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UTILIZATION OF AN ORBITAL LAUNCH FACILITY FOR PLANETARY MISSIONS

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ABSTRACT

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This report presents the results of a study conducted to determine the feasibility, from an orbital mechanics viewpoint, of utilizing a permanent Orbital Launch Facility (OLF) to support missions to Mars and Venus during the 1975 - 1990 time period.

Twenty-seven Earth departure windows were selected for Mars and Venus missions in the 15-year period. The required nodal orientation a vehicle must have for a coplanar injection into an Earth escape trajectory was calculated for each of the Earth departure windows.

An arbitrarily-chosen OLF orbit was then projected through all the 27 windows. This OLF orbit was completely compatible with all Earth departure windows except two, and was compatible with these two with only minor additional velocity requirements.

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RESEARCH AND DEVELOPMENT OPERATIONS

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LIST OF SYMBOLS

Symbol	Definition
V_∞	Hyperbolic excess velocity leaving Earth's sphere of influence, EMOS
$V_\oplus$	Earth's orbiting velocity, EMOS
δ	Declination of hyperbolic excess velocity vector, deg
α	Right ascension of hyperbolic excess velocity vector, deg
Ω_{ss}	Right ascension of ascending node of parking orbit, deg
Ω_h	Right ascension of ascending node of escape hyperbola, deg
i_{ss}	Parking orbit inclination, deg
i_h	Inclination of escape hyperbola
ΔV	Velocity required for plane change and hyperbolic injection from parking orbit, km/sec
J. D.	Julian Date
T_{OB}	Earth to planet trip time, days
T	Julian Date of Earth departure
EMOS	Earth's Mean Orbital Speed (29.7849 km/sec)

UTILIZATION OF AN ORBITAL LAUNCH FACILITY FOR PLANETARY MISSIONS

By Robert M. Croft
George C. Marshall Space Flight Center

SUMMARY

This report presents the results of a study conducted to determine the feasibility, from an orbital mechanics viewpoint, of utilizing a "permanent" Orbital Launch Facility (OLF) to support missions to Mars and Venus during the 1975 - 1990 time period.

Twenty-seven Earth departure windows of approximately 40 days' duration each were selected for Mars and Venus missions in the 15-year period. The required nodal orientation a vehicle must have for a coplanar injection into an Earth escape trajectory was calculated for each of the Earth departure windows.

An arbitrarily-chosen OLF orbit was then established and projected through all the Mars and Venus missions selected for this study. This OLF orbit was completely compatible with all Earth departure windows except two, and was compatible with these latter two with only minor additional energy requirements.

Twenty-six Earth departure windows were investigated for general compatibility and eighteen of these were compatible with all possible nodal orientations of an OLF orbit. The remaining eight departure windows were compatible with 75 to 99 percent of all possible orientations of the OLF orbit.

Although the level of effort available for this study did not permit a comprehensive investigation of the problem, it leaves no doubt that an OLF would be feasible, from an orbital mechanics viewpoint, to support successive missions to Mars and Venus in the 1975 - 1990 time period.

SECTION I. INTRODUCTION

One of the major tasks of the National Aeronautics and Space Administration (NASA) is planning for the manned exploration of space. Because of the long lead time associated with the development of advanced propulsion systems, launch vehicles, and related systems, it is necessary to study various potential missions and their requirements.

Many of the planetary missions under consideration propose an Earth orbital launch operation for mission completion. A study is presently underway by Ling-Temco-Vought (LTV) entitled "Advanced Orbital Launch Operations" (Contract NAS 8-5344) which investigates different modes of providing the orbital support required to assemble, fuel, maintain and repair, check out and count down the mission launch vehicle.

One mode investigated by LTV for Orbital Launch Operations (OLO) is characterized by OLO crewmen and equipment being permanently based in orbit in an Orbital Launch Facility (OLF). The OLF serves as a base of operations around which are centered the operations required for orbital launch.

Since the OLF would be required to support various planetary missions for several years, it is necessary to determine what constraints, if any, are placed on the OLF by Earth departure windows, i.e., will the OLF orbit have the proper nodal orientation such that a coplanar launch can be made at some time within a 40-day Earth departure window regardless of the mission target (Mars or Venus), mission duration (long or short) or launch year (1975 - 1990).

The limited amount of effort which could be expended, although sufficient for the limited objectives of the study, did not permit a detailed analysis of the problem; therefore a representative series of Mars and Venus missions during the 1975 - 1990 time period was selected.

Both long-duration and short-duration missions to Mars were investigated, and 16 Earth departure windows were determined for the 1975 - 1990 time period.

Ten Earth departure windows based on long-duration missions were investigated for Venus. It should be noted that the same Earth departure windows were assumed for both the long- and short-duration

Venus missions, since the velocity requirements at Earth departure did not change appreciably when compared with other windows within a conjunction year.

It should be emphasized that the purpose of this study was not to determine optimum Earth departure windows, but to investigate the orbital mechanics feasibility of utilizing a single permanent Orbital Launch Facility for a variety of missions over several years.

Table 1 summarizes the Earth departure windows selected for this study.

SECTION II. ASSUMPTIONS

The following is a summary of the basic assumptions used in this study:

(1) Patch conic approximation. The patched conic approximation is ideally suited to preliminary analyses of interplanetary trajectories where the rapid computation of a large amount of data is required. In this technique, the interplanetary trajectories are broken into five phases and the vehicle is assumed to be moving in a conic trajectory with respect to the central body of interest during each phase (Earth - Sun - Planet - Sun - Earth). The conics generated are "patched together" to form a complete interplanetary trajectory. The primary area of interest in this study is the Earth-escape portion of the interplanetary trajectory.

(2) All velocity additions are impulsive. This gives a very good approximation and allows an analytical treatment of the problem.

(3) Only single impulse maneuvers are considered. The launch window for a multiple impulse maneuver for planetary escape would be essentially the same as for a single impulse maneuver.

(4) Midcourse maneuvers are not considered. This maneuver is performed during the interplanetary phase of the mission and is not influenced significantly by the planetary departure window.

(5) Planetary oblateness effects. In the patched conic approximation, the gravitational field of the Earth is simulated by a central, inverse square variation force field about a point mass, which ignores the effect of the Earth's oblateness. The oblateness effect is treated as follows:

(a) Oblateness is not considered for the Earth departure trajectory since its effect only becomes noticable at low orbital altitudes after long periods of time.

(b) Since the Orbital Launch Facility may stay in Earth orbit several years, oblateness must be taken into account to describe the OLF's motion. In this study, the effect of oblateness is accounted for by using a first-order approximation for the regression of the line of nodes of the parking orbit.

(6) Parking orbit inclination of the OLF - 32 degrees. The reason for assuming this value is discussed below. However, the inclination has considerable influence on the duration and frequency of occurrence of the orbital launch window. This is an area in which additional study effort would be useful.

(7) Parking orbit altitude of the OLF - 485 km. This altitude was assumed for reasons discussed below. However, a trade-off study of payload to orbit versus orbital launch requirements would be useful.

(8) Perigee altitude of nominal escape hyperbola - 485 km (tangential launch). This is the nominal case for the orbital launch window calculations. Variations in perigee due to a few minutes' variation in launch time do occur, however, and have been investigated in references 1 and 2.

As stated in assumptions (6) and (7) above, the operational orbit selected for the Orbital Launch Facility has an inclination of 32 degrees and an altitude of 485 km. Two main factors influenced the selection of the orbit: (1) The operational orbit selected is a rendezvous-compatible orbit which makes available a daily Earth-to-OLF-orbit launch without a plane change (reference 3); (2) this orbit is based on a study by LTV, entitled "Advanced Orbital Launch Operations." In the LTV study, round trips from Earth orbit to Lunar orbit and then back to Earth orbit were studied from two viewpoints. In one case, a permanent Earth orbital support vehicle was used as a base for the Lunar Ferry employed in this mission. In this case, only two translunar orbital launch windows per 54-day period are possible. The nodal regression rate of the OLF operational orbit selected above is equal to one-half the mean motion of the Moon about the Earth. This synchronization of the two motions allows the whole geometrical picture to recur every two Lunar revolutions (54 days). Therefore, the operational orbit selected would make the OLF available for round trip Lunar missions as well as the Mars and Venus missions (reference 1).

SECTION III. EARTH DEPARTURE AND ORBITAL LAUNCH WINDOWS

A. Earth Departure Window

Figure 1 shows the outbound leg of a typical transplanetary trajectory. The hyperbolic excess velocity (V_∞), as shown in Figure 1, can be defined as the velocity relative to the planet in excess of that required to escape the gravitational attraction of the planet and, when added to the Earth's orbiting velocity ($V_\oplus$), gives the heliocentric velocity of the vehicle. The plane of the transplanetary orbit must contain the position of the departure planet at departure, the Sun, and the position of the target planet at arrival. The inclination of the transfer plane to the orbit plane of the departure planet and the required departure velocity vary considerably with the relative positions of the departure and arrival planets; therefore, the feasible times for launching into these interplanetary transfers are limited to a few weeks during each synodic period. The Earth departure window may now be defined as that range of departure dates, from the Earth's sphere of influence, in which a mission vehicle has the capability to inject into the required transplanetary trajectory and to accomplish the subsequent phases of the mission.

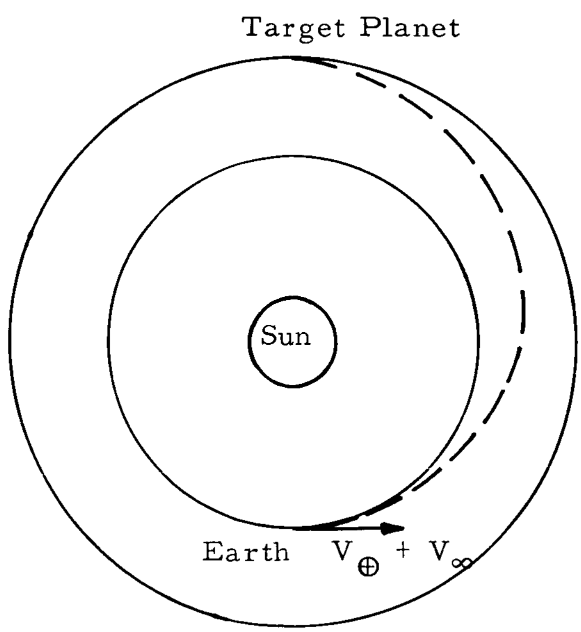


FIGURE 1. - TYPICAL TRANSPLANETARY TRAJECTORY

Figures 4, 6, and 8 show Earth departure windows for Mars and Venus missions in the 1975 - 1990 time period. The variation of the hyperbolic excess velocity with time due to the above mentioned conditions can be seen from these figures. Also shown in these figures is the year-to-year variation of the minimum energy requirements. This variation is due to the positions of the planets in their respective orbits relative to perihelion and the line of nodes of the two orbits.

B. Orbital Launch Window

Earth departure windows are usually defined without reference to how a given geocentric escape hyperbola (which connects to the required transplanetary trajectory) can be entered from an Earth parking orbit. During preliminary studies of interplanetary missions, it is generally assumed that launch from Earth orbit occurs with an instantaneous burn at perigee of an escape hyperbola with the departure trajectory lying in the parking orbit plane. Figure 2 shows this situation and defines the declination (δ) and right ascension (α) of the hyperbolic excess velocity vector (V_∞). For a more detailed analysis of the above-mentioned windows, see references 2 and 3.

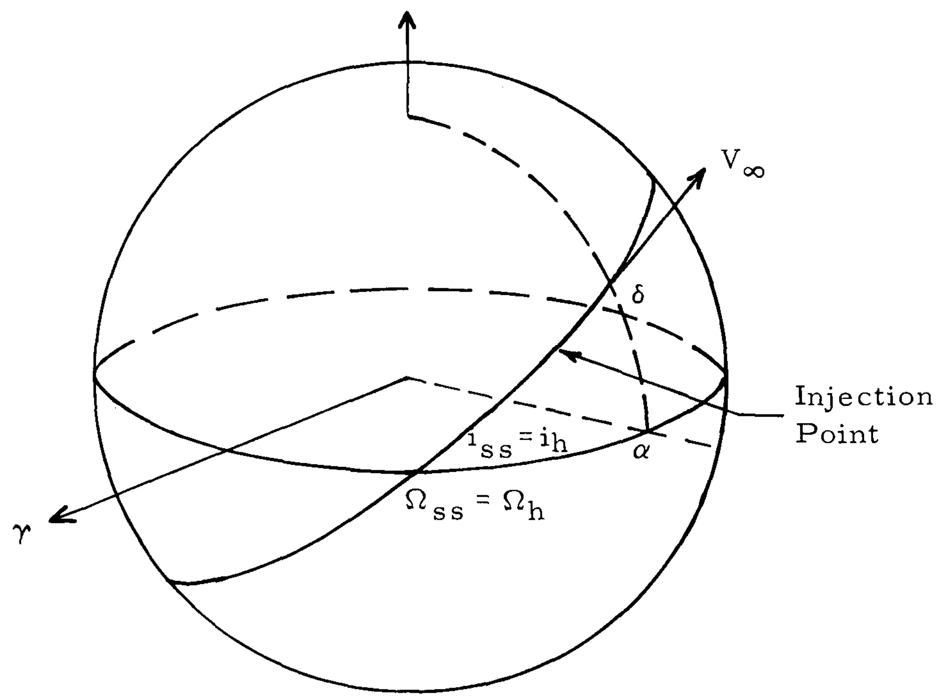


FIGURE 2. - GEOMETRY OF COPLANAR INJECTION

For a coplanar launch, the right ascension of the ascending node of the parking orbit (Ω_{ss}) and escape hyperbola (Ω_h) must be equal. Also, the inclination of the parking orbit (i_{ss}) must equal the inclination of the escape hyperbola (i_h), and the declination of the V_∞ vector must be less than or equal to the inclination of the parking orbit to launch without a plane change. The plane of the parking orbit, however, moves with a nodal regression rate of about 7 degrees per day while the orientation of an escape hyperbola changes rather slowly with time. Thus, the escape hyperbola and parking orbit are coplanar (the condition for minimum injection velocity, ΔV) for only a short period of time. After this time, the parking orbit rotates out of plane (due to the Earth's oblateness) and the injection ΔV increases. Therefore, the orbital launch window may be defined as that range of permissible departure dates from the Earth parking orbit, within the Earth departure window, in which a vehicle has the capability to make the proper plane changes out of Earth orbit and to achieve the required injection velocity into the escape hyperbola.

SECTION IV. METHOD OF ANALYSIS

Interplanetary trajectory data (heliocentric portion) were obtained from references 4 and 5 for Mars missions in the 1975 - 1986 time period, and Venus missions in the 1975 - 1990 time period. Trajectories to Mars in the 1988 - 1990 time period were calculated on a high-speed digital computer using a medium-accuracy interplanetary trajectory program developed for MSFC as a part of contract NAS 8-2469. Both long- and short-duration missions were considered.

Figure 3 shows a typical example of the method employed in this study to determine the orbital mechanics feasibility of a permanent OLF. Earth escape hyperbola orientations required to match the pre-computed heliocentric transfer trajectories of the Earth departure window were calculated as a function of injection time. This nodal orientation (Ω_h) as a function of time is shown in Figure 3-a as a dashed curve. Figure 3-a also shows that two solutions exist for the escape hyperbola orientation (Ω_{h_1}) and (Ω_{h_2}) except when the declination (δ) equals the parking orbit inclination (i_{ss}).

An OLF orientation (Ω_{ss}) is then assumed on some reference date. As time progresses, the orientation of the OLF changes at a constant rate (due to the Earth's oblateness) and the parking orbit becomes coplanar with the required escape hyperbola at point 1, as shown in Figure 3-a. At this time, minimum velocity injection conditions exist since a plane change is

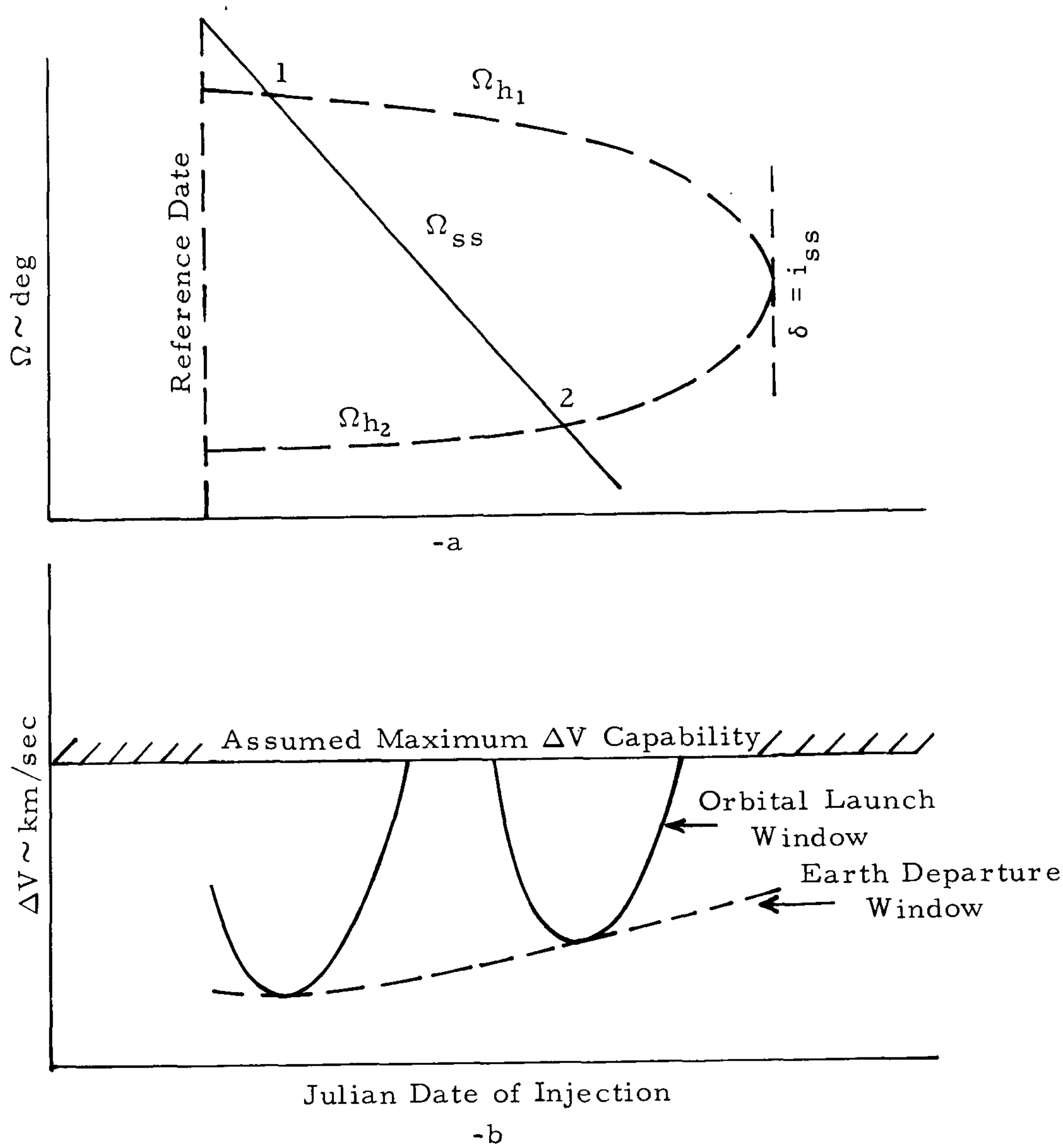


FIGURE 3. - LAUNCH WINDOW COMPATIBILITY AND ΔV REQUIREMENTS

not required at hyperbolic injection. After this time, the parking orbit rotates out of plane and the injection ΔV increases until the parking orbit again becomes coplanar with the second solution of the required escape hyperbola (point 2). Figure 3-b indicates how the velocity requirements vary as a function of injection time for the above-mentioned conditions. The dashed curve in Figure 3-b, which represents the Earth departure window referenced to Earth orbit, was derived under the assumption that the orbit of the OLF is always coplanar with the Earth escape hyperbola connecting to the required interplanetary trajectory. However, it can be seen from Figure 3-a that this coplanarity cannot be maintained for an extended time, and a plane change will be required to enter the required escape hyperbola. The other curves in Figure 3-b represent the orbital launch windows which indicate the ΔV required to compensate for the required plane changes and injection velocity out of Earth orbit.

In summary, the method employed to determine the orbital mechanics constraints on a permanent OLF consists of the following steps:

(1) The required escape hyperbola orientations to match the trans-planetary trajectories of the Earth departure window are calculated and plotted as in Figure 3-a.

(2) A series of OLF nodal orientations ranging from 0 to 360 degrees is assumed on some reference date before the Earth departure window opens (only one OLF orientation is shown in Figure 3-a).

(3) As time progresses, these orientations regress from the reference date into the Earth departure window and intersect the required escape hyperbola orientations.

(4) If all possible OLF orientations (0 to 360 degrees) intersect the escape hyperbola orientations within the Earth departure window, then a coplanar launch could be made regardless of the OLF's orientation on the reference date.

(5) The above procedure must be repeated for all Earth departure windows in the 1975 - 1990 time period to assure that all windows are compatible with the OLF.

SECTION V. DISCUSSION AND RESULTS

The selection of the 32-degree inclination limits the Earth departure declination to a maximum of 32 degrees if injection is to be accomplished without a plane change. Figures 5, 7, and 9 show the declination of the V_∞ vector for the Mars and Venus missions selected for this study. Where this declination exceeds the 32 degrees, the launch windows are terminated as shown in Figures 4 and 8.

The following approach was taken to determine the probability that a single OLF could service a series of Mars and Venus missions. A total of 26 Earth departure windows of approximately 40 days' duration each was selected for Mars and Venus missions in the 1975 - 1990 time period. Figure 4 shows the Earth departure windows (referenced to sphere of influence) for long-duration missions to Mars during this period. Figure 6 shows the short-duration missions to Mars. In the case of Venus missions, there exist 10 conjunctions in the 1975 - 1990 time period from which Earth departure windows can be obtained. Figure 8 shows only 5 of the 10 Earth departure windows. However, the 1975 conjunction is an almost exact repetition of the 1983 conjunction, and can be used as a very close approximation merely by adding 2920 days to the 1975 reference date. The same procedure is applicable for the other conjunctions. The outbound trajectory leg trip times to Venus were not changed for the long- and short-duration missions. Only the stay time at Venus and the inbound leg trip time were changed, which results in long- and short-duration missions as referred to herein.

Orientations of the Earth escape hyperbolas required to match the transplanetary trajectories of the Earth departure windows were then calculated. These orientations (Ω_{h_1} and Ω_{h_2}) are shown in Figure 10 for a short-duration Mars mission in 1975. It was then assumed that an OLF had been placed in orbit previous to 1975, was checked out to launch a vehicle to Mars, and was holding on 244-2490 J.D. The next problem was to determine if the orbit launch vehicle, regardless of the orbit orientation, can hit the launch window which opens on 244-2520 J.D. and closes on 244-2560 J.D. A series of nodal orientations (referenced to 244-2490 J.D.) ranging from 0 to 360 degrees in 30-degree increments was assumed for the OLF orbit. As time progresses, these OLF orbit orientations (Ω_{ss}) regress from the reference point into the Earth departure window. The intersection of the Ω_{ss} trace and the required escape hyperbola orientation (Ω_h) determines the exact escape hyperbola and OLF orbit for coplanar injection conditions. It can be seen from Figure 10 that regardless of the OLF orientation on 244-2490 J.D. a coplanar launch can be made within the 40-day Earth departure window. To more thoroughly explain Figure 10, assume an OLF orbit orientation of Ω_{ss} = 240 degrees on 244-2490 J.D. The first coplanar launch opportunity will occur on 244-2524 J.D. which is the intersection of the 240-degree Ω_{ss} line and the Ω_{h_1} curve. A second coplanar launch opportunity occurs approximately 21 days later on 244-2545.2 J.D. when the OLF has the same orientation as the second solution of the required escape hyperbola. A plane change would be required to launch at any other time within the Earth departure window. Figure 10 also shows an Earth departure window of approximately 28 days would be sufficient to cover all possible OLF orbit orientations of the 1975 opposition.

It is apparent from the above analyses that if all possible OLF orbit orientations are compatible with all the 1975 - 1990 Earth departure windows then, from the standpoint of orbital mechanics, a permanent Orbital Launch Facility could be used for successive launches to Mars and Venus during the 1975 - 1990 time period.

Figures 11 and 12, and Figures 14 through 31 show the launch window compatibility for successive missions to Mars and Venus. The reference point for the OLF orientation is the first date on each figure. These figures are similar to Figure 10, and most provide 100 percent coverage of the OLF orientations. Another example of launch window compatibility is Figure 18 which shows a long-duration Mars mission in 1980. It can be seen from this figure that the two solutions for the required escape hyperbola orientation converge to one solution. This is due to the inclination of the parking orbit being equal to the declination of the V_∞ vector at this point. It can be seen that this window does not provide full coverage (143-210 degrees not covered) of the OLF orientation due to this constraint.

Table 2 presents a summary of the Mars and Venus missions indicating which windows receive full coverage of the OLF orientations. It can be seen from this table that 12 of the 16 Mars windows and 6 or the 10 Venus windows receive full coverage. The 1978, 1980, 1986, and 1988 Venus windows would provide full orientation coverage if the Earth departure windows were extended to 40 days (see Figure 8). This could be accomplished in some cases by having a greater inclination of the OLF orbit.

Since 100 percent orientation coverage did not exist in all cases, it was decided to establish a reference OLF orbit in 1975 and project this orbit through all Earth departure windows to determine the extent of coverage. A 1975 Mars flyby mission was selected as the reference mission. This mission selection was based on an MSFC in-house Venus/Mars flyby study. The optimum Earth departure date for this mission occurs on 244-2680 J.D. with Mars flyby on 244-2810 J.D. Arrival back at Earth occurs on 244-3350 J.D. (reference 6). A minor problem existed in the selection of this mission in that the declination of the V_∞ vector on 244-2680 J.D. was slightly greater than the inclination of the OLF orbit. However, since the declination was only a few degrees larger than the inclination, the plane change was very small (requiring only 40 meters/second more than a coplanar launch). Figure 13 shows the required OLF orientation such that the injection velocity on 244-2680 J.D. will be a minimum. Also shown is the ΔV required for injection before and after the nominal launch date.

The same OLF orbit resulting from the above analyses was then projected through all Earth departure windows calculated for the Mars and Venus missions. The dashed lines in Figures 10 through 31, running parallel to the Ω_{ss} lines, depict the various nodal orientations of this OLF orbit as a function of time.

It should be emphasized that the OLF orbit was chosen for the 1975 Mars flyby mission only. The dashed lines in Figures 10 through 31 represent the nodal regression of this orbit, and indicate the compatibility of the orbit with the other launch windows shown in the figures mentioned. The compatibility of this orbit with each of the Mars and Venus missions for the 1975 - 1990 period is shown in Table 3. A total of 27 missions to Mars and Venus is covered during this time period. The representative orbit indicated by the dashed line is completely compatible with 25 of the missions. The other two cases, the Mars flyby mission (Figure 13) and a 1982 Mars mission (Figure 22), are those where the OLF orbit inclination is slightly less than the minimum inclination of the escape trajectory (declination of V_{∞}). These two can be considered to be compatible since, as mentioned above, an energy of only about 40 meters/second greater than a coplanar launch is necessary to account for this slight difference in inclination.

This indicates that orbit launch window constraints do not significantly affect the feasibility of using a single, permanent Orbital Launch Facility for any desired mission to Mars and Venus.

Additional information on the orbital launch windows resulting from the above analysis is presented in the Appendix.

FIGURE 4. EARTH HYPERBOLIC DEPARTURE SPEED FOR LONG DURATION MARS MISSIONS (OPPOSITION YEARS 1975-1990)

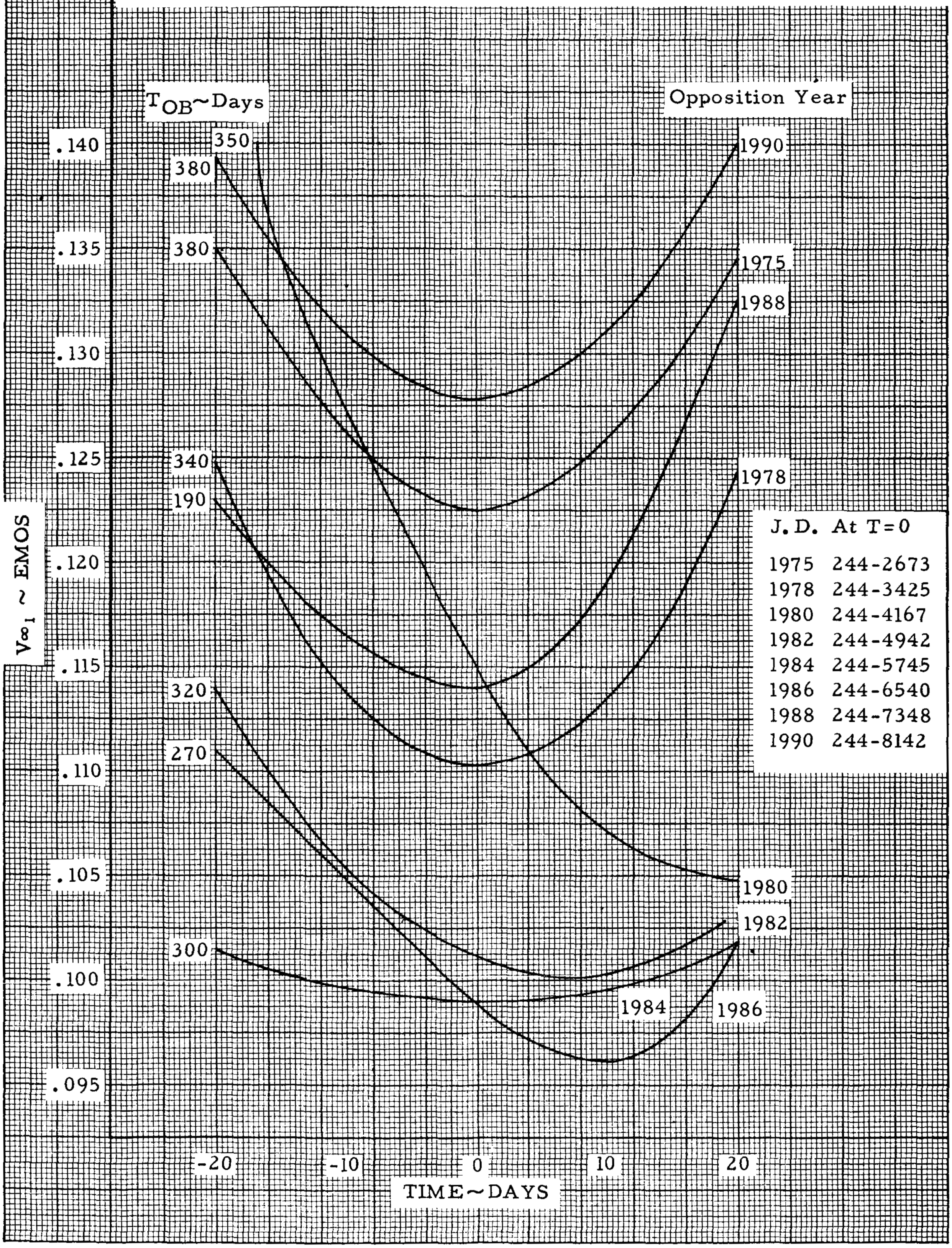


FIGURE 5. EARTH DEPARTURE DECLINATION FOR LONG DURATION MARS MISSIONS (OPPOSITION YEARS 1975-1990)

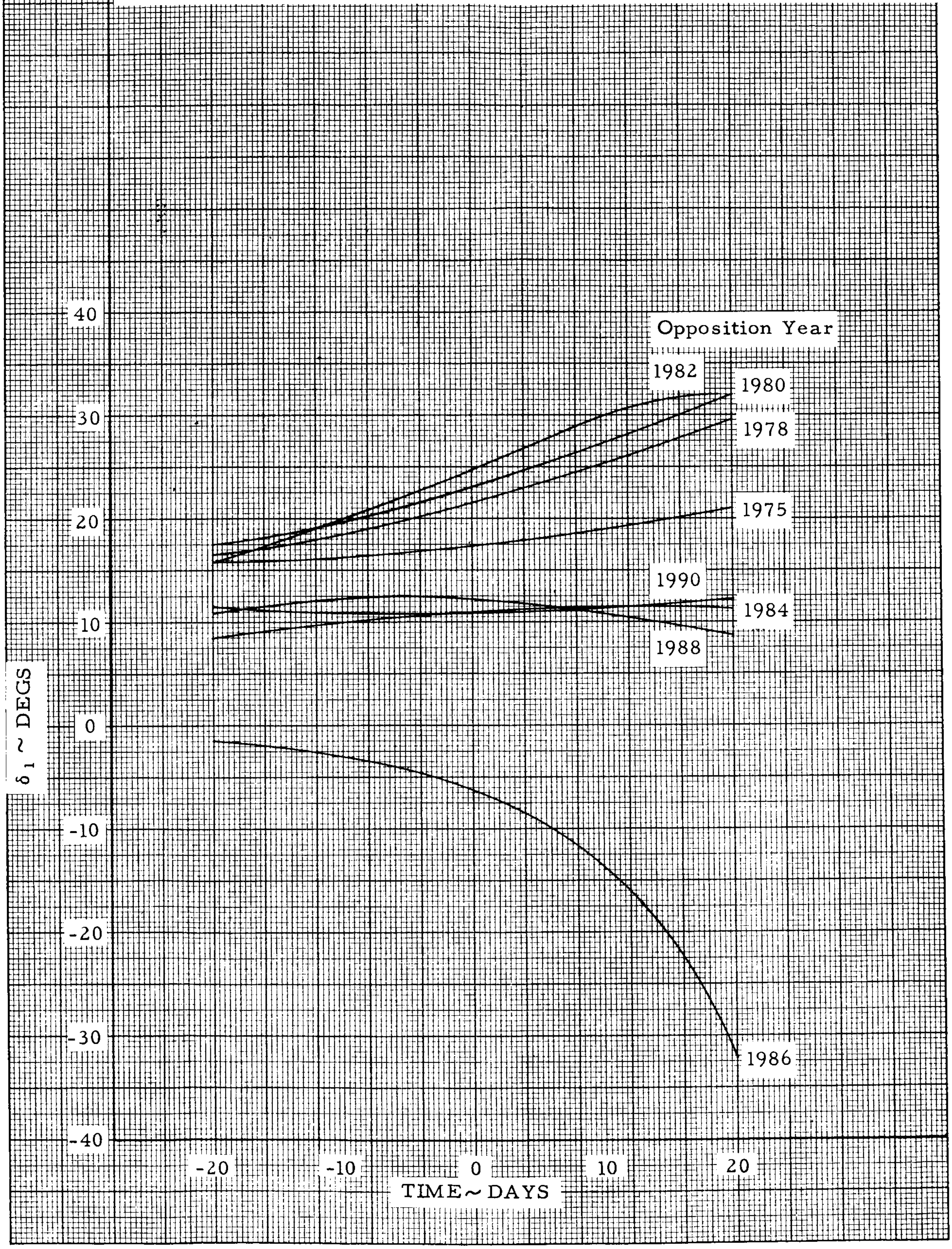


FIGURE 6. EARTH HYPERBOLIC DEPARTURE SPEED FOR SHORT DURATION MARS MISSIONS (OPPOSITION YEARS 1975-1990)

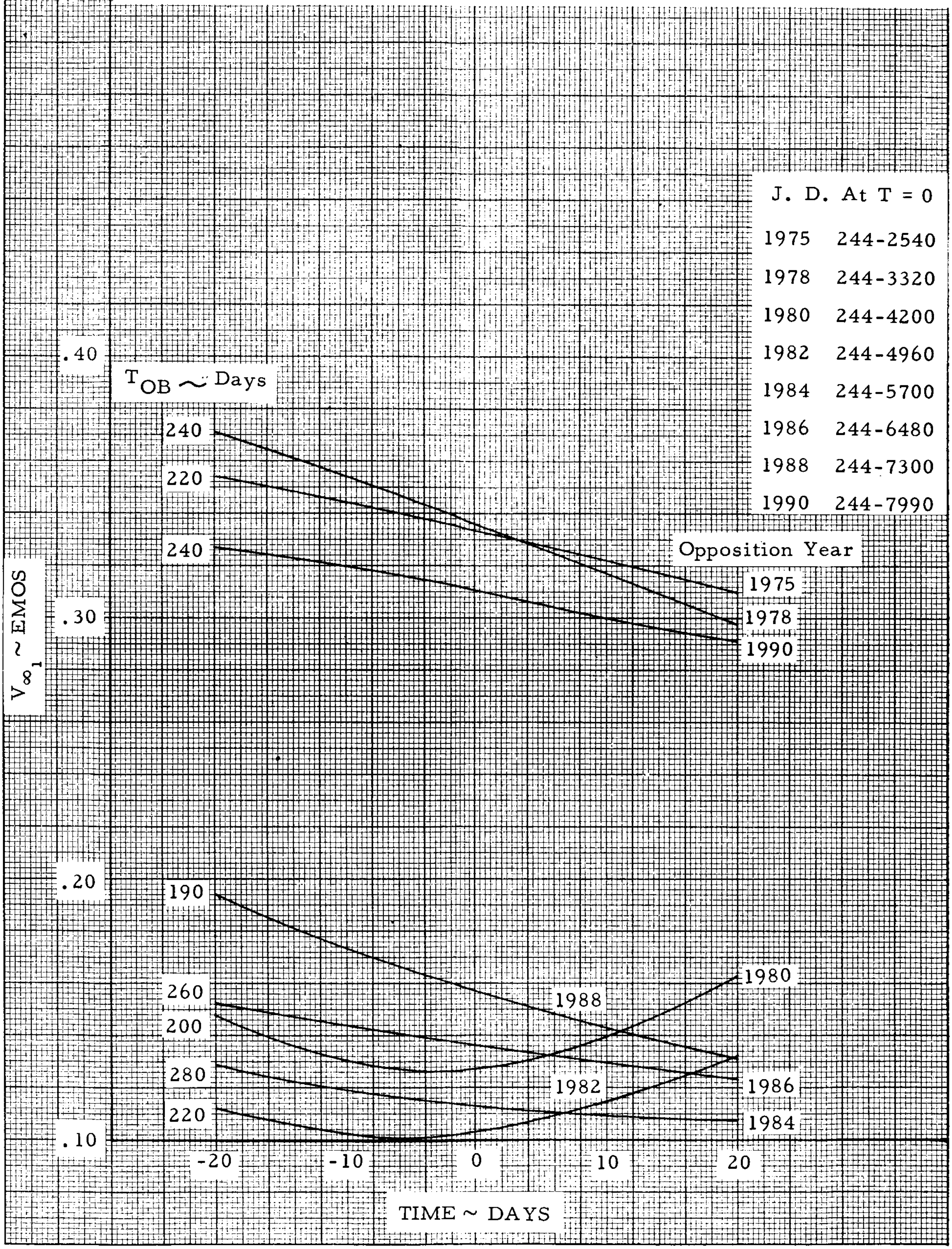


FIGURE 7. EARTH DEPARTURE DECLINATION FOR SHORT DURATION MARS MISSIONS (OPPOSITION YEARS 1975- 1990)

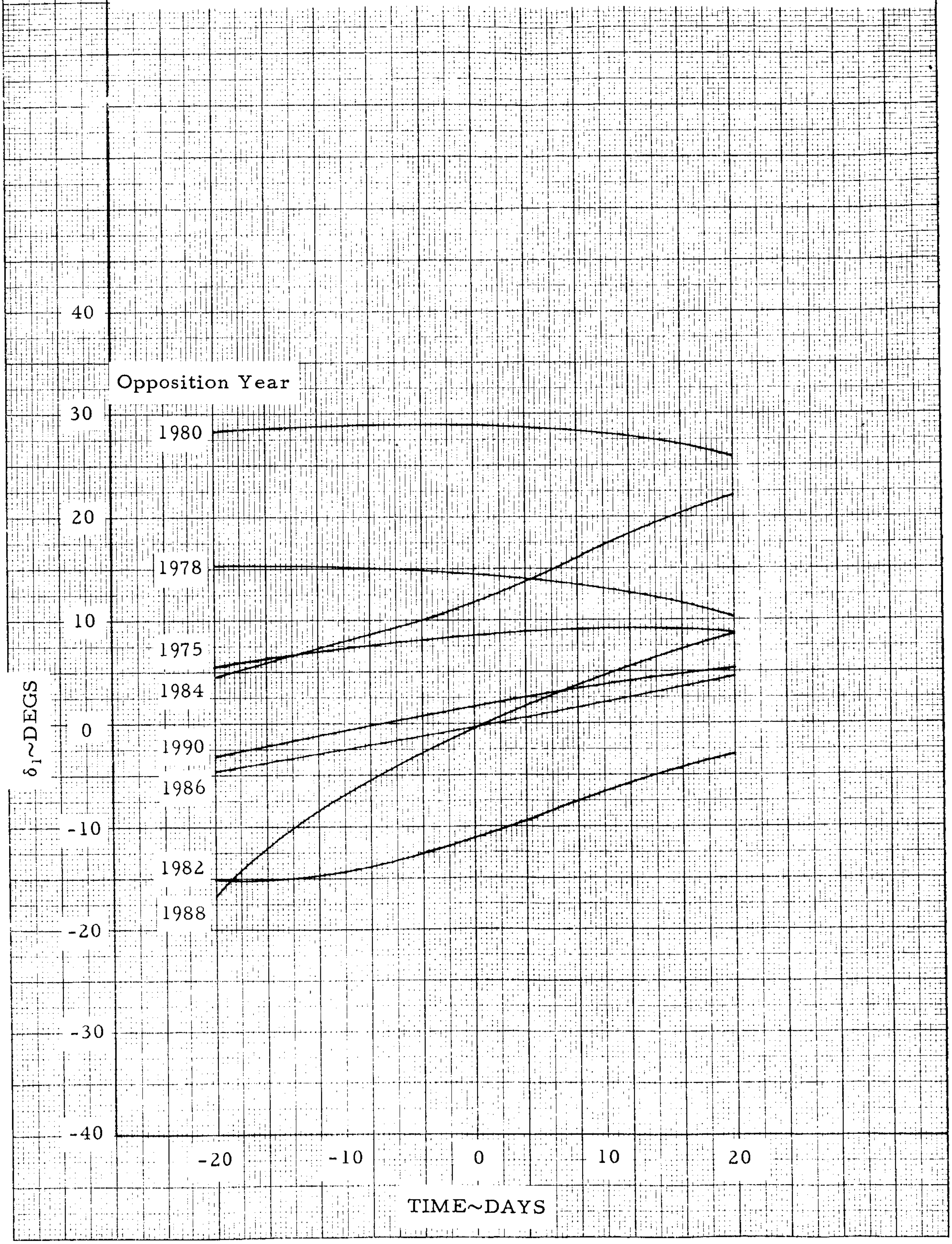


FIGURE 8. EARTH HYPERBOLIC DEPARTURE SPEED FOR VENUS MISSIONS (CONJUNCTION YEARS 1975-1990)

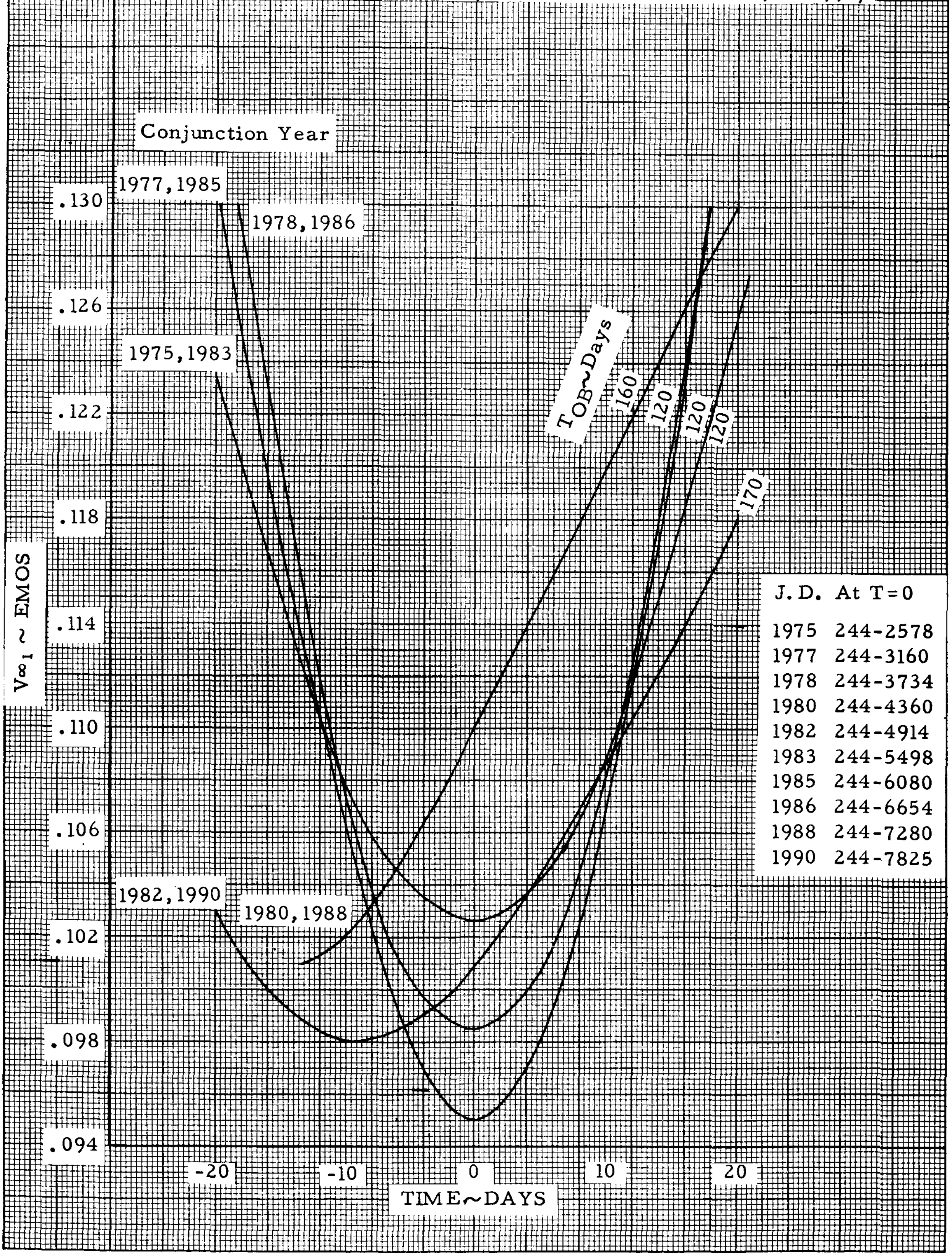


FIGURE 9. EARTH DEPARTURE DECLINATION FOR VENUS MISSIONS (CONJUNCTION YEARS 1975-1990)

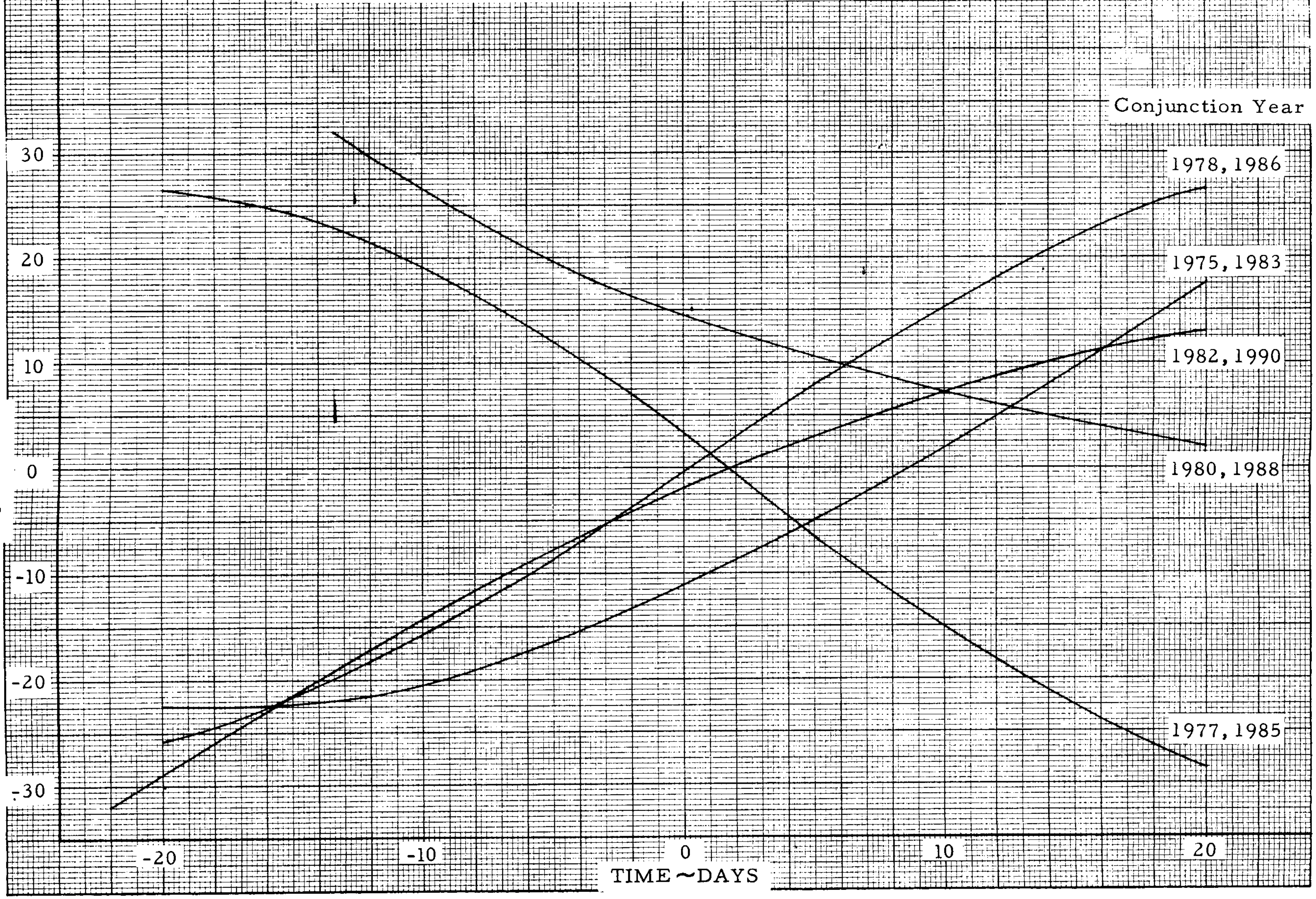


FIGURE 10. LAUNCH WINDOW COMPATIBILITY FOR A SHORT DURATION MARS MISSION (OPPOSITION YEAR 1975)

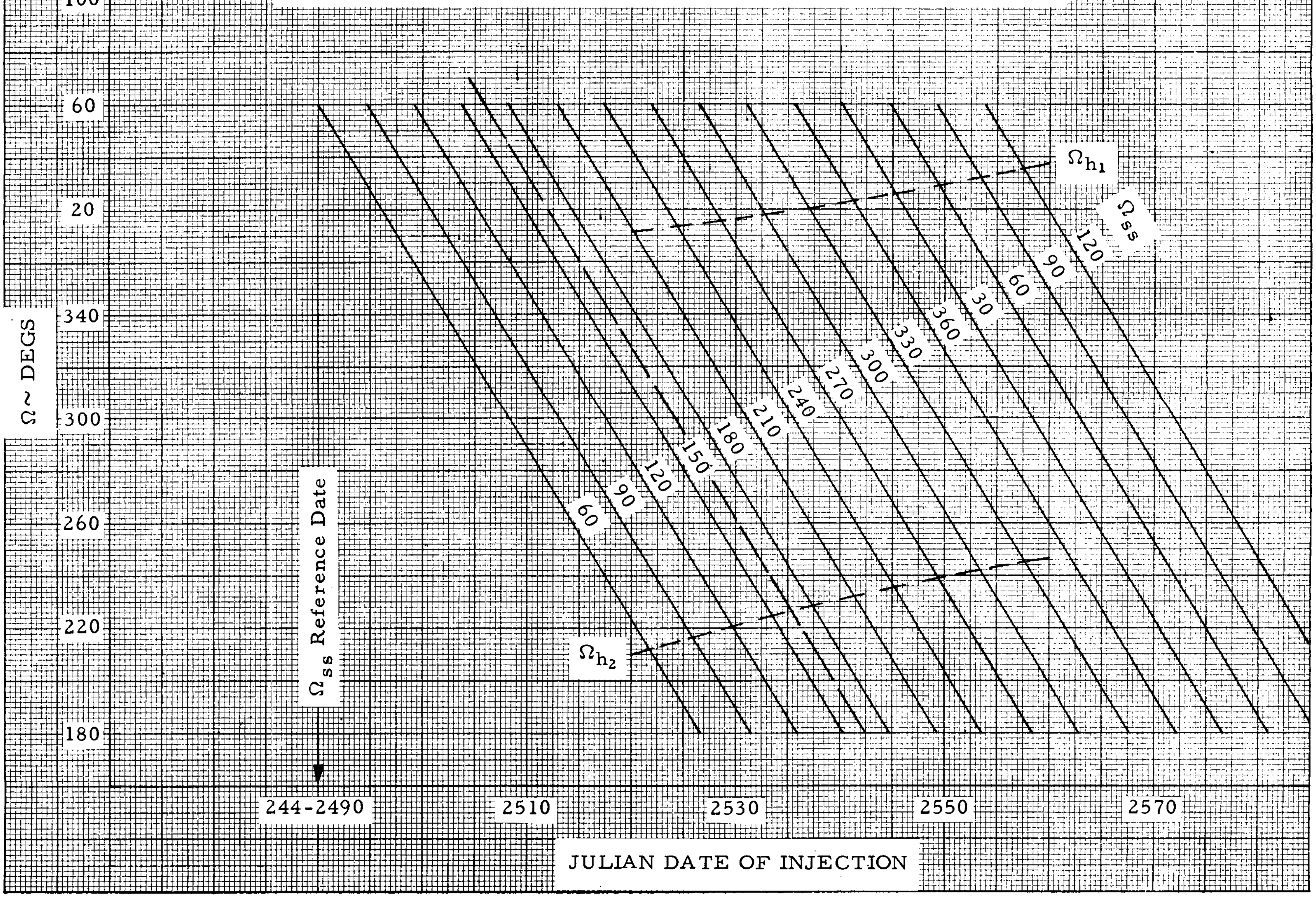


FIGURE 11. LAUNCH WINDOW COMPATIBILITY FOR A VENUS MISSION (CONJUNCTION YEARS 1975-1983)

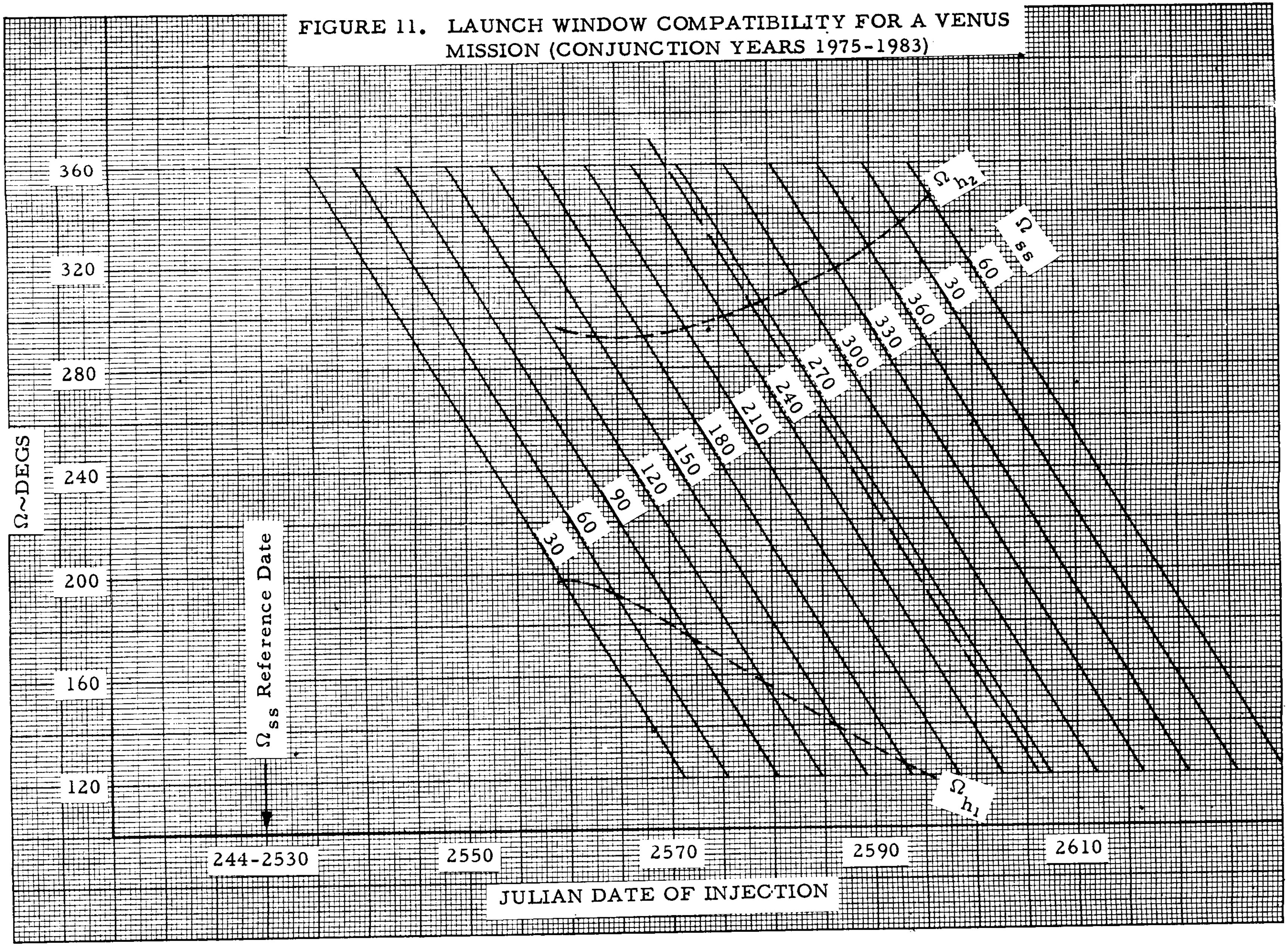


FIGURE 12. LAUNCH WINDOW COMPATIBILITY FOR A LONG DURATION MARS MISSION (OPPOSITION YEAR 1975)

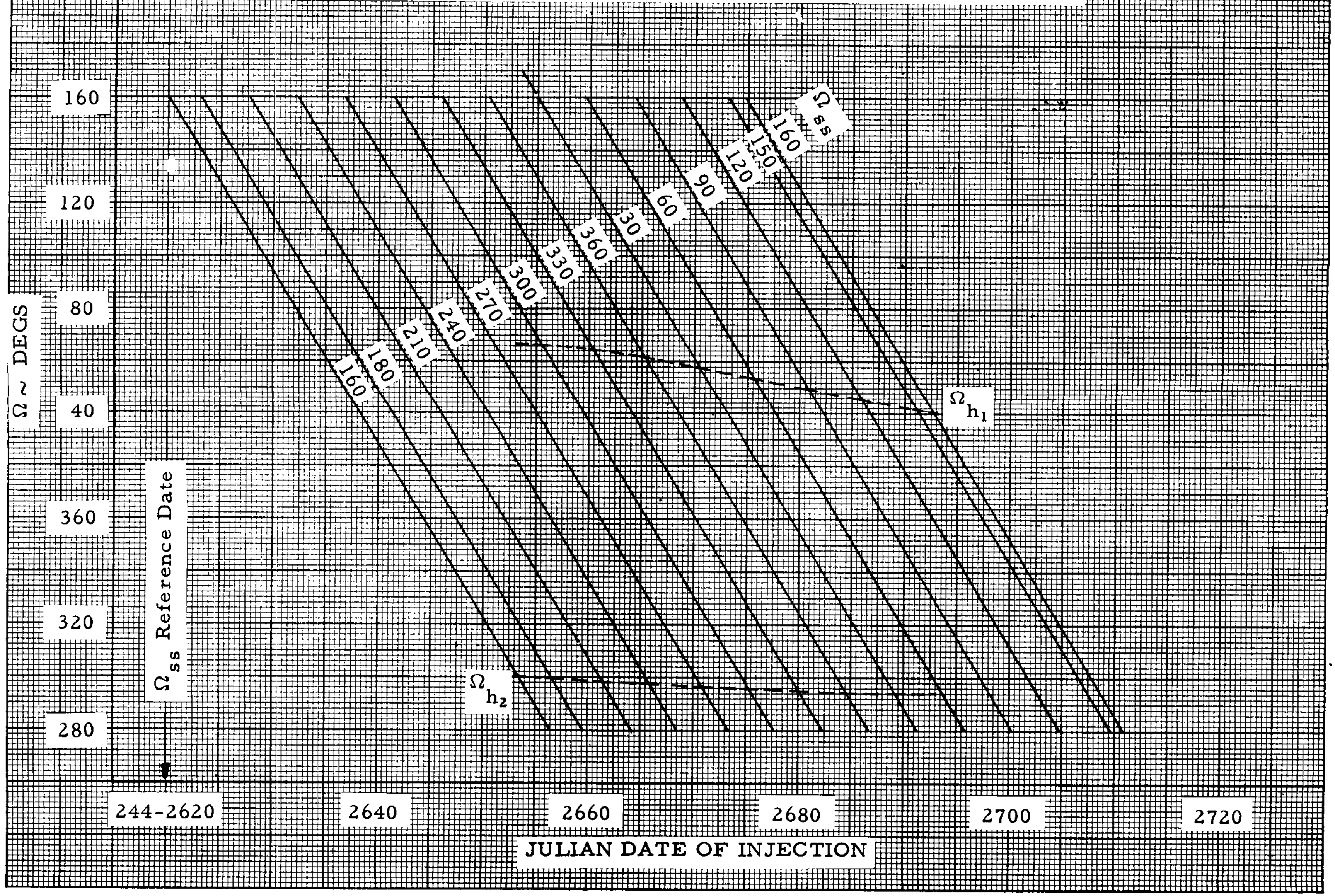


FIGURE 13. EARTH ORBITAL LAUNCH WINDOW AND PARKING ORBIT ORIENTATION FOR A MARS FLYBY MISSION (OPPOSITION YEAR 1975)

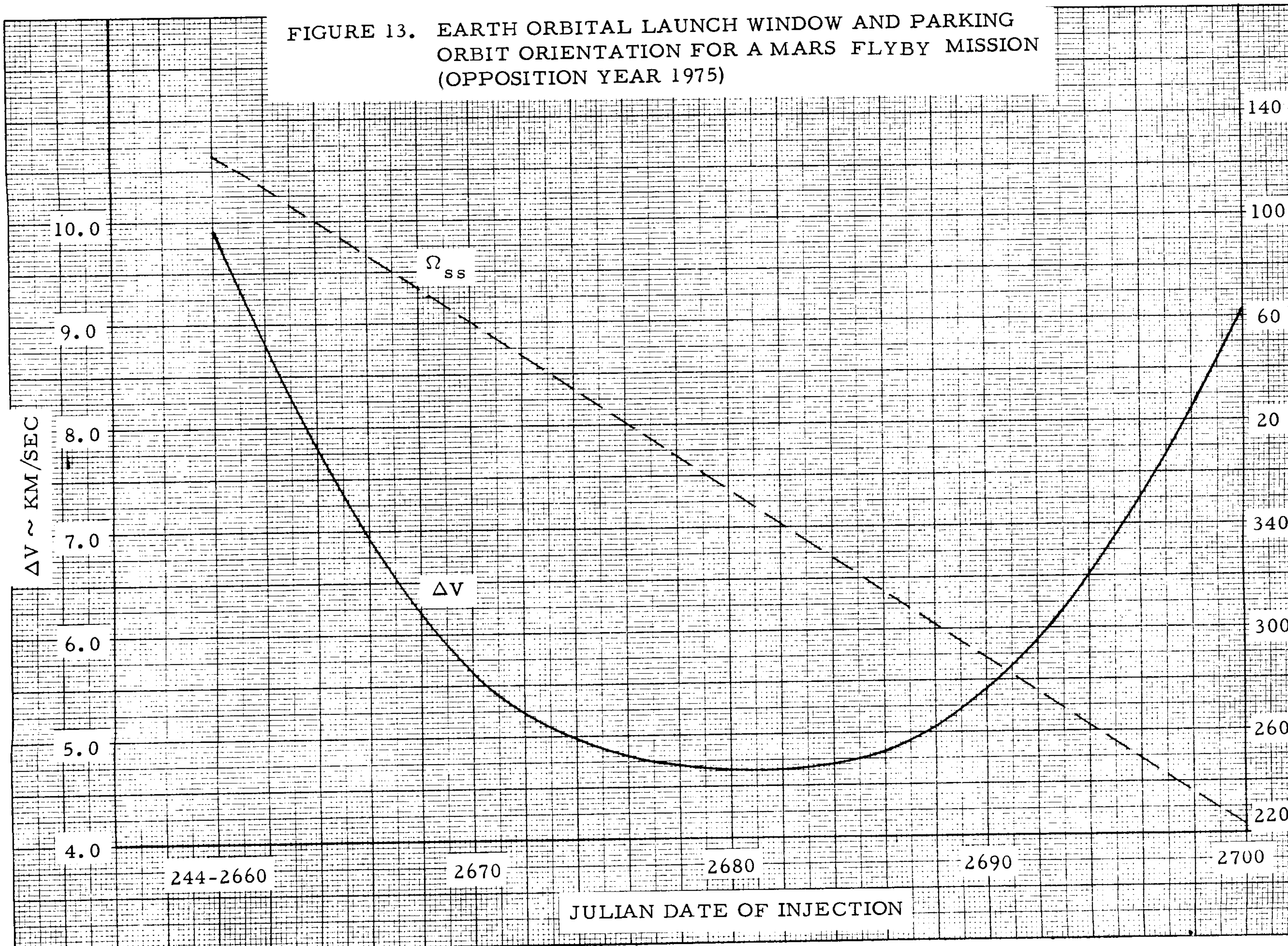


FIGURE 14. LAUNCH WINDOW COMPATIBILITY FOR A VENUS MISSION (CONJUNCTION YEARS 1977 & 1985)

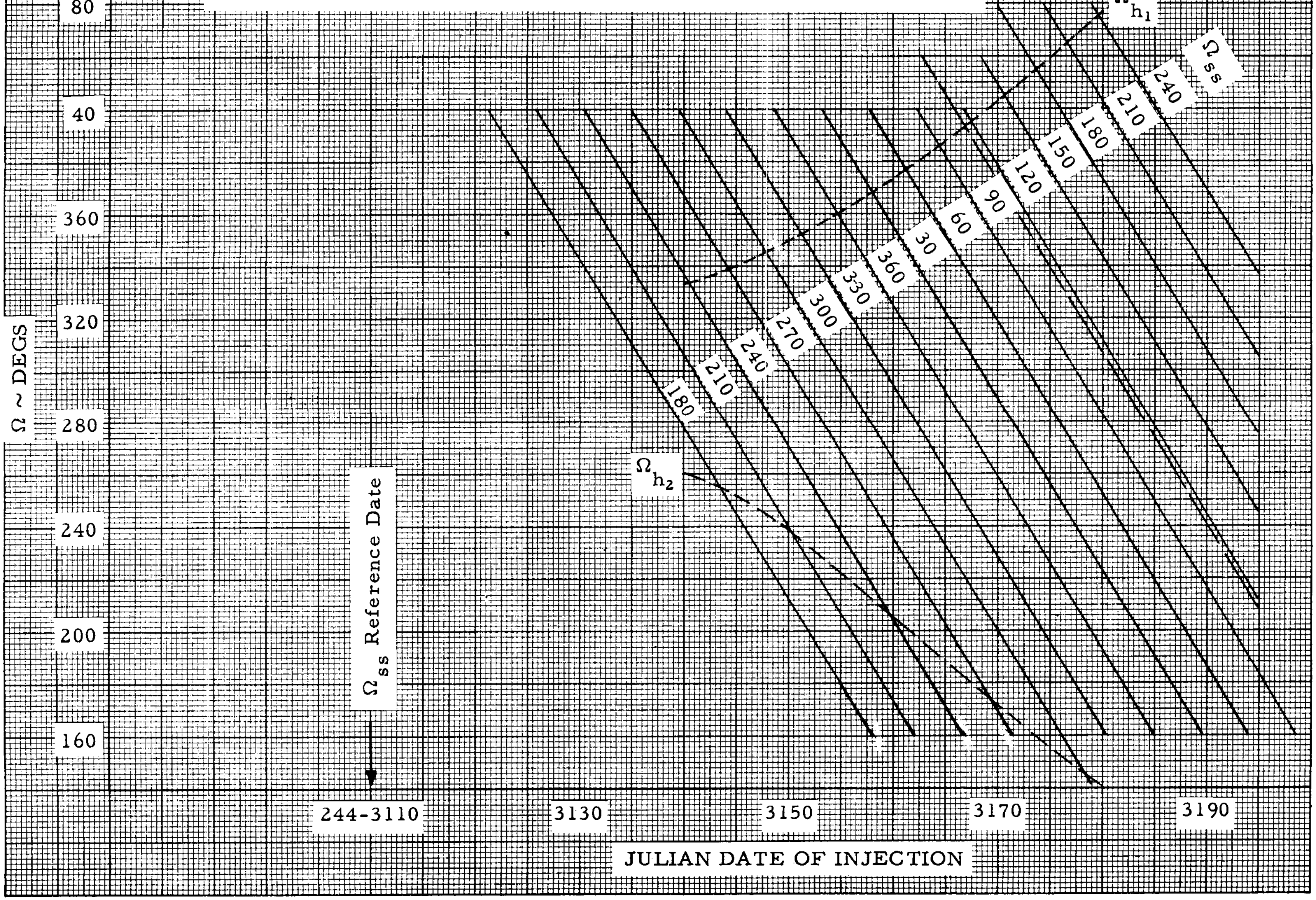


FIGURE 15. LAUNCH WINDOW COMPATIBILITY FOR A SHORT DURATION MARS MISSION (OPPOSITION YEAR 1978)

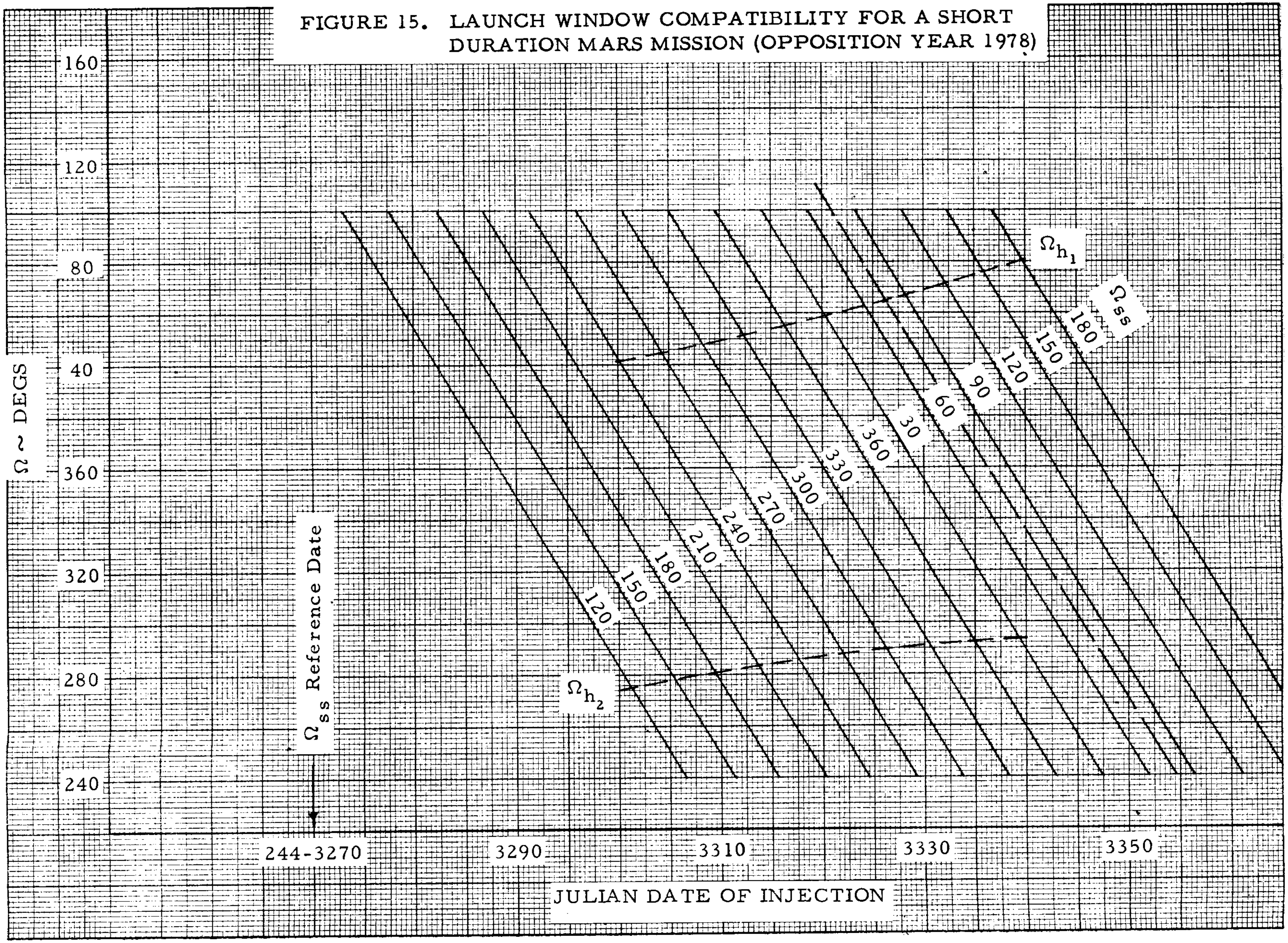


FIGURE 16. LAUNCH WINDOW COMPATIBILITY FOR A LONG DURATION MARS MISSION (OPPOSITION YEAR 1978)

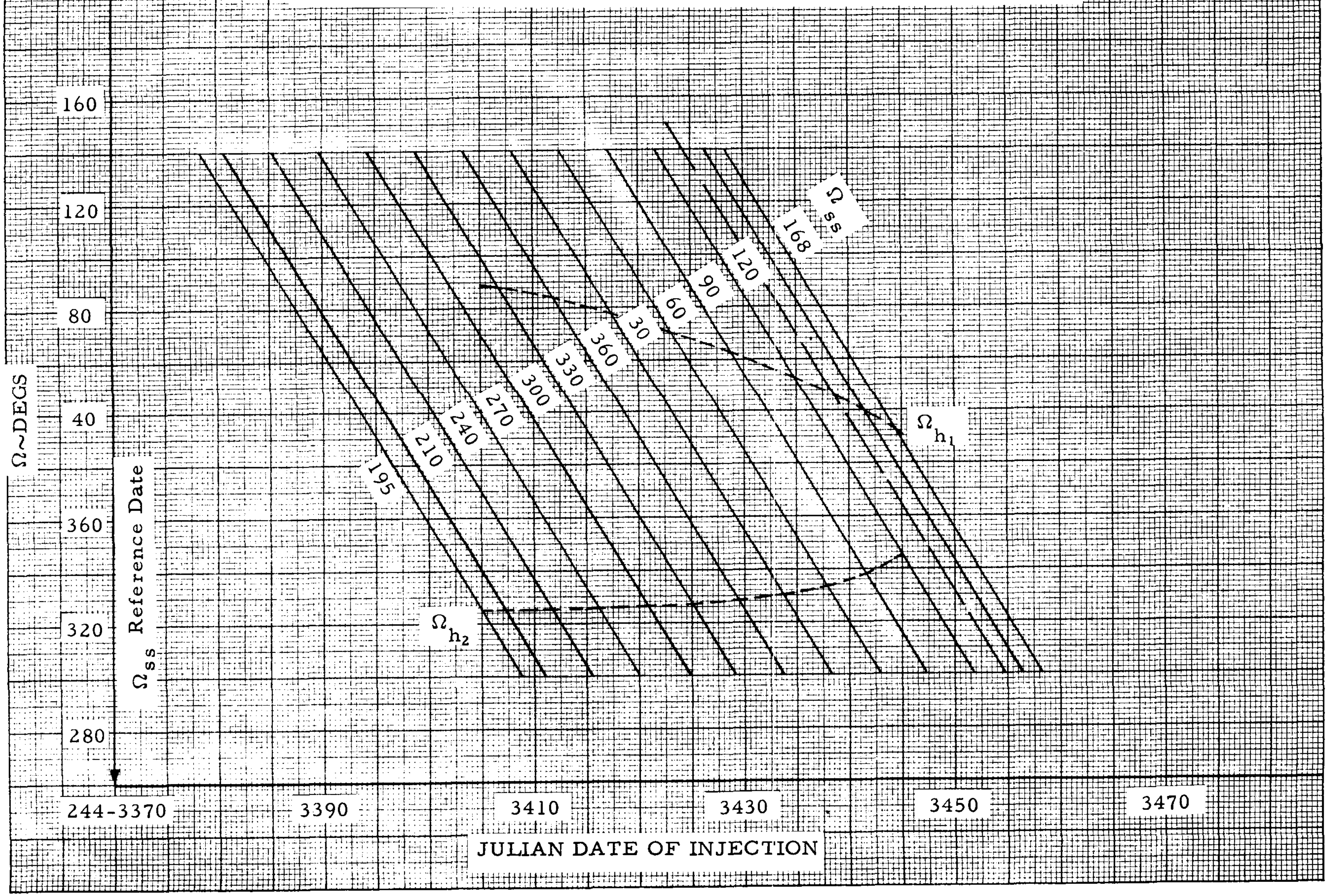


FIGURE 17. LAUNCH WINDOW COMPATIBILITY FOR A VENUS MISSION (CONJUNCTION YEARS 1978 & 1986)

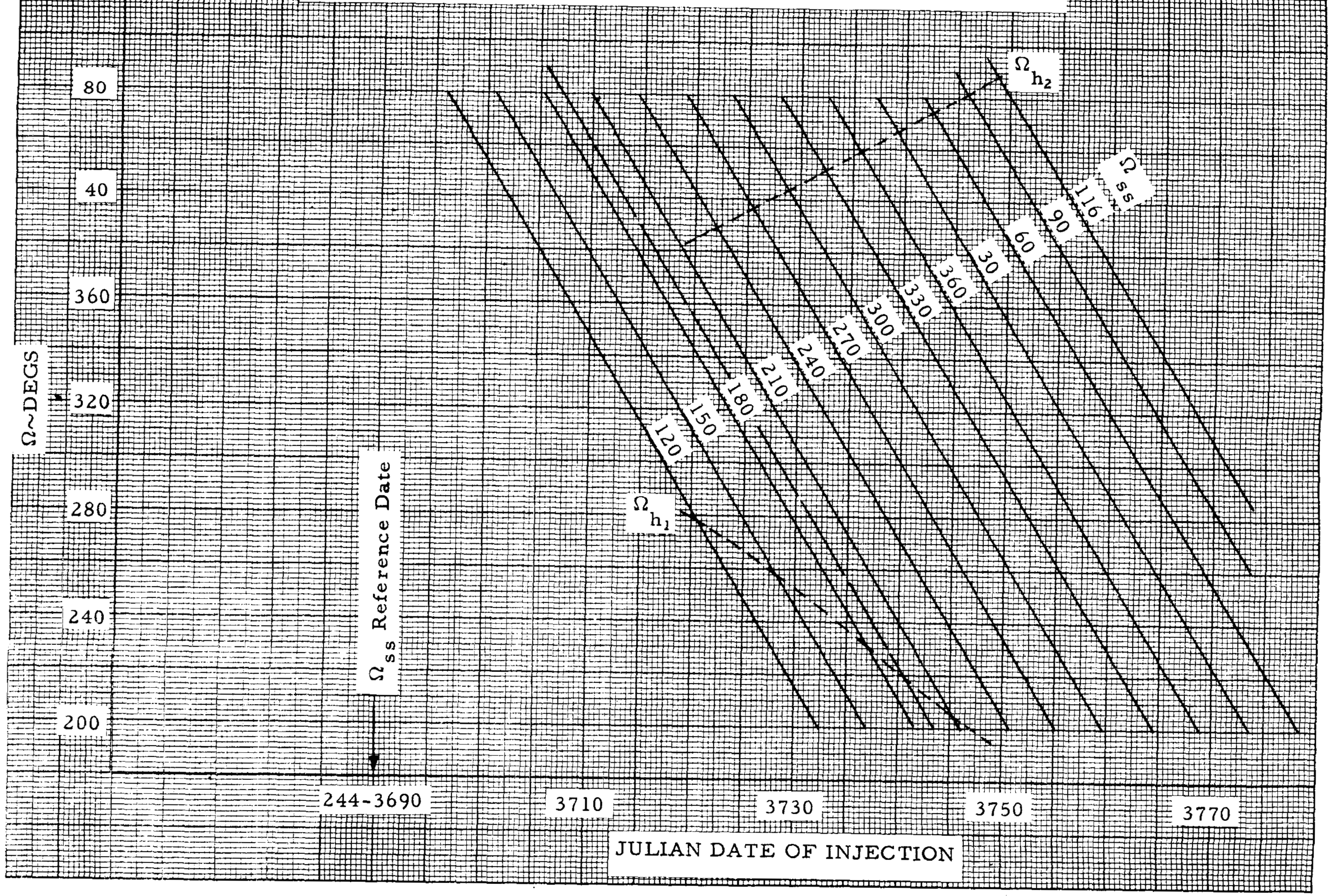


FIGURE 18. LAUNCH WINDOW COMPATIBILITY FOR A LONG DURATION MARS MISSION (OPPOSITION YEAR 1980)

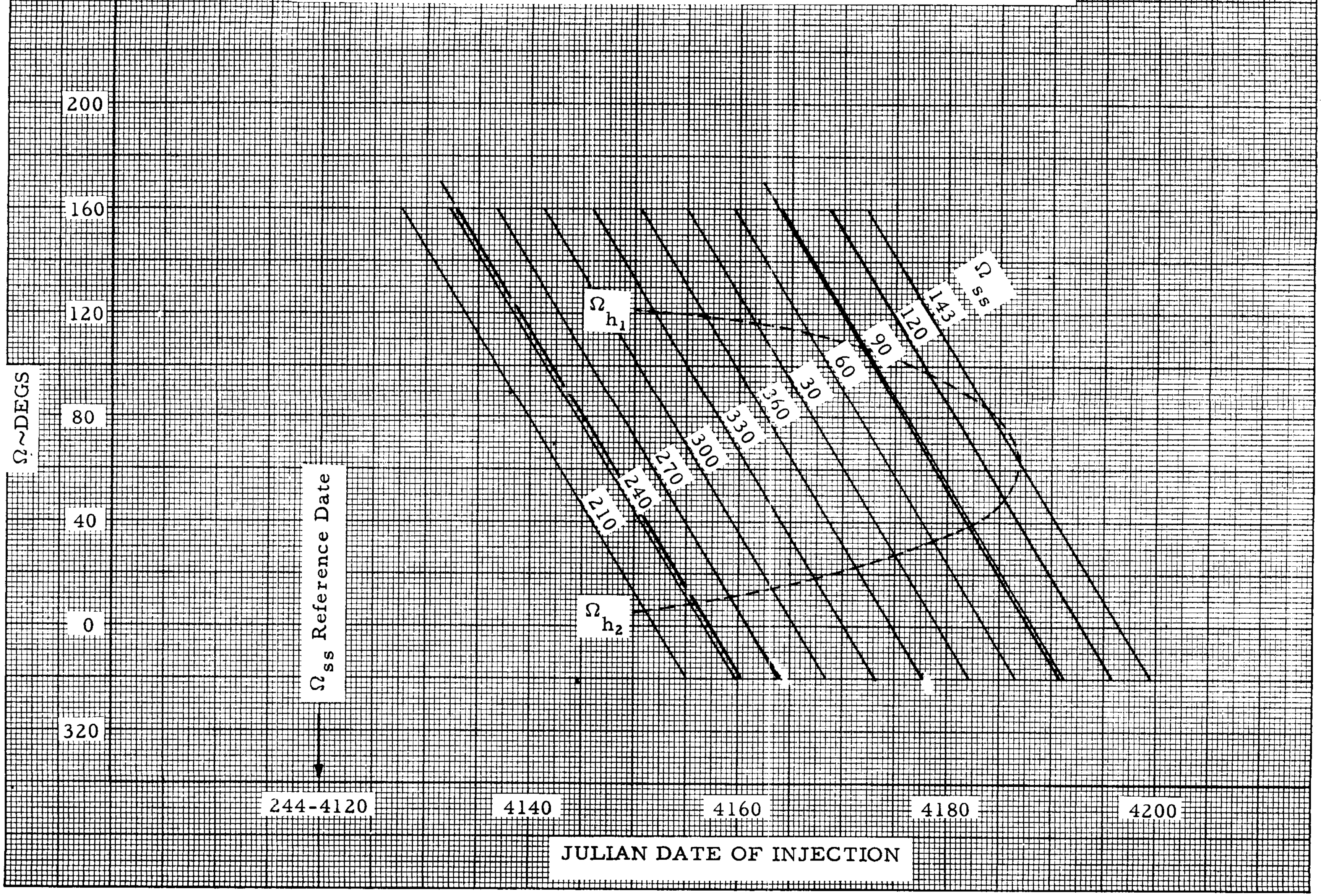


FIGURE 19. LAUNCH WINDOW COMPATIBILITY FOR A SHORT DURATION MARS MISSION (OPPOSITION YEAR 1980)

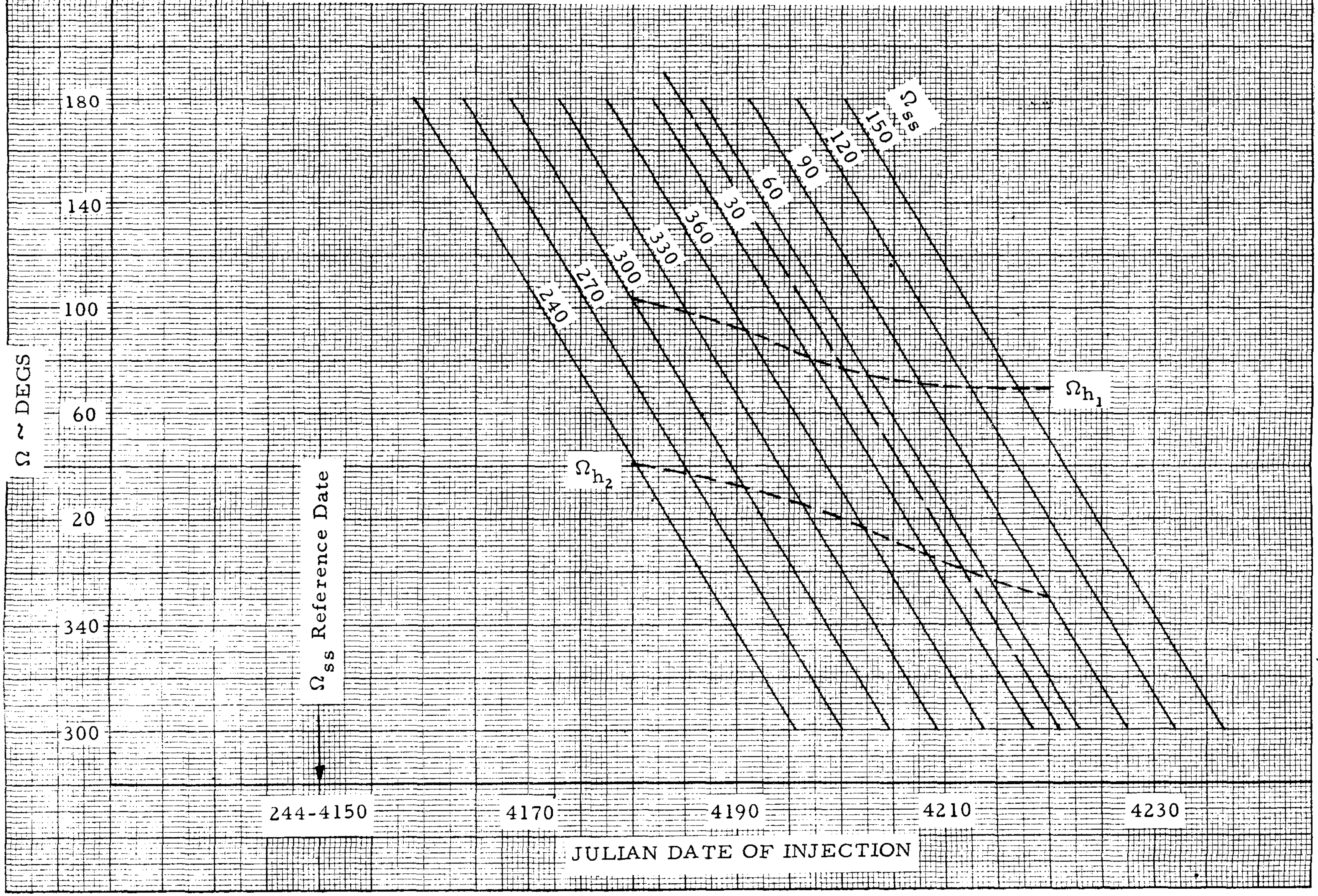


FIGURE 20. LAUNCH WINDOW COMPATIBILITY FOR A VENUS MISSION (CONJUNCTION YEARS 1980 & 1988)

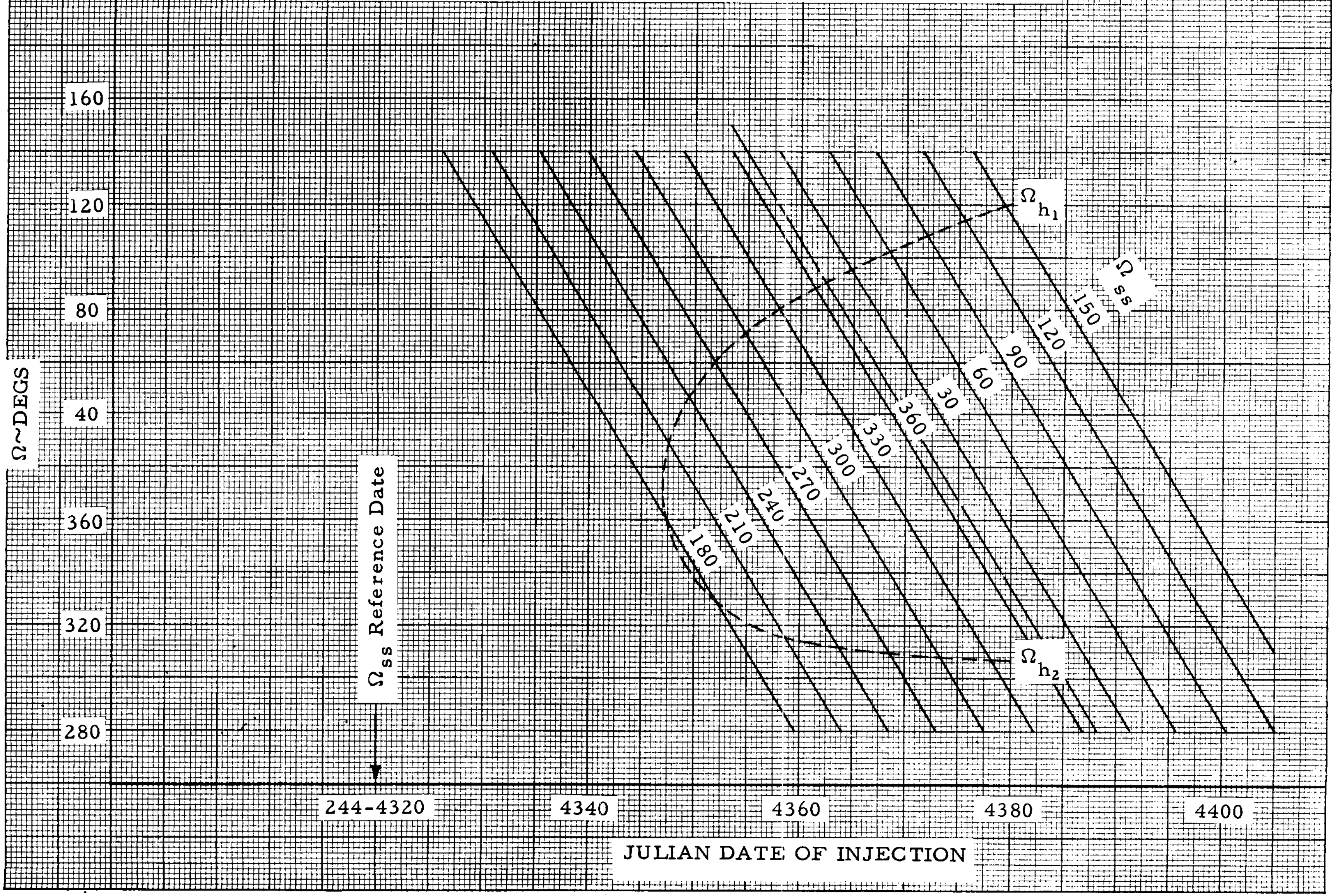


FIGURE 21. LAUNCH WINDOW COMPATIBILITY FOR A VENUS MISSION (CONJUNCTION YEARS 1982 & 1990)

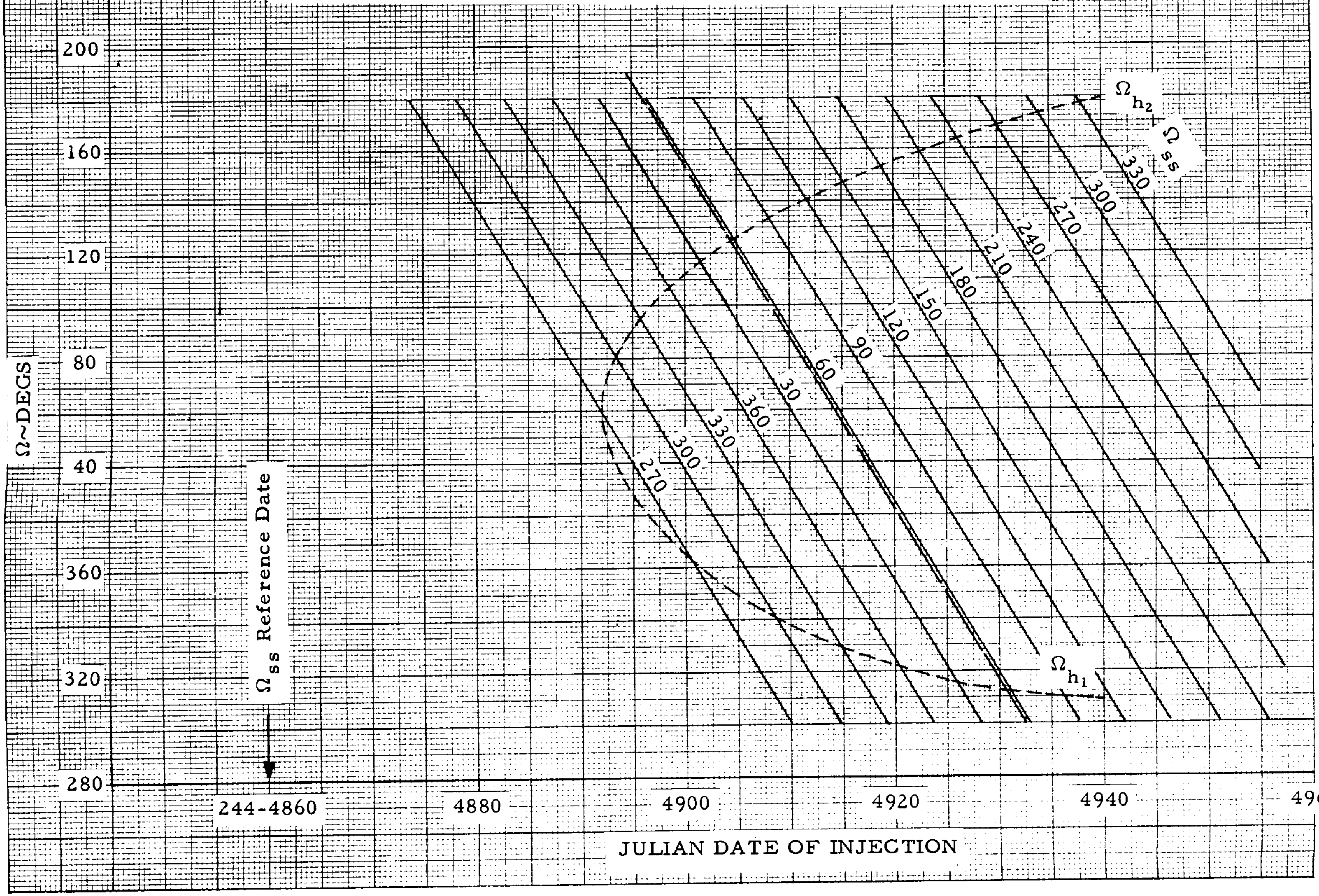


FIGURE 22. LAUNCH WINDOW COMPATIBILITY FOR A LONG DURATION MARS MISSION (OPPOSITION YEAR 1982)

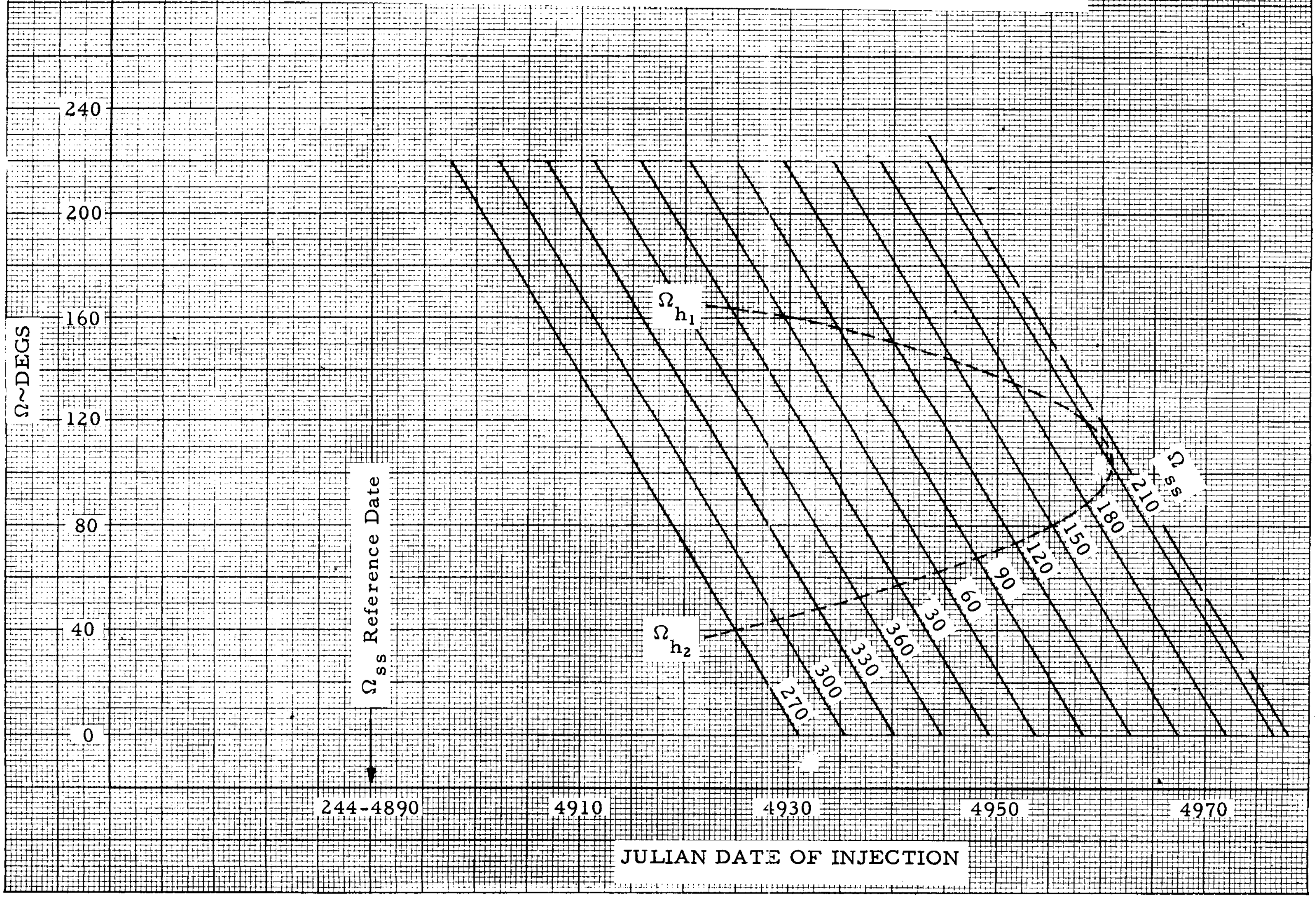


FIGURE 23. LAUNCH WINDOW COMPATIBILITY FOR A SHORT DURATION MARS MISSION (OPPOSITION YEAR 1982)

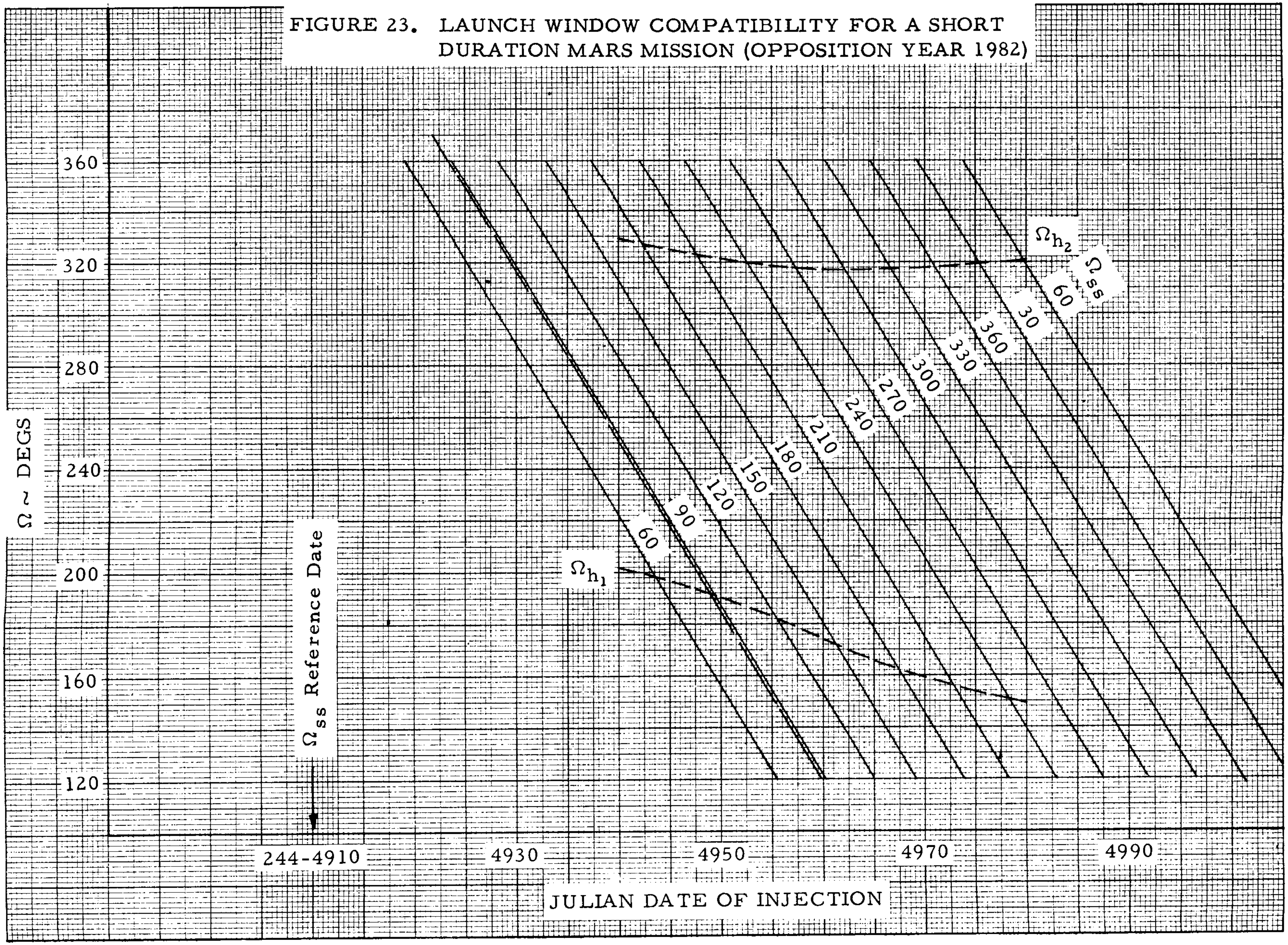
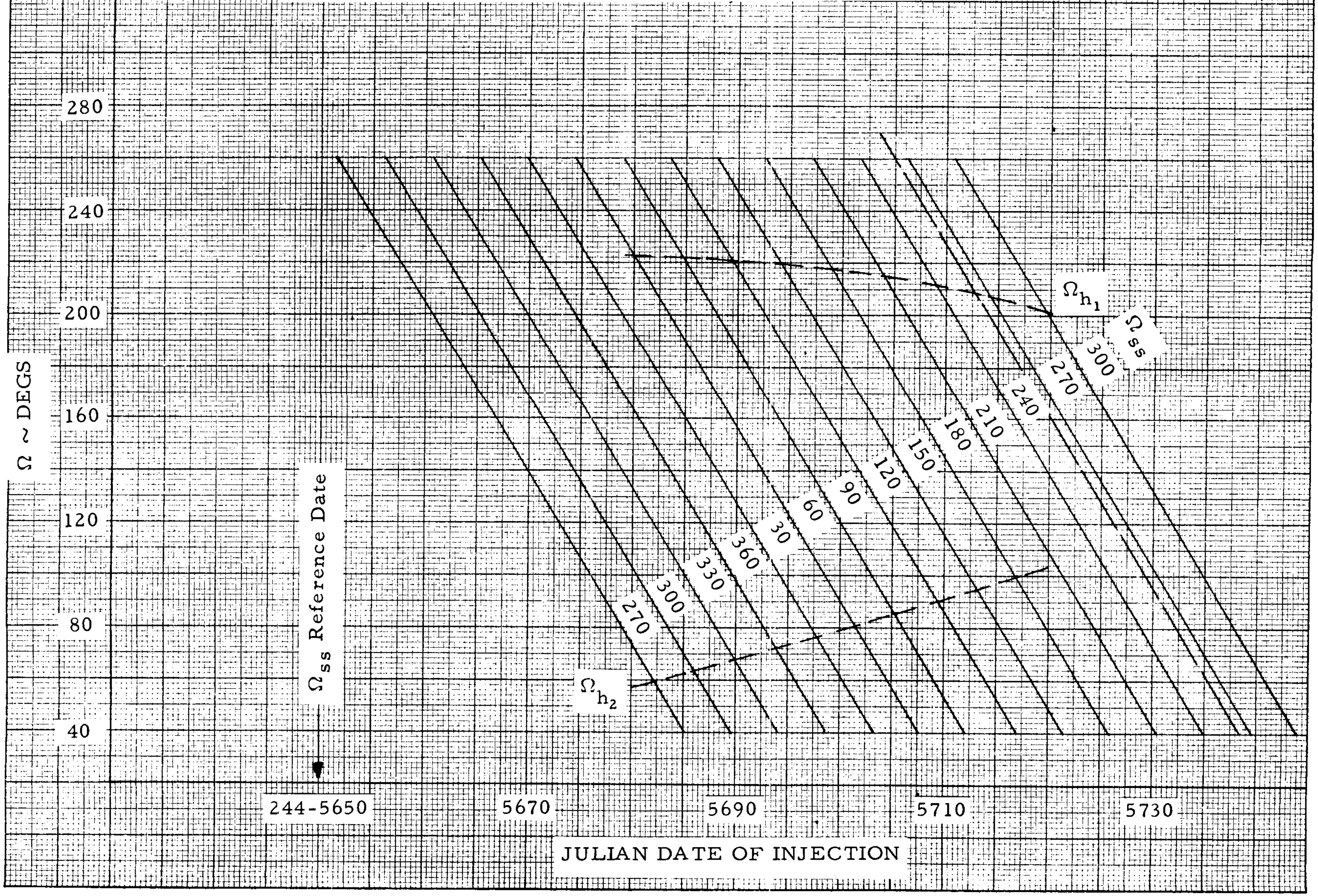


FIGURE 24. LAUNCH WINDOW COMPATIBILITY FOR A SHORT DURATION MARS MISSION (OPPOSITION YEAR 1984)



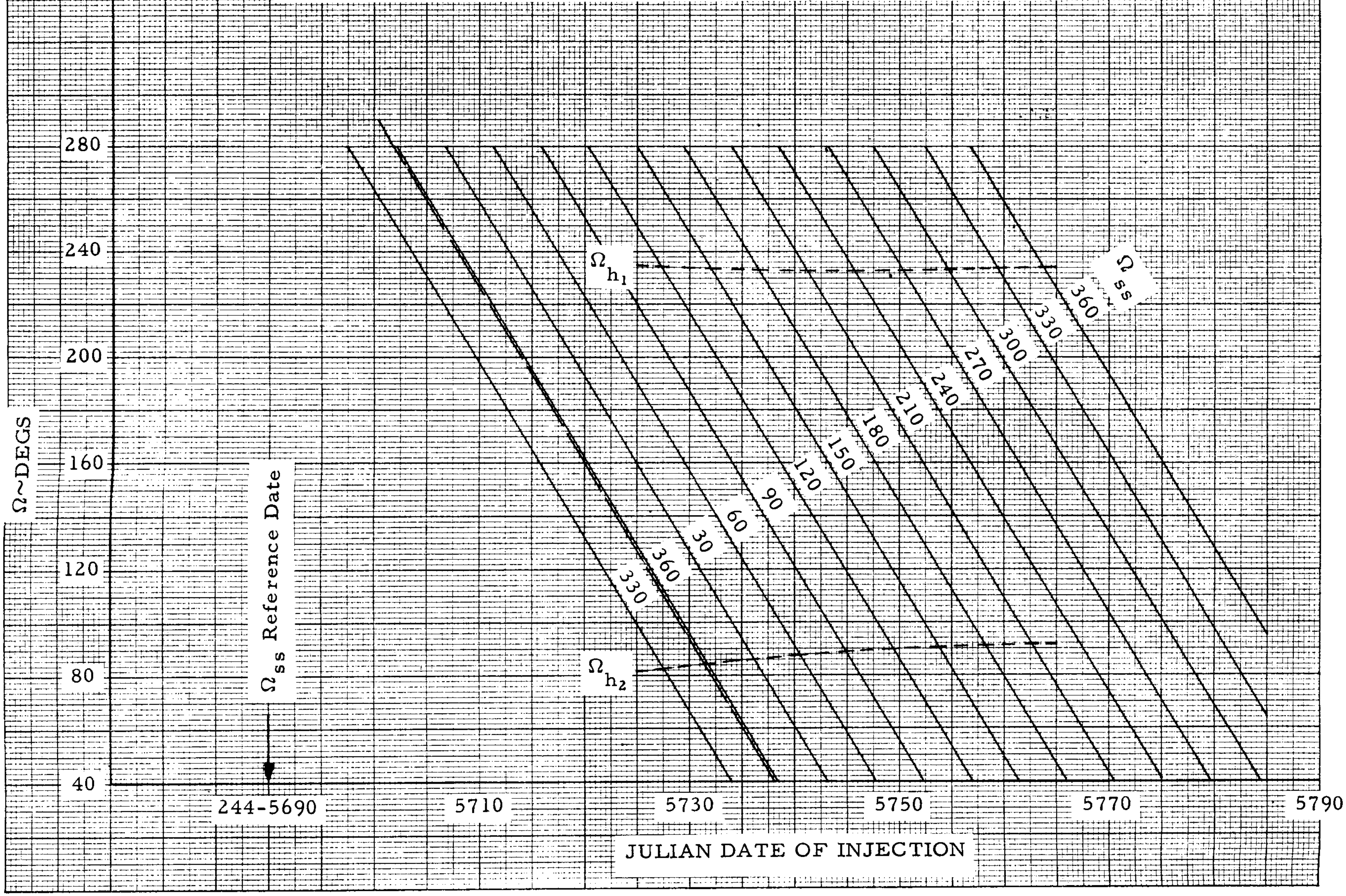


FIGURE 25. LAUNCH WINDOW COMPATIBILITY FOR A LONG DURATION MARS MISSION (OPPOSITION YEAR 1984)

FIGURE 26. LAUNCH WINDOW COMPATIBILITY FOR A SHORT DURATION MARS MISSION (OPPOSITION YEAR 1986)

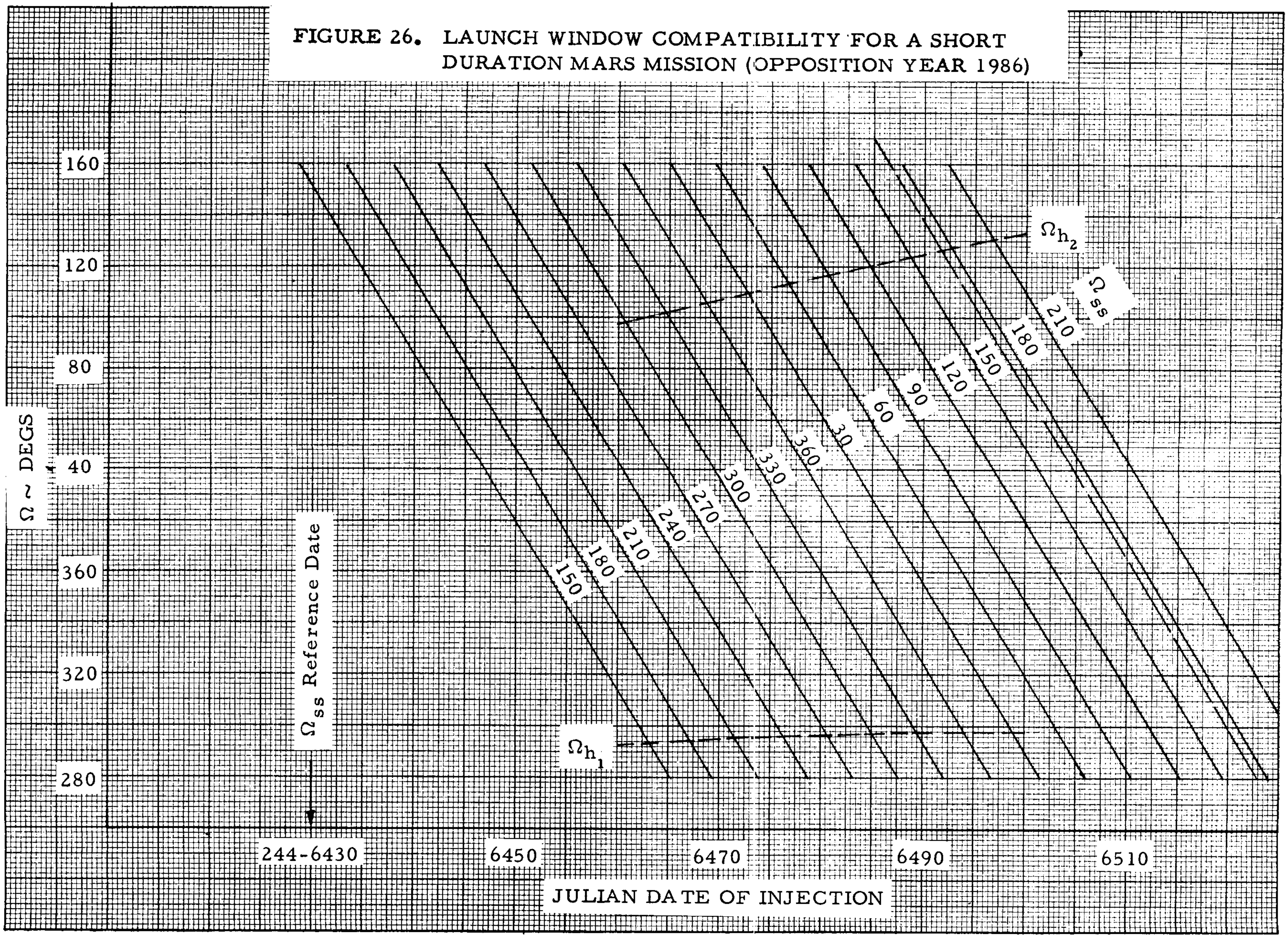


FIGURE 27. LAUNCH WINDOW COMPATIBILITY FOR A LONG DURATION MARS MISSION (OPPOSITION YEAR 1986)

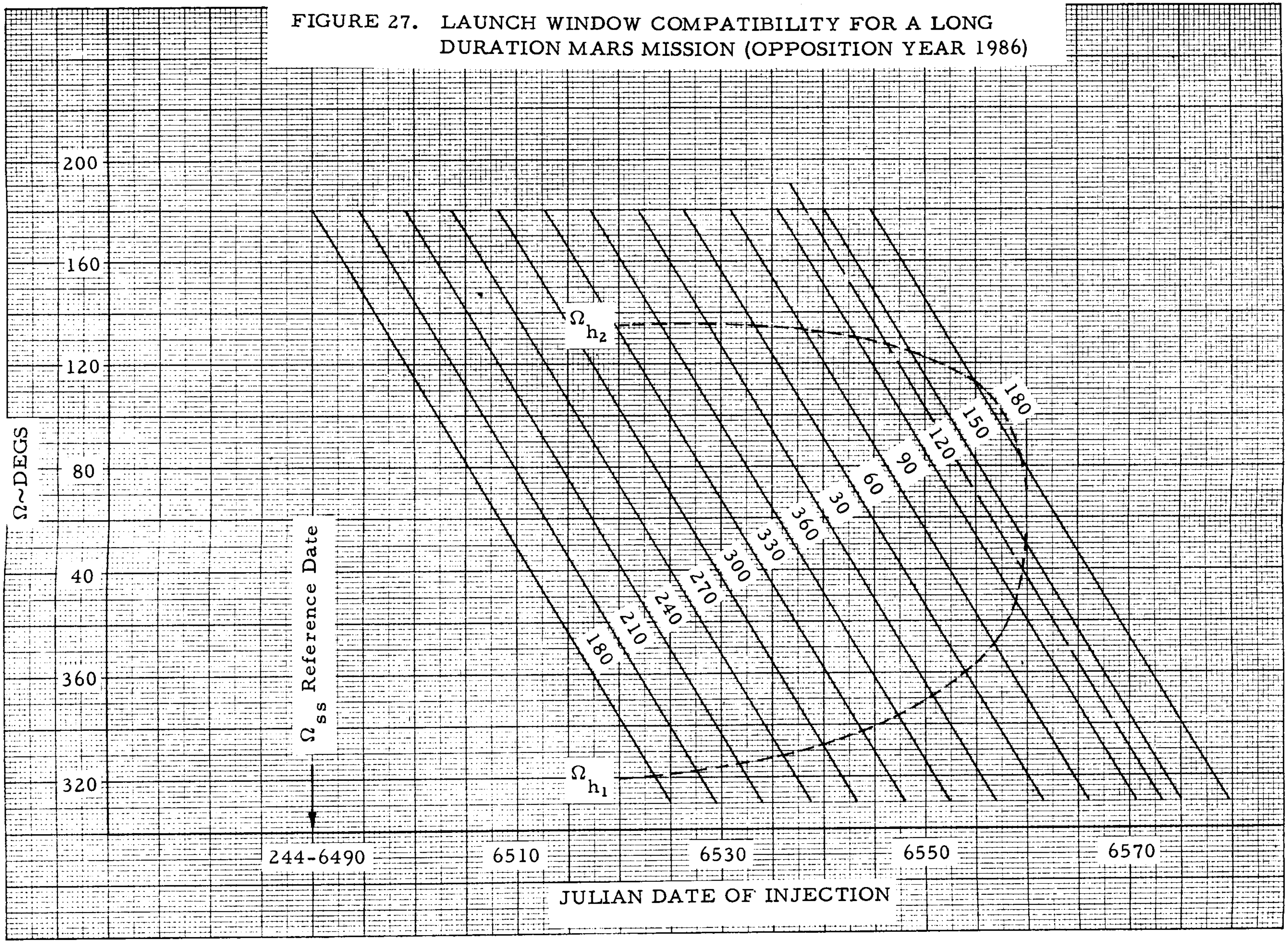


FIGURE 28. LAUNCH WINDOW COMPATIBILITY FOR A SHORT DURATION MARS MISSION (OPPOSITION YEAR 1988)

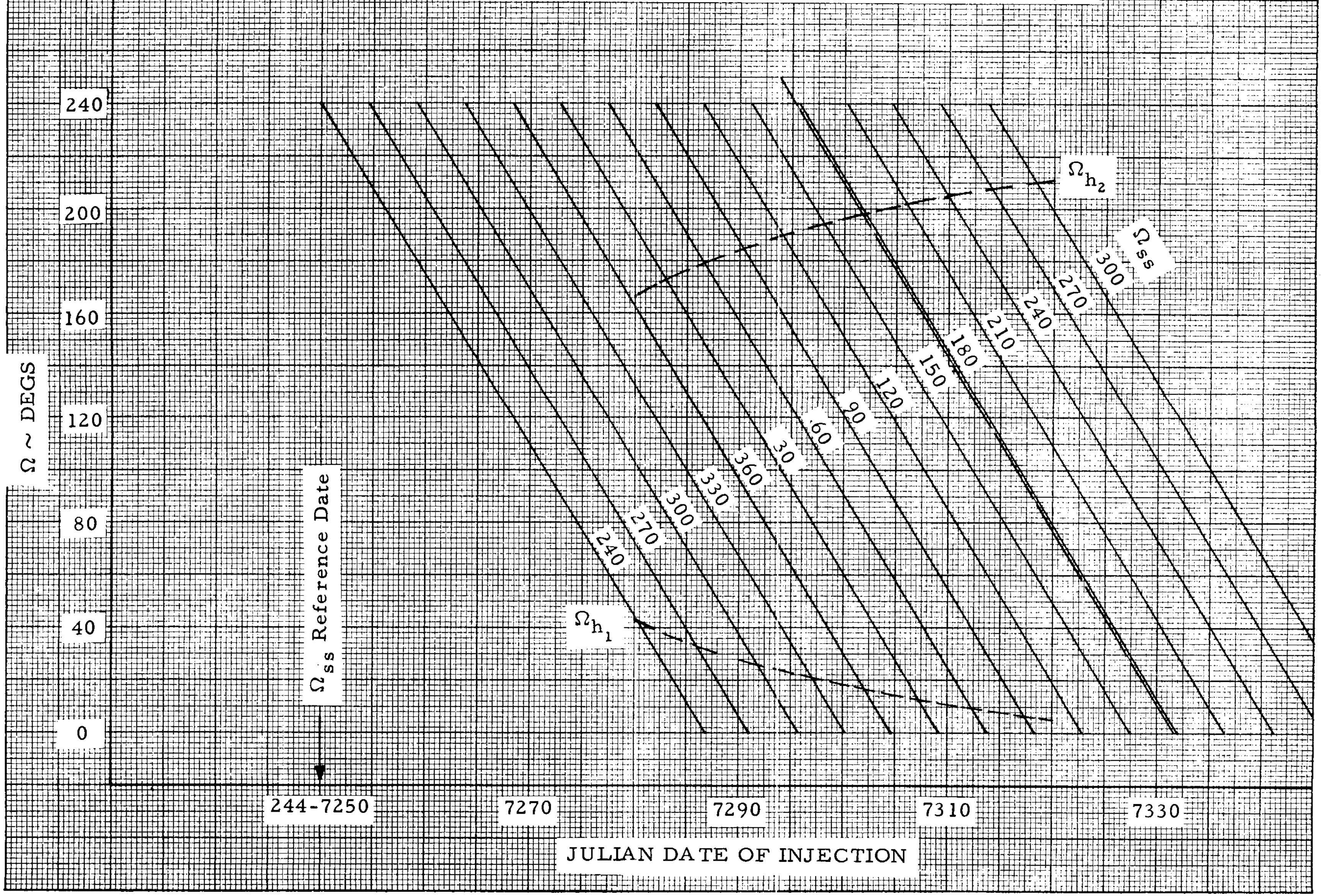


FIGURE 29. LAUNCH WINDOW COMPATIBILITY FOR A LONG DURATION MARS MISSION (OPPOSITION YEAR 1988)

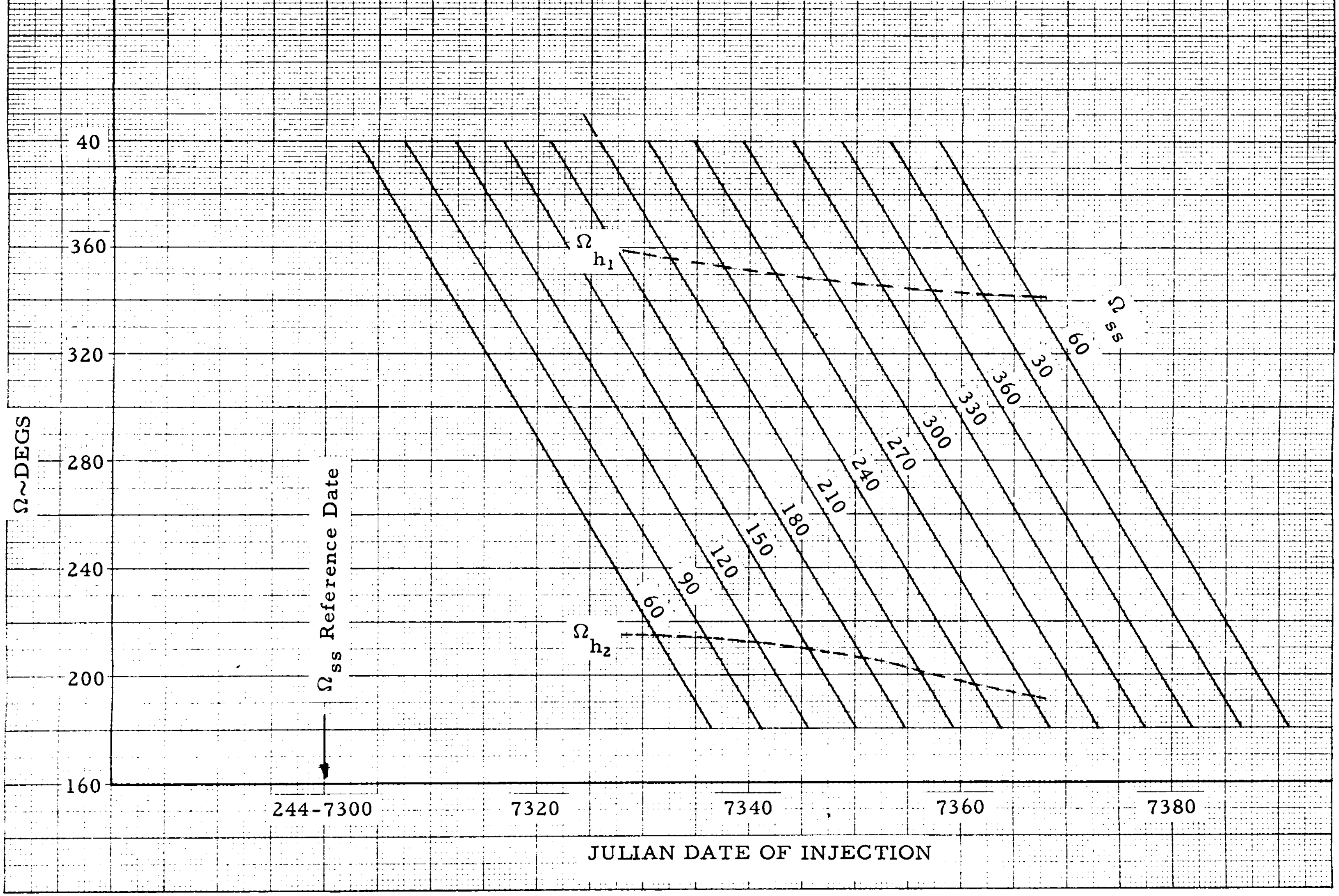


FIGURE 30. LAUNCH WINDOW COMPATIBILITY FOR A SHORT DURATION MARS MISSION (OPPOSITION YEAR 1990)

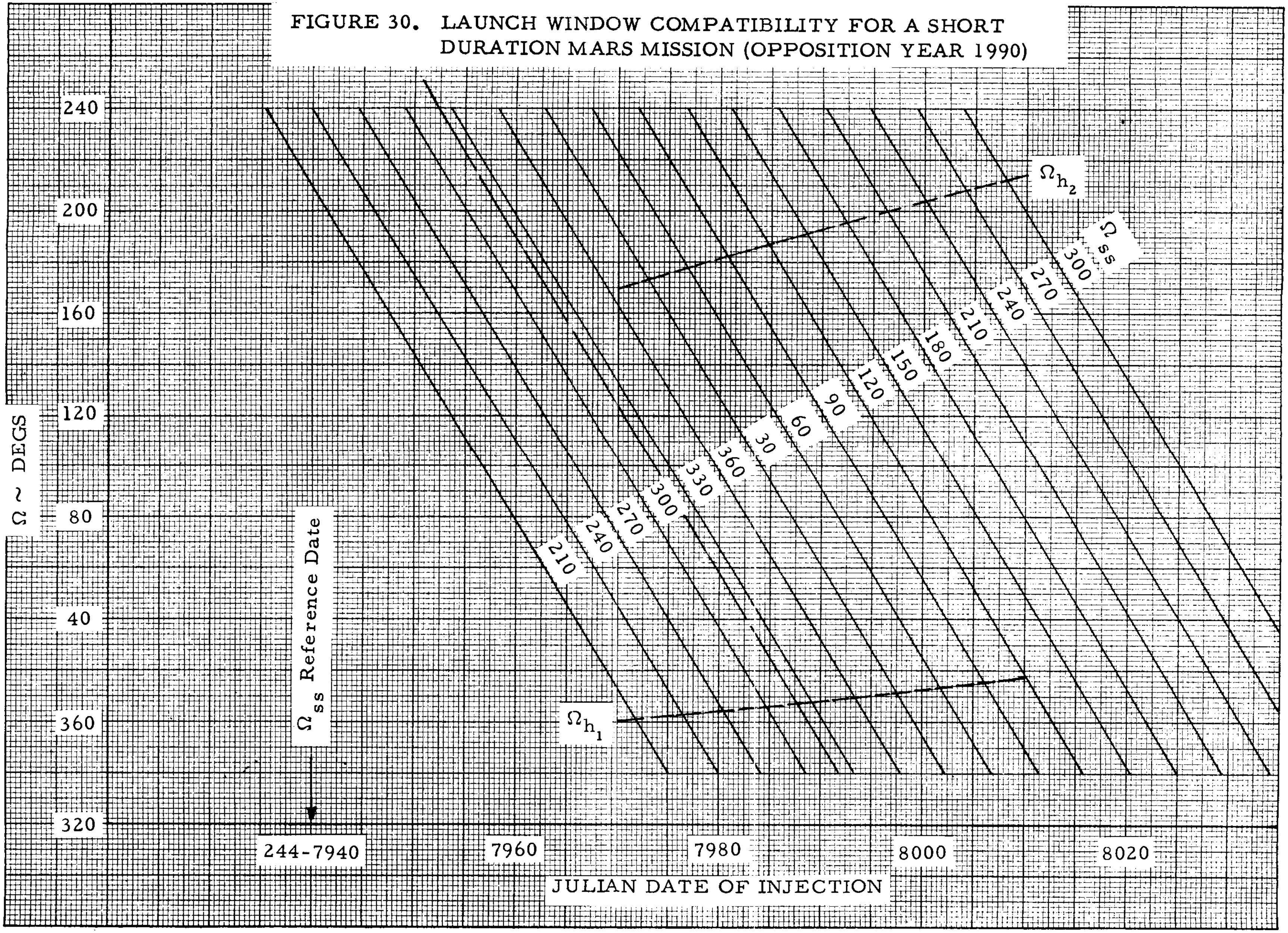


FIGURE 31. LAUNCH WINDOW COMPATIBILITY FOR A LONG DURATION MARS MISSION (OPPOSITION YEAR 1990)

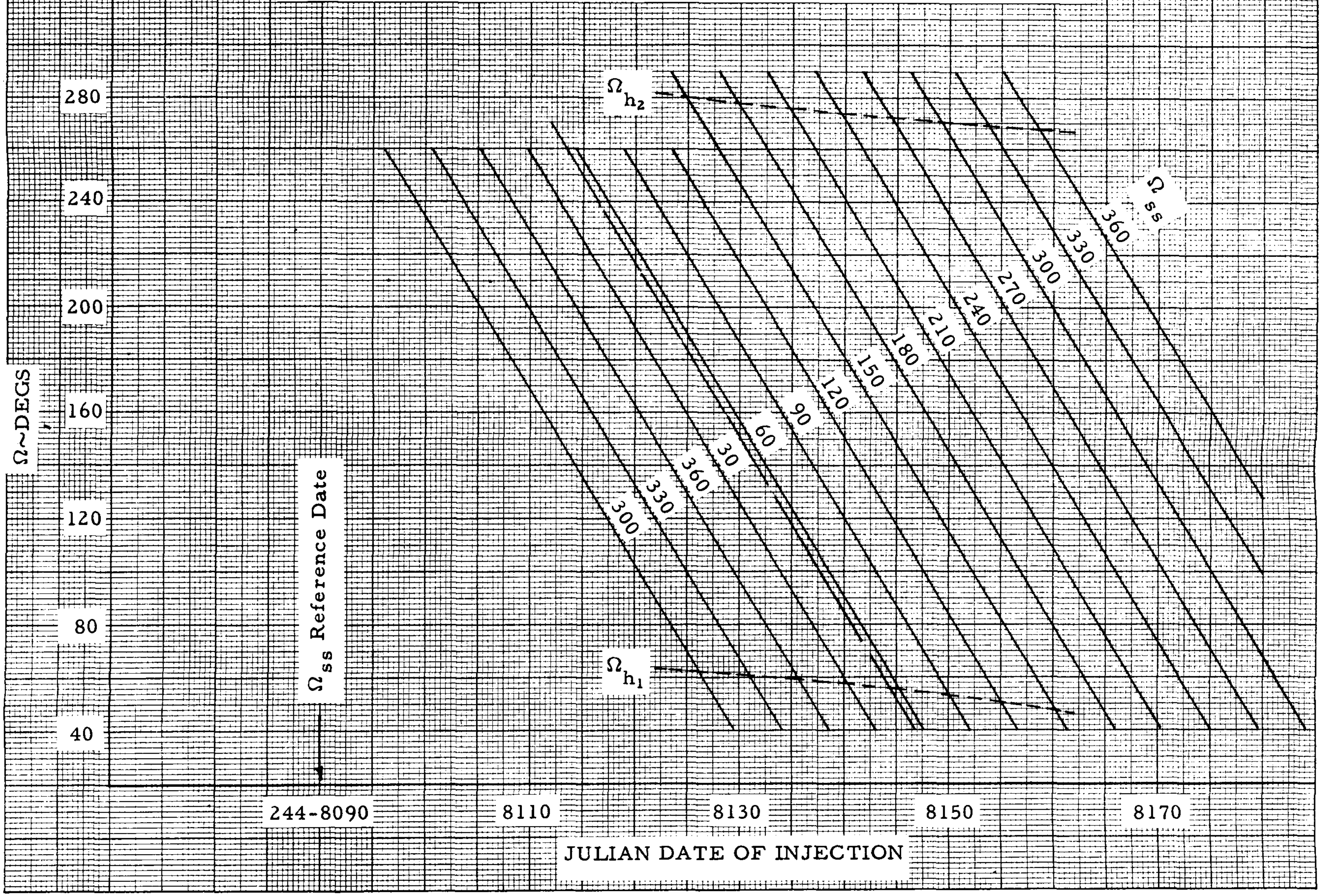


TABLE 1. - SUMMARY OF EARTH DEPARTURE WINDOWS SELECTED FOR STUDY

Oppos Year	Julian Date of Earth Departure ±20 Days	Outbound Time (Days)	Stay Time (Days)	Inbound Time (Days)	Total Trip Time (Days)
		Mars Missions (Long-duration)			
1975	244-2673	380	390	180	950
1978	244-3425	340	430	190	960
1980	244-4167	350	430	200	980
1982	244-4942	320	500	170	990
1984	244-5745	300	480	180	960
1986	244-6540	270	510	180	960
1988	244-7348	190	580	160	930
1990	244-8142	380	370	180	930
		Mars Missions (Short-duration)			
1975	244-2540	220	20	250	490
1978	244-3320	240	20	260	520
1980	244-4200	200	20	200	420
1982	244-4960	220	20	220	460
1984	244-5700	280	20	220	520
1986	244-6480	260	20	220	500
1988	244-7300	190	20	260	470
1990	244-7990	240	20	260	520

Conj Year	Julian Date of Earth Departure ±20 Days	Outbound Time (Days)	Stay Time Long/Short (Days)	Inbound Time Long/Short (Days)	Total Trip Time Long/Short (Days)
		Venus Missions (Long/Short-duration)			
1975	244-2578	120	510/20	110/270	740/410
1977	244-3160	120	490/20	100/280	710/420
1978	244-3734	120	520/20	110/270	750/410
1980	244-4360	160	440/20	110/320	710/500
1982	244-4914	170	450/20	120/320	740/510
1983	244-5498	120	510/20	110/270	740/410
1985	244-6080	120	490/20	100/280	710/420
1986	244-6654	120	520/20	110/270	750/410
1988	244-7280	160	440/20	110/320	710/500
1990	244-7825	170	450/20	120/320	740/510

TABLE 2. - SUMMARY OF LAUNCH WINDOW GENERAL COMPATIBILITY

Opposition/ Conjunction Year	Earth Departure Window Duration (Days)	Orientations Not Covered (Deg)	Orientations Covered (Percent)
Mars Missions (Long-duration)			
1975	40	-	100.0
1978	40	168-195	92.5
1980	37	143-210	81.4
1982	39	210-270	83.3
1984	40	-	100.0
1986	40	-	100.0
1988	40	-	100.0
1990	40	-	100.0
Mars Missions (Short-duration)			
1975	40	-	100.0
1978	40	-	100.0
1980	40	150-240	75.0
1982	40	-	100.0
1984	40	-	100.0
1986	40	-	100.0
1988	40	-	100.0
1990	40	-	100.0
Venus Missions (Long- and Short-duration)			
1975, 1983	37	-	100.0
1977, 1985	40	-	100.0
1978, 1986	30	116-120	98.9
1980, 1988	33	150-180	91.7
1982, 1990	40	-	100.0

TABLE 3. - SUMMARY OF LAUNCH WINDOW COMPATIBILITY
REFERENCED TO 1975 MARS FLYBY MISSION

Opposition/Conjunction Year	OLF Compatible with Earth Departure Window
Mars Missions (Long-duration)	
1975	Yes
1978	Yes
1980	Yes
1982	No (qualified)
1984	Yes
1986	Yes
1988	Yes
1990	Yes
Mars Missions (Short-duration)	
1975	Yes
1978	Yes
1980	Yes
1982	Yes
1984	Yes
1986	Yes
1988	Yes
1990	Yes
Venus Missions (Long- and Short-duration)	
1975	Yes
1977	Yes
1978	Yes
1980	Yes
1982	Yes
1983	Yes
1985	Yes
1986	Yes
1988	Yes
1990	Yes

SECTION VI. CONCLUSIONS

Although this study has been limited in scope and level of effort, it leaves no doubt that a single, permanent OLF can be compatible with almost all possible missions to Mars and Venus during the operational life of the OLF. This is especially true if the series of missions and launch dates is known so that the OLF orbit can be established with the proper initial orientation so as to be compatible with the planned missions.

The following conclusions are a result of this study effort:

(1) The orbital launch window criteria does not impose any particular constraint on the feasibility of a permanent Orbital Launch Facility.

(2) A total of 27 Earth departure windows for Mars and Venus missions during the 1975 - 1990 period was investigated. An arbitrarily-chosen OLF orbit was completely compatible with all of these except two, and was compatible with these latter two with only minor additional energy requirements.

(3) Of the 26 Earth departure windows investigated for general compatibility, 18 were compatible with all possible orientations of an OLF orbit. The remaining 8 launch windows were compatible with 75 - 99 percent of all possible orientations. The 1975 Mars flyby mission launch window was not investigated for general OLF orbit orientation compatibility.

(4) Increasing the inclination angle of the OLF orbit would increase the percentage compatibility of the eight cases that were not completely compatible.

(5) The inclination of the OLF orbit has considerable influence on the attainability and duration of the orbital launch windows. If, for instance, the Earth escape velocity asymptote, V_∞, declination is greater than the OLF orbit inclination, then a coplanar launch is not possible. This area needs additional investigation.

(6) A few possibilities exist for varying the nodal regression rate of the OLF orbit in order to influence the orbit compatibility with a particular launch window. One method of doing this is to permit the orbital altitude of the OLF to vary by natural orbital decay due to air drag. After the increased precession rate has accomplished the desired change, normal station-keeping would reestablish the proper altitude. This area also needs more investigation.

APPENDIX

ORBITAL LAUNCH WINDOWS

This section presents orbital launch windows derived from a portion of the available Earth departure windows for Mars and Venus missions in the 1975 - 1990 time period.

Figure A-1, which was derived from Figure 14, presents a family of orbital launch windows for a Venus mission in 1977 and 1985. It can be seen from Figures 14 and A-1 that regardless of the OLF's orientation it will hit the 1977 and 1985 window. It can also be seen in Figure 14 that two coplanar solutions exist for some orientations, and that three coplanar launch opportunities occur for the 240-degree orientation. The dashed line which envelopes the family of orbital launch windows in Figure A-1 is the Earth departure window referenced to Earth orbit. This Earth departure window defines the velocity required to inject into an escape hyperbola without a plane change. The three points where the 240-degree orbital launch window meets the Earth departure window represent coplanar injection conditions. The coplanar launch opportunities for the 240-degree orientation occur on 244-3140.5, 244-3160, and 244-3179.5 J.D. At all other times within the 40-day Earth departure window a plane change is necessary to inject into the required escape hyperbola. This is evident by the ΔV variation in Figure A-1. A ΔV limit of 6 km/sec was arbitrarily set for the orbital launch windows in Figure A-1 in order to compare the window widths for the various orientations. It can be seen from this figure that the maximum orbital launch window occurs for the 240-degree orientation case. Launch can be made on any of the 40 days without exceeding the 6 km/sec limit. The minimum window duration (approximately 5.6 days) occurs for the 60-degree orientation. Therfore, it can be seen that the orientation of the OLF greatly influences the orbital launch window duration.

Figures A-2 and A-3 show orbital launch windows for short-duration Mars missions in 1978 and 1982, respectively. Orbital launch windows for long-duration missions to Mars in 1984 and 1986 are presented in Figure A-4 and Figure A-5. A summary of these windows for various orientations is shown in Table A-1.

FIGURE A-1. EARTH ORBITAL LAUNCH WINDOWS FOR A VENUS MISSION WITH PARKING ORBIT ORIENTATION AS A PARAMETER (CONJUNCTION YEARS 1977 & 1985)

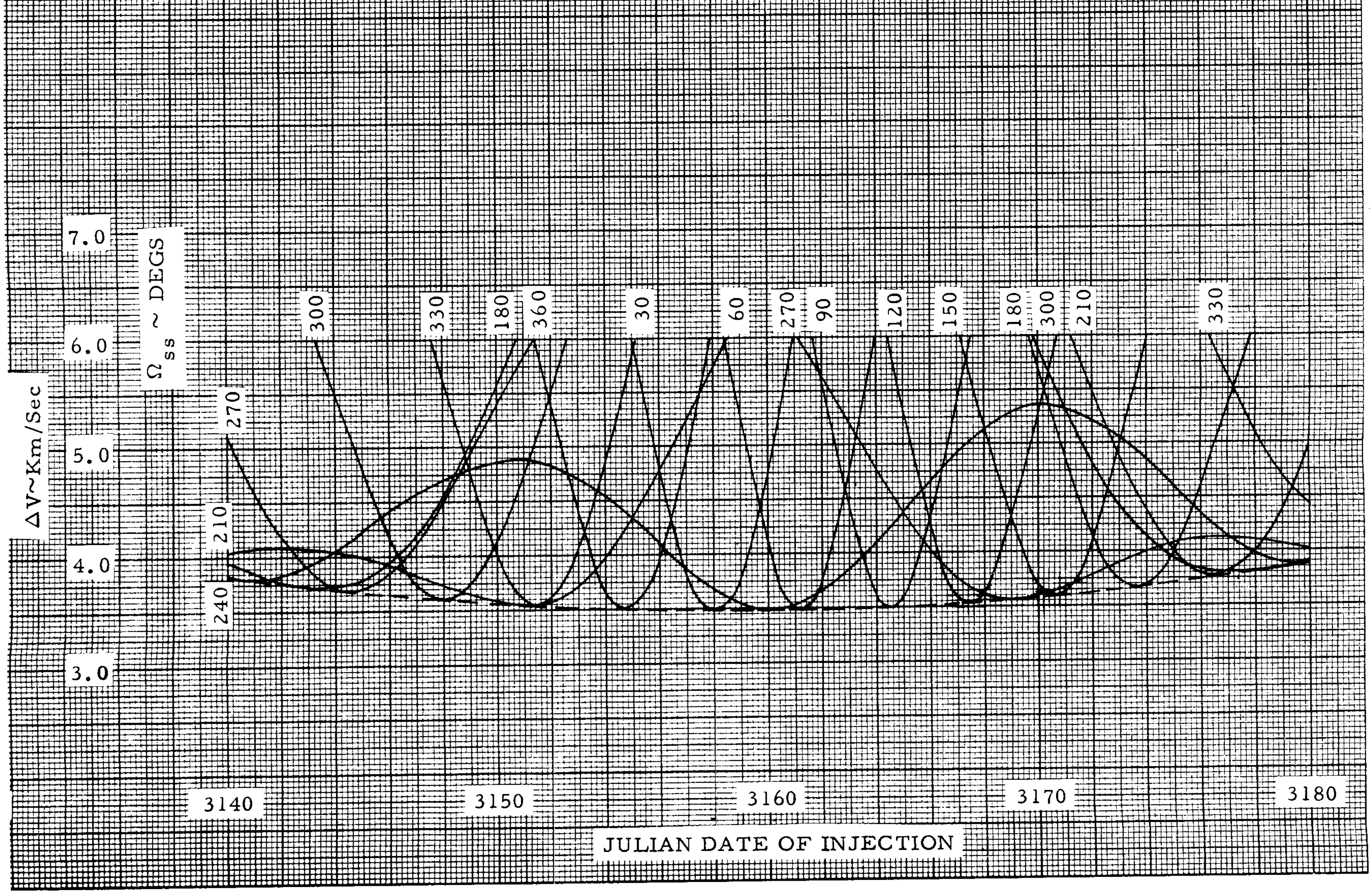


FIGURE A-2. EARTH ORBITAL LAUNCH WINDOWS FOR A SHORT DURATION MARS MISSION WITH PARKING ORBIT ORIENTATION AS A PARAMETER (OPPOSITION YEAR 1978)

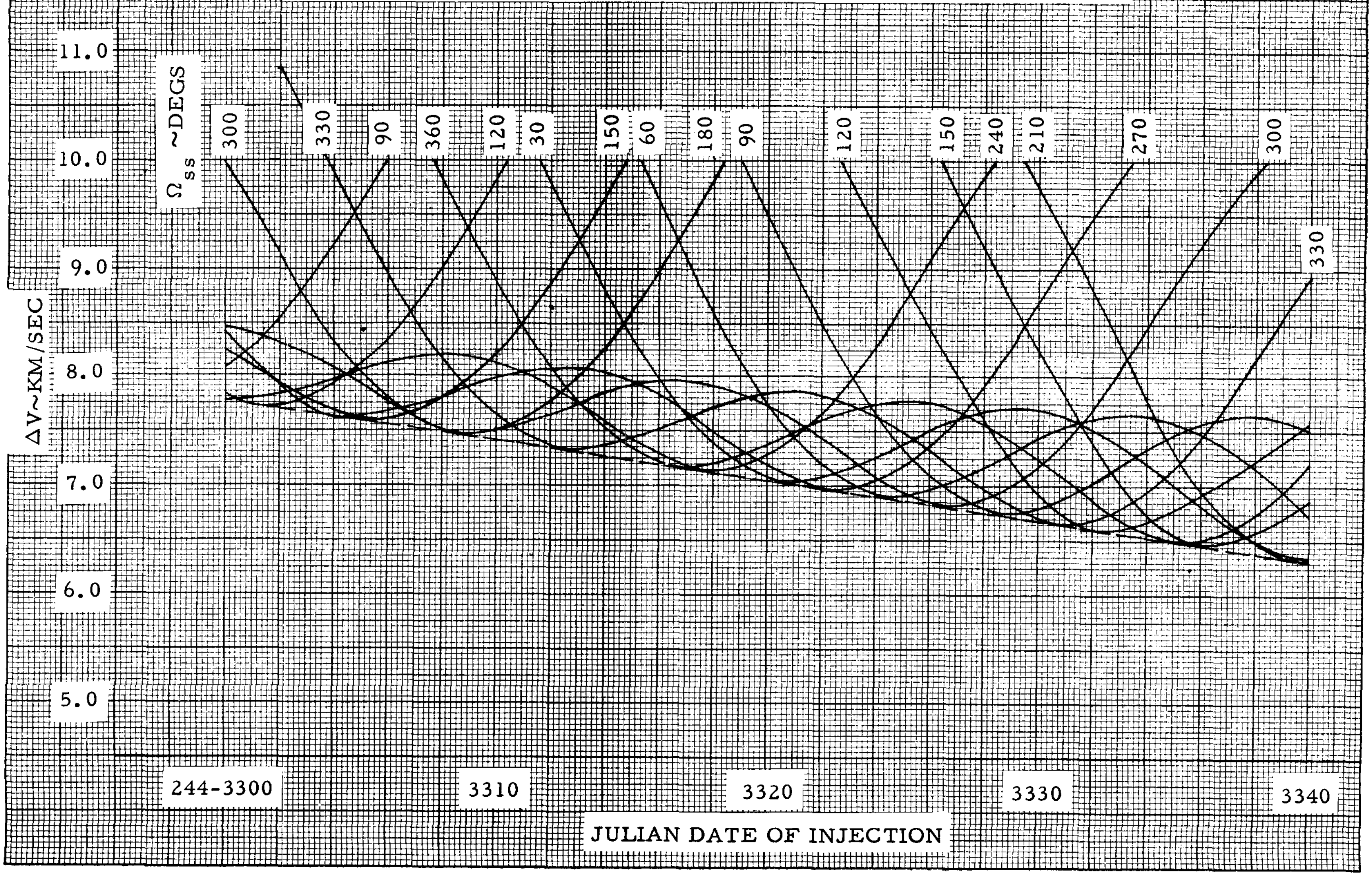


FIGURE A-3. EARTH ORBITAL LAUNCH WINDOWS FOR A SHORT DURATION MARS MISSION WITH PARKING ORBIT ORIENTATION AS A PARAMETER (OPPOSITION YEAR 1982)

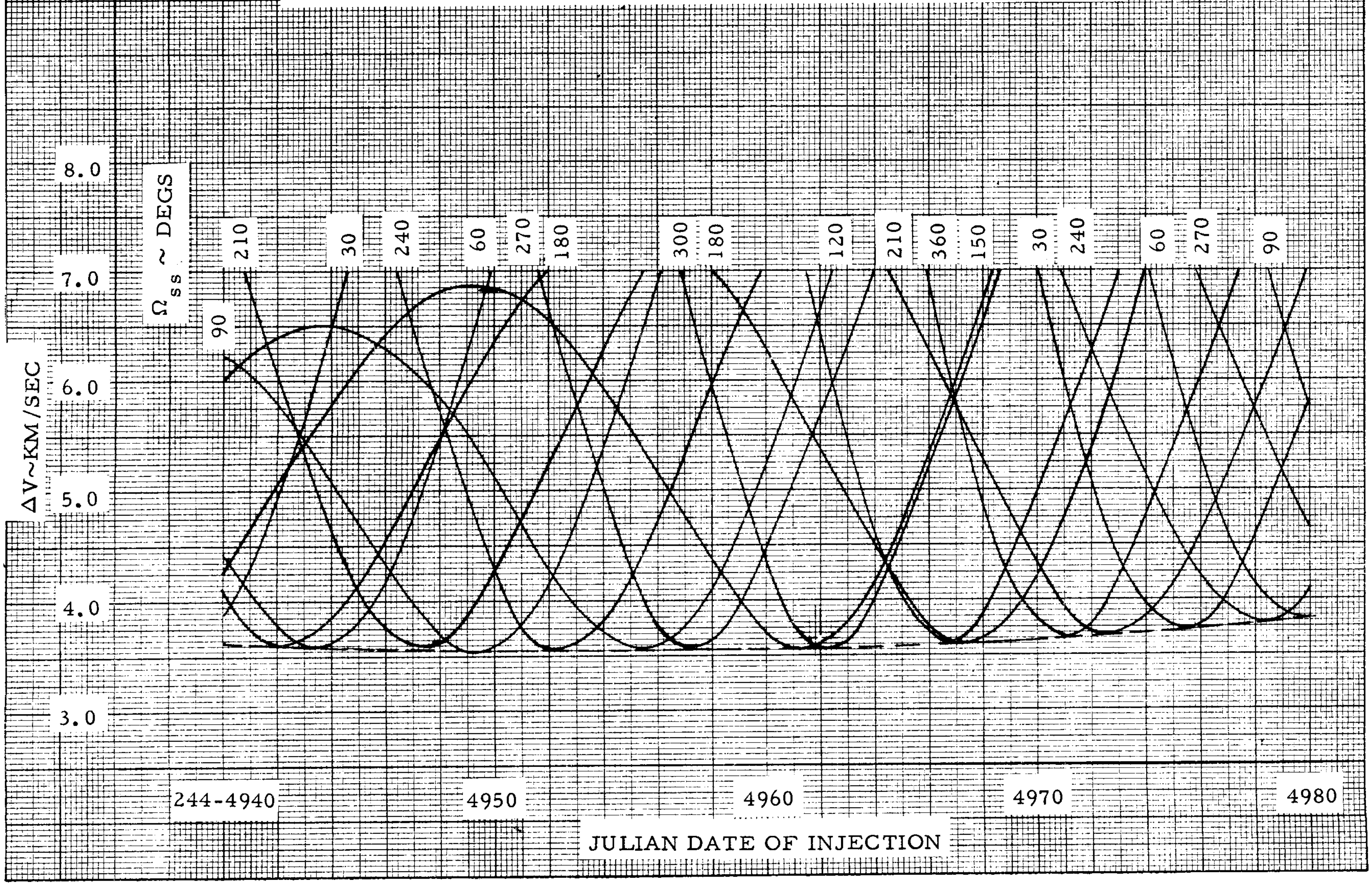


FIGURE A-4. EARTH ORBITAL LAUNCH WINDOWS FOR A LONG DURATION MARS MISSION WITH PARKING ORBIT ORIENTATION AS A PARAMETER (OPPOSITION YEAR 1984)

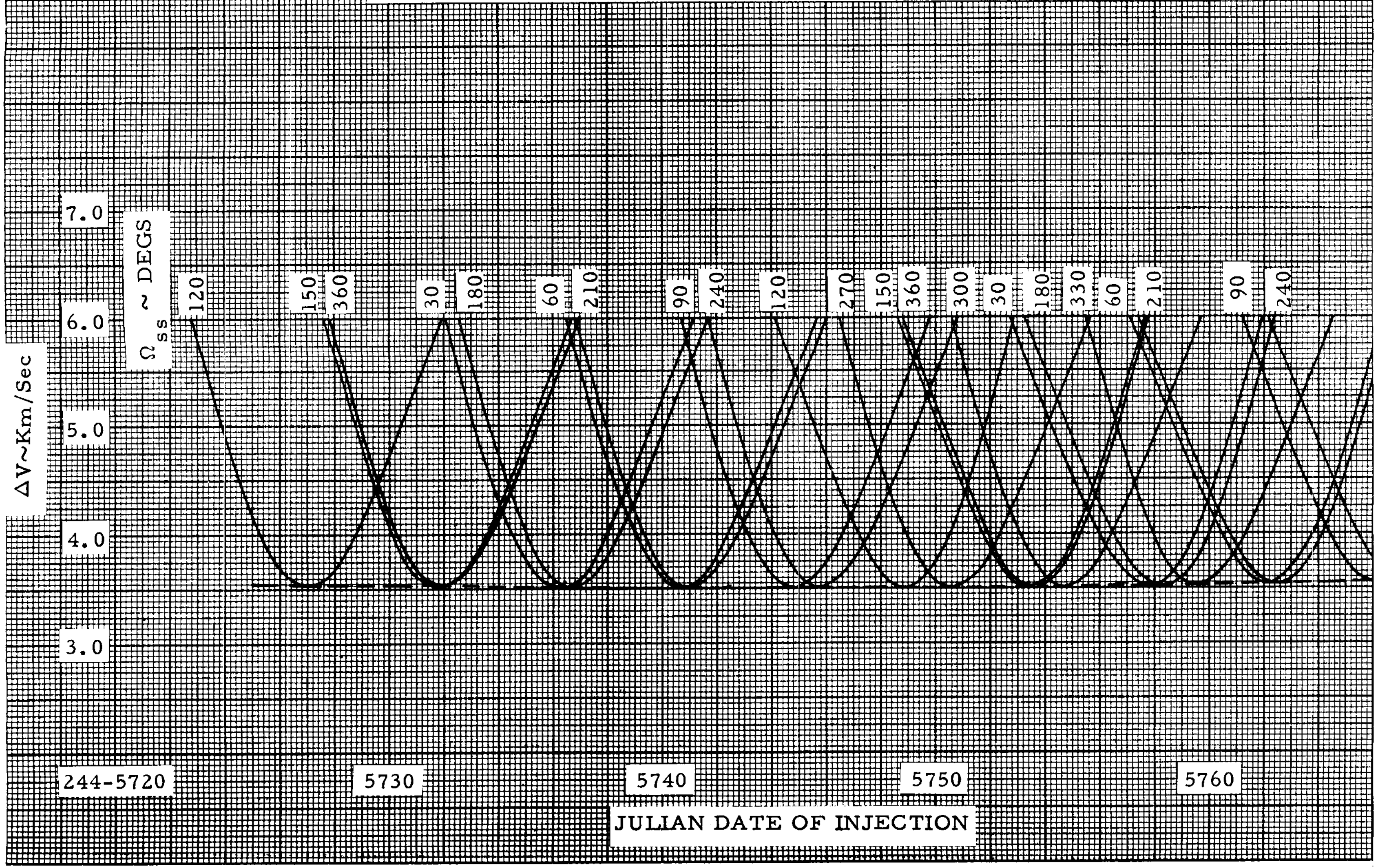


FIGURE A-5. EARTH ORBITAL LAUNCH WINDOWS FOR A LONG DURATION MARS MISSION WITH PARKING ORBIT ORIENTATION AS A PARAMETER (OPPOSITION YEAR 1986)

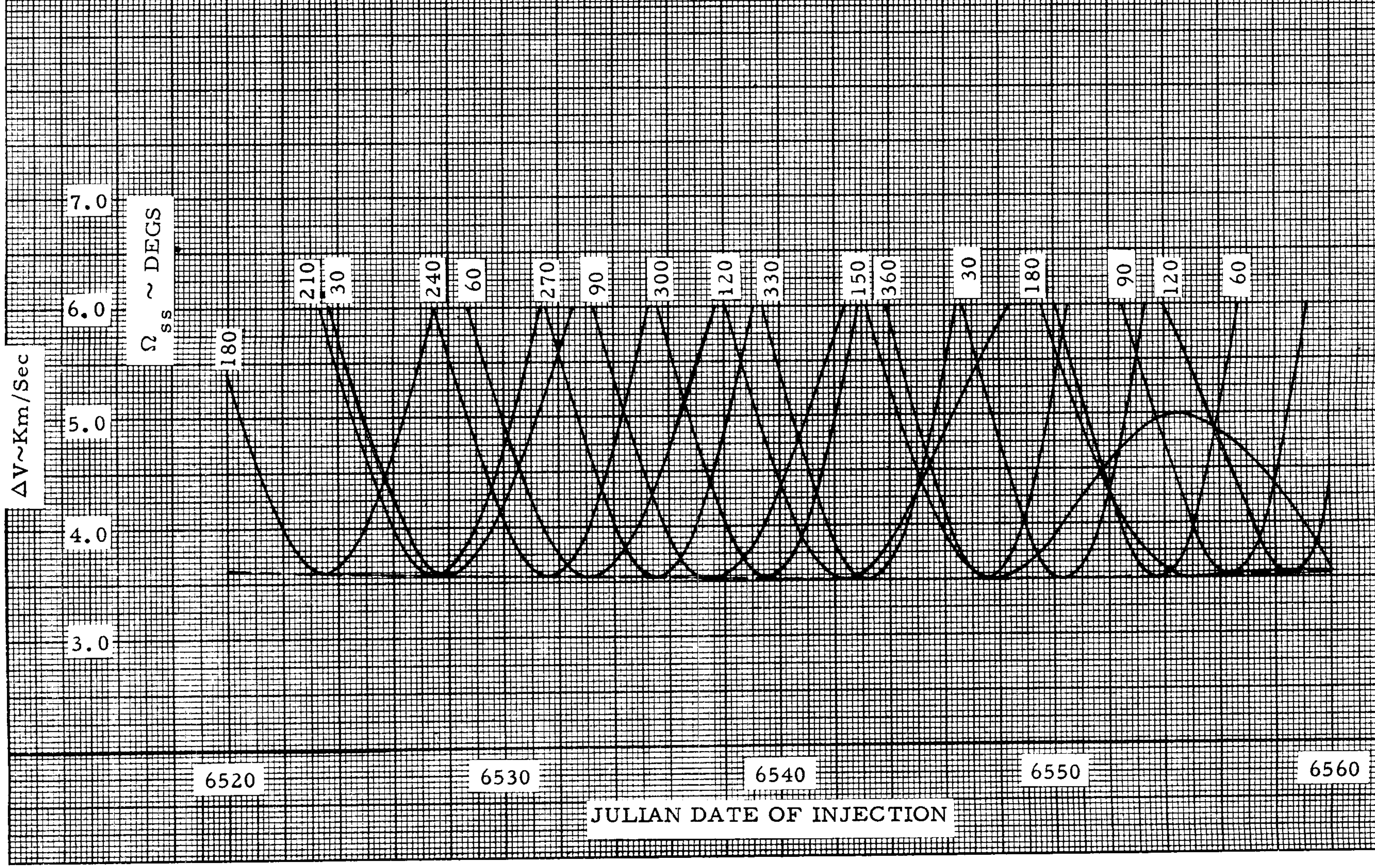


TABLE A-1. - SUMMARY OF ORBITAL LAUNCH WINDOWS

Figure	Mission Year	Mission	Orientation (Degrees)	First Window Duration (Days)	Minimum ΔV (km/sec)	Time Between Windows (Days)	Second Window Duration (Days)	Minimum ΔV (km/sec)	ΔV Limit (km/sec)	Total Window Duration (Days)
A-1	1977 & 1985	Venus	240	40.0	3.48	-	-	-	6.0	40.0
			300	9.3	3.60	17.2	10.2	3.80	6.0	19.5
			60	5.6	3.49	-	-	-	6.0	5.6
A-2	1978	Mars-Short	300	38.4	6.82	-	-	-	10.0	38.4
			360	32.3	6.50	-	-	-	10.0	32.3
			60	24.7	6.90	-	-	-	10.0	24.7
A-3	1982	Mars-Short	210	14.7	3.60	9.0	15.4	3.68	7.0	30.1
			270	12.4	3.58	11.8	4.2	4.65	7.0	16.6
			360	11.5	3.66	-	-	-	7.0	11.5
A-4	1984	Mars-Long	180	8.9	3.52	11.8	10.1	3.53	6.0	19.0
			270	9.2	3.51	11.2	3.2	4.08	6.0	15.2
			300	9.1	3.51	-	-	-	6.0	9.1
A-5	1986	Mars-Long	180	7.5	3.60	22.1	10.4	3.51	6.0	17.9
			240	7.7	3.55	-	-	-	6.0	7.7
			300	7.2	3.52	-	-	-	6.0	7.2

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APPROVAL

UTILIZATION OF AN ORBITAL LAUNCH FACILITY FOR PLANETARY MISSIONS

By

Robert M. Croft

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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