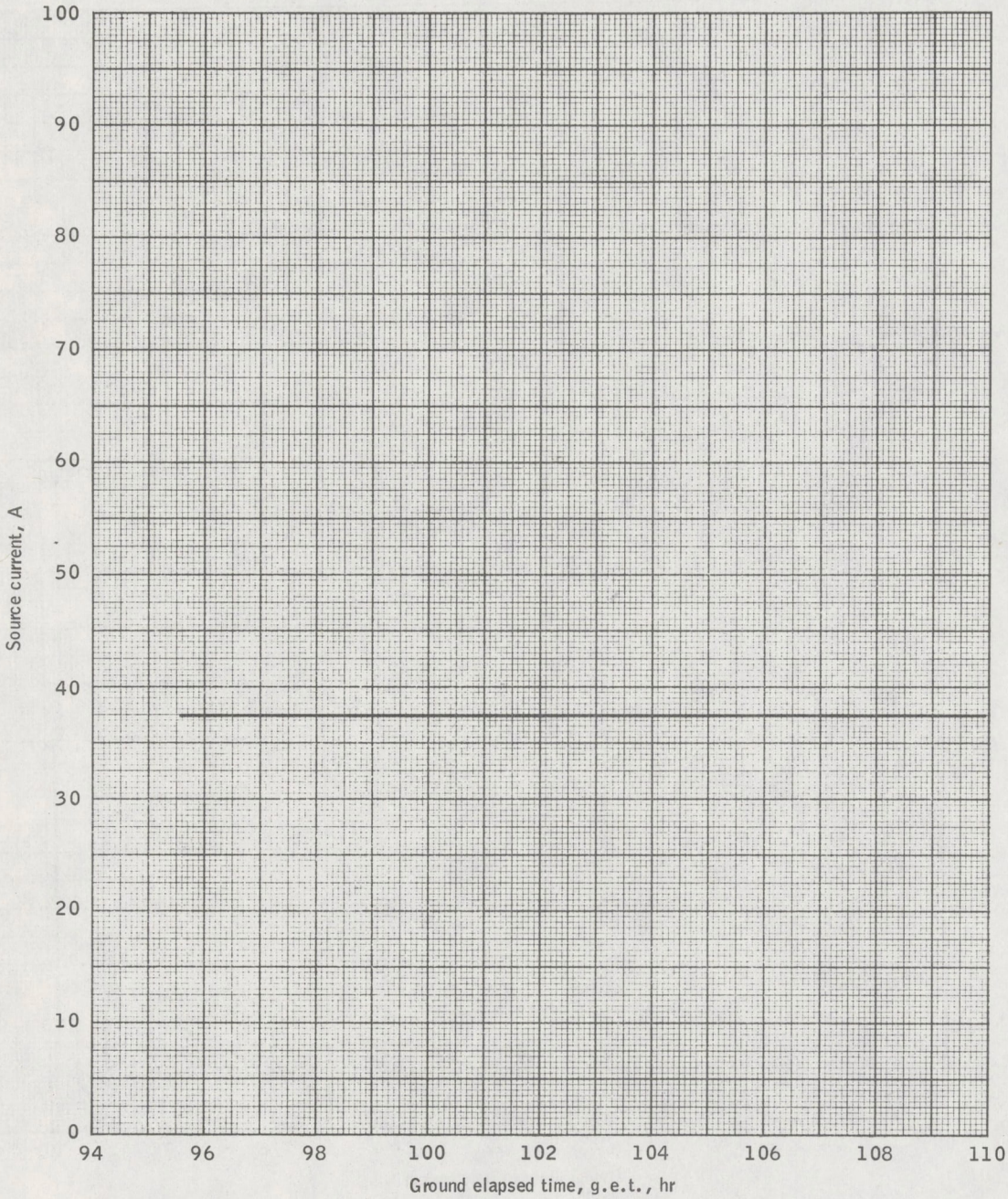
(b) 42 to 50 hours.

Figure 8.- Continued.



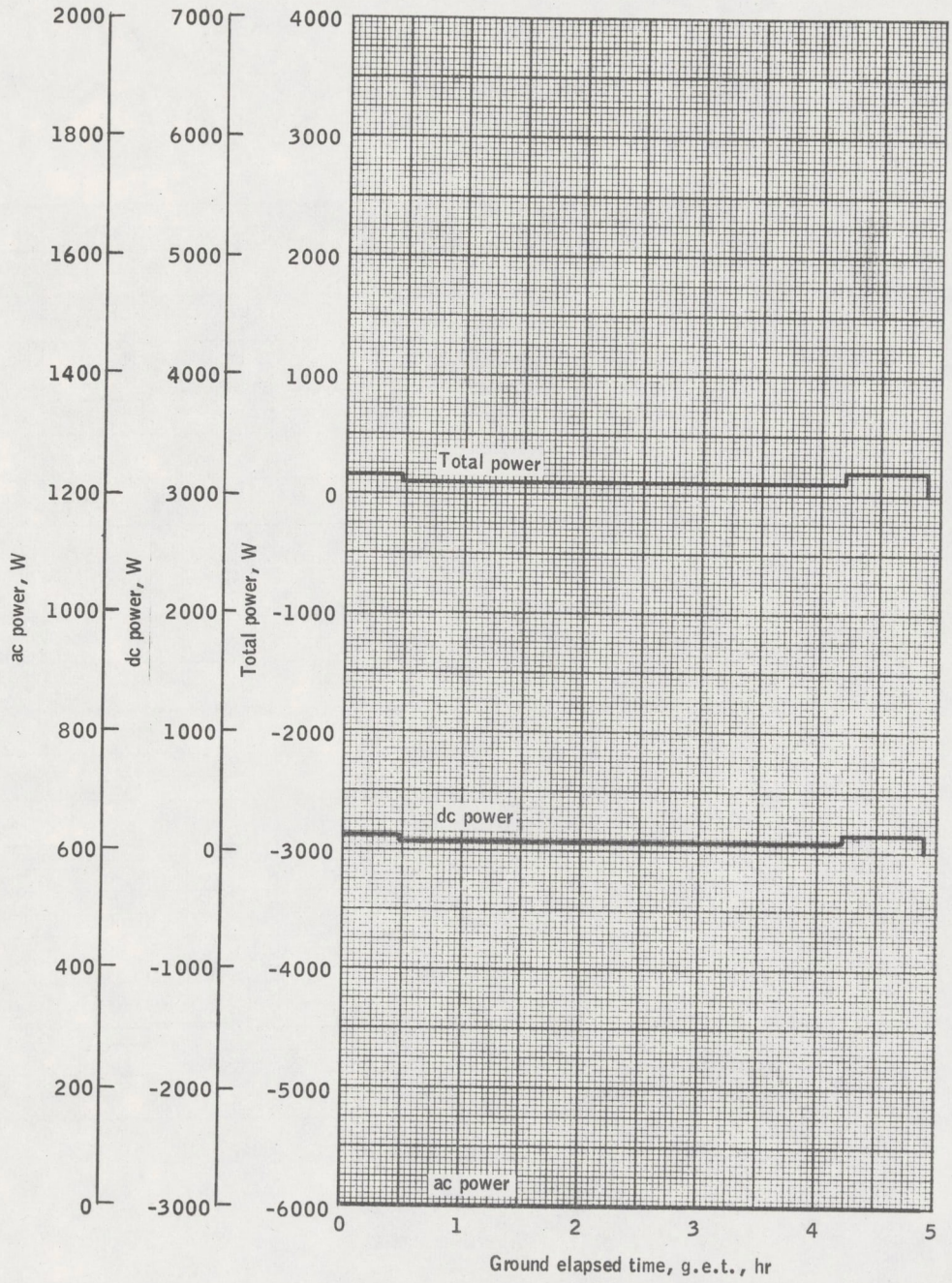
(c) 64 to 80 hours.

Figure 8.- Continued.



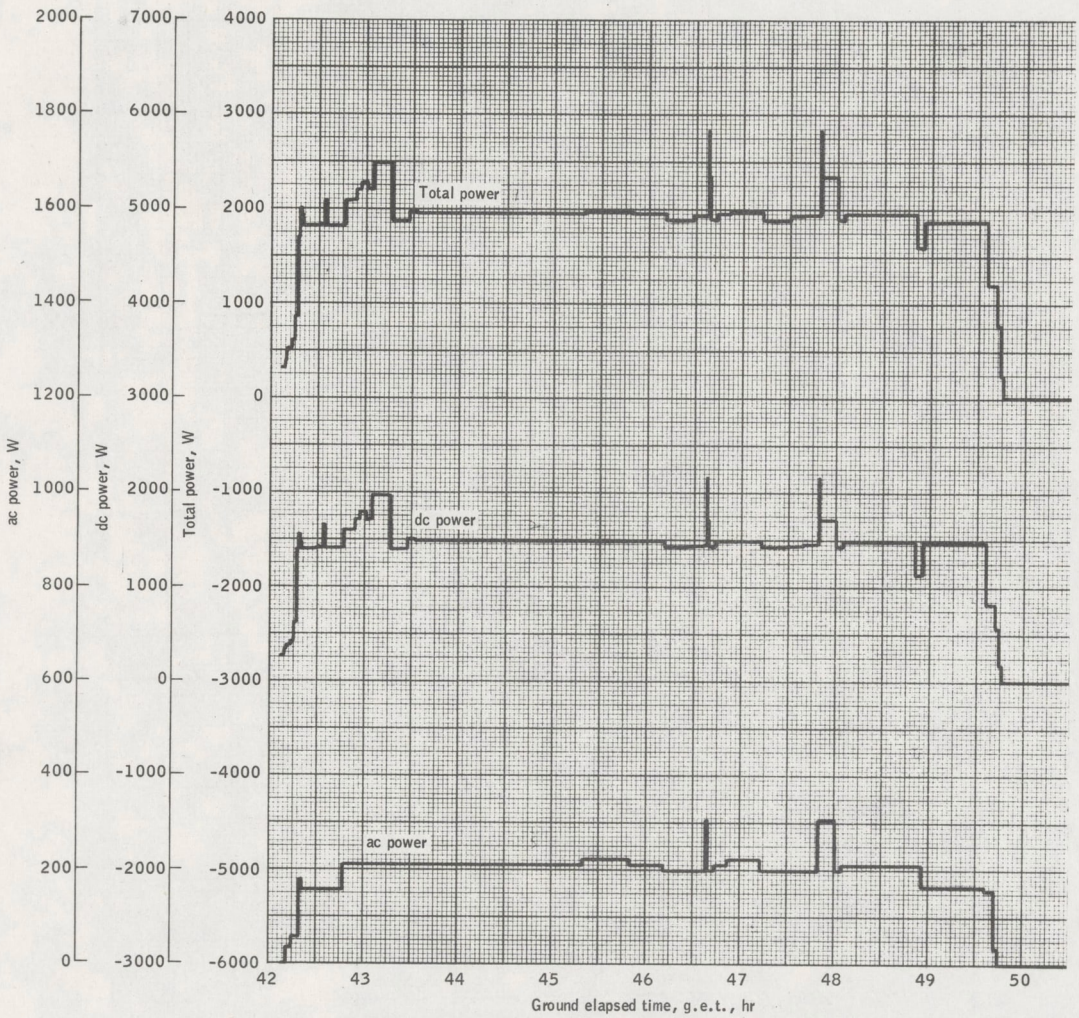
(d) 94 to 110 hours.

Figure 8.- Concluded.



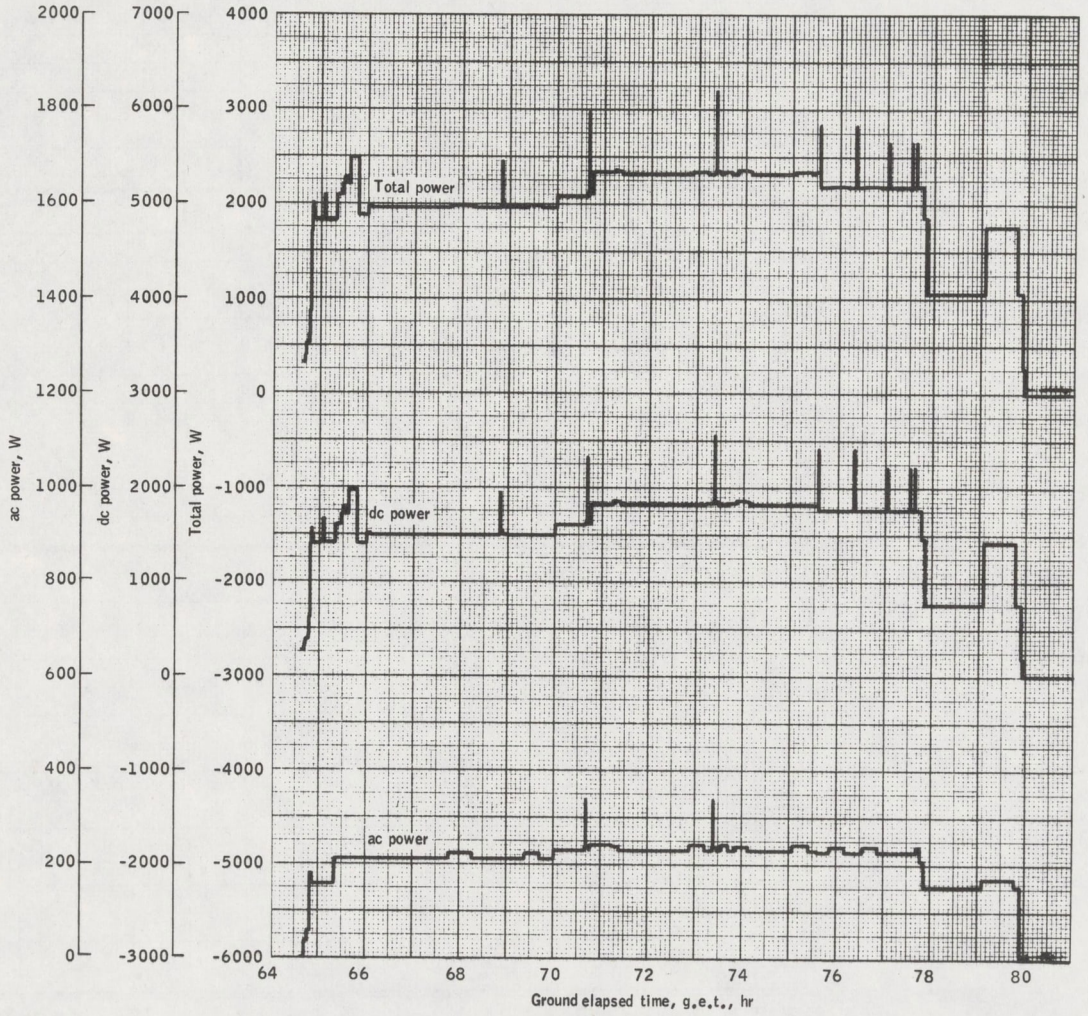
(a) 0 to 5 hours.

Figure 9. - LM ac - dc power profiles.



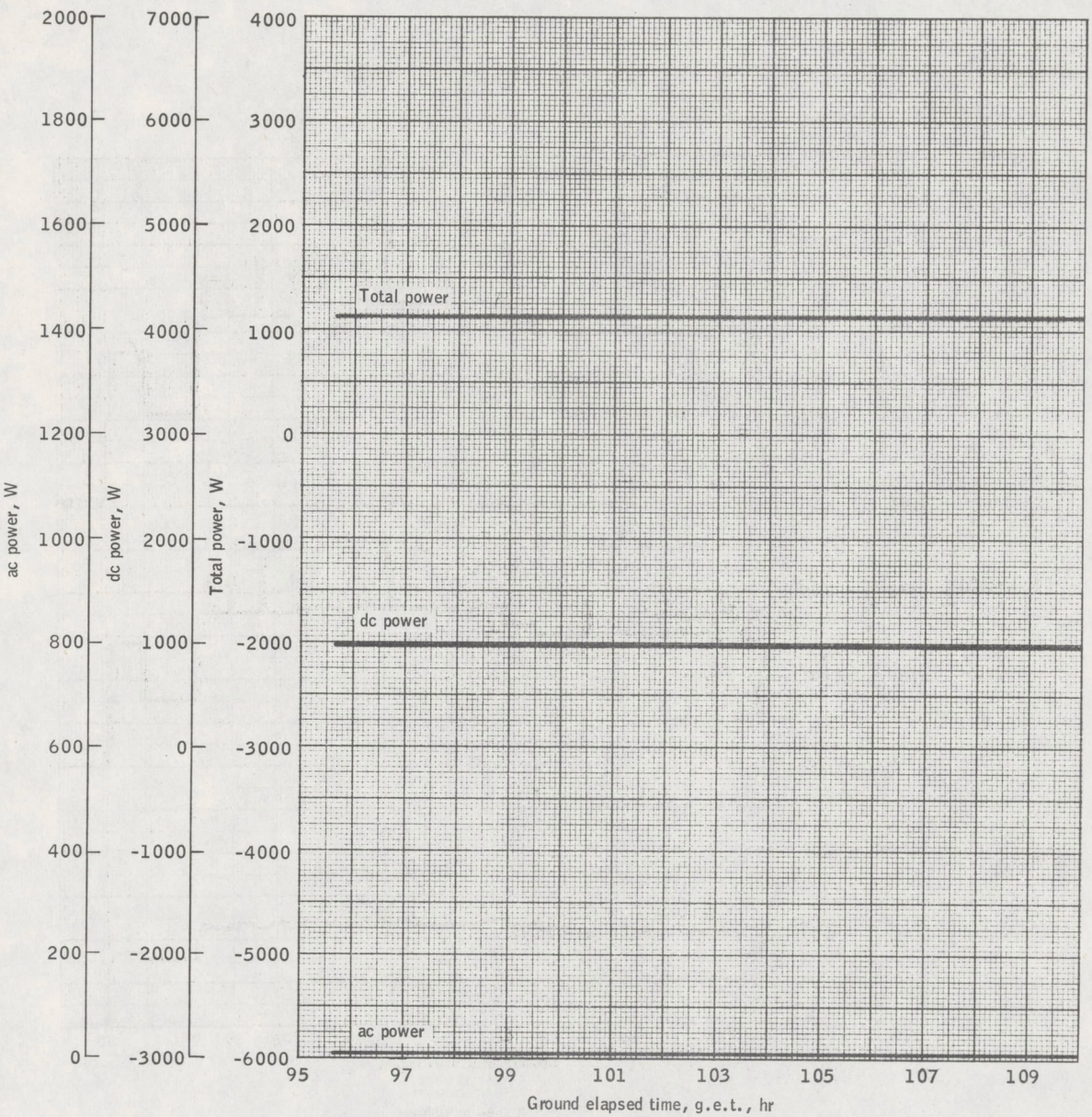
(b) 42 to 50 hours.

Figure 9.- Continued.



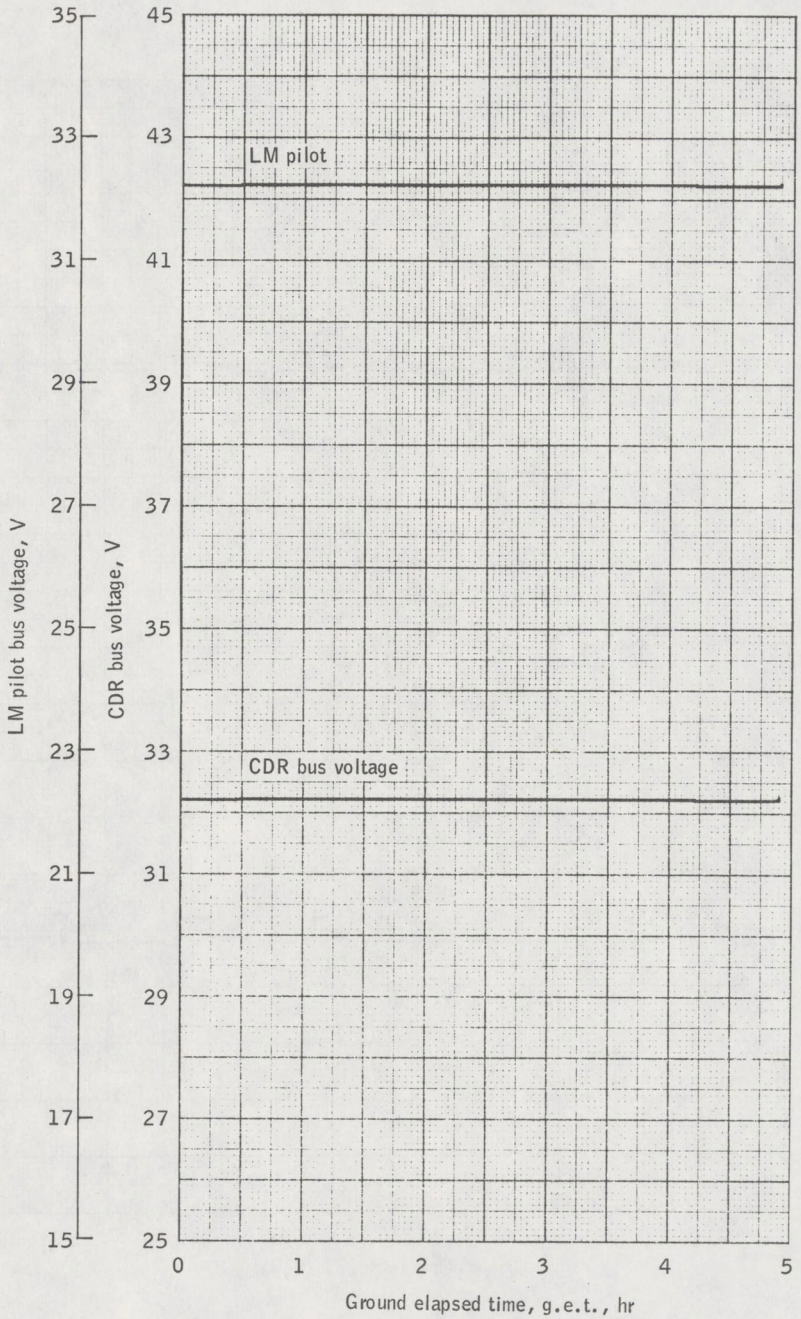
(c) 64 to 80 hours.

Figure 9.- Continued.



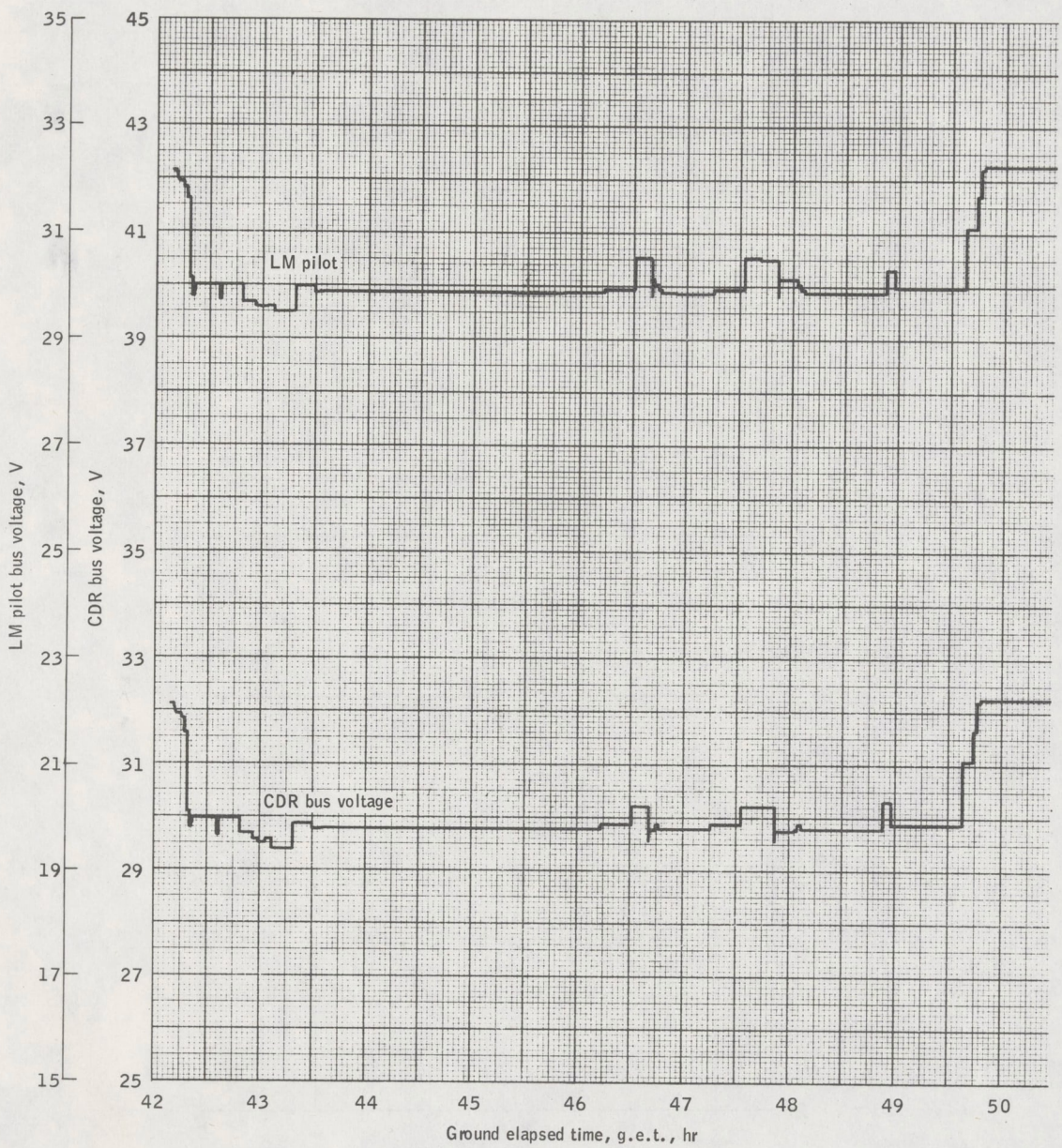
(d) 95 to 109 hours.

Figure 9.- Concluded.



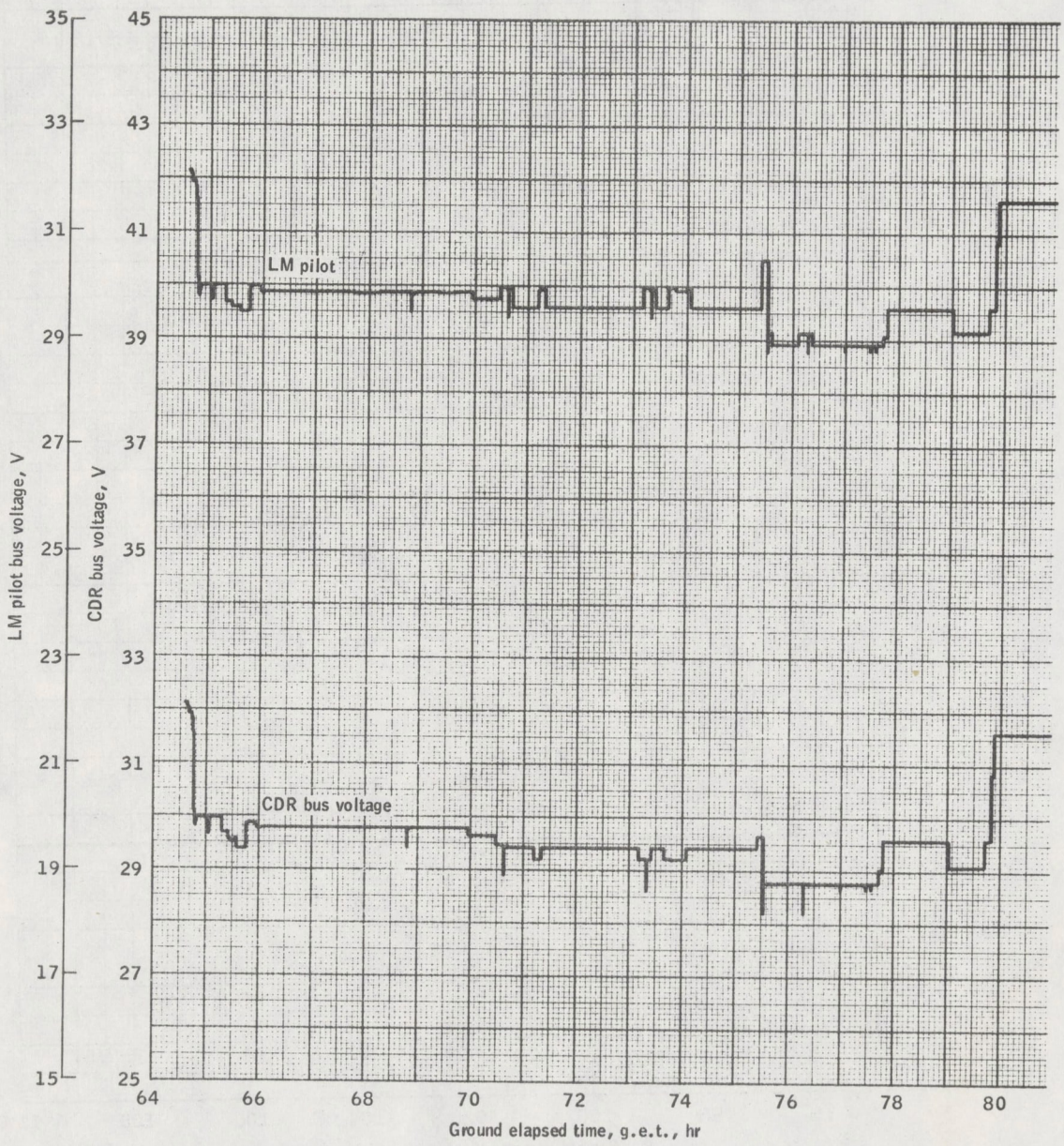
(a) 0 to 5 hours.

Figure 10. -LM pilot and commander buses.



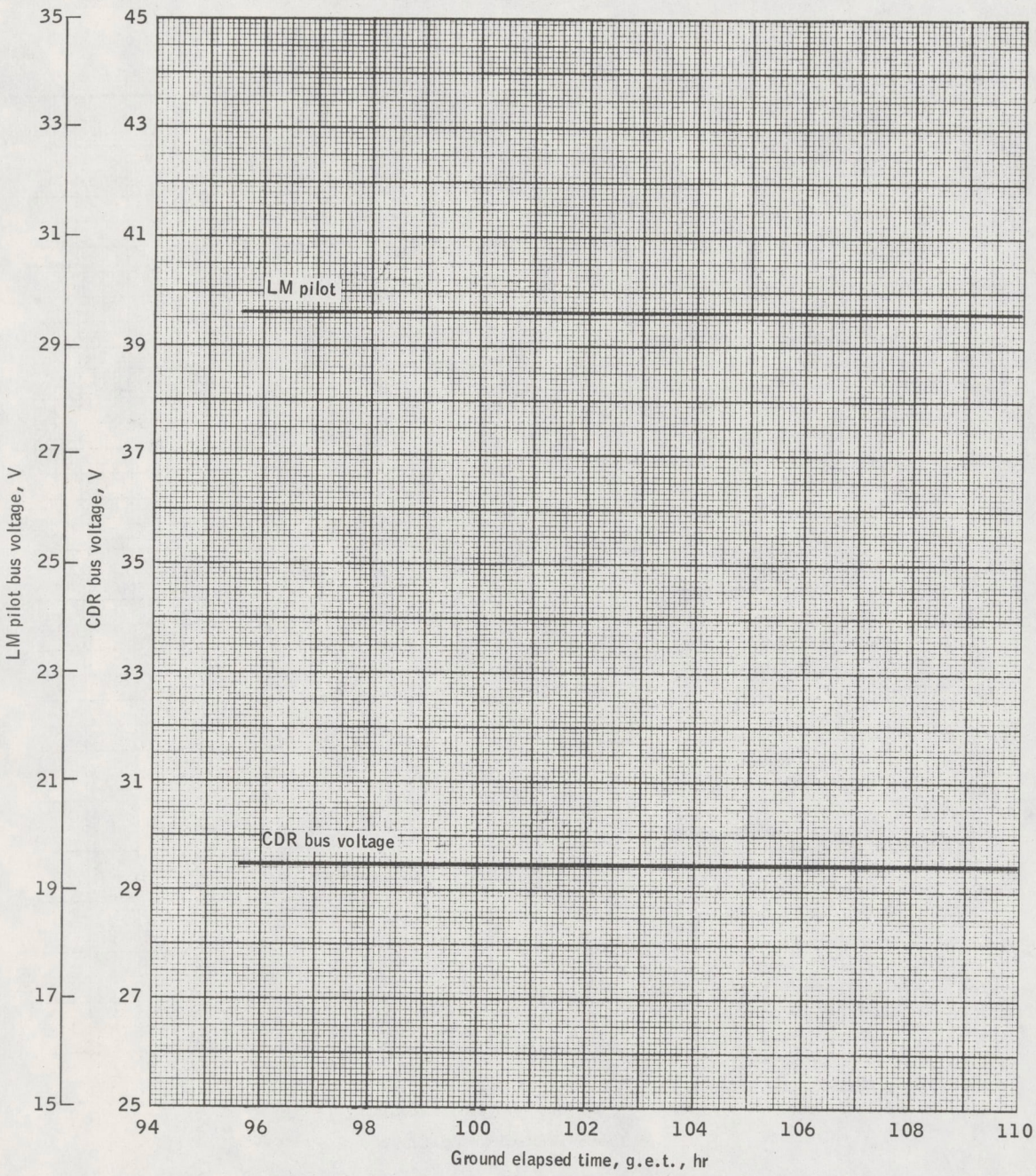
(b) 42 to 50 hours.

Figure 10.- Continued.



(c) 64 to 80 hours.

Figure 10.- Continued.



(d) 94 to 110 hours.

Figure 10.- Concluded.

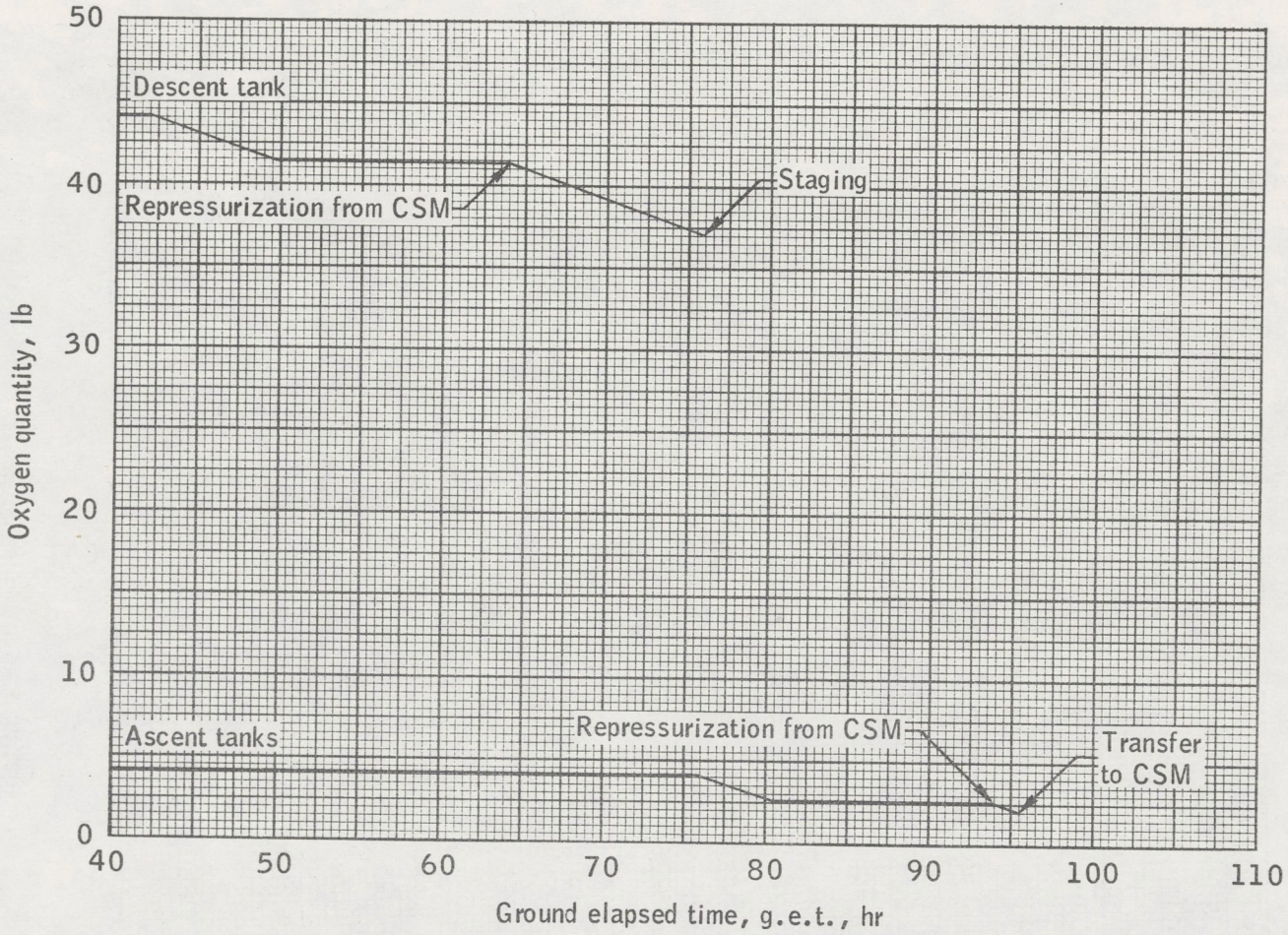


Figure 11.- LM descent and ascent oxygen consumption.

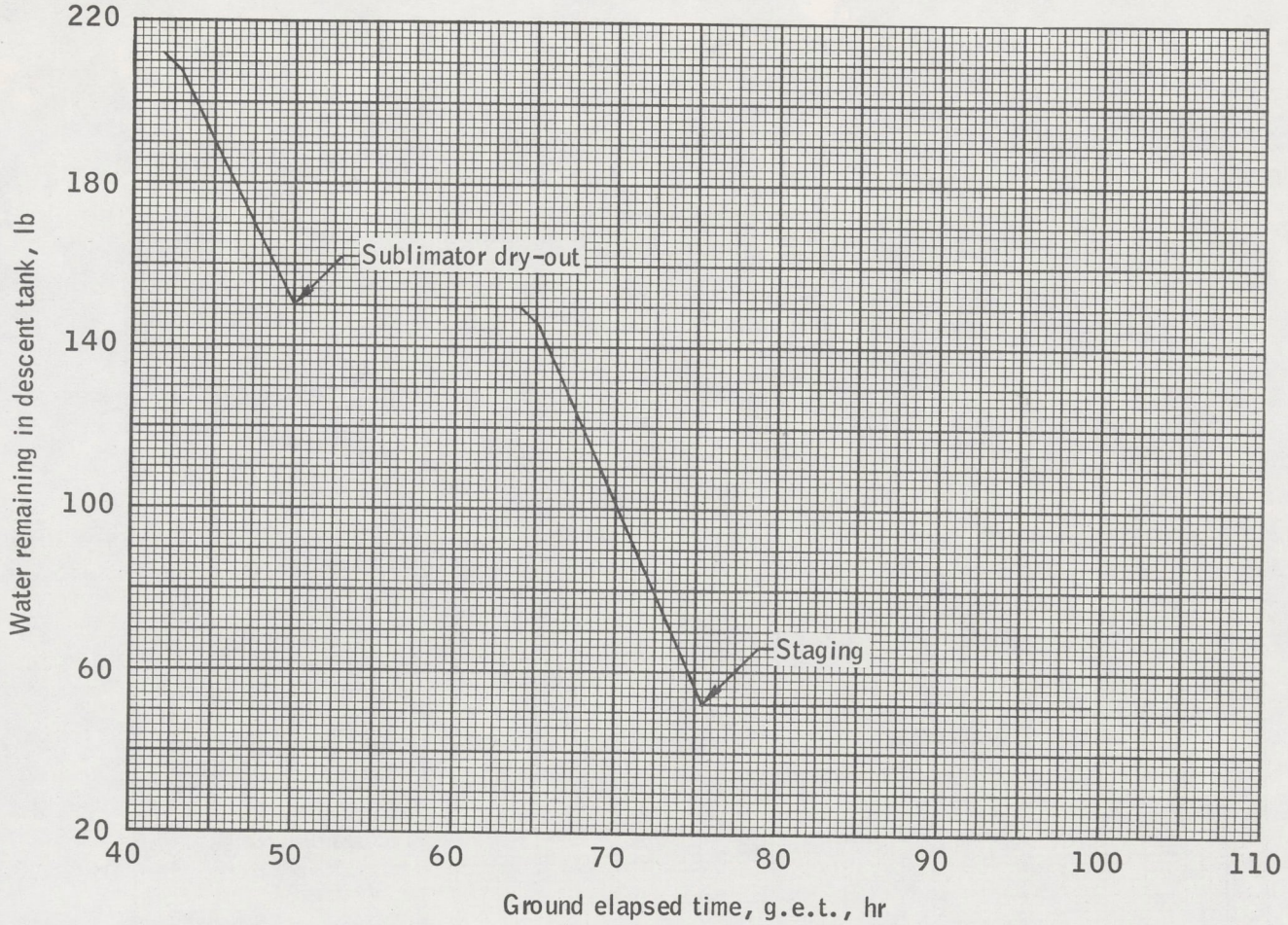


Figure 12. - Usable water remaining in LM descent tank.

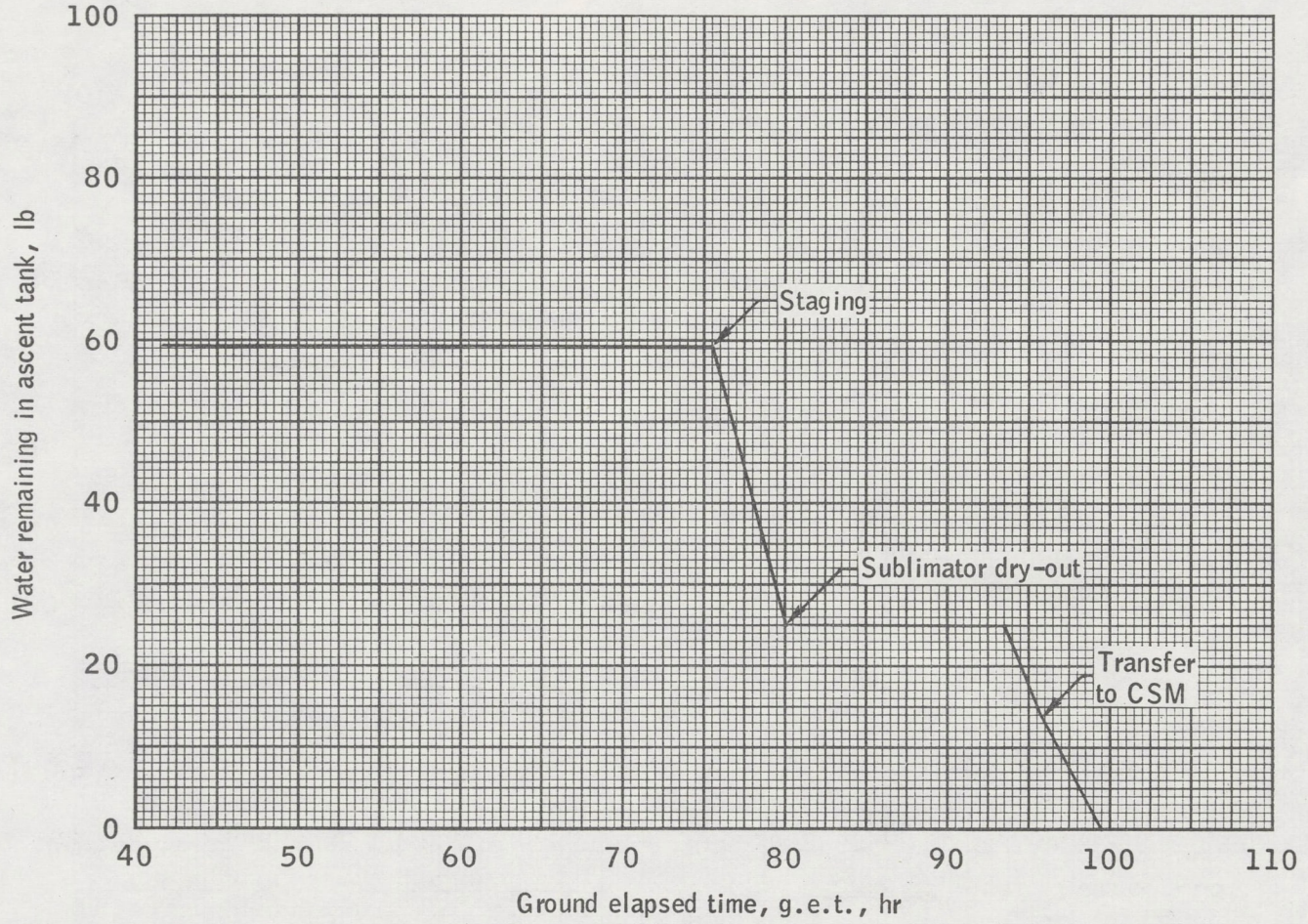


Figure 13. - Usable water remaining in LM ascent tank.

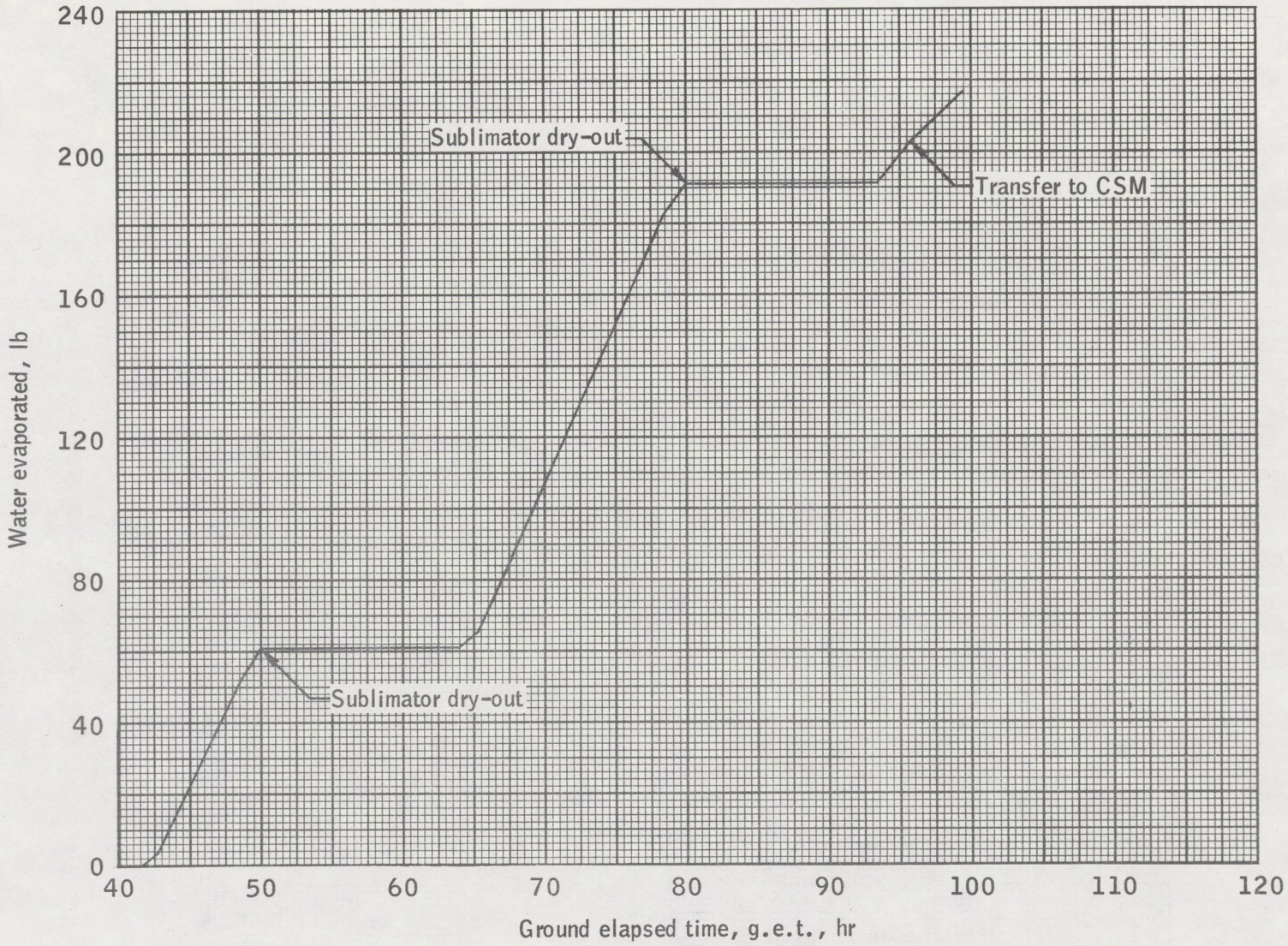
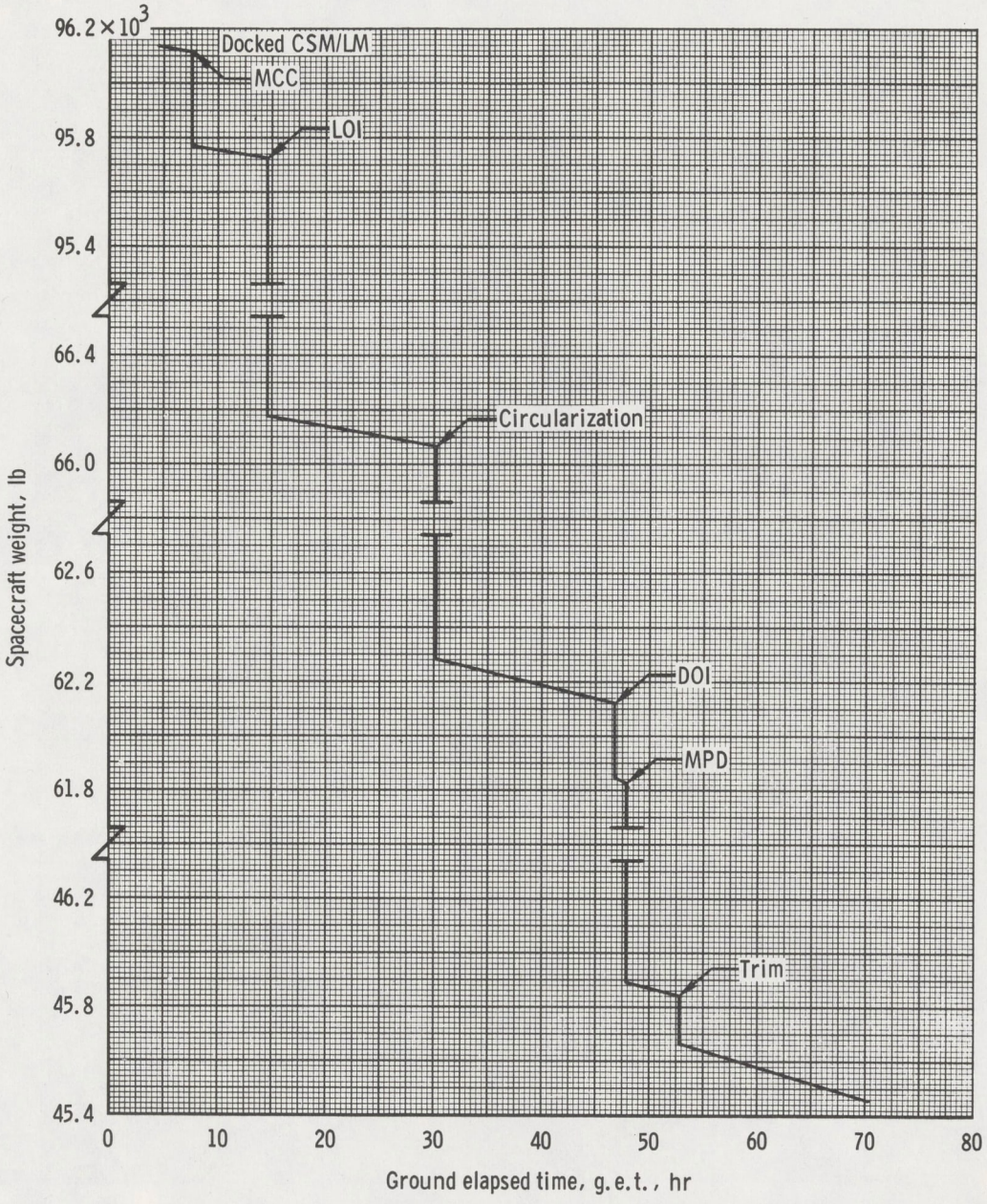
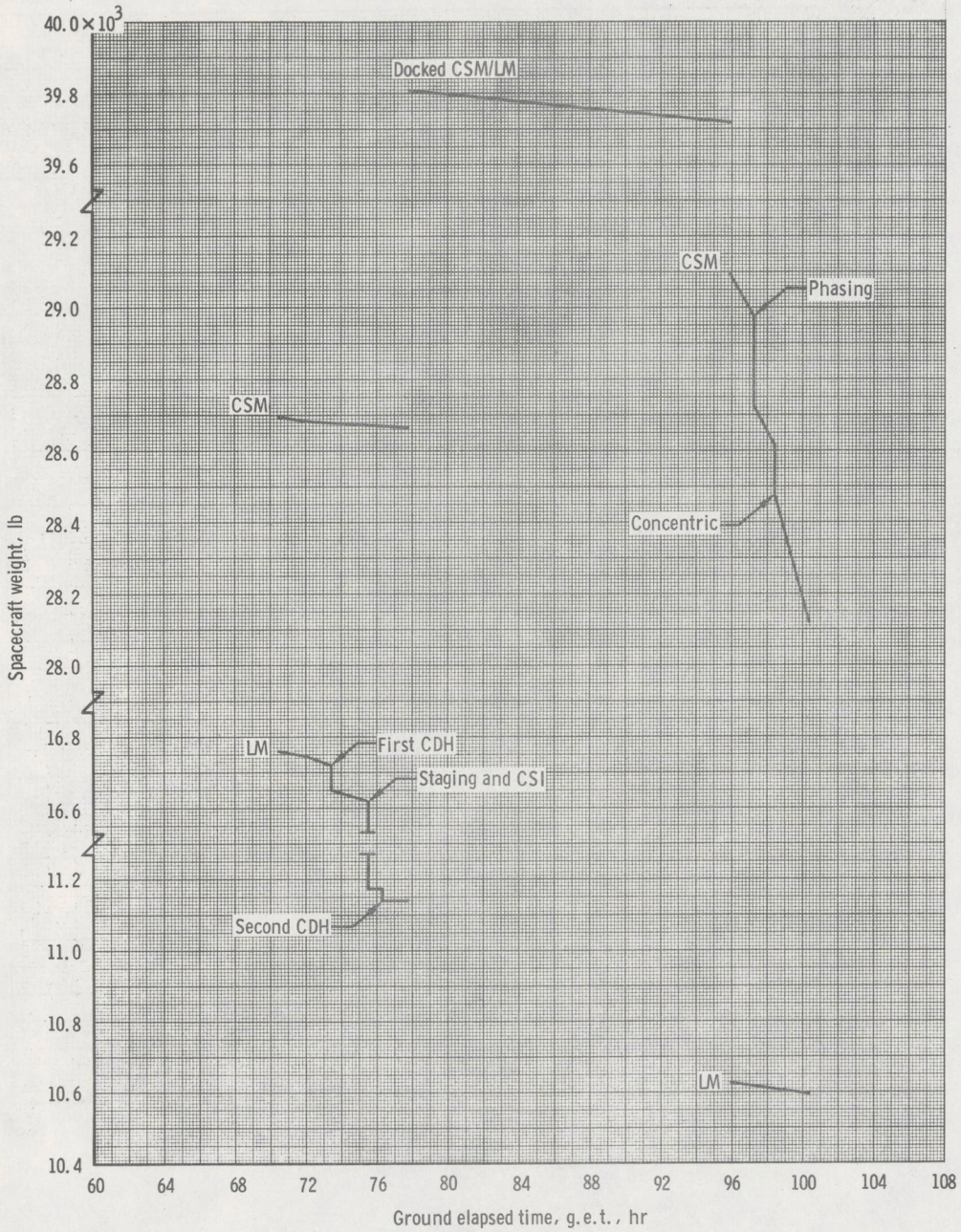


Figure 14.- Water evaporated from LM.



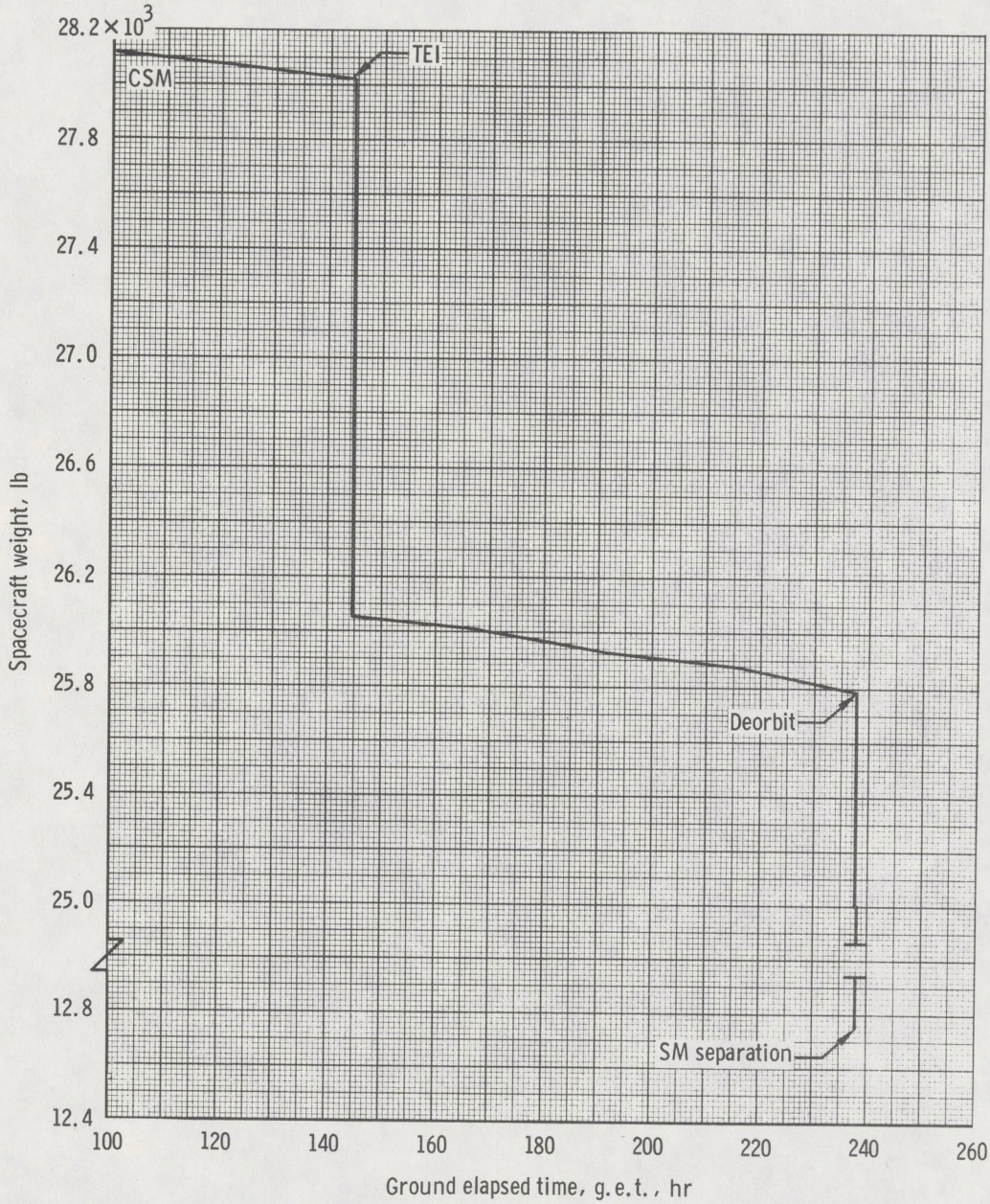
(a) 04:31 to 70:22 (hours:minutes).

Figure 15. - Time history of spacecraft weight.



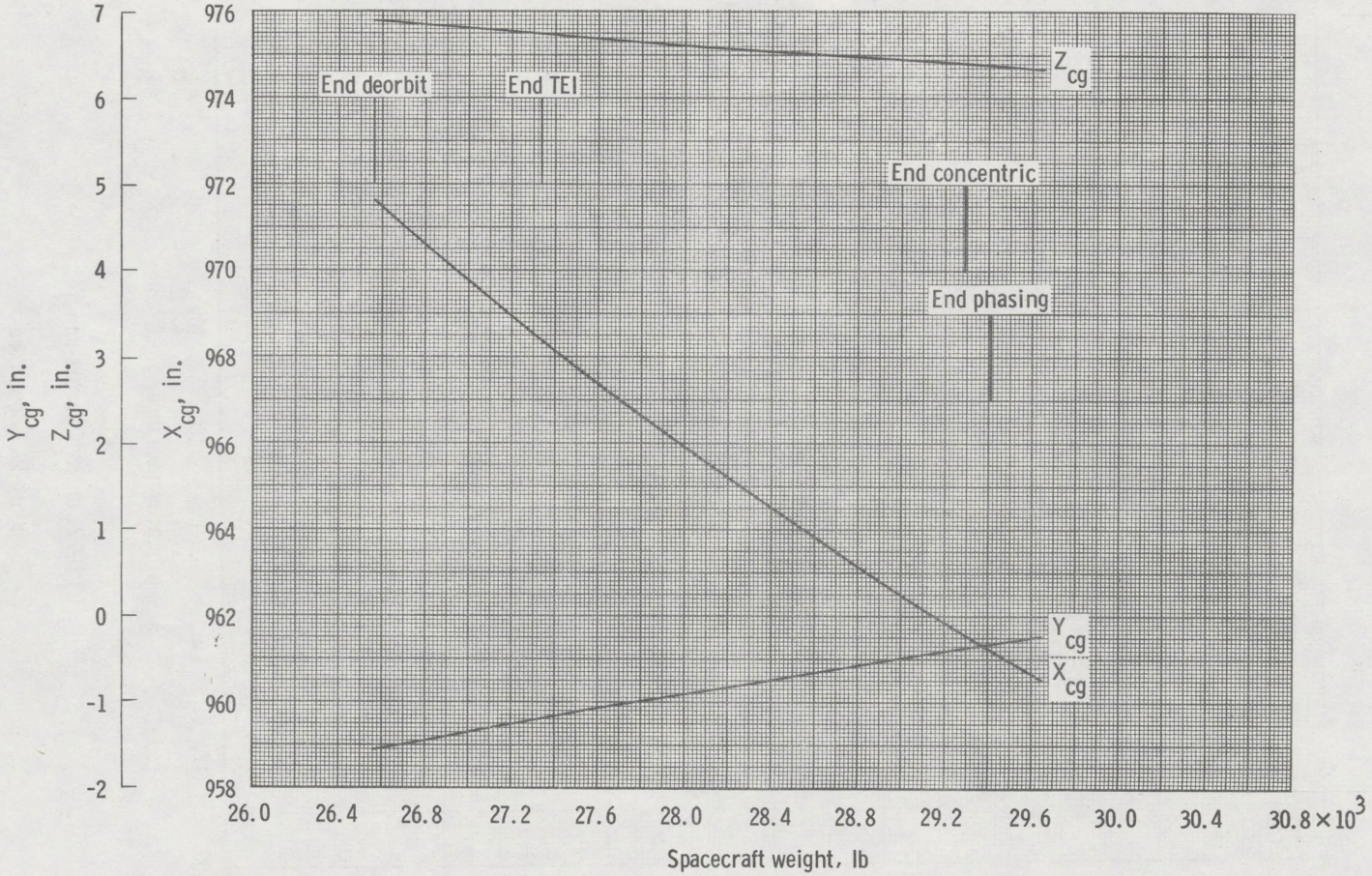
(b) 70:22 to 100:22 (hours:minutes)

Figure 15. - Continued.



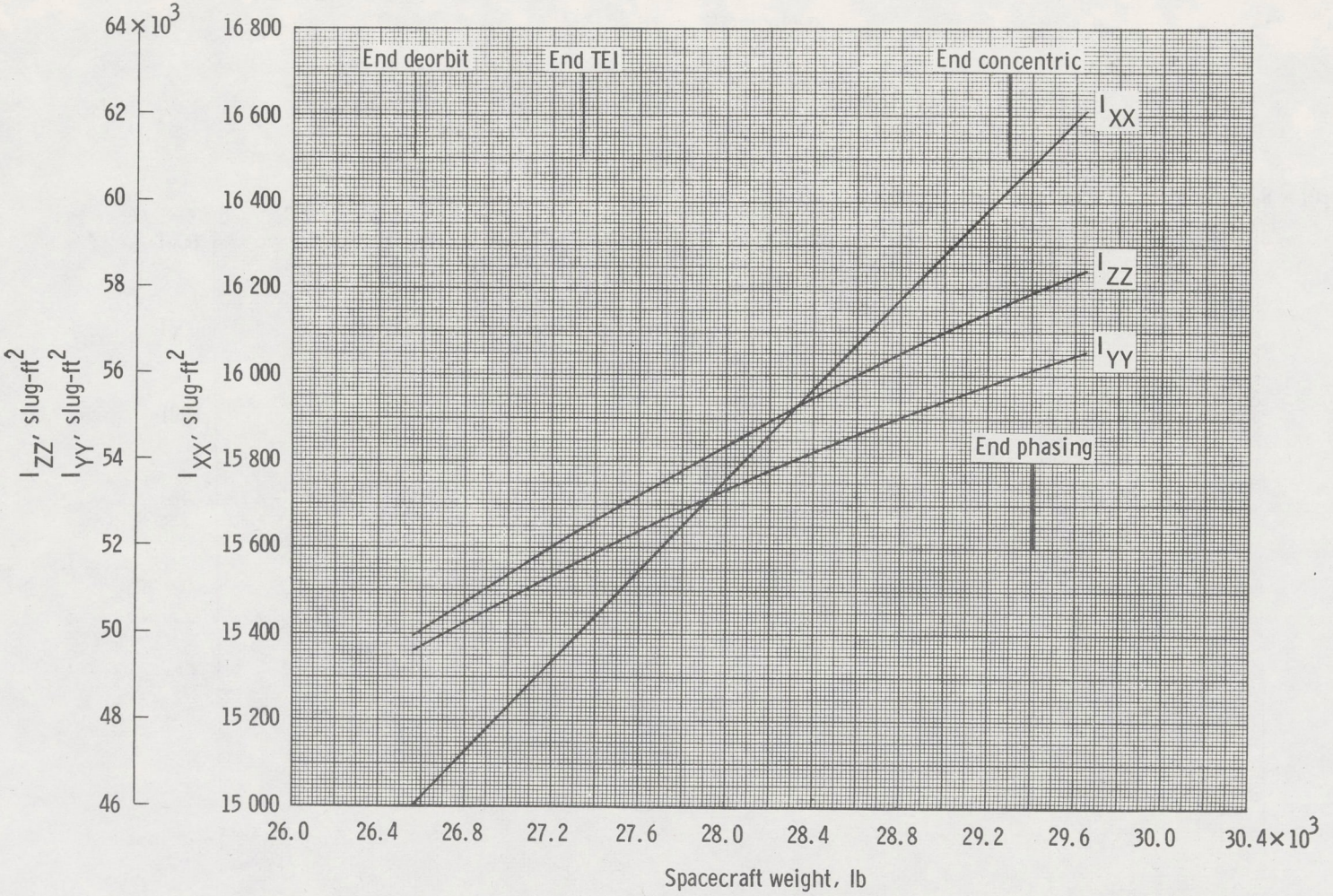
(c) 100:22 to 238:00 (hours:minutes).

Figure 15. - Concluded.



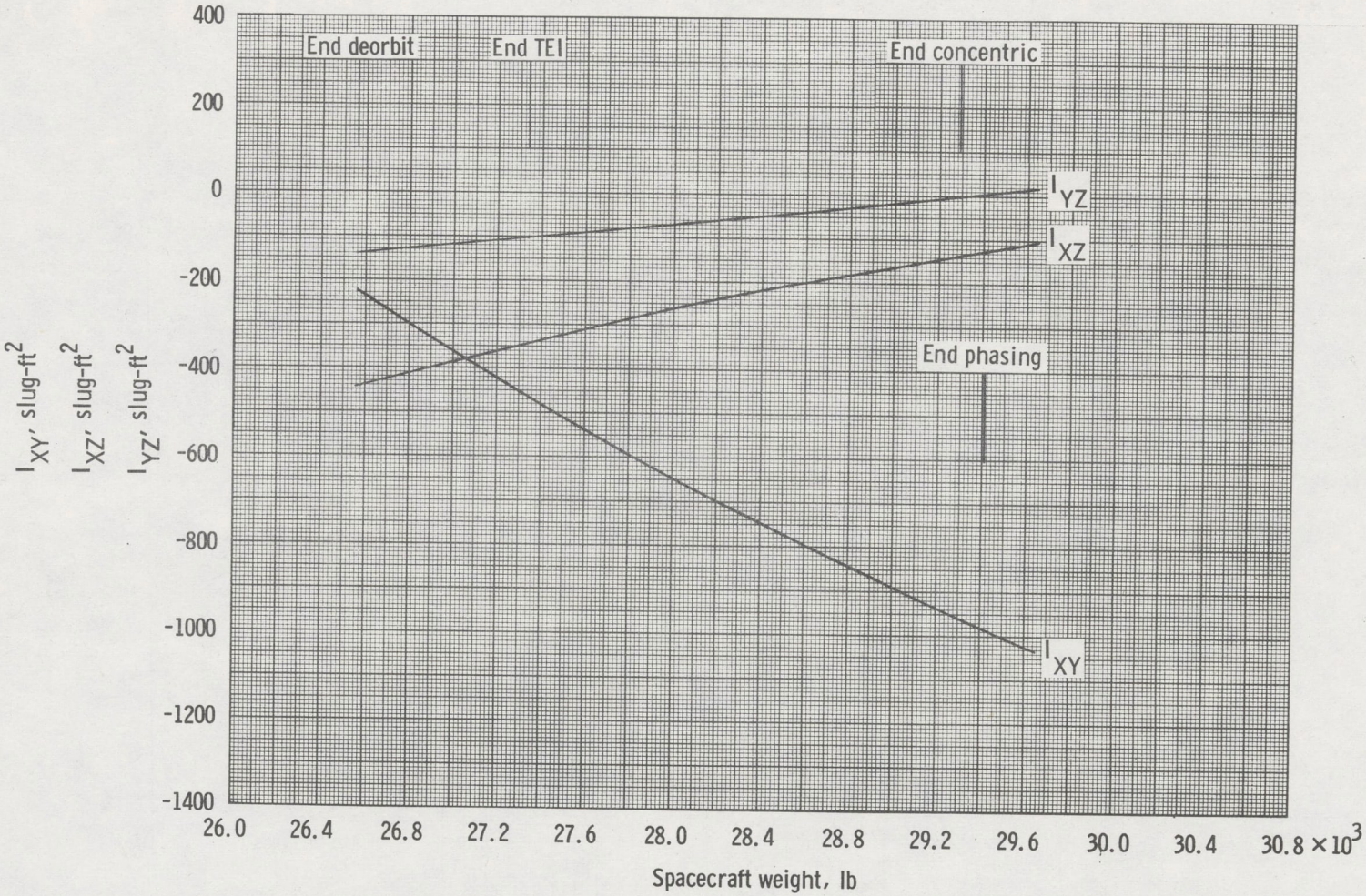
(a) Centers of gravity versus spacecraft weight.

Figure 16.- CSM phase mass properties.



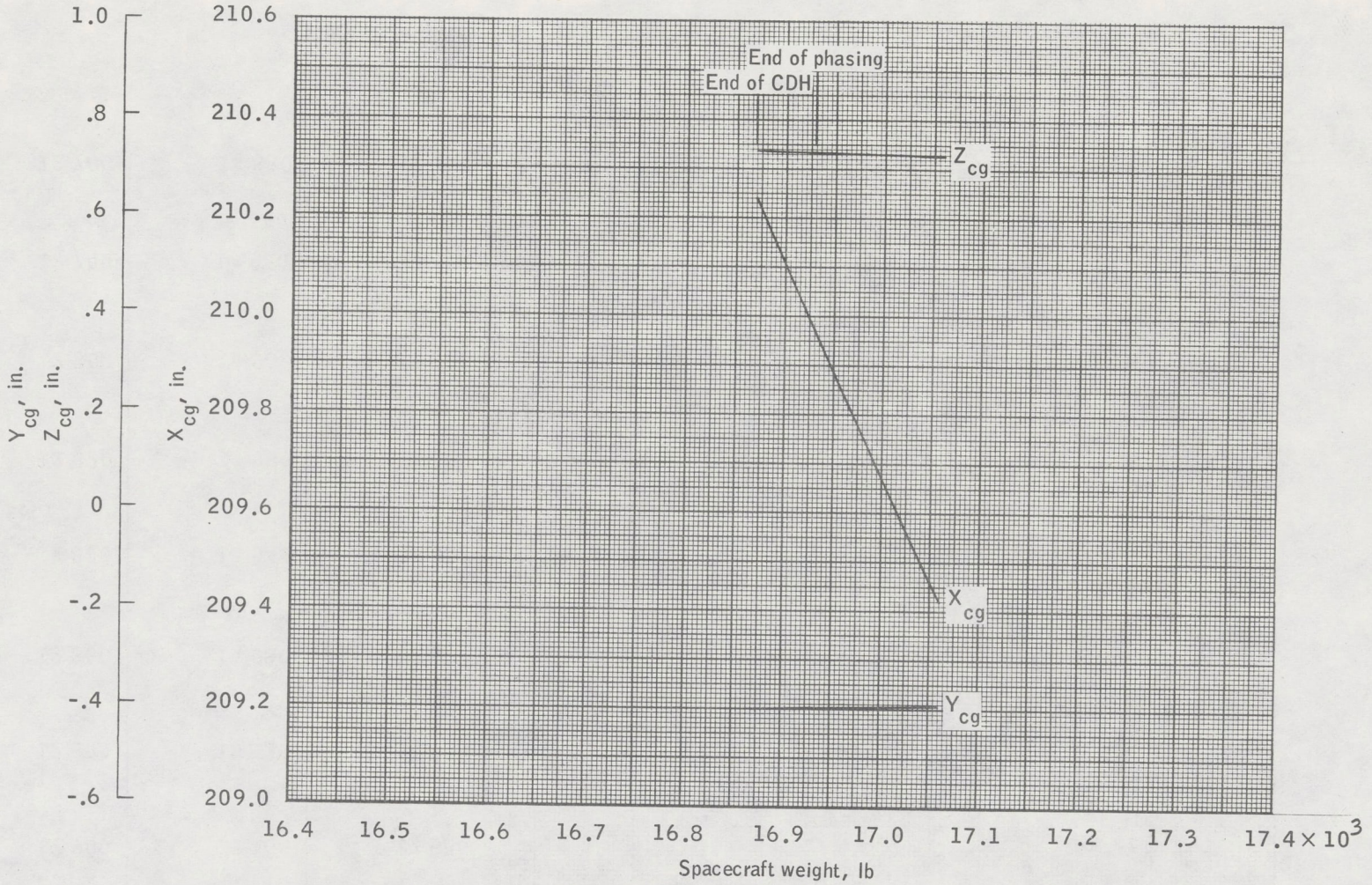
(b) Moments of inertia versus spacecraft weight.

Figure 16. - Continued.



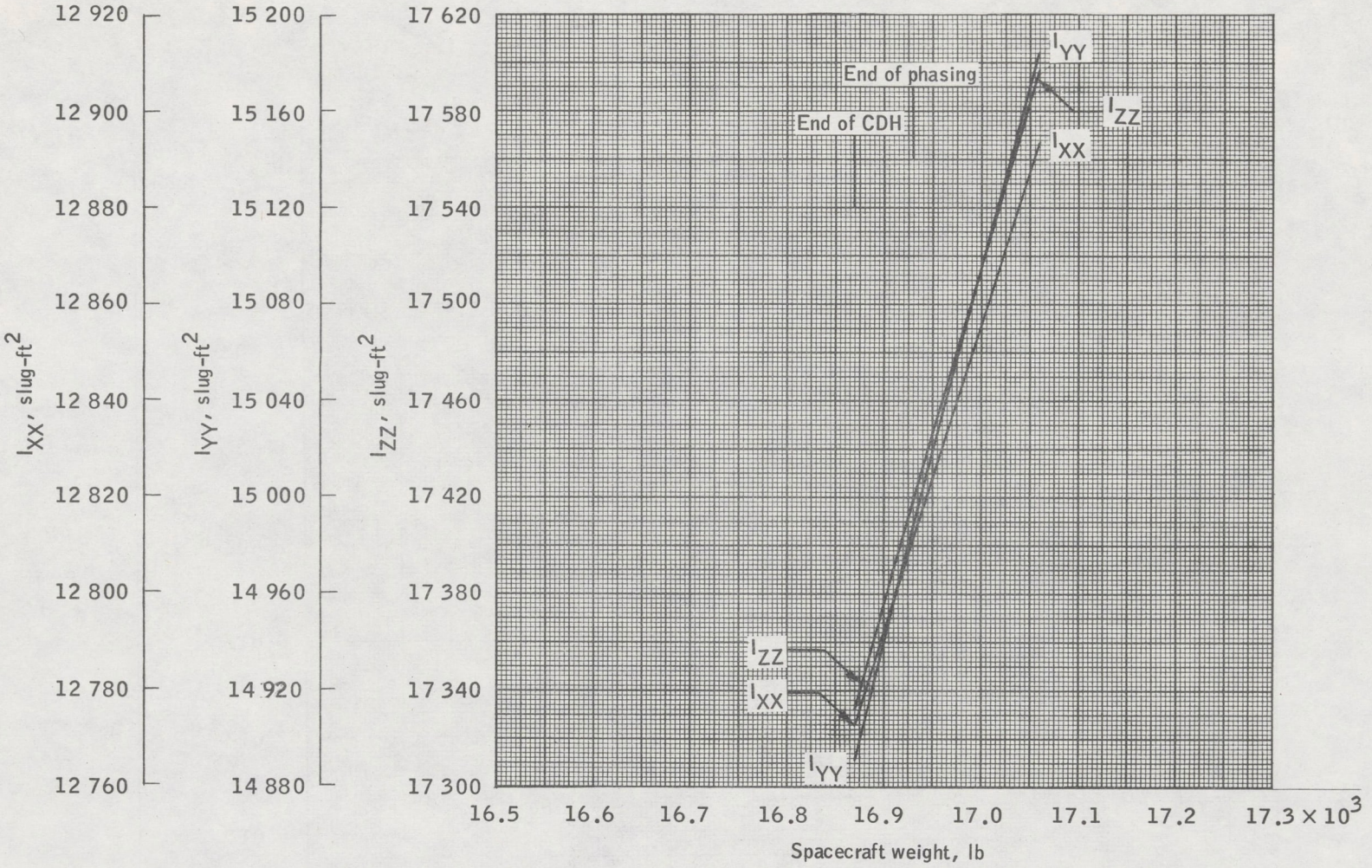
(c) Products of inertia versus spacecraft weight.

Figure 16. - Concluded.



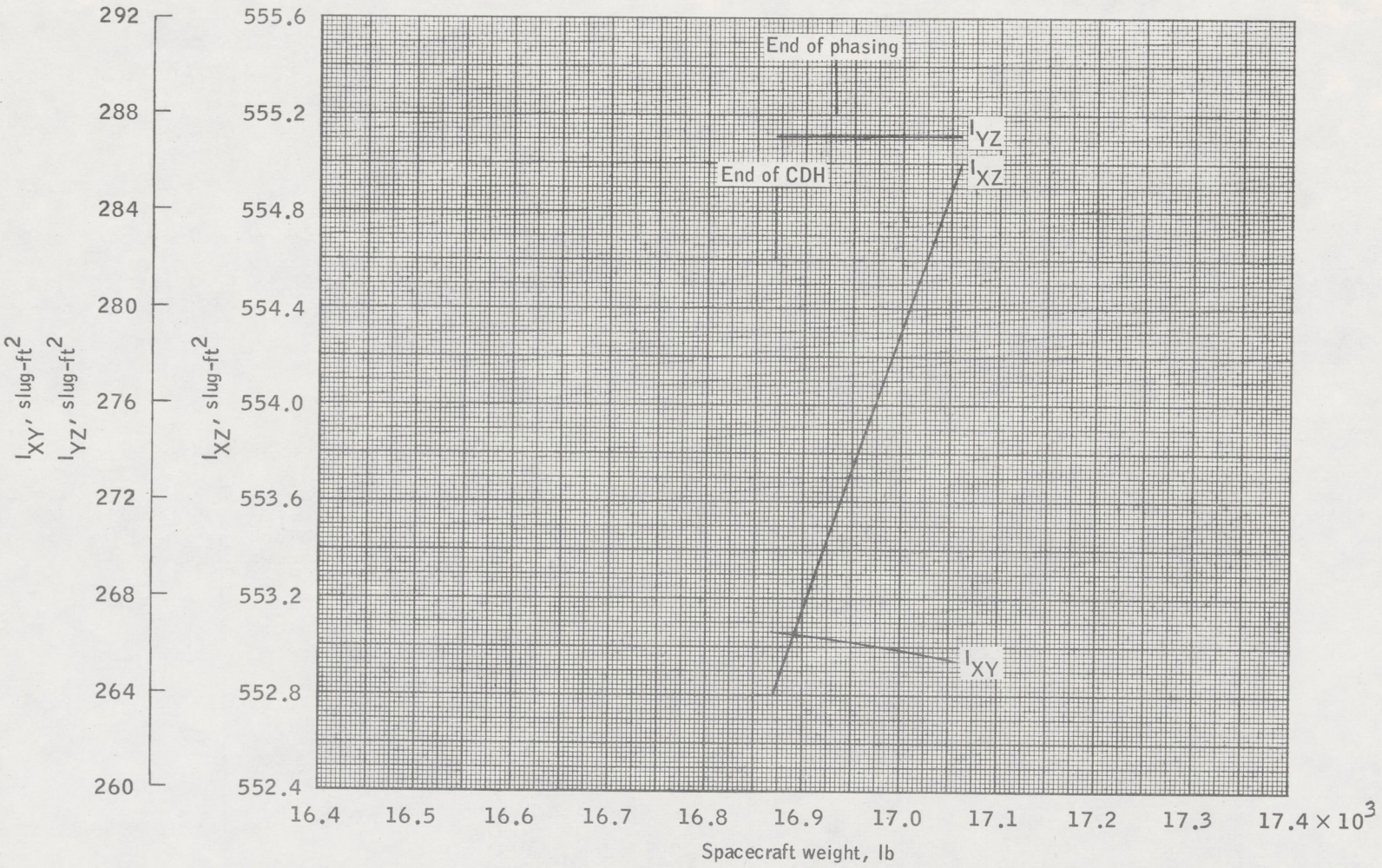
(a) Centers of gravity versus spacecraft weight.

Figure 17.- Unstaged LM mass properties.



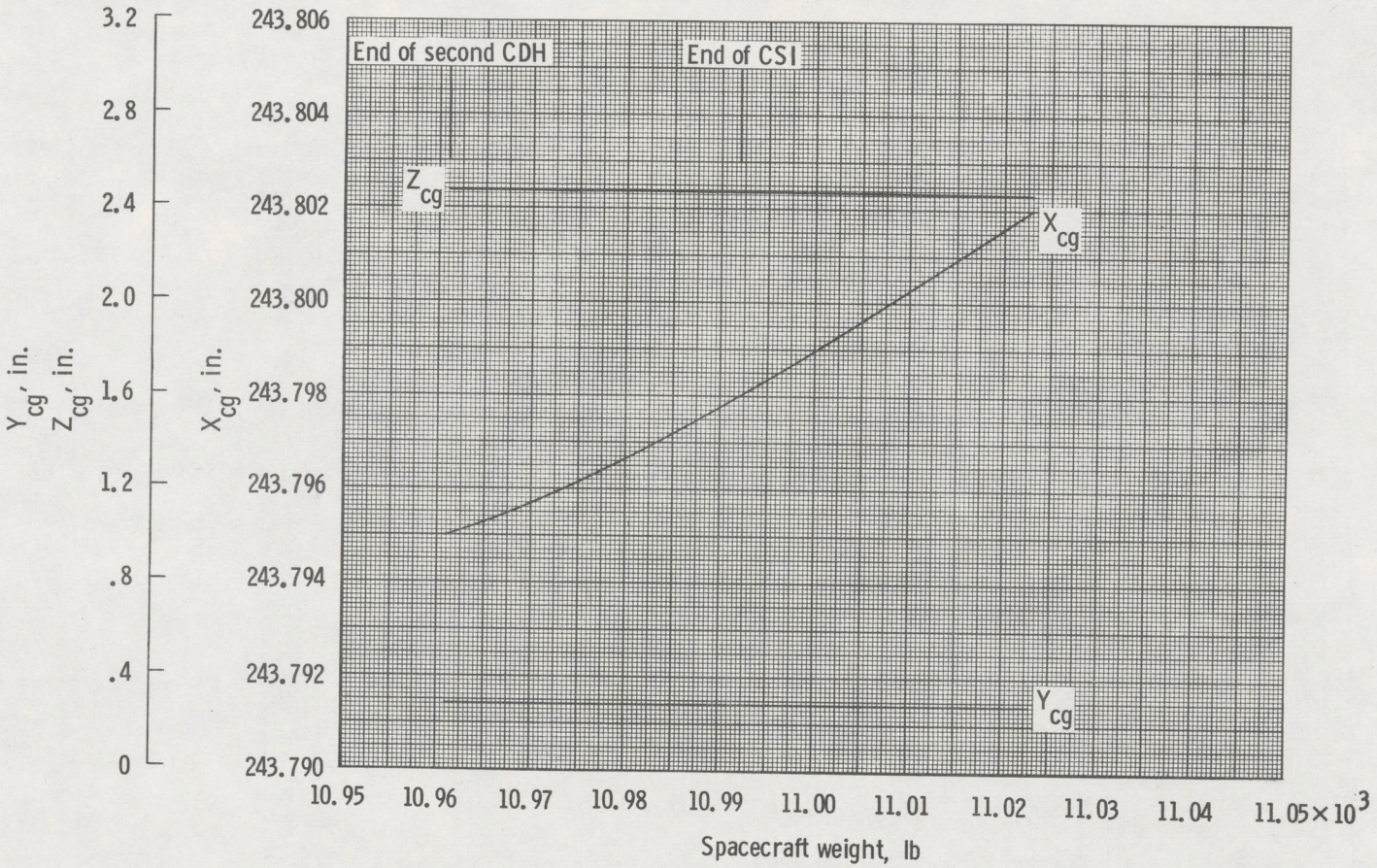
(b) Moments of inertia versus spacecraft weight.

Figure 17. - Continued.



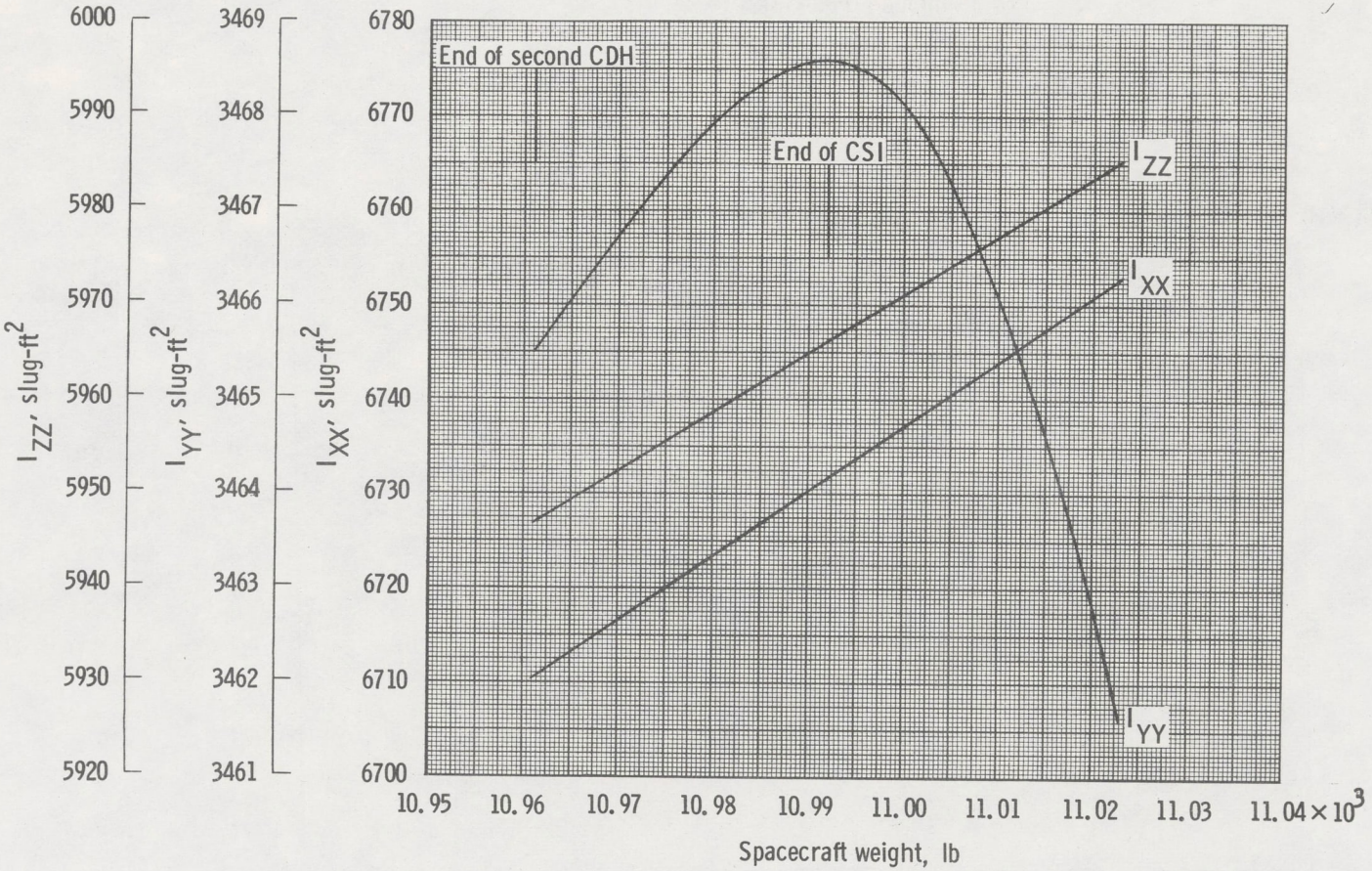
(c) Products of inertia versus spacecraft weight.

Figure 17. - Concluded.



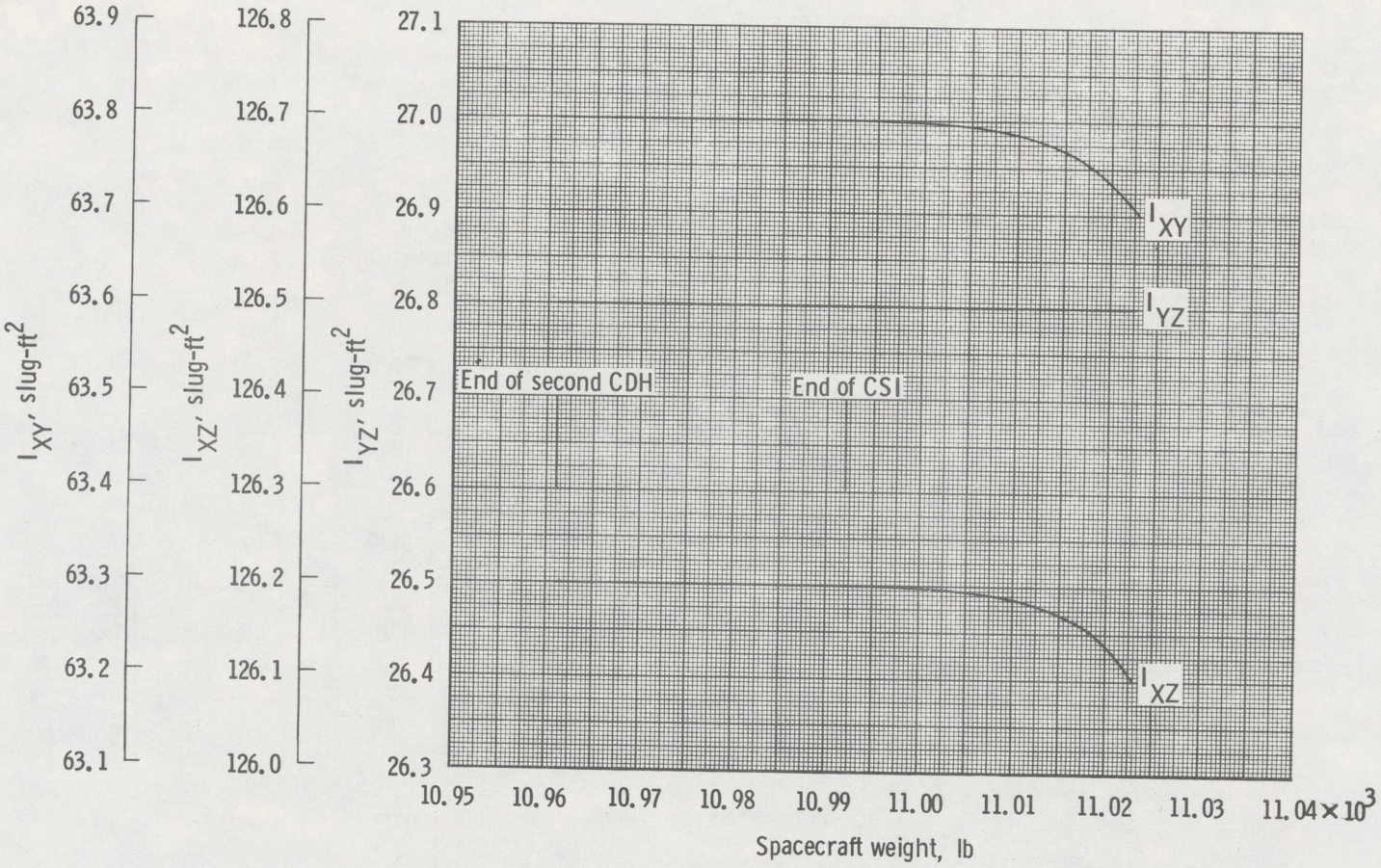
(a) Centers of gravity versus spacecraft weight.

Figure 18.- Ascent LM phase mass properties.



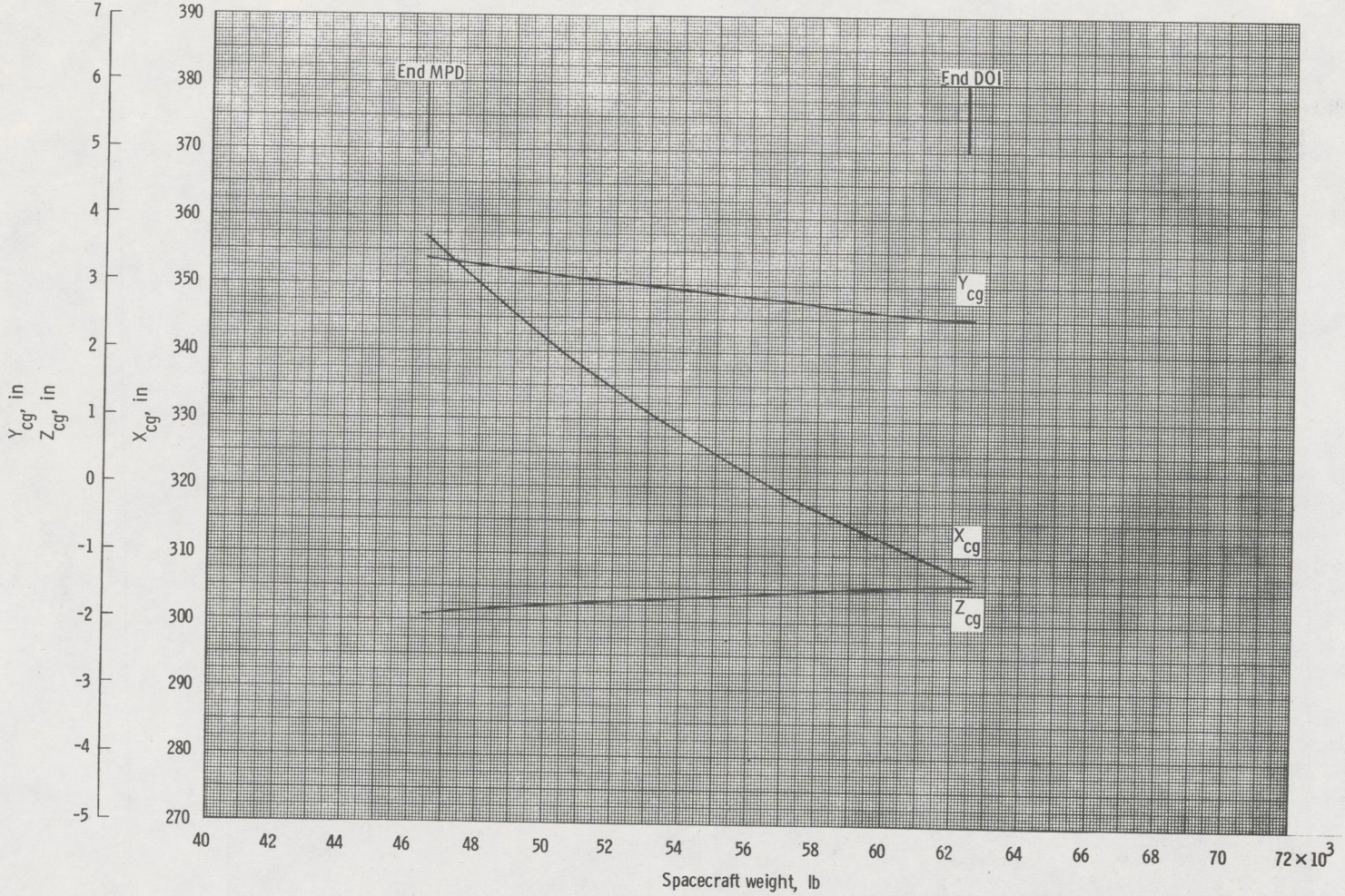
(b) Moments of inertia versus spacecraft weight.

Figure 18. - Continued.



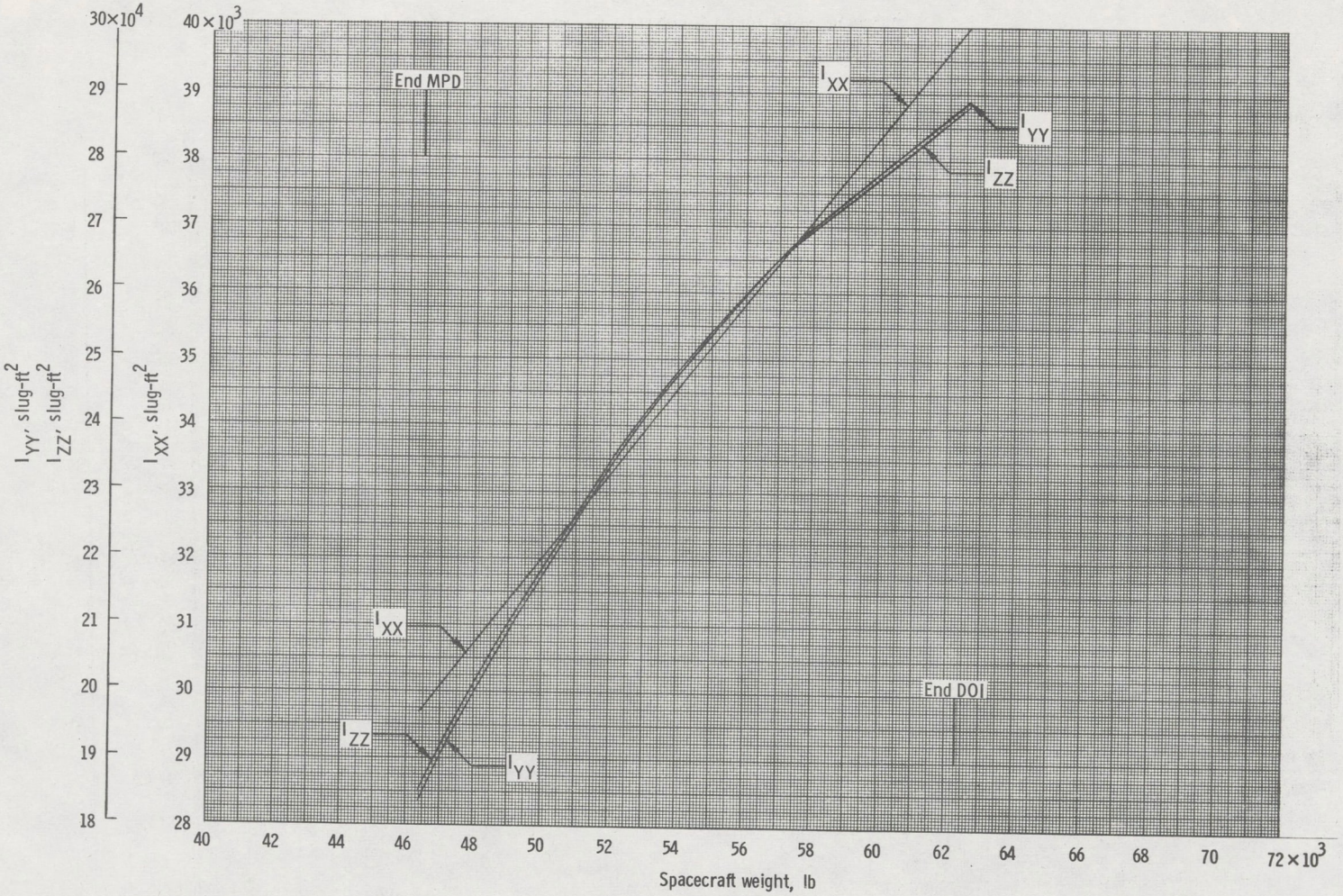
(c) Products of inertia versus spacecraft weight.

Figure 18. - Concluded.



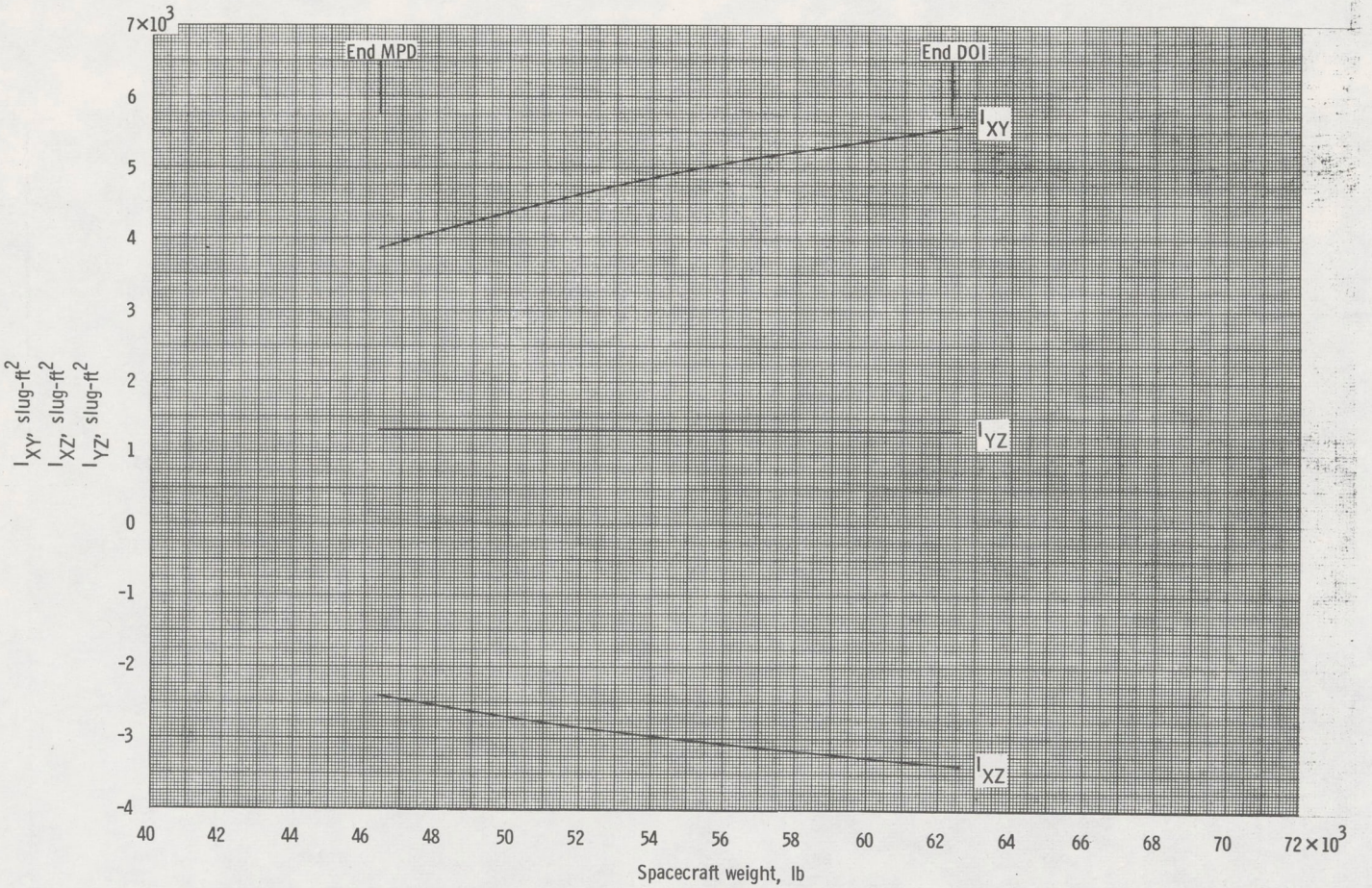
(a) Centers of gravity versus spacecraft weight.

Figure 19. - Mass properties for docked CSM/LM with DPS thrusting.



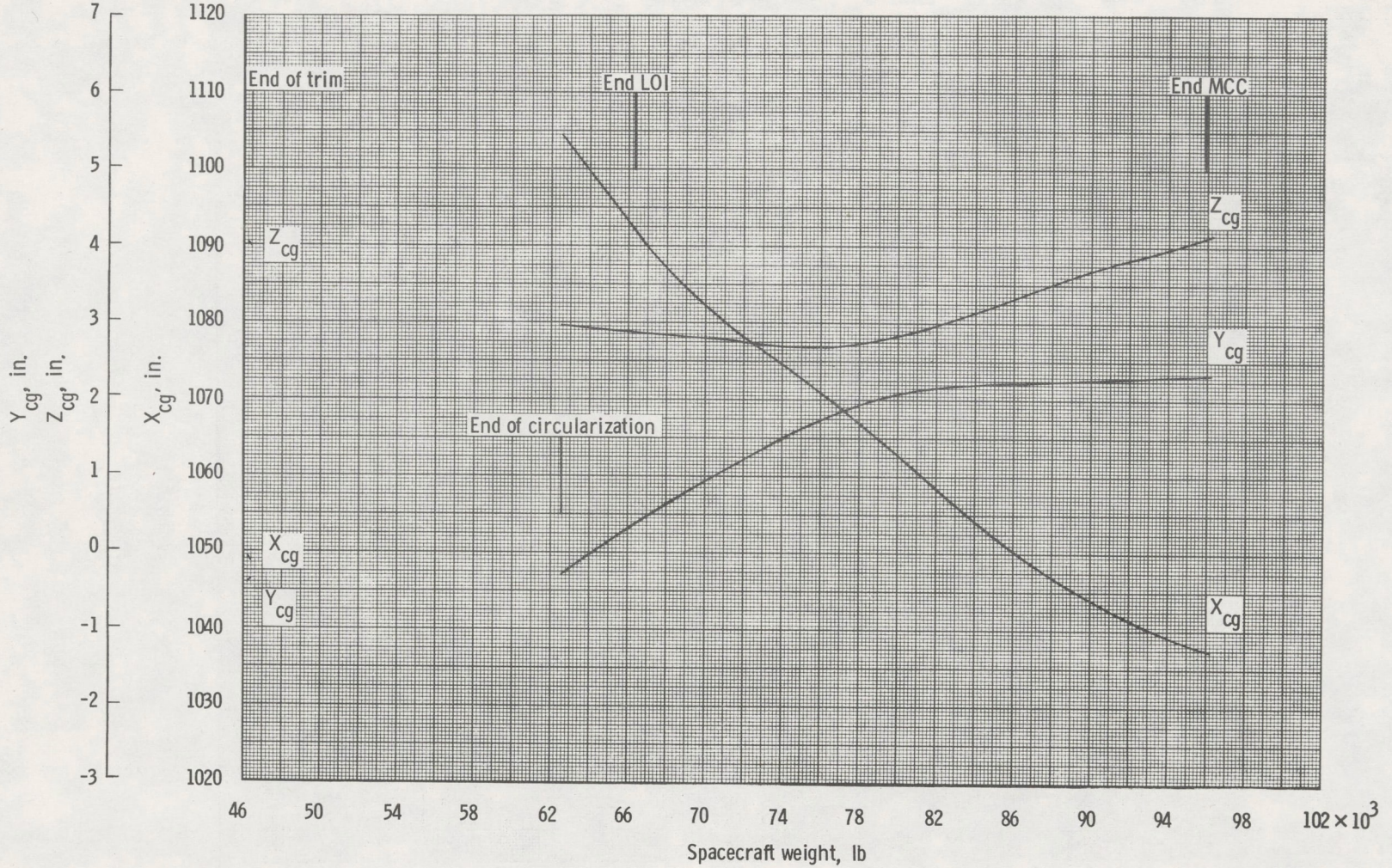
(b) Moments of inertia versus spacecraft weight.

Figure 19. - Continued.



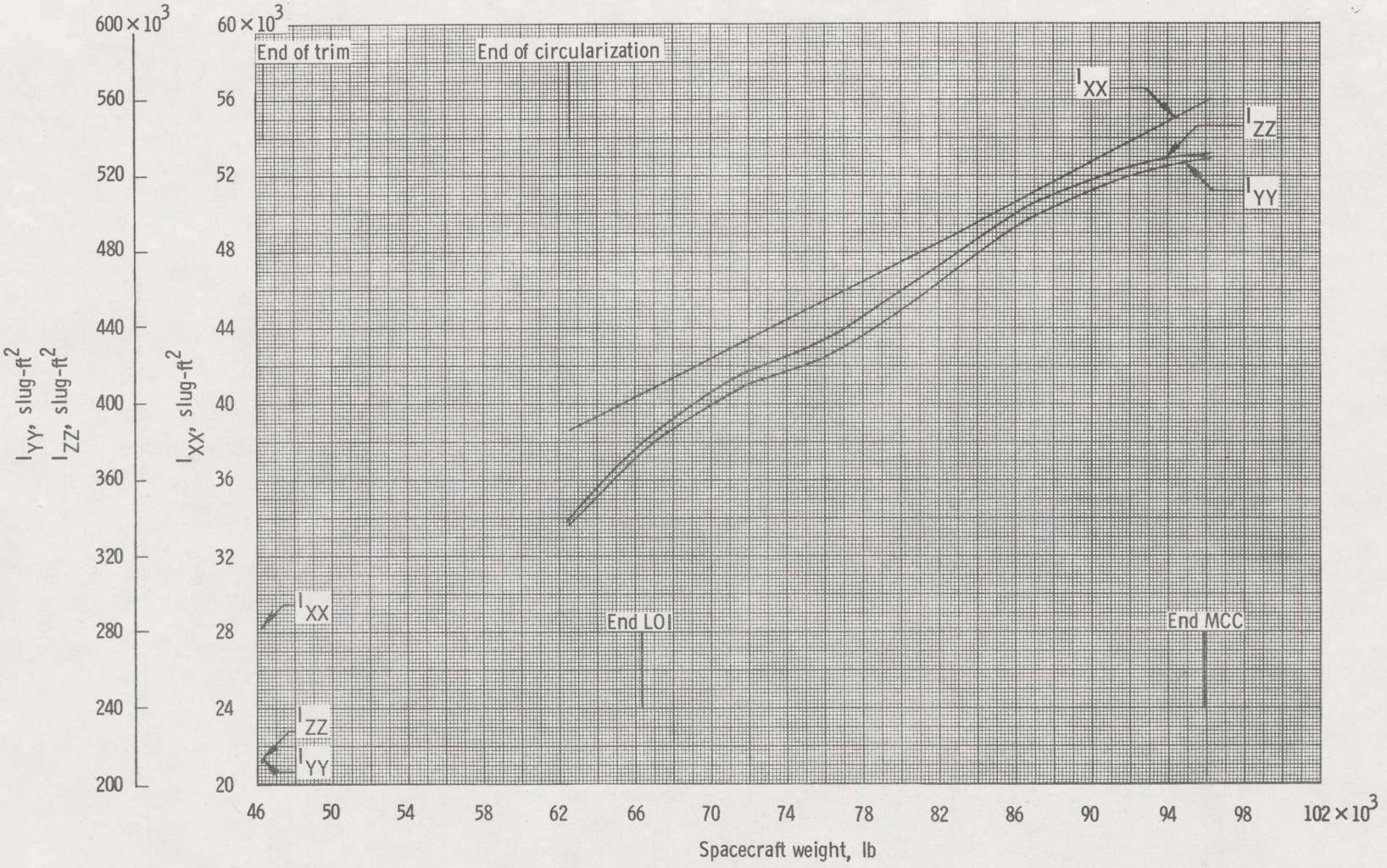
(c) Products of inertia versus spacecraft weight.

Figure 19. - Concluded.



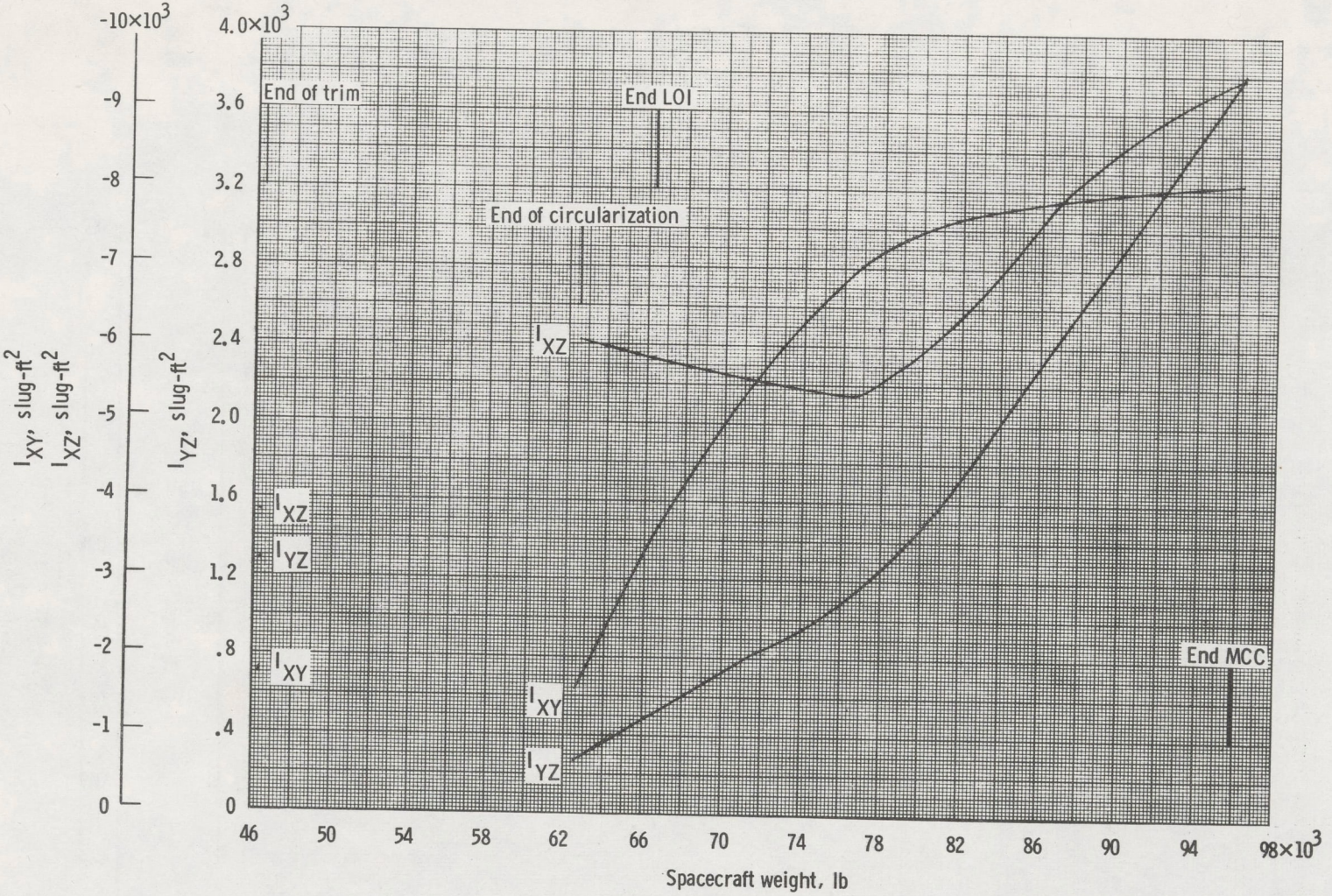
(a) Centers of gravity versus spacecraft weight.

Figure 20. - Mass properties for docked CSM/LM with SPS thrusting.



(b) Moments of inertia versus spacecraft weight.

Figure 20.- Continued.



(c) Products of inertia versus spacecraft weight.

Figure 20. - Concluded.

REFERENCES

1. NAA: Mission Modular Data Book, Block II Earth Orbital Mission. NAA Document SID 66-1501A, March 15, 1967.

2. GAEC: Universal Mission Modular Data Book. GAEC Technical Report LED-500-19, October 15, 1967.

3. De Atkine, David D; Woronow, Alexander; Hill, Oliver; and Rogers, Joseph E.: Apollo Mission E (AS-504/CSM-104/LM-4) Spacecraft Reference Trajectory, Volume I, Mission Profile. MSC IN 68-FM-72, March 27, 1968.

4. De Atkine, David D; Woronow, Alexander; Hill, Oliver; and Rogers, Joseph E.: Apollo Mission E (AS-504/CSM-104/LM-4) Spacecraft Reference Trajectory, Volume II, Trajectory Listing. MSC IN 68-FM-71, March 18, 1968.

5. Holloway, T. W.: Rough Draft Mission E Reference Flight Plan. MSC Memorandum CF342-8M-35, March 27, 1968.

6. MSC: CSM/LM Spacecraft Operational Data Book, Volume III. SNA-8-D-0277, March 1968.

7. Hill, Oliver: Nominal CM-RCS Propellant Consumption for Mission E/CSM-104/LM-4. MSC Memorandum 68-FM53-175, May 7, 1968.

8. TRW: Apollo Spacecraft Propulsion Models. TRW Note No. 67-FMT-498, March 15, 1967.

9. Brown, R. H.: SPS Propellant Loading Definition. MSC Memorandum 67-FM7-312, November 27, 1967.

10. TRW: Apollo Mission Data Specification C, Apollo Saturn 503A. 2131-H006-R8-000.

11. GAEC: Apollo Operations Handbook. LMA-790-3/LM-3, January 1, 1968.

12. Maynard, O. E.: Data Used in LM and CSM EPS Programs. MSC Memorandum PD7/M-6/68, January 6, 1968.