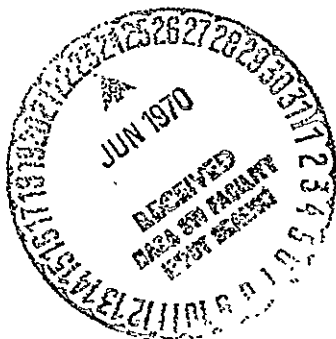
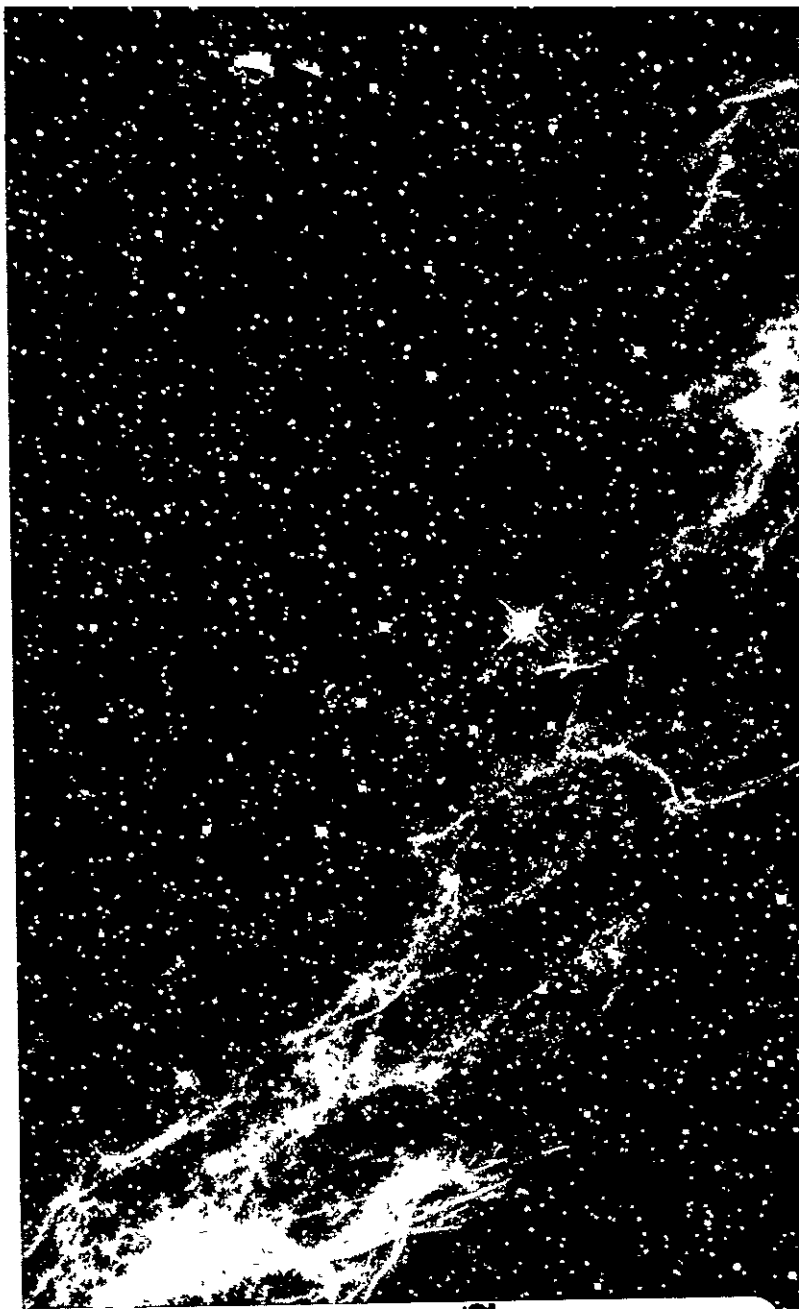


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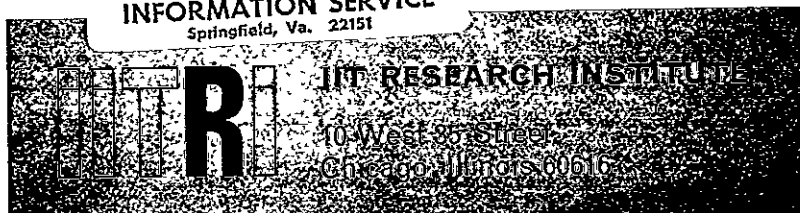
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Semi-Annual Report
(V6105)

LONG RANGE PLANNING FOR SOLAR SYSTEM EXPLORATION

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Semi-Annual Report
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by

Astro Sciences

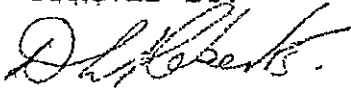
of

IIT Research Institute
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for

Planetary Programs
Office of Space Science and Applications
NASA Headquarters
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May 1970

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Semi-Annual Report V6105

LONG RANGE PLANNING FOR SOLAR SYSTEM EXPLORATION

1. INTRODUCTION

This report covers the first half year of Contract NASW 2023 from November 1, 1969 to April 30, 1970. The first quarterly report was omitted by the contract monitor, Mr. Norri Sirri, due to the fact that the contract had not been completely negotiated. The purpose of this advanced mission study contract is to provide a preliminary understanding of candidate missions and associated requirements which bear on the long range exploration of the solar system. The project schedule of study tasks for the current contract year (11/69 - 10/70) is given in Table 1. The level of effort, in man-months, is shown at monthly intervals for each study task. The Comet Rendezvous Opportunities, Jupiter Orbiter Mission, and Spacecraft Radar Studies are continued tasks from the previous contract (NASW 1837) years.

2. TECHNICAL PROGRESS

The analyses and results obtained during this reporting period are described in the individual task subsections which follow.

2.1 Comet Rendezvous Opportunities (A. Friedlander, J. Niehoff and J. Waters)

This study takes a new look at spacecraft missions to comets in the period 1975-2000. Previous comet mission studies have been restricted mainly to the flyby trajectory mode. Current interest, however, is centering on rendezvous missions which allow the spacecraft many months to monitor the dynamical environment of comets as they pass through perihelion.

The study objectives are: 1) investigate the trajectory requirements of promising comet rendezvous opportunities, 2) compare these requirements with current and

TABLE I
V6105 REVISED SCHEDULE FOR 1969-70

STUDY TASK	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
COMET RENDEZVOUS OPPORTUNITIES	1.5			▽	1.5	●	*								6
COMET RENDEZVOUS MISSION STUDY							2	2	2	2	1.5	1.5	▽	*	12
JUPITER ORBITER MISSION STUDY	2	.5	2	▽	.5		●								7
MERCURY ORBITER MISSION STUDY	.5	1.5					1.5	2	2	1.5	1.5	1.5	▽	*	16
OUTER PLANET SATELLITE MISSIONS	.5	.5				1.5	1.5			●	*				9
ATMOS. ENTRY AT URAN/ NEPT									1.5	1.5			●	*	7
SATURN'S RINGS MODEL							.5			.5		*			3
SPACECRAFT RADAR			.5		.5	●	*								2
VENUS EXPLORER RADAR					.5		.5	●	*						2
STELLAR MISSIONS											2		●	*	4
ADVANCED MISSION PLANNING															12
TOTAL	5.5	4.5	6.5	6	6	6.5	8	8	8.5	7.5	7	6			80

- ROUGH DRAFT READY FOR INTERNAL REVIEW
- ▽ FIRST AND SECOND SEMI-ANNUAL HQ. PRESENTATIONS
- * REPORT DRAFT READY FOR HQ

projected propulsion capabilities and, 3) recommend one or two particularly favorable comets for a subsequent comet rendezvous mission study. Trajectory requirements are considered for the following flight modes

- a. multiple impulse ballistic
- b. gravity-assisted ballistic (via Jupiter)
- c. solar-electric low thrust
- d. nuclear-electric low thrust.

An interim report, TM No. T-21, entitles "Comet Rendezvous Opportunities" was published in November 1969 which presented a selected list of 16 favorable comet apparitions for rendezvous missions and discussed several multi-impulse ballistic, Jupiter gravity-assisted ballistic and nuclear-electric low-thrust comet rendezvous trajectories. During the first quarter of this year the trajectory analysis was extended to include solar-electric low-thrust rendezvous trajectories. During the first quarter of this year the trajectory analysis was extended to include solar-electric low-thrust rendezvous trajectories and completed for all 16 selected comet apparitions.

A trajectory/payload summary of three-impulse ballistic rendezvous opportunities is given in Table 2. Payload data are presented for both 5-segment (3D) and 7-segment (3F) Titan/Centaur launch vehicles. In some cases a Burner II (BII) upper stage is added to the Titan 3D/Centaur vehicle. The payload data are the net spacecraft weight after rendezvous assuming a space-storable propulsion system ($I_{sp} = 385$ sec) has been used to perform the intermediate and final impulses. A 200 m/sec allowance is provided for interplanetary midcourse control. A payload on the order of 1000 lbs. should be representative of a comet rendezvous spacecraft. Of the 16 originally selected comet apparitions neither Tuttle/81 nor Halley/86 had any net payload with this flight mode. The most promising opportunities from Table 2, in terms of flight time and payload, are Encke/80, Kopff/83 and Encke/84.

TABLE 2

TRAJECTORY/PAYLOAD SUMMARY

COMET RENDEZVOUS - 3 IMPULSE BALLISTIC MODE

COMET	FLIGHT TIME (YEARS)	LAUNCH DATE	ARRIVAL (DAYS BPH)	PAYLOAD (lbs)	
				TITAN 3D/CENTAUR	TITAN 3F/CENTAUR
ENCKE/80	3.29	3/ 8/77	169	781	1186
TUTTLE/81	-NOT A PRACTICAL MISSION -				
D'ARREST/82	4.78	8/21/77	104	425	672
GRIGG- SKJELLERUP/82	4.76	4/29/76	101	618 (B11)	955
KOPFF/83	3.72	8/ 2/79	119	913	1354
ENCKE/84	2.95	3/ 6/81	40	474	1015
GIACOBINI- ZINNER/85	5.63	10/ 6/79	106	479 (B11)	718
BORRELLY/87	6.67	12/ 6/80	130	426 (B11)	614
T-G-K/90	5.69	4/ 8/84	119	655 (B11)	1008
FAYE/91	7.57	11/16/83	153	446 (B11)	656
SCHAUMASSE/93	5.48	2/22/87	203	338 (B11)	530
D'ARREST/95	4.60	8/18/90	102	550	939
PERRINE- MRKOS/95	4.46	11/ 9/90	113	681 (B11)	1025
KOPFF/96	6.68	7/17/89	66	1099 (B11)	1604
GIACOBINI- ZINNER/98	7.41	10/ 3/90	128	424 (B11)	621

The trajectory/payload summary of Jupiter-assisted ballistic rendezvous opportunities is presented in Table 3. Seven comets were identified as having potentially favorable phasing with Jupiter during the period 1980-1990. Flight times from launch to rendezvous average at about 4.5 years. Payload data are presented for Titan 3D/Centaur or Titan 3F/Centaur launch vehicles with the same space-storable propulsion stage for the terminal rendezvous impulse that was used in developing ballistic multi-impulse payloads. The d'Arrest/82 apparition is the only opportunity with more than 1000 lbs. net payload which is also one of the 16 selected favorable comet apparitions. Although comet Halley is not favorably located with respect to Jupiter a gravity-assisted opportunity has been identified by Michielson¹ for the 1986 apparition. A Saturn V/Centaur can launch a 1350 lbs spacecraft and the required retro propulsion in September 1977 to rendezvous with Halley 7.7 years later via a Jupiter gravity-assist.

A summary of trajectory/payload data to four selected comets using the solar-electric low-thrust mode is presented in Table 4. Rendezvous missions to Encke/80, d'Arrest/82 and Kopff/83 have flight times of 2-3 years, provide about 1000 lbs net payload and are launched by the Titan 3C. Optimum power ratings are in the range 20-25 kwe. Using a smaller powerplant of around 15 kwe would be more compatible with current SEP technology. An associated reduction in payload of no more than 10% would be expected. The fourth mission, rendezvous with Halley/86, is a special case. The high power rating, long flight time and low payload suggest that the retrograde rendezvous with Halley is not a good application for solar-electric propulsion.

The primary application for the nuclear-electric low-thrust flight mode is a Halley/86 rendezvous mission. In view of the long lead time currently felt necessary to develop a

¹ Michielson, H. F., "A Rendezvous with Halley's Comet in 1985-86", Journal of Spacecraft and Rockets, Vol. 5, No. 3, March 1968, pp. 328-334.

TABLE 3
SUMMARY OF
JUPITER-ASSISTED COMET RENDEZVOUS OPPORTUNITIES

COMET	APPARITION	LAUNCH DATE	JUPITER RCA (R_J)	TRIP TIME (yrs.)	ARRIVAL DATE (dbp)	BRIGHTNESS (mag.)	LAUNCH VEHICLE	PAYLOAD (lbs.)
D'ARREST	1982	SEPT. 13, 1977	72.8	4.68	123	13.6	TITAN 3D/CENT/BII	1109
H-M-P	1985	DEC. 16, 1980	54.8	4.16	100	19.9	TITAN 3D/CENTAUR	1528
	1985	DEC. 31, 1981	7.5	3.12	100	19.9	TITAN 3D/CENTAUR	633
GIACOBINI-ZINNER	1985	NOV. 2, 1979	53.1	5.27	200	19.9	TITAN 3F/CENTAUR	503
WHIPPLE	1986	JAN. 1, 1982	15.8	4.18	100	18.5	TITAN 3D/CENT/BII	662
BORRELLY	1987	DEC. 16, 1980	81.3	6.45	200	18.2	TITAN 3F/CENTAUR	655*
	1987	DEC. 31, 1981	71.5	5.53	150	16.3	TITAN 3F/CENTAUR	642*
ENCKE	1987	MAR. 10, 1984	8.2	3.08	100	17.6	TITAN 3F/CENTAUR	130*
T-G-K	1990	MAY 14, 1985	>150	4.50	150	17.5	TITAN 3D/CENT/BII	753

* TWO-STAGE RENDEZVOUS MANEUVER

TABLE 4

COMET RENDEZVOUS - SOLAR ELECTRIC PROPULSION MODE*

	<u>ENCKE/80</u>	<u>D'ARREST/82</u>	<u>KOPFF/83</u>	<u>HALLEY/86</u>
LAUNCH DATE	March 7, 1978	Sept. 27, 1980	July 29, 1981	May 24, 1978
ARRIVAL (BEFORE PERIHELION)	100 days	20 days	50 days	55 days
FLIGHT TIME, DAYS	900 days	700 days	700 days	2740 days
LAUNCH VEHICLE	Titan 3C	Titan 3C	Titan 3C	Titan 3F/Centaur
LAUNCH HYPERBOLIC VELOCITY	3 km/sec	3 km/sec	2 km/sec	7 km/sec
POWER RATING	20 kwe	20 kwe	25 kwe	50 kwe
SPECIFIC IMPULSE	3500 sec	3500 sec	3500 sec	3500 sec
PAYLOAD (NET SPACECRAFT)	1015 lbs.	910 lbs.	1075 lbs.	415 lbs.

*Propulsion system specific mass, efficiency and tankage

$$\alpha_{ps} = 66 \text{ lbs/kwe}$$

$$\eta = 66\%$$

$$k_t = 6\%$$

nuclear-electric system for space flight, the most reasonable trajectory generated is a 2.5 year flight launched with a Titan 3F/Centaur. The net payload at Halley is 1650 lbs. using a 140 kwe nuclear-electric low-thrust spacecraft based on nominal technology design ($\alpha_{ps} = 56$ lbs/kwe). Ecliptic and normal plots of the low-thrust flight path are presented in Figure 1. Rendezvous occurs 55 days before Halley's perihelion. The comet is near it's minimum geocentric distance and about 4th magnitude in total brightness.

These results were presented to the Director of Planetary Programs, Donald P. Heath, in February and again at the NASA sponsored Comet Symposium at the University of Arizona in April. Four specific conclusions were also cited at these presentations which are as follows:

- 1) Comet rendezvous missions in the time period 1975-95 are attractive and appear possible from a trajectory/payload standpoint.
- 2) Several favorable opportunities utilizing ballistic flights have been identified. Three-impulses or two-impulses plus a Jupiter gravity-assist are necessary with space-storable propulsion systems.
- 3) Low-thrust flight, restricted to solar-electric propulsion until the mid-1980's, offers the best performance of comet rendezvous missions. The advantages include shorter flight time, smaller launch vehicles, larger payloads, power availability and terminal maneuverability.
- 4) To date, the only promising rendezvous trajectories to comet Halley require a nuclear-electric low-thrust propulsion system which would have to be developed by 1983.

During the Comet Symposium (April 8-9) Drs. E. Roemer and B. Marsden offered several suggestions to improve the practicality of the sighting conditions which were used to

TABLE 5
COMET CLASSIFICATION BASED ON EARTH RECOVERY
AND SIGHTING CRITERIA

Class	Original Criteria	New Criteria
Good	Encke/80 Tuttle/81 d'Arrest/82 Grigg-Skjellerup/82 Kopff/83 Giacobini-Zinner/85 Halley/86 Borrelly/87 Tuttle-Giacobini-Kresak/90 Faye/91 Schaumasse/93 d'Arrest/95 Perrine-Mrkos/95 Kopff/96 Giacobini-Zinner/98	Encke/80 d'Arrest/82 Grigg-Skjellerup/82 Kopff/83 Giacobini-Zinner/85 Halley/86 Borrelly/87 Temple-2/88 Faye/91 Forbes/93 Schaumasse/93 Tuttle/93 Perrine-Mrkos/9 Kopff/96 Giacobini-Zinner/98
Fair	Brooks-2/80 Forbes/80 Schwassmann-Wachmann-2/81 Schaumasse/84 Grigg-Skjeuerup/87 Temple-2/88 Pons-Winnecke/89 Encke/90 Kopff/90 Forbes/93	Brooks-2/80 Forbes/80 Schwassmann-Wachmann-2/81 Encke/87 Grigg-Skjellerup/87 Pons-Winnecke/89 Encke/90 Kopff/90 Tuttle-Giacobini-Kresak/90 Giacobini-Zinner/92 d'Arrest/95 Encke/97
Poor	Ashbrook-Jackson/78 Borrelly/81 Areno-Rigaux/84 Honda-Mrkos-Padjuskova/85 Whipple/86 Encke/87 d'Arrest/89 Honda-Mrkos-Padjuskova/90 Daniel/92 Giacobini-Zinner/92 Tuttle/94 Encke/97	Ashbrook-Jackson/78 Tuttle/80 Borrelly/81 Arend-Rigaux/84 Schaumasse/84 Honda-Mrkos-Padjuskova/85 Whipple/86 d'Arrest/89 Honda-Mrkos-Padjuskova/90 Daniel/92

determine the 16 favorable comet apparitions for which rendezvous opportunity data had been generated. Specifically, 1) nuclear comet magnitudes rather than total magnitudes should be used to determine recovery characteristics, 2) a bright moon can delay predicted recovery by as much as two weeks, 3) recovery plates are often obtained when a comet is below 25° elevation at the observing site, and 4) 35° north latitude is more representative of observing sites in the northern hemisphere than is 25°. These conditions have been incorporated into a new set of sighting criteria so that the classifications of the 38 comet apparitions considered could be reexamined. The revised classification of good, fair and poor comet apparitions is compared with the original ordering in Table 5. There are still 16 comets classified as having good apparitions. There are, however, three changes in the good list (those apparitions for which rendezvous trajectory data has been generated). Tuttle/81, Tuttle-Giacobini-Kresak/90 and d'Arrest/95 have been replaced by Temple-2/88, Forbes/93 and Tuttle/94.

Multi-impulse ballistic rendezvous transfer data are currently being run for the three comets added to the good list. In addition, several multi-impulse opportunities are being checked for further performance improvements with added impulses (up to 5 total). A draft of the final report of this study task is in progress and will be submitted during the next reporting period.

2.2 Jupiter Orbiter Mission Study (J. Niehoff, A. Binder, D. Klopp)

This study was initiated during the previous contract year to determine the nature and usefulness of first-generation orbiters to the exploration of Jupiter. Four areas of analysis have been defined for the study, 1) definition and evaluation of science objectives, 2) description of measurement specifications and parameter instrument design, 3) trajectory analysis and related orbit selections, and 4) mission definitions,

comparisons and conclusions. Study results in the first three areas were summarized in Report No. A-7, "Sixth Annual Summary Report". The results of the fourth and final study areas are presented below.

The development of mission definitions is a synthesis of results obtained in the first three study tasks. It quickly became apparent, in developing these definitions, that no single orbit would satisfy all science objective and instrument requirements. In fact, two opposing trends are implied by the requirements, short period orbits versus long period orbits. The advantages of each of these orbit classes are listed for comparison in Table 6. The advantages of small orbits (short periods) pertain to measurements of the planet itself. For altitude (i.e., resolution) limited planetology instruments, short-period orbits provide more opportunities to image the planet over a fixed period of time. Advantages of long-period orbits pertain to, 1) particle and field measurements and their enormous spatial requirements, and 2) spacecraft design including weight and radiation lifetime.

The split in orbit capabilities suggests a logical division of science objectives for Jupiter orbiter missions, 1) particle and field measurements, and 2) planetology measurements. Four different mission profiles are suggested to consider the trade-offs of this situation. These are given in Table 7. Mission no. 1 is specifically a particles and fields mission. It involves two spacecraft in 45-day orbits at two inclinations. The multiple spacecraft and different orbit inclinations are selected to improve the spatial coverage of the enormous region of the Jovian magnetosphere. Mission no. 2 is specifically a planetology mission using a 15-day inclined orbit to maximize the coverage of altitude-limited instruments. Mission no. 3 also a planetology mission, reduces the latitude coverage by using an equatorial orbit in exchange for multiple opportunities to observe the Galilean satellites. Mission no. 4 is designed

TABLE 6
ADVANTAGES
OF
SMALL AND LARGE ELLIPTICAL ORBITS

SMALL ORBITS ($P \approx 7^d$)	LARGE ORBITS ($P \approx 45^d$)
● BETTER OVER-ALL RESOLUTION OF TIME-VARY ATMOSPHERIC PHENOMENON WITH A FIXED IMAGING SYSTEM ● MORE COVERAGE WITH ALTITUDE-LIMITED INSTRUMENTS ● MORE SATELLITE ENCOUNTERS (ASSUMING EQUATORIAL ORBITS) ● MORE COVERAGE IN TRAPPED CHARGED-PARTICLE REGION ● MORE ATMOSPHERIC RF OCCULTATION MEASUREMENTS	● COVERAGE OF INTERACTION OF SOLAR WIND WITH JOVIAN FIELD, i.e. MEASUREMENTS OF SHOCK FRONT, MAGNETOSHEATH, MAGNETOPAUSE AND MAGNETOSPHERE ● BETTER SPATIAL VARIATION IN JUPITERS MAGNETOSPHERE ● MORE PAYLOAD (ASSUMING PERIJOVE RADIUS IS HELD CONSTANT) ● LONGER SPACECRAFT RADIATION LIFETIME

TABLE 7
JUPITER ORBITER MISSION SELECTIONS

MISSION NUMBER	SCIENCE OBJECTIVE	ORBIT PARAMETERS		
		PERIAPSE (R_J)	PERIOD (DAYS)	INCLINATION (DEG)
1	PARTICLES AND FIELDS ¹	3	45	0 AND 120 ¹
2	PLANETOLOGY	3	15	60
3	PLANETOLOGY AND SATELLITE OBSERVATIONS	2.391 (2.290) ²	7.111 (14.222) ²	0
4	PARTICLE AND FIELD AND PLANETOLOGY	3	30	60

1. TWO SPACECRAFT ORBITED AT DIFFERENT INCLINATIONS
2. NEXT ORBIT CHOICE IF PREFERRED ORBIT CANNOT BE ACHIEVE

to do both particles and fields and planetology experiments. Its orbit period of 30 days is definitely a compromise between the opposing measurement requirements on orbit size.

The spacecraft subsystem weight breakdown for mission 1, shown in Table 8, is based on Pioneer F/G technology. The 60-lb science payload consists of a magnetometer, several plasma probes, a variety of high-energy particle detectors, an RF receiver; electric field detector, and two micrometeorite detectors. The total propulsion allowance includes 200 m/sec for mid-course and orbit trim maneuvers. The propulsion system weight is based on a bipropellant system (N_2O_4 -Zerozine) with 310 sec Isp. A total weight requirement of 2050 lbs. (two spacecraft) is within the capability of the Titan 3D/Centaur using 760-day transfers and 10-day launch windows. The selected orbits for the two spacecrafts are shown in the background top view of Jupiter's magnetosphere. Note that only one of the orbits (inclination $\approx 120^\circ$) crosses the predicted shock front, due to the orbit orientation required for an optimum orbit capture maneuver. As time in orbit increases the orbits will slowly rotate clockwise further into Jupiter's magnetosphere.

The spacecraft weight summaries for missions 2, 3 and 4 are presented in Table 9. The subsystem weights are estimates based on a survey of Jupiter orbiter spacecraft designs and a data load on the order of 10^9 bits per orbit. A liberal contingency factor (15%) is added due to the lack of detailed analyses to support the weight allocations. Some adjustments have been made in specific subsystem weights for the individual missions. The total orbited payloads do not differ markedly, however, primarily because imaging planetology instruments, which place the most significant burden on subsystem support requirements, appear on all three missions. The more significant drawback to Mission 4 than its slightly larger weight is the fact that it can obtain only half as much planetology coverage as Missions 2 and 3 in the same interval of time.

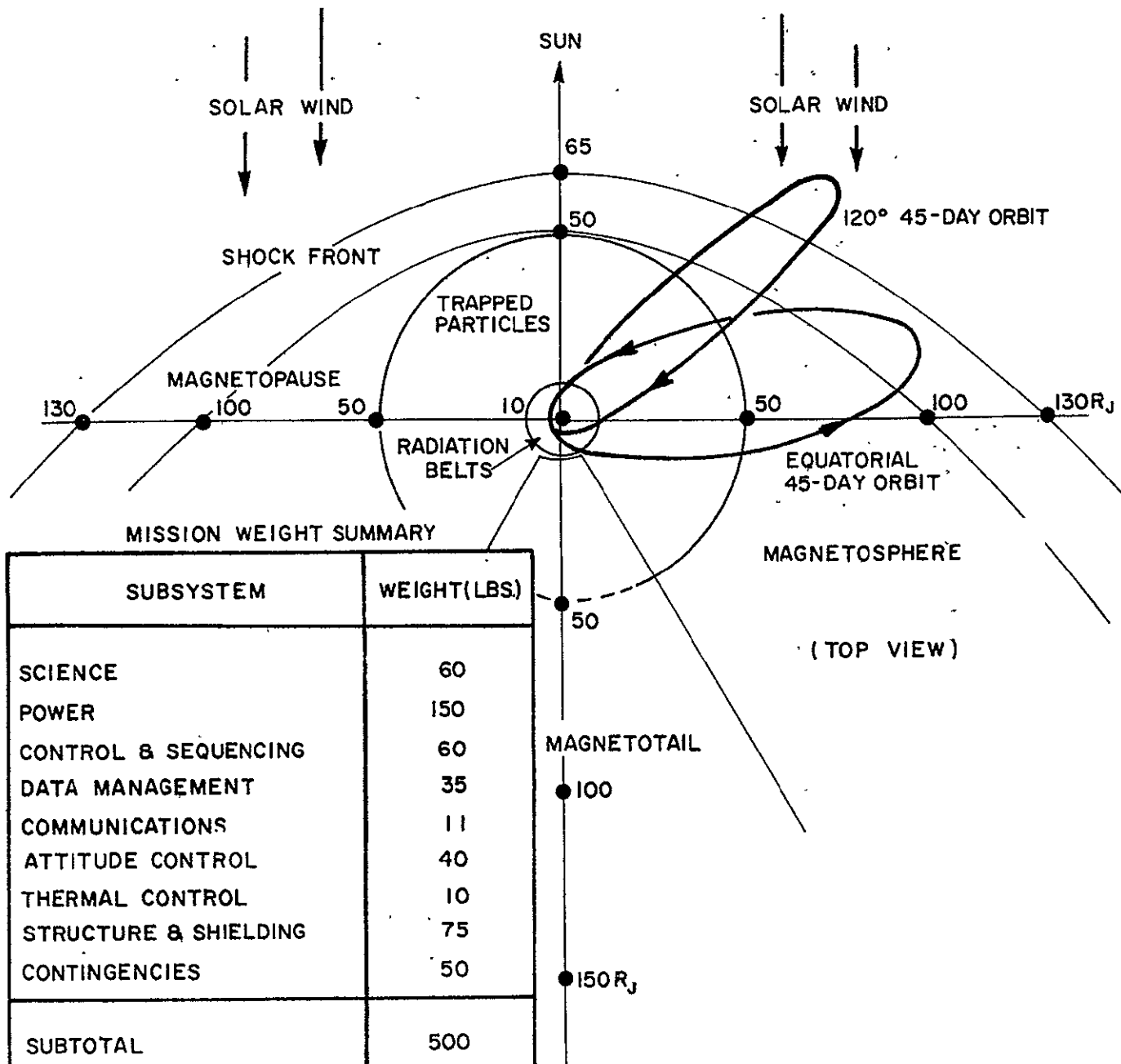


TABLE 8

MISSION NO.1 SUMMARY WEIGHT BREAKDOWN AND ORBIT CONFIGURATIONS

TABLE 9
SPACECRAFT WEIGHT BREAKDOWN
MISSION NOS. 2,3, AND 4 — PLANETOLOGY

SUBSYSTEM	WEIGHT (LBS)		
	PLANETOLOGY	PLANETOLOGY AND SATELLITE OBSERV.	PARTICLE AND FIELDS AND PLANETOLOGY
SCIENCE	190	190	230
PLANETOLOGY INSTRUMENT PLATFORM	35	35	35
IR RADIOMETER COOLING SYSTEM	50	50	50
PARTICLE/FIELD INSTRUMENT BOOMS	—	25	40
RTG POWER AND CONDITIONING	275	275	300
DATA MANAGEMENT	40	40	40
DATA STORAGE	65	65	65
COMMAND CONTROL AND SEQUENCING	45	50	50
TELEMETRY	90	90	90
ANTENNA	75	75	75
ATTITUDE CONTROL	150	150	150
THERMAL CONTROL	25	25	25
GUIDANCE SENSOR SYSTEM	30	30	30
METEOROID SHIELDING	15	15	15
STRUCTURE, WIRING, ETC.	160	165	180
CONTINGENCIES (15 %)	185	190	205
TOTAL ORBITED SPACECRAFT	1430	1470	1580

Measurement arcs on a 15-day orbit (missions 2 and 3) are illustrated in Figure 2 for the selected planetology instruments in the science payloads of Table 9. Each instrument will provide better than 100-km resolution over the subspacecraft ground trace within its measurement arc. Except for the visual imaging return-beam vidicon, all instruments are restricted to a period of operation no longer than two Jupiter days near periaspse (fixed in this study at $3R_J$). This again emphasizes the importance of frequent periaspse passes (short-period orbits) in order to study time-varying phenomenon in Jupiter's atmosphere.

A comparison of surface coverage capability of the 1.5-inch return beam vidicon in equatorial and 60 degree inclination 15-day orbits is presented in Figure 3. The shaded regions depict the coverage of a 1 deg. field-of-view instrument taking one image on each side of the ground trace (a flip-flop mirror system). If lateral scanning is permitted to the point where resolution has degraded to 200 kilometer (limit permitted by measurement specifications) then the dotted curves indicate the amount of latitude coverage available. Note that with the 60 degree inclination orbit both the north and south poles of Jupiter are seen during portions of the orbit at better than 200-km resolution. Even with the equatorial orbit more than 85% of the planet surface is seen at better than 200-km resolution during each Jupiter day.

Fixed flight time transfers were combined with Titan/Centaur family launch vehicles in the third study area (trajectory analysis and related orbit selection) to form selected orbiter delivery modes for use in payload analysis. The selected delivery modes are shown in Table 10 along with injected interplanetary payload capability, in parenthesis, for the required maximum characteristic velocities, V_C . The selections are made so that launch vehicle size and flight time can be traded off while injected payload is kept near the 3000 lbs. mark. Hence, the maximum-payload flight time (760-days with

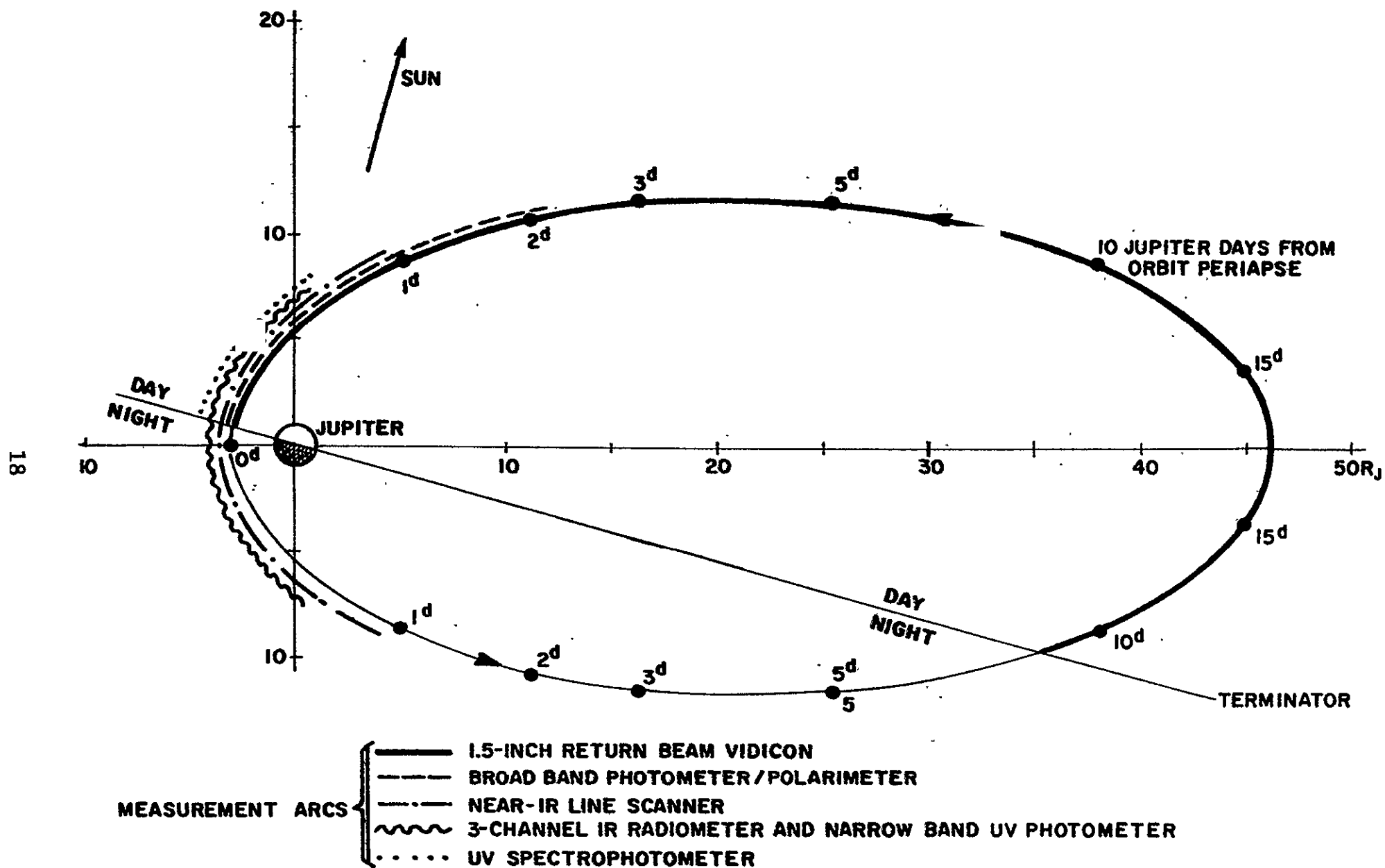


FIGURE 2. PLANETOLOGY INSTRUMENT MEASUREMENT ARCS FOR 15-DAY (EARTH DAYS) ORBIT.

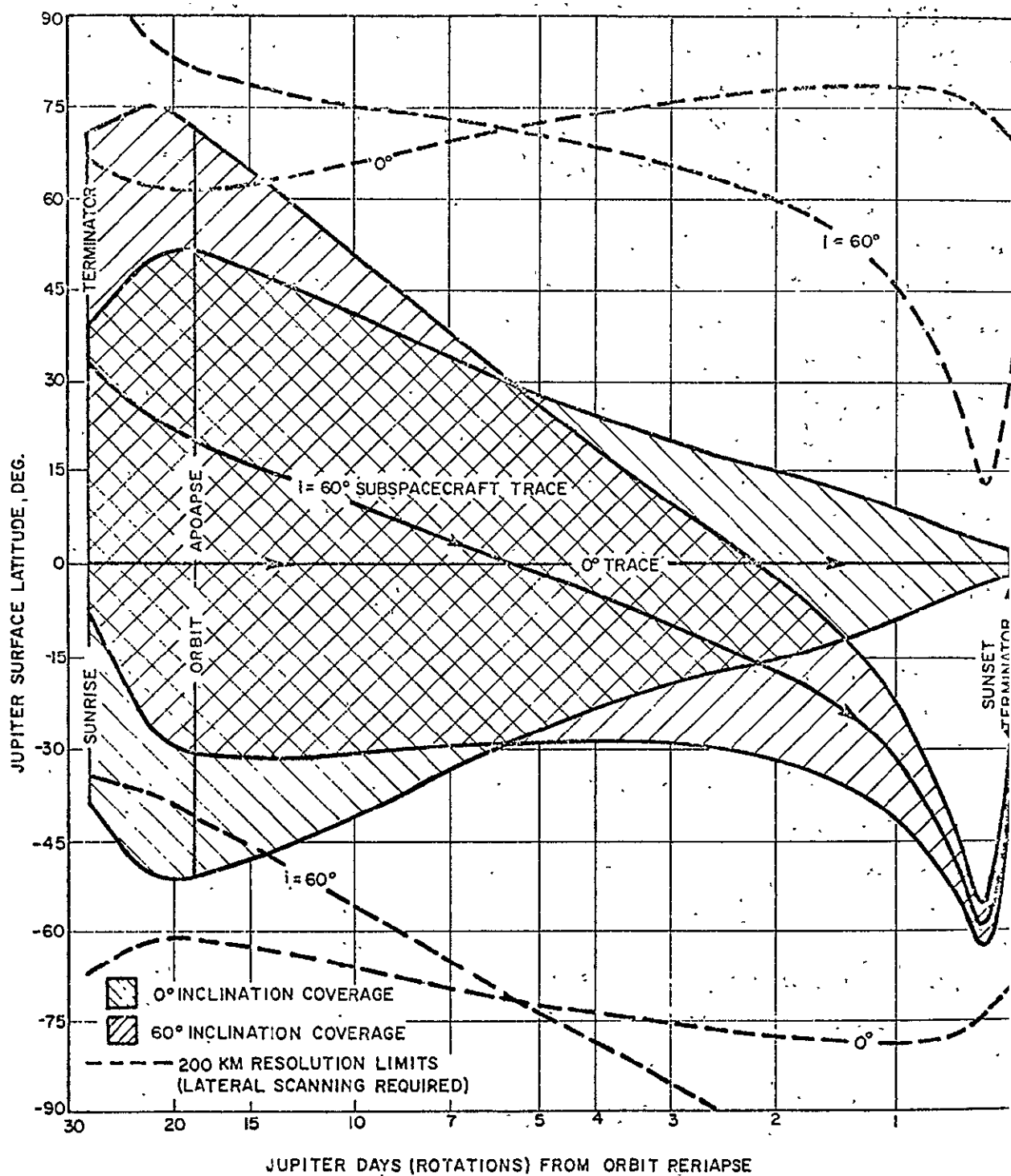


FIGURE 3. COMPARISON OF VISUAL COVERAGE(FOV=2°) FOR 15-DAY ORBIT AT 0° AND 60° INCLINAT

10-day launch windows) is retained in the mode selection until the Titan 3D(7)/Centaur is employed with an injected payload of 3300 lbs. Mode 5 was subsequently rejected because the associated high Jupiter approach velocities of 500-day transfers further reduced useful orbited payload to less than 500 lbs.

The total launch vehicle injected weight required by Missions 2, 3 and 4, assuming either earth-storable ($I_{sp} = 300$ sec) or space-storable ($I_{sp} = 400$ sec) capture propulsion systems are compared with the injected payload capability of each of the orbit delivery modes 1-4 in Table 11. A 200 m/sec allowance for mid-course guidance and orbital trim is provided for Missions 2 and 4. The planetology and satellite observation mission has a 500m/sec allowance to provide more orbit control in connection with satellite observations. Only the three open squares of Mode 3 have payload requirements within the capability of the associated launch vehicle. It is concluded that a Titan IIIF /Centaur launch vehicle and probably a space-storable propulsion system will be required to perform Jupiter planetology orbiter missions. In general, a 760-day transfer with a 10-day launch window will also be required. However, during the low-energy opportunity series of 1974-1976 and 1980-1984 the launch window can be enlarged to more practical values of 15-20 days. The consideration of high-energy upper stages, e.g. a hydrogen/fluorine kick stage or a solar-electric low-thrust stage, on the Titan vehicles has not been considered. Such additions should be studied as alternatives to seven-segment solids for the Titan and development of space-storable retro systems.

Four specific recommendations are made as conclusions to the study:

- 1) Press for a double Pioneer P/F orbiter mission launched by a single Titan 3D/Centaur/Burner II during the series of low-energy Jupiter opportunities from 1974 to 1976.

TABLE 10
SELECTED ORBITER DELIVERY MODES

TRAJECTORIES	LAUNCH VEHICLES			
	TITAN III D CENTAUR	TITAN III D CENTAUR BURNER II	TITAN III F CENTAUR	TITAN III F CENTAUR BURNER II
760-DAY TRANSFER TIME 10-DAY LAUNCH WINDOW	MODE 1 (1950 Lbs.)	MODE 2 (2550 Lbs.)	MODE 3 (3300 Lbs.)	
710-DAY TRANSFER TIME 20-DAY LAUNCH WINDOW			MODE 4 (2700 Lbs.)	
500-DAY TRANSFER TIME 20-DAY LAUNCH WINDOW				MODE 5 (1950 Lbs.)

I. LAUNCH VEHICLES INJECTED WEIGHT.

TABLE II
PAYLOAD/LAUNCH VEHICLE MATCHING

ORBITER DELIVERY MODE	INJECTED PAYLOAD CAPABILITY (LBS)	INJECTED PAYLOAD REQUIRED (LBS)							
		PLANETOLOGY		PLANETOLOGY AND SATELLITE OBSERVATIONS				PARTICLES AND FIELDS AND PLANETOLOGY	
				7.1-DAY ORBIT		14.2-DAY ORBIT			
		300 SEC ¹	400 SEC	300 SEC	400 SEC	300 SEC	400 SEC	300 SEC	400 SEC
1	1950	3760	3000	5540	4000	4060	3190	3430	2880
2	2550	3760	3000	5540	4000	4060	3190	3430	2880
3	3300	3760	3000	5540	4000	4060	3190	3430	2880
4	2700	4070	3180	5970	4220	4350	3360	3700	3040

1. ORBIT CAPTURE PROPULSION ISP: 300 SEC EARTH STORABLE, 400 SEC-SPACE STORABLE

- 2) Encourage the continued development of better planetology instruments to cope with the resolution/intensity problems at Jupiter.
- 3) Plan to initiate planetology orbiter missions after the Grand Tour missions during the series of low-energy Jupiter opportunities from 1980 to 1984.
- 4) Continue with plans for early atmospheric probe missions since orbital instruments will not provide data much below Jupiter's cloud tops.

The study is at this time complete. The construction of the report on the study has been delayed by advanced planning activities but is expected to be completed during the next reporting period.

2.3 Mercury Orbiter Mission Study (W. Wells, D. Klopp, W. Adams)

The overall goals of this study are, 1) to identify scientific objectives for Mercury exploration which can then be related to mission and instrument requirements, and 2) to explore the capabilities of solar-electric low-thrust propulsion for Mercury orbiter missions. A list of study tasks is given in Table 12 summarized in this report. Results of the three tasks under "Development of Science Measurements" and a portion of task C1, "orbit selection", have been obtained during this reporting period.

Task A1: Review of Scientific Investigation of Mercury

While our knowledge of Mercury is limited, some things are known that will be useful in designing an orbiter mission. The orbital elements of Mercury are well known (see Table 13). In 1965 earth-based radar observations established a 59-day rotation period and it is now believed, both from observations and theoretical considerations, that Mercury has a unique 2:3 resonance between its orbital and rotation periods. As a result the length of a Mercury day is 176 earth days. Given the resonance and eccentricity of the orbit, two equatorial

areas (these are the sub-solar points at Mercury perihelions) will receive more solar energy than other equatorial areas and are appropriately known as hot poles. The equatorial areas 90° away are known as warm poles. Other physical elements are also listed in Table 13. The density, which is the highest for any planet, implies that Mercury is about two-thirds iron which could be concentrated in a central core.

Observations of Mercury by earth-based telescopes have been limited by its proximity to the sun. The resolution that can be achieved is about 500 km for which no features other than slight albedo variations have been identified. Photometric observations have shown that in this respect Mercury resembles the Moon. The Moon and Mercury also have similar radar reflectivities and scattering laws which may imply similar surface materials and terrain. Infrared and microwave observations have established that the mean surface temperature at the subsolar point is 615°K while the dark side is about 100°K at the surface.

Polarimetric studies are consistent with a thin atmosphere of about 1 mb while spectroscopic tests have led to upper limits for some possible constituents. Because of the high temperatures and the low escape velocities, an atmosphere seems unlikely. This means that there will be little if any attenuation in surface radiation of either photons or particles.

Unfortunately, little is known about possible surface features, the nature of the solar wind interaction with the planet or whether Mercury has a magnetic field or trapped radiation belts. The Mercury-Venus 1973 mission will provide scientific data that is essential to the final design of a Mercury orbiter mission.

Task A2: Measurables and Techniques

A list of scientific measurables has been derived in a systematic manner by subdividing the goal of Mercury exploration into the exploration regimes of Surface and Interior,

TABLE 12

MERCURY ORBITER MISSION STUDY TASKS

- A. DEVELOPMENT OF SCIENCE MEASUREMENTS
 - 1. Review the present status of scientific investigations of Mercury.
 - 2. Identify the primary measurables for early exploration of Mercury and determine useful sensing techniques for their study.
 - 3. For each "orbital" measurable write a set of specifications which state the required performance of each useful technique.
- B. TRAJECTORY AND PAYLOAD ANALYSIS
 - 1. Review direct Venus swingby and multi-impulse trajectories to Mercury.
 - 2. Generate solar-electric low-thrust trajectories to Mercury for orbiter missions.
 - 3. Perform a payload trade-off study for appropriate combinations of launch vehicles, interplanetary flight modes and orbit capture propulsion systems.
- C. MISSION SYNTHESIS
 - 1. Select orbits based on science measurement requirements and/or trajectory and propulsion system characteristics.
 - 2. Describe instruments capable of performing measurements on the selected orbits.
 - 3. Estimate science payload and spacecraft subsystem weights for specific mission profiles.
 - 4. Compare characteristics of mission profiles.
 - 5. Summarize preferred orbiter mission definitions and their contribution to Mercury exploration.

TABLE 13

MERCURY ORBITAL ELEMENTS

Semi-major axis	0.3871 AU
Eccentricity	0.2056
Inclination	7.004°
Orbital Period	87.969 day

MERCURY PHYSICAL CHARACTERISTICS

Rotation period	58.646 days
Mass/Mass of earth	0.0553
Radius	2434.0 km
Ellipticity	0
Density	5.45 g/cm ³
Escape velocity	4.2 km/se
Surface gravity	372 cm/se

Atmosphere, Particles and Fields, and Biology. The subsequent division of the Surface and Interior Regime is shown in Table 1 where at the last level, X's have been placed before the measurables which we believe deserve a high priority in Mercury exploration. Almost all of these priority measurables deal with the exploration regime of "Surface and Interiors" although a few measurables are included for the atmospheric composition, magnetic field and radiation belts.

The selected high-priority measurables are presented together with measurement techniques in Table 15. Here the measurables have been ordered by the mission modes needed for their study. They fall into categories of 1) measurables best made from orbit, 2) measurables best performed on complimentary orbiter and lander missions, and 3) measurables best made with landers. From an extensive list of possible orbital measurement techniques and some lander techniques, we have indicated which are useful techniques for studying each priority measurable. Imagery techniques especially visual but including other bands, are very useful for orbiter measurables. An orbiter and a lander provide complimentary data for eight measurables. For example, an orbiter frequently employs spectroscopy to study the variations over a planetary surface, while surface sample analysis provides a useful independent measurement at the lander site. For the last group of measurables, a lander mission is required to get a surface sample or to make in situ measurements of the surface.

Task A3: Measurement Specifications

Before either specific instruments or orbits are selected, it is necessary to describe how a scientist would like the measurements to be performed. That is, what operational conditions and measurement accuracies are desired for proper information interpretation. In general, several measurables use the same instrument technique and therefore, several specifications would be written. These have been grouped together under a single summary specification for each technique.

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TABLE 14
EXPLORATION REGIME: SURFACE AND INTERIOR

REGIME CATEGORY	CATEGORY OBJECTIVE	MEASUREABLE
PLANETARY COMPOSITION	ELEMENTAL ABUNDANCES	X SURFACE ELEMENTS
	ISOTOPIC RATIOS	X SURFACE ISOTOPIC RATIOS
	MATERIALS	X PETROLOGY X MINERALOGY LIQUIDS
	MEAN DENSITY	X MASS X RADIUS X OBLATENESS
PLANETARY STRUCTURE	GEOMETRIC SHAPE	X SURFACE ELEVATIONS X CENTER OF MASS
	CRUSTAL STRUCTURE	X LAYERING X CONTACTS X ATTITUDE OF ROCK UNITS X STRUCTURE OF FEATURES
	SURFACE MORPHOLOGY	X SURFACE TOPOGRAPHY X SURFACE APPEARANCE X THERMAL PROPERTIES
	INTERNAL STRUCTURE	X DENSITY DISTRIBUTION X DISCONTINUITIES
ACTIVE PLANETARY PROCESSES	PLANETOCENTRIC MOTION	X ROTATION PERIOD/AXIS
	ACTIVE CRUSTAL PROCESSES	SURFACE WINDS LIQUID MOTION TOPOGRAPHIC CHANGES X THERMAL ANOMALIES X SEISMIC WAVES SURF/ATMOS TRANSFER SURF/ATMOS INTERACTION
	ACTIVE INTERNAL PROCESSES	X MAGNETIC FIELD X HEAT FLOW X SEISMIC WAVES MASS MOTION

TABLE 15

MERCURY
MEASURABLE-TECHNIQUE
COMBINATIONS

		ORBITAL TECHNIQUES															LANDER TECHNIQUES							
		IMAGERY				SPECTROSCOPY				P/F			OTHER											
		Visual Imagery	IR Imagery	Microwave Imagery	Radar Imagery	UV,V Spectroscopy	UV,V Photometry	IR Spectroscopy	IR Photometry	Microwave Radiometry	X-γ-Ray Spectroscopy	Magnetometry	Electrometry	Plasma Detection	Energetic Particle	Micrometeorite Detection	Ranging	Tracking	Occultation	Imagery	Geological Mapping	Sample Analysis	Seismometry	Gravimetry
ORBITER MEASURABLES	Mass																							
	Radius																							
	Oblateness																							
	Surf Elevations	●			●													●	●	●				
	Center of Mass																		●	●				
	Contacts	●	●	●	●	○		●																
	Structure of Features	●	●	●	●																●	●	●	●
	Surf. Topography	●	●	●	●																			
	Surf. Appearance	●	●	●	●		●		●												●			
	Rotation Axis	●	●	●	●																			
	Surf. Thermal Anomalies		●	●																				
LANDER & ORBITER	ATM Mean Molecular Weight																			●		●		
	Gravitational Field Vector																			●				○
	Radiation Belts													●	●									
	Surface Elements						○				●												●	●
	Petrology						○		●														●	●
	Surf. Thermal Properties								●	●													●	●
	Density Distribution																	●	●	●			●	○
LANDER MEASURABLES	ATM Elements & Molecules					●		●															●	●
	Particulate Sizes					●		●															●	
	Magnetic Field Vector											●	●											
	Solar Wind Interaction											●	●	●										
	Surf. Isotopes																						●	●
	Mineralogy																						●	●
	Layering	●				●																●	●	○
	Attitude of Rock Units																					●	●	●
	Internal Discontinuities																						●	●
	Seismic Waves																						●	●
	Heat Flow																							
ATM Isotopes																						●	●	
Particulate Composition																						●	●	
A-Biotic Organics						○		○														●	●	
Life Associated Organics						○		○														●	●	

● VERY USEFUL ● USEFUL ○ NOT VERY USEFUL

It may not always be possible to meet these ideal measurement specifications since any instrument will be state-of-art limited. However, it is recommended that whenever an instrument can be designed within the state-of-art that exceeds these specifications, it be used unless it is significantly heavier, more costly or too demanding of spacecraft subsystems.

An example of a measurement specification summary for the technique of visual imagery is presented in Table 16. The six measurables for which visual imagery is useful are: surface elevations, rotation axis/period, contacts, structure of features, surface topography, and surface appearance. Three levels of investigation are defined: regional, local and detailed. Each of these corresponds to a characteristic feature size based on terrestrial and lunar experience. The first two measurables are defined only on the regional scale. Color images would be useful for contacts, structure of features and surface appearance. Vertical resolution, which can be achieved by either shadows or stereo, applies to surface elevations, structure of features and surface topography.

Task C1: Orbit Selection

The objective of this task is to determine orbits which both maximize the quality and quantity of scientific data collected and minimize the orbit capture and control requirements. The latter objective of minimum ΔV depends upon the characteristics of interplanetary transfers to Mercury, of which study has just started. At this time, therefore, only the choice of an orbit based on the best science data return is discussed.

It would be advantageous to have a circular orbit so that the surface can be studied at constant resolution. Because Mercury rotates slowly, a circular orbit will also give more coverage for instruments that have altitude-limited performance. Since a circular orbit has a short period, it will have more frequent occultations and more opportunities to

TABLE 16

SAMPLE MEASUREMENT SPECIFICATION

Instrument Technique: Visual Imagery

	<u>egional</u>	<u>local</u>	<u>detailed</u>
Ground resolution	1 km	0.1 km	1 m
Vertical resolution	1 km	0.1 km	5 m
Image size	800 km	100 km	1 km
Positional accuracy	10 km	1 km	10 km
Planetary coverage	global	20%	1%
Distribution of coverage	global	global	global
Acquisition time			-
Repetition rate			
Spectral region	0.4-0.7 μ		
Number of bands	1 (3 for color)		
Bandwidth	0.3 μ (0.1 μ for color)		
Image overlap	20% (60% for stereo)		
Solar elevations	10-30° for shadows		
	50-80° for color		
	70-90° for stereo		

observe dynamic phenomena. The main disadvantage is the higher capture ΔV needed. Also a larger fraction of the mission will be spent within the solar occultation zone. A third disadvantage of a circular orbit is the limited volume of near planet space available for particles and fields exploration.

The optimum altitude for the mission is found by considering the field-of-view and foreshortening of an imaging system for regional studies which is 800 km. The altitude could not be considerably less than 800 km because of the increasing ΔV requirements and trajectory control problems. We have selected 500 km as the nominal value. A larger value may mean larger optical system weight for instruments needing good illumination intensity.

The best global coverage for imagery and latitude coverage of occultations is obtained with a polar orbit. This is achieved at the reduction of coverage at specific latitudes which may contain interesting features.

Any additional candidate orbits, particularly elliptical, that may be selected because of smaller ΔV 's will have to meet two conditions. First they must have a reasonable lifetime, say 180 days, under the influence of solar perturbations on the orbit. The second condition is that highly inclined orbits with periapsis near the equator are preferred.

Analyses of the three study tasks under "Development of Science Measurements" (see Table 12) are complete. The results are currently being documented. Review of ballistic trajectory data for Mercury orbiter missions (Task B1) is currently underway. For the next two months major emphasis will be on completing the "Trajectory and Payload Analysis" task, with generation and evaluation of solar-electric low-thrust trajectories being of prime importance. Work is also currently in progress to develop scaling laws for determining spacecraft subsystem weights. The results will directly support the "Mission Synthesis" tasks plan for this Fall.

2.4 Outer Planet Satellites Missions (M. Price and D. Spadoni)

A preliminary study of scientific objectives and payload requirements to send 1500 lbs. landers to each of Jupiter's Galilean satellites was conducted last year. The results (Report No. M-19) indicate that these missions might be possible with Saturn class launch vehicles and/or advanced propulsion systems, e.g. cryogenic or nuclear retro stages, or nuclear-electric low-thrust propulsion. These findings are the motivation for expanding the analysis of outer satellite lander missions in the current study. Specifically, the objectives are:

- 1) to review and classify all the outer planet satellites according to physical properties and orbit parameters,
- 2) to select a subset of these satellites for consideration as lander mission targets,
- 3) to develop a preliminary science payload consistent with a Viking-class mission to these satellites, i.e. an orbiter/lander mission,
- 4) to determine payload requirements and capabilities to perform these missions.

The conclusions of this study will be the basis for the selection of one or two satellites for an expanded satellite lander mission study planned next year.

Task 1: Satellite Review and Classification

On the basis of their physical and orbital parameters, and probable origin, the satellites of the outer planets divide naturally into two groups, Regular and Irregular.

The Regular group has the following properties:

- The orbits are direct with respect to the rotation of the parent planet,
- The orbits are very nearly circular,
- The orbits are very close to the equatorial plane of the parent planet,

- The periods of rotation are equal to the period of revolution,
- The radii range from 50 km through 2500 km,
- The satellites probably originated as the final stage in the systematic process of formation of the major planets.

The Irregular group has the following properties:

- The orbits are either direct or retrograde with respect to the direction of rotation of the parent planet,
- The orbits are appreciably non-circular,
- The orbits are inclined, in some cases substantially to the equatorial plane of the parent planet,
- The satellites are always the outermost in any system,
- The satellites are always small, i.e. less than 500 km in radius,
- The satellites are probably captured asteroids, the gravitational captives having occurred fairly recently on an astronomical time scale.

These groups are listed by planet in Table 17 and 18, respectively. The satellites are listed in order of increasing distance from the planet. The semi-major axes of their orbits, a , and their radii, r , are also given.

Task 2: Satellite Selection

Six satellites have been selected for consideration as lander mission targets. Their selection is based on:

- 1) The physical parameters of the satellite. The largest satellites are obviously prime candidates for exploration.
- 2) The classification of the satellite. The Regular group is more significant in the context of the study of the origin of the solar system.

TABLE 17

REGULAR SATELLITE GROUP

JUPITER			SATURN			URANUS			NEPTUNE		
No.	a (in 10^6 km)	r (km)	No.	a (in 10^6 km)	r (km)	No.	a (in 10^6 km)	r (km)	No.	a (in 10^6 km)	r (km)
V	0.181	70	X	0.160	150	V	0.128	100	I	0.353	2000
I	0.422	1800	I	0.186	300	I	0.192	300	II	5.600	100
II	0.672	2549	II	0.238	300	II	0.267	300			
III	1.070	2621	III	0.295	500	III	0.438	500			
IV	1.883	2389	IV	0.377	500	IV	0.586	400			
			V	0.527	700						
			VI	1.222	2400						
			VII	1.482	200						

TABLE 18

IRREGULAR SATELLITE GROUP

JUPITER			SATURN		
No.	a (in 10^6 km)	r (km)	No.	a (in 10^6 km)	r (km)
VI	11.470	50	VIII	3.560	500
VII	11.740	10	IX	12.950	100
X	11.850	7			
XII	21.200	6			
XI	22.500	8			
VIII	23.500	10			
IX	23.700	8			

The satellites selected are the four Galilean moon of Jupiter, Titan (Saturn VI) and Triton (Neptune I). Table 19 compares them with the smaller planetary bodies in terms of mass, radius and mean density. Ganymede, Titan, Triton and Callisto are all more massive than our moon and Ganymede is slightly larger in size than the planet Mercury. Io is comparable to the moon and Europa is somewhat smaller. All of these objects have probably been directly involved in the origin and evolution of their parent planets. Their exploration promises new knowledge of that process as well as evidence of major events in their own histories.

Task 3: Preliminary Science Payload

A Viking-class orbiter/lander mission is envisioned as being the most practical approach to surface exploration of the outer planet satellites. The inclusion of an orbiter permits real-time site selection, avoids the weight penalties of carrying large bulky (antenna sizes are running 4-5 meters) earth-link communications systems to the surface, and provides complimentary orbital data to enhance interpretation and application of lander measurements. Both a single soft-lander or multiple hard landers are being considered.

A number of lander measurements are particularly appropriate for these missions. Soil sampling analysis is obviously pertinent to investigation of surface composition. Seismometry would provide evidence to the internal physical structure and age of the satellite. Surface (and orbital) magnetometry will also provide clues to the interior structure. High-energy particle detection at the surface, particularly for the Jovian satellites, is important with relation to determining the physical properties of surface material. Thermal monitoring of the surface and subsurface is necessary to investigate thermal flow characteristics and radioactive context of the satellite. A composite experiment would monitor a rarified atmosphere with the following measurements

TABLE 19
PHYSICAL PROPERTIES OF THE MOON, MERCURY, MARS
AND THE SIX LARGEST OUTER PLANET SATELLITES

Celestial Body	Mass (in 10^{25} g)	Radius (in km)	Mean Density (in g/cc)
Mars	63.95	3400	3.95
Mercury	31.68	2420	5.3
Gangmede (Jupiter III)	15.45	2621	2.1
Titan (Saturn VI)	13.69	2440	2.3
Triton (Neptune I)	13.56	2000	4.1
Callisto (Jupiter IV)	9.64	2389	1.7
Moon	7.35	1738	3.343
Io (Jupiter I)	7.22	1800	3.0
Europa (Jupiter II)	4.70	1549	3.0

of composition, velocity vector of surface winds, relative humidity of volatiles, pressure and temperature. Perhaps the most meaningful measurements which can be identified at this time are visual imagery and spectral photometry. Among the measurables investigated would be topography in the vicinity of the landing point, and observation of the formation and melting of any "hoar-frost" during and after solar eclipse by the planet. Rudimentary imagery of the parent planet might also be undertaken.

A list of instruments to perform these measurements is presented in Table 20 in terms of weight and power. The composite science package, suggested for the soft-lander, weighs 100 lbs and requires 150 watts of power. All equipment, except the drill, may be in operation simultaneously. For the hard-landers only one or two of the instruments in Table 20 could be landed in one capsule, its total weight estimated to be on the order of 50-100 lbs. In addition, only certain instruments such as the seismometer, atmospheric monitor, facsimile camera and particle detectors may be designable to the large impact forces.

Objective 4: Trajectory and Payload Analysis

Progress to date on the payload requirements objective of the study has been made primarily in the area of trajectory analysis. Ballistic interplanetary trajectory characteristics have been studied for Jupiter, Saturn, and Neptune. Maneuver sequences have been defined for orbital capture at the satellite and for deploying a lander (soft or hard) to a selected surface site. The direct approach from interplanetary flight to landing (used in the previous study, see Report No. M-19) has been abandoned because it requires a priori site selection and implies rigorous timing and orbit determination to successfully accomplish the terminal maneuvers.

Launch opportunities over the period 1985-1995 have been reviewed for interplanetary transfers to Jupiter, Saturn

TABLE 20
INSTRUMENTATION

Experiment	Weight (lbs)	Power (watts)	Information Source
1. Soil Sampler and Analyzer	23	54-79	Viking
a) Molecular analysis of soil volatiles by gas chromatography/mass spectrometry.			
b) Scanning calorimeter	0.5	10-28	Viking
2. Seismometer	3	1	Viking
3. Magnetometer (Fluxgate or Vector Helium type)	7-10	2.5-3	Pioneer F/G
4. Charged Particle Detectors			and
a) Plasma detectors	8-10	3-4	IITRI 1970
(Electrostatic analyzer or Faraday Cup)			Jupiter
b) High Energy Particle detectors	3-6	1.5-3	Orbiter Study
5. Heat flow meter	10	10.5	Apollo 13
Drill to implant thermal sensors up to 3 meters into soil	24	See text	ALSEP
6. Atmospheric Monitor			
a) Anemometer, pressure and temperature sensors	7.5	11	Viking
b) Mass spectrometers	Included in Soil Sampler and analyzer Equipment		
7. Facsimile Camera	13	10-12	Viking
TOTAL	99-107	103.5-152.5	

and Neptune. Table 21 presents nominal values selected for flight time (TF), characteristic launch velocity (V_c) and hyperbolic approach speed (VHP) for each of the respective target planets. These average values are typical of 10-day launch windows over the 11-year period of opportunities considered.

TABLE 21

Target Planet	TF (days)	V_c (ft/sec)	VHP (km/sec)
Jupiter	760	47840	6.84
Saturn	1625	51657	6.82
Neptune	3400	57214	13.11

The impulse sequence developed for establishing an orbit about a planetary satellite is illustrated in Figure 4. The sequence is a derivative of the bi-elliptic transfer and requires, in general, three impulse. The first impulse establishes a loose elliptical orbit about the parent planet in a plane which contains the hyperbolic approach velocity (VHP) and intersects the satellites orbit at the periapse point of the approach hyperbola. The second impulse occurs at the apoapse of the initial orbit. Its purpose is to change the orbit plane to coincide with the satellite and raise the periapse radius to match the satellite orbit. The final impulse, performed at periapse of the second orbit, establishes the capture orbit about the satellite. It is assumed that the spacecraft's periapse passage is matched with the position of the satellite so that capture can occur.

A polar orbit is specified about the satellite to permit extended surviellance of the surface before a landing site is chosen. Once the site is selected another sequence

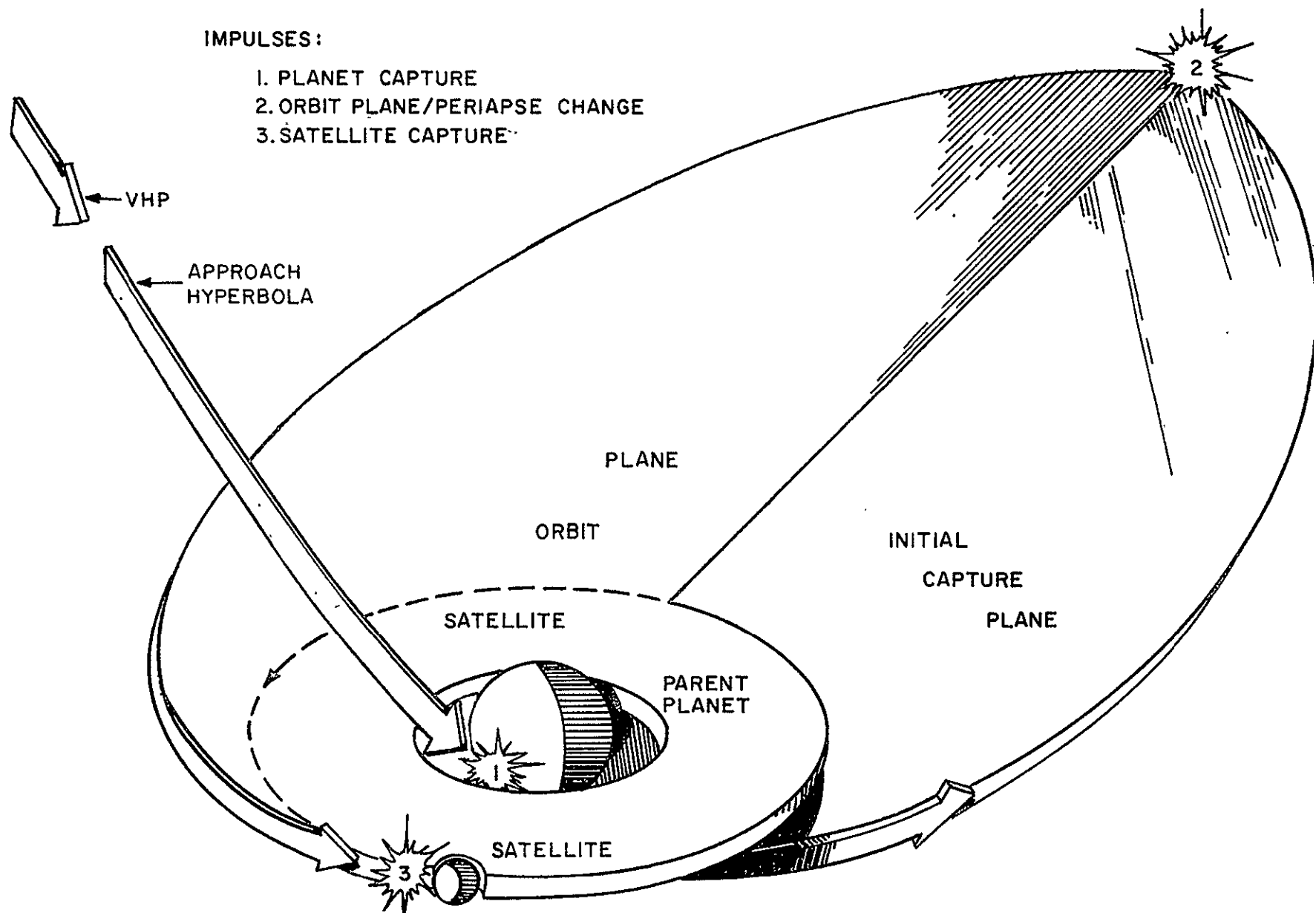


FIGURE 4. SATELLITE CAPTURE SEQUENCE.

improve the utility of the report for advanced planning purposes. Accordingly, a two man-month effort was included in the revised schedule for the current contract year (see Table 1). Typical of the additional material generated for the report is Figure 6, a sequential illustration of the development of the signal to noise equation:

$$S/N = \frac{P_t G \sigma A_e}{(4\pi R_1^2)(4\pi R_2^2)[1.38 \times 10^{-23}(T_a + T_r)B]}$$

where the individual parameters are defined in the figure. This equation is the basis for comparisons of 1) Earth-based and spacecraft monostatic radar systems, and 2) bistatic and monostatic radar operations for several combinations of Earth-based and/or spacecraft systems. The two-month review task is completed. A final summary of the overall study is presented in the following paragraphs.

Earth-based radar studies of the terrestrial planets from such as the Arecibo, Goldstone, and Haystack sites have provided much valuable data. Rotation rates, orbital parameters, surface roughness and even maps of specific planetary topographic features have been furnished by radar observations. It is evident, however, that Earth-based radar observation alone is approaching a limit, a limit beyond which a significant amount of knowledge of the solar system lies. Radar resolution will continue to increase with the application of new techniques like radar interferometry, but sensitivity is already seen to be approaching a physical limit. The resolution will exist for detailed (1 km) study of the terrestrial planets but the sensitivity will not.

Spacecraft radars are the answer to this limiting problem. Though they, 1) suffer a 1000:1 disadvantage in radiated power compared to Earth-based terminals, 2) must contend with high planetary brightness temperatures (noise) compared to the

of three maneuvers is required to deploy the lander. This sequence is illustrated in Figure 5. The first impulse (no. 2 in the figure) places the lander (after separation from the orbiter) on a descent orbit to bring it much closer to the surface. Near the low point of this orbit a fixed-thrust burn (no. 3) is performed to reduce the lander's velocity. The landing is accomplished with a variable-thrust terminal maneuver (no. 4) which immediately follows the braking maneuver. If a hard-lander capsule is used the terminal descent maneuver is omitted. The orbiter is actively maintained after landing as a communications relay link to Earth.

A number of exploratory trajectory computations have lead to a nominal set of orbit and propulsion parameters for the orbit/landing phase of the mission. These include a 100 km altitude circular polar parking orbit, an initial thrust level for the braking maneuver of one-g and a 4:1 throttle ratio for the terminal descent of the soft-lander. The hard-lander impact velocity is on the order of 100 m/sec.

The work planned during the next reporting period is concentrated on low-thrust interplanetary trajectory analysis and development of payload data for the maneuver sequences described above. This will be followed by comparisons of payload requirements with capabilities of various propulsion system combinations. As a final conclusion to the study one or two satellites will be chosen as the objects for a complete lander mission study which is to follow. This selection will be based on relative scientific merit as well as consideration of flight time and propulsion system complexity to reach the surface of the six primary satellites considered.

2.5 Spacecraft Radar (H. Goldman, R. Brandenburg)

A comparison study of earth-based and spacecraft radar capability was performed during the previous contract year. Results from this study were reported in the Sixth Annual Summary Report, A-7. Following a review of the report rough draft it was decided that some additions should be made to

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MANEUVER SEQUENCE:

1. CAPTURE IMPULSE (SAME AS NO.3, FIG. 4)
2. DESCENT ORBIT INJECTION IMPULSE
3. CONSTANT-THRUST BRAKING
4. VARIABLE-THRUST TERMINAL DESCENT

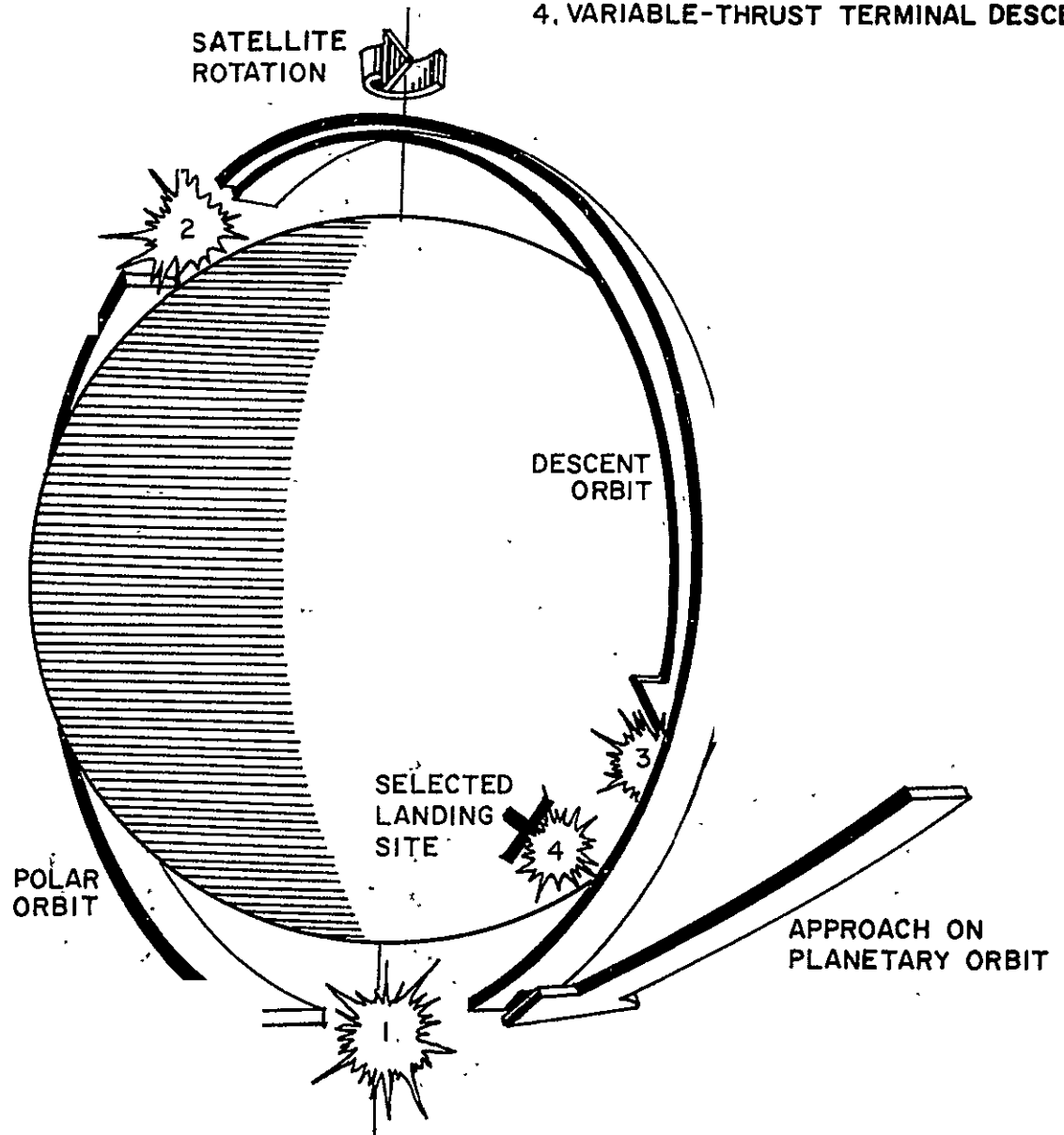
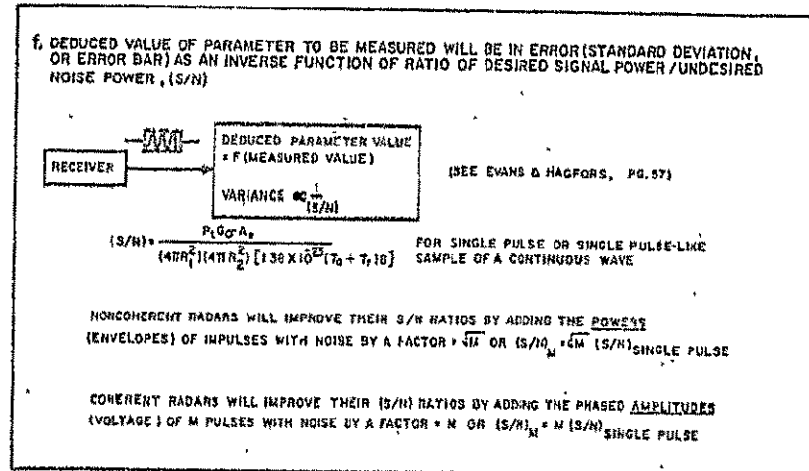
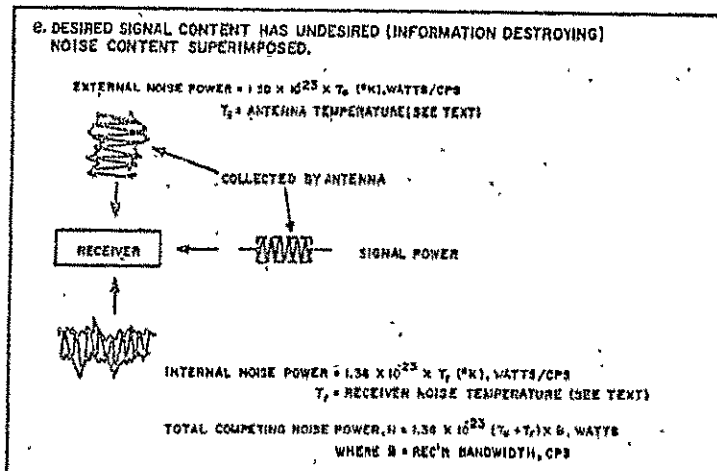
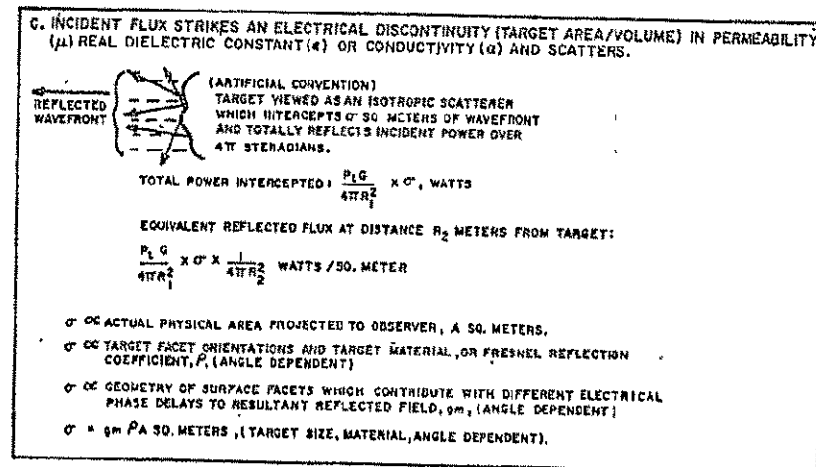
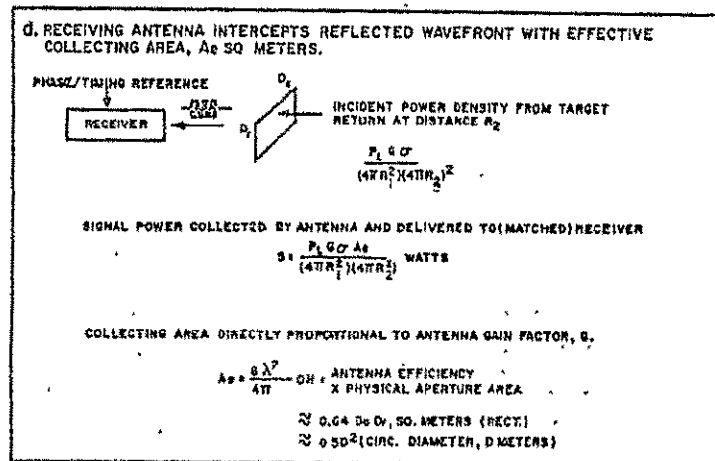
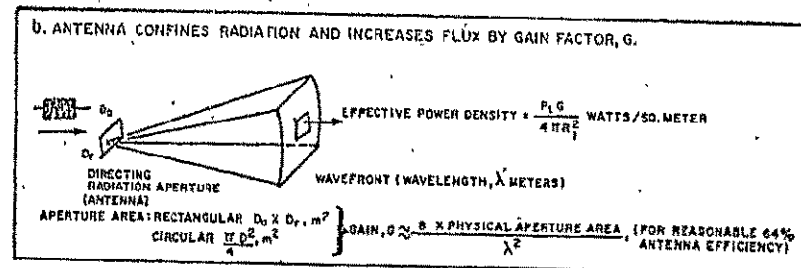
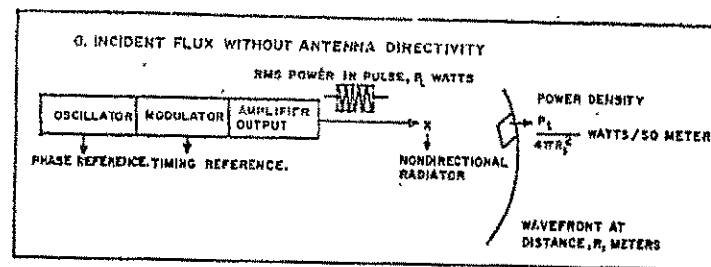


FIGURE 5. SATELLITE LANDING SEQUENCE



FOLDOUT FRAME

FIGURE 6. FLOW DEVEL

* RADAR EQUATION.

FOLDOUT FRAME

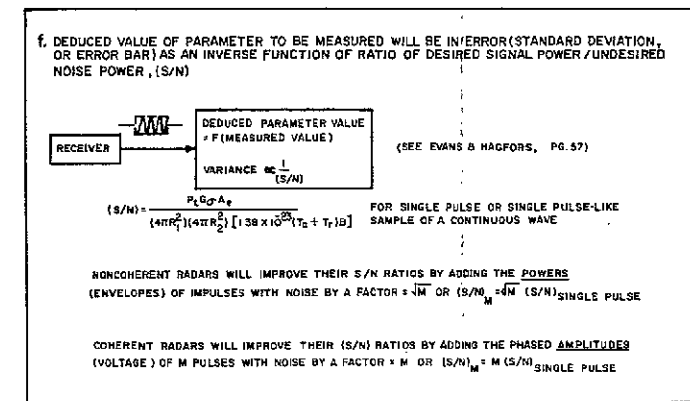
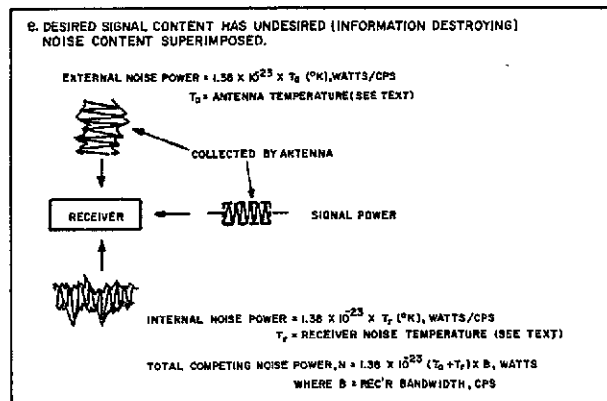
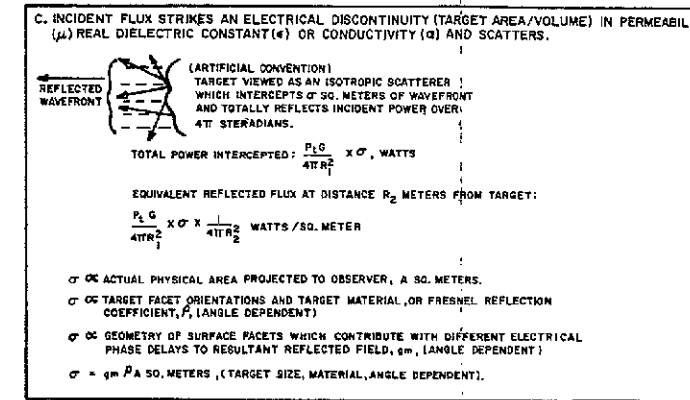
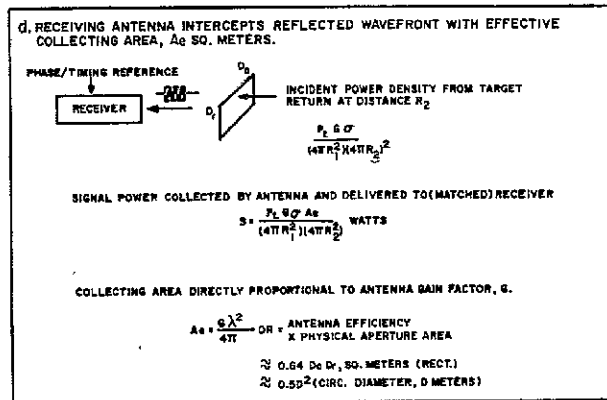
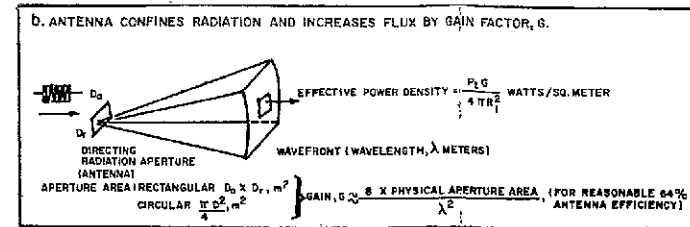
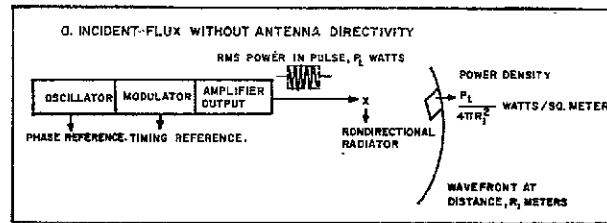


FIGURE 6. FLOW DEVELOPMENT OF RADAR EQUATION.

~100°K sky temperature for Earth-based, and 3). are limited by weight, power, volume, and cooling, they overcome the great problem of distance ($1/R^4$ in the radar equation). Spacecraft radar can also employ time delay, doppler and angular measurements, while Earth-based is limited to just the first two.

Several spacecraft radar modes were studied (see Figure 7). In the radar mapping of a planet's surface, using a bistatic arrangement with an Earth-based and a spacecraft terminal, the Earth-based transmitter and the spacecraft receiver (Mode 1) is favored over the opposite arrangement of a spacecraft transmitter and Earth-based receiver (Mode 2). An Earth-based transmitter is capable of megawatts of peak power compared to the spacecraft's kilowatts, with distance being constant. The Earth-based radar in this mode is also able by itself to simultaneously study the gross characteristics of the planet. The atmospheric and ionospheric transmission of the Earth's atmosphere together with the range factor gives a considerable advantage to a spacecraft monostatic radar system (Mode 3) over the Mode 1 bistatic arrangement except for Jupiter study with a small antenna (10 ft.). For measurements of the planet's atmosphere and ionosphere, using transmissions between terminals through the medium, the use of two spacecraft, one transmitting and one receiving, proved superior to an Earth-based terminal spacecraft configuration (except for operations at Jupiter and Saturn using a small antenna). Two way, inter-spacecraft, transmission proved undesirable.

This study should provide the impetus for an increased technical development aimed at providing light weight antenna apertures (0.025 kg/m^2 densities), 50% efficient solid state power amplifiers in the 1-100 cm. wavelength range, integrated circuit receivers with low noise temperature requiring no active cooling, and lightweight (5 kg) low wattage (20 watt) recorders capable of 10^6 bps for up to 60 minutes.

A non-coherent, sidelooking, monostatic radar orbiting at an altitude of 1000 km or less above a terrestrial planet was found to weigh about 50 kg including antenna (a recorder weighs an additional 25 kg). Data rates of approximately 10^5 bps were found to pose no problem.

Study of the Jovian planets by Earth-based radar has proven nearly impossible because of the great distances and low cross sections involved. This study points out that it appears to be almost as great a problem for spacecraft to study these planets because of the large system weights and antenna sizes required. Weights of 800 kg, antenna dimensions of 100 meters, and several hundred watts of input power (~100 kilowatt peakpower) exceed the limits of practicality. It is perhaps better than a simple altimeter or line sampling radar be used at the Jovian planets rather than complicated, though informative, wide swath, bistatic, or coherent monostatic radars.

2.6 Venus Explorer Radar (H. Goldman, D. Roberts)

The objective of this two-month study is to examine the feasibility and characteristics of a radar experiment on a Venus Planetary Explorer orbiter. The study results will be presented at the NAS Summer Study of Venus Explorer spacecraft experiments. Two small radar systems are being considered for surface mapping from the spin-stabilized explorer, 1) a pulse-width limited monostatic system and 2) a small coherent bistatic receiver. Schematic diagrams of these two systems are illustrated in Figure 7.

The monostatic pulse-width limited system is expected to yield 10-km resolution over the entire northern Venus hemisphere. Complete coverage takes about 240 days with elliptical orbits. A very much smaller bistatic receiver would require an earth-based transmitter, such as the 210-foot dish at Goldstone. The omni-directional antenna would collect specularly-reflected returns from determinable locations. Resolution is expected to be in the range 100-200 km, depending

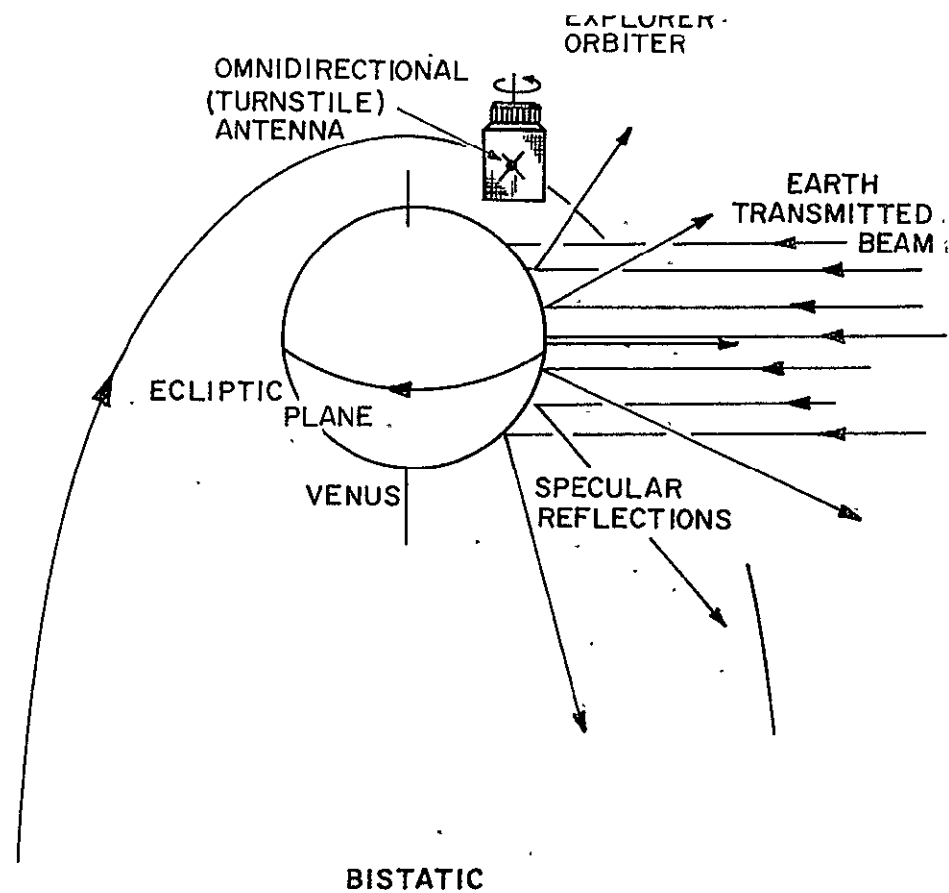
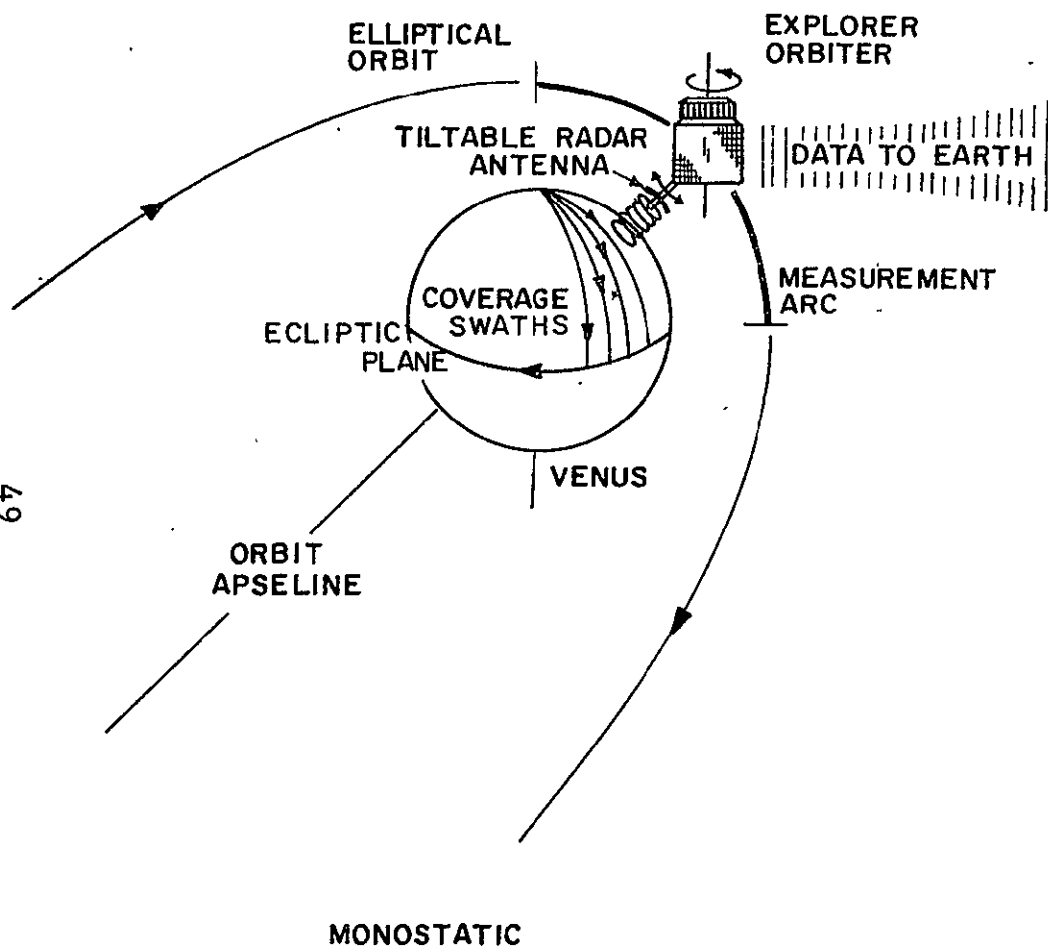


FIGURE 7. CANDIDATE VENUS EXPLORER RADAR SYSTEMS.

upon the rms surface slopes encountered. Coverage potential is also on the order of one hemisphere (50%).

A summary of this work will be submitted to Goddard Space Flight Center during May to be included in a document of Planetary Explorer capabilities for Venus exploration which is being prepared by NASA for the SSB/NAS Venus summer study, June 8, 1970. A broader review of radar systems for Venus exploration will also be submitted, under an IITRI cover, to the conference. It will discuss the potential of all Venus spacecraft radar system to provide a background against which the proposed Explorer designs can be compared.

2.7 Advanced Mission Planning

Launch Vehicle Selection for Outer Planet Missions

(J. Niehoff)

This short-study task was completed during the first quarter of the current contract year. Initially its purpose was to provide quantitative justification for the seven-segment version of the Titan III/Centaur launch vehicle. However, a fair analysis requires comparing the capabilities of a number of launch vehicle-upper stage combinations. The final list of launch vehicle configurations selected for consideration included:

- 1) Titan IIID/Centaur/Burner II
- 2) Titan IIIF/Centaur
- 3) Titan IIIF/Centaur/Burner II
- 4) Titan IIID/Centaur/Solar Electric
- 5) Titan IIIF/Centaur/Solar Electric
- 6) Titan IIIF/Centaur I/Kick
- 7) SIC/SIVB/Centaur
- 8) Titan IIIF/Centaur/Nuclear Electric
- 9) SIC/SIVB/Centaur/Solar Electric
- 10) SIC/SIVB/Nuclear Electric

A comprehensive analysis of launch vehicle requirements also depends on a list of mission representative of an outer planets exploration program. For this, the 1969 PEPP plan for outer planet missions was extended to 1990 on the basis of one mission per year. The resulting mission plan is presented in Table 21. The 12 outer planet missions shown are scheduled so that collected data is in hand at least two years prior to the launch of a succeeding mission to the same planet, i.e. this is a sequential mission-type plan.

A number of constraints and assumptions were made to generate a consistent set of propulsion requirements for the 12 outer planet missions. The base spacecraft weight was set at 1500 lbs. This excludes retro propulsion for planetary orbiters. When atmosphere probes were used they were assumed to have a total weight of 500 lbs. and were added in pairs, i.e. 1000 lbs. Conditions over a 10-day window were considered in determining launch energy requirements. For planetary capture a space-storable propulsion system with an Isp of 385 sec was assumed. The orbit period was constrained to 15 days at all planets, while the periapse radii were selected as follows:

Jupiter	-	3 planet radii
Saturn	-	3 planet radii
Uranus	-	2 planet radii
Neptune	-	2 planet radii

Mission accomplishment, in terms of flight time, with each launch vehicle combination listed above were compared for each of the twelve missions. The comparisons can be summarized by answering the following two questions:

- a) How effective would the seven-segment Titan be in reducing flight time and adding new missions to an outer planets program?
- b) What additional increase in launch vehicle capability is required to complete all missions given in the extended plan in Table 21?

Table 22

EXTENDED OUTER PLANETS MISSION PLAN

	No.	77	78	79	80	81	82	83	84	85	86	87	88	89
Swingby Missions														
Jupiter-Saturn-Pluto	1	X ¹	O(J)	O(S)					O(P)					
Jupiter (Pb) ² -Saturn	2		X		O(J)		O(S)							
Jupiter-Uranus-Neptune	3			X		O(J)		O(U)			O(N)			
Saturn (Pb)-Uranus (Pb)-Neptune	5					X			O(S)			O(U)		
Orbiter Missions														
Jupiter	4				X			O				O		
Saturn	6						X							
Jupiter (Pb)	7								X		O			
Uranus	8									X				
Neptune	10											X		
Saturn (Pb)	11												X	
Jupiter (Pb)	12													X
Lander Missions														
Jupiter Satellite	9										X			O
Rendezvous Missions														
Comet Halley ³								X		O				

1. Symbol key: X - Launch, O - Planet Arrival
2. (Pb) indicates atmospheric probes are included
3. Comet Halley rendezvous mission included as a time-line for introduction of nuclear-electric propulsion.

The answers to these questions are provided by Table 23. The left column lists the particular launch vehicles selected for this summary. The next four columns list, respectively, 1) the mission (by number) which the vehicle is capable of performing, 2) the total number of missions performed, 3) the total flight time involved and 4) the average flight time per mission. The last three columns contain numbers which are to be used in the comparison statement at the bottom of the Table.

Considering the first question a) of the comparison, it can be seen that the seven-segment (IIIF) Titan increases the number of missions performed from 4 to 7. It is also capable of decreasing the total required flight time of the five-segment (3D) Titan mission by 20 percent.

With regards to question b) of the comparison, it is obvious that something more than the Titan IIIF/Centaur/Burner II is needed to complete the program of selected missions. The last three vehicles given in Table 2 are presented as possibilities. A solar-electric stage addition to the Titan IIIF Centaur performs all 12 missions (satellite Callisto only for mission No. 9), with a 16 percent flight time decrease over the Titan IIIF/Centaur/Burner II missions. Similar comparisons are apparent in the table for the addition of a hydrogen-fluorine Kick stage, or advancing to the intermediate SIC/STVB/Centaur launch vehicle. Note that the Kick stage addition cannot perform any of the Galilean satellite lander missions and the Saturn vehicle can also only perform a lander mission to Callisto.

A number of conclusions were drawn from these results. The seven-segment solids would be a worth while launch vehicle investment for outer planet exploration. There seems to be little or no flight time advantage from the Burner II stage on the seven-segment Titan. Something more than the Titan IIIF Centaur

Table 23

SUMMARY COMPARISONS
OF
CANDIDATE OUTER PLANET MISSIONS LAUNCH VEHICLES

Launch Vehicle	Possible Missions (Nos.)	Total Missions	Total Time (Years)	Average Mission Time (Yrs.)	Comparison*		
A					B	C	D
TITAN IIID-CENT-BII	1,2,3,4	4	23.1	5.78	-	-	-
TITAN IIIF-CENT-BII	1-4,6,7,12	7	29.8	4.26	20	4	TITAN IIID-CENT-BII
TITAN IIIF-CENT-SEP	1-12	12	61.5	5.13	16	7	TITAN IIIF-CENT-BI
TITAN IIIF-CENT I-KICK	1-8,10-12	11	58.5	5.32	18	7	TITAN IIIF-CENT-BI
SIC-SIVB-CENTAUR	1-12	12	54.7	4.56	22	7	TITAN IIIF-CENT-BI

* To make comparisons between vehicles insert values from Columns A, B, C and D into the following sentence:

"The (Column A) will provide a (Column B) % improvement in the total flight time of the (Column C) missions which can be performed by the (Column D) launch vehicle."

will be needed to carry outer planet exploration into the 1980's. The solar-electric and high-energy Kick stages are roughly equivalent, although there is an inclination to favor solar-electric propulsion because it can do the Callisto lander mission and may be more versatile for other applications, e.g. Mercury orbiters, comet rendezvous missions, high-data orbiters, etc. Using an intermediate Saturn-class vehicle does not seem like a good solution to shorter flight times (for 1500 lbs. orbiters) since the orbit retro stages become enormous, from 5 to 10 times the weight of the orbiting spacecraft. A better answer to short flight times, particularly for Uranus and Neptune orbiters would be the introduction of the nuclear-electric low-thrust stage. It also would be desirable for the Galilean satellite lander mission.

Only launch vehicle comparisons have been made here. The effects of different retro stages, different orbits and different spacecraft weights also need to be considered. These will receive attention in continuing advanced planning studies during the year.

3. OVERALL PERFORMANCE

Progress on each of the planned studies as of April 3, 1970 is summarized in Table 24. As mentioned earlier additional work is being performed on the Comet Rendezvous Opportunities as a result of suggestions made at the Comet Conference in April. This has delayed initiation of the Comet Rendezvous Mission and Atmos. Entry at Uranus/Neptune Studies. Both of these efforts will get underway in June. Advanced planning short-studies have also delayed writing of the Jupiter Orbiter Mission Study Report. The remaining tasks are on schedule.

The total effort on NASW-2023 is currently somewhat greater (53%) than scheduled (44%). However, vacation time has been light so far and is expected to equalize these values during the summer months. Because of the late start on the Comet Rendezvous Mission Study it will probably not be completed

TABLE 24
V6105 PROGRESS REPORT FOR APRIL 1970

STUDY TASK	EFFORT (MAN MONTHS)				STATUS (% COMPLETION)		
	THIS MONTH	TO DATE	SCHEDULED TO DATE	TOTAL ALLOCATED	CURRENT	SCHEDULED	ESTIMATED NEXT MONTH
COMET RENDEZVOUS OPPORTUNITIES	1.4	7.9	6	6	95*	100	100
COMET RENDEZVOUS MISSION STUDY	—	—	1	12	—	8	0
JUPITER ORBITER MISSION STUDY	.9	7.7	7	7	88*	100	100
MERCURY ORBITER MISSION STUDY	2.2	7.9	6	16	49	37	60
ORBITER PLANET SATELLITE MISSIONS	1.0	5.6	5.5	9	62	61	75
ATMOS. ENTRY AT URANUS/NEPTUNE	—	—	—	7	—	—	0
SATURN'S RINGS MODEL	.2	.2	—	3	7	0	25
SPACECRAFT RADAR	.5	3.8	2	2	95*	100	100
VENUS EXPLORER RADAR	1.0	1.4	1.5	2	70	75	95
STELLAR MISSIONS	—	—	—	4	—	—	—
ADVANCED MISSION PLANNING	1.6	7.5	6	12	63	50	70
TOTALS	8.8	42.0	35	80	53	44	62

* BASED ON AN EVALUATION OF TASK RESULTS

during this contract year. No other problems are foreseen at the present time in meeting the schedules shown in Table 1.