SELECTION OF A COMMON COMMUNICATION LINK GEOMETRY FOR SATURN, URANUS AND TITAN

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DR. HENDRICKS: First of all, I would like to change my title from that shown in the program because I had to reduce it in scope considerably. I am going to primarily be talking about the selection of a common communication link geometry at both Saturn, Uranus, and Titan. A few comments relating to Jupiter will also be made.

To set the stage, I will use Figure 3-52 and talk about what missions are available to the outer planets in the 1970's and 1980's.

Direct missions to both Jupiter and Saturn occur approximately every year with the corresponding launch energies and flight times shown in Figure 3-52. It takes somewhere between a year and a half to two years to get to Jupiter, with launch energies (C_3) in the range of 80 to 115 Km^2/sec^2.

The launch energy required to get to Saturn is increased over that required to get to Jupiter, requiring somewhere between 120 and 140 Km^2/sec^2. So that if you are considering the Pioneer and Mariner class spacecraft, the Saturn direct missions are really viable only for the Pioneer.

The Jupiter-Saturn opportunities occur approximately every three years, and of course we have the MJS flying in 1977. The launch energies, flyby radii, and trip time are somewhat flexible for the Saturn Uranus swingby missions. You can trade reduced launch energy for increased trip time. Increased launch energy corresponds to reduced flyby radii.

One point I want to make here is that the 1979 Jupiter Uranus opportunity is probably the last chance for a derivative Mariner to fly to Uranus. The next chance to go to Uranus via a swingby opportunity would be the S/U missions which start in 1980, but they have launch energies considerably in excess of the kinds of energies you get if you swing by Jupiter first. So this really is a unique opportunity to get a Mariner spacecraft to Uranus by using the gravity field of Jupiter.

OUTER PLANET MISSION SUMMARY

DIRECT MISSIONS

	JUPITER DIRECT	SATURN DIRECT
LAUNCH OPPORTUNITIES	EVERY 13 MONTHS	EVERY 12.4 MONTHS
LAUNCH ENERGY (C_3, km^2/sec^2)	$80 < C_3 < 115$	$120 < C_3 < 140$
FLIGHT TIME (YEARS)	1.5 - 3	3 - 4

SWINGBY OPPORTUNITIES

MISSION	LAUNCH DATE	C_3 (km^2/sec^2)	RCA SWINGBY PLANET (RADII)	ARRIVAL DATE SWINGBY PLANET	TOTAL FLIGHT TIME (YEARS)
JUPITER-SATURN	8/1/76	105	1.0 - 1.2	2/1/78	3.2
	9/1/77	107	2.6 - 15.0	4/16/79	3.4
	10/1/78	110	10.4- 25.0	6/1/80	3.8
JUPITER-URANUS	10/1/78	100	1.2 - 3.9	4/10/80	6.3
	11/1/79	105	4.6 -10.0	6/8/81	6.5
	12/1/80	110	11.0-28.0	8/8/82	6.9
SATURN-URANUS	11/30/80	135	1.2 - 5.5	1/20/84	6.9
	12/15/81	136	4.6 - 6.8	4/30/85	7.3
	12/30/82	140	7.2 -11.6	5/30/86	7.9
MARS-JUPITER	1/11/82	66	(1000 km)	4/20/82	3.5

FIGURE 3-52

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The next mission illustrated is the Mars-Jupiter swingby. You haven't read too much about it because the opportunity occurs infrequently. In 1982 there is a trajectory which takes us by Mars on the way to Jupiter. And we can actually get from Earth, by Mars to Jupiter, with a C_3 of 66 km^2/sec^2. This lower launch energy is reflected in an increased payload capability of approximately 450 kg for the Titan III E/Burner II combination. However, the price you have to pay for this increased payload capability is increased trip time; instead of a year-and-a-half trip time we are talking about a 3.5 years for the Mars-Jupiter opportunity. And this is the penalty that one has to pay; however, if you look at this as a viable option, and I think it is, there are many things you can do with this increased payload. For example, a combined probe and orbiter mission, or an Io rendezvous combined with a probe mission would be feasible mission options.

Figure 3-53 defines some of the relevant mission analysis and communication parameters used in the design of a common relay link. Cone angle defined as the angle from the Earth line to the spacecraft probe line; PAA is a probe aspect angle; and P is range.

A useful mission analysis parameter is T_L which is called lead time. This is the time from probe entry to spacecraft periapsis. Lead time was varied in our link analysis; the specific strategy is illustrated in Figure3-53 and will be described next.

The nominal probe mission was targeted so that the spacecraft was directly overhead half way through the descent phase of the mission. This gave the relative inclinations of the probe and the spacecraft trajectories. Then fixing inclination, lead time was varied for the Saturn and Uranus missions. Shown on Figure 3-54 is the cone angle at entry and end of mission (EOM), probe aspect angle and range as a function of lead time. With this information it is an easy task to select the appropriate lead times at

RELAY LINK PARAMETERS

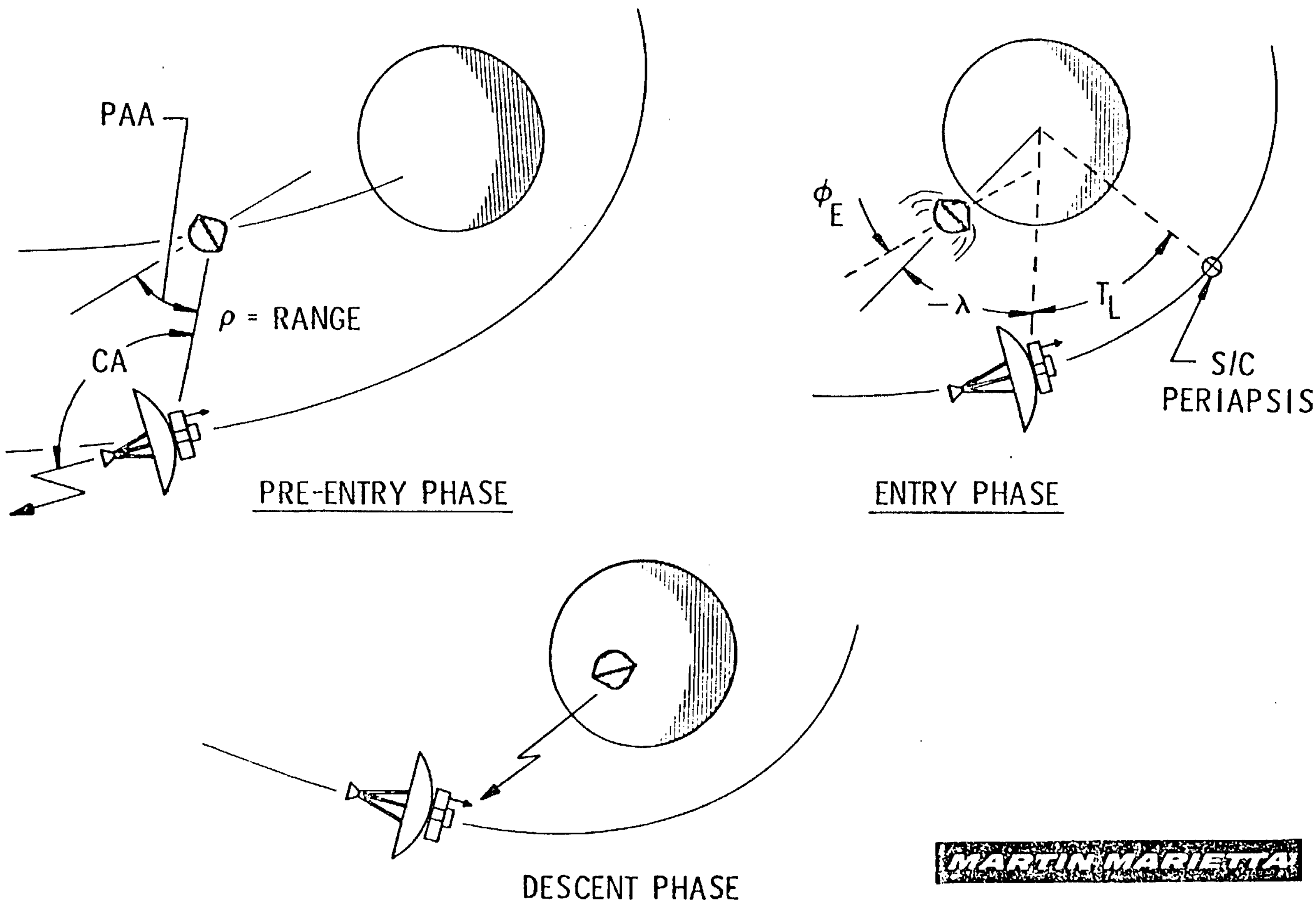

FIGURE 3-53

COMPARISON OF SATURN AND URANUS LINK GEOMETRY

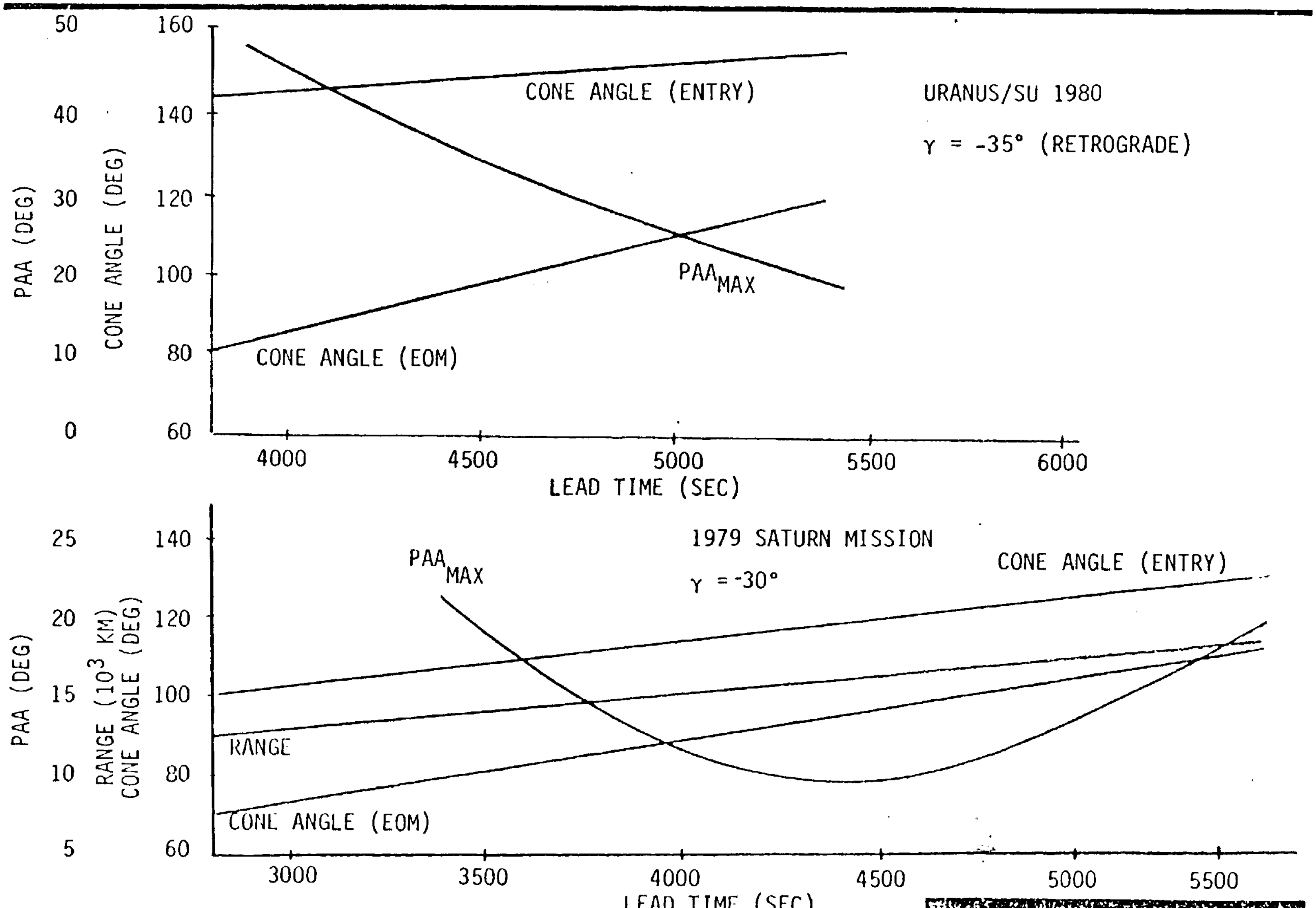

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FIGURE 3-54

Saturn and Uranus to yield a common set of cone angles, reasonable ranges (in the order of 100,000 km) and acceptable probe aspect angles. For our baseline designs, the respective lead times at Saturn and Uranus were 5200 sec and 5300 sec. The major constraint in selecting the baseline mission was the cone angle at end of mission. To insure a practical communication link requires a cone angle greater than 90° which in turn sets the lower limit on lead time.

As Byron pointed out, we did pick the retrograde approach at Uranus in order to minimize the angle of attack. This worked out very well. We had the entry flight path angle for our nominal mission of minus 35 degrees, and on Figure 3-55 we'll show you some dispersions associated with the Uranus mission. For the Saturn direct mission, the entry flight path angle was minus 30 degrees.

Figure 3-55 shows in perspective, the probe and spacecraft trajectories and Saturn and Uranus in addition to the probe release sequence. Displayed on each planet are contours of constant flight path angle, the ground traces of the probe and the spacecraft trajectories, the terminator, and the 3σ entry footprints. Of particular significance is the 30 degree by 10 degree entry footprint at Uranus which is primarily the result of the large ephemeris error.

Navigational uncertainties when combined with the execution errors associated with the deflection event produce dispersions in the link related parameters. There are uncertainties in range, the bus and probe aspect angles. All of these have been incorporated in the link analysis.

We are primarily concerning ourselves with the Pioneer type bus with the spacecraft flying in an Earth-pointing attitude. At the deflection event, the spacecraft deploys the probe and then fires the axial and radial thrusters in the Earth, and perpendicular to Earth line, direction in order to establish the

SATURN/URANUS MISSION SUMMARY

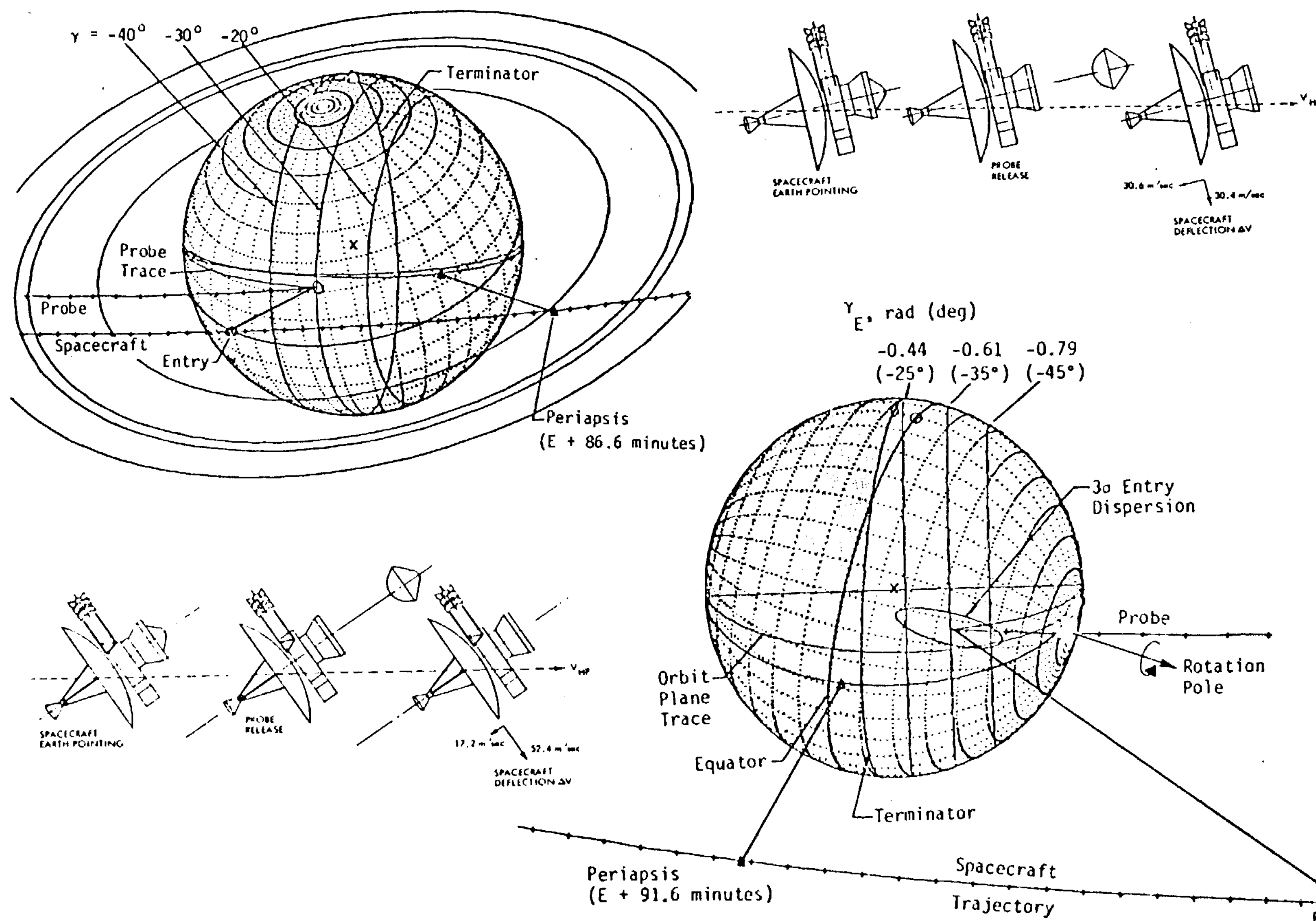

FIGURE 3-55

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communication geometry. The magnitude of the spacecraft Delta-V at the deflection event is summarized in Figure 3-55.

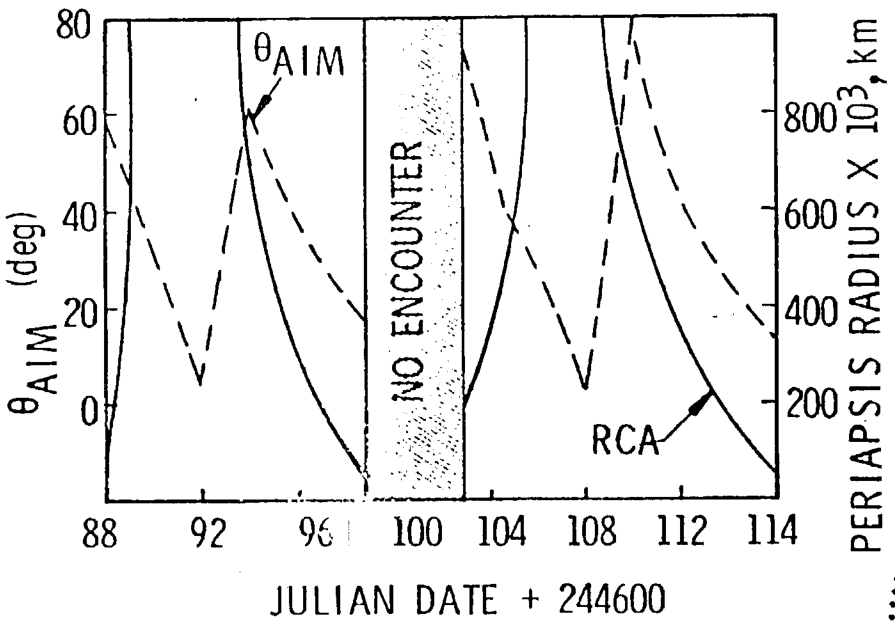
Figure 3-56 shows some interesting mission analysis link parametrics that were performed relative to Titan. This is a rather busy Figure. Let me try to explain what we have here.

The illustration to the right shows Saturn and its natural satellites along with the spacecraft trajectory. The orbits of the spacecraft and satellites are shown at one hour intervals. The position of Titan at spacecraft periapsis corresponds to where the title is printed. The Earth and sun shadows are projected onto the spacecraft orbit plane. From this plot the occultation times are easily calculated. The spacecraft trajectory shown corresponds to what we call a pre-periapsis encounter. That is, the spacecraft encounters Titan before it encounters Saturn. Typical link parameters associated with this mission are shown in the table labelled Mission Summary. The range, cone angle, probe aspect angle and other link parameters are similar to what was obtained at Saturn and Uranus.

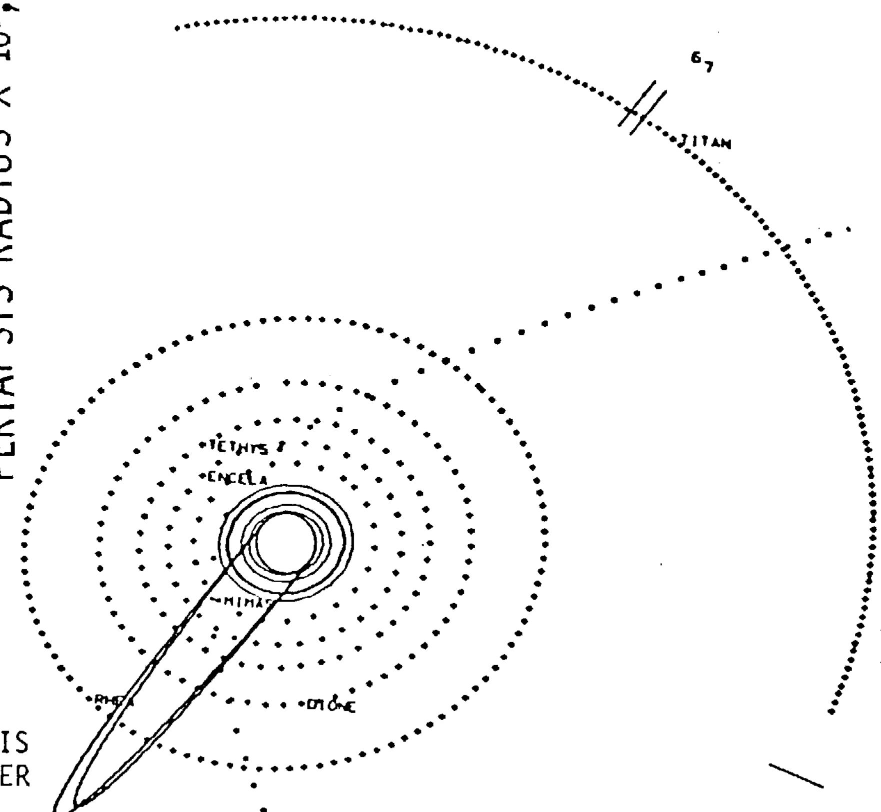
In summary, I would like to point out that it was possible to obtain a common link geometry at both Saturn, Uranus and Titan. If instead of the Pioneer baseline we had a Mariner baseline, the problem from the mission analysis point of view would have been somewhat easier.

In summary I refer to Figure 3-57. Analysis has shown that we have an ephemeris problem at Uranus. In view of this, I think it is justified that we continue Earth-based observations of Uranus in order to reduce the ephemeris error. I might also point out at this time that there is going to be an activity at Arecibo in 1975 where they are going to be taking radar observations of the Galilean satellites and also of Titan. It was estimated by Professor Pettengil of MIT that there is a good chance of reducing the Galilean satellite ephemeris errors to somewhere in the vicinity of maybe ten or fifteen kilometers, which is fairly sig-

TITAN MISSION SUMMARY



TARGETING



APPROACH TRAJECTORY

	PRE-PERIAPSIS ENCOUNTER	PERIAPSIS ENCOUNTER
RANGE (KM)	93,200	100,000
CONE ANGLE (DEG)	143.2	147.7
PROBE ASPECT ANGLE (DEG)	47.9	51.6
ANGLE OF ATTACK (DEG)	13.9	19.3
TITAN RCA (KM)	50,000	70,000
SATURN RCA (KM)	385,000	1,290,000

MISSION SUMMARY

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FIGURE 3-56

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SUMMARY AND CONCLUSIONS

- o CONTINUED INVESTIGATION OF MISSION OPTIONS (e.g., MARS-JUPITER).
- o FURTHER PROCESSING OF EARTH BASED MEASUREMENTS OF PLANET AND SATELLITE EPHEMERIS - URANUS EPHEMERIS REDUCTION.
- o DIRECT LINK TO ARECIBO GOOD THROUGH 1981.
- o GOOD PROSPECTS FOR REDUCED GALILEAN SATELLITE EPHEMERIS UNCERTAINTIES (ARECIBO TRACKING) IO (10 km).
- o FURTHER INVESTIGATION OF COMBINED PROBE/ORBITER MISSION SEEMS WARRANTED, ALSO PROBE MISSIONS TO THE SATELLITES.
- o MAXIMIZE UTILIZATION OF EXISTING HARDWARE.

FIGURE 3-57

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nificant, since we are talking now about errors of 200 and 300 km. He is talking about maybe order of magnitude reductions in the ephemeris errors of both Jupiter and Saturn also.

I think we should continue to look at various mission options, combining probe and orbiter missions, and looking at probe missions also to the Galilean satellites. Io is a particularly interesting object.

Another option that hasn't been looked into very extensively is the possibility of a direct link with the probe to Arecibo. And a direct Jupiter link to Arecibo is good through 1981. After this time, the geocentric declinations at Jupiter get so negative that you cannot see it with Arecibo. But it is certainly an interesting mission option. It unfortunately cuts off in 1981.

In order to reduce program costs, and this is an important consideration, future studies should be directed toward the use of existing hardware whenever possible. Viking, Pioneer Venus, the Pioneer 10 and 11 programs all offer hardware which has potential in reducing the cost of an outer planet probes program.