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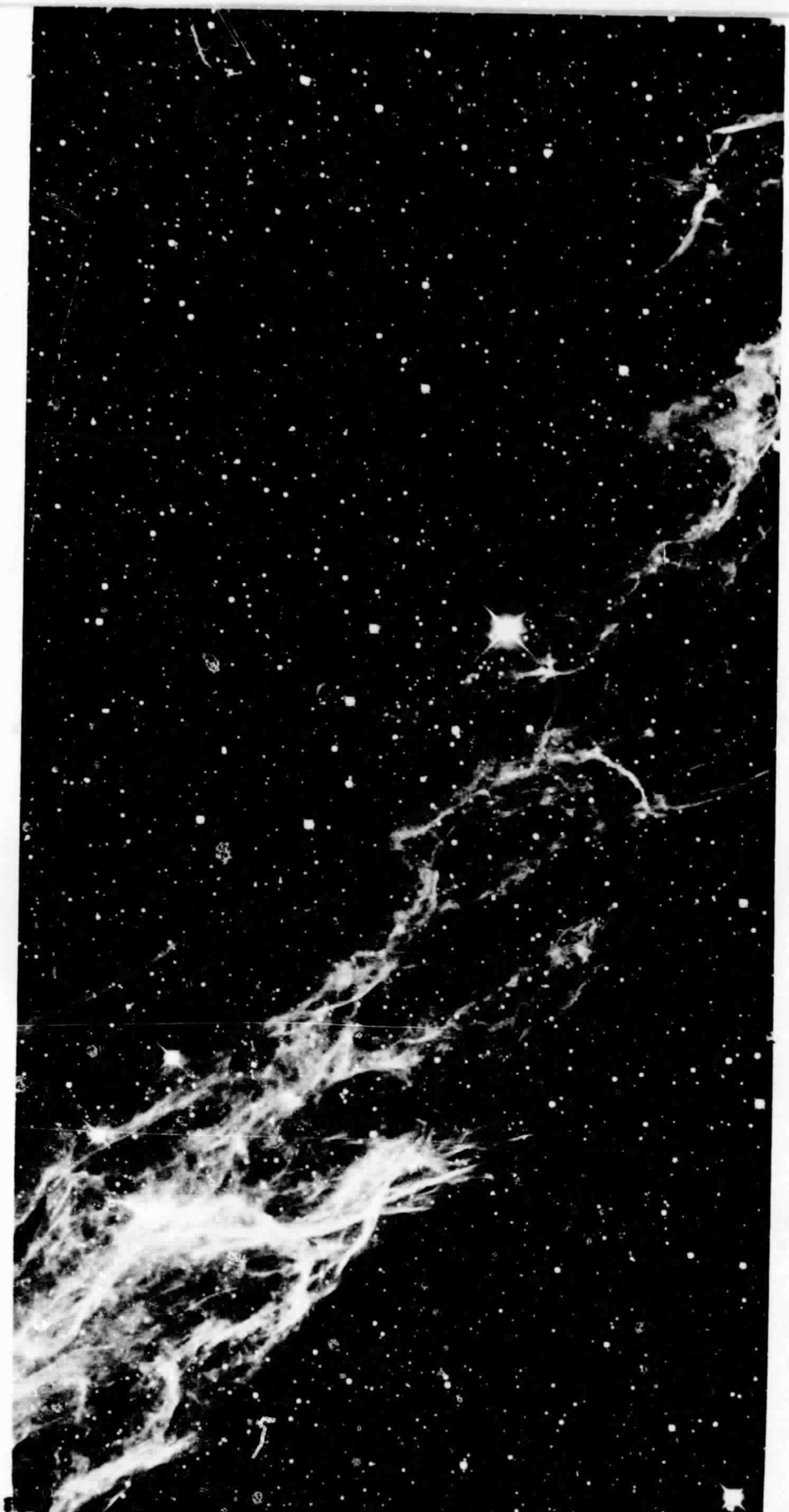

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Report No. A-5

FIFTH ANNUAL SUMMARY REPORT

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Report No. A-5

FIFTH ANNUAL SUMMARY REPORT

by

Astro Sciences Center
of
IIT Research Institute
Chicago, Illinois

for

Lunar and Planetary Programs
Office of Space Science and Applications
NASA Headquarters
Washington, D.C.

Contract No. NASr-65(06)

APPROVED:

D. L. Roberts, Manager
Astro Sciences Center

July 1968

FOREWORD

This annual report summarizes the reports published and the special tasks performed by the Astro Sciences Center of IIT Research Institute during the 12 month period from July 1967 through June 1968. A total of seven reports or technical memoranda are summarized together with a description of technical notes on which formal reports have not been written. In addition, four technical papers have been published in the open literature. The work has been performed under NASA Contract NASr-65(06).

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Report No. A-5

FIFTH ANNUAL SUMMARY REPORT

1. INTRODUCTION

The Astro Sciences Center of IIT Research Institute (ASC/IITRI) has been engaged in a continuing program of research, study, and analysis for the Lunar and Planetary Programs Division under Contract No. NASr-65(06). The contract was last renewed on November 1, 1967. This report covers the period from July 1967 through June 1968 during which a total of 80 man months of effort were expended.

The program during the last year has been constrained very much by the fiscal climate within the NASA. However it has been possible to continue the broad interest in advanced missions. In addition methodologies and analytical techniques have been developed which aid considerably in evaluating the worth of future missions. Systematic approaches to the development of exploration objectives and of mission values have been pursued.

The areas of study necessary to meet the broad objectives of planning support can be defined briefly as:

(a) Cost estimation methods

(b) Objectives of advanced missions

(c) Analysis of mission requirements

(d) General trajectory studies

(e) Spacecraft technology studies in support of mission analysis

(f) Special study assignments.

While the ongoing activities of ASC/IITRI are reported to Lunar and Planetary Programs Division in monthly progress reports, the more tangible output is in the form of technical reports. For the 12 month period reported here a total of 11 reports and documents have been submitted. Of these, 3 will be included in Scientific and Technical Aerospace Reports (STAR) and 4 publications will have been published in the open literature. Summaries of these reports and technical memoranda are given in Section 2. The technical notes of Section 3 summarize study efforts that have been performed and capabilities that exist but for which no formal reports have been written. Section 4 lists the papers published and presented as a result of work performed under this contract. Finally Section 5 is a bibliography of the reports and technical memoranda published under this contract since its inception. An appendix to this report is included to identify the way in which the reports are designated and to show the standard distribution lists for all reports.

2. SUMMARY OF REPORTS PUBLISHED JULY 1967 - JUNE 1968

The study areas listed above have been subdivided into subject categories. All reports are identified by a code letter, indicating its technical subject category, and by a sequential number reflecting the order of submission.

The eight report categories are as follows:

A - Annual Summary Reports
C - Cost Estimation Methods
M - Mission Analysis
P - Objectives of Advanced Missions
R - Success Probability Determinations
S - Spacecraft Technology
T - General Trajectory Studies
W - Project Scheduling

An individual document in each of these categories may be published as a report, a digest report, or a technical memorandum. Reports present the results of major studies, digest reports are summaries or condensations of reports, and technical memoranda include the results of studies in narrow technical areas, interim reports and other documents involving very limited distribution. These report types are discussed together with the distribution lists in Appendix A.

2.1 Reports

Report No. P-23

"A Preliminary Evaluation of the Applicability of Surface Sampling to Mars Exploration"

W. H. Scoggins and D. L. Roberts

May 1968

This report presents a preliminary evaluation of the applicability of surface sampling to the total exploration of Mars. The primary purposes were to identify the value of sampling as an investigation technique, to define the constraints imposed upon sampling by the objectives, and to assess the value of samples from a single landing site. Sampling, as used in this study, is defined as the process of obtaining samples of the Martian surface or near-surface rocks or rock materials at several surface sites. A sample is considered as one or more specimens of material taken at a single surface site on the Martian surface. The present state of the art of surface sampling as applied to planetary bodies is rather primitive, especially when considering unmanned automated systems. Consequently, no attempt was made to determine whether or not the samples should be returned to Earth for analysis.

There is, at present, a lack of knowledge of even the general crustal nature of Mars. A fairly extensive literature search for surface models of Mars was made during the initial phase of this study. Many of the models were based on spectroscopic and visual telescopic observations, while others were based solely on Earth considerations (i.e., mineral types and their abundances). The surface models were used in conjunction with the Martian exploration objectives stated by the Space Science Board, as the basis for the overall scientific objectives for Mars. These objectives were considered in five categories: Record of Life, Physical Constitution, Active Processes, Chemical Composition, and History of Events in Martian Rocks. The objectives were each broken down into "attributes" which identify the properties of the planet and which must be measured in order to satisfy the objectives. A total of 110 attributes were developed. The measurement techniques which could be applied to each of the attributes were identified and included surface sampling, remote sensing, photographic mapping, topographic mapping, surface geophysical sensing, atmospheric sampling, and surface geological mapping. The usefulness of sampling was then evaluated in view of all the applicable techniques for all of the objectives and attributes.

The four major conclusions of this report are the following:

(1) Sampling, in general, is a valuable investigating technique for obtaining information for the accomplishment of certain exploration objectives;

(2) The disciplines most dependent on sampling as an exploration technique are geology and biology;

(3) Samples at a single site on the Martian surface apply to the majority of objectives, but only to a very limited extent;

(4) Samples at a single site will provide much more information with regard to characterizing the general nature of the Martian surface than in determining specific properties of Mars.

In order for sampling to be maximum value when used as an exploration technique, sampling must be carried out in such a manner as to provide samples adequate, both in number and type, for understanding the overall nature of Mars. However, due to the remoteness of the planet and the inherent problems in obtaining proper samples, especially with unmanned automated systems, it will be difficult to investigate certain problems by samples alone. For example, in the investigation of structural features, such as folds and faults, by sampling, it is essential that samples be obtained at certain locations with respect to the feature under investigation and the orientation of key samples be known to within a few degrees. Other investigating techniques, both orbital and surface, are in some cases much more applicable to investigating certain properties of the surface and subsurface than is ampling. This can come about as a result of either the difficulty of obtaining certain types of samples or because other techniques may be much more expedient for obtaining the desired information.

The average values of surface sampling for the accomplishment of the exploration objectives are shown in the summary table which follows.

Summary Table

AVERAGE VALUES OF SAMPLING/SINGLE SAMPLE TO OBJECTIVES

Objective Categories	Objectives	Average Value of Sampling	Average Value of Single Sample
Record of Life	Evidence of extinct life	High	Very low
	Presence of living matter	High-Medium	Very low
	Prebiotic matter	High	Very low
Physical Constitution	Physical properties of planet	Very low	Very low-No value
	Geophysical properties of planet	Very low	No value
	Atmospheric properties of planet	No value	No value
	Structural properties-land forms	Medium	No value
	Physical properties of rocks	High	Very low
	Structural properties of rocks	High-Medium	Very low
	Geophysical properties of materials	Medium	Very low
Active Processes	Abiological activity	High	Very low
	Seismic activity	Very low	Very low-No value
	Erosion, deposition & transportation	Medium	Very low
	Processes responsible for land forms	High-Medium	Very low-No value
	Nuclear processes	Low	Very low-No value
Chemical Compositions	Chemical composition of materials	High	Very low
	Chemical composition of atmosphere	No value	No value
	Composition of surficial fluids	High	Very low
	Macromolecular distribution	High	Very low
	Cosmic or other foreign material	Medium	Very low
	Surficial water distribution	High	Very low
History of Events Recorded in Martian Rocks	Age of Martian materials	High	Very low-No value
	Stratigraphic sequence of rocks	High	Very low-No value
	Relationship of structural features	High-Medium	Very low-No value
	Remnant magnetism	High	Low
Overall Value of Sampling		Medium	Very low

Report No. S-3

"Telemetry Communications Guidelines"

M. Stein

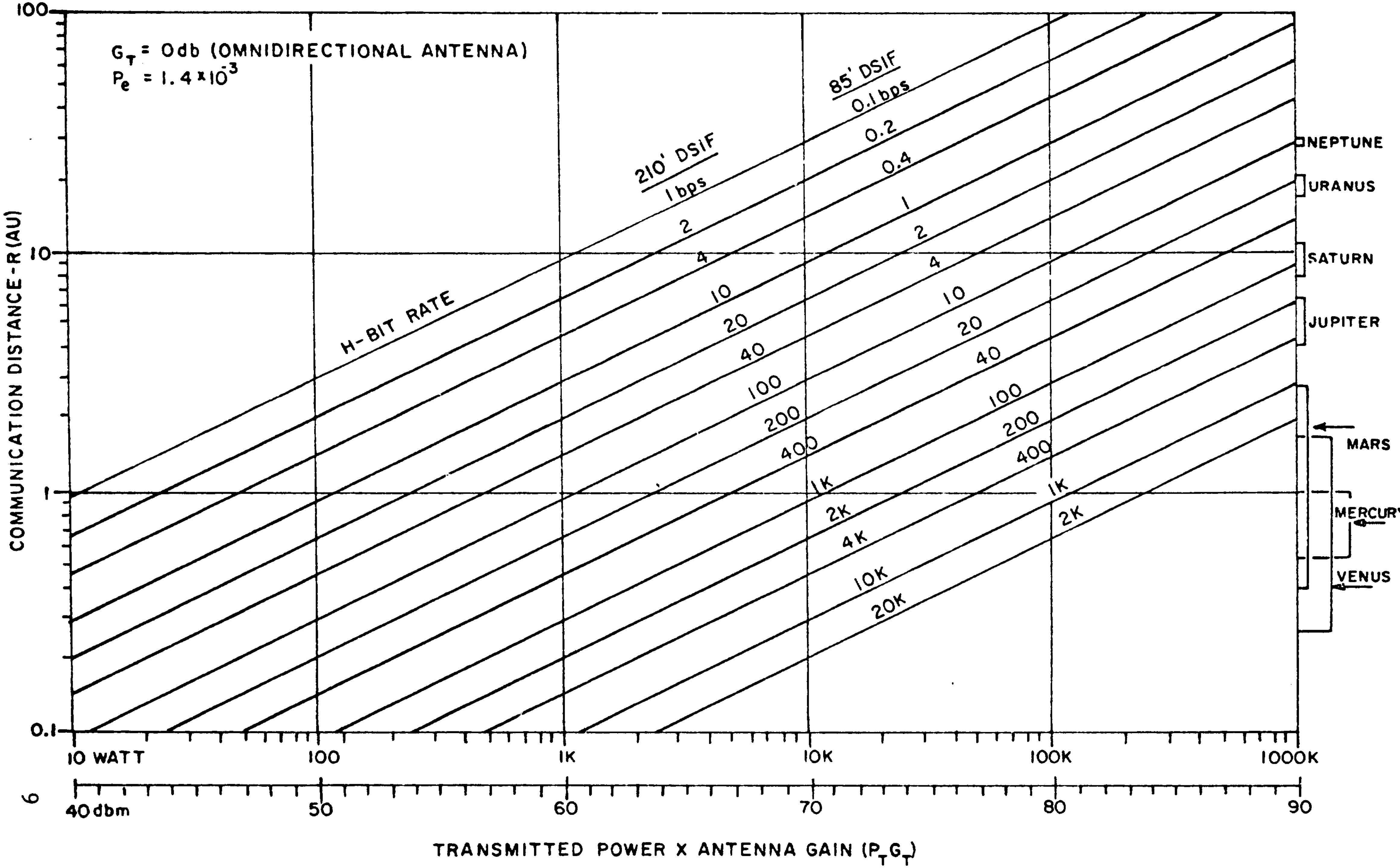
August 1967

This report considers the information transfer capability of spacecraft telemetry communication systems. Its purpose is to provide the advanced mission planner with general telemetry guidelines which will apply to space missions up to the 1975-1980 time frame.

The first section of the report considers the major limitations to a communication system, together with the present and projected performance capabilities for various subsystems, such as antennas, transmitters, and receivers. With these physical constraints, a set of generalized telemetry communication guideline curves are provided for determining the attainable data rates transmitted from a spacecraft, as a function of spacecraft transmitter power; the spacecraft and ground antenna sizes; and distance from the Earth to the spacecraft. Figures 3 and 4 are illustrative examples of such guideline curves given in the report; a number of examples are presented to familiarize the reader in the use of such curves.

The theoretical maximum data rate improvement which can be effected by means of error coding techniques are discussed. They are shown to offer improvements up

FIGURE 3: TELEMETRY COMMUNICATIONS CURVES
S-BAND (2300 MHz)



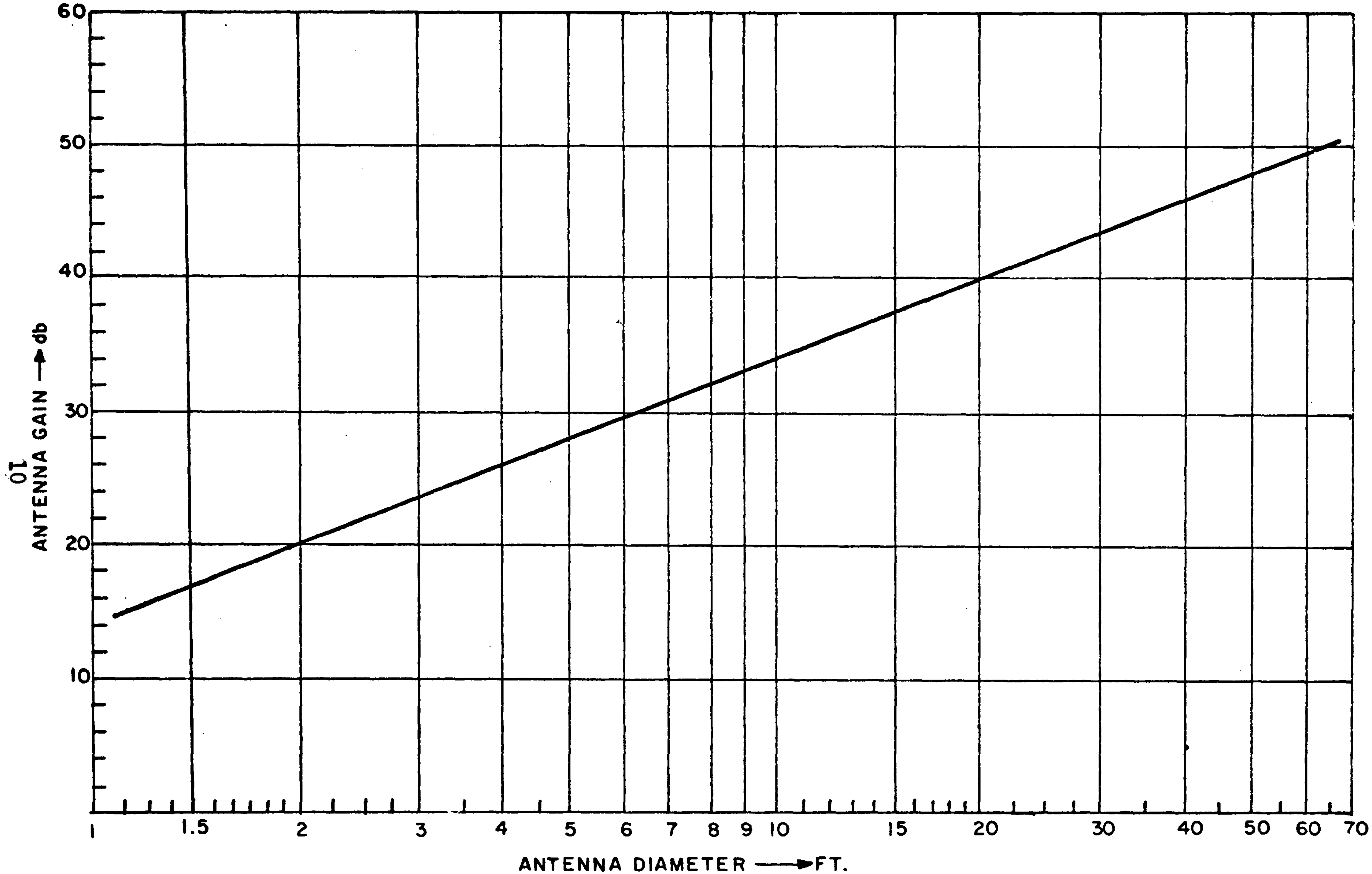


FIGURE 4. ANTENNA GAIN VS. DIAMETER AT S-BAND (2300 MHz)

to a factor of 6.5. The difference between a given channel capacity and the actual transmission bit rate as developed in the report (Appendix A) is expressible as,

$$C_M(\text{db}) - H\ (\text{db}) = 1.6 + ST/N/B \qquad \text{(A14)}$$

where, C_M is the theoretical maximum channel capacity, H is the actual bit rate, S represents the signal power, T the bit period and N/B is the noise power per unit bandwidth. This equation shows that by lowering the value of ST/N/B through the use of improved coding methods which can be made available, the theoretical transmission rate can be approached. (IITRI Technical Memorandum S-6 discusses coding for error detection/correction).

A section of the report covers a minimum weight configuration for spacecraft and indicates how the weight constraints of the spacecraft's telemetry equipment may be optimized with respect to the antenna size and transmitter power. For a specified communications distance and transmission rate, the required antenna size, transmitter power, and optimum weights, are obtainable directly from the curves presented in this report. Figure 5 illustrates this graphical tool; several examples are given to aid the reader in the use of these curves.

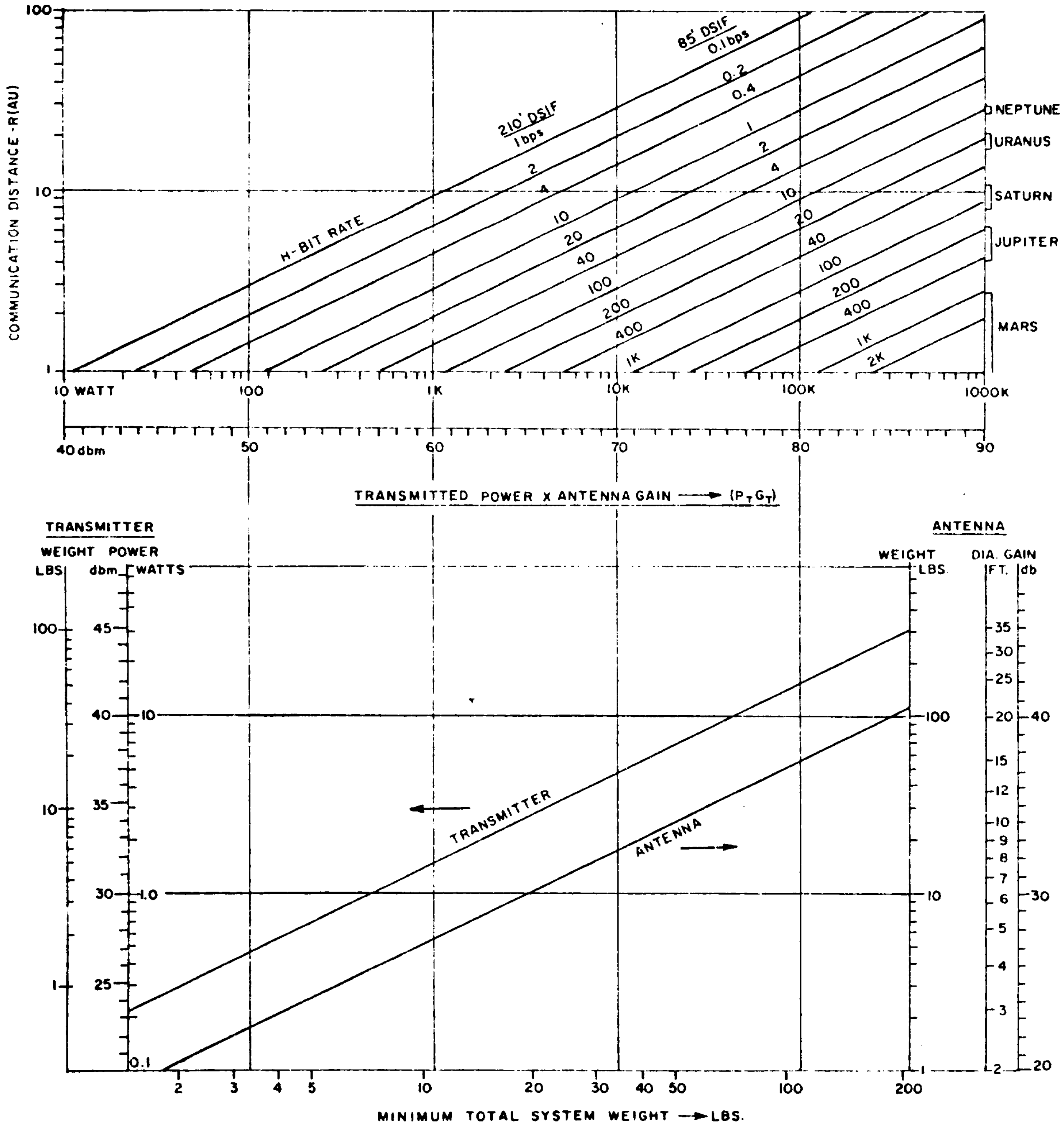


FIGURE 5. MINIMUM WEIGHT CONFIGURATION FOR SPACECRAFT COMMUNICATION SYSTEM

In summary, the communications guidelines are presented to assist advanced mission planners in assessing the approximate requirements of spacecraft telemetry systems. They are intended to apply up to the 1980 time frame and hence may predict a capability slightly in excess of that presently being realized. No attempt has been made here to guide the future development of communications systems, but rather, simply to predict it.

Report No. T-20

"Trajectory Opportunities to the Outer Planets for the Period 1975-2000"

B. J. Rejzer

December, 1967 NASA STAR No.

The five outer planets, Jupiter, Saturn, Uranus, Neptune and Pluto will, with the possible exception of Pluto, be targets for space missions between 1975 and the end of the century. For purposes of advanced mission planning, a definitive set of trajectory data for these planets, is essential. This report presents such trajectory data as an advanced mission planning guide to the outer planets, for launch opportunities between 1975-2000.

Data available from initial studies (Ross, 1966), (Richard, 1966), have provided launch energy data for minimum energy trajectories to these planets. Such data point to impractically long flight times (e.g., Uranus 13 years) and are, therefore, of limited use. This report considers trajectories having constant flight times, in addition to the minimum energy ones, to each of the outer planets in the 1975-2000 period. The constant times of flight have been selected for each planet to represent the trade-off between launch energy and flight time. Also, four launch windows between 0 and 30 days are presented to allow for anticipated reductions in launch operation times in the future.

The trajectory data (as a function of launch data) presented in this report was computed by means of the JPL Space Research Conic (SPARC) program. The minimum energy opportunity given by Richard (1966) for each calendar year was used to determine a starting date.

The minimum energy opportunities were located by obtaining launch dates in 5 day increments from the starting for an interval of 30 days. From this data 0, 10, 20, and 30 day windows could be delineated. Each end of the launch window was required to have approximately the same launch energy requirements.

The constant flight time trajectories used the same starting date information but the SPARC program searched for the minimum energy trajectory for the selected flight time. Additional trajectories were then calculated at 5 day intervals each side of this minimum until the 10, 20, and 30 day launch windows could be defined.

The trajectory data is reported in a series of tables for each planet (excluding Pluto, which is discussed below). Sample report extracts of these for 1975, are presented in Tables 1 through 4. For any given planet, the report presents a separate table for each of the annual opportunities up through the year 2000.

Table 1

TARGET DATA FOR EARTH LAUNCHED ONE WAY TRANSFERS

Target JUPITER Opportunity June-July 1975

Launch Window (days)	Parameters	Constant Flight Times			Minimum Energy	
		400 days 1.10 years	500 days 1.37 years	600 days 1.64 years	Type I	Type II
0	1st launch date	7/2/75	6/26/75	6/23/75	7/6/75	7/1/75
	V_c (ft/sec)	53580	49690	47920	46610	46510
	C_3 (km^2/sec^2)	145.2	107.8	91.8	80.2	79.4
	VHP (km/sec)	16.16	11.68	8.82	5.70	5.68
	Rc (AU)	5.15	4.04	4.96	5.55	5.36
	TF (years)				2.73	2.76
10	1st launch date	6/27/75	6/21/75	6/18/75	6/26/75	6/26/75
	V_c (ft/sec)	53810	49870	48110	46710	46770
	C_3 (km^2/sec^2)	147.4	109.5	93.4	81.1	81.6
	VHP (km/sec)	16.37	11.32	8.91	5.84	5.91
	Rc (AU)	5.22	4.05	5.04	5.6	6.2
	TF (years)				2.32-2.78	2.72-3.08
20	1st launch date	6/22/75	6/16/75	6/13/75	6/21/75	6/21/75
	V_c (ft/sec)	54480	50440	48630	46950	46960
	C_3 (km^2/sec^2)	154.1	114.7	98.1	83.2	83.3
	VHP (km/sec)	16.56	11.92	9.0	6.23	6.12
	Rc (AU)	5.29	4.08	5.12	6.0	6.2
	TF (years)				2.14-2.89	2.63-3.33
30	1st launch date	6/17/75	6/11/75	6/8/75	6/16/75	6/21/75
	V_c (ft/sec)	55630	51590	49510	47470	47290
	C_3 (km^2/sec^2)	165.9	123.8	106.1	87.7	86.2
	VHP (km/sec)	16.76	12.07	9.08	6.78	6.68
	Rc (AU)	5.36	4.11	5.20	6.2	6.2
	TF (years)				1.99-2.97	2.63-3.78

JUPITER 1975

Table 2

TARGET DATA FOR EARTH LAUNCHED ONE WAY TRANSFERS

Target SATURN Opportunity Sept.-Oct. 1975

Launch Window (days)	Parameters	Constant Flight Times: 500 days 1.37 years	875 days 2.40 years	1250 days 3.42 years	1625 days 4.45 years	Min. Energy Type I
0	1st launch date	10/14/75	9/28/75	9/26/75	10/6/75	9/30/75
	V_c (ft/sec)	72510	54630	51690	52310	51690
	C_3 (km^2/sec^2)	366.8	155.7	126.6	132.6	126.6
	VHP (km/sec)	28.06	13.90	8.44	6.19	7.48
	Rc (AU)	8.22	8.22	8.32	8.43	9.78
	TF (years)					3.74
10	1st launch date	10/9/75	9/22/75	9/21/75	9/30/75	9/25/75
	V_c (ft/sec)	72880	54960	52050	53000	52060
	C_3 (km^2/sec^2)	371.9	159.1	130.1	139.3	130.2
	VHP (km/sec)	28.25	13.99	8.49	6.24	8.19
	Rc (AU)	8.27	8.23	8.32	8.44	10.4
	TF (years)					3.50-4.06
20	1st launch date	10/4/75	9/17/75	9/16/75	9/30/75	9/20/75
	V_c (ft/sec)	73950	55730	53260	55140	52670
	C_3 (km^2/sec^2)	386.5	167.0	141.9	160.8	136.1
	VHP (km/sec)	28.44	14.06	8.55	6.24	8.84
	Rc (AU)	8.31	8.25	8.34	8.45	10.4
	TF (years)					3.32-4.46
30	1st launch date	9/29/75	9/12/75	9/11/75		9/15/75
	V_c (ft/sec)	75730	56920	56360		53370
	C_3 (km^2/sec^2)	411.2	179.4	173.5		143.0
	VHP (km/sec)	28.63	14.13	8.64		9.55
	Rc (AU)	8.37	8.27	8.36		10.5
	TF (years)					3.16-4.94

SATURN 1975

IIT RESEARCH INSTITUTE

Table 3

TARGET DATA FOR EARTH LAUNCHED ONE WAY TRANSFERS

Target URANUS Opportunity Dec. 1975-Jan. 1976

Launch Window (days)	Parameters	Constant Flight Times				Min. Energy
		1225 days 3.35 years	1600 days 4.38 years	1975 days 5.41 years	2350 days 6.43 years	Type I
0	1st launch date	1/5/76	12/29/75	12/24/75	12/21/75	12/29/75
	V_c (ft/sec)	67610	59730	56080	54180	51690
	C_3 (km^2/sec^2)	303.0	209.9	170.6	151.1	126.7
	VHP (km/sec)	23.78	17.34	13.33	10.64	4.92
	Rc (AU)	17.66	17.72	17.78	17.85	19.19
	TF (years)					12.71
10	1st launch date	12/31/75	12/23/75	12/18/75	12/16/75	12/24/75
	V_c (ft/sec)	67930	60090	56440	54440	51820
	C_3 (km^2/sec^2)	307.1	213.8	174.3	153.7	127.9
	VHP (km/sec)	23.86	17.39	13.37	10.66	5.23
	Rc (AU)	17.68	17.73	17.79	17.86	20.4
	TF (years)					11.66-13.82
20	1st launch date	12/26/75	12/18/75	12/13/75	12/11/75	12/19/75
	V_c (ft/sec)	68890	60950	57250	55150	52030
	C_3 (km^2/sec^2)	319.3	223.5	182.9	161.0	129.9
	VHP (km/sec)	23.92	17.43	13.39	10.68	5.61
	Rc (AU)	17.69	17.74	17.80	17.88	20.4
	TF (years)					10.79-15.07
30	1st launch date	12/21/75	12/13/75	12/8/75	12/6/75	12/14/75
	V_c (ft/sec)	70530	62280	58490	56300	52420
	C_3 (km^2/sec^2)	340.5	238.7	196.3	172.9	133.7
	VHP (km/sec)	23.98	17.47	13.42	10.70	6.09
	Rc (AU)	17.72	17.76	17.82	17.90	20.5
	TF (years)					9.99-16.25

URANUS 1975-1976

Table 4

TARGET DATA FOR EARTH LAUNCHED ONE WAY TRANSFERS

Target NEPTUNE Opportunity Jan-Feb 1975

Launch Window (days)	Parameters	Constant Flight Times 2350 days 6.43 years	2700 days 7.39 years	3050 days 8.35 years	3400 days 9.31 years	Min. Energy Type I
0	1st launch date	1/31/75	1/27/75	1/24/75	1/22/75	2/4/75
	V_c (ft/sec)	64050	60710	58510	57010	52380
	C_3 (km^2/sec^2)	259.6	220.9	196.5	180.4	133.3
	VHP (km/sec)	20.37	17.34	15.00	13.17	4.07
	Rc (AU)	29.34	29.25	29.27	29.41	31.04
	TF (years)					29.97
10	1st launch date	1/25/75	1/21/75	1/19/75	1/16/75	1/30/75
	V_c (ft/sec)	64420	61090	58800	57360	52620
	C_3 (km^2/sec^2)	264.0	225.2	199.6	184.1	135.6
	VHP (km/sec)	20.41	17.37	15.02	13.17	4.16
	Rc (AU)	29.38	29.25	29.03	29.47	31.1
	TF (years)					26.71-31.37
20	1st launch date	1/20/75	1/16/75	1/14/75	1/11/75	1/25/75
	V_c (ft/sec)	65340	62000	59650	58240	52910
	C_3 (km^2/sec^2)	275.1	235.6	208.9	193.5	138.4
	VHP (km/sec)	20.44	17.40	15.04	13.18	4.56
	Rc (AU)	29.42	29.27	29.33	29.53	31.1
	TF (years)					22.68-33.03
30	1st launch date	1/15/75	1/11/75	1/9/75	1/6/75	1/20/75
	V_c (ft/sec)	66780	63410	61040	59650	53280
	C_3 (km^2/sec^2)	292.7	252.0	224.5	209.0	142.1
	VHP (km/sec)	20.47	17.42	15.06	13.19	5.36
	Rc (AU)	29.47	29.29	29.38	29.60	31.2
	TF (years)					19.10-34.82

NEPTUNE 1975

As noted in these illustrative data extracts, the following parameters are tabulated:

a) Launch date (at beginning of the window)

b) Characteristic velocity, V_c^* (ft/sec)

c) Vis viva energy, C_3 (km^2/sec^2)

d) Planet hyperbolic approach velocity, VHP (km/sec)

e) Intercept communication distance, RC (AU)

f) Time of flight, TF.

Each of the tables gives the trajectory data for one opportunity for one planet. Launch windows of 0, 10, 20, and 30 days are included. For C_3, VHP, and RC the maximum values across the launch window are given. Hence, with the exception of the 0-day launch window, the trajectory data shown has been accumulated from several trajectories flown during the launch period and are not necessarily the properties of any one trajectory. The constant flight times were selected to be less than ten years, to provide tractable mission durations and, except for Jupiter, to give minimum communications distance at intercept. The values selected for Jupiter are those that are of general interest and do not necessarily yield minimum communication distance.

$^*V_c = 3280.8333 \sqrt{C_3 + 121.5964}$

For minimum energy trajectories to Jupiter, both Type I and Type II were obtained, but for Saturn, Uranus, and Neptune only Type I trajectories have been presented. This is due to the longer flight times associated with Type II trajectories to these furthermost planets.

Because of Pluto's highly inclined orbit, the truly minimum energy trajectories tend to intercept Pluto when it crosses the ecliptic plane around the year 2020. The times of flight associated with minimum energy windows (composed of segments of both Type I and Type II trajectories) range between 41 and 47 years for the 1975-76 opportunity to between 17 and 29 years for the 2000 opportunity. Since these two cases indicate the trend of Pluto's trajectories and because the flight times involved are too long, no additional minimum energy data to Pluto were generated. Instead, the more practical constant flight time trajectories of 5 and 10 years were run for every fifth year between 1975 and 2000. These again were sufficient to indicate the nature of the trajectories to Pluto. In view of the uncharacteristic nature of the Pluto data it has been presented graphically as illustrated in Figure 1, which is an extract of one of the six figures presented in the report for this planet.

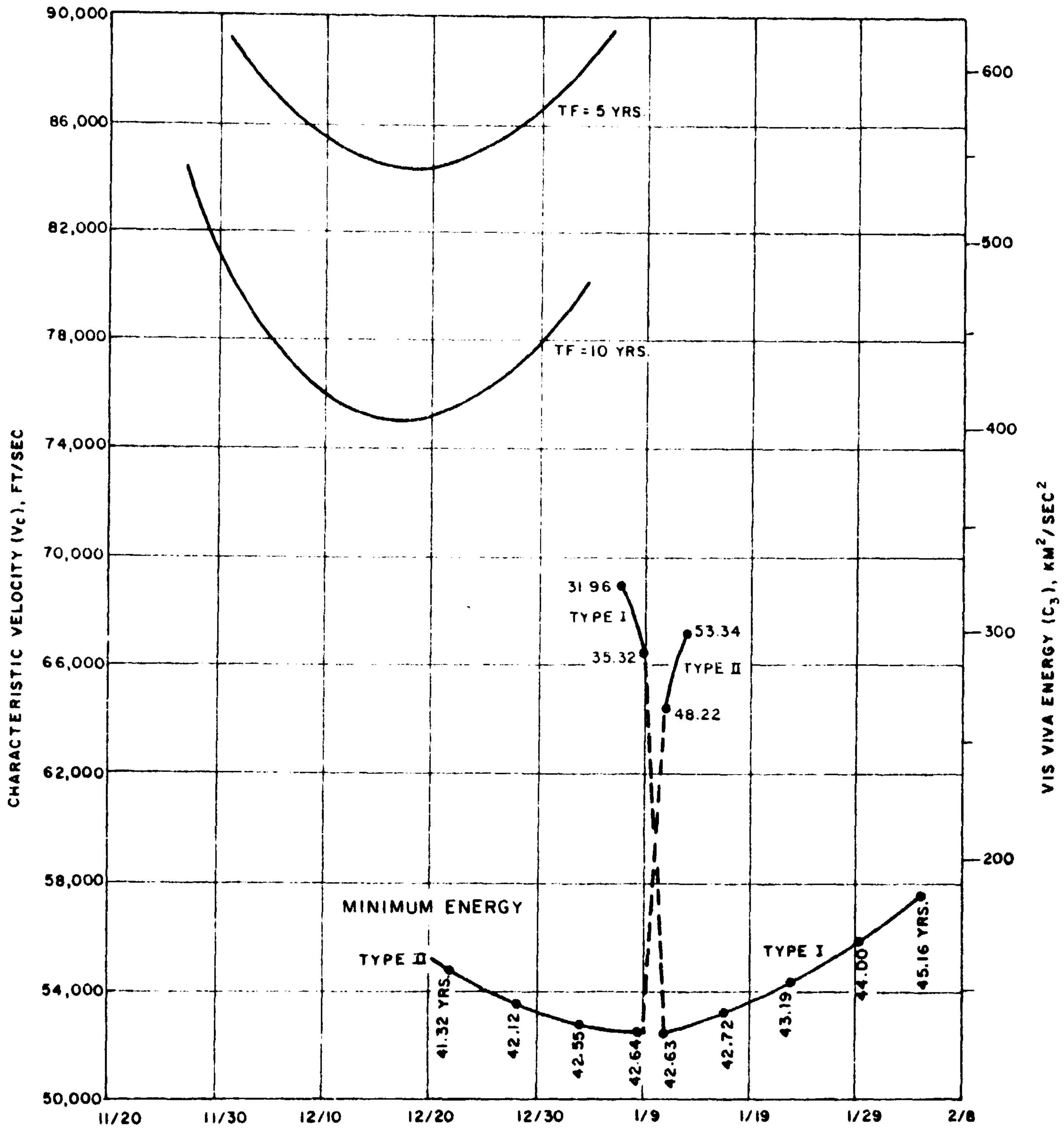


FIGURE 1. ENERGY CURVES FOR 1975-76 PLUTO OPPORTUNITY

In summary, the trajectory data presented provides an adequate advanced mission planning guide to the outer planets launch opportunities between 1975 and 2000. The quoted launch dates are correct to within 2 or 3 days and the C_3 energies with the exception of the three cases involving Saturn are within 5 km^2/sec^2. Since the energy requirements tend to rise rapidly as launch windows are increased, it is suggested that, wherever possible, windows for the outer planets be restricted to 20 days or less. The constant flight times selected for each planet correspond to those that minimize communications distance at intercept. This is true for all planets considered except Jupiter where times of flight of general interest were run and do not necessarily minimize communications distance. Due to Pluto's inclined orbit, a minimum amount of data was obtained, but enough to indicate the trend of trajectories to this planet. Data for Jupiter, Saturn, Uranus, and Neptune are presented in tabular form while data for Pluto is in graphical form.

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2.2 Technical Memoranda

Technical Memorandum M-15

"A Solar System Total Exploration Planning System (STEPS)"

J. Witting

April 1968

Advanced mission planning is an essential to the space program particularly in view of the long lead times associated with the definition of mission, with the design of spacecraft and with the development of the required technology. Indeed over the last few years the OSSA Prospectus has contained exploration plans extending over a twenty year period. However, these plans are not, and probably cannot be, specified in great detail and it therefore becomes difficult to evaluate them in anything but a subjective sense. The purpose of this study is to develop an evaluation scheme for total exploration plans wherein the scientific value of a plan (and its cost) is expressed quantitatively to help reduce the element of subjectiveness.

In addition to the requirement for simplicity, the following criteria were used as guides in formulating the evaluation scheme:

(1) it must relate the result of a particular proposed plan to the overall goals of space exploration

(2) it must afford quick evaluation of plans and subsequent modifications,

(3) it must be flexible enough to easily accomodate modifications in the goals of space exploration,

(4) it must be useful in generating better plans by learning, and,

(5) the method must use the limited description of missions associated with long range plans.

In a preliminary discussion, the report describes the overall method proposed for plan evaluation, together with summary definitions of its various components. Some essentials of this discussion can be gleaned from the illustrative Figures 1 and 2 which are extracts of this section.

In order to assign a scientific value to an entire plan it was necessary to identify exactly where, in the execution of that plan, scientific value is achieved. Value is assigned to a set of measurements, made on a given mission, with a particular type of instrument, relevant to a particular scientific objective. One can also assign value to the scientific objectives themselves, in order to separate those of major importance from those of lesser importance. The critical problem discussed in Section 3 is the determination of how well a particular scientific objective is satisfied by a given set of measurements. The discussion

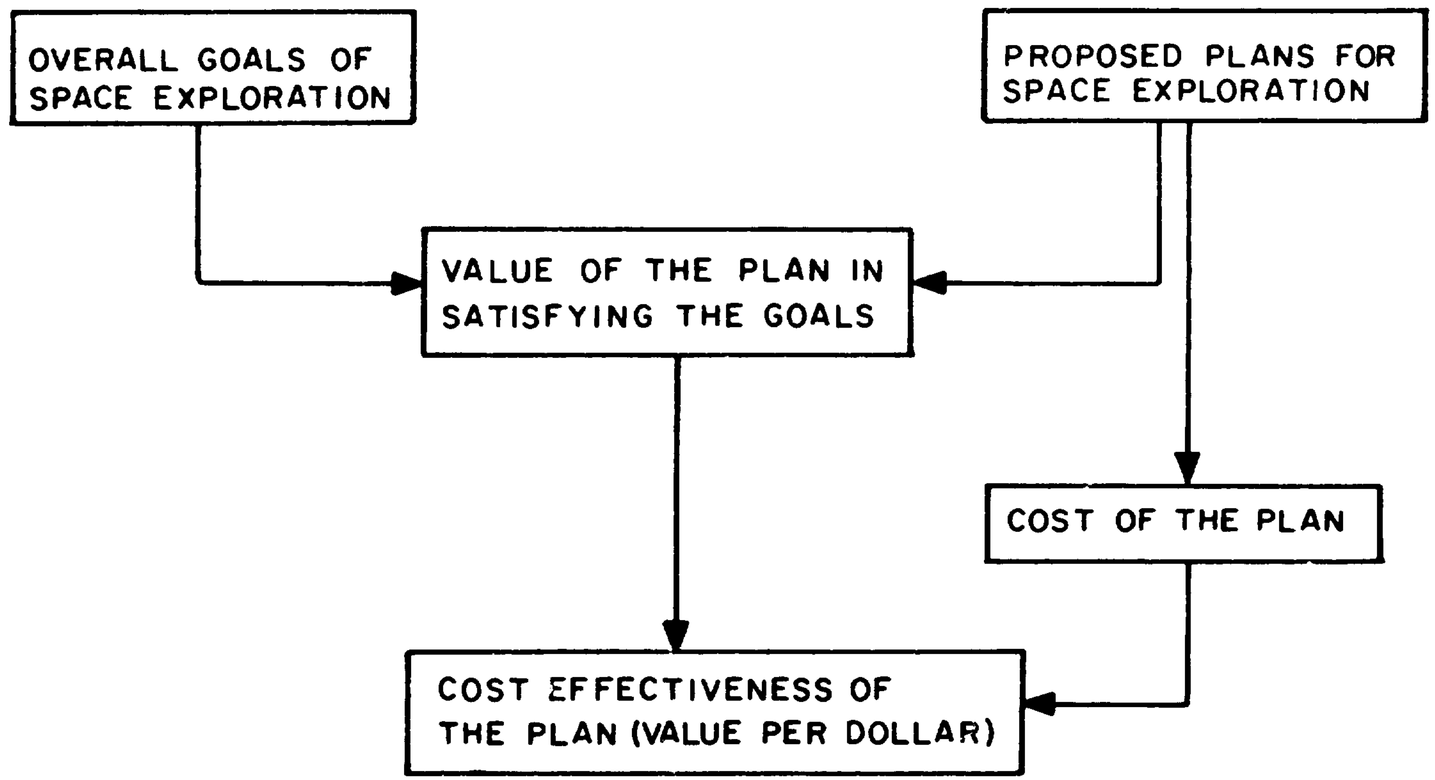

FIGURE 1. OVERALL METHOD FOR EVALUATING PLANS

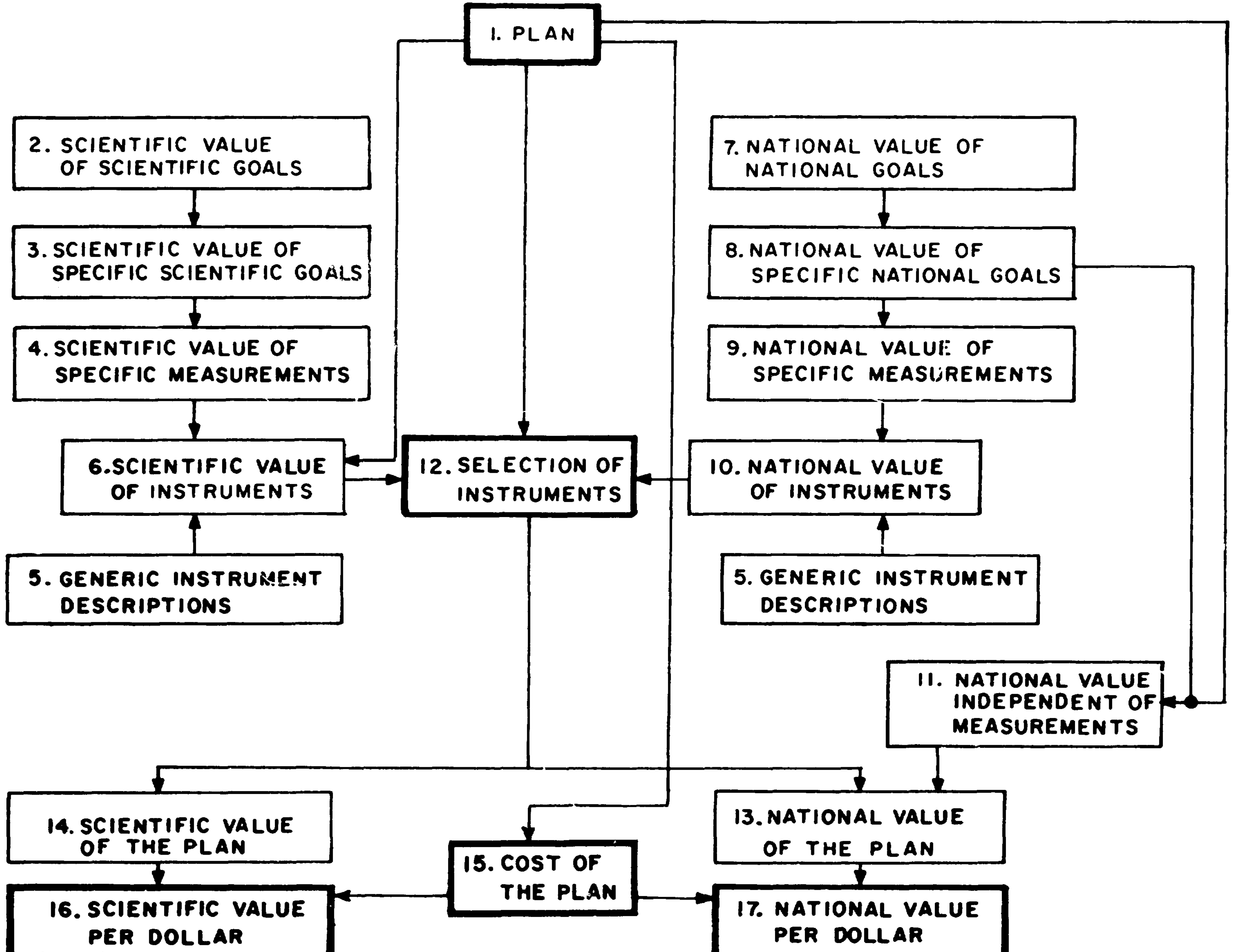

FIGURE 2. FLOW CHART FOR PLAN EVALUATION

centers about developing a quantitative expression for the value of a set of measurements, V_{ij}, made by the j^{th} instrument accomplishing, in part, the i^{th} scientific objective, as a function of a number of parameters of most significant importance. The resultant expression is presented as,

$$V_{ij} = V_{io} R_{ij} Q_{ij} C_{ij} L_{ij} \qquad \text{(Eq. 2 of M-15)}$$

where, V_{io} is the value of the i^{th} scientific objective, R_{ij} is the relevance factor defined as the fraction of the i^{th} objective which can be obtained by the measurements using a particular j^{th} instrument, assuming perfect measurements. Q_{ij}, or instrumental quality, is a factor which describes quantitatively how far short of perfection does the instrument perform in making such measurements (function of its resolution, sensitivity etc.), C_{ij} or measurement coverage, is a factor which quantitatively expresses how much of the area (or number of sites, or volume, etc.) required for complete coverage, is actually satisfied by the mission profile using the j^{th} instrument in support of the i^{th} objective, (includes the number of measurements) and L_{ij} or location factor, is a numeric describing the degradation in making a measurement with a given mission profile at a location other than at those selected as optimum locations.

Section 3 concludes with more detailed analyses of these most important parameters and demonstrates that one can express each of these in relatively simple forms (primarily exponential); the functional forms of these factors use easily available variables such as estimated distances of closest approach for the spacecraft, ratios of actual mission coverage to total required coverage, etc. Although considerable detail can be incorporated into these functional forms to add greater validity to an ultimately-used accepted expression, the discussion in this section demonstrates that a quantitative evaluation approach is feasible.

Succeeding discussion extends that of Section 3 and outlines the logic in obtaining actual parameter values, given plans for the exploration of the solar system. Table 1 illustrates some input parameters required from a minimum definition of a mission for realistic evaluation using the method proposed. Other studies already have provided, in part, some of the needed values. For example, ASC/IITRI Technical Memorandum P-21, developed one method for obtaining the relative value of specific scientific objectives; one result of this effort is illustrated in Table 2.

Concluding discussions in the report treat the selection of instruments and total packages for a given mission to maximize the scientific value of that mission. A section on cost estimating of a given plan is presented, using an IITRI cost model (Finnegan, 1966).

Table 1

PARAMETERS REQUIRED FOR MINIMUM DEFINITION OF A MISSION

1.	Target
2.	Spacecraft Type (Flyby, Orbiter, etc., and Mariner, etc.)
3.	Date of Launch
4.	Range at Intercept
5.	Target Periapsis
6.	Target Apoapsis
7.	Total Power
8.	Number of Orbits
9.	Weight of Spacecraft Bus, Base Mission
10.	Weight of Orbiter Retro Propulsion, Base Mission
11.	Weight of Probe, Base Mission
12.	Weight of Lander, Base Mission
13.	Launch Vehicle
14.	Weight of Instrument Payload

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Table 2

THE RELATIVE VALUES (IMPORTANCE) OF SCIENTIFIC OBJECTIVES

OVERALL SCIENTIFIC OBJECTIVES	SPECIFIC SCIENTIFIC OBJECTIVES	TOTAL	SUN 1	MOON 2	MERCURY 3	VENUS 4	MARS 5	JUPITER 6	SATURN 7	URANUS 8	NEPTUNE 9	PLUTO 10	COMETS 12	ASTEROIDS 13
1. Isotopic Abundances and Ratios (8.13 pts)	1. D/H	1.90	.31		.11	.07		.39	.10	.05	.05		.68	.14
	2. He^3/He^4	1.11	.31			.07		.39	.10	.05	.05			.14
	3. Li^6/Li^7	1.26	.21		.11	.07		.19	.05	.02	.02	.11	.34	.14
	4. B^{10}/B^{11}	1.26	.21		.11	.07		.19	.05	.02	.02	.11	.34	.14
	5. C^{13}/C^{12}	.91	.31			.07		.19	.05	.02	.02	.11		.14
	6. Th^{230}	.45		.45										
	7. K^{40}	.45		.45										
	8. Rb^{87}	.45		.45										
	9. A^{40}	.34					.34							
		8.13	1.35	1.35	.33	.35	.34	1.35	.35	.16	.16	.33	1.36	.70
2. Elemental and Chemical Abundances and Ratios (7.07 pts)	1. Noble Gas Abundances	1.14	.63			.07	.05	.21	.10	.04	.04			
	2. Solar Abundances	1.25	1.25											
	3. Outgassing Rates	.24		.24										
	4. Atmospheric Constituents	1.47		.24	.47	.13	.16					.47		
	5. H_2O Abundance	.23				.13	.10							
	6. O_2-O_3 Abundance	.13				.13								
	7. Polar Cap Composition	.16					.16							
	8. He/H_2	.55						.31	.16	.04	.04			
	9. Oxidizers	.47						.21	.10	.08	.08			
	10. Hydrocarbons	.47						.21	.10	.08	.08			
	12. Light Element Compounds and Radicals	.24											.24	
	13. Xe Abundance	.36											.12	.24
	14. A Abundance	.36											.12	.24
		7.07	1.88	.48	.47	.46	.47	.94	.46	.24	.24	.47	.48	.48
3. Mineralogical Abundance (4.25 pts)	1. Surface Silicates	1.13		.31	.08	.31	.19					.08		.16
	2. Surface Carbonate	1.13		.31	.08	.31	.19					.08		.16
	3. Mineral Surface Phases	1.13		.31	.08	.31	.19					.08		.16
	5. Surface Degree of Hydration	.38					.38							
	6. Solid Surface Composition	.18						.06	.06	.03	.03			
	7. Care Composition	.18						.06	.06	.03	.03			
	8. Nucleus Composition	.12											.12	
		4.25		.93	.24	.93	.95	.12	.12	.06	.06	.24	.12	.48
4. Thermal Effects (5.76 pts)	1. Interior Temperature Distribution	.31	.31											
	2. Exospheric Temperature	2.95		.21	.41	.41	.41	.41	.31	.16	.16	.47		
	3. Thermal Flux from Interior	2.50		.10	.21	.21	.21	.83	.31	.16	.16	.16		.15
		5.76	.31	.31	.62	.62	.62	1.24	.62	.32	32	.63		.15
5. Seismic Activity (3.03 pts)	1. Outgassing Rates	.13		.13										
	2. Tectonic Patterns	.85		.06	.08	.08	.08	.15	.15	.06	.06	.13		
	3. Volcanism	.99		.13	.15	.15	.15	.08	.08	.06	.06	.13		
	4. Seismic Waves	1.06		.06	.15	.15	.15	.15	.15	.06	.06	.13		
		3.03		.38	.38	.38	.38	.38	.38	.18	.18	.39		
6. Motions and Properties of Condensed Bodies (3.00 pts)	1. Differential Rotation	.52	.52											
	2. Orbit and Perturbations	.90			.13	.09	.06	.12	.13	.05	.05	.08	.12	.07
	3. Rotation	.55			.13	.17		.12		.09		.04		
	4. Satellite Orbit and Perturbations	.41					.06	.12	.13	.05	.05			
	5. Red Spot Properties	.17						.17						
	6. Rotation Period	.11							.07					.04
	7. Ring Particle Motion	.20							.20					
	11. Flux and Motion of Small Particles	.07												.07
	12. Distribution of Asteroids	.07												.07
		3.00	.52		.26	.26	.12	.53	.53	.19	.10	.12	.12	.25
7. Internal and Bulk Properties (6.04 pts)	1. Moments of Inertia	1.00	.32	.11	.07	.13	.09	.06	.05	.03	.03	.11		
	2. Oblateness	.32	.32											
	3. Mass Distribution	.64	.64											
	4. Figure	1.24		.11	.14	.26	.18	.13	.09	.06	.06	.21		
	5. Differentiation	1.24		.11	.14	.26	.18	.13	.09	.06	.06	.21		
	6. Mass	.55			.14		.09					.32		
	7. Density	.20			.14									.06
	8. Shape	.15					.09							.06
	9. Ring Structure	.09							.09					
	10. Diameter	.32										.32		
	11. Albedo	.13										.11		.02
	12. Nucleus Size	.04											.04	
	13. Nucleus Density	.04											.04	
	14. Coma Mass Distribution	.04											.04	
	15. Tail Mass Distribution	.04											.04	
		6.04	1.28	.33	.63	.65	.63	.32	.32	.15	.15	1.28	.16	.14
8. Surface Properties (3.13 pts)	1. Topographical Relief	.76		.08	.10	.10	.13	.06	.06	.05	.05	.13		
	2. Surface Texture	.64		.08	.10	.05	.06	.06	.06	.05	.05	.13		
	3. Surface Structure	.83		.08	.10	.10	.06	.13	.13	.05	.05	.13		
	4. Crater Properties	.08		.08										
	5. Outgassing Rates	.08		.08										
	6. Surface Features	.64			.10	.05	.13	.13	.13	.05	.05			
	7. Presence of Oceans	.10				.10								
		3.13		.40	.40	.40	.38	.38	.38	.20	.20	.39		
9. Magnetic Fields (2.51 pts)	1. General Magnetic Field	.30	.30											
	2. Field Fluctuations	.42	.30					.12						
	3. Field Magnitude	.56		.03	.05	.06	.06	.12	.05	.03	.03	.05	.08	
	4. Field Configuration	.52		.03	.05	.06	.03	.12	.05	.03	.03	.05	.07	
	5. Paleomagnetism	.49		.09	.05	.03	.06	.06	.05	.03	.03	.05		.04
	6. Satellite Hydromagnetic Disturbances	.18						.18						
	8. Hydromagnetic Turbulence	.04												.04
		2.51	.60	.15	.15	.15	.15	.60	.15	.09	.09	.15	.15	.08
10. Charged Particle Flux and Distribution (1.18 pts)	1. Solar Activity and Emissions	.28	.28											
	2. Ionospheric Electron Density	.23		.01	.02	.03	.03	.03	.05	.02	.02	.02		
	3. Interaction with Solar Wind	.35		.03	.05	.04	.04	.03	.05	.02	.02	.02		.05
	5. Flux Distribution in Radiation Belts	.04						.04						
	6. Satellite Hydromagnetic Disturbances	.04						.04						
	7. Radiation Belt Properties	.07							.05			.02		
	8. Interaction with Stellar Winds	.01										.01		.02
	9. Flux	.02												
	11. Coma Flux and Distribution	.07											.07	
	12. Tail Flux and Distribution	.07											.07	
		1.18	.28	.04	.07	.07	.07	.14	.15	.04	.04	.07	.14	.07
	TOTALS	44.10	6.22	4.37	3.55	4.27	4.11	6.00	3.46	1.63	1.54	4.07	2.53	2.35

Computer codes to implement the evaluation of the scientific value of a plan, and to obtain the cost, have been written. Each of many subprograms in the sets of computer codes have been tested, using artificial input data. Their compatibility has also been tested. Only a complete test using actual input data remains to be done. A code has also been written and tested which simplifies the job of deriving those plan parameters which are not specifically given in the prospectus from those which are given. A description of the codes will be provided after the entire system has been tested.

Thorough testing of the entire system, using sample plans, has not been completed. Because of the limited input data available at this time, only "plans" involving orbiter and flyby missions can be used, and the scientific value obtained is only that appropriate for the origin and evolution of the Earth, Sun and planets. This should be enough to test the system logic, coding, and basic data relevant to this goal and to these types of missions.

In summary, this technical memorandum describes the progress made in generating a system for evaluating proposed solar system exploration plans. The end product envisioned in STEPS (Solar System Total Exploration Planning System) is a well-tested computer program capable of taking as input a plan consisting of a series of relatively simple mission descriptions, and producing as output, an evaluation of the plan and of each mission in the plan. The bulk of this report is devoted to a description and justification of the logic involved in the formulation of the system. A limited set of input data has been set forth and is available in a form convenient for computer. Individual computer codes have been written and tested to automate the scientific and cost evaluation processes. The entire system has not yet been tested. The individual codes are not described in this memorandum as they are still open to considerable change.

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JPL 1967, "Study of A 1973 Venus/Mercury Mission With A Venus Probe," EPD 467, Jet Propulsion Laboratory.

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Technical Memorandum P-22

"Role of Ground Based Observations in the Exploration of Venus"

J. T. Dockery

July, 1967 (Limited distribution - copies not available)

As a terrestrial planet with approximate earth mass and density, Venus should provide a rewarding goal for scientific exploration. Because of the perpetual and featureless clouds possessed by Venus, our store of scientific data on that planet is sparse. Most of what we know comes from recent sources. These are radar investigations, radio noise measurements, and Mariner 2 and 5 observations as well as the Russian Venus 4 spacecraft. This report presents the results of a study to determine the role of ground based observations (GBO) in support of the space exploration plans for Venus.

Ground based observations have been considered to include all near earth observing stations (observatories, sounding rockets, balloons and earth orbiting spacecraft). The report attempts to emphasize the utilization of GBO to answer questions which have a direct bearing on spacecraft design or which aid in the selection of mission experiments.

The series of Venus missions which are considered in this report include flybys, orbiters, non-surviving entry probes, buoyant stations, hard and soft landers, and a surface roving vehicle. The GBO equipments have been grouped under three headings optical, radio and radar, having platforms which may be ground-based, at intermediate altitudes and at near-Earth orbital altitudes.

The initial discussions in the report present a breakdown of general GBO techniques and a summary of some recent published results (Appendix 1), based on some of these techniques. The latter is incorporated into a tabulation (Section 2) which presents the parameter values currently established for Venus in terms of (a) astronomical data, (b) atmospheric data, (c) surface data and (d) biological data.

Section 3 relates the manner in which ground-based observations will or will not augment the advanced mission planning for Venusian flybys, orbiters, non-surviving probes, buoyant stations (balloons), landers and surface-roving vehicles. A summary of supporting measurement requirements for spacecraft design in such missions, and which may be supplied (entirely or in part) by GBO is presented in Table 2.

Table 2

VENUS MEASUREMENT REQUIREMENTS
IN SUPPORT OF INDIVIDUAL MISSION TYPES

Mission Type	Spacecraft Support Parameters	Required Measurements
Flyby	Guidance and Control Scan rates Miss distance Experiment backup	Ephemeris Atmosphere and surface properties
Orbiter	Orbit Selection Orbit lifetime Orbit precession Experiment selection	Geoid Atmosphere profiles Atmosphere and surface properties
Non-Surviving Entry Probe	Heat shield design Ablator composition	Atmosphere constituents Pressure profile Atmosphere depth
Buoyant Station	Descent Control Gondola dynamics Balloon material	Atmosphere profiles Wind regimes Cloud composition
Lander (hard or soft)	Descent profile Plasma sheath frequency Touch down dynamics g-loading	Atmosphere profiles Atmosphere abundances Bearing strength Slope distribution Wind regimes Surface temperatures Cloud composition Surface illumination
Surface Roving Vehicle	Wheel/drive design	Surface features Surface materials Surface structure Surface temperature Surface illumination

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Succeeding discussion (Section 4) presents details of existing, commissioned, or projected GBO equipments which are treated under the following titles:

A. Surface Based

1. Optical Telescopes and Ancillary Equipment
2. Radio Telescopes and Ancillary Equipment
3. Radar Ranging and Ancillary Equipment

B. Intermediate Altitudes

1. Balloon Platforms
2. Aircraft
3. Sounding Rockets

C. Near-Earth Orbital Altitudes

1. Optical Telescopes
2. Radio Telescopes
3. Radar Telescopes

The capabilities and limitations of such GBO equipments are summarily discussed in Section 5.

A number of recommendations are given in Section 6 concerning ground based observations of Venus. This discussion treats, (a) the coordination of effort between the various GBO techniques, (b) the reevaluation of existing data, (c) the expansion of existing facilities, (d) incorporation of equipments not involved in the program now, (e) the possible uses of orbital and other non-surface equipments and (f) a sample program of measurements which can be made by GBO in support of space missions to Venus.

Table S1, illustrates the results of the study in the form of a sample observing program which combines GBO in support of:

1. Orbiter/Flyby Missions to Venus
2. Entry Probes in the Venusian Atmosphere
3. Surviving Balloons
4. Landers/Surface Exploration Vehicles

Table S1

A SAMPLE OBSERVING PROGRAM

1. GBO in Support of Orbiter/Flyby Missions

Ground tracking and occultation experiment; already included for the 1967 flyby.

Backup visual, radio, and IR observation from the ground.

UV observation from a balloon platform for the life of the orbiter.

Measurement of albedo as function of wavelength from surface andorbit to look for clearings which may be examined at encounter in more detail.

2. GBO in Support of Entry Probes

Measurement of the LBH bands in the UV to settle the N_2+ presence question for the upper atmosphere of Venus. Further spectroscopy from orbit to determine other major constituents of the Venus atmosphere.

Use of the interferometric techniques to determine minor constituents in the Venus atmosphere for comparison with ratios predicted from models based on cosmic abundance.

Careful radar measurement of the planetary diameter to establish the height of the cloud layer to a greater degree of accuracy; to the order of 5-10 percent.

Table S1 (Continued)

A search for auroral effects from surface equipment as an alternative backup to the orbital search for atmospheric components on Venus.

Determination of the atmospheric lapse rate to get the atmospheric temperature profile for the planet.

Further use of polarization information from the radar to look for atmospheric vagaries.

3. GBO in Support of Surviving Balloons

Settlement of the question of H_2O vapor in clouds using earth balloon platforms.

Obtain the temperature profile in the atmosphere from a measurement of CO_2 bands from successively deeper in the atmosphere. Generate Monte Carlo calculations, to account for a highly scattering atmosphere if predictions exceed surface temperatures inferred from radio listening.

Search, using polarization and radar, to determine if the Venus atmosphere clouds are primarily of particulate nature.

Observation via radio in the centimeter wavelength to establish the period of secular variations for the Venus atmosphere. This is to produce time constants for mixing effects, e.g., winds, updrafts, etc. important in meteorology. This search should be simultaneous with IR observation and polarization measurements. A reduction of existing polarization data to a common standard is also indicated.

Table S1 (Continued)

	Use of the RAE to determine if long wave spherics exist on Venus which may infer violent electrical discharge.
4.	<u>GBO in Support of Landers and Surface Exploration Vehicles</u>
	Surface temperature profile from continuing radar scans of the surface.
	Surface topography estimates, and surface roughness estimates to be improved through continued radar observation.
	Measurement in earth based laboratories of possible materials which may match radar echoes, and their behavior with wavelength. What is anticipated is similar to what has already been conducted for the Moon and to some extent for Mars.
	The construction of surface pressure, and wind models based on inferred heat transport to the ground.
	An estimate of the degree of visual illumination at the Venus surface.

Technical Memorandum S-6

"Deep Space Communications: Command Link and Atmospheric Probe Entry"

M. S. Stein and D. L. Roberts

August 1967

In a recent ASC/IITRI study of deep space communications requirements a set of guidelines was derived for the selection of an onboard telemetry system (ASC/IITRI Report No. S-3). During the course of this study, two potential problem areas for future communications were recognized but could not be interpreted into guidelines. These problems which are now discussed in this separate report involve:

(1) the Earth-to-spacecraft command link for for outer planet missions, and

(2) the telemetry link between outer planet atmospheric probes and orbiting or flyby spacecraft.

These are treated separately in Sections 2 and 3 of this memorandum.

Complete message reiteration, involving two-way propagation paths, to reduce the chances of a spacecraft acting on an incorrectly-received command, will introduce serious or impractical time delays in command links for outer-planet missions. This illustrated in Figure 2, an extract from the memorandum, which presents the one-way

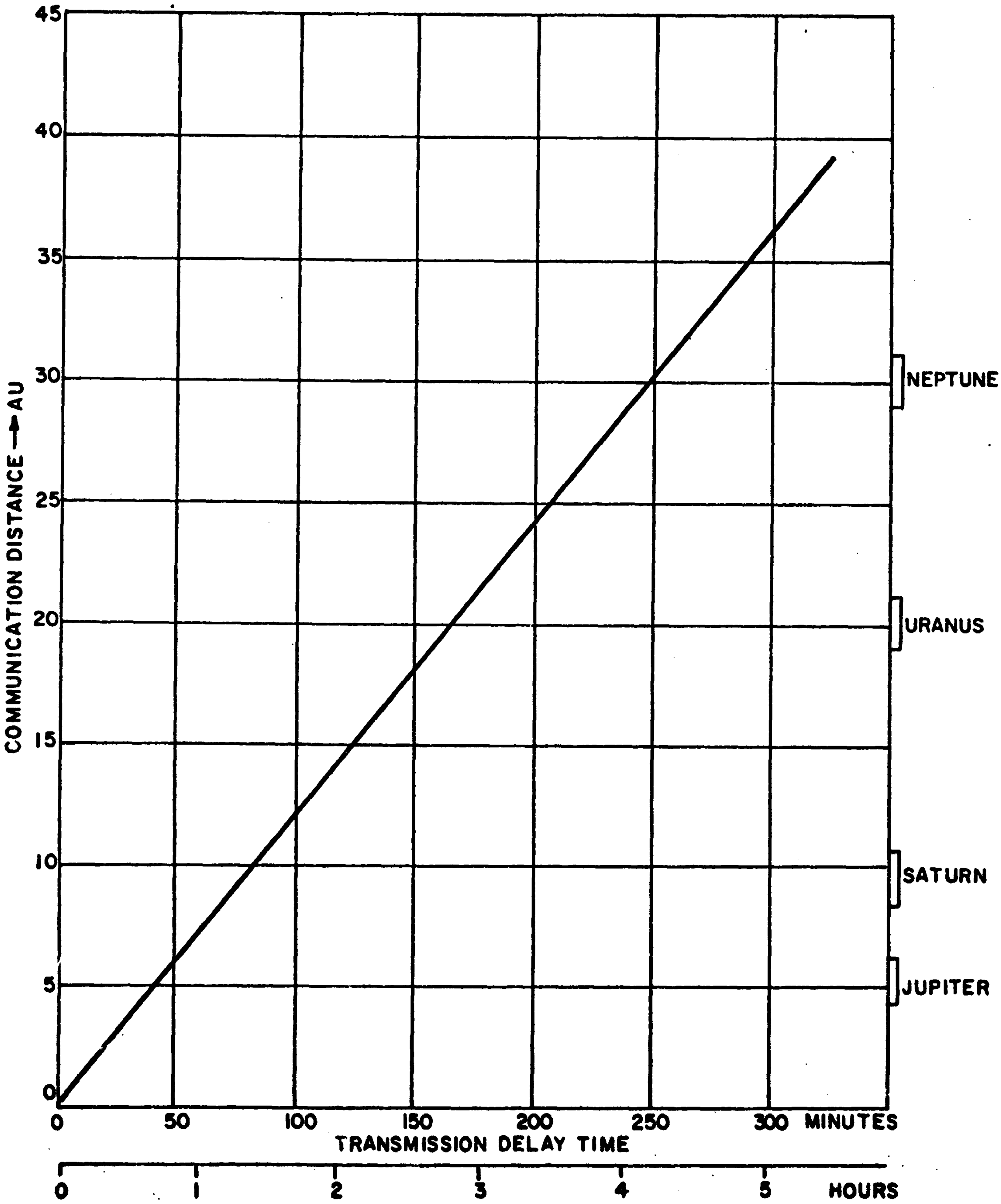

FIGURE 2. COMMUNICATION DELAY TIME VS. DISTANCE

time delay for some of the outer planets. For example, a single message repeat to a spacecraft in the vicinity of Neptune (after the retransmitted message from the spacecraft indicated incorrect reception), will invoke a time delay of about 12 hours. The implications that this order of time delay may have on the design or operation of space missions are not treated in the report. Rather, two coding methods for ensuring a low probability of command error are discussed.

One possibility involves the detection of errors in a command (using parity symbols) and transmission of a rejection statement to Earth if any error is found or an acceptance if none is found. This system has been used on Mariner missions (Springett 1962) and has a probability of acting on an incorrect command of about 10^{-17} for a fifty bit message. It has a probability of rejecting one command in every thousand in which case a retransmission becomes necessary. The problem associated with this method is that a critical command may be rejected without a priori knowledge thereby still leaving critical operations vulnerable to excessive time delays. Section 2.1 in the report discusses this error-detection system employing feedback; Appendix A presents a more detailed analysis of this approach.

The other method considers one-way command transmission which involves error detection and error correction on a majority decision basis by simply sending each bit 3, 5, 7, or any odd number of times, consecutively. The spacecraft will always make a decision based on a majority decision and initiate operation. The probability of it making the wrong decision is about 10^{-16} for a 50 bit message if the digits are repeated just three times but is reduced to about 10^{-24} if 5 repetitions are used. This method always ensures that only a one-way transmission time delay will be involved for all commands. Coding schemes allowing such majority decisions to be made by the spacecraft receiver so that only one-way delays are now introduced in the link, are discussed in Section 2.2 with more detailed analysis given in Appendix B.

The second problem area discussed in this report is telemetry between an atmospheric probe and a nearby spacecraft. This is felt to be particularly important for probes entering the dense atmospheres of the outer or giant planets with the associated very high entry velocities and hence short transmission times.

The bit rate capability of omni-omni systems is clearly limited. For a communication range equivalent to one Jupiter radius (7×10^4 km) a bit rate of only 1 bit per second is available for 15 watts of transmitted power or 10 bits per second for 150 watts. It should be noted that a fifteen watt transmitter will require about fifty watts of raw power.

The major problem therefore is being able to obtain adequate information rates from a probe for probe-spacecraft separations larger than say 10^4 km. The requirements for high bit rate include:

(a) The high probe entry velocity (60 km/sec) caused by the large gravitational fields of the outer planets (Jupiter in particular). This means that only about 1 to 100 seconds will be available before a shock wave builds up and the blackout phase starts. This range in time is a function of entry angle - the longest times applying for shallow entry angles.

(b) The entry probes may "burn out" in the dense atmospheres of the outer planets and therefore will probably not be able to store data and transmit it after the blackout phase.

The report discusses a number of possibilities for improving the total data output from a probe, albeit with some penalties, and are outlined below:

(1) Improvement in data rates by using large antennas at each terminal. This approach offers an enhancement in bit rates of about 100 but at the expense of pointing requirements,

the aerodynamics introduced, and potential blocking of the fields-of-view of the sensing instrumentation onboard the spacecraft probe

(2) The use of higher transmitter powers is feasible but the improvement in bit rate is marginal since it is only linearly proportional to transmitter power.

(3) The application of a high degree of data compression is another method of improving the information transfer rate, but in general is limited to one or two orders of magnitude improvement.

(4) Reducing the communications distance below the 10^4 km will allow a higher data rate to be transmitted. However, the planetary miss distance is determined also by the guidance errors throughout the mission and by the requirements of the other experiments. At this time it is difficult to assess a minimum planet-spacecraft miss distance.

Two further possibilities are discussed, both requiring an advance in the state of the art. One is to develop adequate methods of transmitting through the plasma sheath of the entry shock wave, and the other is to utilize the high data capacity of laser communication systems.

In summary, the two communication problem areas considered are only problems in terms of present operational techniques. The command of spacecraft at distances as far as 30 AU is certainly possible and attention has been drawn to command coding techniques which will ensure correct spacecraft interpretation. The transmission time delays to outer planet spacecraft may require that every command be sent only once. In this event, an error detection and correction capability must be included in the spacecraft.

The atmospheric probe communication problems for the outer planets are considerably more severe than for the Earth, Mars, or Venus. The entry velocities are extremely high, the atmospheres are quite different, and the probes may not survive. Thus data transmittal could be limited to a very short period of time. Omnidirectional antennas on the probe and spacecraft would appear to give inadequate data rates although the use of a directional antenna at least on the spacecraft will give a significant improvement. Further improvements could probably be obtained from advanced technological developments in communication through ion sheath blackouts and in laser communication systems.

Technical Memorandum W-5

"Project Plan for Period, November 1967 - November 1968"

Astro Sciences Center of IIT Research Institute

January, 1968 (copies not available)

The Astro Sciences Center of IIT Research Institute (ASC/IITRI) has been engaged, since 1963, in a continuing program of research, study, and analysis for the Lunar and Planetary Programs Division (Code SL), OSSA under Contract No. NASr-65(06). During this time a uniform background of knowledge of the solar system has been developed, an understanding of the mission requirements for exploring the solar system has been created and an objective systematic analysis capability for both scientific and technological objectives has been generated. This memorandum presents a discussion of the basic criteria used in the selection of study tasks and a capsule summary of each task proposed for the contract period from November 1967 to November 1968. Inputs to the selection of the study tasks proposed for this period are directed by the overall framework of advanced mission planning to which ASC/IITRI contributes, as illustrated in Figure 1. A discussion is presented in the memorandum which treats the requirements for each of the functional areas in Figure 1. An illustration of such treatment

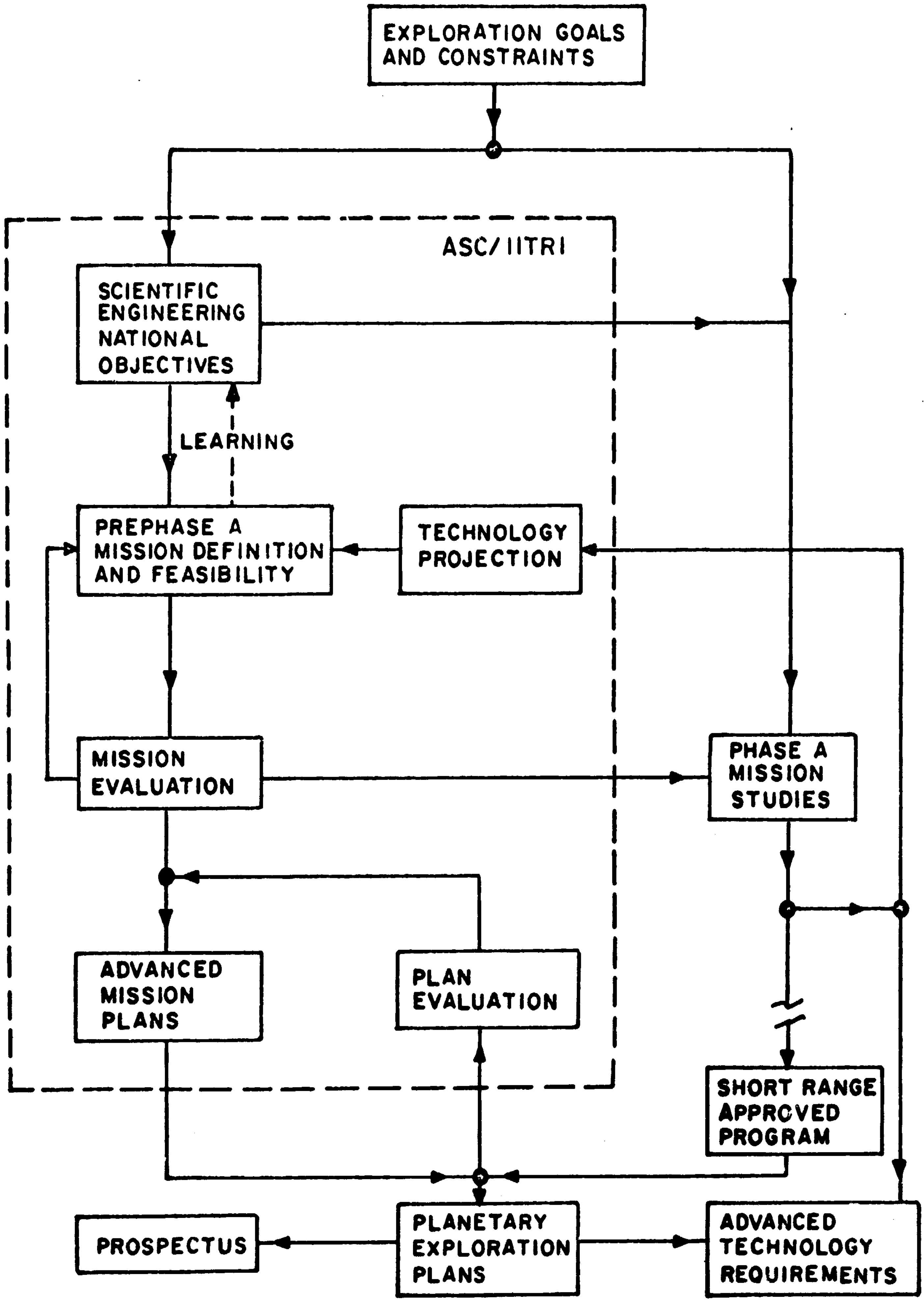

FIGURE I. SCHEMATIC FLOW DIAGRAM FOR SL ADVANCED PLANETARY MISSION PLANNING.

considers the discussion pertaining to the requirements for Advanced Mission Definition and Feasibility. Here, the status of definition for all tractable mission modes is presented and a summary given as shown in Figure 2.

Such discussions are followed by a section which deals with summary descriptions of each task and its associated man-month effort proposed for 1967-1968. Figure 3 presents a convenient summary of this section in terms of tasks and their respective schedules.

In summary, Technical Memorandum W-5 presents a program of study tasks to be performed by ASC/IITRI under Contract No. NASr-65(06) for the period from November 1967 to November 1968.

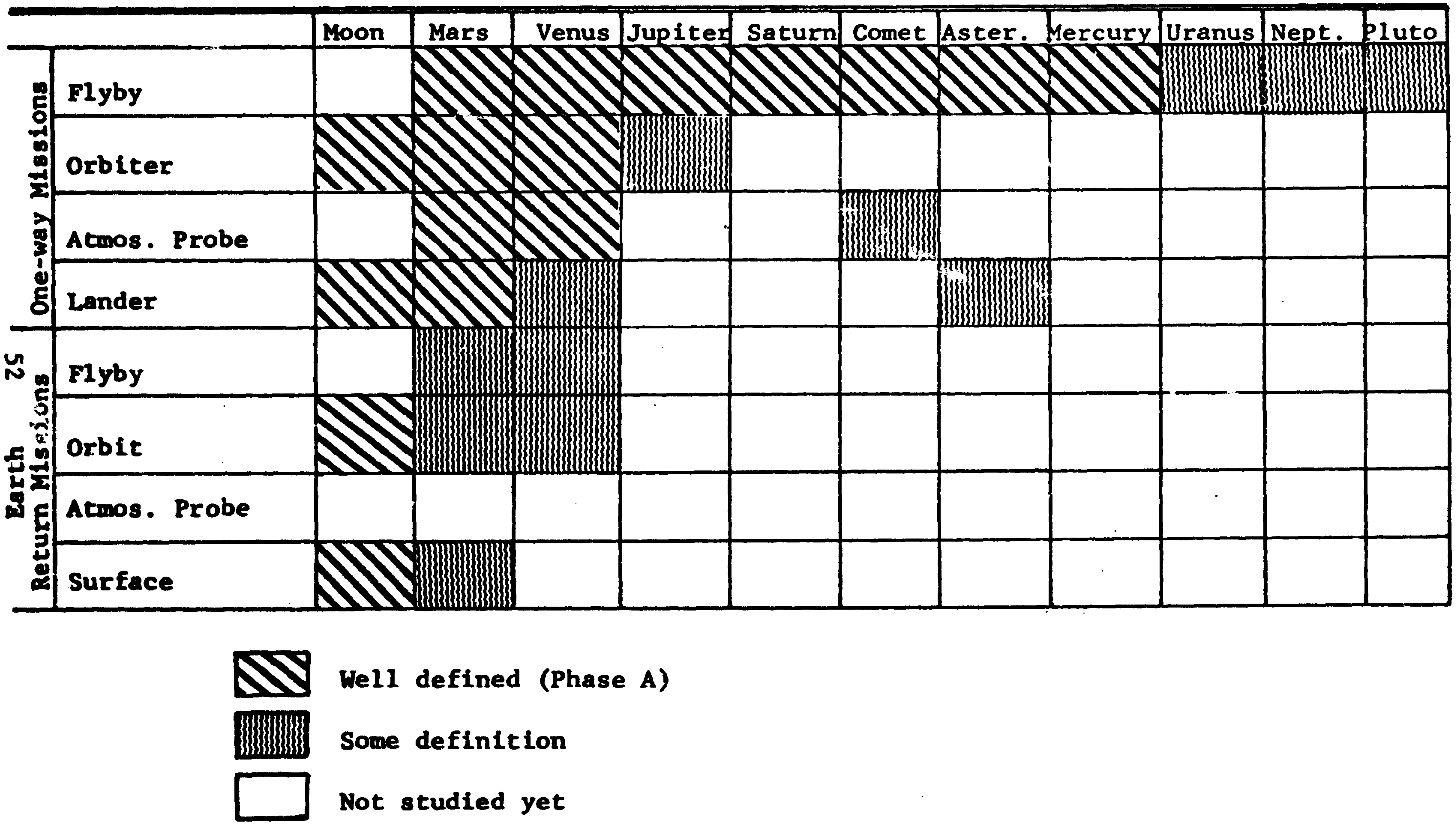

Figure 2 STATUS OF ADVANCED MISSION SURVEYS

Figure 3

TASK SCHEDULES

Task	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.
1. Total Planetary Exploration Science					////	////	////	////	////		*		
2. Jupiter Atmospheric Probe			////	////	////	////		*					
3. Venus Atmospheric Sample Return								////	////	////	////		*
4. Multiple Outer Planet Mission Study	////	////	////	////		*							
5. Jupiter Orbiter Mission Study											////	////	→
6. STEPS (Solar System Total Exploration Planning Study)								////	////	////	////	////	*
7. Prospectus 1968			////	////	////	////	////						
8. Scientific Evaluation of Venus Missions				////	////	////	////						
9. Annual Report									*				

* Report Milestone

3. TECHNICAL NOTES

3.1 Prospectus 68

Mission data has been provided as an input to the OSSA Planetary Programs Prospectus for 1968. The mission data included rationales for solar system exploration, the generation of payload computations, mission flight parameters and the manipulation cost slide rules for both spacecraft and launch vehicles. A complete set of initial inputs were provided for the NASA computerized Prospectus. At this point, all responsibility for Prospectus 68 was assumed by the OSSA Planetary Working Group.

3.2 Planetary Working Group

The Astro Science Center acted as a quick response source of mission data for the Planetary Working Group. A complete set of mission opportunities were generated, background material was provided for the scientific objectives definitions, and numerous sample exploration plans and options were compiled to conform with specified target funding levels. Data and reference material was supplied for the Program Memorandum which resulted from the activity of the Planetary Working Group.

3.3 Starlite

A special assignment was accepted to review and discuss a new spacecraft concept which had been submitted to NASA. A new technology had been suggested for inflatable light weight antennas which could double as solar collectors. This would lead to a light weight spacecraft which could be coupled with a new high performance launch vehicle. The spacecraft concept was reviewed with particular emphasis on its capability for the scientific exploration of the solar system. A presentation was made to the Space Sciences Steering Committee to solicit an estimate of its scientific potential.

3.4 Operational Computer Codes

The following are the main computer codes which have been added to the Astro Sciences Center's program inventory during the last year.

3.4.1 PROFYL

PROFYL, written in FORTRAN IV, computes encounter profiles of a spacecraft with respect to a target planet. The program assumes a hyperbolic flyby and calculates various trajectory and experiment related parameters to be used for orbit selection and experiment evaluation. The code has been used extensively in support of the Grand Tour Mission Study.

3.4.2 RINGER

This is a FORTRAN IV code which computes the true anomalies and radii of a Saturn flyby spacecraft as it crosses Saturn's ring plane. The program was written as part of a hazard analysis of ring crossings during the Saturn flyby of the Multiple Outer Planet Mission.

3.4.3 Celestial Tracking Code

A FORTRAN IV code was developed to evaluate the performance of a celestial tracking system for orbit determination during planetary approach. Input consists of the directional angles of the planet as seen from the spacecraft and of the planet's angular diameter. Since the error sources are best described statistically the program computes the error covariance matrix associated with estimating the target parameters. Optimal statistical filtering of the tracking data is assumed. Both the Kalman filter and Weighted Least-Squares algorithms (for covariance computation) are available as options to the program. This code was used in the Grand Tour Mission study.

4. PAPERS PRESENTED AND PUBLISHED

The following are the technical papers presented and published since July 1967 largely as a result of work performed on Contract No. NASr-65(06).

4.1 "New Aspects of Thermophysics in Advanced Planetary Exploration"

by J. E. Gilligan

Presented at Second Space Simulation Conference, Philadelphia, Pennsylvania (September 1967).

4.2 "Automated (Unmanned) Mars Sample Return Missions"

by J. C. Niehoff, J. T. Dockery, and D. L. Roberts

Presented at the Annual Meeting of the American Society of Mechanical Engineers, Pittsburgh, Pennsylvania, (November 1967).

4.3 "Low Thrust Trajectory and Payload Analysis for Solar System Exploration"

by A. Friedlander

Presented at the AIAA 4th Aerospace Sciences Conference, (July 1967)

4.4 "Early Missions to the Asteroids"

by D. L. Roberts and F. Narin

Published in Advances in Space Sciences and Technology, 9 pp 123-160 (1968).

5. BIBLIOGRAPHY OF ASC/IITRI REPORTS, TECHNICAL MEMORANDA, AND MAJOR COMPUTER CODES

5.1 Reports and Technical Memoranda

The following bibliography of ASC/IITRI reports and technical memoranda includes all those published since the beginning of the contract in 1963.

TM C-3 An Empirical Approach to Estimating Space Program Costs, by J. Beverly, C. Stone and R. Vickers (copies not available)

R C-4 Progress on Spacecraft Cost Estimation Studies, by J. Beverly and C. Stone (copies not available)

TM C-5 An Analysis of the Correlation Between Spacecraft Performance and Cost Complexity Factor, by W. Finnegan (copies not available)

R C-6 Spacecraft Cost Estimation, by W. Finnegan and C. Stone, NASA STAR No. N66-29740

R C-7 Spacecraft Program Cost Estimating Manual, by W. Finnegan and C. Stone, NASA STAR No. N66-30762

R M-1 Survey of a Jovian Mission, by ASC staff, NASA STAR No. N64-20643

R M-2 Survey of a Jovian Mission (U), Confidential (copies not available)

R M-3 Survey of Missions to the Asteroids, by A. Friedlander and R. Vickers, NASA STAR No. N64-19566

R M-4 Summary of Flight Missions to Jupiter, by ASC staff, NASA STAR No. N64-26597

R M-5 Missions to the Asteroids, by ASC staff (copies not available)

R P-7 Scientific Objectives of Deep Space Investigations - Venus, by P. J. Dickerman, NASA STAR No. N66-32439

R P-8 Scientific Objectives of Deep Space Investigations - Non-Ecliptic Regions, by D. L. Roberts (copies not available)

R P-9 Compendium of Data on Some Periodic Comets, by D. L. Roberts, NASA STAR No. N64-28524

R P-10 Critical Measurements on Early Missions to Jupiter, by J. Witting, M. W. P. Cann, and T. Owen, NASA STAR No. N66-15807

R P-11 Scientific Objectives of Deep Space Investigations - Saturn, Uranus, Neptune and Pluto, by P. J. Dickerman, NASA STAR No. N66-17090

TM P-12 Regularities in the Solar System Pertaining to its Origin and Evolution, by J. Witting (copies not available)

TM P-13 Comparison Criteria for a Total Lunar Scientific Exploration Program Study, by C. A. Stone (copies not available)

R P-14 Analytical Methods and Observational Requirements for Interpretations of Asteroid Distributions, by J. Ash, NASA STAR No. N67-17961

TM P-15 Analytical Techniques for the Investigation of Distributional Features of the Asteroids, by J. Ash (copies not available)

R P-16 Mission Requirements for Exobiological Measurements on Venus, by W. Riesen and D. L. Roberts, NASA STAR No. N67-12073

TM P-17 A Geological Analysis for Lunar Exploration, by W. Scoggins

R P-18 Scientific Objectives of Deep Space Investigations: The Origin and Evolution of the Solar System, by J. Witting, NASA STAR No. N67-10880

R M-6 A Study of Interplanetary Space Missions, by D. L. Roberts, NASA STAR No. N65-25003

R M-7 A Survey of Comet Missions, by D. L. Roberts, NASA STAR No. N65-30481

TM M-8 Cometary Study by Means of Space Missions, by F. Narin, P. Pierce and D. L. Roberts (copies not available)

R M-9 Missions to the Comets, by F. Narin, P. Pierce and D. L. Roberts, NASA STAR No. N66-15978

TM M-10 The Satellites of Mars, by D. L. Roberts (copies not available

R M-11 A Survey of Missions to Saturn, Uranus, Neptune and Pluto, by F. Narin et al., NASA STAR No. N67-14253

R M-12 A Survey of Multiple Missions Using Gravity-Assisted Trajectories, by J. C. Niehoff, NASA STAR No. 66-32440

R M-13 Preliminary Payload Analysis of Atuomated Mars Sample Return Missions, by J. C. Niehoff

R M-14 Digest Report: Missions to the Outer Planets, by F. Narin

TM M-15 A Solar System Total Exploration Planning System (STEPS), by J. Witting

R P-1 Scientific Objectives of Deep Space Investigations - Jupiter, by D. L. Roberts, NASA STAR No. 64-19467

R P-2 Scientific Objectives of Deep Space Investigations - The Satellites of Jupiter, by D. L. Roberts, NASA STAR No. N64-19568

R P-3 Scientific Objectives of Deep Space Investigations - Comets, by D. L. Roberts, NASA STAR No. N64-19569

R P-4 Scientific Objectives of Deep Space Investigations - Asteroids, by D. L. Roberts, NASA STAR No. N64-19579

R P-5 Scientific Objectives of Deep Space Investigations - Interplanetary Space Beyond 1 AU, by D. L. Roberts, NASA STAR No. N64-19471

R P-6 Scientific Objectives for Mercury Missions, by T. Owen NASA STAR No. N64-26599

R P-19	Scientific Objectives of Deep Space Investigations: Jupiter as an Object of Biological Interest, by ASC staff
R P-20	Suggested Measurement/Instrument Requirements for Lunar Orbiter Block III, by W. Scoggins and D. L. Roberts
TM P-21	Scientific Objectives for Total Planetary Exploration, by ASC staff
TM P-22	Role of Ground Based Observations in the Exploration of Venus, by J. T. Dockery
R P-23	A Preliminary Evaluation of the Applicability of Surface Sampling to Mars Exploration, by W. H. Scoggins and D. L. Roberts
TM R-1	Comparative Reliability Estimation Method for Mission Programming, by H. Lauffenberger (copies not available)
R R-2	Probability of Biological Contamination of Mars, by A. Ungar, R. Wheeler and D. L. Roberts (copies not available)
TM S-1	Study of Photographic and Spectrometric Subsystems for Voyager, by P. N. Slater and G. Johnson (copies not available)
R S-2	Scientific Questions Requiring Advanced Technology: Asteroid Fly-Through Mission, by J. A. Greenspan, NASA STAR No. N66-23631
R S-3	Telemetry Communications Guideline, by M. Stein (copies not available)
R S-4	Thermophysical Effects and Feasibility of Jupiter Atmospheric Entry, by J. E. Gilligan
TM S-5	Low-Thrust and Ballistic Payload Comparison for Jupiter Orbiter Missions, by D. Healy and D. L. Roberts (copies not available)
TM S-6	Deep Space Communications: Command Link and Atmospheric Probe Entry, by M. S. Stein and D. L. Roberts
R T-4R	Summary of One Way Ballistic Trajectory Data: Earth to Solar System Targets, by F. Narin and P. Pierce, NASA STAR No. N64-19572

R T-5 Accuracy and Capabilities of ASC/IITRI Conic Section Trajectory System, by P. Pierce and F. Narin, NASA STAR No. N64-19603

R T-6 Accessible Regions Method of Energy and Flight Time Analysis for One-Way Ballistic Interplanetary Missions, by F. Narin, NASA STAR No. N64-28840

R T-7 Perturbations, Sighting and Trajectory Analysis for Periodic Comets: 1965-1975, by F. Narin and P Pierce, NASA STAR No. N66-13398

TM T-8 Comparison of Atlas Centaur and Floxed Atlas Centaur Capabilities in Interplanetary Explorations Using the Accessible Regions Method, by F. Narin (copies not available)

R T-9 Spatial Distribution of the Known Asteroids, by F. Narin NASA STAR No. N65-30471

TM T-10 Collected Launch Vehicle Curves, by F. Narin (copies not available)

R T-11 Sighting and Trajectory Analysis for Periodic Comets: 1975-1986, by F. Narin and B. Rejzer, NASA STAR No. N65-28347

R T-12 Analysis of Gravity Assisted Trajectories in the Ecliptic Plane, by J. Niehoff, NASA STAR No. N65-34460

R T-13 Trajectory and Sighting Analysis for First Apparition Comets, by P. Pierce, NASA STAR No. N65-35845

R T-14 Low-Thrust Trajectory and Payload Analysis for Solar System Exploration Utilizing the Accessible Regions Method, by A. Friedlander, NASA STAR No. N66-13992

TM T-15 Mission Requirements for Unmanned Exploration of the Solar System, by F. Narin (copies not available)

TM T-16 Selection of Comet Missions: 1965-1986, by F. Narin, P. Pierce and D. L. Roberts (copies not available)

R T-17 Low-Thrust Trajectory Capabilities for Exploration of the Solar System, by A. Friedlander, NASA STAR No. N67-12224

R T-18 The Accessible Regions Presentation of Gravity Assisted Trajectories Using Jupiter, by D. A. Klopp and J. C. Niehoff

R T-19 On the Problem of Comet Orbit Determination for Spacecraft Intercept Missions, by A. Friedlander

5.2 Major Computational Codes

5.2.1 Interplanetary Transfers

Conic Section Codes

SPARC: The JPL general conic section code for ballistic and ballistic-gravity assist flights.

ASC CONIC: An extensive collection of programs and subprograms for ballistic and gravity assist flights and accessible regions calculations, and for conic guidance analysis.

High Precision Codes

NBODY(II): The Fortran II version of the Lewis Research Center code has been used for comet perturbation analysis, considering the gravitational effects of Sun and planets simultaneously.

NBODY(IV): The Fortran IV version of this is being revised at ASC for multibody, high precision targeting and guidance analysis.

Low Thrust Codes

JPL CODE: The JPL Calculus of Variations Optimized Thrusted Trajectory Code has been used for optimum interplanetary nuclear electric flight with variable thrust, constant thrust, or constant acceleration.

5.2.2 Near Planet Operations

ATMENT: One of a series of codes for integrating the atmospheric entry for a spacecraft.

ZAYIN: A Fortran II code (from W. P. Overbeck) modified for calculating satellite orbits around the Earth, including oblateness and air drag.

GRNDTRC: Generates lunar ground traces for specified lunar orbits.

TRACE: Generates Earth ground traces for specified Earth orbits.

PROFYL: A planetary encounter profile definition code.

RINGER: A code of calculating crossings of Saturn's ring plane during flyby.

5.2.3 Guidance and Orbit Determination

ORBDET: Orbit determination for an over-determined set of points by Dalman filtering.

LTNAV: A low thrust navigation code

PARODE: A radio tracking performance evaluation code for orbit determination during planetary approach.

CELESTIAL TRACKING: A celestial tracking performance evaluation code for orbit determination during planetary approach.

5.2.4 Combinatorial Codes

XPSLCT and COMBSC find various sets of payloads from experiments and instruments, subject to spacecraft constraints.

HFIT: A code for least square fit of a set of points to a hyperbola.

BIMED: A general statistical analysis package from UCLA; used for multiple regression analysis.

IMP3: An integer programming code.

5.2.5 Space Sciences Codes

ASTA: A set of codes for analysizing spatial and velocity distributions of the asteroids.

HAZARD: A code for calculating spacecraft to asteroid and meteor stream distances.

SIGHT: A code for analyzing position of celestial objects.

INTEGRALS: A set of codes for evaluating various special integrals which arise in planetary atmosphere analysis.

5.2.6 Special Features and Systems

GPSS-III: An IBM system for analyses of systems of discrete transactions.

MIMIC: A Fortran IV-like system for simulating, on the 7094, an analog computer and thereby easily doing integrations.

KWIC-II: The IBM key word in context system used to catalog the ASC library of some 8000 documents.

Orbital Elements Tape: An extensive collection or orbital elements for solar system objects, including planets, 1600 numbered asteroids, 2000 unnumbered asteroids and hundreds of comets.

Appendix A

REPORT DESIGNATION AND DISTRIBUTION

Appendix A

REPORT DESIGNATION AND DISTRIBUTION

Distribution of ASC/IITRI reports is determined on the basis of range of interest or the subject matter. Those felt to be of general interest receive the widest distribution. This category includes some reports as written and digests of the long or technically detailed reports. Reports given wide distribution (see List A) are bound in red for visual identification.

Reports felt to be of more specialized interest including some mission studies and trajectory calculations are given a smaller distribution (see List B). These reports can be identified by the black binder.

Technical memoranda include results of special studies in narrow technical areas, interim reports and other documents involving very limited distribution (see List C). White binders are used to identify technical memoranda.