Outer Planet Mission Guidance and Navigation for Spinning Spacecraft

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Theme

THE missions analyzed in this study are: a 1979 direct Saturn; a 1980 Saturn/Uranus; and a 1980 Jupiter/Uranus. Reference 1 lists the specific nominal trajectory characteristics of the missions and all maneuver, radio, and optical navigation assumptions employed in the analysis. In general, all three missions can be characterized by high launch energies ($C_3 \approx 130$ km^2/sec^2), spacecraft launch mass of 475 kg, spinning Pioneer-type spacecraft consisting of a bus and a probe for planetary entry, and Titan IIIE/Centaur/TE-364-4 launch vehicle.

The planetary entry strategy is the deflected bus mode in which the spacecraft is aimed for planetary entry and a velocity impulse of 100 m/sec is imparted to the bus to fly by the planet. The bus serves as a communications link between Earth tracking stations and the probe descending into the planetary atmosphere measuring indigenous environmental elements.[2]

Navigation: As contrasted to inner planet missions for which poor solar radiation pressure modeling results in a corruption of the filtered state estimate of the spacecraft, outer planet mission navigation analysis must contend with small time varying attitude control leakages on board the spacecraft, Earth-based tracking station location errors, low declination trajectories, and very large planet ephemeris and mass errors. To overcome low-declination and attitude control difficulties, differenced, near-simultaneous range and range-rate data are used in conjunction with deweighted, conventional range and range-rate data[3] and an optical V-slit sensor capable of observing outer planet satellites and stars is employed to reduce the problems associated with planetary ephemeris errors. The V-slit concept utilizes a 3° cone angle sweep as the spacecraft spins to measure cone and clock angles of stars and planetary satellites acquired when their magnitude reaches 4 and terminates when their target images exceed 20 arc sec.

Maneuver Strategy: A "Full Pioneer Precession" maneuver is employed at 5 days after launch to correct the launch injection errors. A second restricted direction maneuver at 200 days before the first encounter planet's periapsis is performed to remove state errors caused by propagation of the first maneuver execution errors. At 5 days before periapsis, a third maneuver is performed to remove the encounter errors determined by radio and/or optical tracking. For the two-planet missions, the remaining periapsis state errors are determined and their resulting mapped errors at the second encounter planet (in these cases Uranus) are removed by a fourth maneuver at 50 days past the first encounter planet. At 200 days before Uranus encounter a fifth maneuver is made to correct the execution errors of the previous maneuver. At 24 days before Uranus encounter a sixth maneuver is performed to correct state errors learned from Uranus satellite optical tracking. The bus is then separated from the probe and the bus/probe relative state errors from this separation maneuver are mapped to probe entry into Uranus.

Received April 26, 1974; synoptic received February 18, 1975. Full paper available from the National Technical Information Service, Springfield, Va., 22151 as N75-17396 at the standard price (available upon request). This research was sponsored by NASA Contract NAS 7-100 and conducted at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

Index category: Navigation, Control, and Guidance Theory.

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Contents

Direct Saturn Mission: The spacecraft can be delivered to Saturn's sphere of influence with two midcourse velocity corrections with an accuracy ellipse of about 1000 km × 300 km aligned roughly in the ecliptic plane. Since the Earth-based position error of Saturn is roughly 1000 km, radio-only tracking results in a state error of 1500 km at Saturn periapsis.

Saturn/Uranus Mission: Figure 1 illustrates the planet-centered *B*-plane† error at spacecraft periapsis for both Saturn and Uranus encounters. The figure reveals the negligible effect of data epoch for the radio results at Saturn and the significance of Earth-based tracking station calibration accuracy on Saturn encounter results ("tight" roughly 3 times more accurately located than "loose"[1]). The large ephemeris error of Uranus (10,000 km in position) prevents radio tracking improvement in spacecraft positional accuracy at Uranus encounter. The V-slit sensor analysis results are indicated for the various satellites of Saturn and Uranus. These curves indicate that one complete satellite orbit of data is required to achieve navigation accuracies of less than 3000 km; that for a given length of tracking time, greater accuracy can be achieved by tracking a satellite of shorter period than one of longer period, and that the navigation accuracy varies inversely with the square root of the sampling rate.[1] Figure 2 shows the delivery accuracies for the Earth-Saturn (ES) leg (radio only) and the Saturn-Uranus (SU) leg (radio and optical considered at Saturn encounter).

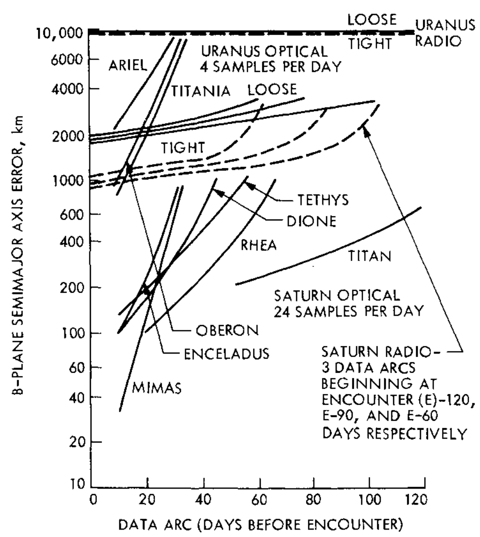

Fig. 1 Saturn and Uranus navigation errors.

†Fictitious plane passing through planet center and normal to incoming hyperbolic velocity asymptote of spacecraft.

Table 1 Midcourse velocity requirements

Velocity correction number	Saturn			Saturn/Uranus			Jupiter/Uranus		
	M^a	A^b	N^c	M	A	N	M	A	N
1	74.7	31.1	74.1	80.1	29.2	79.6	79.3	30.6	78.9
2	13.6	14.1	8.6	14.0	12.0	10.7	4.6	2.5	4.3
3	104	104	0	7.0	6.4	4.5	9.8	5.3	9.2
4				(139.3, 23.2)	(38.6, 11.4)	(138.9, 22.4)	(34.4, 7.9, 19.2)	(2.8, 2.2, 13.2)	(13.2, 7.7, 16.2)
5				(18.7, 2.9)	(3.9, 0.9)	(18.7, 2.8)	(1.8, 1.1, 2.2)	(0.8, 0.6, 1.8)	(1.8, 1.0, 1.6)
6				110.4	44.6	65.8	117	57	60

[a] M is mean plus three-sigma velocity magnitude in m/sec. [b] A is the along-Earth-line mean plus three-sigma velocity component in m/sec. [c] N is the normal-to-Earth-line mean plus three-sigma velocity component in m/sec.

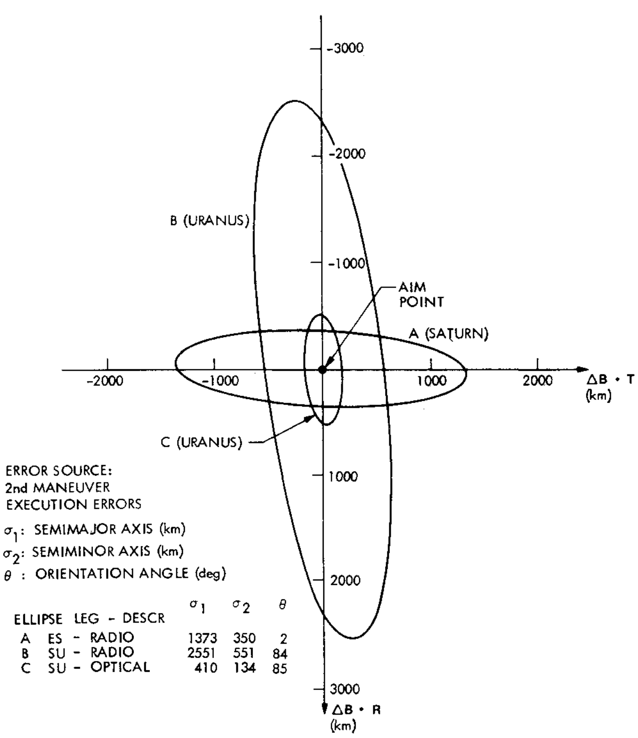

Fig. 2 Saturn Uranus mission-B-plane dispersion ellipses.

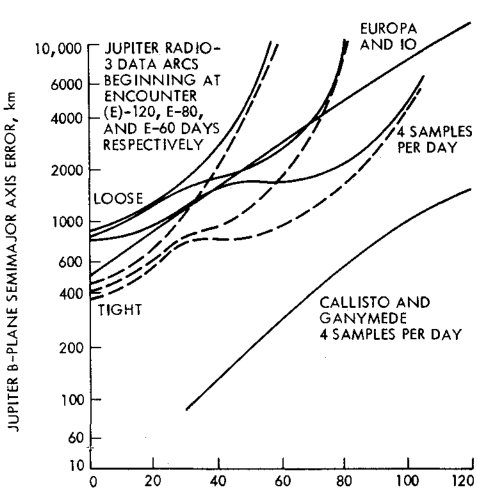

Fig. 3 Jupiter navigation errors.

Jupiter/Uranus Mission: The Jupiter encounter results for both radio and optical navigation are illustrated in Fig. 3. These curves reveal that since Jupiter's satellites are so large that tracking must be terminated twenty days before encounter, the V-slit sensor offers no improvement in

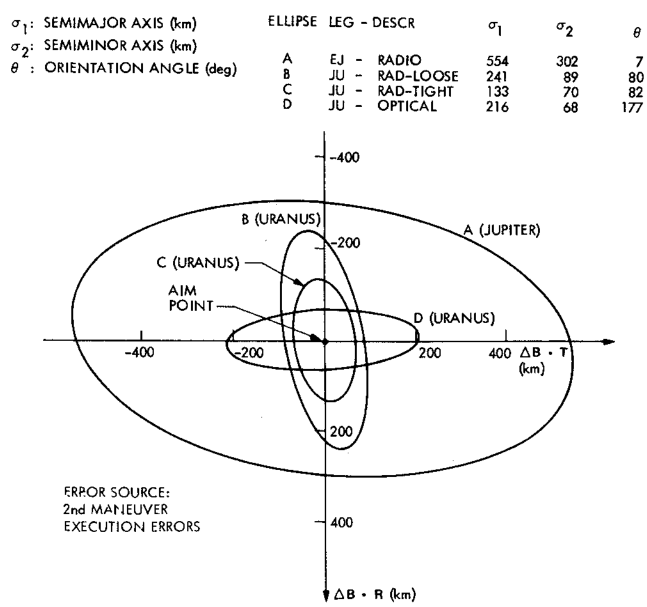

Fig. 4 Jupiter Uranus mission-B-plane dispersion ellipses.

navigation accuracy over that gained by radio-only tracking. The Uranus encounter results are essentially the same as those illustrated in Fig. 1. The delivery accuracies are illustrated in Fig. 4 for Jupiter encounter assuming radio-only tracking and for Uranus with radio "loose" and "tight" assumptions and optical tracking at Jupiter encounter.

Summary: The velocity requirements for the three missions are indicated in Table 1. For the Saturn/Uranus mission, the first value of each pair at velocity correlation numbers 4 and 5 pertains to radio-only navigation at Saturn while the second value pertains to the optical V-slit sensor. For the Jupiter/Uranus mission, the triplet at velocity correction numbers 4 and 5 correspond in order to radio "loose," radio "tight," and optical tracking on Amalthea at Jupiter. Table 1 clearly demonstrates the contribution of the V-slit sensor for the Saturn/Uranus mission by the reduction by a factor of 6 in the post-Saturn encounter velocity correction (number 4) from 139 to 23 m/sec. To meet probe entry navigation constraints at Uranus, the V-slit type sensor or equivalent is required for Uranus approach navigation.

References

[1] Paul, C.K., Russell, R.K., and Ellis, J., "Advanced Pioneer Planetary Probe Mission Guidance and Navigation Requirements," Nov. 1973, Jet Propulsion Lab., Pasadena, Calif., Rept. 760-88.

[2] Swenson, B.L., Tindle, E.L., and Manning, L.A., "Mission Planning for Pioneer Saturn/Uranus Atmospheric Probe Missions," TM-X-2824, Sept. 1973, NASA.

[3] Ondrasik, V.J. and Rourke, K.H., "Application of New Radio Tracking Data Types to Critical Spacecraft Navigation Problems," *JPL Quarterly Technical Review*, Vol. 1, No. 4, Jan. 1972.