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TWO REFERENCE APOLLO LUNAR PARKING ORBITS

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SUMMARY

This report investigates the variation of the orbital parameters for the forty hour period after insertion into two reference Apollo Lunar Parking Orbits¹. It is found that while the variation of most of the parameters under the influence of a triaxial Moon and other perturbing forces is small, the change in pericyynthion height is significant. In Table 1 the amount of change in the various elements during this time is shown.

The most pertinent piece of information derived from this investigation is with regard to the choice of hypothetical lunar landing sites on the surface of the Moon (see Figure 1). Choosing a point on the earthward side of the trace which satisfies the constraint that it has a longitude of between 315° and 45° and a latitude of +5° and -5° with respect to a selenographic coordinate system one has a hypothetical landing site. It is found that any subsequent trace of the sub-module point at the same longitude will always lie within 0°5 in latitude of the initial landing site chosen during the forty hours under consideration. Therefore, landing sites chosen in the above manner meet the two requirements as described in Apollo Navigation Technical Report² which states that the two constraints on the lunar parking orbit mission are as follows:

- (1) the plane of the trajectory must contain a landing site vector on the earth side of the Moon which has a longitude of between 315° and 45° and a latitude of between +5° and -5° in selenographic coordinates.
- (2) the plane of the orbit must be oriented so that the lunar landing site doesn't move out of the orbital plane more than 0°5 during the period of 3 to 39 hours after lunar insertion.

¹pp. 3-10 Apollo Navigation Group Technical Report 65-AN-1.0, February 5, 1965.

²pp. 3-6, 3-7.

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INTRODUCTION

The basic concept behind this report was to see how the orbital parameters for the two reference lunar parking orbits behaved during the forty hour period after lunar insertion. To this end two 7090/7094 computer programs were used to generate this information which is presented as two series of graphs. Series A graphs are associated with the 1968 reference trajectory. Series B graphs are associated with the 1969 reference trajectory. It should be noted at the outset that several coordinate systems are in use throughout this report. The three coordinate systems in use are the following:

center: selenocentric
fundamental plane: parallel to the earth's equatorial plane
x-axis: mean equinox of date

center: selenocentric
fundamental plane: lunar orbital plane
x-axis: earth-moon line of date

center: selenocentric
fundamental plane: true equator of the moon
x-axis: intersection of the prime meridian and the equator of the moon.

The two computer programs used as sources of data are the Jet Propulsion Laboratory's Space Trajectory program and the Goddard Interplanetary Trajectory Encke Method program. Both programs numerically integrate the orbit by the Encke Method hence one program serves as an independent check of the validity of the data generated by the other program.

I. General Description of the Reference Trajectories

The lunar parking orbit is constrained to be near-circular with a semi-major axis of 1018.5 nautical miles (1886 km) with an altitude above the lunar surface of 80 nautical miles \pm 5 nautical miles (148 \pm 9 km). The duration of this trajectory is constrained to be between two to sixty hours³. In this study both cases meet these requirements. The insertion conditions for the two reference⁴ trajectories under consideration (study) are:

Date of Lunar Insertion Reference Trajectory #1	Date of Lunar Insertion Reference Trajectory #2
May 9, 1968 15 hrs/54.0 mins/56.610 secs.	September 20, 1969 5 hrs/10 mins/12.176 secs.
X = -1012.437 0 n.mi.	X = + 165.639 36 n.mi.
Y = - 51.263 872 n.mi.	Y = - 919.376 95 n.mi.
Z = - 20.120 039 n.mi.	Z = - 415.861 51 n.mi.
\dot{X} = - 287.896 06 ft/sec	\dot{X} = -5208.366 5 ft/sec
\dot{Y} = +4914.267 5 ft/sec	\dot{Y} = - 817.043 16 ft/sec
\dot{Z} = +1967.337 7 ft/sec	Z = - 268.213 99 ft/sec
X = -1875.033 324 km	X = + 306.764 095 km
Y = - 94.940 691 km	Y = -1702.686 111 km
Z = - 37.262 312 km	Z = - 770.175 517 km
\dot{X} = - 0.087 750 895 km/sec	\dot{X} = - 1.587 513 284 km/sec
\dot{Y} = + 1.497 871 730 km/sec	\dot{Y} = - 0.249 035 253 km/sec
\dot{Z} = + 0.599 645 730 km/sec	\dot{Z} = - 0.081 751 788 km/sec

conversion factors: p 4-8

COORDINATE SYSTEM

center: selenocentric
 fundamental plane: plane parallel to earth's mean equator of date
 x-axis: mean equinox of date at insertion.

³p 3-7.

⁴p 3-11.

In terms of orbital elements, the insertion conditions, using the same coordinate system above, are:

Reference Trajectory #A 1968					Reference Trajectory #B 1969				
a =	1878.568	7		km	a =	1894.577	9		km
e =	0.000	456	745	28	e =	0.000	440	130	77
i =	158°183	34			i =	155°804	72		
Ω =	180°056	73			Ω =	182°414	08		
ω =	357°744	42			ω =	262°877	16		
m =	0°804	456	93		m =	0°001	540	415	8

II. Discussion of the Graphical Results

The series of graphs A-1 through A-6, and B-1 through B-6 are related to the reference trajectories A and B respectively and show similar trends. Hence only the first set of graphs will be discussed in detail with much of the discussion being applicable to both sets.

By inspecting graphs A-1 to A-4 the graphs of the semi-major axis, eccentricity, inclination, and longitude of the ascending node it can be seen that the orbit chosen is relatively a very stable orbit. The semi-major axis varies at most about 0.5 kilometers from its original length during the 40 hours of investigation. The inclination changes less than 0.05 degrees. The eccentricity is plotted to a scale with a factor 10^{-3} . Its fluctuations during the forty hour period are of the order of magnitude of 0.3×10^{-3} as a maximum. The longitude of the ascending node for all practical purposes changes linearly with respect to time, varying less than 0.5 degrees during the time interval considered. The purpose of the preceding discussion was to show quantitatively how these various elements varied with time. Figure A-5 and Figure A-6, however, provide the most useful information directly affecting a lunar parking orbit. In Figure A-5, height (radius vector minus the mean lunar radius) versus hours from epoch, shows how the height varies periodically with the period being the time for one circumlunar orbit. This variation is less than 0.15 kilometers. Figure A-6 shows the limiting cases, the first and the last orbit data, of the trace of the command module on the lunar surface or the lunar sub-module point. It can be seen that for the worst case by choosing a particular point on the trace of the first trajectory and then choosing a point on the trace of the last trajectory at the same longitude, the variation in latitude would be at worst 0°2. A considerable portion of the time, this variation is less than 0°2.

CONCLUSIONS

(1) Based on the graphical data presented, either the 1968 or 1969 reference trajectory could provide an orbit stable enough to meet the mission requirements of having suitable landing sites on the lunar surface which do not vary more than 0°5 in latitude from the original landing site. This information is presented in graphs A-6 and B-6 respectively where arbitrary hypothetical landing sites have been chosen.

(2) The use of two computer programs, one to serve as an independent check on the data generated by the other, is justified as the inter comparison of the data on the various graphs indicates.

In Table 1 the maximum changes in the parameters for the two cases are shown. Essentially, the results are identical.

Table 1
Maximum Changes in Orbital Parameters

	Δa	Δe	Δi
Case #1 1968 Data	0.5 km	0.3×10^{-3}	0°05
Case #2 1969 Data	0.45 km	0.3×10^{-3}	0°05

	ΔΩ	ΔHp*	ΔLatitude
Case #1 1968 Data	0°45	0.15 km	0°2
Case #2 1969 Data	0°50	0.20 km	0°5

*Hp = pericynthion height.

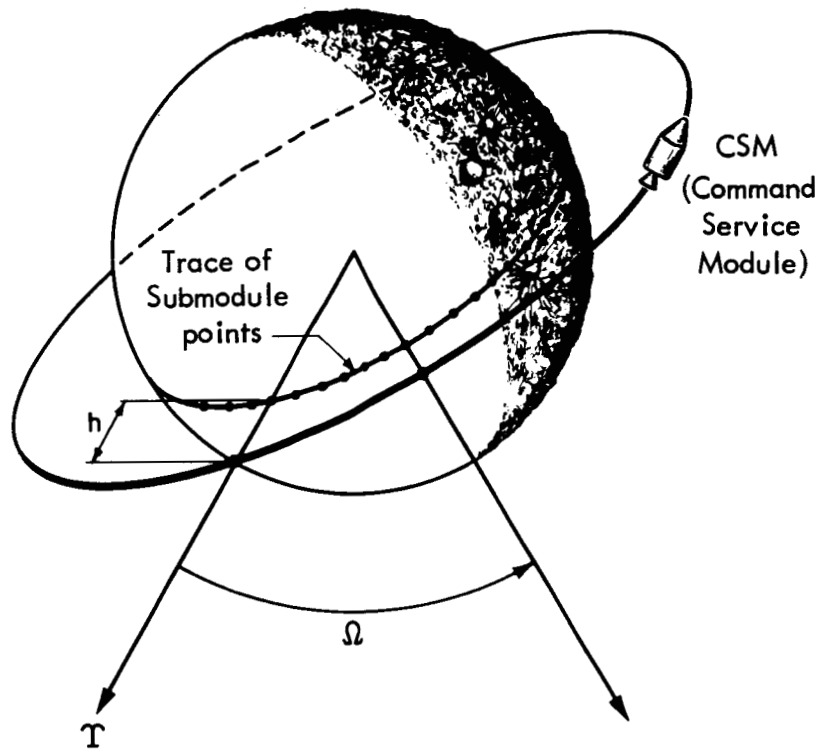
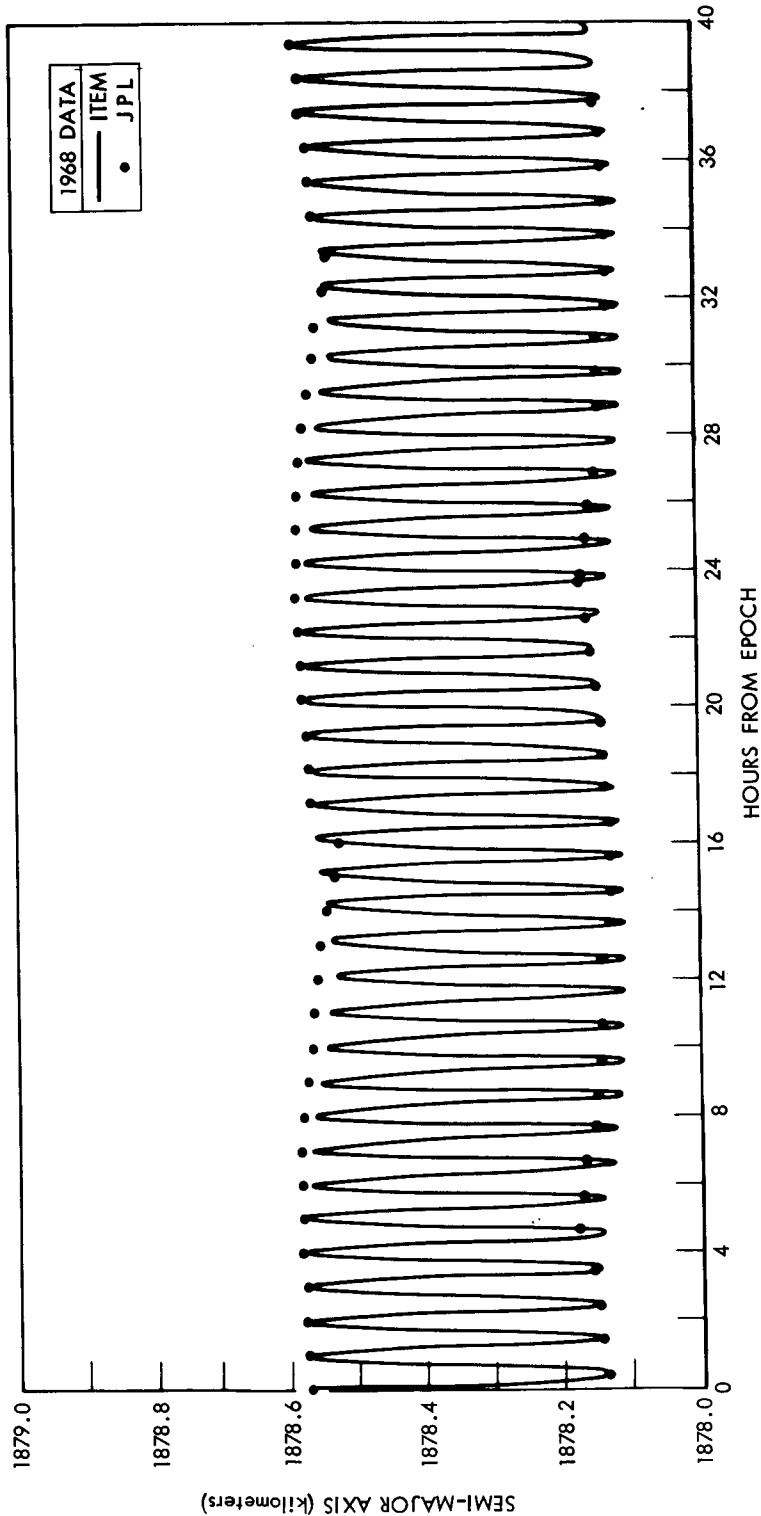


Figure 1



INJECTION CONDITIONS

Semi-major Axis : 1878.5687 km
 Eccentricity : 0.00045674528
 Inclination : 158°183.340
 Long. of Ascending Node : 180°056.730
 Argument of Pericynthion : 357°744.420
 Mean Anomaly : -0°804.45693

EPOCH

May 9, 1968 Lunar Insertion
 15 hours/54.0 minutes/56.610 seconds

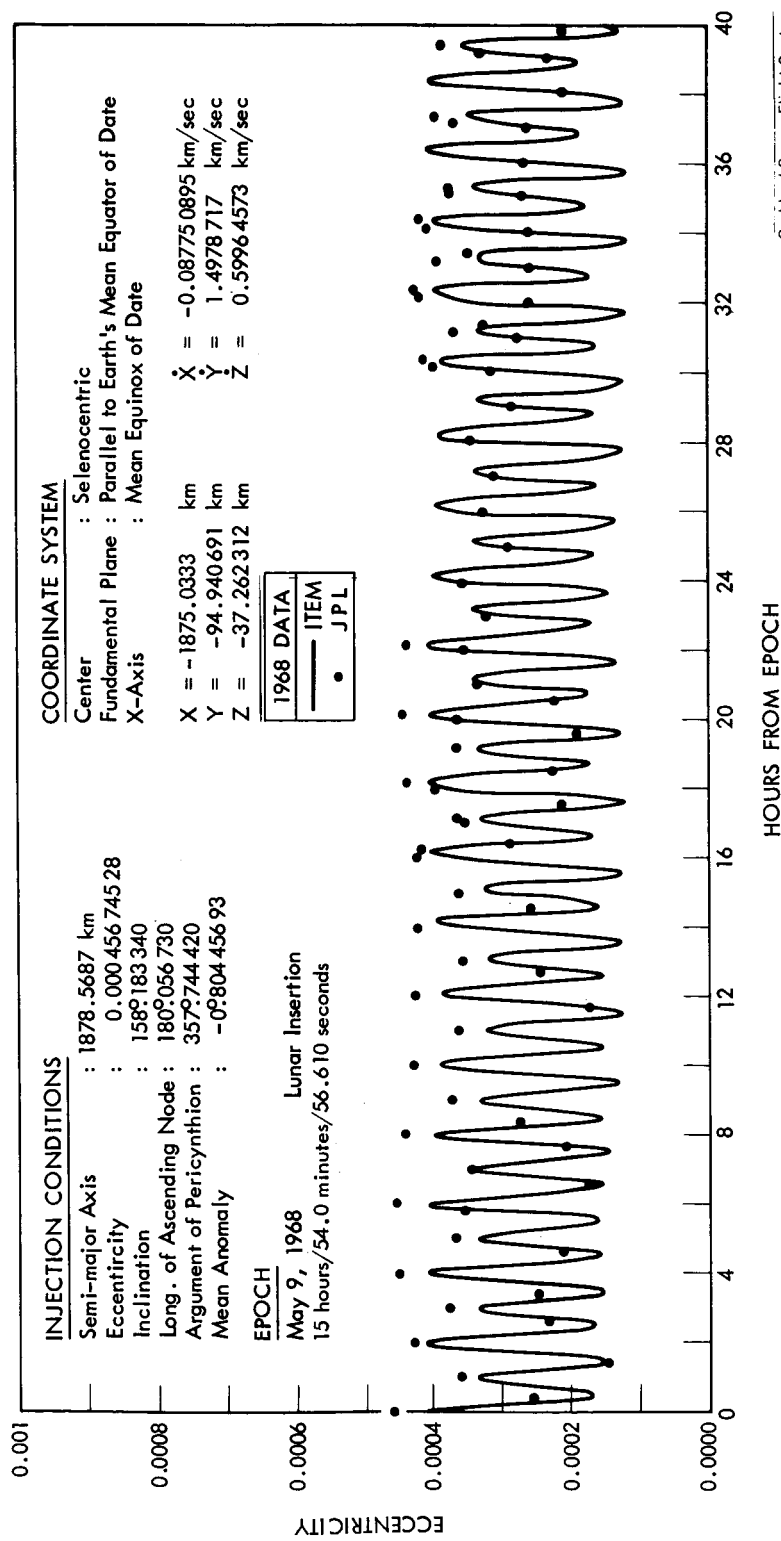
COORDINATE SYSTEM

Center : Selenocentric
 Fundamental Plane : Parallel to Earth's Mean Equator of Date
 X-Axis : Mean Equinox of Date

X = -1875.0333 km \dot{X} = -0.087750895 km/sec
 Y = -94.940691 km \dot{Y} = 1.4978717 km/sec
 Z = -37.262312 km \dot{Z} = 0.59964573 km/sec

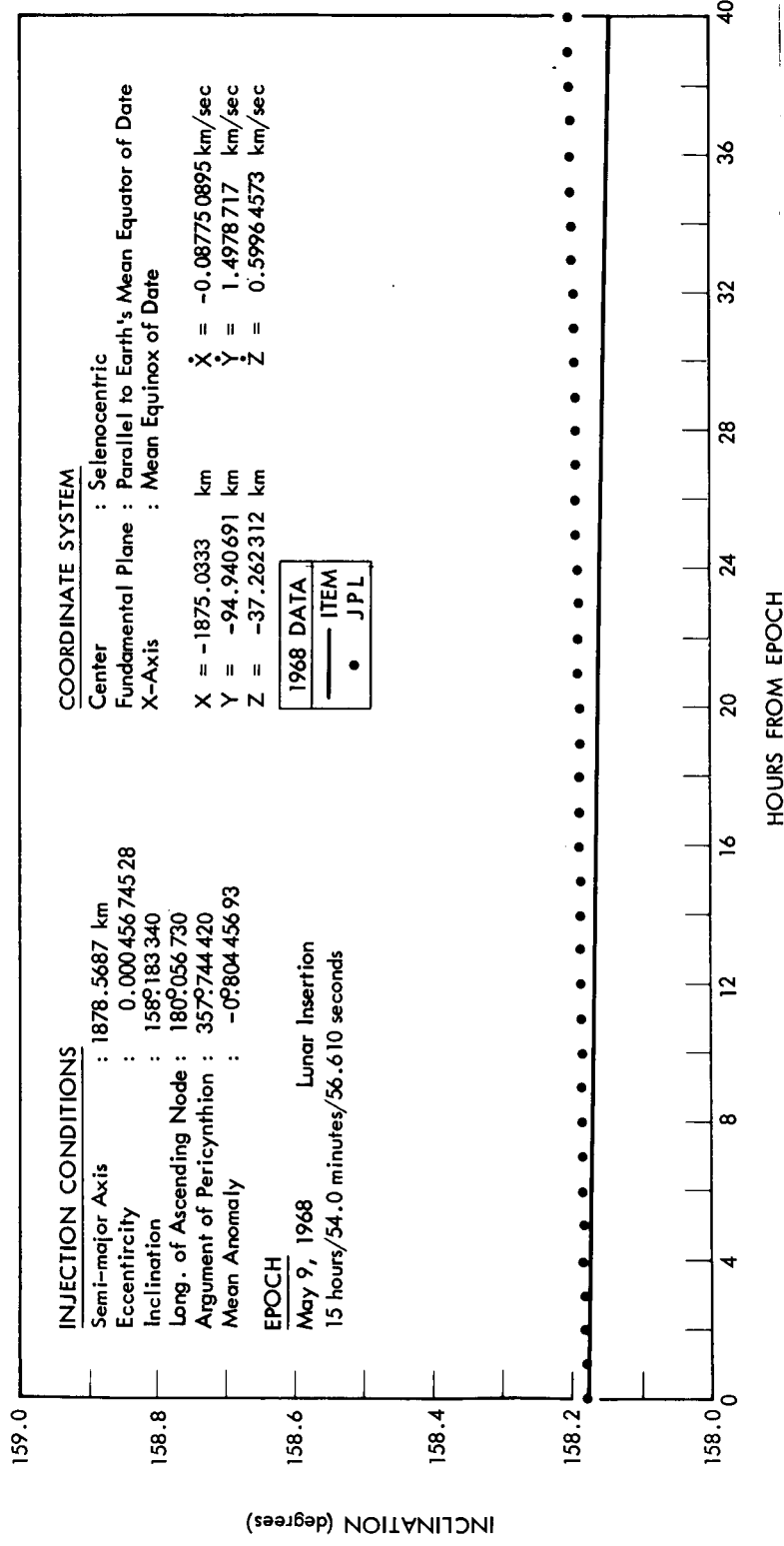
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Figure A-1 Semi-major Axis Vs Hours from Epoch



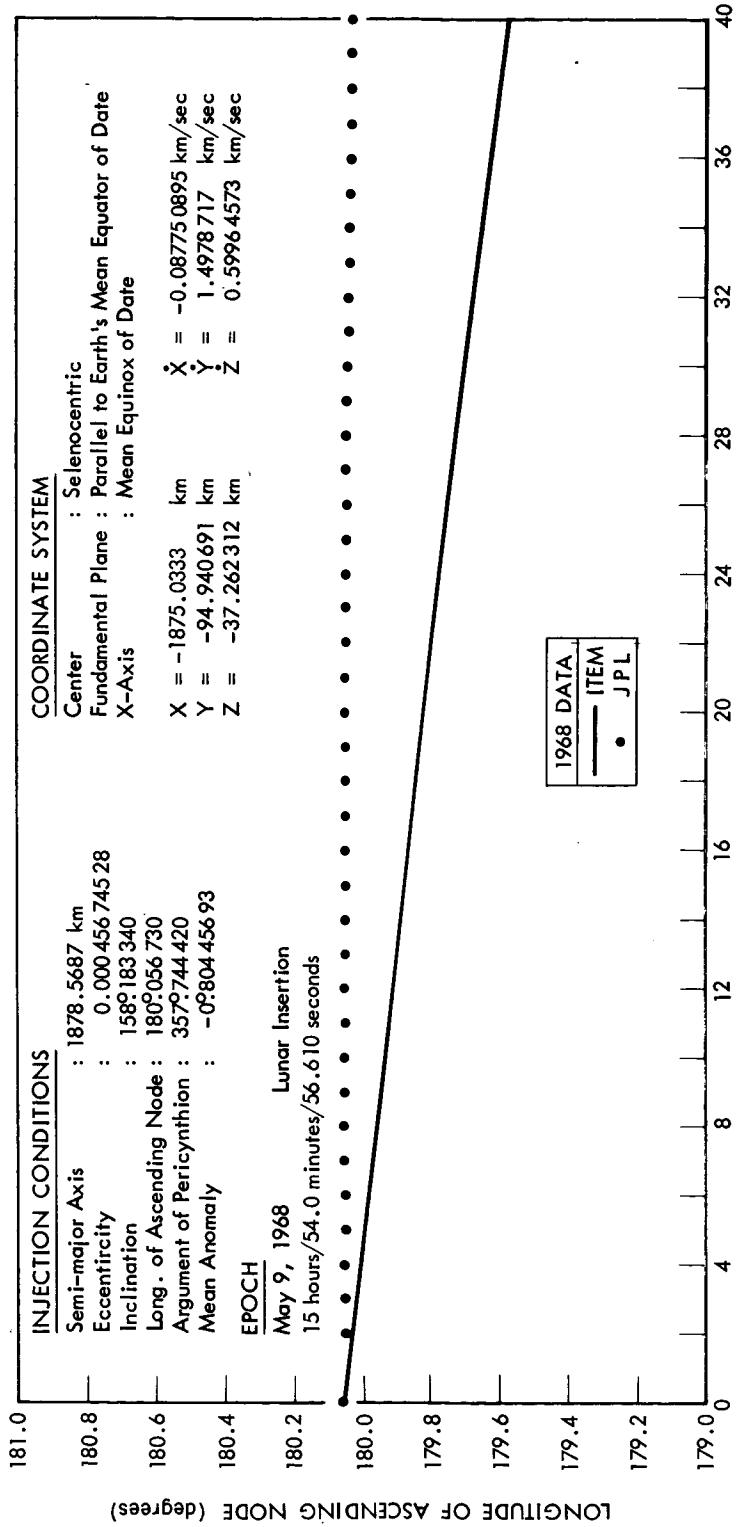
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Figure A-2 Eccentricity Vs Hours from Epoch



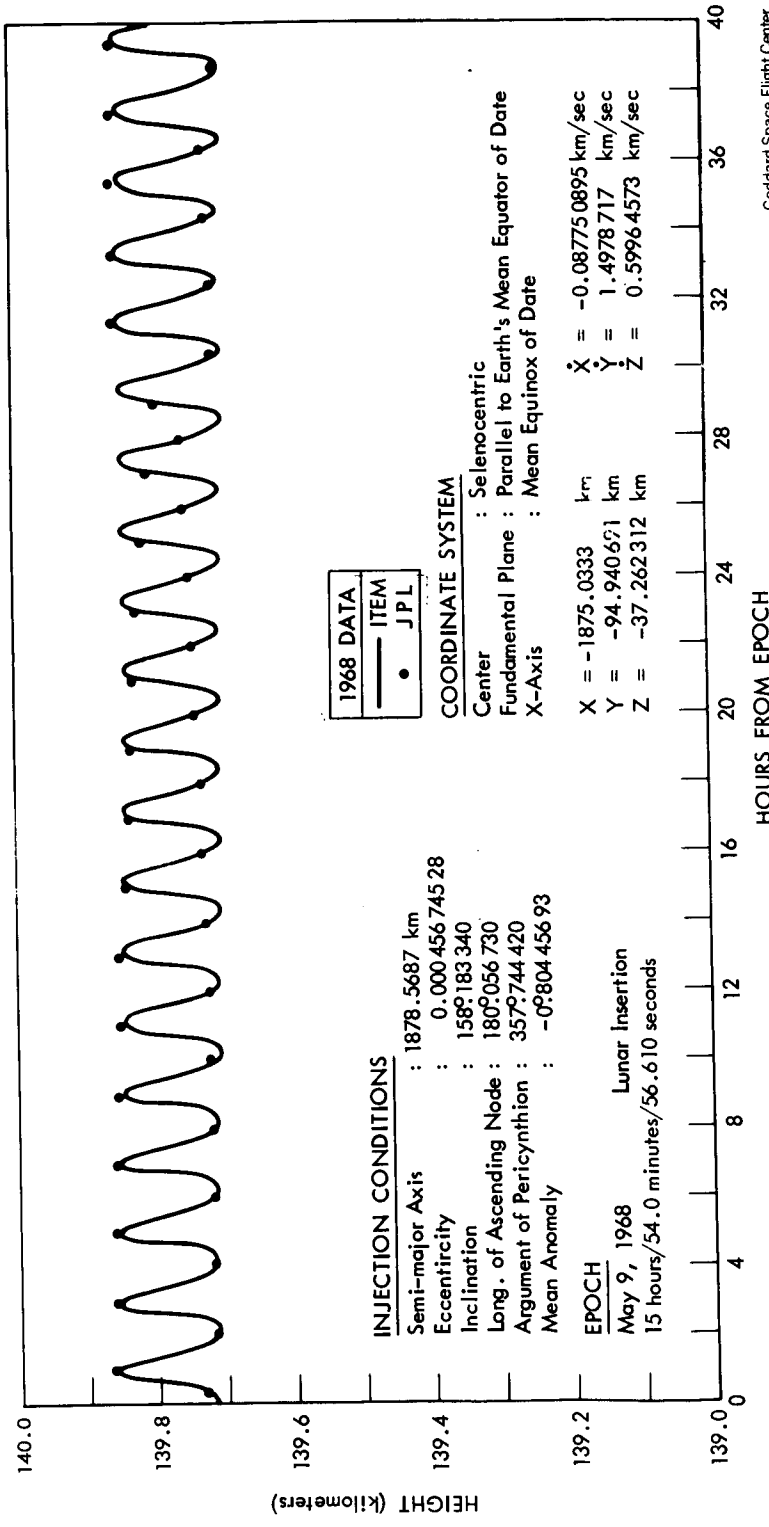
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Figure A-3 Inclination (degrees) Vs Hours from Injection



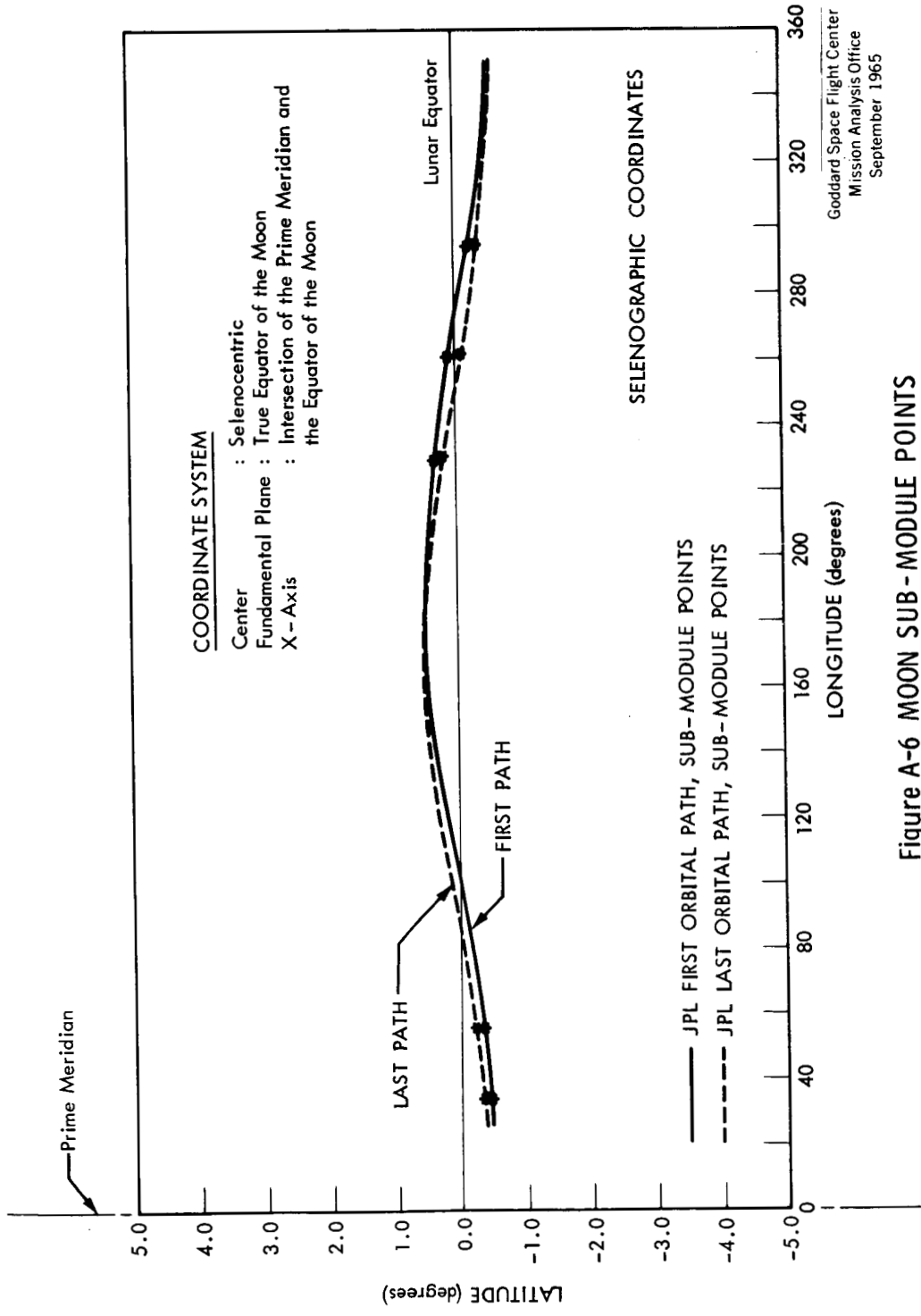
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Figure A-4 Longitude of Ascending Node Vs Hours from Epoch



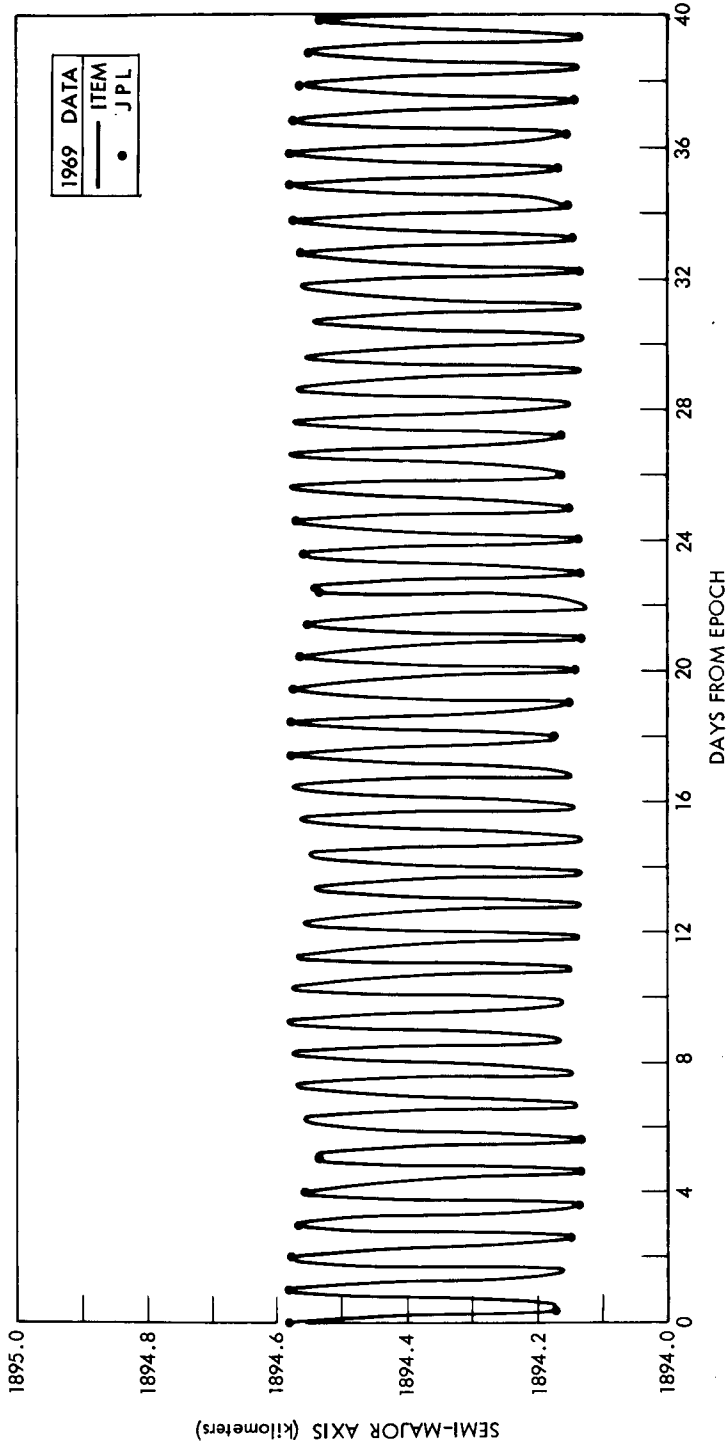
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Figure A-5 Height Vs Hours from Epoch



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Figure A-6 MOON SUB - MODULE POINTS
 Latitude Vs Longitude



INJECTION CONDITIONS

Semi-major Axis : 1894.5779 km
 Eccentricity : 0.00044013077
 Inclination : 155° 804' 720
 Long. of Ascending Node : 182° 414' 080
 Argument of Pericynthion : 262° 877' 160
 Mean Anomaly : 0° 001' 540' 4158

EPOCH

Sept. 20, 1969 Lunar Insertion
 5 hours/10 minutes/12.176 seconds

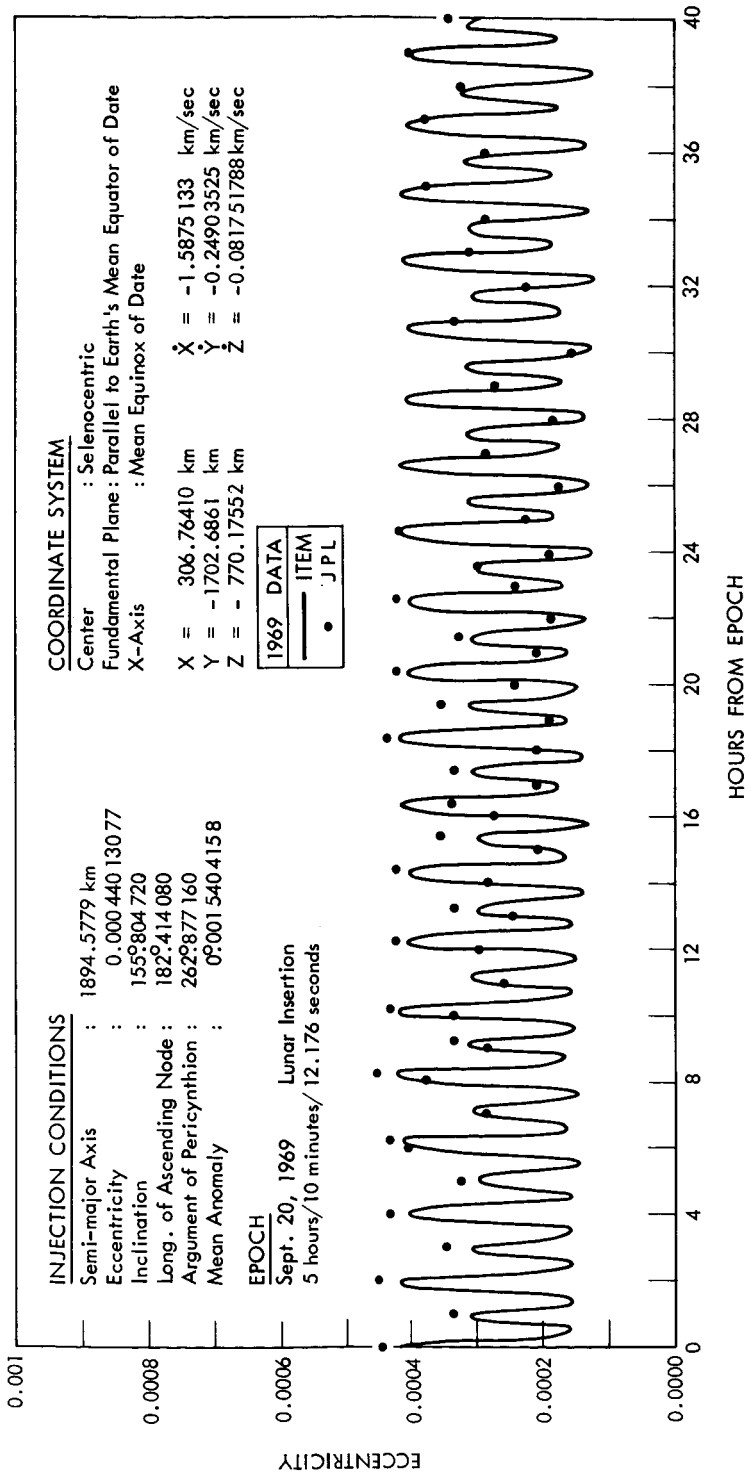
COORDINATE SYSTEM

Center : Selenocentric
 Fundamental Plane : Parallel to Earth's Mean Equator of Date
 X-Axis : Mean Equinox of Date

X = 306.76410 km \dot{X} = -1.5875133 km/sec
 Y = -1702.6861 km \dot{Y} = -0.24903525 km/sec
 Z = -770.17552 km \dot{Z} = -0.081751788 km/sec

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Figure B-1 Semi-major Axis (kilometers) Vs Days from Epoch



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Figure B-2 Eccentricity Vs Hours from Epoch

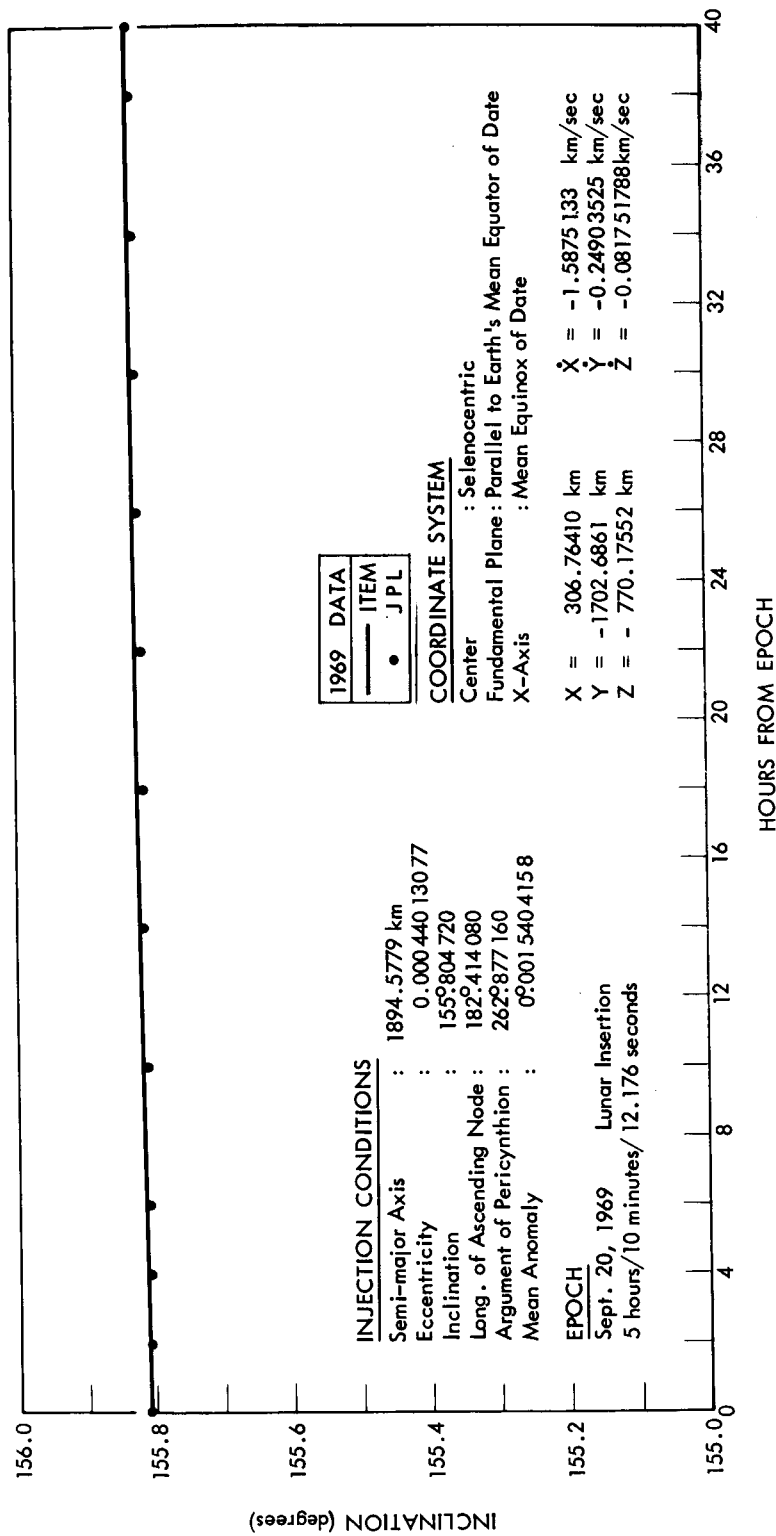
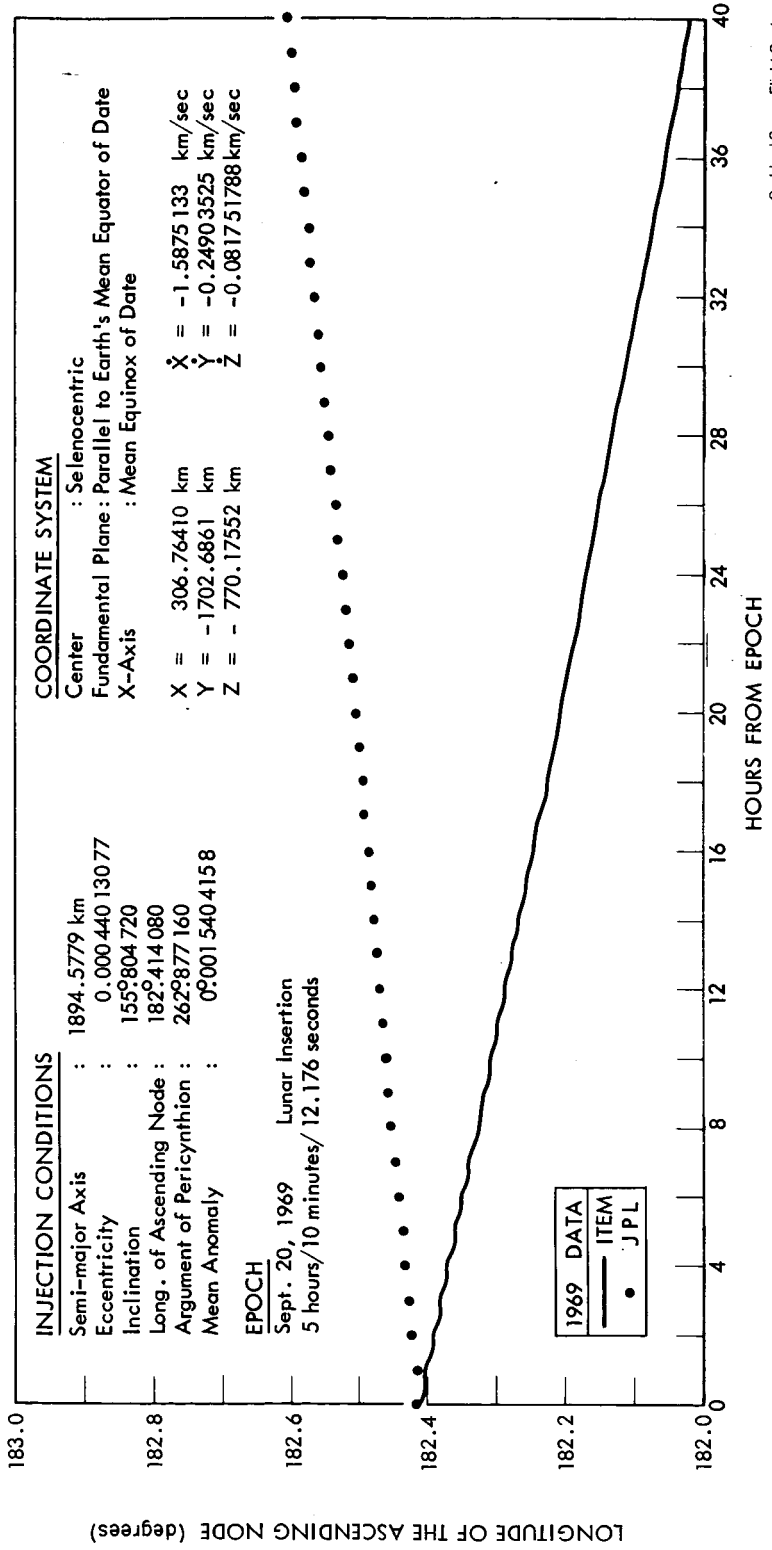
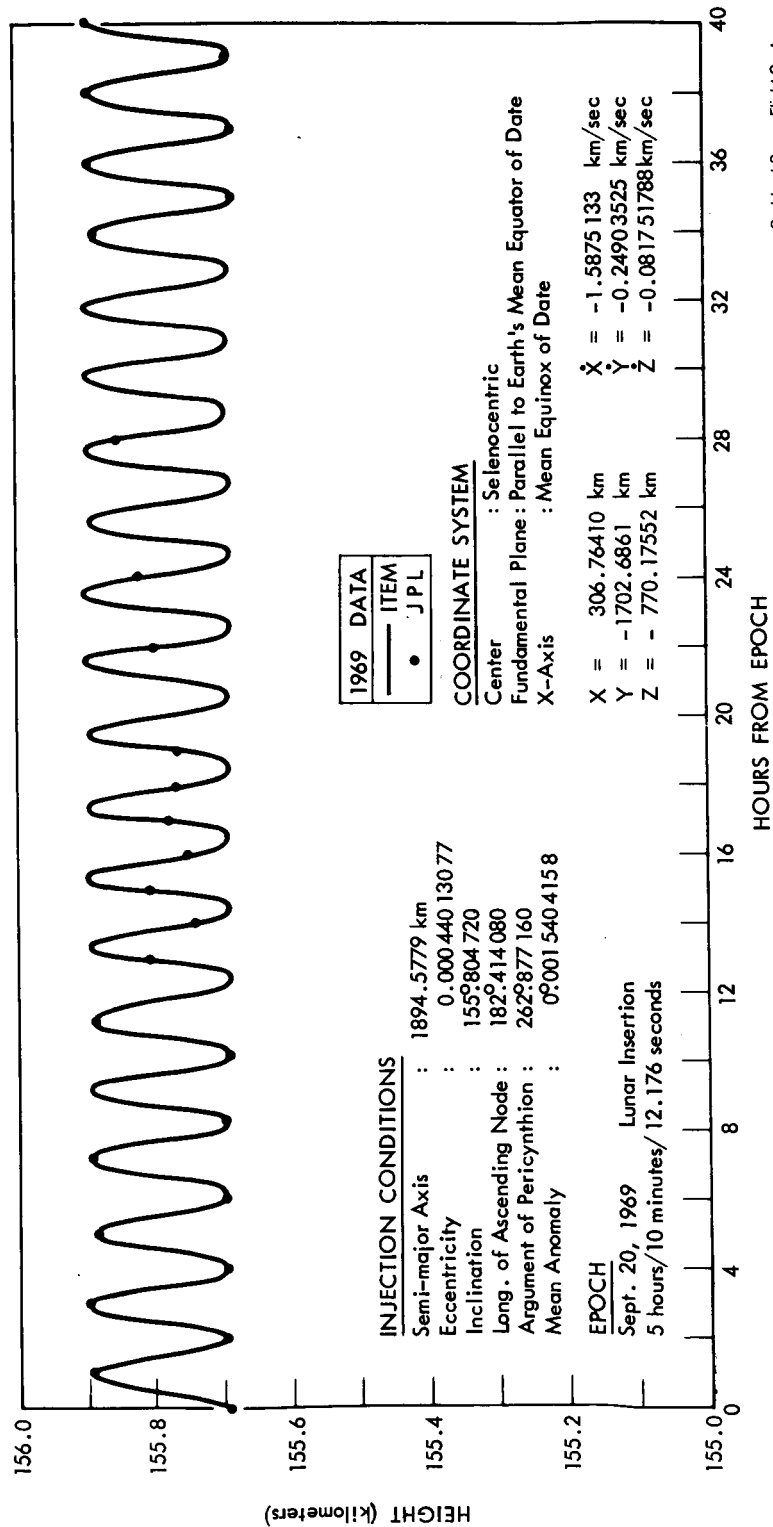


Figure B-3 Inclination (degrees) Vs Hours from Epoch



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Figure B-4 Longitude of the Ascending Node Vs Hours from Epoch



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Figure B-5 Height Vs Hours from Epoch

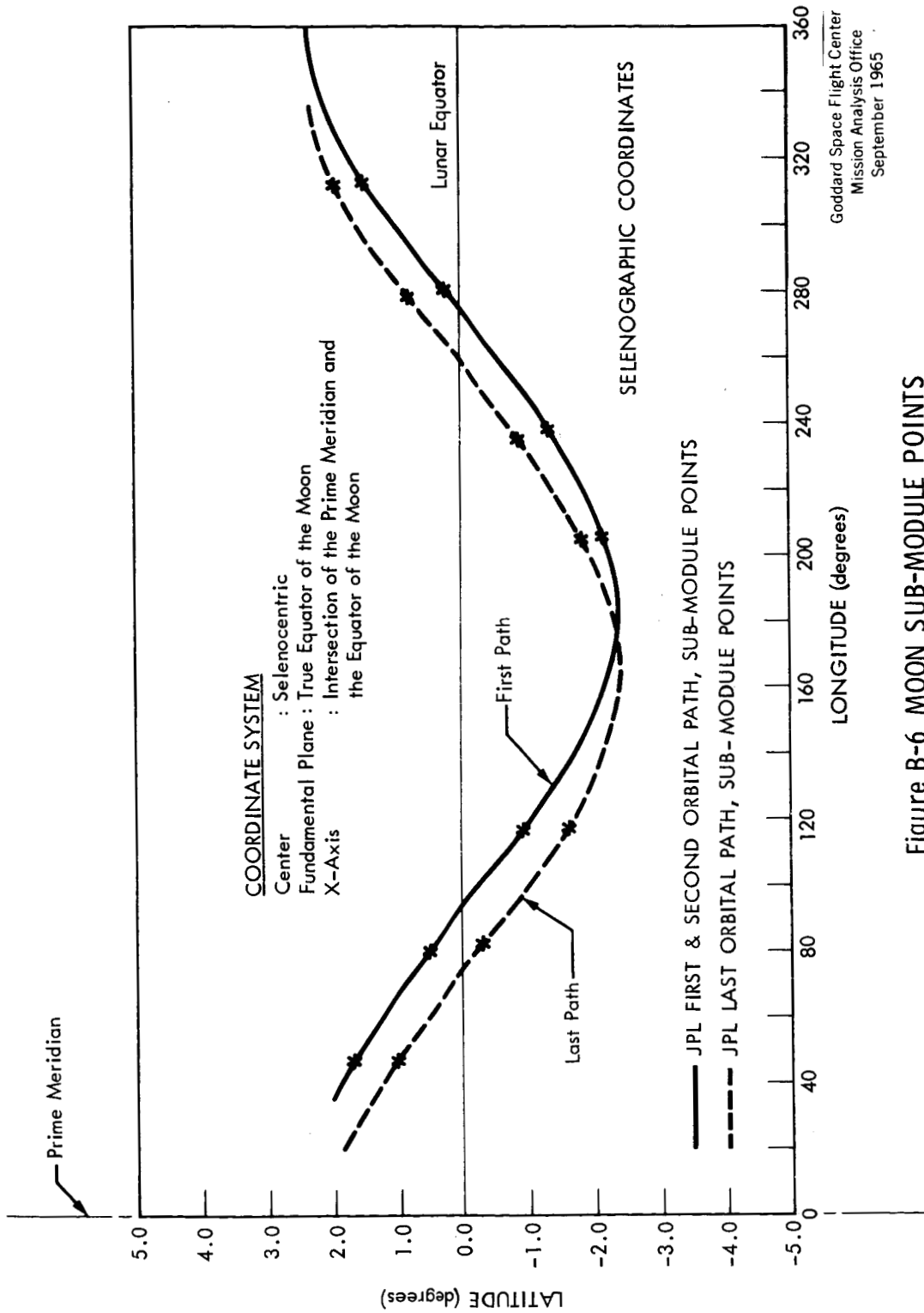


Figure B-6 MOON SUB-MODULE POINTS
 Latitude Vs Longitude