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SUMMARY OF SATURN SWINGBY MISSIONS TO URANUS

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16. Abstract

The report summarizes the interplanetary trajectory characteristics for missions to Uranus, which employ an intermediate swingby of Saturn to reduce the total trip time. Opportunities for such swingby missions will occur from 1979 through 1987 and not again until 2025. The general trajectory characteristics (C_3; departure, swingby, and arrival dates; swingby radius; and arrival speed) are evaluated, and payload and launch window information for a Titan IIIE/Centaur/TE-364-4 class launch vehicle is provided.

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SUMMARY

The report summarizes the interplanetary trajectory characteristics for missions to Uranus, which employ an intermediate swingby of Saturn to reduce the total trip time. Opportunities for such swingby missions will occur from 1979 through 1987 and not again until about 2025. The general trajectory characteristics (C_3; departure, swingby, and arrival dates; swingby radius; and arrival speed) are evaluated, and payload and launch window information for a Titan IIIE/Centaur/TE-364-4 class launch vehicle is provided.

INTRODUCTION

The trip time for missions to the outer planets increases with the radius of the planetary orbit. Beyond Saturn, calculated trip times exceed the capabilities of currently available launch vehicles and spacecraft, for which 5 to 7 years' reliable performance is considered maximum. Swingbys of Jupiter or Saturn provide one means of achieving a reduction in trip time. Launch opportunities for such missions to Uranus with Jupiter swingbys occur from 1978 to 1983, with trip times in the later years of that period approaching those of direct trips due to the distant (120-200 r_J) passages at Jupiter (ref. 1); swingbys of Saturn to Uranus are possible between 1979 and 1987, with the early opportunities in that period constrained by the requirement to clear Saturn's rings.

In effect a handbook of Saturn swingbys to Uranus, this report provides the data necessary to select launch opportunities of interest for a particular mission and to determine the principal mission constraints. The data also are interpreted in terms of present launch vehicle payload capability in the last two sections.

GENERAL TRAJECTORY CONTOURS

Heliocentric trajectories between Earth and Saturn and subsequent trajectories between Saturn and Uranus were calculated by a patched conic digital computer program similar to the program described in reference 1. Ephemeris data for Earth, Saturn, and Uranus were also taken from that report.

Trajectory data are shown in contour diagrams of Uranus arrival date vs. Earth departure date for each of the eight launch opportunities from 1979 through 1987 (figs. 1–8). All dates are measured in the Julian calendar. The data consist of the following contours: (1) the Earth departure hyperbolic excess speed V_∞, in emos; (2) the Saturn swingby date, *SD*; (3) the Saturn swingby radius r_p, in Saturn radii; and (4) the Uranus arrival hyperbolic excess speed, V_a, in emos. The entire region is not available for use, however, because of the rings of Saturn, which extend in the equatorial plane 2.26 r_S; and perhaps even further ($\approx$ 5 r_S) if some recent observations are verified (ref. 2).

The launch energy C_3 is computed by multiplying V_∞ by the Earth's mean orbital speed (29.8 km/sec) and squaring the result. One parameter of concern, but not shown, is the Earth departure declination, which determines the launch vehicle azimuth and departure plane change penalties. Values between ±28.5° incur no penalty. Declinations greater than this occur for combinations of early launch date and long trip times during the 1979 and 1980 launch opportunities. The effect of this parameter is further discussed in the payload analysis section.

The use of swingby radius of greater than 2.26 r_S reveals some interesting features of the early opportunities. Figures 1 and 2 indicate that for V_∞ = 0.4 emos, the arrival date at Uranus is about the same for launches in both 1979 and 1980. In addition, launch windows of about 16 days are the maximum that can be achieved. Launch windows maximize in 1982-1989 and then reduce again for trip times of less than those for direct Uranus missions (i.e., about 3000 days). Swingby parameters at Saturn are seen to be effectively constant for a fixed arrival date at Uranus.

LAUNCH VEHICLE PAYLOAD

The utility of the preceding results in mission planning was enhanced through their application to the payload capability of the Titan IIIE/Centaur/TE-364-4 launch vehicle as shown in figure 9. A spinning class of interplanetary spacecraft (e.g., Pioneer 10 and 11) with a Viking type shroud was assumed. The TE-364-4 is spun up prior to ignition; therefore, a spin table is required on top of the Centaur stage. Spacecraft heavier than 545 kg (1200 lb) require additional interstage structure, and curve therefore is not continuous for larger payloads. Figure 9 also shows the relationship between V_∞ and C_3 for the payload range of interest.

PAYLOAD CONTOURS

Data from the preceding sections were combined to obtain the launch capability and windows for the Titan IIIE/Centaur/TE-364-4 vehicle (figs. 10 through 17). A payload range of 420 to 500 kg was selected as representative of a variety of outer planet missions (e.g., flyby or probe), and trip times were constrained to be less than those for direct Uranus missions of similar payload (3000 days).

Each figure has two parts, designated (a) launch window, and (b) passage conditions. Contours of Uranus arrival date are shown in part (a) as a function of Earth departure date for constant payload with lines of constant trip times superimposed. The curves in part (b) indicate the variations in

Saturn swingby date and the associated swingby radii. The swingby date and radius are shown for roughly the middle of the launch window. Small variations exist across the window so that the lines shown are actually narrow bands; additional data for the appropriate opportunity are provided in the opening section.

The curves of figures 10 through 17 are used as follows. Starting with a given payload requirement and a desired launch window length, part (a) provides the departure date range and the Uranus arrival date. The possibility of conjunction at either Uranus or Saturn can be checked, as well as the departure declination and its implications for launch. From the selected Uranus arrival date part (b) can be entered and the Saturn swingby date determined from the abscissa. The Saturn swingby radius for each swingby date is given on the scale to the right.

Figures 10 through 17 indicate several constraints. A swingby radius constraint of 2.26 r_S is imposed to avoid the outer limit of the ring system. Any resulting limit on the available Uranus arrival date region is shown on the swingby date line. The possibility of passage through gaps in the ring or inside the inner edge of the accepted ring system was not considered. Shaded bands denote arrival times corresponding to periods of Earth-Uranus conjunction or swingby times at Earth-Saturn conjunction; these regions are to be avoided for reasons of degraded communications and Earth-based observations.

The line where the Earth departure declination equals 28.5° (i.e., the latitude of the launch site) is shown for the 1979 and 1980 launch opportunities. For later arrival dates at Uranus, this declination is exceeded and a small payload penalty (5 kg or less) for azimuths other than 90° must be considered. For declinations greater than 33°, an additional penalty must be considered to account for the necessary "dogleg" (i.e., plane change) Earth orbit departure maneuvers. A 5° change typically reduces the payload by less than 15 kg for the class of spacecraft considered. The payload contours shown account for these penalties. For all other launch opportunities, the departure declination is less than 28.5° for the arrival-departure region shown.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif. 94035, June 22, 1973

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2. Feibelman, W. A.: Concerning the "D" Ring of Saturn. Nature, vol. 214, 1967, p. 793.

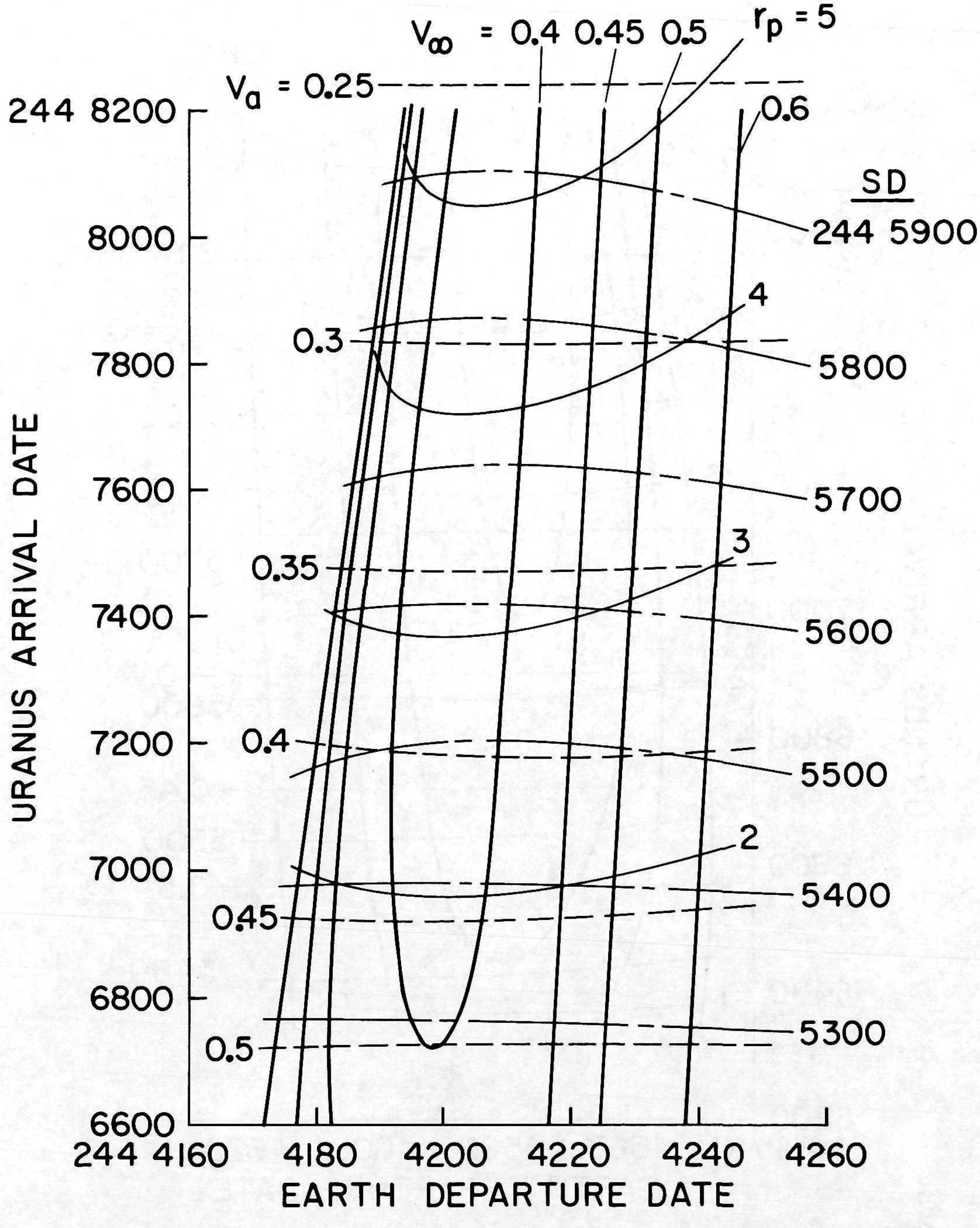


Figure 1.– Uranus missions using Saturn swingby (1979). V_∞: Departure hyperbolic excess speed, emos. *SD*: Saturn swingby date, Julian. r_p: Saturn swingby radius, Saturn radii. V_a: Uranus arrival hyperbolic excess speed, emos.

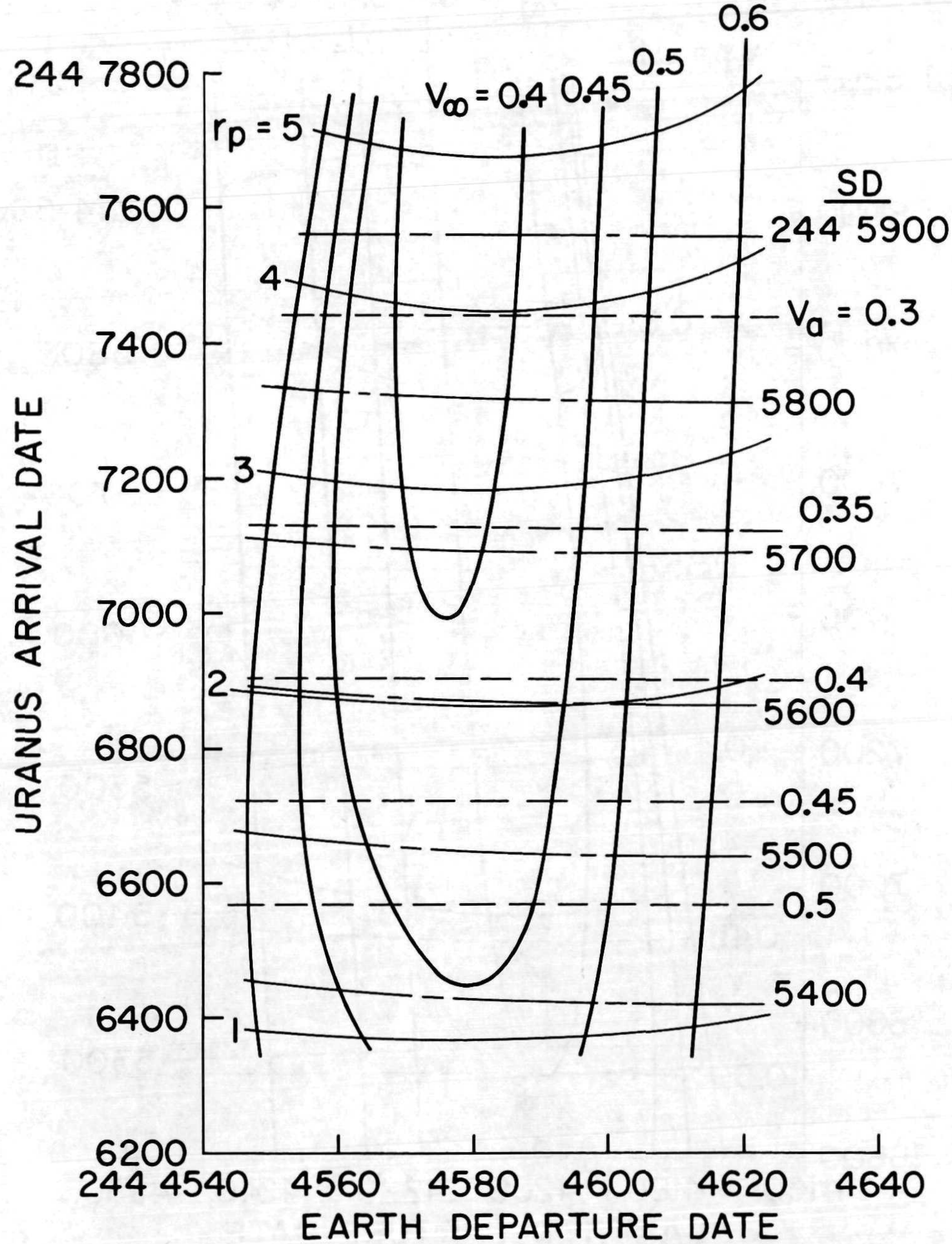


Figure 2.– Uranus missions using Saturn swingby (1980). V_∞: Departure hyperbolic excess speed, emos. *SD*: Saturn swingby date, Julian. r_p: Saturn swingby radius, Saturn radii. V_a: Uranus arrival hyperbolic excess speed, emos.

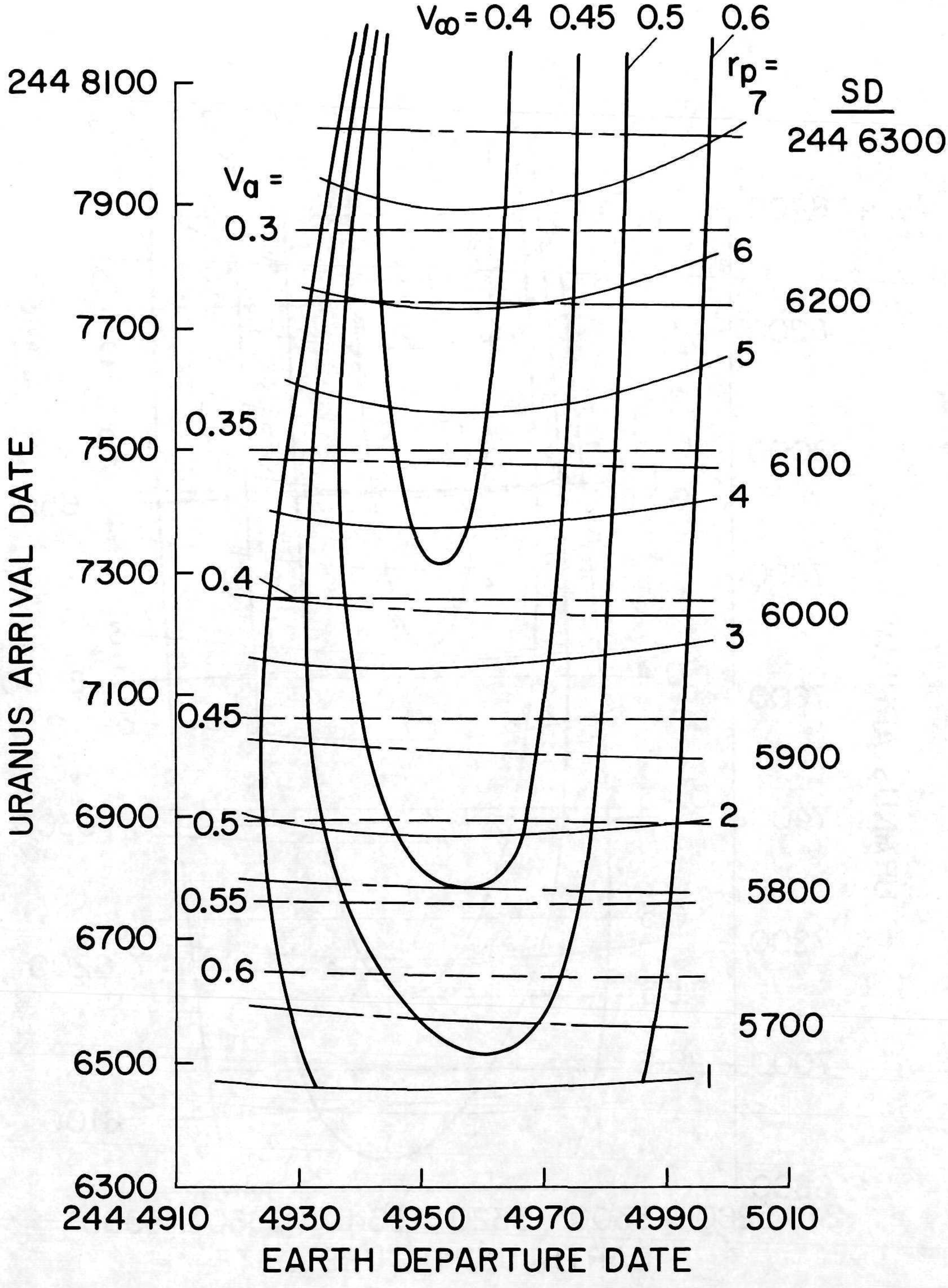


Figure 3.– Uranus missions using Saturn swingby (1981). V_∞: Departure hyperbolic excess speed, emos. *SD*: Saturn swingby date, Julian. r_p: Saturn swingby radius, Saturn radii. V_a: Uranus arrival hyperbolic excess speed, emos.

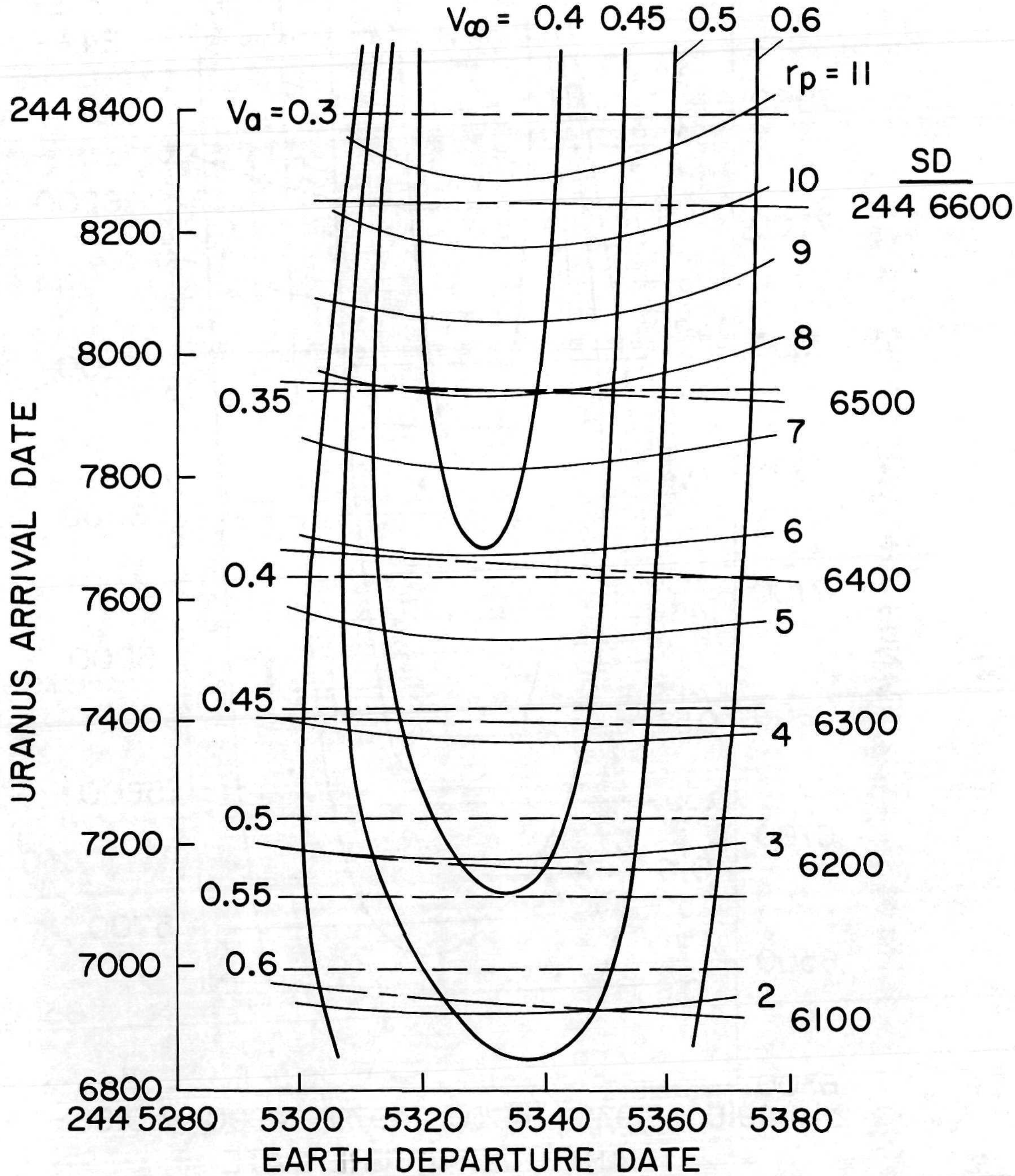


Figure 4.– Uranus missions using Saturn swingby (1982). V_∞: Departure hyperbolic excess speed, emos. SD: Saturn swingby date, Julian. r_p: Saturn swingby radius, Saturn radii. V_a: Uranus arrival hyperbolic excess speed, emos.

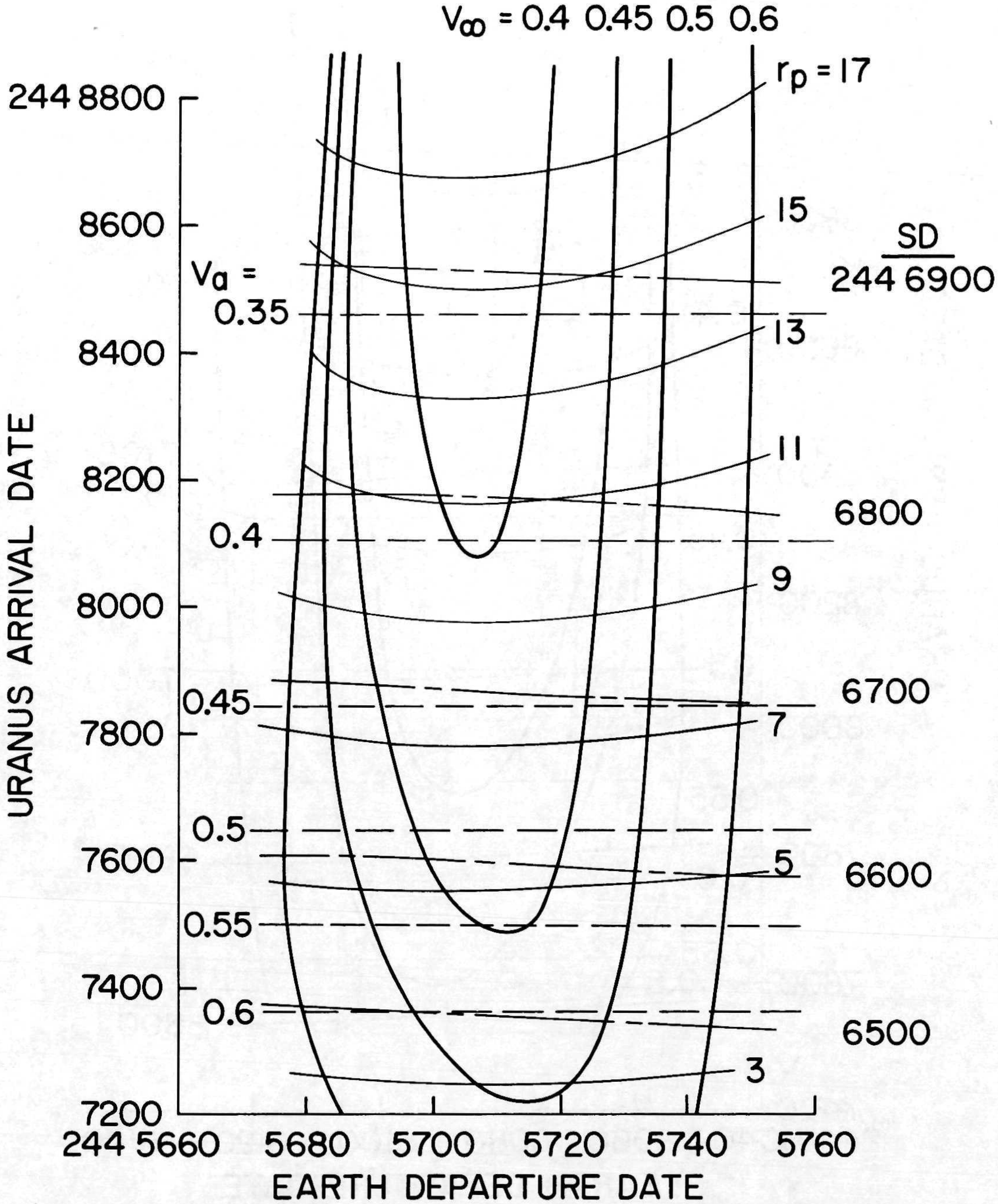


Figure 5.– Uranus missions using Saturn swingby (1984). V_∞: Departure hyperbolic excess speed, emos. *SD*: Saturn swingby date, Julian. r_p: Saturn swingby radius, Saturn radii. V_a: Uranus arrival hyperbolic excess speed, emos.

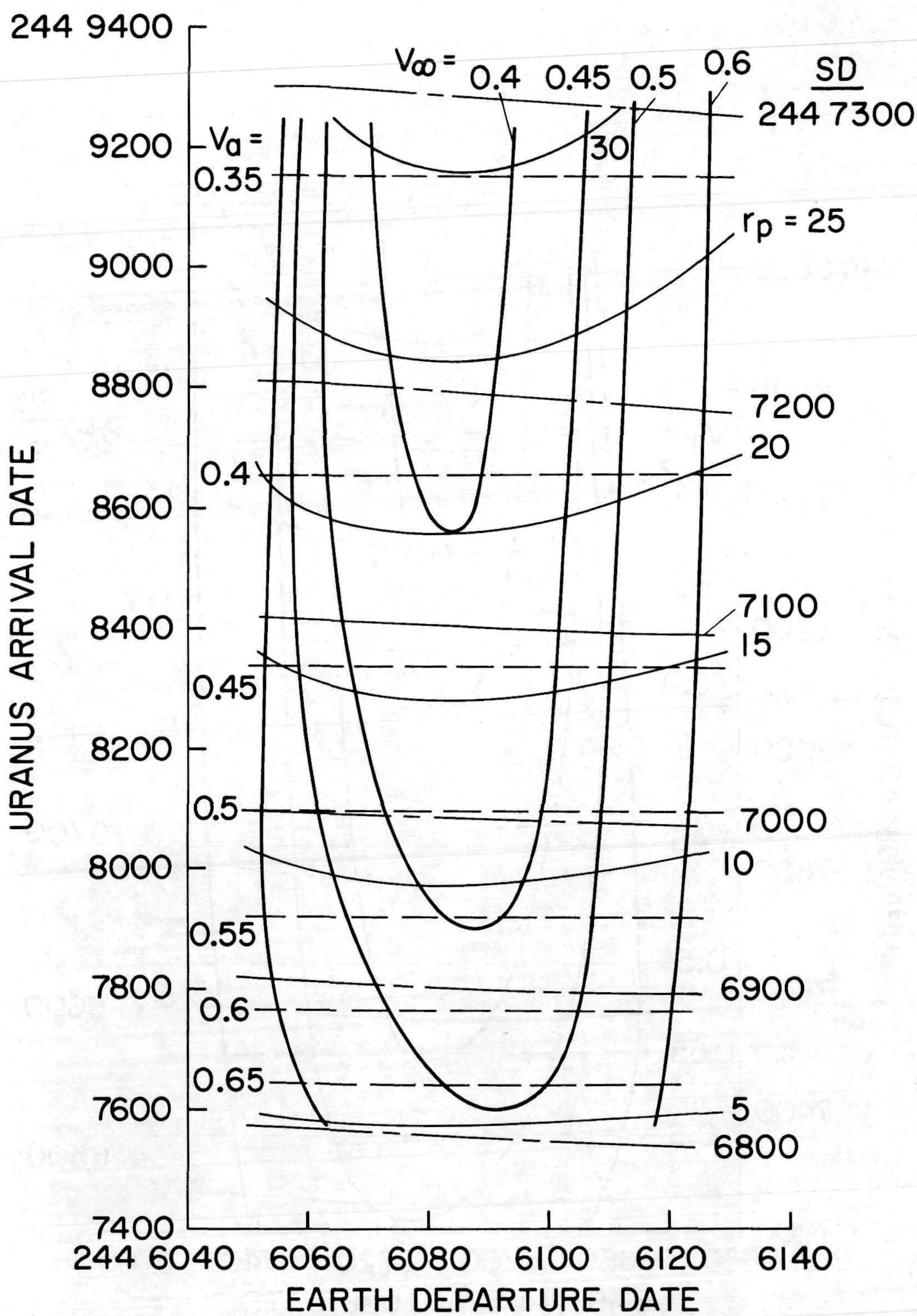


Figure 6.– Uranus missions using Saturn swingby (1985). V_∞: Departure hyperbolic excess speed, emos. *SD*: Saturn swingby date, Julian. r_p: Saturn swingby radius, Saturn radii. V_a: Uranus arrival hyperbolic excess speed, emos.

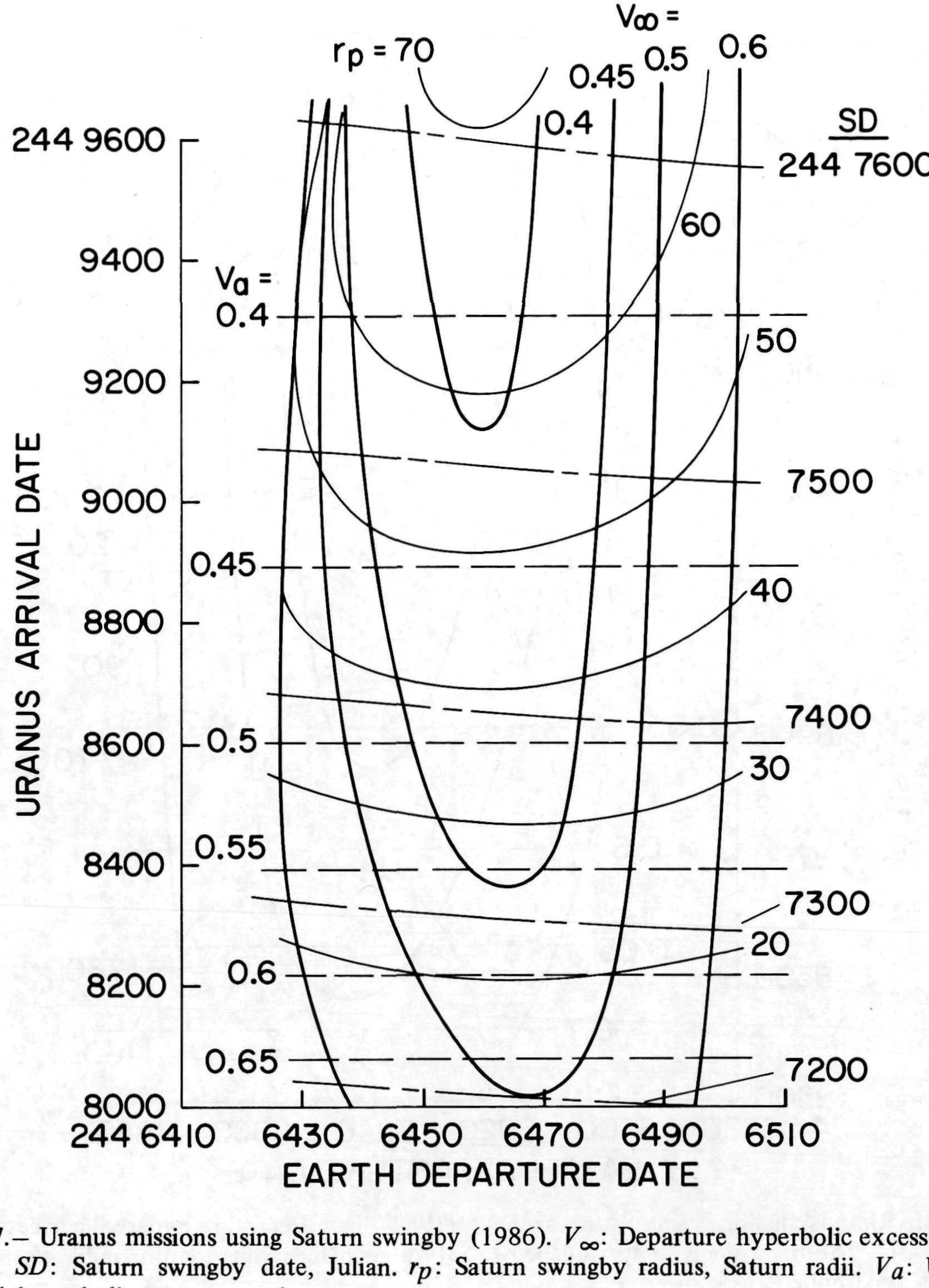


Figure 7.– Uranus missions using Saturn swingby (1986). V_∞: Departure hyperbolic excess speed, emos. *SD*: Saturn swingby date, Julian. r_p: Saturn swingby radius, Saturn radii. V_a: Uranus arrival hyperbolic excess speed, emos.

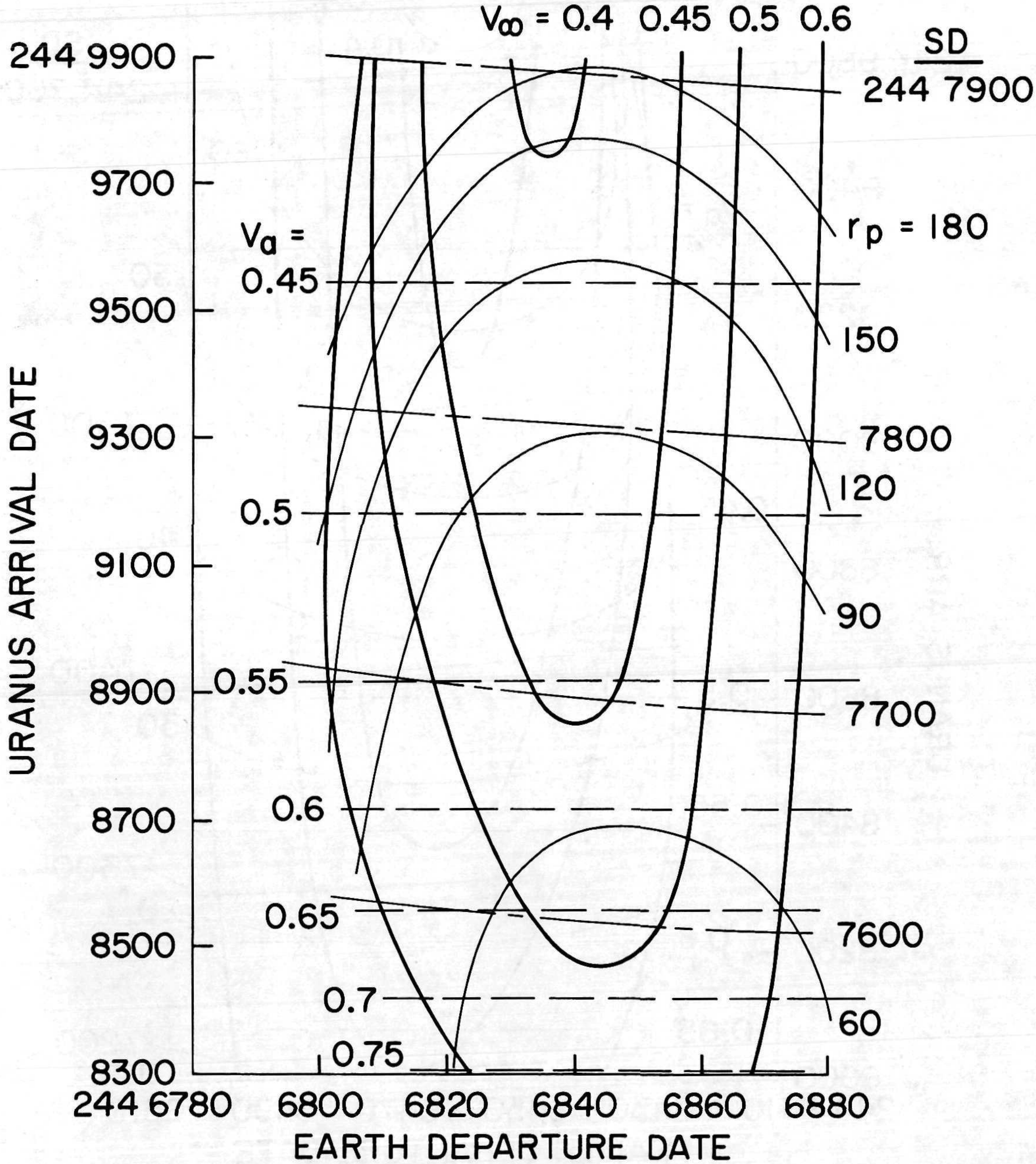


Figure 8.– Uranus missions using Saturn swingby (1987). V_∞: Departure hyperbolic excess speed, emos. *SD*: Saturn swingby date, Julian. r_p: Saturn swingby radius, Saturn radii. V_a: Uranus arrival hyperbolic excess speed, emos.

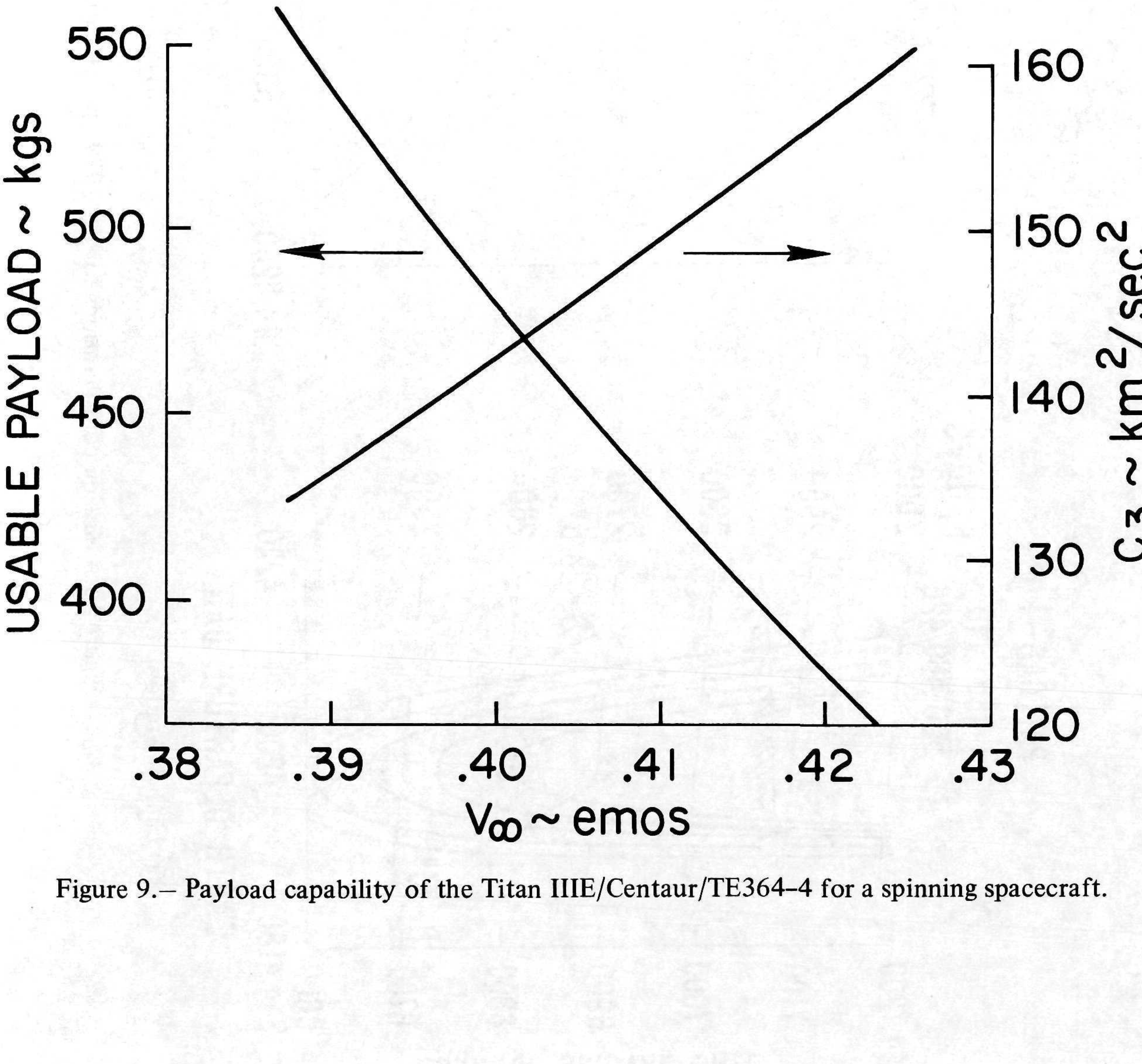
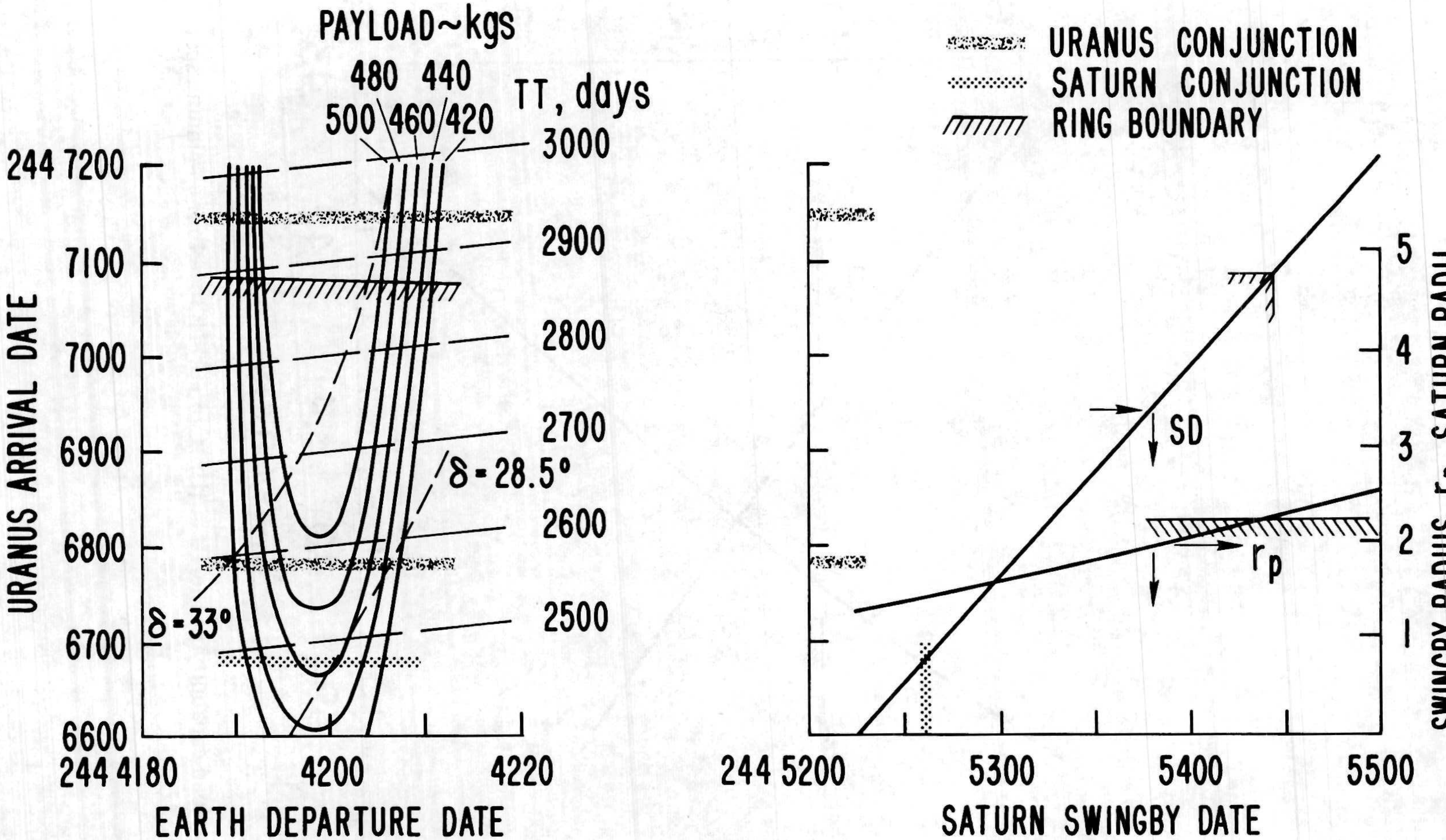


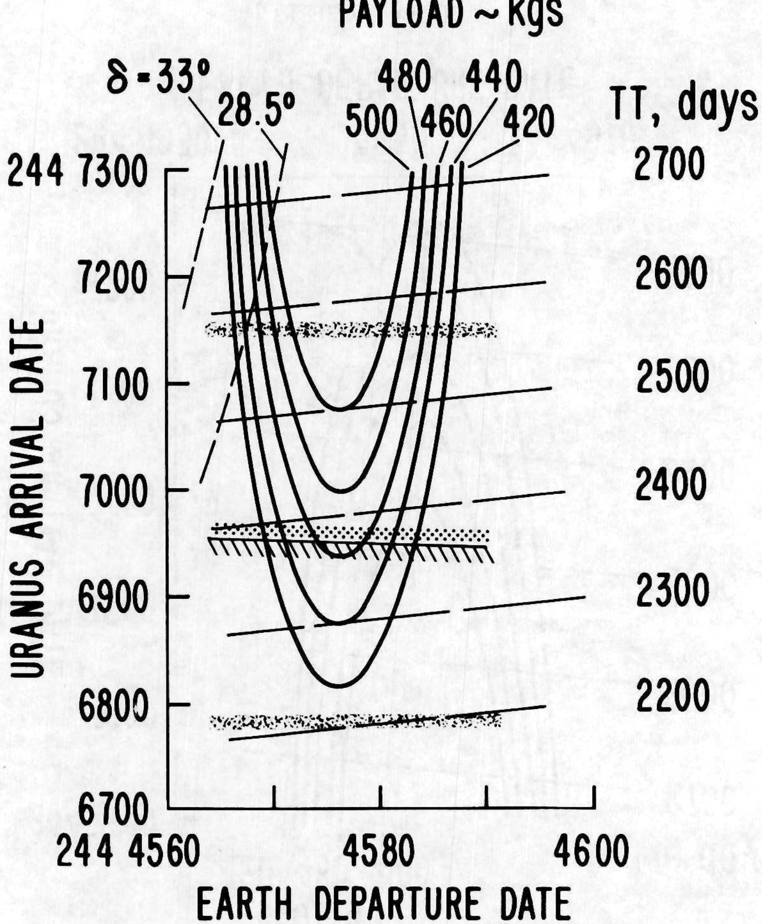
Figure 9.– Payload capability of the Titan IIIE/Centaur/TE364-4 for a spinning spacecraft.



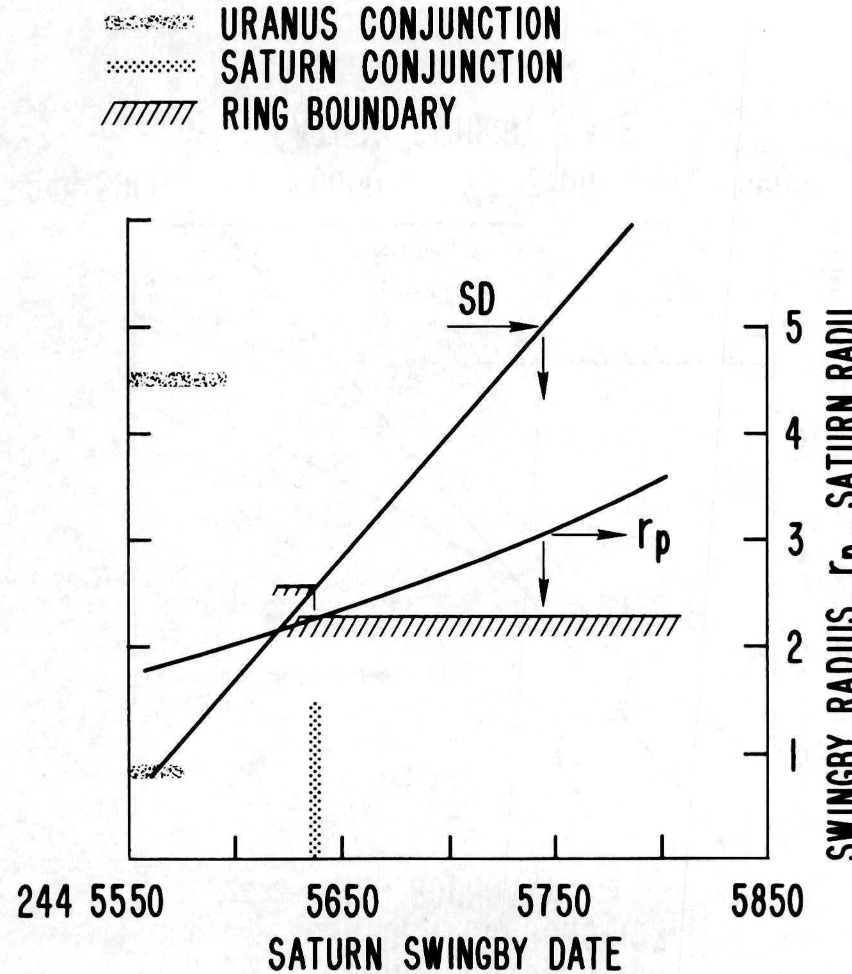
(a) Launch window.

(b) Passage conditions.

Figure 10.– Mission considerations for the 1979 opportunity.

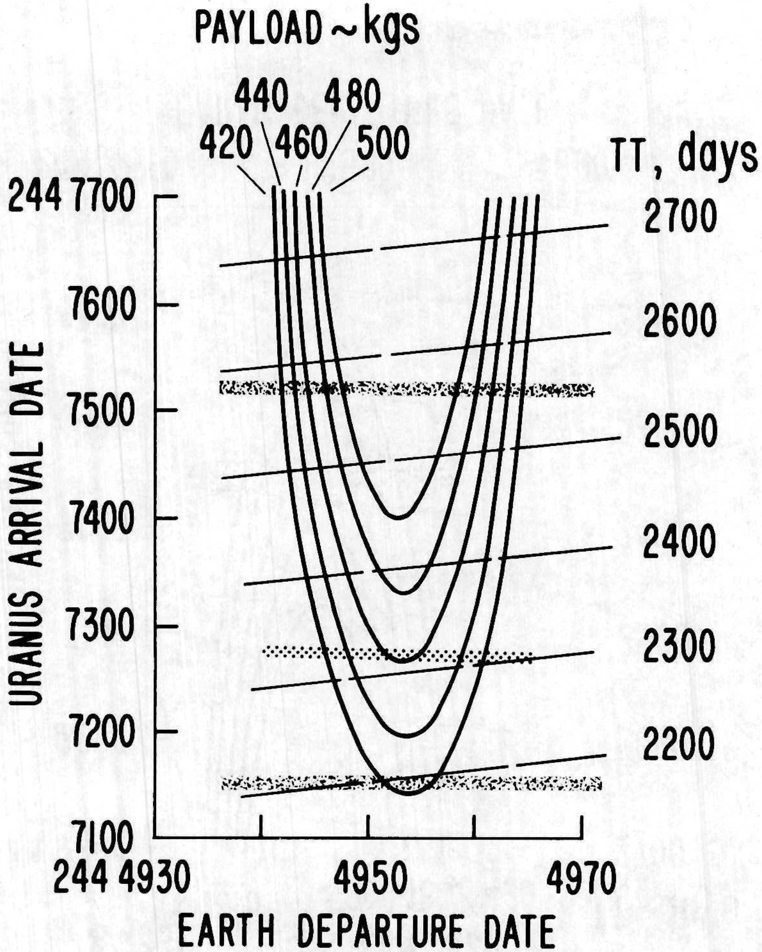


(a) Launch window.

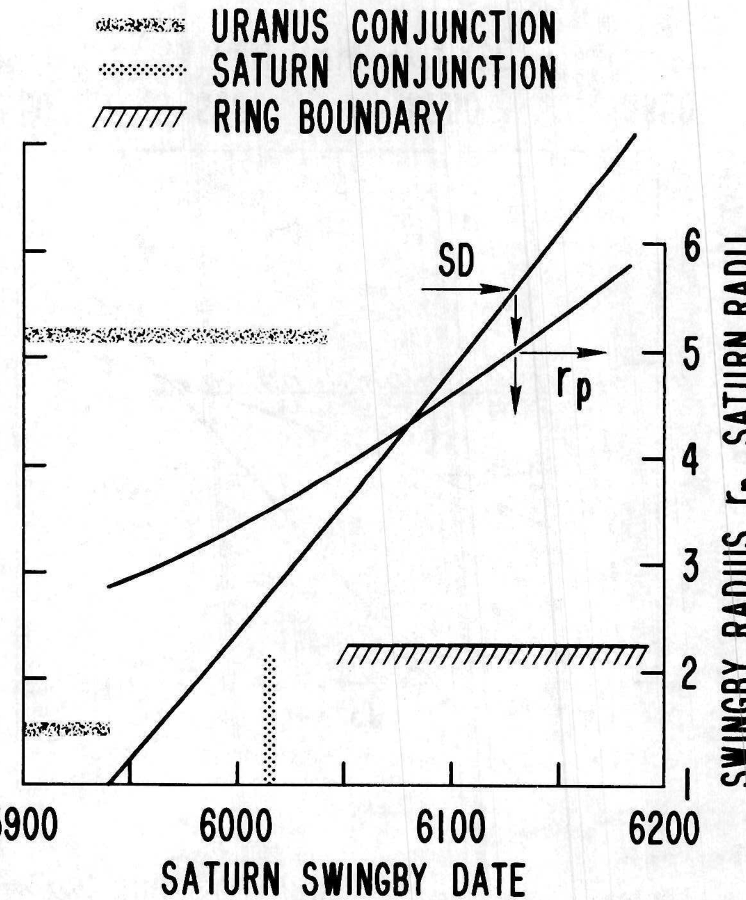


(b) Passage conditions.

Figure 11.– Mission considerations for the 1980 opportunity.

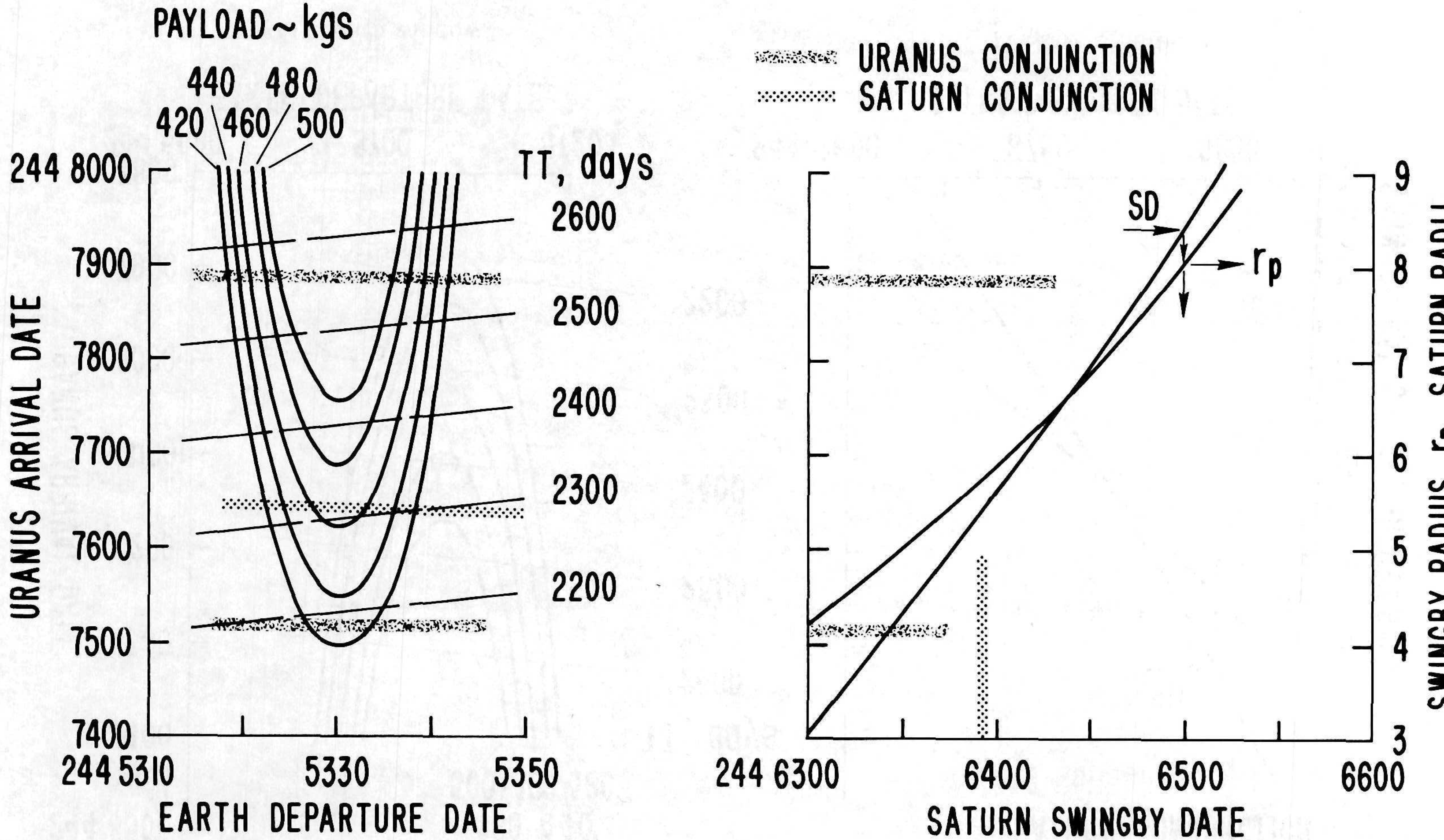


(a) Launch window.



(b) Passage conditions.

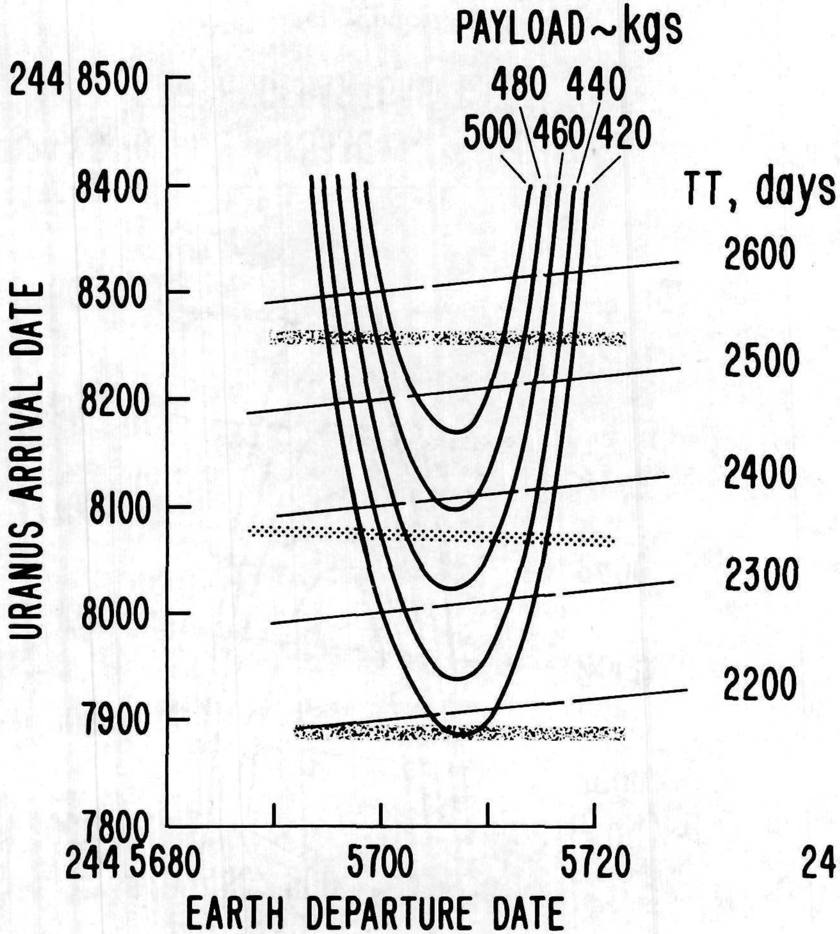
Figure 12.– Mission considerations for the 1981 opportunity.



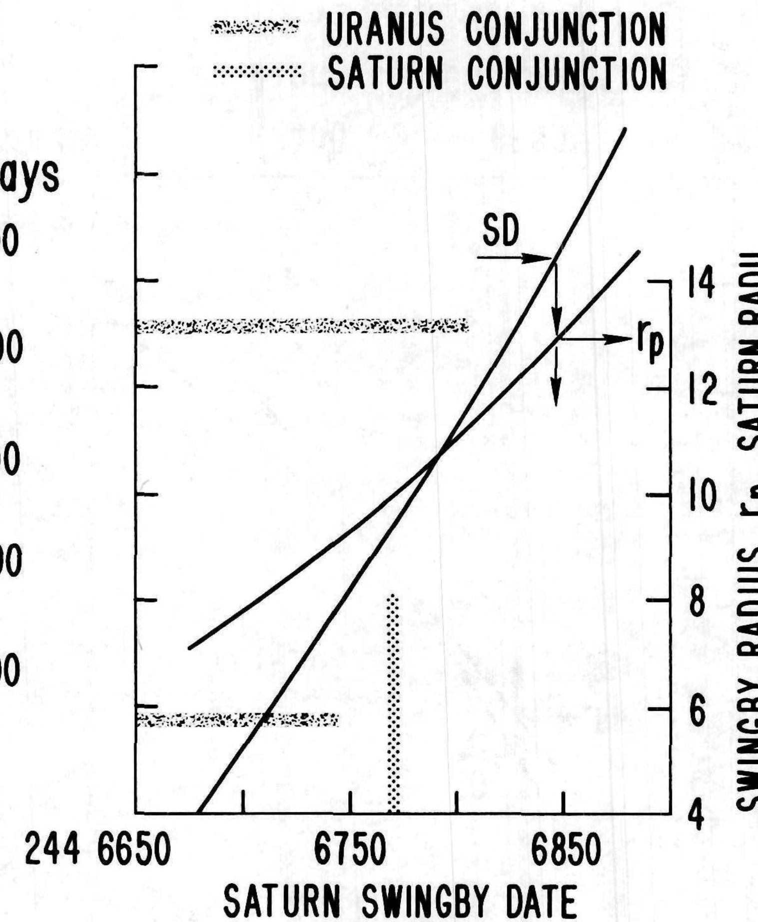
(a) Launch window.

(b) Passage conditions.

Figure 13.– Mission considerations for the 1982 opportunity.

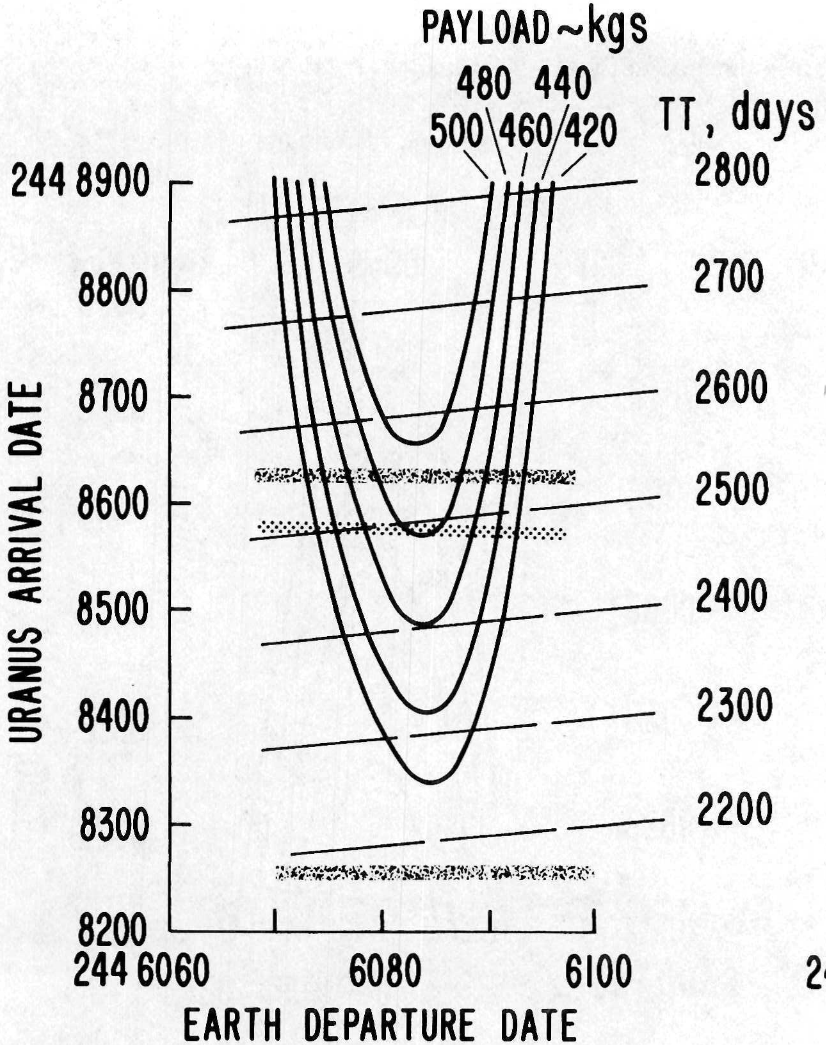


(a) Launch window.

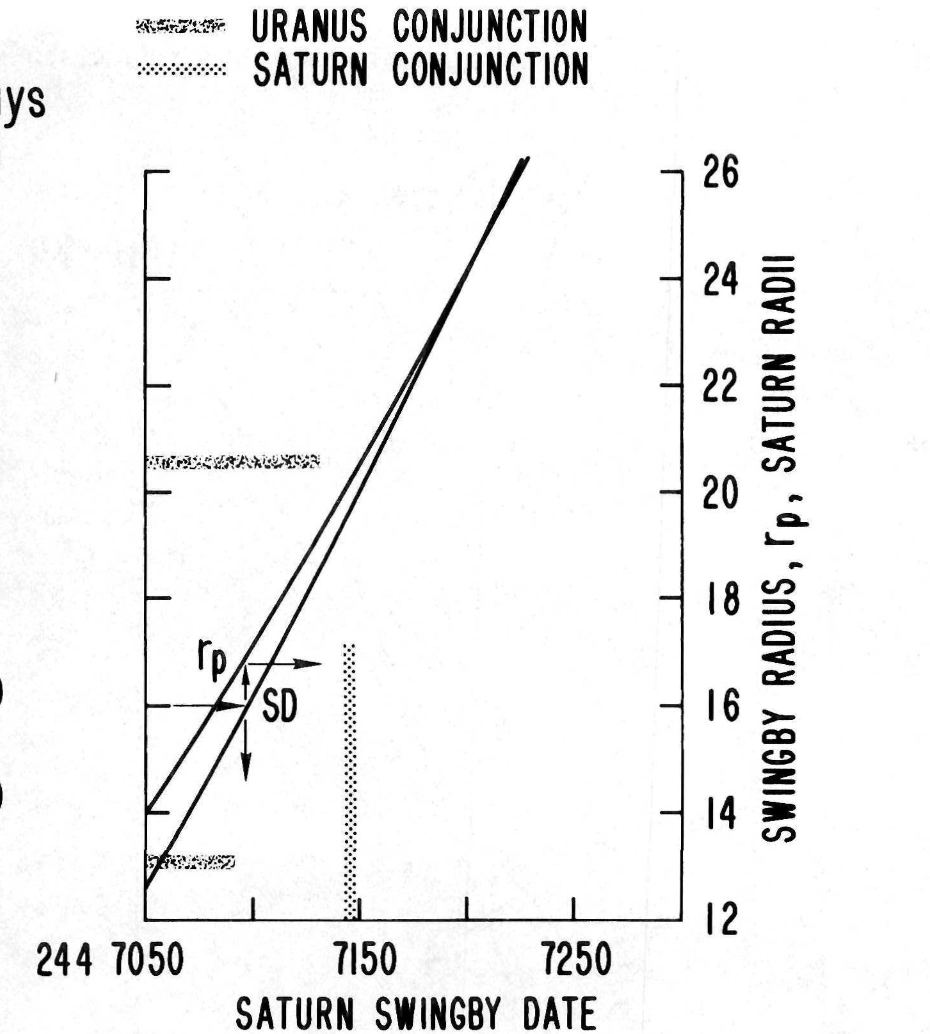


) Passage conditions.

Figure 14.– Mission considerations for the 1984 opportunity.

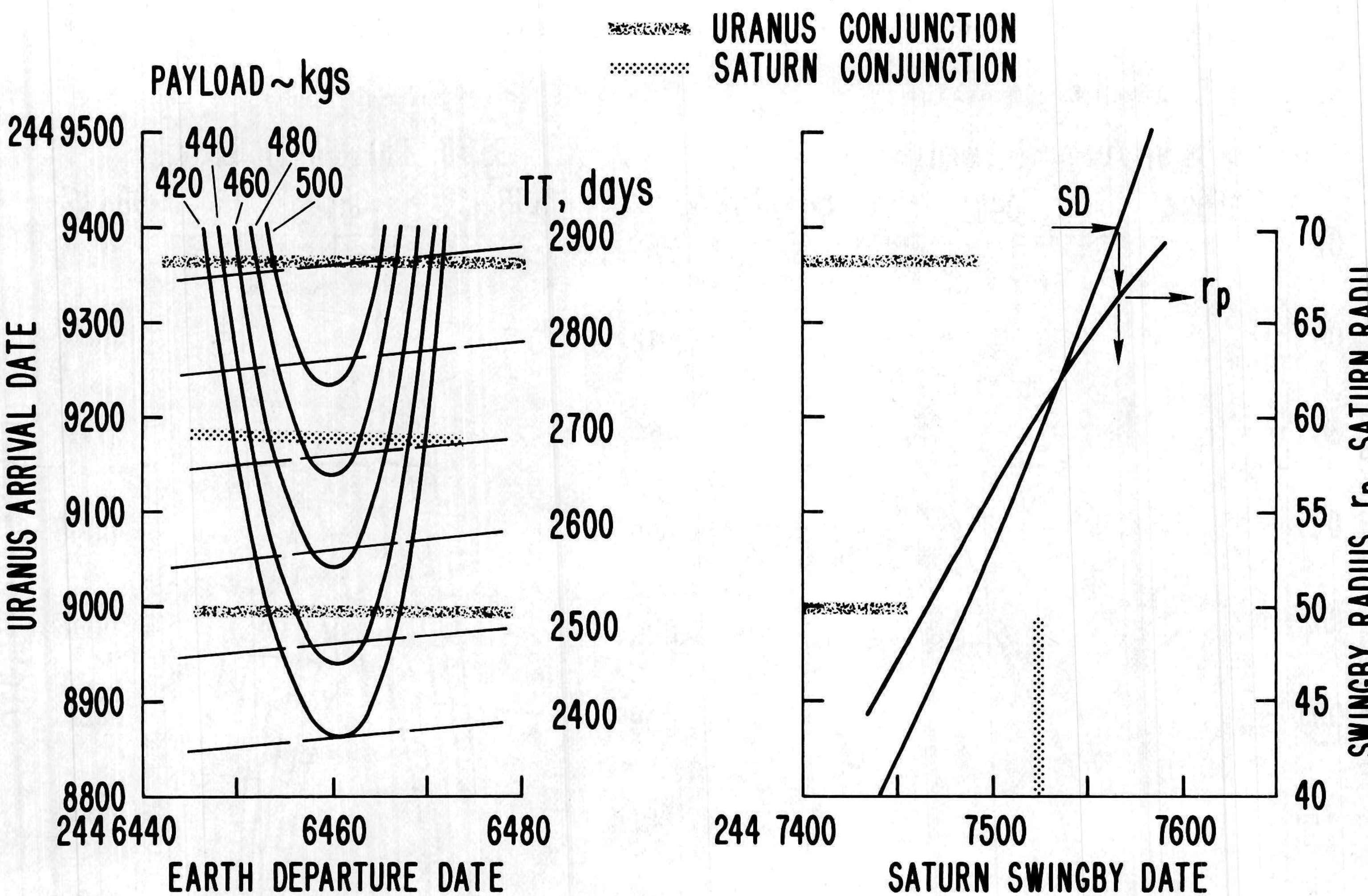


(a) Launch window.



(b) Passage conditions.

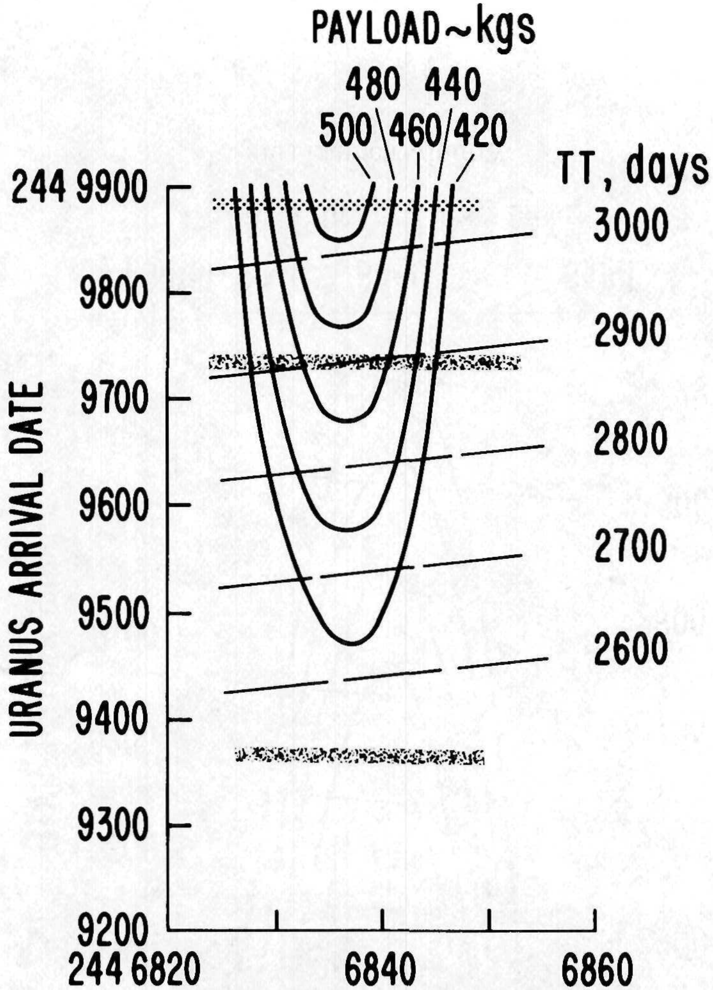
Figure 15.– Mission considerations for the 1985 opportunity.



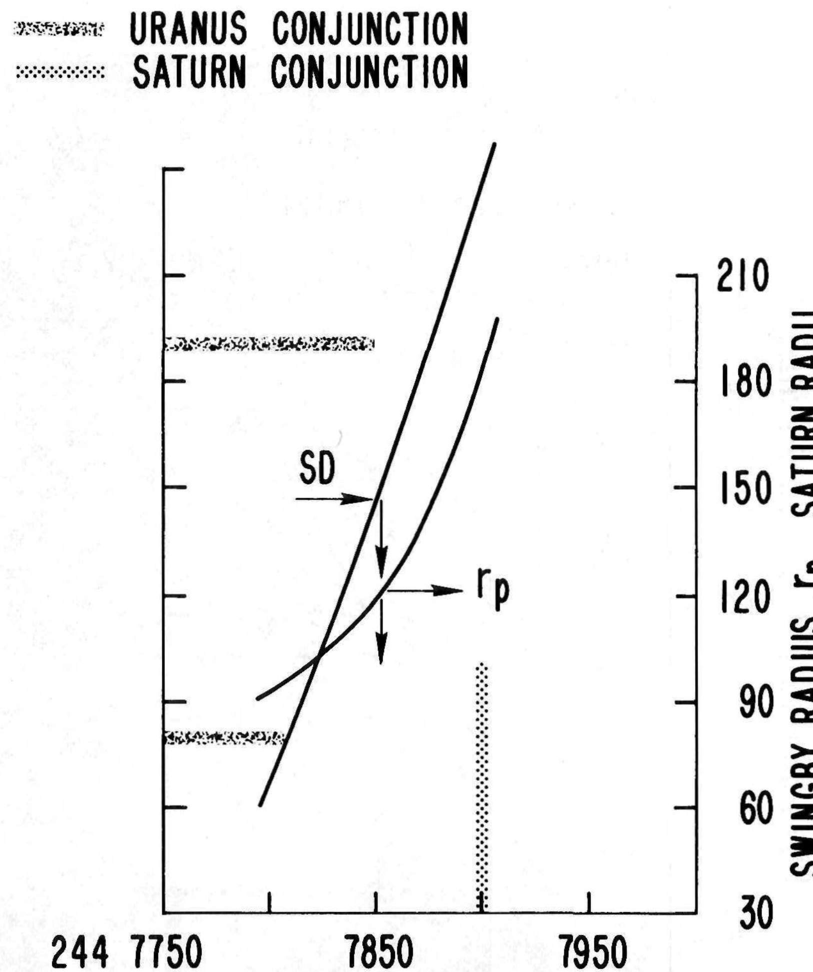
(a) Launch window.

(b) Passage conditions.

Figure 16.– Mission considerations for the 1986 opportunity.



(a) Launch window.



(b) Passage conditions.

Figure 17.– Mission considerations for the 1987 opportunity.

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