BELLCOMM, INC.
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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE- The 1978 Venus-Swingby-To-Mercury Mission

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AUTHOR(S)-

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ABSTRACT

The general characteristics of the 1978 Earth-Venus-Mercury mission opportunity are discussed, and detailed results of the trajectory analysis are presented in the form of contour plots. A nominal trajectory is selected, and its characteristics are tabulated for reference purposes.

Cyclic considerations of Earth-Venus-Mercury missions are studied. It is observed that the 8-year apparent repetition cycle cannot be reliably used for predicting future mission characteristics.

It is concluded that, in light of several attractive features, the 1978 mission will present an attractive Venus-swingby-to-Mercury opportunity.

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FROM: A. A. VanderVeen

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TECHNICAL MEMORANDUM

INTRODUCTION

Minovitch (1) recognized that the high launch requirements for direct missions to Mercury could be significantly reduced by using a carefully planned close approach to Venus enroute. Earth-Venus-Mercury trajectories have been subsequently studied by several investigators (2-6), and mission opportunities have been observed to occur regularly every 1.6-year with the cycle of Earth-Venus trajectory opportunities. However, it was observed in Reference 3 that in 1977 and 1978 no acceptable trajectories were found to exist below a specific value of launch energy, which was dictated by launch vehicle performance considerations prevailing at the time of the study.

The 1978 trajectories presented here were identified on the basis of a predicted 8-year repetitive cycle of opportunities. Although the cyclic properties of these missions are not as generally reliable as was hoped, they served to identify an area of mission opportunities that was not adequately investigated in the past.

Preliminary results of this 1978 Venus-swingby-to-Mercury mission opportunity were highlighted in a previous memorandum (7). The results presented here document the detailed analysis and reveal several attractive features of this opportunity.

CYCLIC CONSIDERATIONS

It is well known that minimal energy Earth-Venus trajectories occur with regularity every 1.6 years--Venus' synodic period. Because the orbits of Venus and Earth are so nearly circular, little thought is usually given to the fact that at the end of five such synodic periods, or eight years, the slight variation among opportunities will be found to repeat. When the trajectories considered involve Earth, Venus and a third planet, the absolute repetitive period must be equivalent to a multiple of that planet's synodic period as well as that of Venus, and each multiple must also be an integer number of years. Therefore, regardless of the third planet involved, the absolute cycle

of repetition must always be a multiple of eight. In the case of Venus-Mars trajectories it has been demonstrated that the absolute repetitive period is 32 years. Venus swingbys to Jupiter or other outer planet target missions have not been found practical, so cyclic data are not available for other 3-planet Venus missions.

Manning, Reference 6, established empirically a 13-year cycle of repetition for direct trips to Mercury. Such a period comprises forty-one 116-day Earth-Mercury synodic periods. Since thirteen is a prime number, obviously the product of eight and thirteen will yield the shortest absolute repetition period available, one-hundred four years. However, such a long period is essentially useless for short-term mission analyses.

Settling for something less accurate but more useful, hopefully, it may be observed that during a single 1.6-year Venus synodic period, five Mercury synodic periods and four Venus-Mercury mutual synodic periods occur--within an accuracy of about six days. Projected over the 8-year absolute Venus cycle, twenty-five Mercury synodic periods would elapse, and a twenty-five-day Mercury position error would accrue. In light of Mercury's high angular rate of rotation (its period being only 88 days), high inclination and eccentricity, little confidence could be placed in this "apparent" 8-year repetition period; however, it was hoped that the predicted Earth-Venus dates would be valid and the Mercury date would be close enough to identify a given opportunity.

The orbital characteristics of the planets Earth, Venus, and Mercury were plotted as a function of time spanning an 8-year period of interest. The resulting graphs, shown in Figure 1, reveal the variation to be expected from a given geometrical configuration over this duration. Note how the selected period ends with the simultaneous alignment (intersection of longitude traces) of the three planets although Mercury was not initially aligned with the Earth-Venus alignment.

RESULTS

Eight years--to the day--were added to the known 1970 reference mission dates (Reference 2) for purposes of obtaining trajectory date estimates for a 1978 mission search. The computer results indicated that an energy match at Venus occurred and that the launch velocities were not prohibitively high. Succeeding runs identified the minimal energy region of the trajectory surface; a 50-day span of launch dates and a 20-day span, approximately, of Mercury arrival dates were found to cover a broad spectrum of mission characteristics, including an acceptable range of Venus passage altitudes.

Figure 2 presents the trajectory surface for the 1978 mission opportunity in the form of contour plots of specific trajectory parameters. The 20-day range of ordinates is bounded below by the 1.0-radius Venus impact zone caused by too-early arrival dates and is bounded above by a second-leg 180° transfer ridge located at Mercury arrivals of about JD 244 3878. A nominal trajectory, indicated by the triangular marker on the graphs, was selected for purposes of establishing a representative set of trajectory characteristics and a typical mission profile. The nominal trajectory parameter values are given in Table 1.

TABLE I - NOMINAL CHARACTERISTICS--1978 EARTH-VENUS-MERCURY MISSION

EVENT	DATE[a] CALENDAR (JULIAN)	V_{∞}[b] KPS (EMOS)	ΔV[c] KPS (FPS)	RADIUS[c] KM (NM)
EARTH DEPARTURE	10 AUG 78 (3730)	5.49 (.1843) (C_3 =30.2 KPS^2)	4.50 (14,760)	315 (170)
VENUS PASSAGE	7 NOV 78 (3820)	11.94 (.3918)	14.40 (47,250)	2950 (1590)
MERCURY ARRIVAL	28 DEC 78 (3870)	12.25 (.4020)	9.84 (32,300)	463 (250)

[a]JULIAN DATES ARE FROM 244 0000.

[b]EARTH-MEAN-ORBITAL-SPEED NORMALIZING FACTOR; ONE EMOS = 29.8 KPS OR 97702 FPS.

[c]INJECTION FROM 170 NM CIRCULAR EARTH ORBIT; PERIAPSIS VELOCITY AT VENUS RADIUS INDICATED; ENTRY INTO 250 NM CIRCULAR ORBIT AT MERCURY.

Figure 3 shows the nominal mission profile in the conventional form of an ecliptic projection. Identified on this figure are the three nodal lines of intersection, indicating where the orbital planes of Earth, Venus and Mercury intersect.

Figure 4 is useful in understanding the inherent out-of-the-ecliptic plane trajectory requirement of Mercury missions because of the 3-dimensional information it contains. The three separate graphs of this figure are projections of heliocentric distance, latitude and longitude of the planets and of the spacecraft on its nominal trajectory as functions of time. Figure 4b, for example, shows how the Venus encounter is used to advantage to nearly match the spacecraft's orbital

inclination on the second leg with that of Mercury (7°), while permitting it to depart from Earth's orbit with an inclination of only about 2°. Since little angular change is noted in the distance-trace of the spacecraft's trajectory during the Venus encounter (Figure 2 or Figure 4a), it is surmised that the Venus influence contributes mainly to an out-of-plane inclination change and less significantly to in-plane turning. Figure 5 bears out this hypothesis somewhat by virtue of the flyby symmetry and the low (-38°) declination of periapsis. A ballistic flyby trajectory is always symmetrical about its peripoint, but in this case, since the spacecraft's heading is due East at peripoint, the trajectory is also symmetrical with respect to Venus' equator. The spacecraft approaches Venus from above its equator on a southeasterly heading but emerges above the equator on a northeasterly course. Hence, the out-of-plane turning angle is approximately twice the angle of incidence with the equator, and the effect already observed in Figure 4b provides almost 4° of inclination change.

ALTERNATE TYPE TRAJECTORIES

Examination of the sequence of first-leg characteristics of missions recorded from 1965 through 1973 by Minovitch (1) reveals that the transfer angles alternate between less-than (type I) and greater-than (type-II) 180° according to Table 2. If this sequence should continue, the 1978 outbound leg should be a type-II transfer. Yet, the 1978 opportunity reported here has a type-I outbound leg, as does the 1970 mission upon which it was based. Apparently the recorded data are incomplete and both types exist during some opportunites.

TABLE 2 - SEQUENCE OF EARTH-VENUS-MERCURY MISSION CHARACTERISTICS--1965-1973

LAUNCH DATE:	18 DEC 65	19 JUN 67	23 JAN 69	18 AUG 70	1 APR 72	4 NOV 73
1ST-LEG TRANSFER ANGLE:	250°	108°	257°	110°	265°	103°
DURATION: (DAYS)	170	96	189	101	197	94
2ND-LEG TRANSFER ANGLE:	228°	190°	214°	146°	152°	138°
DURATION:	108	72	108	59	85	58
TOTAL TRANSFER ANGLE:	478°	298°	471°	256°	417°	241°
DURATION:	276	168	297	160	282	152

A type-II outbound trajectory was sought during the 1978 opportunity based on the general characteristics of other Earth-Venus-Mercury missions in which that type occurs. Another family, at a 90-day earlier launch date, was found. However, only a 10-day launch window, which will provide Venus clearances greater than fifty n.m., appears to exist. Typical characteristics are given in Table 3. On the basis of these results, it would appear likely that additional launch windows, not yet identified, may be available in years of known mission opportunities to Mercury via Venus.

TABLE 3 - RANGE OF TRAJECTORY CHARACTERISTICS OF ALTERNATE (TYPE II) 1978 EARTH-VENUS-MERCURY OPPORTUNITY

DATE (JULIAN)	EARTH DEPARTURE	VENUS PASSAGE	MERCURY ARRIVAL
	244 3640 - 3650	3809.9 - 3811.4	3878 - 3882
$V_{INFINITE}$(EMOS)	.2349 - .2196	.2785 - .2800	.2916 - .3093
$V_{INJECTION}$ (FPS)[a]	17,220 - 16,430		
$V_{PASSAGE}$ (FPS)		42,900 - 43,090	
V_{ENTRY} (FPS)[b]			22,210 - 23,790
PASSAGE DISTANCE (NM)		105 - 78	

[a]FROM 170 NM CIRCULAR ORBIT

[b]TO 250 NM CIRCULAR ORBIT

CONCLUSIONS

The detailed analysis of the 1978 Earth-Venus-Mercury mission reveals that moderately low launch requirements over a wide launch window prevail for this opportunity, that a suitable range of Venus passage distances is available, that Mercury arrival velocities are relatively moderate, and that total trip durations are relatively short. These features make a 1978 mission an attractive launch opportunity.

Little reliability can be found in the apparent 8-year repeatability cycle for Earth-Venus-Mercury missions since the rapidly changing encounter characteristics at Mercury will preclude identifying "replicas" of previous missions.

It is suspected that more than one launch window is available during several of the "established" opportunities. An opportunity should also be available in 1977, although this has not yet been identified.

A. A. VanderVeen

1013-AAV-nma

Attachments
Figures
References

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2. Cutting, E., and Sturms, F. M., Jr., "Trajectory Analysis of a 1970 Mission to Mercury Via a Close Encounter with Venus," JPL Technical Memorandum 312-505, December 7, 1964.

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6. Manning, L. A., "Minimal Energy Ballistic Trajectories for Manned and Unmanned Missions to Mercury," NASA TN D-3900, Apr. 1967.

7. VanderVeen, A. A., "Preliminary Results of an Attractive Earth-Venus-Mercury Mission in 1978, Bellcomm Memorandum for File, October 9, 1968.

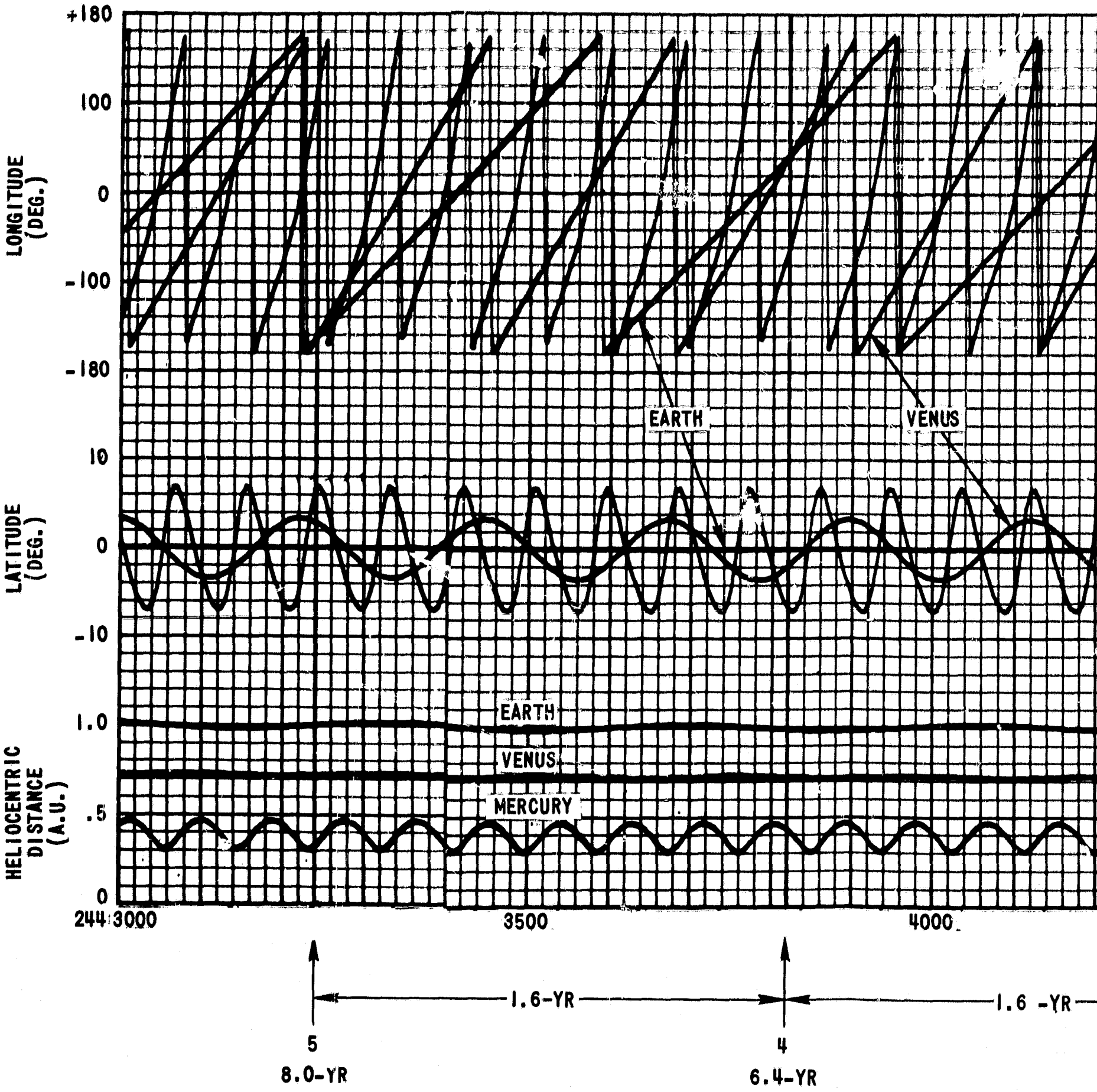
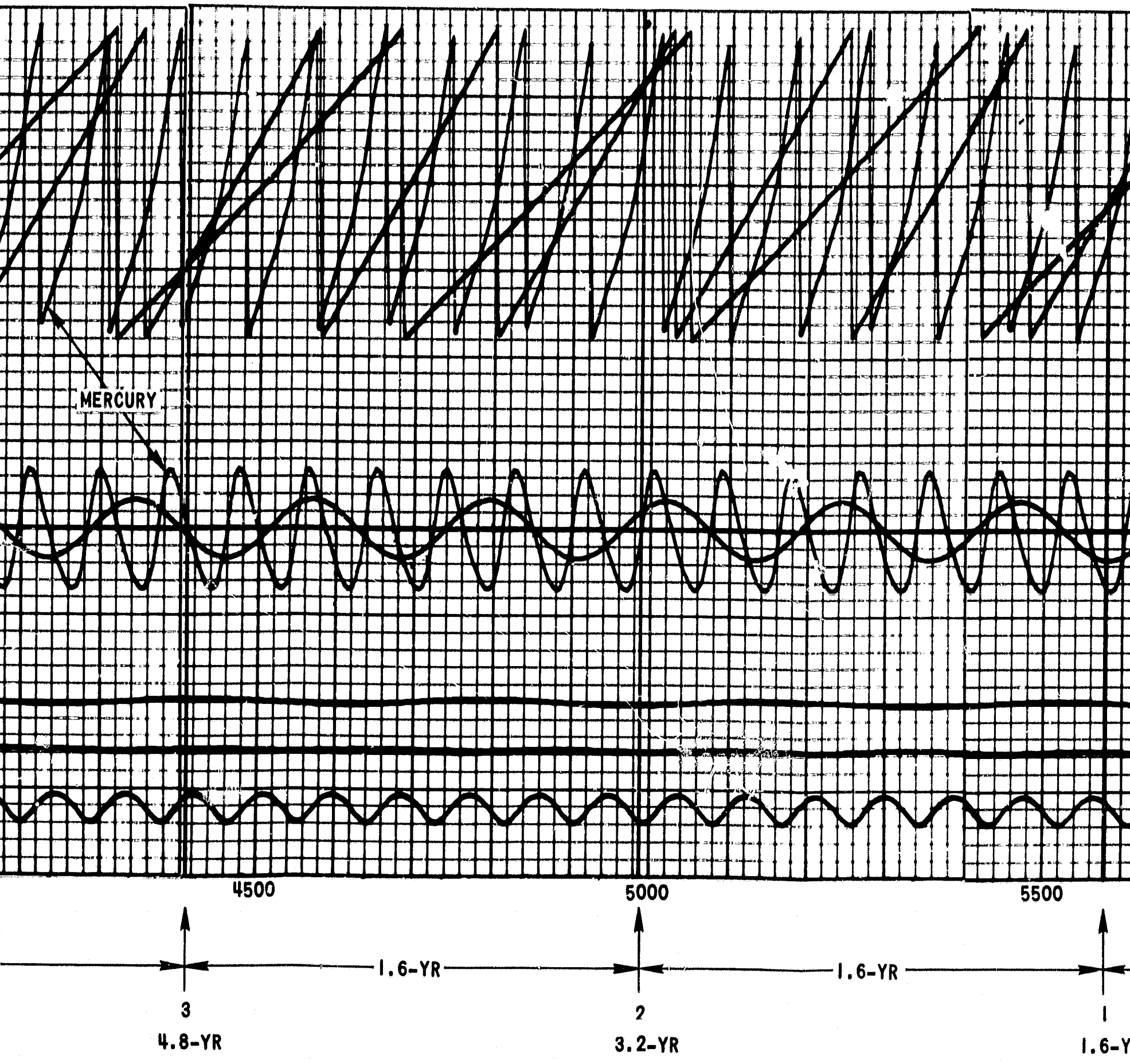
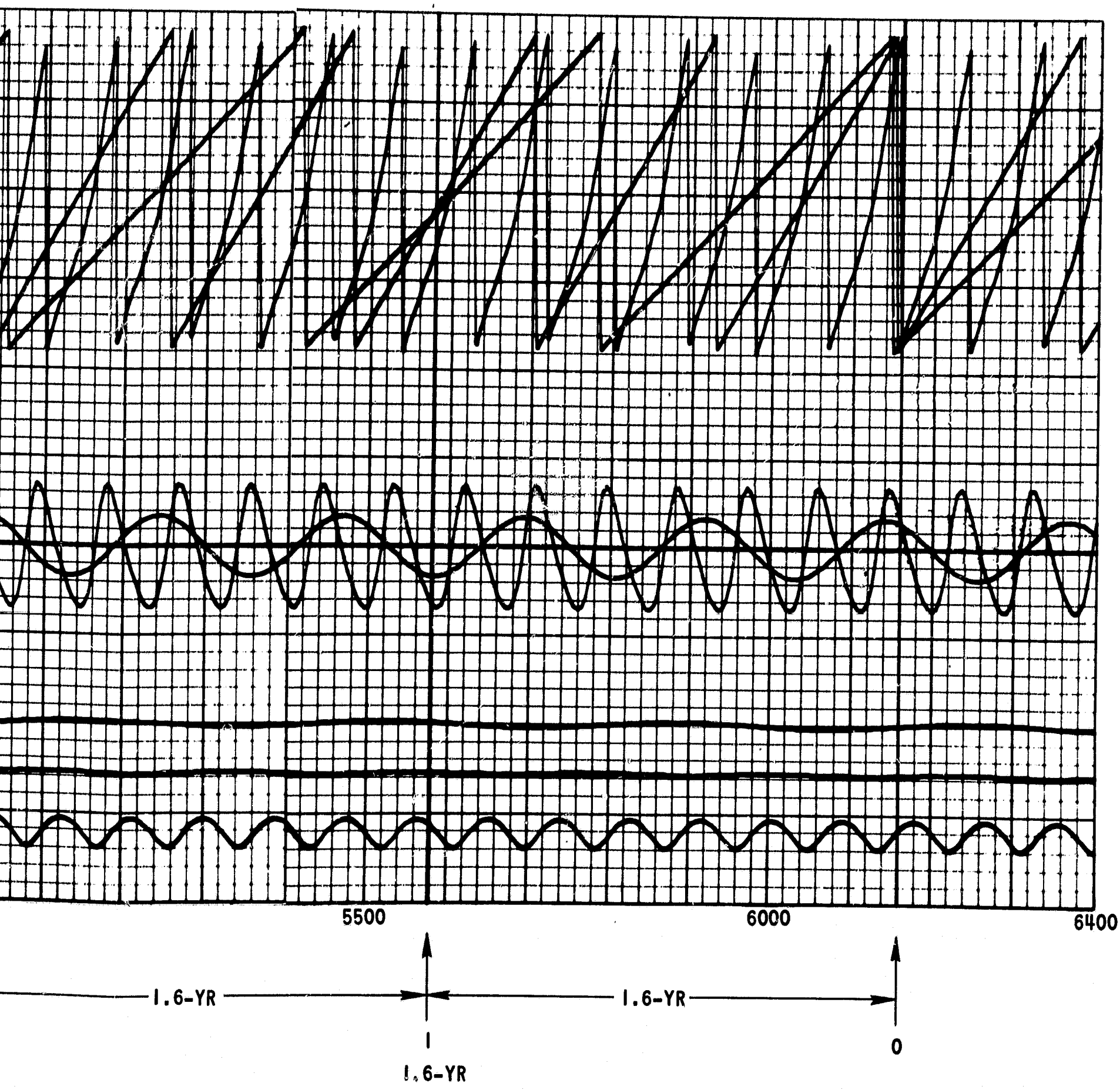


FIGURE 1 - ORBITAL CHARACTERISTICS OF EARTH, VENUS, AND MERCURY OVER AN 8

Fold Out
a



8-YR TIME PERIOD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1.6-YR
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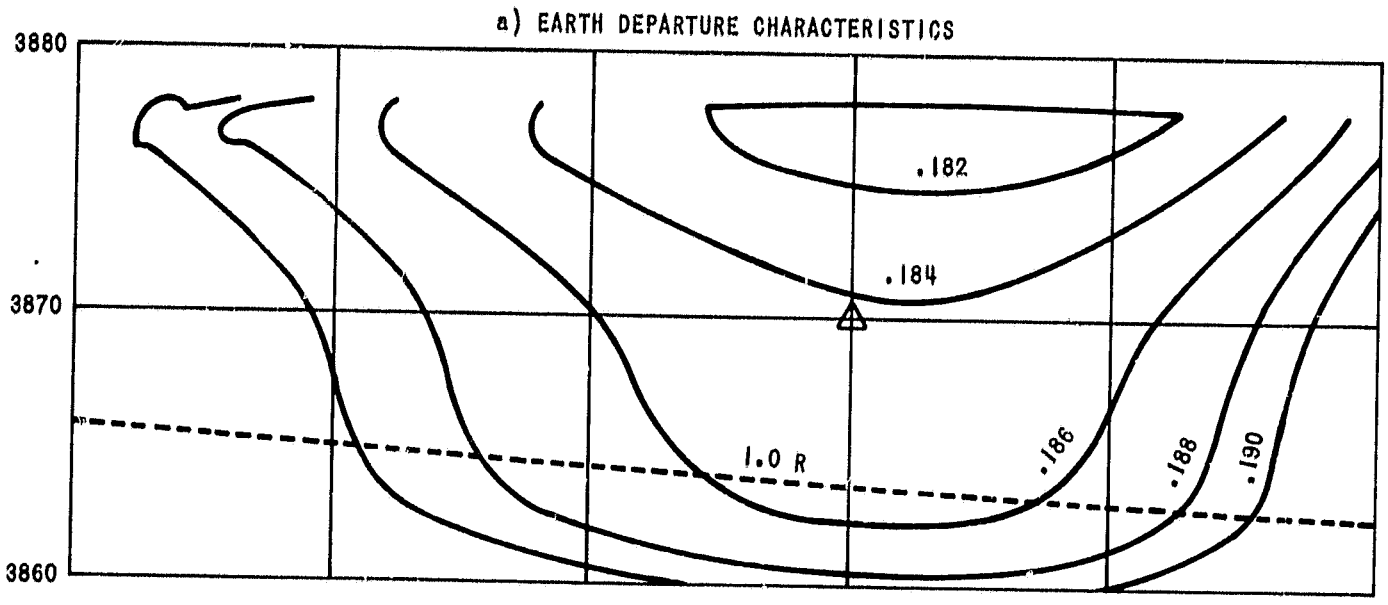
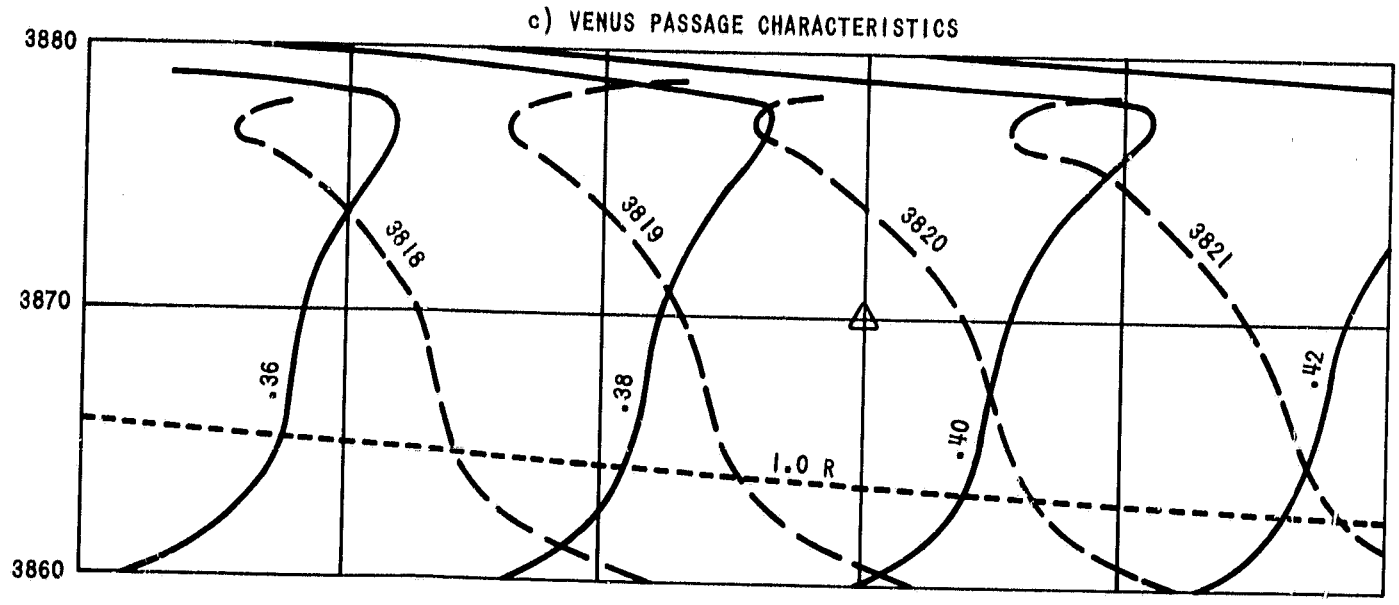
1.6-YR

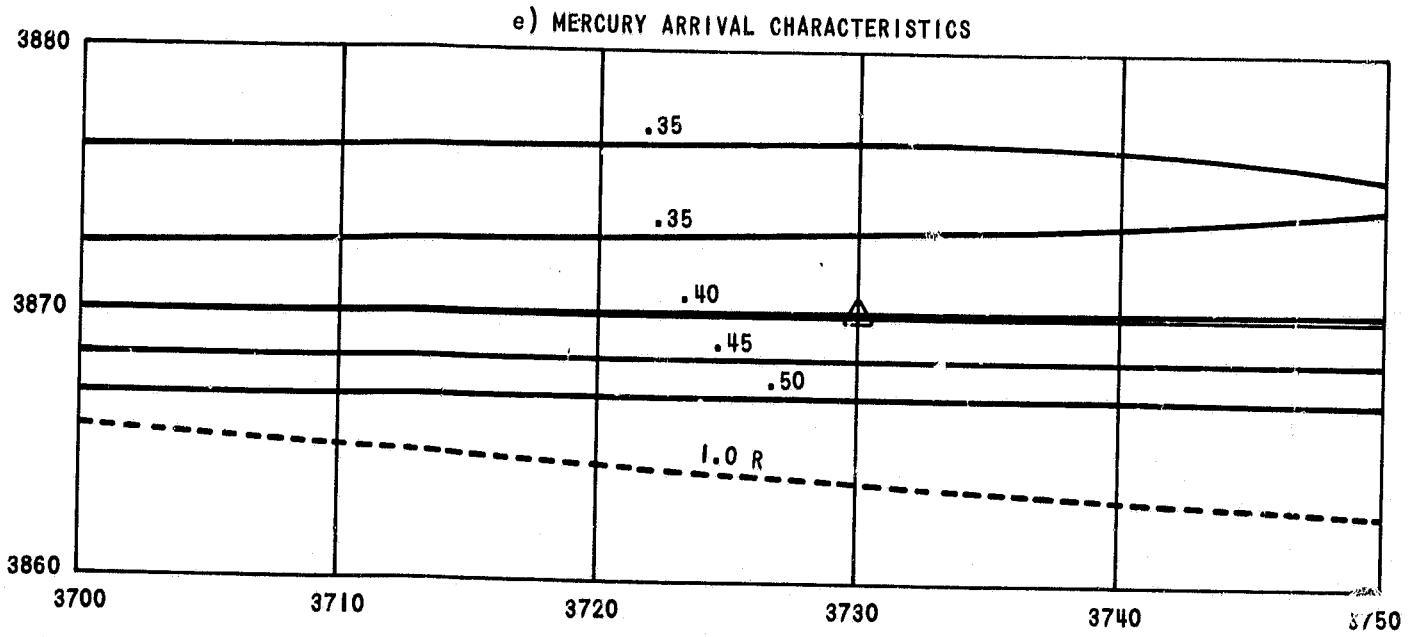
a) EARTH DEPARTURE CHARACTERISTICS



c) VENUS PASSAGE CHARACTERISTICS

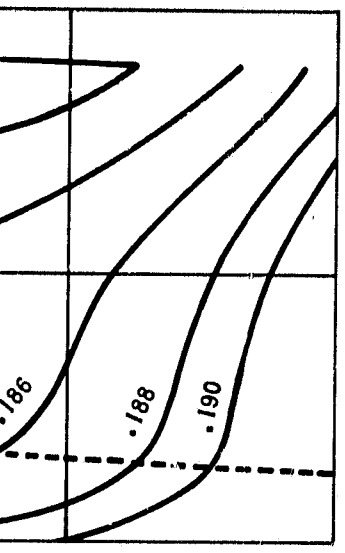


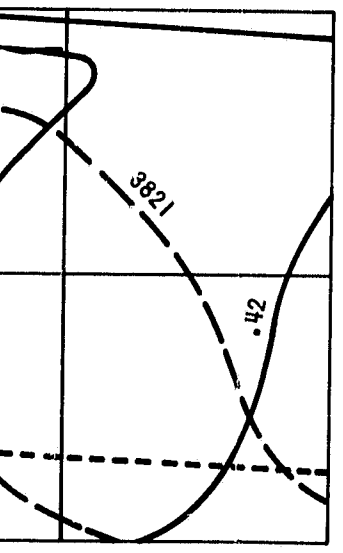
e) MERCURY ARRIVAL CHARACTERISTICS

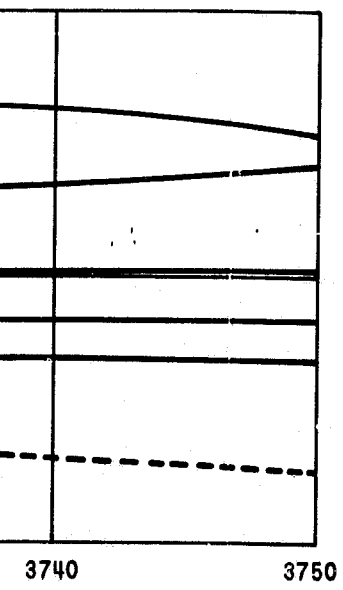


Fold Out

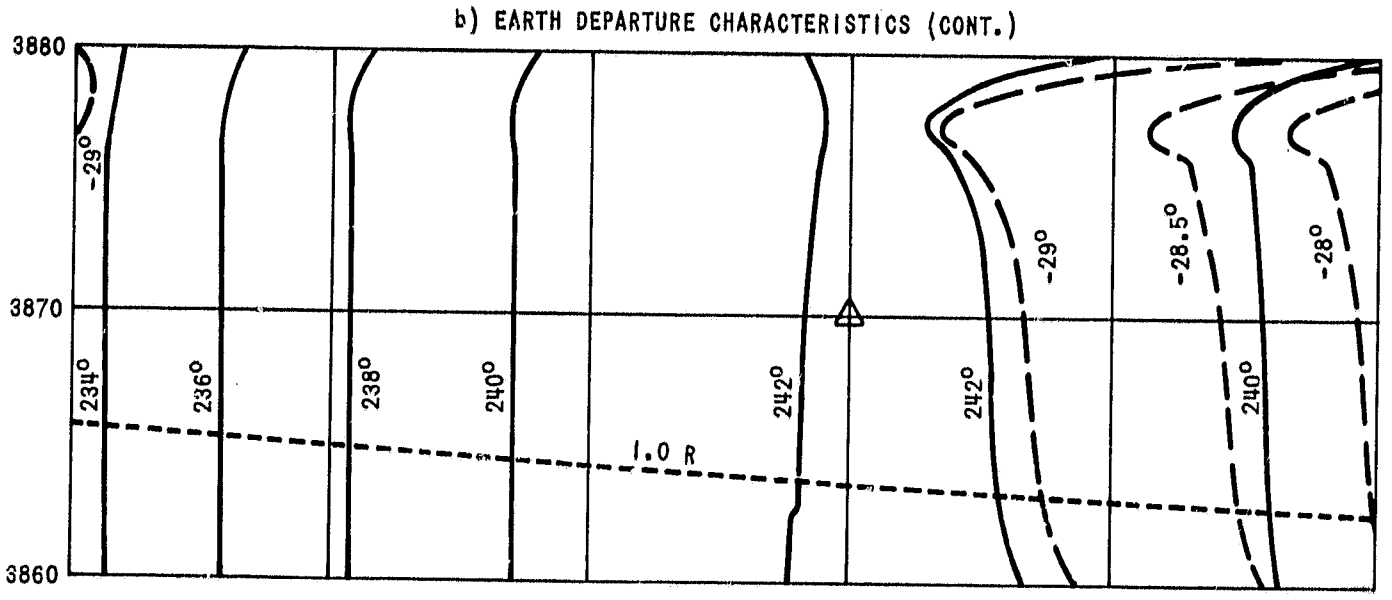
FIGURE 2 - 1978 EARTH-VENUS-MERCURY TRA



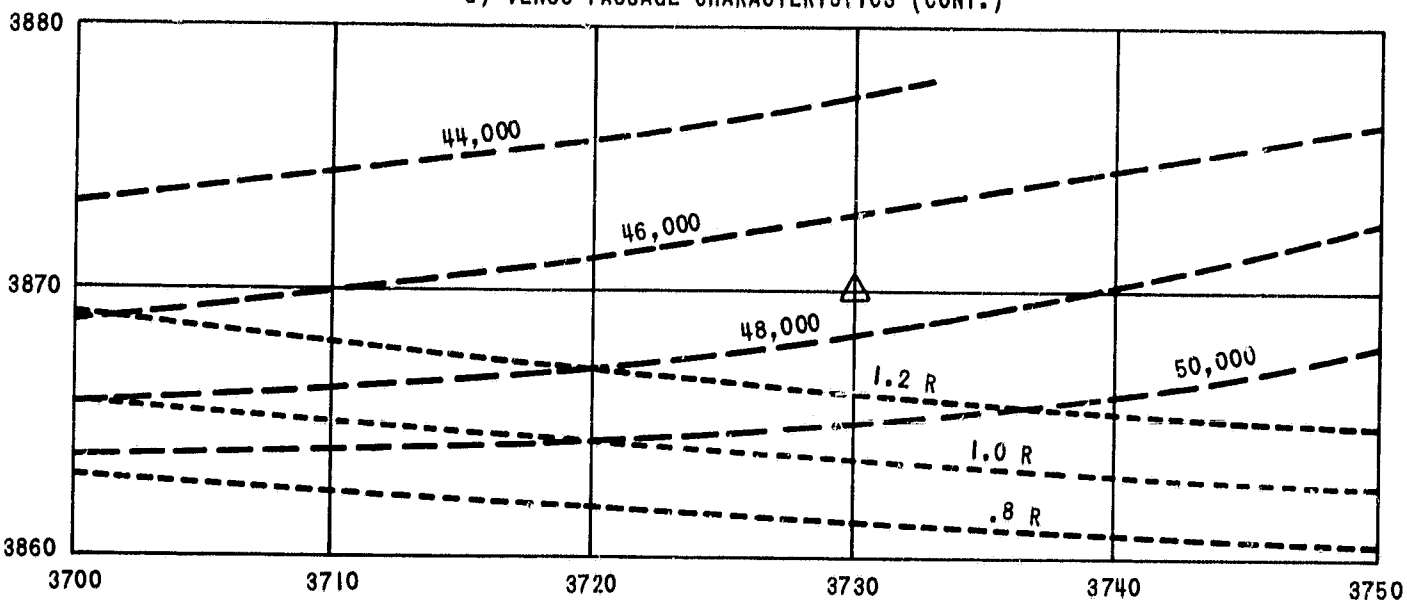




b) EARTH DEPARTURE CHARACTERISTICS (CONT.)



d) VENUS PASSAGE CHARACTERISTICS (CONT.)



MERCURY ARRIVAL DATE

EARTH DEPARTURE DATE

HYPER. EXCESS SPEED (EMOS), OR RIGHT ASCENSION (DEG)

ARRIVAL VELOCITY (FPS), PASSAGE DATE (J.D.), OR DECLINATION (DEG)

VENUS PASSAGE RADII (P.R.)

△ NOMINAL TRAJECTORY

FIGURE 2 - 1978 EARTH-VENUS-MERCURY TRAJECTORY SURFACE

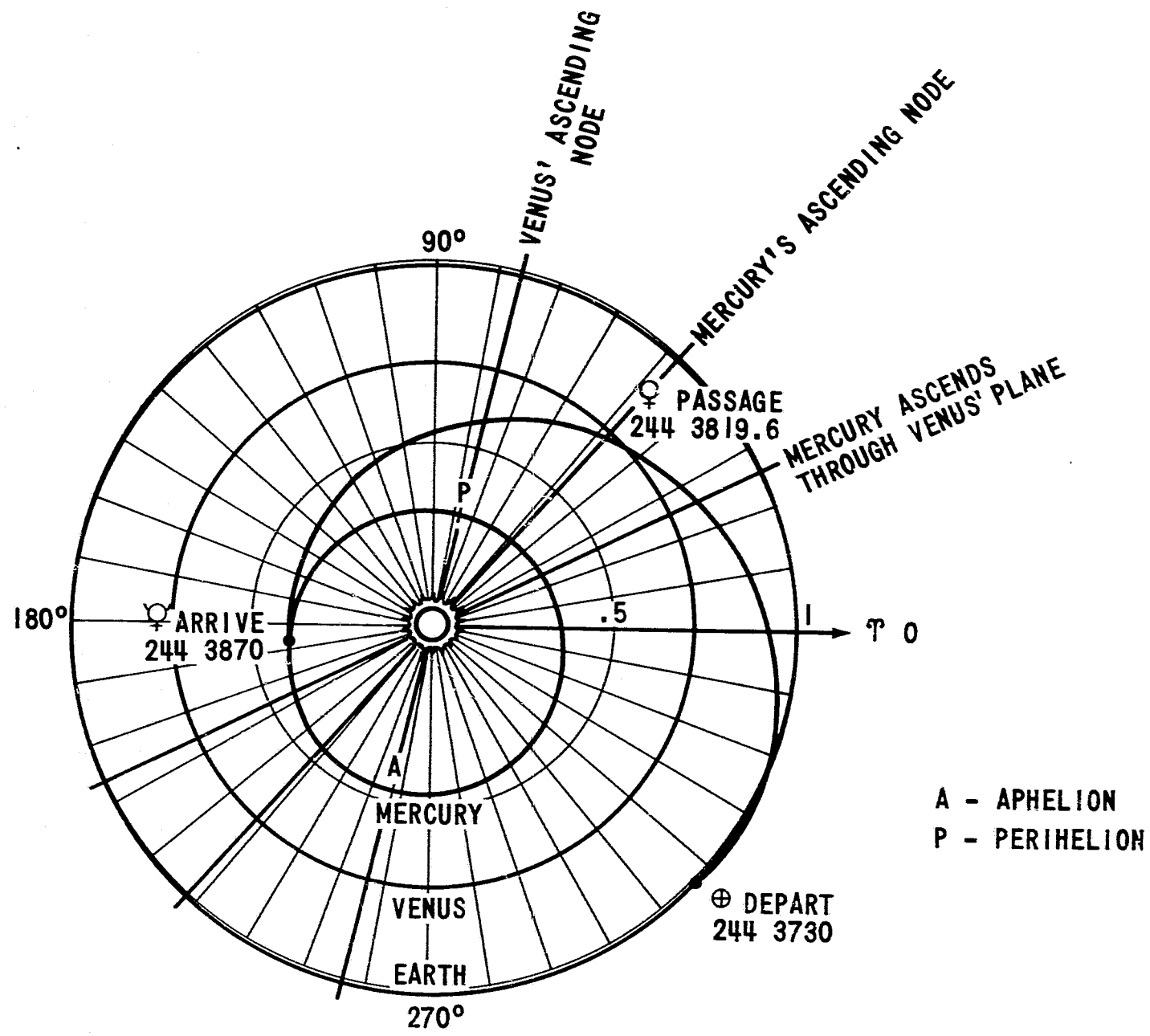


FIGURE 3 - 1978 EARTH-VENUS-MERCURY MISSION PROFILE

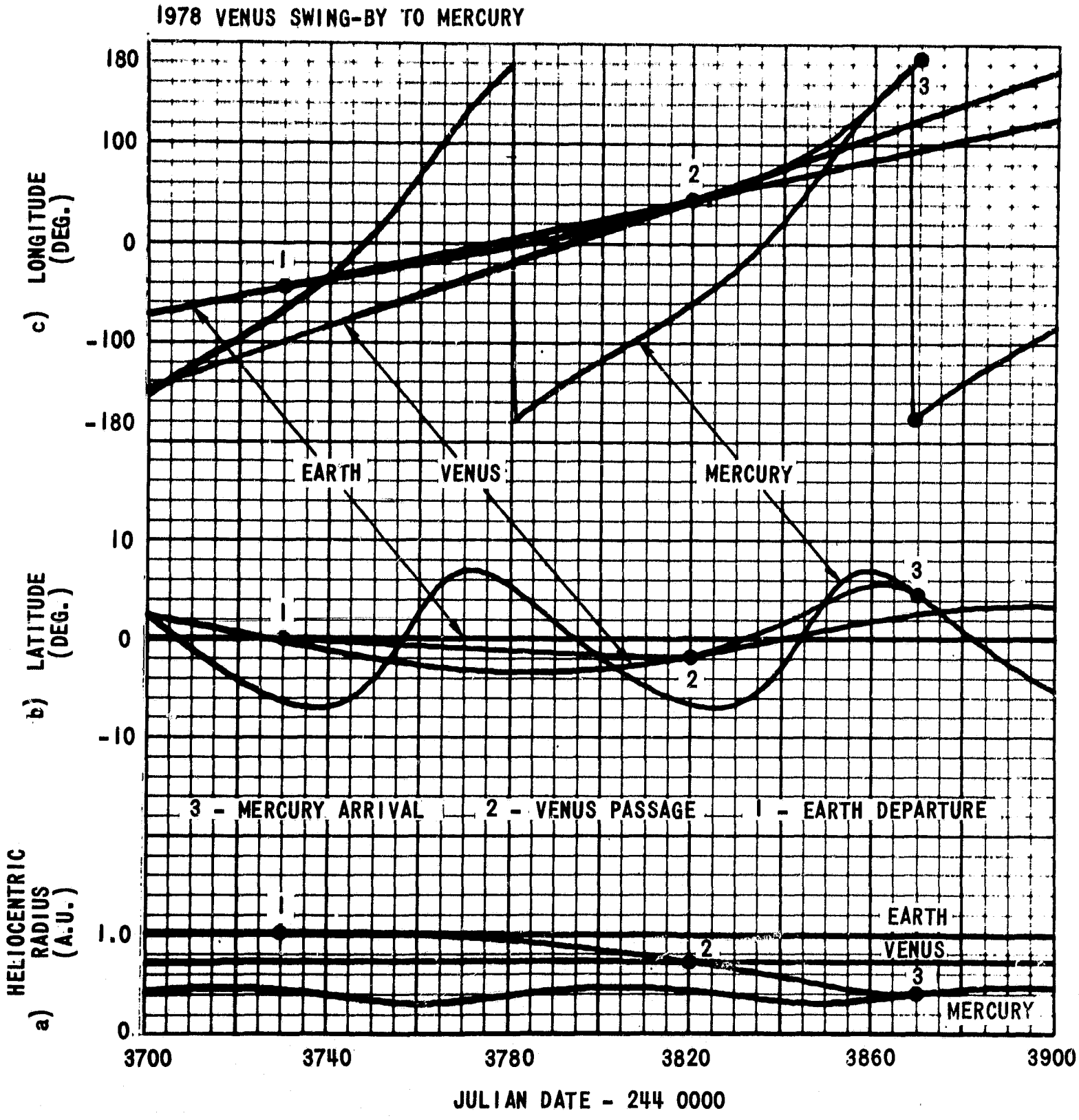


FIGURE 4 - POSITION vs. TIME PROFILE OF 1978 EARTH-VENUS-MERCURY MISSION

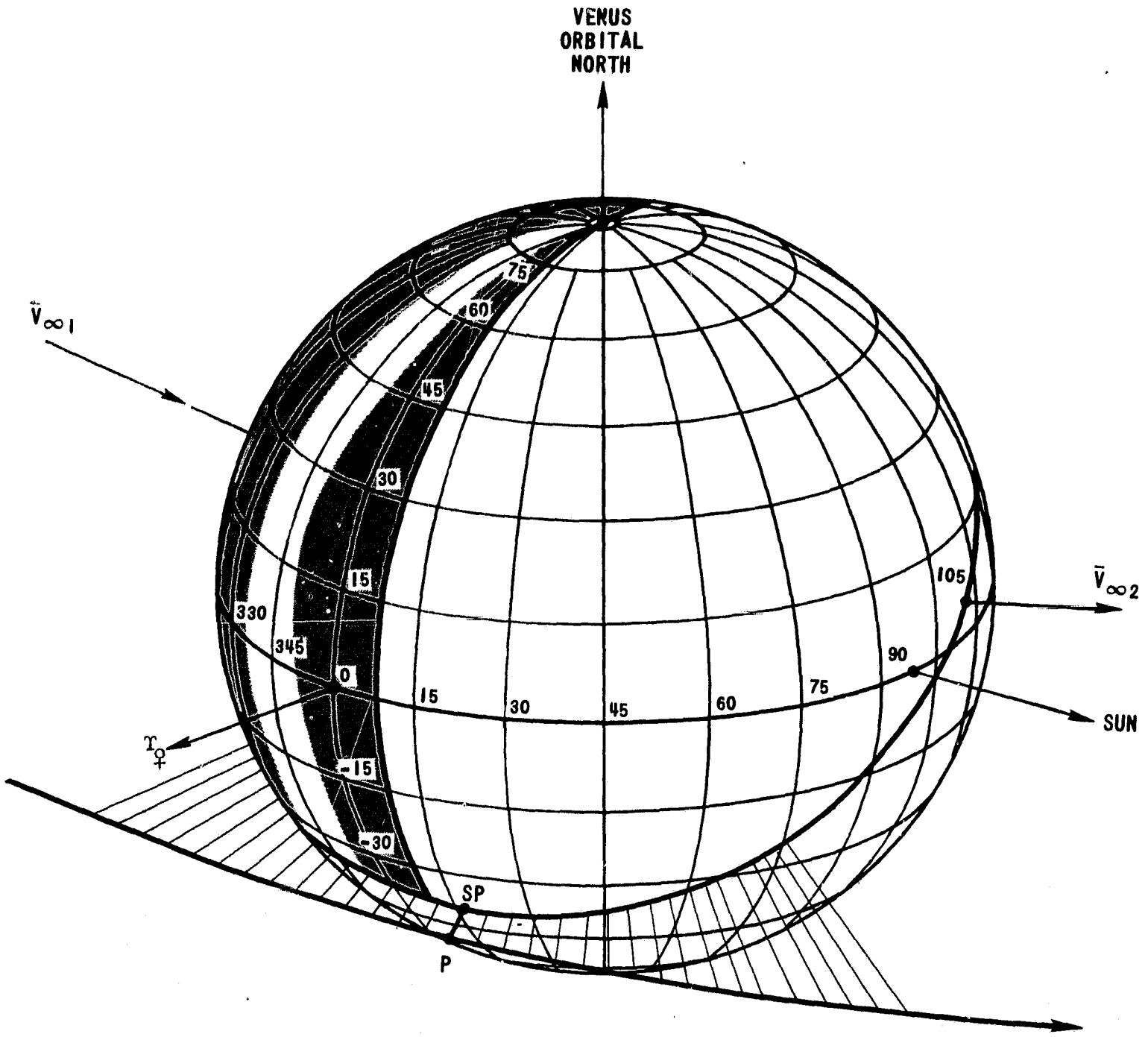


FIGURE 5 - VENUS PASSAGE PICTORIAL OF THE 1978 EARTH-VENUS-MERCURY MISSION