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THE MARRINER SPACECRAFT AS A PROBE CARRIER

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Early in 1973, the Outer Planets Science Advisory Committee expressed interest in both a Mariner flyby mission to Uranus, and a Pioneer Saturn/Uranus Probe mission. JPL was also conducting a study to determine the feasibility of carrying the Ames/Pioneer Probe on a Mariner spacecraft of the Mariner Jupiter Saturn '77 design to Uranus. Further study of the combined flyby/probe mission by both JPL and Ames resulted in the establishment of the MJU-Science Advisory Committee (SAC) by NASA in December 1973.

This new effort was directed at developing the science objectives and rationale and mission design options in sufficient detail in order to estimate the Project costs and prepare the pre-project plans. Today I plan to briefly cover the work done in the past several months in developing the Mariner Jupiter Uranus 1979 mission with a probe.

The rare alignment of the outer planets in the last half of the 1970's affords a variety of multi-planet launch opportunities. In particular there are three Jupiter/Uranus launch opportunities allowing deep space penetration and unique approach and encounter geometry with Uranus. Of the three opportunities, the 1979 Jupiter/Uranus (JU79) opportunity is the most attractive from the standpoint of both launch energy and flight time. Additionally the JU79 Jupiter flyby is the most reasonable, since the JU78 flybys passes less than 2 Jupiter radii from the planetary surface and the JU80 flybys provide only distant Jupiter encounters with closest approaches of from 30 to 40 Jupiter radii.

The MJU 1979 mission is a very exciting mission. (Figure 3-39). It has a number of very unique characteristics that make it particularly different from any previous planetary mission we have undertaken.

The JU79 launch opportunity provides an approach unique to Uranus in this century. The rotational pole of Uranus and the satellites are tilted 98° with respect t the ecliptic plane and the spacecraft approach vector to Uranus from the Earth is almost collinear with the approach from the Sun. When viewed from the approaching MJU79 spacecraft, the satellite orbit tracks appear to describe an archery target, or giant bull's eye, with the satellites traveling in concentric circles about Uranus. This kind of spacecraft approach permits a very long observational period of almost all of the northern hemisphere of Uranus. Since Uranus also has an orbital period of 84 years, the alignment of spacecraft approach with the planet pole and Sun and Earth vectors will not occur for another 42 years.

Approaching Uranus, with the Earth and the Sun behind the spacecraft, we will target fairly close to Uranus, between Uranus itself and Miranda. Actual geometries will be discussed in more detail later.

Note that Uranus' satellite system is quite regular, beginning with Miranda at about 5 R_U out to Oberon at twenty R_U or so.

URANUS SYSTEM AS SEEN ON APPROACH

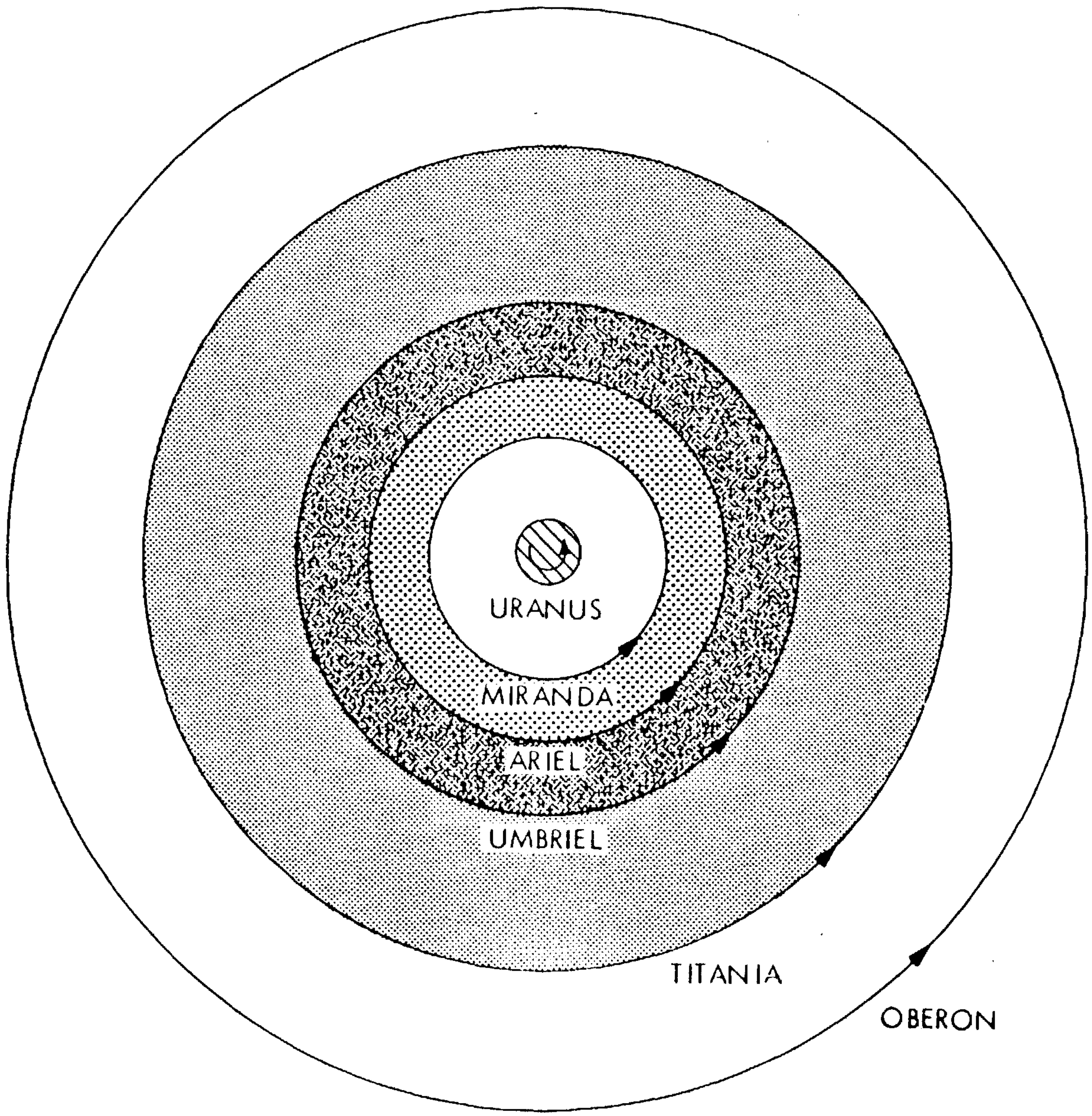

FIGURE 3-39

The first mission consideration I want to discuss relates to Launch Vehicle performance. We are assuming, as baseline, the Titan Centaur with the TE 364-4 adaptation that MJS'77 is using. This adaptation is called the MJS Propulsion Module.

A typical MJU79 trajectory would be launched in late October/early November of 1979 arriving at Jupiter about 1.7 years after launch. After the gravitational field of Jupiter has bent and added energy to the heliocentric trajectory, the spacecraft will proceed to Uranus traveling to a distance of about 20 AU in a little over 5 years, arriving at Uranus late in the Fall of 1986.

Applying the launch vehicle capability to the MJU79 launch energy requirements and requiring a minimum of 21 launch days results in the payload performance curve shown in Figure 3-40.

Flight time to Uranus is a function of flyby altitude at Jupiter and spacecraft mass, which is plotted on this chart. The predominate factor is Jupiter flyby altitude. At this point in the study, we are considering two baseline spacecraft cases, an MJU flyby without probe at 725 kilograms, and MJU_p with a probe, in the 825 range. A more detailed weight statement will be given shortly.

The slope of the performance curve is about one year of added flight time per added 100 kilograms of spacecraft mass. We can operate almost anywhere in the 6-7 year regime with certain exceptions. The Uranus encounter in 1986,

PAYLOAD PERFORMANCE FOR 21 day LAUNCH PERIOD

- LAUNCH VEHICLE: TITAN IIIE/CENTAUR D-IT/P.M.
- FIRST LAUNCH DATE: ~27 OCTOBER 1979

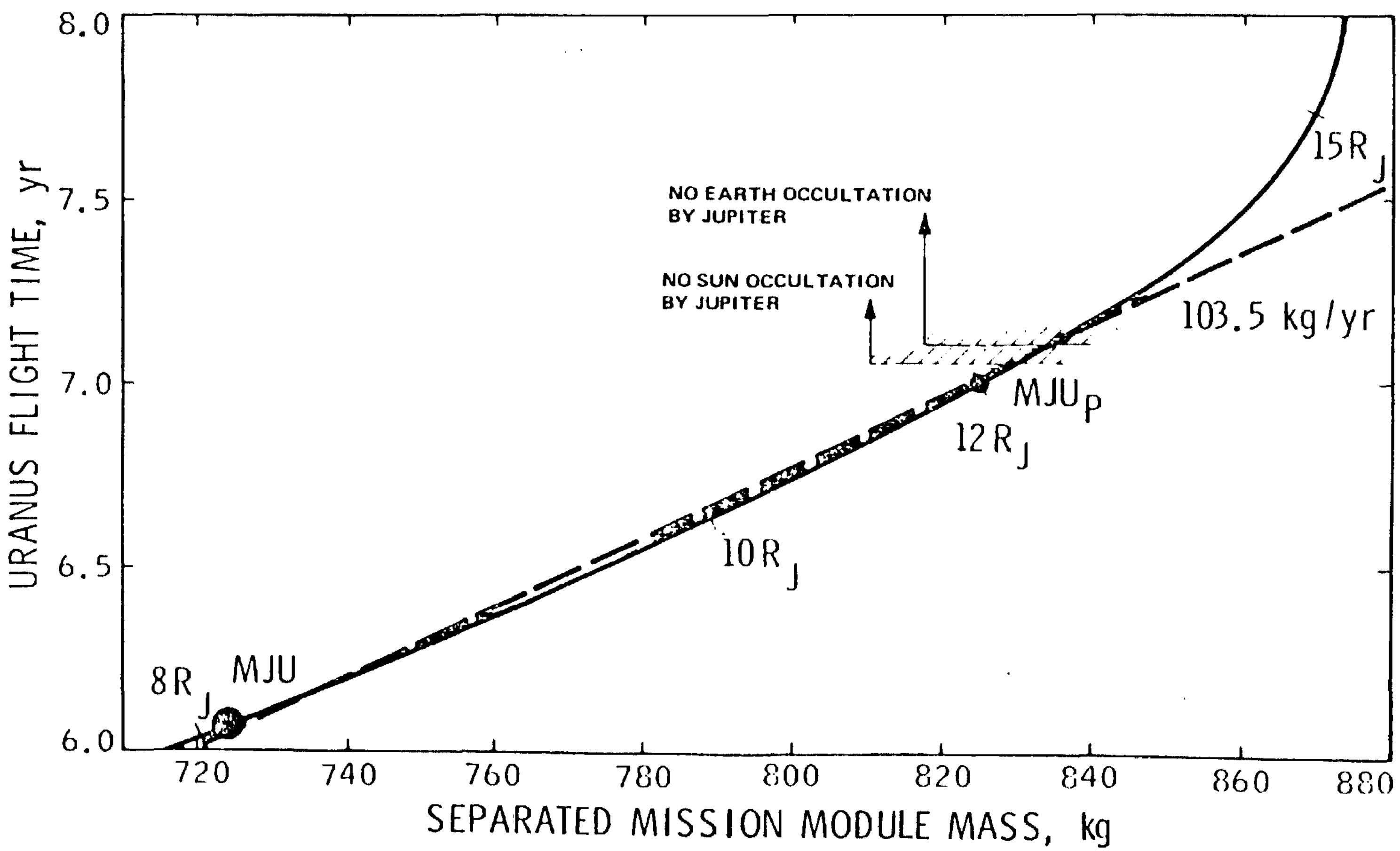

FIGURE 3-40

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is constrained to occur away from the 6.2 to 6.4 trip time due to pointing restrictions of the ground based antennas. The 64m DSN antennas would be looking right into the sun at that time of year, so there will be a constraint on arrival time to preclude encounter in this region.

One other constraint; for very high Jupiter flyby altitudes, the flight times get very long, very quickly. Note also, that for spacecraft masses above 825 kg or so, neither Earth or Sun occultations are achievable at Jupiter.

Figure 3-41 summarizes our current understanding of the Probe design requirements. We have assumed the McDonnell-Douglas conceptual design and configuration. First, it is a requirement at this time that the Probe be both Pioneer and Mariner compatible. The Probe must also be compatible with both Saturn and Uranus entries. The Uranus mission and environmental design conditions that drive its design characteristics are: the cold, dense atmosphere, the entry velocity (26 kilometers per second), the entry angle (40 ± 10°), and the descent time. This is the reference case for the Probe and for determining the Probe interface implications on Mariner.

I have summarized these implications on Figure 3-42. These are the areas we believe to be necessary to consider to integrate the Probe into the design. Probe support, which includes structural adapters, thermal control allocation, spacecraft receiver and relay link antenna, and spin mechanization are all lumped within a ten kilogram weight allowance. The four watt temperature

AMES URANUS PROBE DESIGN REQUIREMENTS

- PIONEER AND MARINER COMPATIBLE
- PROBE COMPATIBLE WITH BOTH SATURN AND URANUS ENTRY
- URANUS DESIGN CONDITIONS
  - WARM AND COOL ATMOSPHERES
  - 26 k/s ENTRY VELOCITY
  - -30^0 to -50^0 ENTRY ANGLE
  - 26 to 76 min ATMOSPHERIC DESCENT TIME TO 10 BAR
  - 800 g MAXIMUM DECELERATION
  - 72 to 108 x 10^3 km RELAY COMMUNICATION DISTANCE

FIGURE 3-41

5-21-74

PROBE REQUIREMENTS ON SPACECRAFT

- 91 kg PROBE MASS, 10 kg PROBE SUPPORT
- TEMPERATURE CONTROL DURING CRUISE - 4 watts
- POWER REQUIRED FOR PERIODIC HEALTH CHECKS, CHARGE/DISCHARGE BATTERIES, PRE-SEPARATION CHECKOUT, ARM ORDINANCE
- PROBE SPIN-UP (3-8 rpm), SEVER UMBILICAL
- ADDED FUEL FOR BUS DEFLECTION MANEUVER (20 kg)
- DELIVERY ACCURACY AT $40^{\circ} \pm 10^{\circ}$ ENTRY ANGLE
- 400 mHz RELAY LINK REQUIRES 3 ft DIAMETER BODY FIXED ANTENNA (9 db) PLUS RECEIVER
- 88 sps DATA RATE, APPROXIMATELY 4.3×10^{5} bits TOTAL, TRANSMIT REAL TIME AND STORE ON-BOARD

5-21-74

FIGURE 3-42

control requirement is the same as for Pioneer. The Probe also requires periodic health status checks, charge/discharge of its batteries, pre-separation checkout and arming of the ordnance. Mariner would handle these requirements in the same way Pioneer does and fit them into the spacecraft duty cycle as appropriate.

Mariner must also provide the capability to spin-up the Probe, in the 3 to 8 RPM range, and then sever an umbilical. At the moment, Mariner does not have the capability to do this, but we do not see this as any major problem. Its a relatively straight forward design problem.

To perform the bus deflection maneuver, since this is a "dumb" probe, we would have to add additional hydrazine to our hot gas attitude propulsion system. On the order of 20 kilograms of hydrazine is required for a maneuver of 80 meters per second. The actual magnitude of the maneuver is a direct function of Probe release from the spacecraft relative to encounter. We are considering a nominal separation and maneuver of order 15-25 days. One added point: Mariner has no constraints on this maneuver relative to Earth or Sunline pointing.

The delivery accuracy requirement, I think Lou Friedman convinced you, is an easy requirement for Mariner to achieve with either improved ephemeris or optical guidance. In fact, Mariner can deliver to any desired target within the entry corridor, at ±1° accuracy, and an initial zero angle of attack.

We have mechanized, at this point, the 400 megahertz relay link as for Pioneer. This, however, is not a firm requirement. We could accommodate significantly higher frequencies if that is desired, which might have some implications in easing the job on the Probe. Further, we can accommodate receiving antennas with much higher gain, thus improving overall relay link performance.

The Probe data rate, 88 s/s, and 4.5×10^5 total bits, for either real time transmission or on-board storage are really inconsequential requirements compared to the Mariner capability. The downlink data rates and on-board mass storage requirements are driven so heavily by the imaging system requirements that the Probe numbers look like engineering data.

Figure 3-43 presents the MJU 79 spacecraft configuration. The MJU 79 spacecraft is based entirely on the Mariner Jupiter Saturn 1977 spacecraft design with minor modifications necessitated by Uranus science data requirements, by the longer mission lifetime, and by its Probe-carrying capability. The spacecraft is three-axis stabilized, obtaining attitude information from celestial and inertial sensors and maintaining/attaining the required attitude by the hydrazine-fueled hot-gas jets. Additionally, reaction wheels provide attitude stability for precise instrument pointing. The hot-gas jets, part of the attitude/propulsion subsystem, also provide velocity increments for maneuvers such as spacecraft deflection after Probe separation. The programmable guidance electronics deliver the Probe and also control articulation of the scan platform, in two degrees of freedom, to an accuracy of 2.2 mrad in each axis. All the remote sensing science is on the scan platform. This

SPACECRAFT AND PROBE

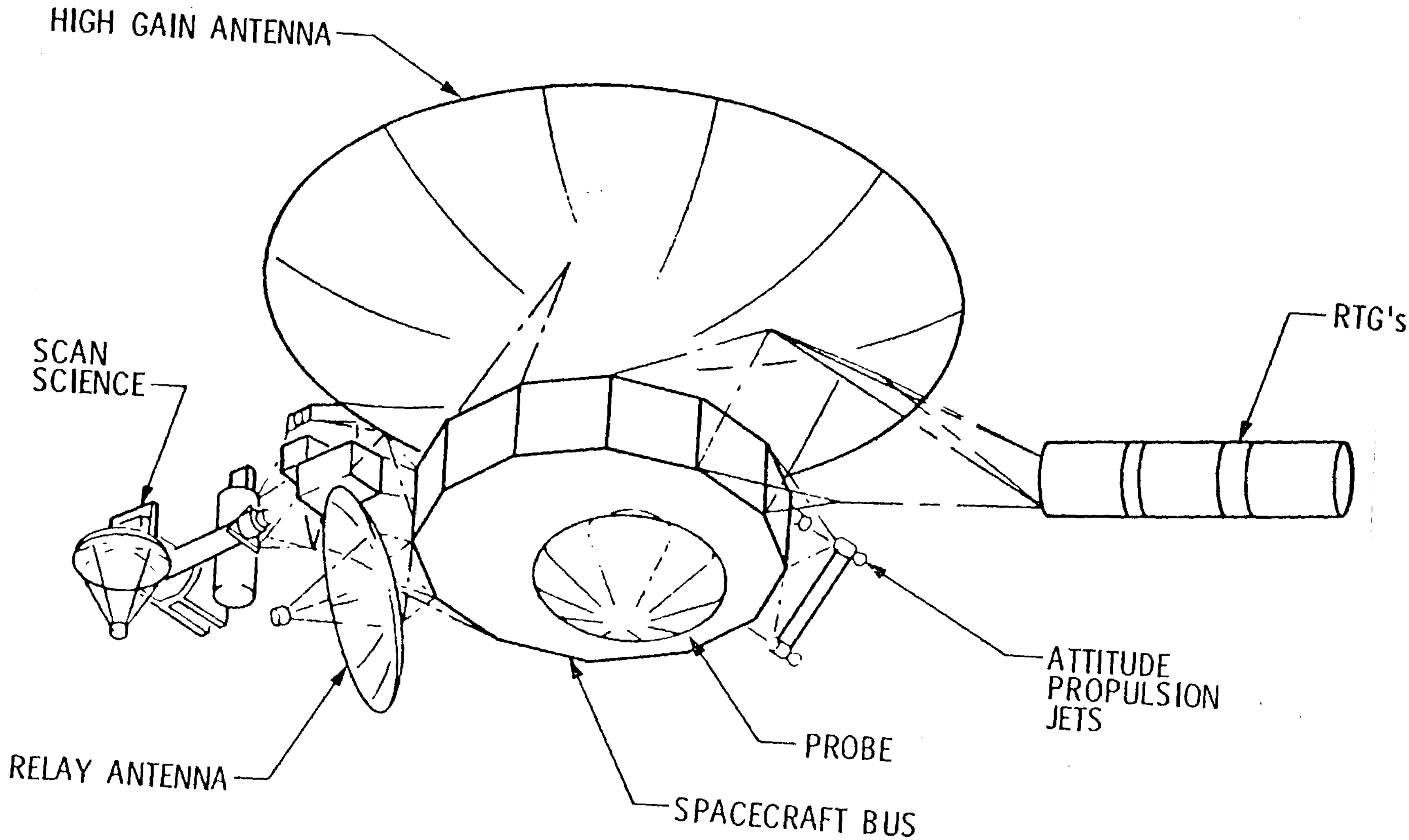


FIGURE 3-43

5-21-74

includes a pair of new cameras that we are considering for this mission. The principle change from the MJS cameras is the use of CCD sensors. Because of its superior IR response over selenium vidicons, an important science consideration at Uranus, the MJU SAC has recommended its incorporation.

The main electronics housing contains the major spacecraft electronics such as: the power distribution system, the attitude control electronics, radio, computer/command, etc. Power is obtained from three radioisotope thermoelectric generators (RTG) and is also stored in a battery. On-board command and data handling electronics supply an extensive capability for both on-board stored and ground-transmitted commands as well as programmable selection and formatting of engineering, science and probe-relay data. Data can also be stored in a 9×10^6 bit solid-state (MNOS) buffer for later transmission to Earth. Two-way communications are provided by an S- and X-band radio transmitter/receiver system. Downlink transmissions of data streams containing science data are normally sent on X-band. Additionally, a 400 MHz probe-to-spacecraft relay link handles Probe data during entry. Non-imaging science data can be Golay coded resulting in a bit error rate of less than 1×10^{-5}. MJU79 receives and transmits over the 12 foot diameter high gain antenna. The antenna feeds are located on the Sun side of the spacecraft and both the S and X feeds are boresighted together. The lo-gain antenna is also on the Sun side. This would be the side away from you as viewed from the audience. The Probe is carried on the anti-Sun side of the spacecraft which is also closest to the launch vehicle. We would have to make slight changes in the MJS'77 adapter to accommodate the Probe but we do not see this as a significant impact.

For the relay antenna, we are currently carrying a body-fixed 3' diameter dish.

Figure 3-44 is the same as the one Dan Herman showed this morning. Note again the pole orientation of Uranus, (and the bull's eye effect). Both the Sun and the Earth are approximately co-linear with the pole. The spacecraft is targeted between Uranus and Miranda at approximately 3.5 R_U. This targeting affords the best over-all compromise for maximum time overhead for the Probe, high resolution remote sensing of Uranus, and a reasonably close flyby of Miranda to achieve fairly high resolution satellite imagery. At the end I will show a typical near encounter sequence to indicate the options on near encounter timing that can be considered.

Figure 3-44 is shown again in a slightly different view on Figure 3-45. This is a view of Uranus which is essentially normal to the ecliptic plane and also shows Miranda's orbit, and the trajectories of the flyby Bus and the Probe. The Probe was separated at about 17 days. Entry commences at about E-2 hours and is complete at about E-40 min. Probe zenith occurs at entry plus about 40 minutes.

You will note that closest approach occurs after all of the data gathering activity from the Probe is complete. A significant amount of time is therefore available to conduct near encounter high resolution Uranus science or to concentrate on Miranda or the other satellites.

MJU_P ENCOUNTER GEOMETRY

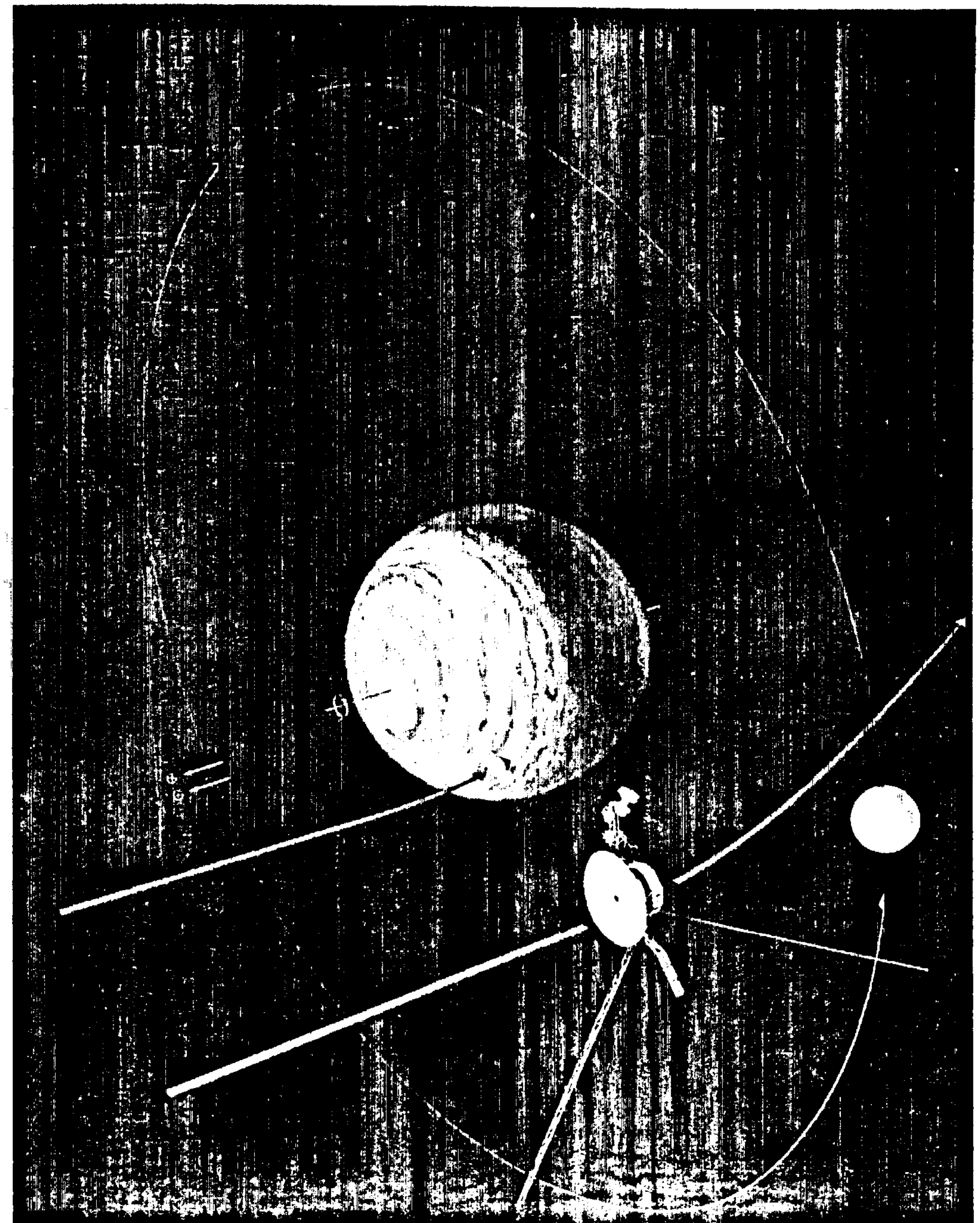
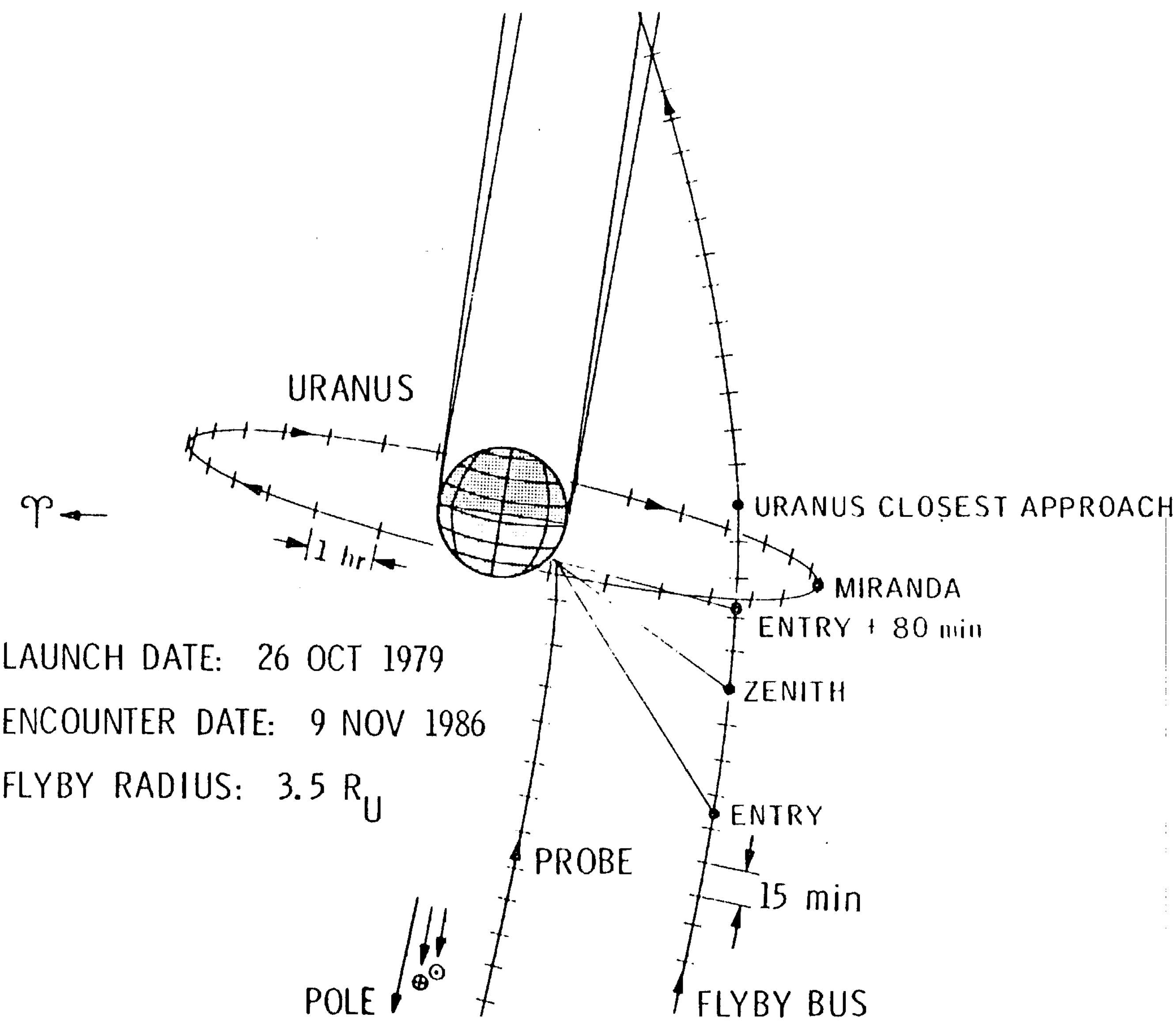


Figure 3-44

5-21-74

MJU$_p$ TRAJECTORY PLANE (3.5 R$_U$)



5-21-74

FIGURE 3-45

The occultation region is shown, and occurs approximately four to five hours after Uranus closest approach.

There are a number of tradeoffs available. For example, if you target very close to Uranus to achieve lots of trajectory bending so as to provide a very good post-Uranus pass for added satellite surveillance, you tend to shorten the available communication time with the Probe and hence to compromise the Probe data return. A far out pass near Miranda at say 5 R_U tends to cause occultation to occur very, very late relative to Uranus, and that is not very desirable from a science standpoint; so the best compromise at this point looks to be an aiming point on the order of 3 to 3.5 R_U.

I might also point out that, that this is also consistent with the targeting requirements to proceed on to Neptune.

As shown on Figure 3-45, I also have a summary of our latest estimates on the 3-46
gas budget. I was pleased to hear Lou Friedman's earlier discussion on the post-Jupiter correction allocation which now looks more like 15 m/s instead of 50. We are currently carrying a budget of 75 kilograms.

Figure 3-47 is an overall spacecraft mass summary. It was current as of last Friday when we received the new Reference Science Payload requirements from the MJU Science Advisory Committee. The science allocation is now 53 kg.

SPACECRAFT GAS BUDGET

Post Injection Expendables

	m/s	kg
MANEUVERS (4 PER LEG)	55	20.0
POST JUPITER CORRECTION	50	18.2
BUS DEFLECTION	80	29.1
ATTITUDE CONTROL (equiv.)	18	6.6
HOLDUP	3	1.1
TOTAL	206	75.0

FIGURE 3-46

5-21-74

MJU_P MASS SUMMARY

	kg
MJU DRY SPACECRAFT	565.5
PROBE*	91.0
PROBE SUPPORT	10.0
ATTITUDE CONTROL AND TRAJECTORY CORRECTION FUEL (206 m/s)	75.0
REFERENCE FLYBY SCIENCE PAYLOAD	63.0
	804.5

* NO ALLOCATION FOR PLANETARY QUARANTINE

5-21-74

FIGURE 3-47

The spacecraft mass is also coming down because of probable changes in mechanization of the data system. Other allocations are: Probe at 91 kg, Probe support at ten, and 75 kg for the Delta V budget.

These mass numbers do not incorporate any margin or allocation for planetary quarantine effects on the Probe design; which, as I understand it from Ames, is on the order of an additional 10 kilograms.

Figure 3- 48 is a summary of what Lou Friedman presented earlier. This relates to what we can do with optical navigation. Radio only does not meet the delivery requirements without improved ephemeris.

With improved ephemeris we can achieve 6, 000 kilometers accuracy. With the MJU 1500 mm camera, photographs of Uranus with Earth-based resolution can be taken 1-1/3 years before actual encounter. From an optical navigation standpoint the MJS vidicon and 1500 mm telescope, without stars but with Ariel provides a delivery accuracy of 5, 000 km. The new candidate CCD with the same telescope, with stars, provides 600 kilometers. The vidicon would provide about 300 km. The baseline, however, is the CCD, therefore, we think we will be able to deliver the Probe on this mission to about 600 km accuracy. This delivery corresponds to a one degree entry dispersion.

Figure 3- 49 is presented to give you some understanding of some of the competing characteristics for the Near Encounter sequence.

NAVIGATION CAPABILITY FOR PROBE DELIVERY

99% Requirements

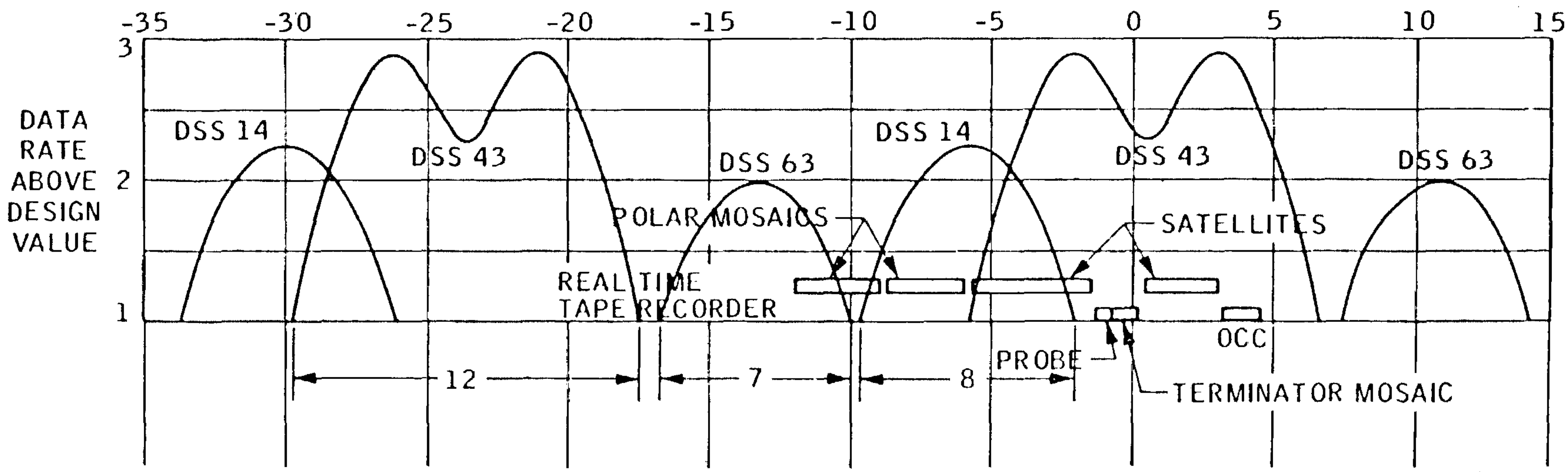
VIDICON/1500 mm OPTICS	ARIEL/W STARS	300 km
CCD/1500 mm OPTICS	ARIEL/W STARS	600 km
VIDICON/1500 mm OPTICS	ARIEL/WO STARS	5000 km
RADIO ONLY (IMPROVED EPHEMERIS)		6000 km
RADIO ONLY		18,000 km

ALL SYSTEMS DELIVER PROBE TO 6000 km ACCURACY. OPTICAL NAVIGATION PROVIDES 300 km OR ± 1° ENTRY

FIGURE 3-48

5-21-74

REFERENCE URANUS ENCOUNTER SEQUENCE



X-BAND DESIGN VALUE 12.5 kbps

FIGURE 3-49

5-21-74

Because of Uranus' declination, DSS-43 will be the prime station for the encounter. Uranus is down about 22 degrees in 1986, so we obtain the best coverage from DSS-43, with roughly 12 hour passes.

There is some overlap with DSS-14 but none with DSS-62.

We have hypothesized a typical science sequence. Full planet imaging mosaics are taken from about 12 hours down to nine hours and then repeated. Then the spacecraft performs a satellite imaging sequence from about E-6 hours down to about E-2 hours. Next we devote a dedicated period of time to receipt of Probe data, storing it on-board, and also transmitting it in real time. After completion of the Probe data sequence, the spacecraft begins a high resolution planet mosiac where we image just one-half of the planet's disk, but we get the high resolution data at the terminator. This is where we obtain scale heighth resolution. Next, we return to another satellite imaging sequence post-closest approach and finally the spacecraft enters occultation.

Incidentally, one of these sequences is set up to do in real time and the other on the tape recorder.

Now there is some flexibility in where you pick the closest approach and the Probe data taking sequence. We can select it as shown or with overlapping station coverage. You might want to time the encounter in such a way as to have the longest period of time for the DSS-43 pass to obtain the maximum amount of imaging data return. As you can see, if we time the closest approach for maximum imaging return we can obtain factors of two and a half or so above the 12.5 kb/s communication rate.

I am including two other charts for the Proceedings which I will not address. (Figures 3-50 and 3-51).

MJU$_P$79 COMMUNICATION PARAMETERS

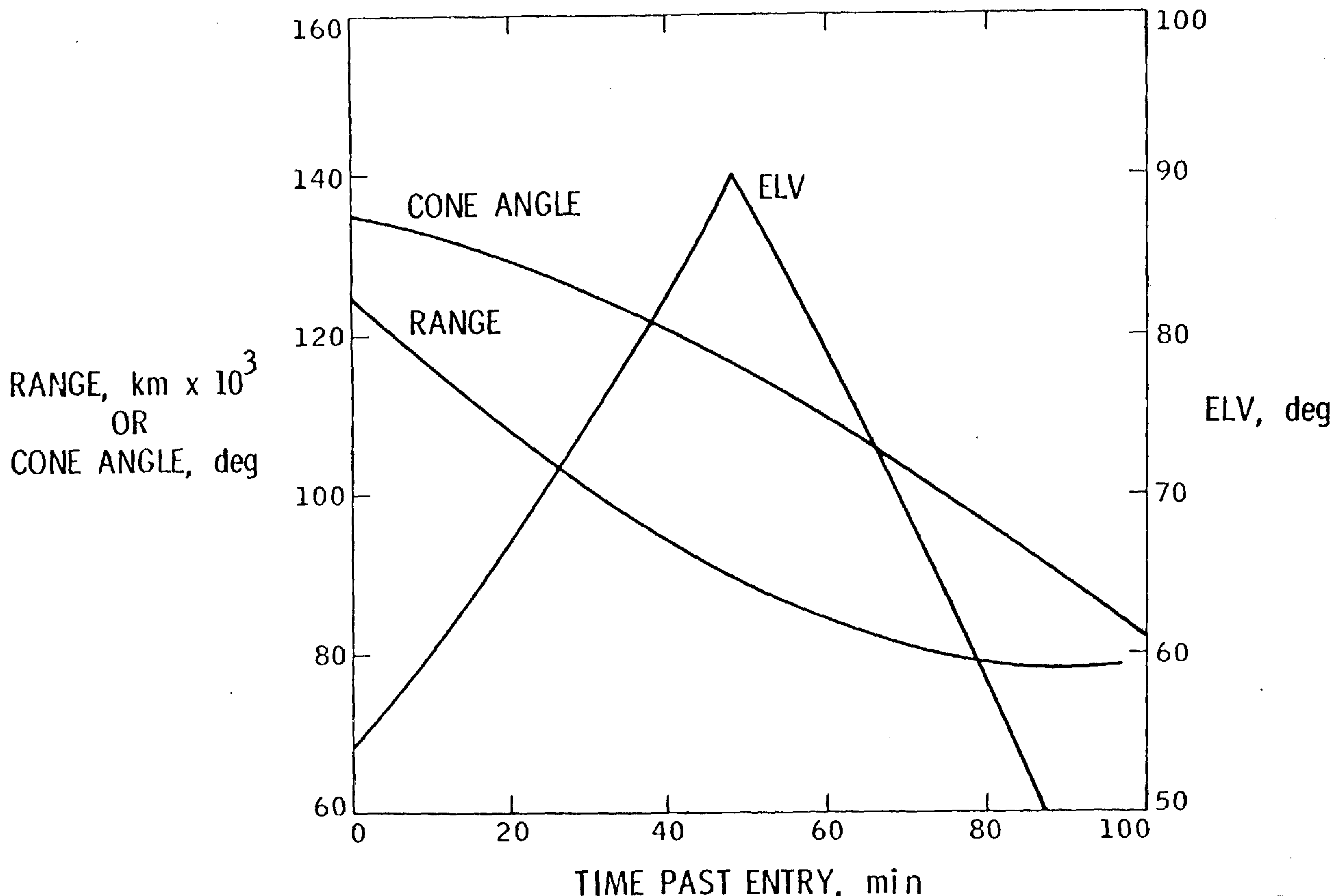


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FIGURE 3-50

URANUS ENCOUNTER SEQUENCE

E - 12.0 hr E - 9.0 hr	}	POLAR MOSAIC
E - 9.0 hr E - 6.0 hr	}	2nd POLAR MOSAIC
E - 6.0 hr E - 2.5 hr	}	SATELLITE IMAGING SEQUENCES
E - 2.5 hr E - 45 min	}	PROBE ENTRY DATA
E - 45 min E - 0 min	}	TERMINATOR MOSAIC

5-21-74

FIGURE 3-51