E-3987

NASA TECHNICAL MEMORANDUM

NASA TM X-52311

NASA TM X-52311

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) $3.00

Microfiche (MF) .65

ff 653 July 65

MANNED VENUS ORBITING MISSION

by Edward A. Willis, Jr.

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION · WASHINGTON, D.C. · 1967

ABSTRACT

Manned orbiting stopover round trips to Venus are studied for departure dates between 1975 and 1986 over a range of trip times and stay times. The use of highly elliptic parking orbits at Venus leads to low initial weights in Earth orbit compared with circular orbits. For the elliptic parking orbit, the effect of constraints on the low altitude observation time on the initial weight is shown. The mission can be accomplished with the Apollo level of chemical propulsion, but advanced chemical or nuclear propulsion can give large weight reductions. The Venus orbiting mission can be done for lower initial weights than the corresponding Mars mission.

SUMMARY

Venus is our nearest planetary neighbor and is an interesting object for scientific exploration following the manned lunar landings in the early 1970s. In this paper manned orbiting stopover round trip missions to Venus are studied for the 1975 to 1986 time period for trip times ranging from 360 to 660 days, stay times up to 100 days, for Venus parking orbit eccentricities from 0 to 1.0, and several levels of propulsion technology.

An elliptic parking orbit (eccentricity $\approx$ 0.9) was found to be essential to achieving low initial weights in Earth orbit, and 1980 was found to be the most difficult launch year. In 1980 with an elliptic parking orbit and for the Apollo level of propulsion technology, the minimum initial weight in Earth orbit is estimated to be 1.5×10^6 lbs for a trip of 565 days duration with 40 days stay at Venus. Trips as short as 400 days and with a 20-day stay are possible for a 10% increase in weight.

The initial weight can be reduced by as much as 50% by using a nuclear rocket for the Earth departure maneuver, and high energy chemical propellants for the Venus arrival and departure maneuvers.

An elliptic orbit of eccentricity = 0.9, and having 40 days stay at Venus provides a total time of 2 days spent below an altitude of 3 Venus radii above the Venus surface. Data of this type helps to specify the on-board equipment needed to gather observational information about the planet surface. More stringent observation requirements in terms of longer times at lower altitudes can cause large increases in the initial weight in Earth orbit. The Venus orbiting mission can be done for about a 40 percent lower initial weight than a Mars orbiting mission.

INTRODUCTION

Venus, our nearest planetary neighbor, is about the same size as Earth and has a dense atmosphere. Despite its closeness, little is known about Venus because its surface is completely covered by a layer of dense clouds. The major scientific objectives for studying Venus are discussed in ref. 1. It is interesting to note that contemporary scientific opinion, ref. 2, does not reject the possibility that some form of life could have developed on Venus, and that there may be suitable sites for a manned landing. In general, Venus is a planet of great scientific interest.

Mars is the next closest planet. Compared with Venus, it is much smaller, one-eighth the mass, and has an atmosphere about 1/30 that of the Earth. Because of its small mass, a vehicle for men to land and take off from Mars is of reasonable size when chemical propulsion systems are used. Also, the surface conditions in terms of winds and temperatures can be estimated and appear tolerable. Thus, a manned landing on Mars can be considered. In contrast, little is known of the surface conditions at Venus, and the larger mass of Venus makes a manned landing and takeoff system appear extremely difficult and heavy. Thus, only an orbiting mission to Venus is considered here.

It is the objective of this report to study the trajectories and vehicle weights for manned orbiting stopover round trips to Venus and to discuss the data gathering characteristics of such a mission. Important to achieving a low initial weight in Earth orbit for the Venus mission is the use of an elliptic parking orbit at Venus. Earlier studies of the use of an elliptic parking orbit (e.g., ref. 3) have several deficiencies: They used inefficient Venus arrival or departure maneuvers; they neglected the interaction between the planetocentric and heliocentric trajectories; and no consideration was given to the observation characteristics of the elliptic parking orbit. The present report accounts for these factors.

Several criteria are used to judge the merit of a scientific space mission: the initial weight in Earth orbit, the total trip time, and the useful information obtained. While several observation characteristics are considered, an important one is related to the fact that Venus is cloud-covered. It is likely that one important part of the mission will be related to electromagnetic measurements such as radar mapping of the Venus surface. The equipment for, and the resolution of, the mapping will depend on the range to the surface and the time available. Thus, the time below a specified altitude above the surface of Venus is one of the observational parameters evaluated.

The payloads assumed herein are most suitable for manned missions; however, the trends shown are applicable to unmanned round trips. The effects of the ellipticity of the Venus parking are relevent also to one way probes.

The present analysis considers manned Venus orbiting round trips from the years 1975 to 1986, for total trip times of 360 to 660 days, and for stay times up to 100 days. The effects of varying the Venus parking orbit eccentricity from 0 to 1.0 and the propulsion system from the Apollo level of chemical propulsion to the nuclear rocket are shown.

SYMBOLS

D direct orbital motion

F thrust

h slant range from spacecraft to surface of Venus

R retrograde orbital motion

r	radius
T	time
V	velocity
ΔV	characteristic propulsive velocity increment
W	weight
η	true anomoly (fig. 2)
θ	turning angle (fig. a)
λ	parking orbit orientation angle (fig. 2)
ψ	heliocentric travel angle (fig. 1)

Subscripts:

a	apoapsis
CM	command module
E	Earth entry
g	gross
H	heliocentric velocity vecotr
jett	jettison
L	payload
max	maximum
obs	observation
p	periapsis
prop	propellant
s	stay
$\oplus$	Earth
∞	planetocentric velocity vector at the sphere of influence
♀	Venus
1	Earth departure

2 Earth/Venus midcourse

3 Venus arrival

4 Venus departure

5 Venus/Earth midcourse

6 Earth arrival

ANALYSIS

The general approach to the analysis is discussed here. Details of the numerical procedures may be found in the references indicated.

Trajectories and $\triangle$Vs

The general mission analyzed is shown in fig. 1. The mission is assumed to begin in a 400-mile-altitude orbit about Earth, point 1. After departing from Earth, a midcourse correction is applied at point 2. At Venus (point 3) the vehicle decelerates into an elliptic parking orbit and gathers information about Venus. The vehicle then leaves Venus, point 4, a midcourse correction is applied at point 5, and atmospheric braking is used at Earth return, point 6.

Several kinds of trajectory profiles were considered. These are distinguished by whether the Earth-to-Venus heliocentric travel angle ψ_o is less than 180° (type I) or greater than 180° (type II). Another distinguishing feature is whether the motion of the vehicle in its parking orbit about Venus is direct, D, (i.e., used here to mean the same motion as Venus about the sun) or retrograde, R. Thus, a type 'I-R' trajectory is one with an outbound leg of less than 180° and a retrograde motion parking orbit. Trajectories that yield the lower initial weight in Earth orbit are sought.

The characteristics of the interplanetary trajectories in terms of propulsive $\triangle$Vs, travel angles and travel times were calculated by the successive two-body method of ref. 4. The planets are assumed to be in elliptic orbits in mutually inclined planes. (The plane inclinations are not shown in fig. 1 to keep the figure simple.) The elliptic parking orbit at Venus was of special interest in this study. The difference between the vehicle heliocentric velocity vector V_H (see fig. 1) and the heliocentric velocity of Venus $V_♀$ at the Venus sphere of influence gives the hyperbolic excess velocity V_∞ relative to Venus. These hyperbolic excess velocities at Venus arrival $V_{\infty 3}$ and departure $V_{\infty 4}$ are the boundary conditions for the Venus capture-parking orbit-escape sequence that is illustrated in fig. 2. The orientation of the major axis of the parking ellipse, defined by λ_3, and the true anomalies of the arrival and departure maneuvers (η_3 and η_4 respectively) that yield a minimum propulsive $\triangle$V or a minimum vehicle weight can be found using a systematic search such as that discussed in ref. 5.

Assumptions

Inputs.- Table I shows the structural and propulsion system weight fractions, propulsion system specific impulse and $\triangle V$ reserve allowances for each stage and for the three technology levels considered. For the "Apollo" case, the stage parameters were extracted from the Titan and Saturn design data presented in references 6 and 7. The other values were selected to span the range from "pessimistic" to "optimistic" for high thrust systems in the decade beginning in 1975. Gravity loss $\triangle V$ allowances were derived from ref. 8; other reserves were computed to provide $\pm$10-day launch windows for both Earth and Venus departure and to correct for representative guidance errors.

Table II shows the basic payloads. The Earth-return items are the same ones used in ref. 9. Venus payloads were selected with the idea that at least an order of magnitude more apparatus should be available for a manned mission than for a probe.

Vehicle Configuration.- Tandem staging was selected because it yields both good mission performance and abort capability. Earth or space storable rather than deep cryogenic propellants were used for all except the Earth-departure stage because preliminary calculations (not illustrated here) indicated only a few percent weight penalty for doing so. In return, the problem of furnishing lightweight, long term thermal and meteroid protection for bulky liquid hydrogen tanks is by-passed.

Observational Criteria

The present study considers only orbiting the crew at Venus, rather than landing them on the surface as is frequently assumed for the Mars mission. Information gathering at Venus will thus depend on the transmission of signals from the Venus surface to the spacecraft or reflection of signals originating on the spacecraft from the Venus surface back to the spacecraft. Some of the factors limiting such transmission are illustrated in fig. 3. The simplest condition is that the point to be observed must be in the line of sight of the spacecraft, fig. 3(a). The longest times available for observation occur for surface points located directly below the apoapsis of the orbit, but these involve the longest transmission distances. These long distances may be acceptable for probes sent to the surface to transmit data to the spacecraft.

For observations like radar mapping, which depend on signals reflected from the surface, the surface resolution obtainable with a given radar instrument depends both on the range to the surface and the time available, with short ranges and long times being desirable.

Fig. 3(b) illustrates the portion of an elliptic orbit below a limiting range h_{max} that gives acceptable resolution, and the corresponding planet surface area visible from ranges less than h_{max}. The present study considers constraints on the time below specified values of h_{max}. For a complete mission evaluation, the effect of imposing such constraints on the trajectory would be balanced against the cost of providing more powerful or heavier observational equipment.

The trajectory computer program of ref. 10 was extended to include the elliptic parking orbit calculations and vehicle weight calculations referred to earlier. Also, an automatic numerical search procedure, ref. 11, was added to find those trips that gave a minimum initial weight in Earth orbit for specified constraints such as stay time or observation time at Venus.

RESULTS AND DISCUSSION

First, the selection of the Venus parking orbit and the effects of observational constraints at Venus are discussed. Next, the effects of total trip time, trajectory type, propulsion system, and launch date are presented. Finally, a comparison is made between similar Venus and Mars missions.

Selection of the Venus Parking Orbit

Effect of parking orbit eccentricity.- Both $\triangle V$ and observational requirements indicate that the parking orbit periapse radius r_p should be as low as possible (e.g., $r_p = 1.1\ r_♀$). The eccentricity e then completely specifies the size and shape of the orbit. The effect of this parameter, neglecting observational constraints, is shown by the dashed curve in fig. 4.

The initial gross weight W_{g1} is plotted against e for type I-R trajectories in 1980, with a stay time of 20 days and the optimum trip time, which varies from 410 to 440 days. The Apollo technology level (Table I) and payloads of Table II were used in this example. The W_{g1} decreases from 9×10^6 lbs at $e = 0$ (a low circular parking orbit) to about 1.5×10^6 lbs as e increases toward 1.0, a 6:1 weight reduction. The powerful effect of parking orbit ellipticity on weight is clearly evident.

Effect of observational constraints.- While increasing eccentricity is beneficial from a vehicle weight point of view, it is detrimental to some observational properties of the orbit. At high eccentricities, a large part of the time in orbit is at high altitudes above Venus. These large distances can pose a problem for such observations as radar mapping because, for at least some types of mapping, the received signal strength is the transmitted signal strength attenuated by the fourth power of the altitude above Venus. For such measurements the low altitude portion of the orbit is most useful; but, for highly eccentric orbits, the time at low altitudes is limited. For example, for an eccentricity of 0.98 the period of the orbit is about 40 days, a typical stay time at Venus. In this case the vehicle would make only two close passes of Venus, and the time below 3 Venus radii is only several hours. This is only slightly better than a non-stop flyby mission.

To justify a stopover, it is felt that the low altitude observation time should be much better than for a flyby. Hence, low altitude observation times of a day or two will be considered as constraints. The effect of adopting a constraint that $T_{obs} \geq 2$ days for a specified value of h_{max} leads to a preferred value for the parking orbit eccentricity. The specified time T_{obs} can be obtained by short stay times at Venus at low parking orbit eccentricities, or by long stay times at high parking orbit eccentricities. The former case tends to give high propulsion requirements at Venus because of the low parking orbit eccentricity. The latter case tends to give high $\triangle V$s at Venus because the stay time becomes long. There is thus a 'trade-off' that can be made as a function of parking orbit eccentricity based on minimizing the initial weight required at Earth. The solid lines of fig. 4 illustrate typical cases. For example, for $T_{obs} \geq 2$ day and $h_{max} = 3.0$, a minimum initial weight occurs at $e = 0.9$. The corresponding stay time at Venus is 40 days. At this value of eccentricity most of the advantage of the elliptic orbit has been realized. Very low values of h_{max} like 0.1 for $T_{obs} \geq 2.0$ days can cause marked increases in the required initial weight at Earth.

Based on this example, the remaining discussion will use values of $e = 0.9$ at $T_s \geq 20$ days, which corresponds to $T_{obs} \geq 1$ day for $h_{max} = 3r_♀$. The last two items now impose requirements on the observation equipment.

Variations from Nominal Mission

The preceding example dealt with the I-R type trajectory profile, used the Apollo level of propulsion technology, and was for an optimum trip time, launched in 1980. The following is a discussion of the effect of these parameters.

Effect of trip time.- Minimum initial gross weight is plotted against trip time in fig. 5 for $T_s \geq 20$ days and $e = 0.9$. The upper curve, corresponding to the 'Apollo technology', will be discussed first; however, all the curves show the same trends. Of the two types of profiles shown, I-R and II-D, the former gives the lower weights for trips of less than 470 days. The minimum weight for the I-R profile occurs at 440 days, although the trip time can be reduced to 380 days before the weight increases sharply. These trips all have 20 days stay at Venus.

For trips longer than 470 days the II-D profile gives the lower weights. For trip times between 500 and 620 days the weights are up to 10% less than minimum value for the I-R profile. In this range of trip times the stay time for minimum weight occurs for values greater than 20 days. The overall minimum weight trip, point A, occurs at 565 days trip time, for which the stay time is about 40 days. For this case, the stay time-to-initial weight ratio, which may be roughly equated to the mission value to cost ratio, is twice that for the 440 day I-R trip.

It is of interest to note that the II-D trajectories have optimum stay times of around 40 days, while the I-R (were it not for the constraint $T_s \geq 20$ days) would minimize at $T_s = 0$. This is because the ΔV for the capture maneuver/elliptic orbit/escape maneuver sequence at Venus (recall fig. 2) depends as much on the angle θ from $V_{\infty 3}$ to $V_{\infty 4}$ as on the magnitudes of these vectors. For I-R trajectories, an increase in T_s causes these magnitudes to increase and also causes θ to depart farther from its optimum value. For the II-D (and I-D) trajectory, while increasing T_{stay} also causes $V_{\infty 3}$ and $V_{\infty 4}$ to increase, θ moves toward its optimum value. These opposing effects for the II-D trajectory result in a minimum value of initial weight for a stay time greater than zero.

For all the vehicles represented in fig. 4 the atmospheric entry velocity at Earth return is less than 48,000 feet per second.

Effect of propulsion system technology.- The upper curve of fig. 5 gave the weights for the Apollo level of propulsion technology. A minimum weight of about 1.5×10^6 lbs occurs at 565 days trip time, point A. A conceptual sketch of this vehicle, a weight breakdown, and ΔV distribution are presented in fig. 6. This vehicle, as mentioned before, uses an O_2 - H_2 Earth departure stage which is very similar to the S-II stage; it is likely that this stage (S-II) could be used for the present purposes without major modification. The two stages for the maneuvers to arrive and depart Venus are so similar in size (note the arrival and departure propellant weights) that one stage design could satisfy both requirements.

Returning to fig. 5, the next curve down (dotted) represents advanced chemical vehicles with a deep cryogenic (OF_2 - H_2) Earth departure stage and space-storable (OF_2 - CH_4) upper stages. The higher propulsion system performance values thus obtained (c.f. Table I) lead to minimum gross weights of around 1.0×10^6 lbs, a 33% reduction from the Apollo level of technology.

A large nuclear rocket engine is now being developed for advanced space missions. Using a nuclear rocket stage for the relatively high ΔV Earth-departure maneuver, with Apollo-level chemical upper stages,leads to even lower weights than the all advanced-chemical case. This is shown by the dashed curves on fig. 5. The minimum weight is 800,000 lbs. A further reduction to about 650,000 lbs is available by combining a nuclear Earth-departure stage and advanced chemical upper stages. This is illustrated by the dot-dash curve on fig. 5.

Effect of departure year.- In fig. 7, the initial gross weight is plotted against launch dates from 1975 to 1986 for the Apollo level of technology. Two trajectory profiles are considered, I-D and II-D. The D class of trajectories is the one that, for elliptic parking orbits and a specified total trip time, yields stay times for minimum initial weight that are 20 days or greater, as was shown in fig. 5. The calculations for fig. 7 were made by selecting a stay time of 40 days and then finding the total trip time that minimized the initial gross weight. The total trip times for the I-D profile, the triangle symbols, range from 450 to 480 days; and for the II-D profile, the square symbols, from 530 to 565 days. If one selects the type of profile that yields the lower weight with the condition that the time between launch opportunities not exceed two years, then the trips numbered 1 through 8 is the sequence of best trips; and of these, the trip in 1980 (No. 4) has the highest weight. The year discussed in the preceding sections is 1980, and point 4 represents the vehicle illustrated in fig. 6.

The weight variation between the vehicles represented by points 1 through 8 is due almost entirely to the variation in the weight of the Earth departure stage. Hence a vehicle designed for 1980, the heaviest initial weight, can accomplish the mission with the specified payloads in any other year by simply under-filling the tank of the Earth departure stage. An alternative to the above is to use the full capability of the propulsion system to decrease the trip time, or to increase the mission payloads as shown in fig. 8.

The solid line of fig. 8 gives the payload that can be delivered to Venus (excluding 10,000 lbs allowed for an atmospheric probe). While in 1980 30,000 lbs can be carried, in the other opportunities this same vehicle could carry 80,000 to 100,000 lbs. Another option to increasing the Venus payload is to increase the command module weight. For the 1980 mission the command module has a weight of 60,000 lbs; this could be increased to 80,000 or 100,000 lbs in the other opportunities.

It is concluded from this study of the effect of departure date that a standardized vehicle could be designed to perform a Venus orbiting mission in any two-year period.

Comparison with Mars Missions

Thus far, Venus missions have been discussed with particular reference to the most difficult opportunity, 1980 (c.f., fig. 7). Corresponding results for the Mars stopover mission, also with an elliptic parking orbit and 40 days stay time, are presented in Table III, for the easiest launch year, 1986. On the basis of identical payloads and stage performance factors, the easiest Mars mission weighs 2.4×10^6 lbs, or is 70% heavier than the hardest Venus mission. In more representative years the disparity is considerably larger.

The above comparison was based on an orbiting mission to Mars. It is generally felt that the final objective of a manned flight to Mars should be a manned landing and surface exploration. Such a mission would be still heavier than the orbiting mission and could best be done using nuclear propulsion for some of the stages. A manned landing on Venus is not now under consideration, and the orbiting mission can be done for an acceptable weight using Apollo level technology. This suggests that in terms of difficulty and timing, the Venus orbiting mission has a place ahead of the Mars orbiting and landing missions.

CONCLUDING REMARKS

A study has been made of the manned orbiting stopover roundtrip mission to Venus in the 1975 to 1986 time period. The following results were obtained.

1. A typical trip in 1980 has the following characteristics:

Total trip time	565 days
Stay time at Venus	40 days
Earth atmosphere entry velocity	47,000 fps
Venus parking orbit	
Periapse, Venus radii	1.1
Apoapse Venus radii	20.9
Time below 3 Venus radii	2 days
Initial weight in Earth orbit for Apollo level of technology	1.4×10^6 lbs

2. Essential to achieving low initial weights is a highly elliptic ($e = 0.9$) parking orbit at Venus. The elliptic parking orbit may adversely affect information gathering. Further study of the best tradeoffs between parking orbit ellipticity, stay time at Venus, and weight of observation equipment is required.

3. A Venus mission can be accomplished using Apollo level technology. S II stages can possibly be used for the Earth departure maneuver. One new stage using Earth-storable propellants is required for the Venus arrival and departure maneuvers.

4. While the Venus orbiting mission can be accomplished using the Apollo level of technology, reductions in weight are possible using advanced propulsion. For example, using a nuclear rocket stage for the Earth departure maneuver can reduce the initial gross weight by 30 percent. If, in addition, OF_2-CH_4 stages are used for the maneuvers to arrive and depart Venus, a total weight reduction of 50% is possible.

5. A single vehicle design for the 1980 launch opportunity can accomplish the Venus mission in any other synodic period.

6. To accomplish a Mars orbiting mission in the easiest year would require a vehicle 70% heavier than that for the Venus orbiting mission in the most difficult year. The disparity can be much larger in other years.

REFERENCES

1. Anon: Space Research-Direction for the Future. Report by the Space Science Board (H. H. Hess, Chairman), Woods Hole, Mass. (1965).

2. Plummer, W. T. and Strong J.: Conditions on the Planet Venus. Astronautica Acta, Vol. II No. 6 (1965).

3. Anon: Manned Mars and Venus Exploration Study. General Dynamics/Convair Report No. GD/C AOK 65-002-2 (1965) (Contract NAS 8-11327)

4. Anon: Space Flight Handbook Vol. III: Planetary Flight Handbook NASA SP-35, 1963.

5. Luidens, R. W. and Miller, B. A.: Efficient Planetary Parking Orbits with Examples for Mars. NASA TN D-3220 (1966).

6. Anon: Program 624A-Standard Data Book for Titan IIIA and IIIC Vehicle Performance Calculations. Aerospace Corp. Report No. TOR-269(4116-22)-4 Revision VII, 1 Feb. 1966.

7. NASA-Marshall Space Flight Center: Saturn V Launch Vehicle Design Data Reissued July 15, 1964.

8. Willis, E. A., Jr.: Finite-Thrust Escape from and Capture into Circular and Elliptic Orbits. NASA TN D-3606 (1966).

9. Luidens, R. W., et al: Manned Mars Landing Mission Using High-Thrust Rockets. NASA TN D-3181 (1965).

10. Willis, E. A., Jr.: Optimization of Double-Conic Interplanetary Trajectories. NASA TN D-3184 (1966).

11. Powell, M. J. D.: An Efficient Method for Finding the Minimum of a Function of Several Variables Without Calculating Derivatives. The Computer Journal Vol. 7 pp. 155-162, (1964).

TABLE I PROPULSION STAGE INPUTS

Item	Earth departure stages — Propulsion technology: Apollo	Earth departure stages — Propulsion technology: H_2-O_2	Earth departure stages — Propulsion technology: Nuclear	Venus arrival and departure stages — Propulsion technology: Apollo	Venus arrival and departure stages — Propulsion technology: OF_2-CH_4	Midcourse stages — Propulsion technology: Apollo	Midcourse stages — Propulsion technology: Adv. Chem.
Vehicle thrust to weight ratio, F/W_G	0.4	0.4	0.2	0.2	0.2	0.01	0.01
Engine thrust to weight ratio, F/W_e	0.03	0.02	0.20	0.02	0.01	0.2	0.1
Thrust structure % of transmitted load	0.01	0.01	0.01	0.01	0.01	0.1	0.05
Engine specific impulse, I_s (sec.)	425	460	800	320	400	285	380
Tank fraction % of propellant weight	0.09	0.06	0.12	0.06	0.04	0.3	0.2
Interstage structure % of transmitted load	0.02	0.02	0.02	0.02	0.02	none	none
$\triangle V$ allowances gravity losses % of impulsive $\triangle V$ (typ.)	0.04	0.04	0.07	0.02	0.02	none	none
Trajectory control and launch or arrival window $\triangle V$ (mi/sec)	0.10	0.10	0.10	0.10	0.10	0.070	0.070

TABLE II Payload Weights

1)	Earth Re-entry vehicle* . . . . (includes crew and stored data)	14,000 lbs
2)	Life Support module*	66,000 lbs + 50 lbs/day
3)	Scientific payload to Venus orbit	30,000 lbs
4)	Venus atmospheric entry probes	10,000 lbs
	Total payload	120,000 lbs + 50 lbs/day

*From Reference 9

TABLE III Comparison of Venus Orbiting Stopover Roundtrip in 1980 with Similar Mars Trip in 1986. (Inputs from Tables I & II. Apollo level of propulsion technology, Parking orbit: r_P/r_{PLANET} = 1.1, e = 0.9)

	Venus	Mars
Launch year	1980	1986
Total trip time	565	451
Atmospheric entry velocity at Earth return, fps	48,000	52,000
Inbound leg time, days	320	252
$\triangle$V to leave destination planet, mi/sec	1.14	2.35
Weight at beginning of destination planet departure maneuver, lbs	197,000	394,000
Stay time at planet, days	40	20
$\triangle$V to arrive at destination planet, mi/sec	0.64	0.97
Weight at beginning of destination planet arrival maneuver, lbs	332,000	740,000
Outbound leg time, days	205	178
$\triangle$V to leave Earth orbit, mi/sec	2.80	2.36
Initial weight in Earth orbit, lbs	1.41×10^6	2.43×10^6

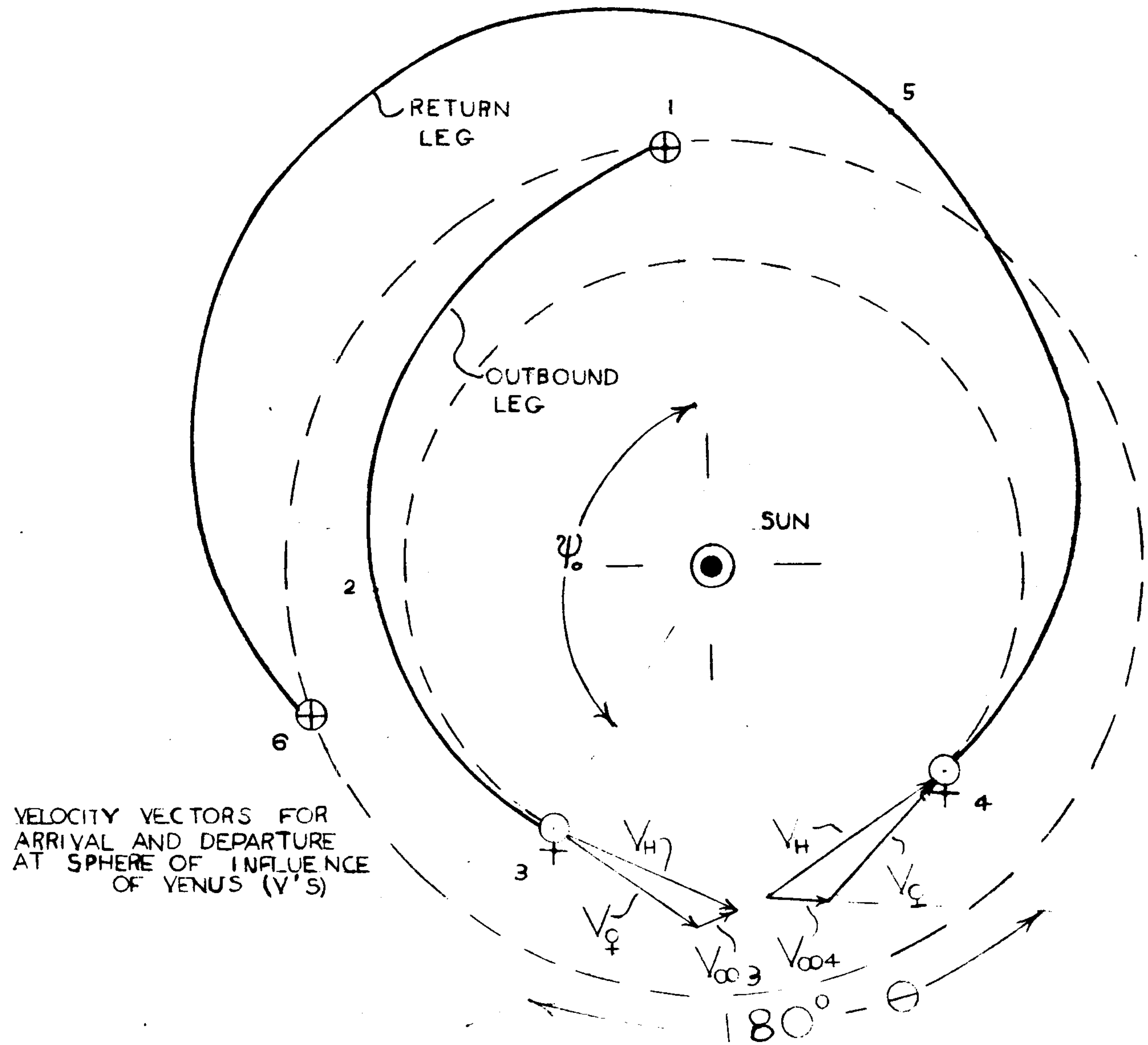


Figure 1 - Typical Heliocentric Trajectory for a Venus Orbiting Stopover Round Trip (Co-planar Trajectories Illustrated).

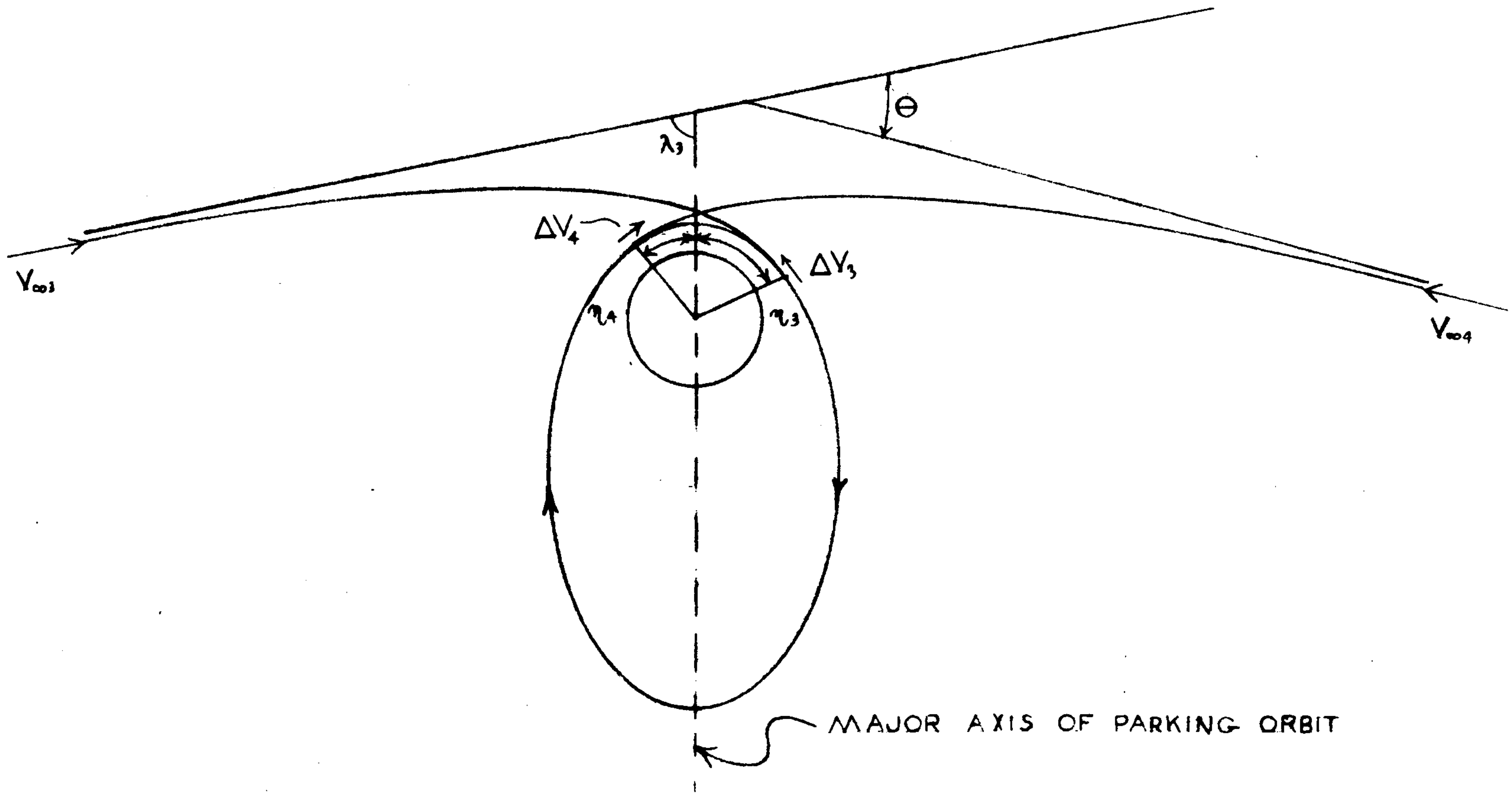


Figure 2 - Venus Capture Maneuver - Parking Orbit - Escape Maneuver Sequence (Shown in Plane of Parking Orbit).

A. LINE-OF-SIGHT COMMUNICATION ZONE

B. TIME AND OBSERVABLE SURFACE AREA BELOW h_{MAX}

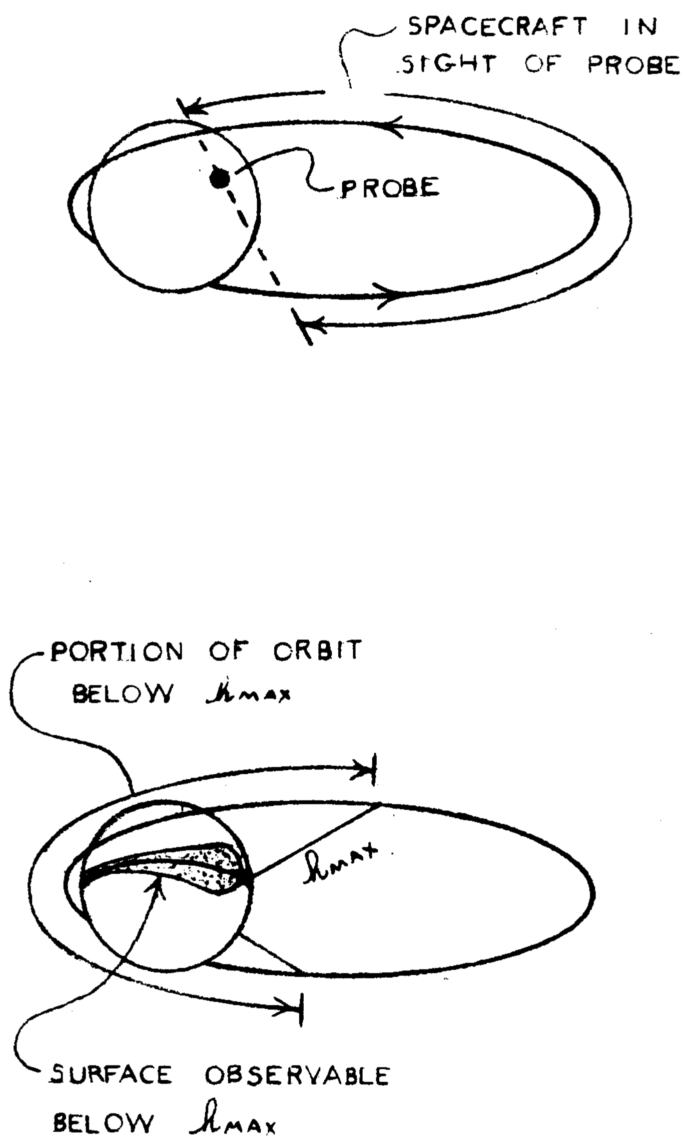


Figure 3 - Observational Criteria for Parking Orbits

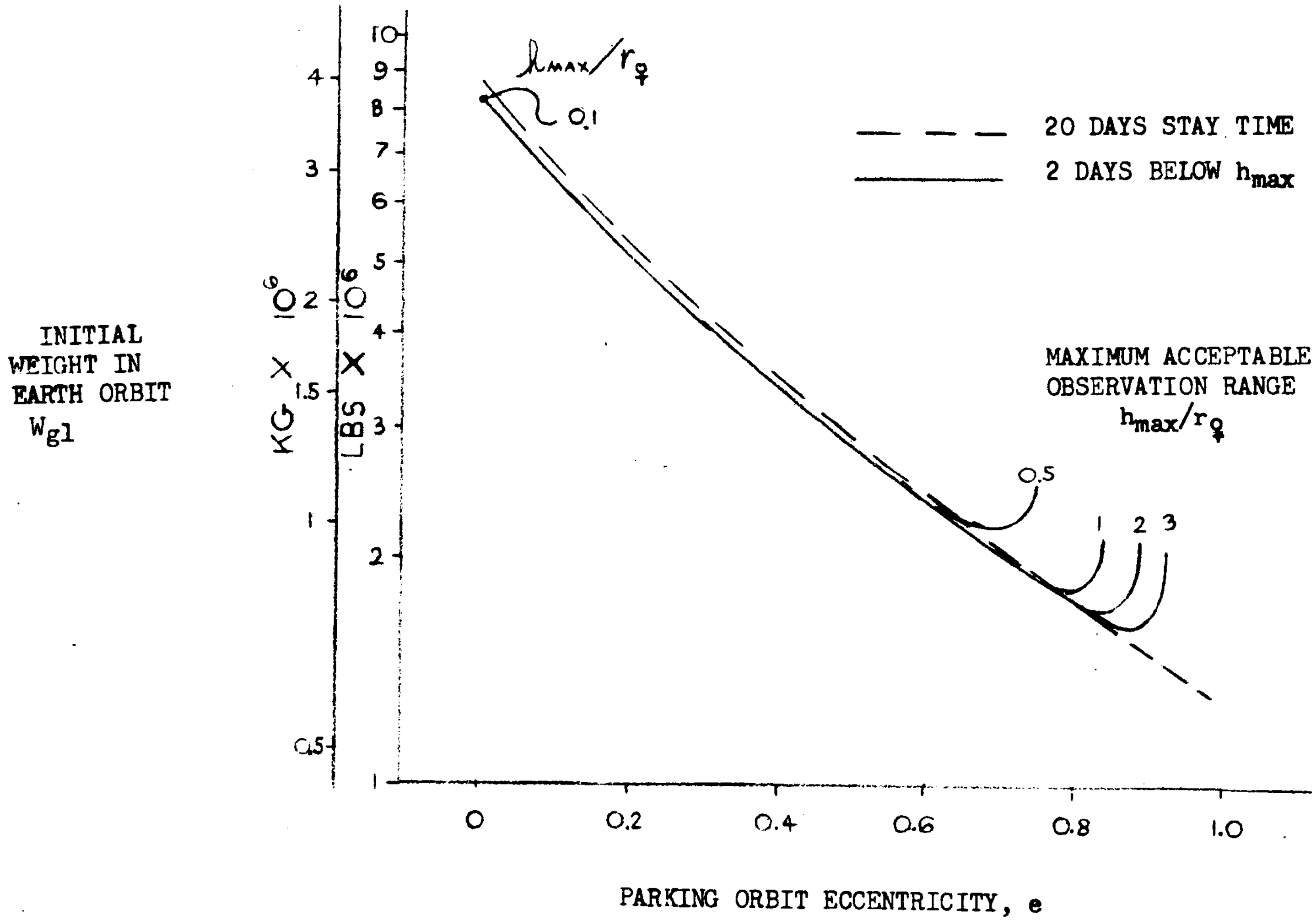


Figure 4 - Selection of Venus Parking Orbit. IR Trajectory in 1980. Optimum Trip Times. W_L = 30,000 lbs., W_{CM} = 60,000 lbs. Apollo Propulsion Technology.

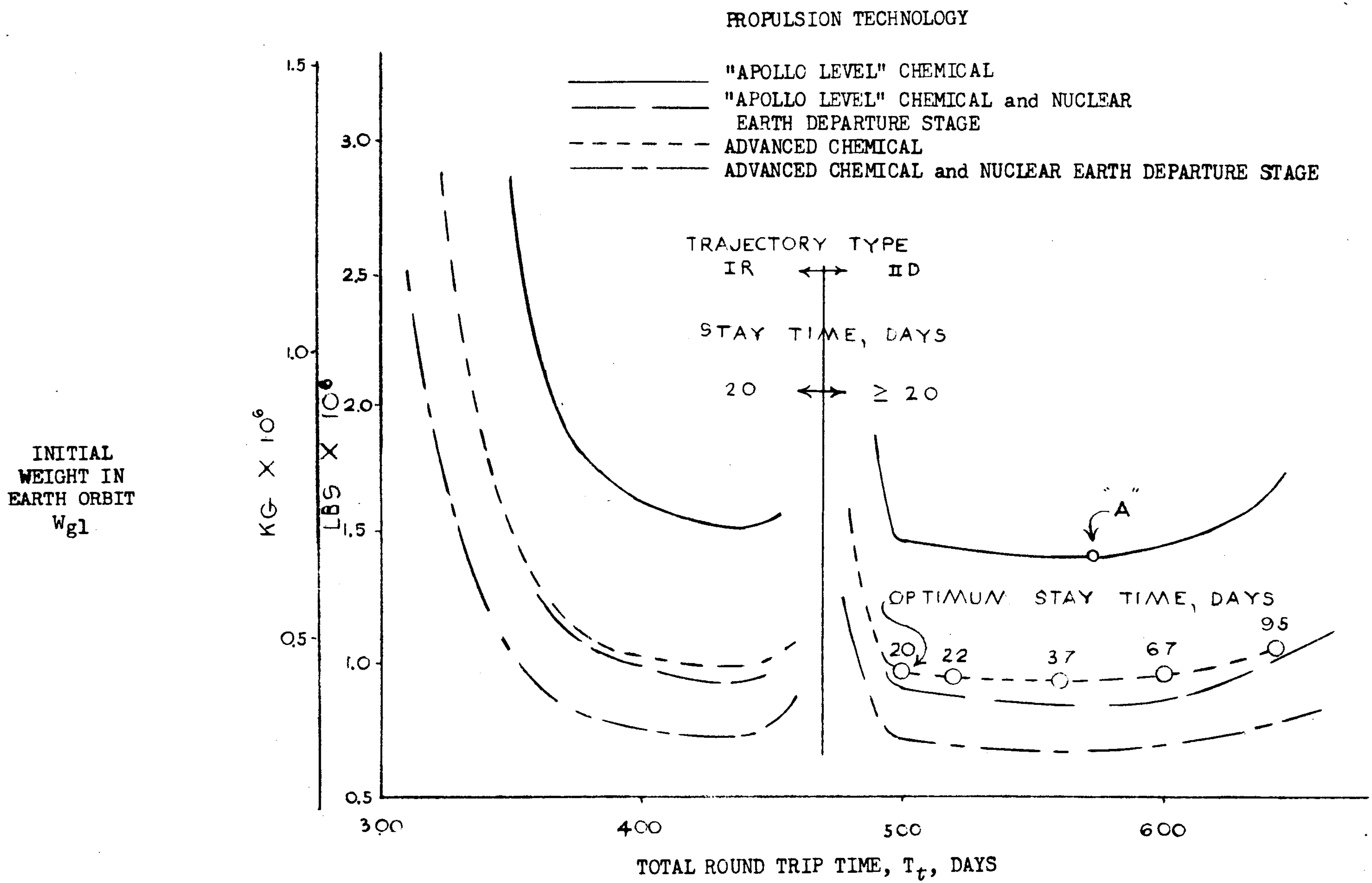
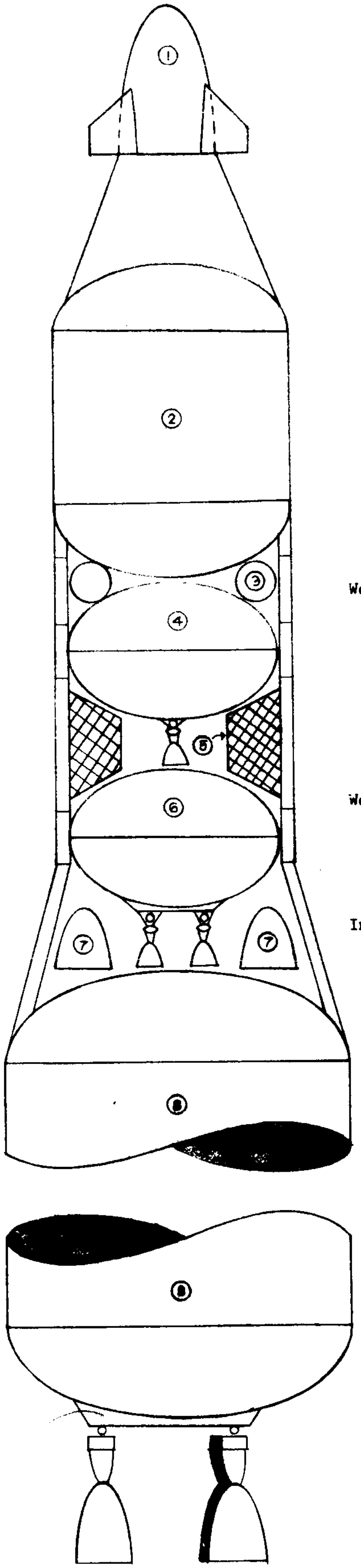


Figure 5 - Effect of Total Trip Time, Trajectory Type, and Propulsion Technology in 1980.
e = 0.9, W_L = 30,000 lbs, W_{CM} = 60,000 lbs, $V_{\oplus E} \leq$ 48,000 fps.



	ΔVs mi/sec	Weights lbs.	
1 Earth atmospheric entry system		15,250	
2 Command module		66,000	
3 Venus-Earth midcourse stage	.07	4,000	
Supplies for Venus to Earth		16,000	
4 {Venus departure stage propellant	1.14	86,970	
Venus departure stage hardware		8,150	
Weight at beginning of Venus departure maneuver			197,300
5 Venus payload		30,000	
Supplies for Venus stay		2,000	
6 {Venus arrival stage propellant	0.64	91,950	
Venus arrival stage hardware		11,050	
Weight at beginning of Venus arrival maneuver			332,000
7 Venus atmospheric entry probes		10,000	
Supplies for Earth to Venus		9,000	
8 Earth-Venus midcourse fuel in this stage	.07	12,500	
8 {Earth departure stage propellant	2.80	930,000	
Earth departure stage hardware		118,000	
Initial weight in Earth orbit			1,412,000

Figure 6 - Typical Space Vehicle; 565 Day Venus Orbiting Stopover Round Trip in 1980, e= 0.9. 40 Day Stay at Venus, Type II-D Trajectory. Apollo Level of Propulsion Technology. See Tables I and II for Other Inputs.

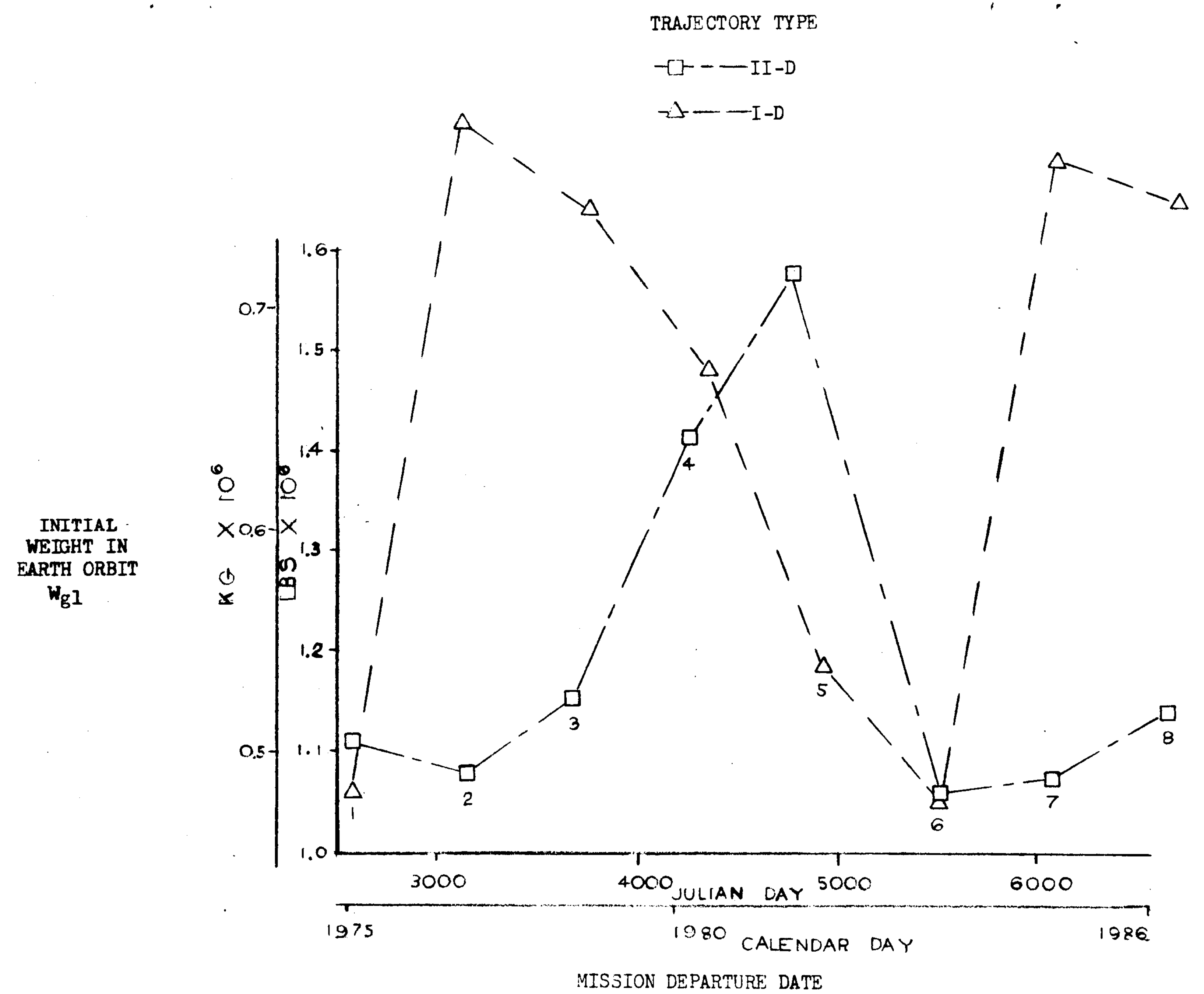


Figure 7 - Effect of Departure Year on Minimum Initial Weight in Earth Orbit. Apollo Level of Propulsion Technology. Parking Orbit, $r_p/r_♀ = 1.1$, $e = 0.9$. Venus Stay = 40 days, W_L = 30,000 lbs, W_{CM} = 60,000 lbs.

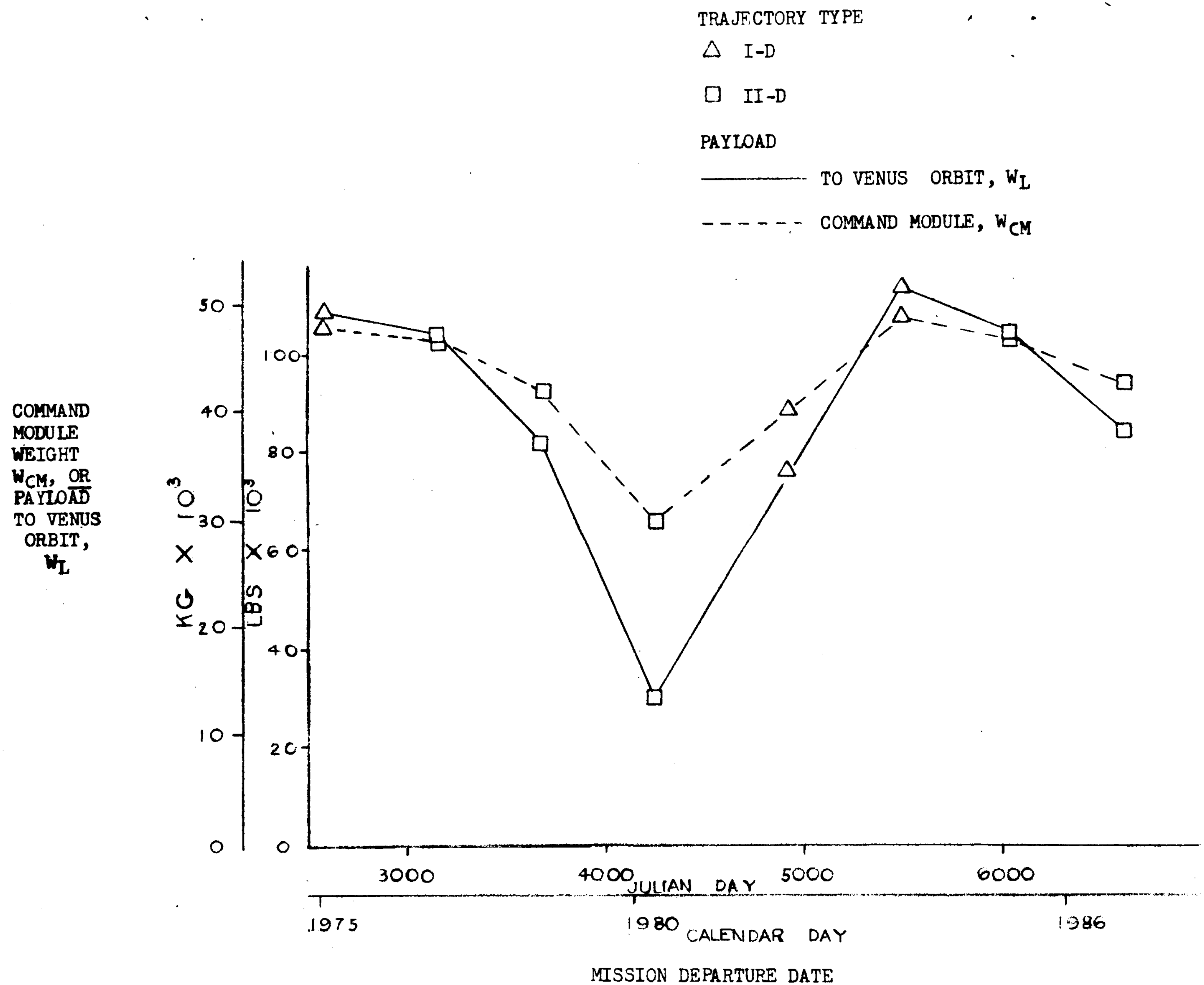


Figure 8 - Effect of Departure Date on Payload Capability of Vehicle of 1.5 million lb. Initial Weight in Earth Orbit. Apollo Level of Propulsion Technology. Parking orbit; $r_p/r_♀ = 1.1$, $e = 0.9$. Venus stay 40 days.