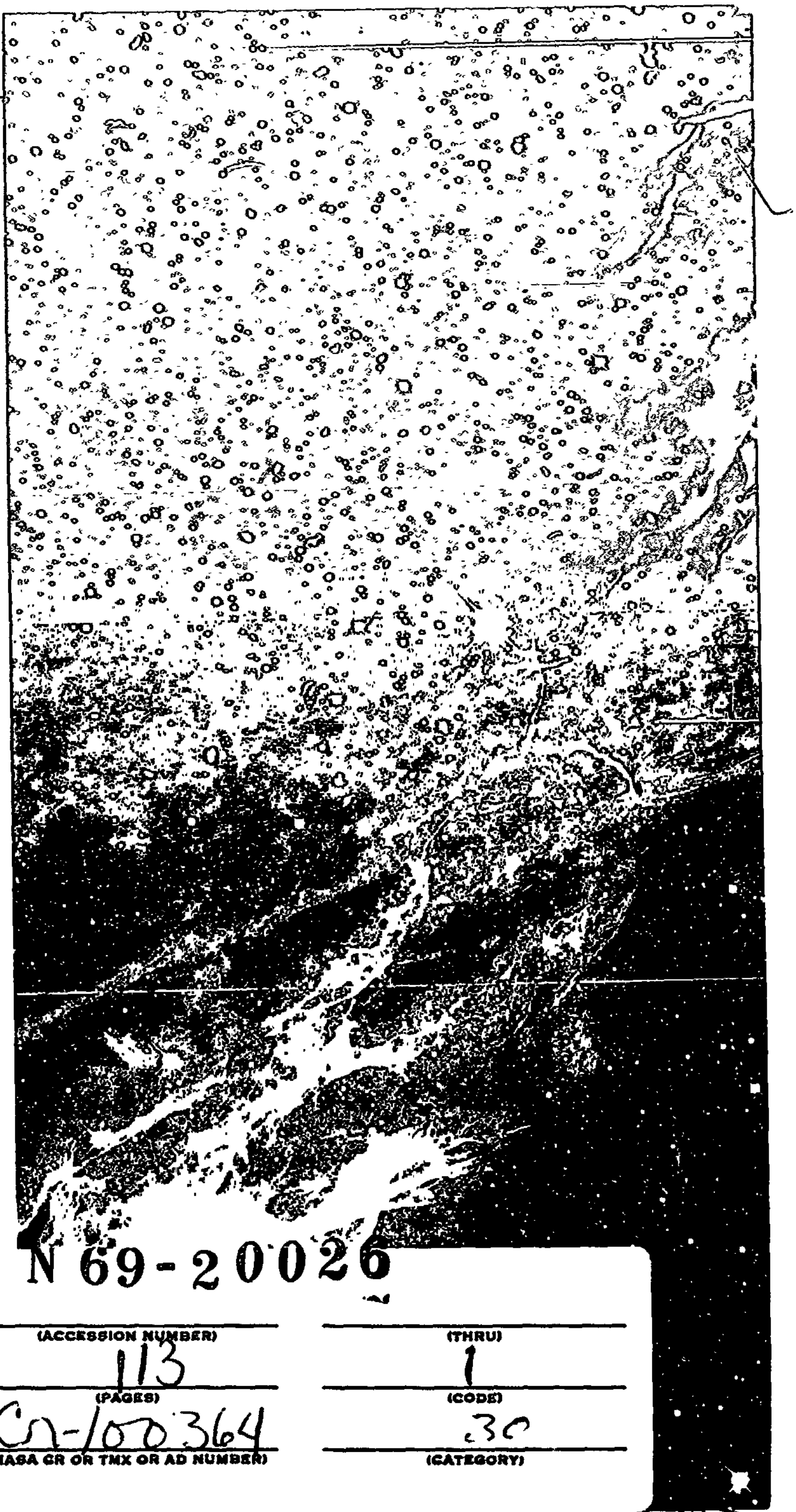
ASC
ASTRO
SCIENCES
CENTER



N 69-20026

FACILITY FORM 602

N 69-20026	
(ACCESSION NUMBER)	(THRU)
113	1
(PAGES)	(CODE)
CR-100364	30
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

Report No. A-6

FINAL REPORT

LONG RANGE PLANNING STUDIES FOR SOLAR SYSTEM EXPLORATION

IIT RESEARCH INSTITUTE
10 West 35 Street
Chicago, Illinois 60616

Report No. A-6

FINAL 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

D. L. Roberts, Manager
Astro Sciences Center

January 1969

FOREWORD

This is the summary report for work performed under NASA Contract NASr-65(06) by the Astro Sciences Center of IIT Research Institute between March 1963 and December 1, 1968. A total of 73 published reports or technical memoranda are summarized together with descriptions of special studies, technical notes and major computer codes. Also included is a list of the 21 technical papers presented and published as a result of work performed under the contract.

TABLE OF CONTENTS

Page

1. INTRODUCTION 1

2. SUMMARIES OF REPORTS AND TECHNICAL MEMORANDA PUBLISHED 4

2.1 Cost Estimation Methods

2.1.1 An Empirical Approach to Estimating Space Program Costs 6

2.1.2 Progress Report on Spacecraft Cost Estimation Studies 7

2.1.3 An Analysis of the Correlation Between Spacecraft Performance and Cost Complexity Factor 7

2.1.4 Spacecraft Cost Estimation 8

2.1.5 Spacecraft Program Cost Estimating Manual 9

2.1.6 Spacecraft Comparison Study for Mars-Venus Fields and Particles Orbiters 10

2.2 Mission Analysis

2.2.1 Survey of a Jovian Mission 13

2.2.2 Survey of a Jovian Mission (Confidential) 13

2.2.3 A Survey of Missions to the Asteroids 14

2.2.4 Summary of Flight Missions to Jupiter 14

2.2.5 Missions to the Asteroids 15

2.2.6 A Study of Interplanetary Space Missions 16

2.2.7 A Survey of Comet Missions 17

2.2.8 Cometary Study by Means of Space Missions 17

2.2.9 Missions to the Comets 18

2.2.10 The Satellites of Mars 19

2.2.11 A Survey of Missions to Saturn, Uranus, Neptune, and Pluto 20

2.2.12 A Survey of Multiple Missions Using Gravity-Assisted Trajectories 21

2.2.13 Preliminary Payload Analysis of Automated Mars Sample Return Missions 22

2.2.14 Missions to the Outer Planets 22

2.2.15 A Solar System Total Exploration Planning System (STEPS) 23

2.2.16 The Multiple Outer Planet Mission (Grand Tour) 24

2.2.17 A Preliminary Study of Jupiter Atmospheric Missions 26

2.3 Objectives of Advanced Missions

2.3.1 Scientific Objectives of Deep Space Investigations - Jupiter 30

2.3.2 Scientific Objectives of Deep Space Investigations - The Satellites of Jupiter 31

2.3.3 Scientific Objectives of Deep Space Investigations - Comets 31

2.3.4 Scientific Objectives of Deep Space Investigations - Asteroids 32

2.3.5 Scientific Objectives of Deep Space Investigations - Inter-Planetary Space Beyond 1 AU 33

2.3.6 Scientific Objectives for Mercury Missions 33

2.3.7 Scientific Objectives of Deep Space Investigation - Venus 34

2.3.8 Scientific Objectives of Deep Space Investigations - Non-Ecliptic Regions 34

2.3.9 Compendium of Data on Some Periodic Comets 35

2.3.10 Critical Measurements on Early Missions to Jupiter 36

2.3.11 Scientific Objectives of Deep Space Investigations-Saturn, Uranus, Neptune, and Pluto 37

2.3.12 Regularities in the Solar System Pertaining to its Origin and Evolution 38

2.3.13 Comparison Criteria for a Total Lunar Scientific Exploration Program Study 39

2.3.14 Analytical Methods and Observational Requirements for Interpretation of Asteroid Distributions 40

2.3.15 Analytical Techniques for the Investigation of Distributional Features of the Asteroids 41

2.3.16 Mission Requirements for Exobiological Measurements on Venus 41

2.3.17 A Geological Analysis for Lunar Exploration 42

2.3.18 Scientific Objectives of Deep Space Investigations: The Origin and Evolution of the Solar System 43

2.3.19 Scientific Objectives of Deep Space Investigations:Jupiter as an Object of Biological Interest 44

2.3.20 Suggested Measurement/Instrument Requirements for Lunar Orbiter Block III 45

2.3.21 Scientific Objectives for Total Planetary Exploration 46

2.3.22 Role of Ground-Based Observations in the Exploration of Venus 47

2.3.23 A Preliminary Evaluation of the Applicability of Surface Sampling to Mars Exploration 48

2.3.24 The Scientific Objectives for Venus Landers 49

2.3.25 Preliminary Study of Atmospheric Sample Return from Venus 50

2.4 Success Probability Determination

2.4.1 Comparative Reliability Estimation Method for Mission Programming 53

2.4.2 Probability of Biological Contamination of Mars 54

2.5 Spacecraft Technology

2.5.1 Study of Photographic and Spectrometric Subsystems for Voyager 56

2.5.2 Scientific Questions Requiring Advanced Technology: Asteroid Fly-Through Missions 56

2.5.3 Telemetry Communications Guideline 57

2.5.4 Thermophysical Effects and Feasibility of Jupiter Atmospheric Entry 58

2.5.5 Low-Thrust and Ballistic Payload Comparison for Jupiter Orbiter Missions 59

2.5.6 Deep Space Communcations: Command Link and Atmospheric Probe Entry 60

2.6 General Trajectory Studies

2.6.1 Summary of One Way Ballistic Trajectory Data: Earth to Solar System Targets 63

2.6.2 Accuracy and Capabilities of ASC/IITRI Conic Section Trajectory System 64

2.6.3 Accessible Regions Method of Energy and Flight Time Analysis for One-Way Ballistic Interplanetary Missions 64

2.6.4 Perturbations, Sighting, and Trajectory Analysis for Periodic Comets: 1965-1975 65

2.6.5 Comparison of Atlas Centaur and Floxed Atlas Centaur Capabilities in Interplanetary Explorations Using the Accessible Regions Method 66

2.6.6 Spatial Distribution of the Known Asteroids 67

2.6.7 Collected Launch Vehicle Curves 68

2.6.8 Sighting and Trajectory Analysis for Periodic Comets: 1975-1986 69

2.6.9 Analysis of Gravity Assisted Trajectories in the Eclipic Plane 70

2.6.10 Trajectory and Sighting Analysis for First Apparition Comets 71

2.6.11 Low-Thrust Trajectory and Payload Analysis for Solar System Exploration Utilizing the Accessible Regions Method 72

2.6.12 Mission Requirements for the Unmanned Exploration of the Solar System 73

2.6.13 Selection of Comet Missions: 1965-1986 74

2.6.14 Low-Thrust Trajectory Capabilities for Exploration of the Solar System 76

2.6.15 The Accessible Regions Presentation of Gravity Assisted Trajectories Using Jupiter 77

2.6.16 On the Problem of Comet Orbit Determination for Spacecraft Intercept Missions 78

2.6.17 Trajectory Opportunities to the Outer Planets for the Period 1975-2000 79

3. Special Studies and Technical Notes

3.1 Prospectus 81

3.2 Scientists in the Fields of Selenodesy and Lunar Theory 81

3.3 Survey of Bioclean Facilities 84

3.4 Asteroid Movie 84

3.5 Space Mission Slide Chart 85

3.6 Preliminary Outline of a Planning Methodology for Total Lunar Exploration 85

3.7 Planetary Working Group 86

3.8 Starlite 86

4. Major Computer Codes

4.1 Interplanetary Transfers 88

4.2 Near Planet Operations 88

4.3 Guidance and Orbit Determination 89

4.4 Combinatorial Codes 89

4.5 Space Sciences Codes 89

4.6 Special Features and Systems 90

5. Papers Presented and Published

5.1 Cometary Study by Means of Space Missions 92

5.2 Selection of Comet Missions: 1965-1986 92

5.3 Satellite Roles in Radio Emission from Jupiter 92

5.4 An Analysis of Gravity Assisted Trajectories to Solar System Targets 92

5.5 Spatial Distribution and Motion of the Known Asteroids 93

5.6 Choice of Flight Mode for Outer Planet Missions 93

5.7 Mars Surface Simulator: Design Considerations 93

5.8 Comet Orbit Determination 93

5.9 Missions to Mars Spur Survey of Bioclean Rooms 93

5.10 An Empirical Method for Estimating Unmanned Spacecraft Program Costs 93

5.11 Mission Requirements for the Unmanned Exploration of the Solar System 94

5.12 Post Apollo Space Exploration 94

5.13 The Requirements of Unmanned Space Missions to Jupiter 94

5.14 Results of Bioclean Room Survey 94

5.15 Low-Thrust Trajectory and Payload Analysis for Solar System Exploration 94

5.16 New Aspects of Thermophysics in Advanced Planetary Exploration 94

5.17 Automated (Unmanned) Mars Sample Return Missions 95

5.18 Early Missions to the Asteroids 95

5.19 Guidance Analysis of the Multiple Outer Planet (Grand Tour) Mission 95

5.20 Jupiter Gravity-Assisted Trajectories 95

5.21 Relevance of Future Space Missions to Origin of the Solar System 95

Appendix A-Report Designation and Distribution A-1

SECTION 1

INTRODUCTION

The Astro Sciences Center of IIT Research Institute (ASC/IITRI) has been engaged in a continuing program of research, study, and analysis to provide support for advanced mission planning for the Lunar and Planetary Programs Division under Contract No. NASr-65(06). This program was initiated on March 1, 1963 and renewed on December 1, 1963, January 1, 1965, November 1, 1965, November 1, 1966, and November 1, 1967. During this period five Annual Summary Reports have been submitted, the last one of these covering the period up to July 1, 1968. This report is a final summary report of all the work done under the contract between March 1, 1963 and December 1, 1968. Since the initiation of the contract in 1963, ASC/IITRI has developed a uniform background of knowledge of the solar system, has obtained an understanding of the mission requirements for exploring the solar system, and has generated an objective, systematic analysis capability for both scientific and technological objectives. The general areas of work which have been pursued to meet the broad objectives of planning support required by NASA may be summarized 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.

The ongoing activities have been reported to the Planetary Programs Division in monthly progress reports and in review and planning meetings. In addition, at the completion of each study a technical report covering the study is submitted. Seventy-three such reports have been submitted since March 1963, including 6 for the period July 1, 1968 through December 1, 1968. Of these 73 reports, 40 have been included in Scientific and Technical Aerospace Reports (STAR). Summaries of the 73 reports and technical memoranda are given in Section 2. The special study assignments and technical notes of Section 3 summarize study efforts that have been performed for which no formal reports have been written. Section 4 outlines the major computer capabilities which have been developed under the contract. Finally, Section 5 contains the 21 papers which have been presented and published in the open literature as a result of work performed under this contract. 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.

SECTION 2

REPORTS AND TECHNICAL MEMORANDA PUBLISHED

This section consists of summaries of reports and technical memoranda in the areas of:

Page

1. Cost Estimation Methods 5
2. Mission Analysis 12
3. Objectives of Advanced Missions 28
4. Success Probability Determinations 52
5. Spacecraft Technology 55
6. General Trajectory Studies 61

2.1 The following reports are in the area of cost estimation methods:

Page

2.1.1 C-3 An Empirical Approach to Estimating Space Program Costs 6

2.1.2 C-4 Progress Report on Spacecraft Cost Estimation Studies 7

2.1.3 C-5 An Analysis of the Correlation Between Spacecraft Performance and Cost Complexity Factor 7

2.1.4 C-6 Spacecraft Cost Estimation 8

2.1.5 C-7 Spacecraft Program Cost Estimating Manual 9

2.1.6 C-8 Spacecraft Comparison Study for Mars-Venus Fields and Particles Orbiters 10

2.1.1 Technical Memorandum C-3

"An Empirical Approach to Estimating Space Program Costs"

J. Beverly, C. Stone and R. Vickers

January 1965

A simple cost estimation method is derived on the basis of program costs and spacecraft subsystem data for fourteen NASA spacecraft and satellite projects.

The total program cost, C_p, in millions of dollars is

$$C_p = 0.055 \, N \, \frac{W_t}{W_{S/C}} \, W_1 + C_f$$

where N is the number of flight-ready spacecraft, W_t is the weight of the spacecraft plus experiments, $W_{S/C}$ is the weight of the spacecraft alone, W_1 is the combined weight of the telecommunications/data and power subsystem, and 0.055 is a coefficient having units of millions of dollars per pound which is determined as the best fit for eleven programs. C_f is the non-spacecraft cost.

The root mean square error for the fourteen programs is ± 30 percent.

2.1.2 Report No. C-4

"Progress Report on Spacecraft Cost Estimation Studies"

J. Beverly and C. Stone

July 1964

This report summarizes the progress to date (July 1964) in the attempt to evolve cost estimating methods for unmanned spacecraft. A cost estimating expression or model to estimate total spacecraft program costs in millions of dollars was developed from the study of costs and subsystem weights of eleven unmanned NASA programs. Updated information on spacecraft subsystems and program costs led to an improved and more simplified model. For both models the root mean square percentage error is approximately ± 30 percent.

2.1.3 Technical Memorandum C-5

"An Analysis of the Correlation Between Spacecraft Performance and Cost Complexity Factor"

W. Finnegan

May 1965

This is an attempt to find a correlation between the factor

$$C_f = \frac{\text{Weight of the Telemetry and Data Handling Subsystem}}{\text{Weight of the Spacecraft Less Experiments}}$$

and the success ratio of a spacecraft series. The factor

C_f appears to be a measure of mission complexity and is proportional to the cost per pound of spacecraft.

The conclusions of the study are as follows:

1. There is no correlation between complexity and success as defined in this report.
2. Generally, the initial spacecraft in a series does poorly when compared with its successors.
3. Three methods of success estimation were used. They did not produce significantly different average success percentages.
4. An estimation of success based solely on experimental data returned does not properly weight spacecraft performance.

2.1.4 Report No. C-6

"Spacecraft Cost Estimation"

W. Finnegan and C. Stone

May 1966.

The relative cost significance of each of the spacecraft subsystems, and the accuracy with which a linear model based on spacecraft weights could be expected to predict future spacecraft costs were studied. A linear cost estimation equation was evolved which includes three subsystem weights as parameters. This equation yields a significant reduction in root mean square percentage error, and was used in evaluating predictability. The significance of individual subsystem cost estimation, the significance of relative costs of spacecraft subsystems, and the multivariable cost estimation model are discussed. It was concluded that the relative cost significance of spacecraft subsystems in a linear regression model is established. Telecommunications and data handling was found to be the most important single factor, with structure and propulsion also being significant. It was further concluded that this model can easily provide cost estimates for long range planning purposes.

2.1.5 Report No. C-7
"Spacecraft Program Cost Estimating Manual"
W. Finnegan and C. A. Stone
May 1966

An equation for estimating program costs for design, development, and manufacture of spacecraft has been empirically developed based on the number of complete spacecraft (full prototypes, flight spares, and flight models) and the weights of three spacecraft subsystems (telecommunications and data handling, structure, and propulsion). The accuracy of prediction is, of course, in part dependent upon the quality of the input data, but root mean square errors of less then ± 30 percent have been demonstrated using program level information. The cost estimation method is intended for use in long range planning and this report summarizes definitions, presents examples, and supplies graphical aids for utilizing the equation developed.

2.1.6 Technical Memorandum No. C-8

"Spacecraft Comparison Study for Mars-Venus Fields and Particles Orbiters"

W. O. Adams and H. J. Goldman

December 1968

A cost comparison of four spacecraft was made to determine the most inexpensive means for sending a fields and particles payload into orbit around Venus and Mars. The four spacecraft compared were: (1) Mariner V (modified), (2) Lunar Orbiter (modified), (3) Planetary Explorer, (4) Pioneer E. The technique for comparison included defining a standard payload and associated orbiter which in turn placed definite constraints on spacecraft performance. The four spacecraft were then compared with the performance requirements, and estimates for modifications were made where necessary. The cost of the existing/modified spacecraft was then estimated through the use of a cost model. The results of the comparison indicated that weight was the most significant factor. Basically, the weight influenced cost in three areas: (1) cost of the spacecraft itself, (2) cost of the deboost engine for planetary orbital insertion, and (3) cost of the launch vehicle of the four spacecraft. Mariner V and Lunar Orbiter were significantly more costly due to their greater weight. The Pioneer spacecraft was estimated as the least expensive.

Some of the many difficulties in cost estimating are illustrated by the report. Consequently, the importance of the assumptions and constraints pertaining to the report is emphasized.

2.2 The following reports and technical memoranda are in the area of mission analysis:

			Page
2.2.1	M-1	Survey of a Jovian Mission	13
2.2.2	M-2	Survey of a Jovian Mission (U)	13
2.2.3	M-3	A Survey of Missions to the Asteroids	14
2.2.4	M-4	Summary of Flight Missions to Jupiter	14
2.2.5	M-5	Missions to the Asteroids	15
2.2.6	M-6	A Study of Interplanetary Space Missions	16
2.2.7	M-7	A Survey of Comet Missions	17
2.2.8	M-8	Cometary Study by Means of Space Missions	17
2.2.9	M-9	Missions to the Comets	18
2.2.10	M-10	The Satellites of Mars	19
2.2.11	M-11	A Survey of Missions to Saturn, Uranus, Neptune, and Pluto	20
2.2.12	M-12	A Survey of Multiple Missions Using Gravity-Assisted Trajectories	21
2.2.13	M-13	Preliminary Payload Analysis of Automated Mars Sample Return Missions	22
2.2.14	M-14	Missions to the Outer Planets	22
2.2.15	M-15	A Solar System Total Exploration Planning System (STEPS)	23
2.2.16	M-16	The Multiple Outer Planet Mission (Grand Tour)	24
2.2.17	M-17	A Preliminary Study of Jupiter Atmospheric Missions	26

2.2.1 Report No. M-1

"Survey of a Jovian Mission"

W. O. Davies, F. Narin, D. L. Roberts, L. A. Schmidt, and L. C. Scholz

March 1964

A survey of the requirements for Jovian missions was made. Scientific questions concerning Jupiter were used to select minimum experimental payloads to increase knowledge of the planet. Approximate payload weights were derived from instrumentation estimates, data handling and transmission requirements, electrical power demands, guidance and control requirements, spacecraft structure, shielding, and terminal maneuver energy needed. Three launch vehicles were postulated with performance sufficient to cover the range expected in the next decade. The requirements for additional propulsion and the launch restrictions associated with Jovian missions were assessed on the basis of these three vehicles. The addition of a final stage for injection to transfer orbit is necessary to achieve most missions. The characteristics of a hypothetical high-performance stage were derived for several combinations of mission parameters.

2.2.2 Report No. M-2

"Survey of a Jovian Mission" (U)

Confidential (Copies Not Available)

March 1964

2.2.3 Report No. M-3

"A Survey of Missions to the Asteroids"

A.L. Friedlander and R.S. Vickers

April 1964

A survey has been made of possible missions to the asteroid belt, and to asteroids whose orbits bring them in close proximity to the earth. Experimental techniques for elucidating the scientific questions associated with the asteroids have been examined, and suitable experimental packages for the various missions are outlined. The guidance requirements for asteroid missions have been examined in some detail. Specific calculations on the guidance requirements for the target bodies considered have been made, and the results are tabulated.

2.2.4 Report No. M-4

"Summary of Flight Missions to Jupiter"

ASC Staff

July 1964

The feasibility of an unmanned scientific mission to Jupiter to obtain astrophysical information concerning the planet and its environment was studied. The report deals primarily with an overall assessment of the problem areas that must be considered in successfully completing a Jovian mission, as well as attempts to establish the feasibility of achieving such a mission using present state-of-the-art vehicle technology, and the scientific payload. The results of the study indicate that a useful scientific mission to Jupiter is feasible with presently available chemical propulsion techniques, sensors, power supplies, telemetry links, and boosters. The development of a high-performance final-stage rocket compatible with the vehicles considered was found to be desirable for either a flyby or orbiter mission.

2.2.5 Report No. M-5

"Missions to the Asteroids"

ASC Staff

August 1964

This report is a digest of ASC/IITRI Report No. M-3 entitled "A Survey of Missions to the Asteroids." That study explored the feasibility of unmanned scientific missions to the asteroid belt with the objective of obtaining data on the composition of the belt, the size and density distribution of particles, surface properties of large asteroids, magnetic characteristics of the asteroids, etc. The class of missions required was delineated together with the problem areas associated with such missions. No detailed mission analyses with optimization and reliability considerations were made in this survey.

This report presents the major findings and conclusions of the original study and includes some recent trajectory information which indicates the careful assessment required for some missions to the asteroids.

2.2.6 Report No. M-6
"A Study of Interplanetary Space Missions"
D.L. Roberts
March 1965

A survey of interplanetary space exploration, which was initiated with a previous investigation of the scientific objectives of solar system exploration, is reported. The gross requirements for interplanetary missions are discussed in respect to the following mission profiles: ecliptic to 5.2 AU; absolute min. ΔV to $\beta = 13.5°$ lat; absolute min. ΔV to $\beta = 22°$ lat; and min. ΔV to $r = 3$ AU, $\beta = 15°$. The launch vehicles assumed for the missions are the Atlas Centaur and the Saturn 1B. Emphasized is the region of space between heliocentric radii of 0.5 AU and 5 AU, and heliocentric latitudes of $\pm 50°$. Included are data on the scientific objectives, a basic experimental payload, guidance propulsion, trajectory, and communications requirements. Suggestions are made for constructing multiple missions where the value lies in obtaining data simultaneously from two or more predetermined positions in space. Speculation is made concerning the influence of this approach on the present knowledge of the propagation of irregular zones through interplanetary space.

2.2.7 Report No. M-7

"A Survey of Comet Missions"

D. L. Roberts

June 1965

Ways in which cometary missions can complement and significantly add to the present understanding of comets are discussed, and mission profiles for cometary intercept missions are outlined. Consideration has also been given to the importance of further observations of comets from the earth, laboratory study of simulated cometary phenomena, and the use of man-made artificial comets launched into orbit and observed from the earth. The areas of present understanding of the physics of comets are reviewed, and methods of investigating the major problem areas through a combination of earth-based study and comet missions are discussed.

2.2.8 Report No. M-8

"Cometary Study by Means of Space Missions"

F. Narin, P. Pierce and D. L. Roberts

August 1965

The feasibility of unmanned scientific missions to well known short-period comets and to new comets in the years 1965-1986 is discussed. An analysis of the possible opportunities for missions to periodic comets indicates that the apparitions of at least 17 periodic comets are suitable for intercept missions in the next 20 years, and that 5 are of particular interest. In addition, given a modest sky-searching facility such as can be provided with Baker-Nunn or similar cameras, the potential opportunities for intercept missions to new comets are nearly 1 per year. It is shown that not only are the number of opportunities for comet missions sufficient, but both the experimental and the total payloads are also within the foreseeable state of the art and are compatible with projected launch vehicle capabilities.

2.2.9 Report No. M-9

"Missions to the Comets"

F. Narin, P. Pierce, D.L. Roberts

December 1965

This report is a digest of six reports covering the general area of preliminary selection and assessment of missions to comets in the years 1965-1986. These reports consider the feasibility of unmanned scientific missions to well known short-period comets and to new comets. These reports lead to the following conclusions. Opportunities for missions to short-period comets occur at an average rate of one per year; about one in four of these is particularly attractive. If a comet detection network and a quick response launch facility are available in the future, nearly one new comet mission per year would be feasible. In most cases a launch vehicle of the Atlas-Centaur class would be adequate. For almost all missions the fundamental experiments would be measurements of charged particles, dust, and magnetic field in the comet coma and tail, together with measurements aimed at determining the properties of the comet nucleus.

2.2.10 Technical Memorandum M-10

"The Satellites of Mars"

D. L. Roberts

November 1965

The satellites of Mars, Phobos and Diemos, are difficult to observe from the Earth because of their small size, their closeness to Mars and their faintness compared to Mars itself. The limited existing data extend only to approximate orbital elements and estimates of their size and mass. There appears to be a secular variation in the orbital elements of the inner satellite, Phobos, which is causing its orbit to decay, but the orbit of Diemos seems comparatively stable.

The following information should be obtained on the satellites. Accurate orbital elements should be determined, the sizes measured, and the surface characteristics observed. A second accurate determination of the orbital elements after an interval of two years or more should enable any secular variations in the elements to be calculated. It is probable that only space missions can provide the required data.

Without an accurate knowledge of the orbits of the satellites, and their positions in their orbits, a detailed study of rendezvous missions to Phobos or Diemos is unwarranted. Rather ~~it~~ is suggested that orbiting missions to Mars should be used to obtain the necessary basic data on which a detailed study can be based.

2.2.11 Report No. M-11

"A Survey of Missions to Saturn, Uranus, Neptune, and Pluto"

F. Narin

June 1966

Potential missions to Saturn, Uranus, Neptune, and Pluto are considered technically feasible; and flight times range from 1 to 3 years to Saturn to a minimum of 4 years for Pluto with a nuclear electric low thrust stage. For 600 to 2000 lb Saturn V-Centaur and Saturn 1B-Centaur loose orbiters to Saturn, Uranus, and Neptune, flight times are considered to range from 2.5 to 10 years. In years when possible, a gravity assist flight mode should be used for flyby missions; in years when gravity assist is not possible or if guidance requirements are too high for gravity-assisted flights, direct ballistic flights will be satisfactory. Missions to each of the planets could be quite similar, and a basic payload of 85 lb and a total payload of about 1000 lb can be used. Guidance requirements for flyby missions are considered within present state-of-the-art; and for initial flyby flights, a miss distance of 3 or more planet radii, with an uncertainty of one planet radius, appears satisfactory. An extensive program of flyby flights is not recommended because such results are limited to comparisons with orbiter data.

2.2.12 Report No. M-12

"A Survey of Multiple Missions Using Gravity-Assisted Trajectories"

J. C. Niehoff

April 1966

Gravity-assisted multiple missions to a number of specific solar system targets were briefly analyzed in order to assess the practical advantages these missions may have over direct missions to the same targets. The targets analyzed included Mercury, outer planets (Saturn and beyond), out-of-the-ecliptic regions, solar probes, reconnaissance (Earth return), asteroids as a group and individually, comet rendezvous, and planetary satellites. Gravity-assisted and direct trajectories were restricted to ballistic flight. Six multiple missions are recommended for further study: Earth-Venus-Mercury; Earth-Jupiter-Saturn-Uranus-Neptune; Earth-Jupiter-90° out-of-the-ecliptic; Earth-Venus (single or multiple)-solar probe; Earth-Jupiter-solar probe; and Earth-Mars-asteroid fly-through. The launch opportunities, principal objectives, advantages over a direct mission, the ideal velocity, and the trip time for each are summarized.

2.2.13 Report No. M-13

"Preliminary Payload Analysis of Automated
Mars Sample Return Missions"

J. C. Niehoff

May 1967

The study objective was to identify by preliminary analysis mission modes which could be launched in the mid-1970's by a single Saturn V vehicle using available chemical propulsion systems throughout the mission. Twelve candidate mission modes are formulated from an analysis of many mission phase options. Four of these modes are shown to satify study constraints and have payload requirements within the capability of a single Saturn V launch vehicle. Three of the four modes are one year Mars stay time, 975-day round trip missions. They differ in near-Mars orbital maneuvers which are either direct entry/direct escape, out-of-orbit entry/direct escape, or out-of-orbit entry/escape via rendezvous. The fourth possible mode is a 12-day stay time, 550-day round trip mission with a Venus swingby return transfer. The near-Mars orbital maneuvers are out-of-orbit entry/escape via rendezvous.

2.2.14 Report No. M-14

Digest Report: "Missions to the Outer Planets"

F. Narin

May 1967

Radical technological departures from the current Mariner and Voyager programs do not appear to be required for early missions to the outer planets. For flyby flights, the preferred flight mode is ballistic to Jupiter, and ballistic gravity assist to the other outer planets. For orbiter missions, a gravity assist mode should not be used, because the high approach velocity in gravity assisted missions actually reduces the payload in orbit to less than that obtainable from direct ballistic flights. For most loose (highly eccentric) orbiters, the ballistic flight mode is satisfactory. However, many circular near planet orbits are not feasible ballistically even with the Saturn V-Centaur; for these missions a nuclear electric low thrust stage is very attractive.

2.2.15 Technical Memorandum M-15

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

J. Witting

April 1968

An evaluation scheme for total solar system exploration plans which expresses the scientific value of a plan and its cost quantitatively has been developed. In this scheme, value is assigned to scientific objectives of solar system exploration to separate those of major importance from those of lesser importance. Value is also assigned to a set of measurements, made on a given mission, with a particular instrument, relevant to a particular scientific objective.

The evaluation is done by a computer program whose input is a plan consisting of a series of relatively simple mission descriptions and whose output is an evaluation of the scientific value and a computation of the cost of the plan and each mission in the plan.

Although computer codes to implement the evaluation of the scientific value of the plan, and to obtain the cost, have been written and tested, a thorough testing of the entire system, using sample plans, has not been completed.

2.2.16 Report No. M-16

"The Multiple Outer Planet Mission (Grand Tour)"

Compiled by D.L. Roberts
Contributors: A.B Binder, A. Friedlander, L. Golden, H. Goldman, M. Hopper, J.C. Jones, J.C. Niehoff, D.L. Roberts, K.L. Uherka

December 1968

The Multiple Outer Planet Mission is a flyby mission of the outer planets utilizing gravity assist at Jupiter, Saturn, and Uranus. Trajectory opportunities for the mission exist from 1976 through 1980 and will not reoccur for 179 years. The aims of this study were to:

1) determine the guidance requirements to perform the mission,
2) identify the scientific commonality between the planets Jupiter, Saturn, Uranus, and Neptune,
3) define "minimum" and "representative" scientific payloads, and

4) estimate the launch vehicle requirements to perform the mission.

Because the 1977 and 1978 opportunities are the most acceptable in terms of planet miss distances, characteristic velocity, and time of flight, four trajectories from these years were examined in detail and the results were used as inputs to the guidance and scientific experiment analyses.

A capsule summary of the results of the study is that:

1) Although the guidance requirements for the mission are severe, they are not beyond the current state-of-the-art and they are greatly reduced when an on-board planet tracker is used.
2) There is a clear scientific commonality among the target planets which holds for all the opportunities considered. The highest priority scientific objectives are related to the atmospheres of the planets but the highest priority experiments are related to particles and fields.
3) Four sizes of payload are defined. The "minimum" payload consists of four particles and fields experiments and weighs about 20 lbs. The "small" payload, weighing approximately 50 lbs., consists of the four particles and fields experiments plus four planetary experiments. The "medium" payload

weighs about 140 lbs. and includes a television, and the "large" payload, weighing about 200 lbs., consists of 17 experiments including low- and high-resolution television and radar.

4) Spacecraft weights were computed for each of the four selected trajectories using the four payload sizes described above.

It is recommended that conceptual spacecraft designs be developed and that complete feasibility of the mission be verified.

2.2.17 Technical Memorandum M-17

"A Preliminary Study of Jupiter Atmospheric Missions"

J. E. Gilligan and D. L. Roberts

December 1968

This brief study was performed to identify the major problem areas associated with Jupiter atmospheric probe missions and to determine if it is worthwhile to perform a detailed mission study at this time.

Because the present knowledge of Jupiter is restricted to its basic physical parameters and the gross properties of its upper atmosphere, significant scientific objectives could be accomplished with an atmospheric probe. Possible mission modes, and the problems associated with each, are discussed for four mission phases: 1) the interplanetary transfer up to the sphere of influence of Jupiter, 2) the encounter phase up to the point of atmospheric entry, 3) the entry phase up to the point of entering the clouds, and 4) the measurement phase below the cloud tops. A typical minimum scientific payload is discussed and includes a mass spectrometer, chemical spot tests for molecular species, and pressure, temperature, and density guages. Its total weight is approximately 15 lbs and its power requirement, some 7 watts.

The following two recommendations are made as a result of the study:

1) that NASA promote basic scientific research in the area of hypervelocity atmospheric entry;
2) that a Phase 0 Mission Study of the encounter and measurement phases of a Jupiter atmospheric probe mission be performed.

2.3 This section consists of summaries of reports and technical memoranda dealing with objectives of advanced missions.

Page

2.3.1 P-1 Scientific Objectives of Deep Space Investigations - Jupiter 30

2.3.2 P-2 Scientific Objectives of Deep Space Investigations - The Satellites of Jupiter 31

2.3.3 P-3 Scientific Objectives of Deep Space Investigations - Comets 31

2.3.4 P-4 Scientific Objectives of Deep Space Investigations - Asteroids 32

2.3.5 P-5 Scientific Objectives of Deep Space Investigations - Interplanetary Space Beyond 1 AU 33

2.3.6 P-6 Scientific Objectives for Mercury Missions 33

2.3.7 P-7 Scientific Objectives of Deep Space Investigations - Venus 34

2.3.8 P-8 Scientific Objectives of Deep Space Investigations - Non-Ecliptic Regions 34

2.3.9 P-9 Compendium of Data on Some Periodic Comets 35

2.3.10 P-10 Critical Measurements on Early Missions to Jupiter 36

2.3.11 P-11 Scientific Objectives of Deep Space Investigations - Saturn, Uranus, Neptune, and Pluto 37

2.3.12 P-12 Regularities in the Solar System Pertaining to Its Origin and Evolution 38

2.3.13 P-13 Comparison Criteria for a Total Lunar Scientific Exploration Program Study 39

2.3.14 P-14 Analytical Methods and Observational Requirements for Interpretation of Asteroid Distributions 40

2.3.15 P-15 Analytical Techniques for the Investigation of Distributional Features of the Asteroids 41

2.3.16 P-16 Mission Requirements for Exobiological Measurements on Venus 41

2.3.17 P-17 A Geological Analysis for Lunar Exploration 42

2.3.18 P-18 Scientific Objectives of Deep Space Investigations: The Origin and Evolution of the Solar System 43

2.3.19 P-19 Scientific Objectives of Deep Space Investigations: Jupiter as an Object of Biological Interest 44

2.3.20 P-20 Suggested Measurement/Instrument Requirements for Lunar Orbiter Block III 45

2.3.21 P-21 Scientific Objectives for Total Planetary Exploration 46

2.3.22 P-22 Role of Ground-Based Observations in the Exploration of Venus 47

2.3.23 P-23 A Preliminary Evaluation of the Applicability of Surface Sampling to Mars Exploration 48

2.3.24 P-24 The Scientific Objectives for Venus Landers 49

2.3.25 P-25 Preliminary Study of Atmospheric Sample Return from Venus 50

2.3.1 Report No. P-1

"Scientific Objectives of Deep Space Investigations - Jupiter"

D. L. Roberts

March 1964

The theories of origin of Jupiter are discussed and are followed by a summary of the physical properties of Jupiter. The measurements that are proposed are (1) spectrometry and polarimetry of the Jovian atmosphere and, if possible, of the surface; (2) photography of the complex atmospheric appearance of Jupiter, including observations through holes in the cloud cover either at the poles or over the Red Spot; (3) magnetic field measurements throughout the mission and in the supposedly high-intensity field of Jupiter, which may extend to 1 AU from the surface; (4) temperature measurement using microwave techniques to measure temperatures under the cloud layer; (5) detection of plasma and particles in space and in the proposed intense radiation belts; and (6) measurement of interplanetary dust and, in particular, any dust cloud associated with Jupiter.

2.3.2 Report No. P-2

"Scientific Objectives of Deep Space Investigations - The Satellites of Jupiter"

D. L. Roberts

March 1964

The satellites of Jupiter are arranged in three distinct groups, the outermost group having retrogarde motion. The origins of the three groups are discussed and are followed by a summary of the known physical properties of the satellites. The majority of the available data is restricted to the four largest satellites that are in the group closest to Jupiter. The basic measurements suggested are (1) visual measurements using photography or television, (2) spectrometry and polarimetry to provide data on the gross nature of the surface, (3) magnetic field measurements in interplanetary space, in the Jovian field, and, if possible, in any local satellite magnetic field, (4) micrometeorite and charged particle measurements, and (5) biological measurements.

2.3.3 Report No. P-3

"Scientific Objectives of Deep Space Investigations - Comets"

D. L. Roberts

March 1964

The aspects of comets dealt with are their origin and their structure. The measurements that are briefly considered from a space probe on approach to and within the coma and tail are (1) visual, using television to look at the nucleus in particular; (2) plasma and charged particle experiments; (3) micrometeorite and dust measurements; (4) magnetic field plotting; and (5) spectral measurements with mass spectrometry as the more important spectral measurement. The comets that are considered for interception are short period ones having perihelion passages in the next 10 to 15 years. A brief discussion is included on the use of artificial comets that can be released into earth orbit either as gases or as simulated ice nuclei.

2.3.4 Report No. P-4

"Scientific Objectives of Deep Space Investigations - Asteroids"

D. L. Roberts

March 1964

More than 1,500 separate asteroids of magnitude down to 18 have been detected and cataloged in the literature showing an average eccentricity of 0.15 and an average inclination of 10°. The origin of the asteroids is discussed in general terms, as is the connection between the asteroids and meteorites. The physical properties of the asteroids are given, but the limited amount of data that exists applies mainly to the four largest asteroids, Ceres, Pallas, Juno, and Vesta.

2.3.5 Report No. P-5

"Scientific Objectives of Deep Space Investigations - Interplanetary Space Beyond 1 AU"

D. L. Roberts

March 1964

Aspects dealt with are the solar wind, the interplanetary magnetic field, cosmic rays, and the distribution of interplanetary matter. The primary concern has been to describe what is and what is not known about the interplanetary medium, and to point out what further information is urgently needed and can be obtained from space probes.

2.3.6 Report No. P-6

"Scientific Objectives for Mercury Missions"

T. Owen

April 1964

Work in the following areas is summarized: (1) solid-state device design; (2) materials research; (3) band structure and spectroscopy of solids; (4) spectroscopy of magnetic solids; (5) transition-metal and rare-earth compounds; and (6) optics and infrared.

2.3.7 Report No. P-7

"Scientific Objectives of Deep Space Investigations - Venus"

P. J. Dickerman

June 1966

The Venusian astronomical and orbital characteristics are summarized, and available physical and environmental data are reviewed in relation to developing models for the planetary environment. The methods and types of instrumentation used for the various measurements are discussed, and the relative advantages of each are weighted. These include visual and photographic observations, photometry, polarimetry, spectroscopy, infrared radiometry, microwave radiometry, radar reflectivity, and magnetometry. The way in which these data can be used to construct models for the planetary environment and interior is described, and several examples are given. Basic scientific questions which missions to the planet should answer are listed, and a set of measurements based on these questions is suggested.

2.3.8 Report No. P-8

"Scientific Objectives of Deep Space Investigations - Non-Ecliptic Regions"

D. L. Roberts

September 1964

Scientific objectives for deep space investigations of non-ecliptic regions consist mainly of determining the characteristics and of obtaining an understanding of the cause and variation of (1) the solar wind; (2) the solar magnetic field; (3) solar and galactic cosmic rays; (4) interplanetary matter, and (5) solar electromagnetic radiation.

Not enough data are available to describe the basic configuration of particles and fields in interplanetary space, especially in the non-ecliptic regions. For this reason the early non-ecliptic missions will be largely exploratory in nature. The mission suggested for the first stage of the exploration [illegible] a minimum energy trajectory to a heliocentric latitude of about 20° and to heliocentric distances between 0.75 and 1.2 AU.

2.3.9 Report No. P-9

"Compendium of Data on Some Periodic Comets"
D. L. Roberts
July 1964

This compendium of data presents ordered information on all periodic comets already observed twice and expected to pass perihelion within the next 25 years. In addition to the retrospective data, also included are predictions of the future dates of perihelion, within the time period considered and based on detailed perturbation calculations. The periodic comet of outstanding scientific interest is Halley's comet, due to return in 1986. A valuable experiment will be to send a probe through the coma and tail of Halley's comet and to pass as near the nucleus as possible. Due to its long orbital period and the potential scientific value of an intercept with Halley's comet, launching some comet probes before 1986 is advisable so that the experimental techniques can be evaluated and perfected; suitable comets are listed.

2.3.10 Report No. P-10

"Critical Measurements on Early Missions to Jupiter"

J. Witting, M. W. P. Cann, and T. Owen

December 1965

Existing knowledge of Jupiter's magnetosphere, ionosphere, atmosphere, and interior is summarized and critical measurements which can be made from fly-by missions to Jupiter are indicated. Estimates place Jupiter's surface magnetic field strength at about 10 gauss, indicating the presence of radiation belts with 1000 times greater particle densities than those of Earth. The presence of an ionosphere was deduced theoretically, assuming a model atmosphere. Spectral analyses of Jupiter's atmosphere established the presence of hydrogen, methane, and ammonia. Temperature measurements at various wavelengths showed a fluctuation from 125°K to 200°K in the wavelength range 8μ to 3 cm, indicating that the thermal emission at different wavelengths comes from different depths of the Jovian atmosphere. Model studies of Jupiter's interior indicated the possible presence of metallic hydrogen and a high density core near the center of the planet. Several parameter measurements of the Jovian magnetosphere or atmosphere at future fly-by missions are suggested.

2.3.11 Report No. P-11

"Scientific Objectives of Deep Space Investigations - Saturn, Uranus, Neptune, and Pluto"

P. J. Dickerman

January 1966

A study was made of scientific objectives for the four outermost planets: Saturn, Uranus, Neptune, and Pluto. Differences between these planets and planets nearer the sun are shown in a general survey of their structure and composition, and in detailed discussions of the individual bodies. Descriptions of the atmospheres are given, primarily with the aid of spectroscopic and radiometric observations, and better known characteristics are tabulated. Reasons for making probes to these planets are given, and proposed measurements are discussed. These include magnetic field determinations throughout the mission and in the region of the planets; spectrometry and polarimetry of the planetary atmospheres; microwave radiometry and radar probing; charged particle detection in trapped radiation belts; optical occultation experiments for Saturn's ring system and atmospheric studies; rf occultation experiments for atmospheric density determinations; and photography of cloud structure and surface features.

2.3.12 Technical Memorandum P-12

"Regularities in the Solar System Pertaining to Its Origin and Evolution"

J. Witting

January 1966

Regularities in the solar system are studied to determine whether they lead to boundary conditions for the origin and evolution of the solar system.

Observations of nearby stars have indicated that planetary systems are probably quite common so that the assumption of the occurrence of an unusual event for planetary formation, as suggested in some older theories for origin of the solar system, is unwarranted.

The low inclinations and eccentricities of the planets and asteroids are probably a boundary condition for the origin of the solar system.

Gross physical properties which divide the planets into terrestial and Jovian are felt to be boundary conditions for the evolution of the solar system.

Properties which could be boundary conditions for either the origin or the evolution of the solar system are:

1. The similarity in rotation periods of the planets from Earth to Neptune.
2. The mass gap in the solar system between 1.3 and 4.0 AU.
3. The Titus-Bode law.

2.3.13 Technical Memorandum P-13

"Comparison Criteria for a Total Lunar Scientific Exploration Program Study"

C. A. Stone

February 1966

Criteria for the review and analysis of lunar exploration programs are presented. Scientific criteria are discussed in terms of their priority, clear definition, complementarity,and success probability. Spacecraft criteria are discussed in terms of universal definitions of system and subsystem configurations. Operational criteria are discussed in terms of scheduling, cost reliability,and the role of safety of man.

Four basic ground rules for applying the criteria are suggested:

1. A decision must be made whether to include or exclude ground support costs.
2. The allocation of payload fractions and fractional costs must be standardized for those missions with a multiplicity of goals.
3. A uniform method of predicting costs must be established.
4. A basic method of predicting and applying advances in technology must be developed.

2.3.14 Report No. P-14

"Analytical Methods and Observational Requirements for Interpretations of Asteroid Distributions"

J. Ash

June 1966

Questions are raised whether ordering mechanisms exist capable of arranging the asteroids in some identifiable distribution, or whether the asteroidal material is more or less randomly distributed throughout an essentially toroidal ring extending from Mars to Jupiter. The conclusion is reached that the planets, in particular Jupiter, exert small perturbing forces which over long periods of time produce distinctive distributional features. These features are deterministic, and through suitable interpretation, the mechanical history of solar system events may possibly be traced back through time and contribute to the understanding of the solar system origins. The deeper understanding of distributional features can also be of value for the prediction of possible hazards to interplanetary space missions. General methods of analysis for the interpretation of asteroid observational data are outlined, and further observations to extend and support existing hypotheses and theoretical approaches are recommended.

2.3.15 Report No. P-15

"Analytical Techniques for the Investigation
of Distributional Features of the Asteroids"

J. Ash

January 1967

This report examines the more important existing analytical methods of determining the distributional features of the asteroids as well as suggesting a new method.

The existing methods which are discussed critically are statistical analyses based upon empirical and heuristic distribution hypotheses and methods relying upon perturbation theory from classical celestial mechanics.

The new method suggested for computation of expected lifetimes of asteroid fragments is based upon ergodic theory. This method should provide a number-frequency plot of the asteroids versus lifetimes. Clustering of asteroids at distinct points will provide a criterion for distinguishing groups with probable common origins. In addition to providing a basis for the formation of dynamically significant groups, this method could yield a direct estimate of the group age.

2.3.16 Report No. P-16

"Mission Requirements for Exobiological
Measurements on Venus"

W. Riesen and D. L. Roberts

June 1966

As the initial biological exploration of Mars and Venus will be based largely on the knowledge and experience gained with terrestrial life forms, these data are briefly reviewed. A possible evolutionary sequence, expressed in terms of chemical and biological constituents in the Earth's environment, is tabulated. Two major considerations in determining the possible existence of life on Venus are identified: the ability of the present Venusian environment to support life; and the plausibility of life, of a terrestrial or nonterrestrial type, originating, becoming established, and evolving. The environmental parameters on Venus are listed and compared with the conditions under which life exists on Earth. The biological measurements which should be made in the early exploration of Venus are discussed; these include entry probes for detecting organic compounds and life forms, and atmospheric probes which can remain at given altitudes for several days. Among the conclusions drawn are: (1) Life could survive on Venus probably in localized biotic zones. (2) Venus should be treated as a biological preserve.

2.3.17 Technical Memorandum P-17
"A Geological Analysis for Lunar Exploration"
W. Scoggins
August 1966

A systematic plan of lunar exploration is defined. The plan is based upon satisfying the following three scientific objectives for lunar exploration suggested by the Space

Science Board: 1) to determine the structure and processes of the lunar interior; 2) to determine the composition, structure, and processes of the lunar surface; and, 3) to determine the history of the moon.

First, the three objectives are rephrased and expanded into a set of 21 questions which can be answered by making specific measurements.

Twenty measurement techniques are considered. They are ranked in order of importance according to how many of the 21 questions they can answer. Sample return ranks first, providing information on 11 questions. Medium and high resolution photography and surface geological mapping rank second answering 8 questions each.

This priority list of measurement techniques, together with information on the weight, power, and volume of the experiments is used to define a mission plan for lunar exploration.

2.3.18 Report No. P-18

"Scientific Objectives of Deep Space Investigations: The Origin and Evolution of the Solar System"

J. Witting

September 1966

One of the primary goals of the space program is understanding the origin and evolution of the solar system. In this study spacecraft measurements and other future work which contribute to this goal have been isolated.

The study is subdivided into the following three areas:

(1) Present day observations, theories, and experiments which are thought to be boundary conditions on the origin and evolution of the solar system, i.e., facts which must be explained by any complete theory.

(2) A broad sampling and critique of the more prominent theories which have been derived to explain the origin and evolution of the solar system.

(3) Future work and experimentation which is necessary to advance our understanding, either by distinguishing among proposed theories, or existing boundary conditions.

2.3.19 Report No. P-19

"Scientific Objectives of Deep Space Investigations: Jupiter as an Object of Biological Interest"

ASC Staff

May 1967

The following topics are discussed: the Jovian environment; some of the biological systems that could conceivably evolve under such conditions; ideas about the origin of terrestrial life; the importance of Jupiter from a biological point of view; and the effect of this information on the planning of conventional observations and spacecraft missions to the planets.

Jupiter has a highly reducing atmosphere. Relatively temperate regions, containing liquid water as clouds or seas may exist below the level of the clouds. In these regions, which cannot be observed from Earth or from flyby or orbiting spacecraft, primitive life could conceivably exist. For this reason, both survivable and nonsurvivable atmospheric probes may be required to explore the really interesting regions of the planet from a biological viewpoint.

However, additional ground-based or near-Earth observations to obtain information about the presence of organic molecules, water, and temperature regimes at the various atmospheric levels is important in order to supplement the existing data on the planet. Such data could be refined later by spacecraft flyby and orbiter missions.

2.3.20 Report No. P-20

"Suggested Measurement/Instrument Requirements for Lunar Orbiter Block III"

W. Scoggins and D. L. Roberts

May 1967

Measurement and instrument requirements for Lunar Orbiter Block III type missions are suggested for the exploration of the moon. Measurement parameters are designated. These were derived by subdividing, restating, and interpreting the fifteen lunar questions presented by the Space Science Board. Thirty restated questions are presented in terms of measurable quantities. Specifications are provided for 13 instruments which will satisfy the derived orbital measurement requirements.

2.3.21 Technical Memorandum P-21

"Scientific Objectives for Total Planetary Exploration"

ASC Staff

May 1967

This study provdies a first order method of ordering the objectives of total solar system exploration and of indicating the relative importance of the solar system targets in answering the objectives. It is presented as a possible way of arriving at a total exploration priority system.

The overall goals of space exploration as stated by the Space Science Board have been taken as the starting point. Each goal has been successively expanded into subgoals, gross characteristics of subgoals, scientific objectives, and, finally,measurable quantities. For each scientific objective, and its related measurable quantities, the importance of each solar system target has been indicated using a 4 symbol rating (I, II, III, IV). These assignments are made on the basis of the contribution of the target to the objective and the contribution of the objective to the overall goals of exploration.

The results of the study indicate that the scientific exploration of Mars, Venus, and Jupiter are about equally important and that they extend some way ahead of the other targets. In terms of scientific objectives, the exobiological ones rank uniformly high.

2.3.22 Technical Memorandum P-22

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

J. T. Dockery

July 1967

This report discusses the role of ground-based observations in experiment selection or in spacecraft design for the following types of missions to Venus: flyby, orbiter, non-surviving probe, buoyant station, hard and soft landers, and surface roving vehicles. Ground-based observations have been taken to include all near-Earth observing stations such as observatories, sounding rockets, balloons, and Earth orbiting spacecraft. Ground-based equipment is grouped into three categories: optical, radio, and radar and these may have platforms on the ground, at intermediate altitudes, and at near-Earth orbital altitudes.

The report is divided into five sections as follows:

(1) a summary of ground-based observation techniques;

(2) ways in which ground-based observations will or will not aid mission planning, with a summary of those support measurements which can be supplied entirely or in part by ground-based observations;

(3) existing, commissioned,or projected ground-based observation equipment and the capabilities and limitations of such equipment;

(4) recommendations for ground-based observations of Venus;

(5) a sample observing program.

2.3.23 Report No. P-23

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

W. Scoggins and D. L. Roberts

May 1968

The purpose of this report is to identify the value of sampling as an investigation technique at Mars, to define the constraints imposed upon sampling by the scientific objectives for Martian exploration and to assess the value of samples taken from a single landing site.

Five categories of overall scientific objectives are considered for Mars. The objectives are broken down into 110 attributes, identifying properties of the planet which must be measured to satisfy the objectives. The measurement techniques which could be applied to the attributes include surface sampling, remote sensing, photographic mapping, topographic mapping, surface geophysical sensing, atmospheric sampling,and surface geological mapping. The usefulness of sampling is evaluated in view of all the measurement techniques applicable to satisfying any given attribute.

2.3.24 Report No. P-24

"The Scientific Objectives for Venus Landers"

J. E. Gilligan

September 1968

The scientific objectives of lander missions to Venus have been selected from a list of scientific objectives for exploring the entire solar system by considering those objectives which apply to Venus as a planet and to lander type missions in particular. No account has been taken of the difficulty of fulfilling an objective. The application of constraints due to measurement or instrument problems has been left for later study.

The ten specific scientific objectives of Venus lander missions, listed in approximate order of importance are to determine:

(1) the abundance of water;

(2) the amount of free and combined CO_2 in the surface;

(3) the composition of surface materials;

(4) the thermal radiation intensity spectrum on the dark and bright sides of the planet;

(5) the isotopic abundance of key isotopes and their ratios;

(6) the existence of and fluctuations in the magnetic field;

(7) the abundance of radioactive heat sources;

(8) the planet's age;

(9) the stratigraphic column;

(10) the seismic activity of the planet.

2.3.25 Technical Memorandum P-25

"Preliminary Study of Atmospheric Sample
Return from Venus"

J. Woodman

September 1968

This study evaluates the usefulness of atmospheric sampling in providing answers to the current scientific objectives for Venus. The overall objectives of exploration of Venus are presented and the "observables" related to each objective are delineated. Next, the applicability of a range of mission modes to the measurement of each of the observables is assessed. The mission modes considered are 1) flybys, 2) orbiters, 3) atmospheric probes, 4) atmospheric samplers, and 5) landers. It is found that sampling applies only to a limited number of objectives, mainly related to atmospheric composition and the search for life,and that atmospheric sampling does not offer a significant advantage over other mission modes in any case. For this reason a detailed mission analysis of Venus atmospheric sample return missions is not called for at this time. However, as new data on the atmosphere and surface of Venus become available over the next few years, it will be possible to reassess the objectives for the next order of investigation. It is probable that at that time the relative value of sampling will be much greater because the questions to be answered will be more sophisticated. At that time the value of atmospheric sample return missions should be reviewed.

2.4 This section consists of a technical memorandum, R-1, and a report, R-2, in the category of success probability determinations.

Page

2.4.1 R-1 Comparative Reliability Estimation Method for Mission Programming 53

2.4.2 R-2 Probability of Biological Contamination of Mars 54

2.4.1 Technical Memorandum R-1

"Comparative Reliability Estimation Method for Mission Programming"

H. Lauffenberger

March 1964

The process of evaluating the probability of success for a given spacecraft mission is usually one involving much detailed knowledge of the spacecraft's structure, from system organization to component specification. Such well defined information is rarely available at the initial stages of mission planning, when an overall feel for at least the relative reliability of different mission configurations would be welcome.

A method of meeting this latter requirement using only data at the system level is discussed, and later applied to the specific example of a 500-day Jupiter flyby. The relative decrease in success probability with flight time is shown, and those systems for which redundancy provides the greatest gains are pointed out. The assumptions and limitations involved in using this approach are discussed.

2.4.2 Report No. R-2

"Probability of Biological Contamination of Mars"

A. Ungar, R. Wheeler and D. L. Roberts

March 1966

In this study of the probability of biological contamination of Mars, the contamination model proposed by Sagan and Coleman has been reviewed and a separate IITRI contamination model has been generated.

The IITRI model is based upon a specific mission profile and for a defined number of missions. It is an alternative to the Sagan and Coleman model which considers a series of biological experiments which may continue until all the scientific questions have been satisfactorily answered. The mission profile assumed for the IITRI model is that of a proposed Voyager mission to Mars. A range of probabilities has been assigned to each event in the mission and an overall probability of contamination per mission has been derived parametrically. The probability of contamination per mission has been used to compute the overall probability for a series of N missions.

Also included is a sensitivity analysis of each of the parameters used in the formulation of the probability of contamination per mission.

2.5 This section consists of technical memoranda and reports in the area of spacecraft technology.

			Page
2.5.1	S-1	Study of Photographic and Spectrometric Subsystems for Voyager	56
2.5.2	S-2	Scientific Questions Requiring Advanced Technology: Asteroid Fly-Through Mission	56
2.5.3	S-3	Telemetry Communications Guideline	57
2.5.4	S-4	Thermophysical Effects and Feasibility of Jupiter Atmospheric Entry	58
2.5.5	S-5	Low-Thrust and Ballistic Payload Comparison for Jupiter Orbiter Missions	59
2.5.6	S-6	Deep Space Communications: Command Link and Atmospheric Probe Entry	60

2.5.1 Technical Memorandum S-1

"Study of Photographic and Spectrometric Subsystems for Voyager"

P.N. Slater and G. Johnson

June 1965

The first part of this study is an investigation of the quantity of photographic data with a specific resolution that could be transmitted to Earth during a Voyager mission lifetime. Constraints in selection of photographic systems include a range of values on the data transmission rate, a limit of 400 pounds to the weight of the optical systems and a maximum surface resolution of 3 meters.

The second part of the study determines the adaptability of four specific spectrometric experiments proposed for the 1966 and 1969 Mariner Missions to a Voyager-type orbit. It is found that all the instruments are suited to a Voyager-type orbit but it appears that the experiments do not benefit by reducing the altitude below 2000 kilometers.

2.5.2 Report No. S-2

"Scientific Questions Requiring Advanced Technology: Asteroid Fly-Through Mission"

J.A. Greenspan

April 1966

Technical areas are defined in which instrumentation and instrumental techniques can be used for satisfying the scientific requirements of an asteroid fly-through mission.

The particles of the asteroid belt were divided into five size ranges: sub-micron, micrometeorite (1μ to 100μ), sub-millimeter to 3-cm, 3-cm to 1-km, and greater than 1-km diameter. Scientific questions concerning the spatial distribution, structure, and composition of each size class were formulated. Existing and proposed experimental techniques were then examined for each class.

2.5.3 Report No. S-3

"Telemetry Communications Guideline"

M. Stein

August 1967

The information transfer capability of spacecraft telemetry communication systems is considered in order to provide general guidelines for the 1975 to 1980 space missions. Major limitations to a communication system are identified as the maximum available transmitter power, size and characteristics of the transmitting and receiving antennas, free space propagation loss, receiving system sensitivity, and modulation method. Transmission capabilities are estimated as a function of the distance of the spacecraft from earth, spacecraft transmitter power level, and sizes of spacecraft and ground antennas. Error coding techniques for improving the theoretical maximum data rate are discussed, which would be effective up to a factor of 6.5. A minimum weight configuration is given to indicate how a minimum total communications weight may be achieved. Transmission rate equations are derived, together with equations to determine the minimum transmitter system weight.

2.5.4 Report No. S-4

"Thermophysical Effects and Feasibility of Jupiter Atmospheric Entry"

J. E. Gilligan

June 1967

The objective of this study is to determine the thermodynamic feasibility of Jupiter atmospheric entry and to delineate the major technical problem areas.

Atmospheric entry velocities at Jupiter range from 48-60 km/sec. This implies at least an order of magnitude increase in the heat transfer magnitudes as compared to Earth and inner planet entries. A successful entry is considered to be an entry into the cloud tops under the conditions that the entry probe retain at least 10 percent of its initial mass and that its velocity be no more than 1 km/sec.

The results of the study show that only grazing entry trajectories are feasible. This is under conservative estimates of heat absorption, so it may be better to say that grazing entries are superior to either direct or angle entries.

The four major technological problem areas that need development before detailed entry studies can be made are:

1) planetary atmospheric composition and structure, especially helium abundance;

2) theoretical and experimental helium and hydrogen radiative data and laboratory helium and hydrogen thermodynamic and transport data;

3) comprehensive hypersonic heat transfer prediction schemes (for radiation-dominated flow fields);

4) ablator materials performance.

2.5.5 Technical Memorandum S-5

"Low-Thrust and Ballistic Payload Comparison for Jupiter Orbiter Missions"

D. Healy and D.L. Roberts

May 1967

The purpose of this study was to compare the mission effectiveness of a nuclear electric orbiter at Jupiter with a ballistic Voyager type orbiter. In terms of the study constraints it became apparent that there were no general criteria which could be used to compare low-thrust and ballistic payloads and further that there does not appear to be a need for a payload greatly in excess of the Voyager-type capability for early Jupiter orbiter missions unless atmospheric probes or landers are included. Only unmanned missions were considered.

2.5.6 Technical Memorandum S-6

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

M. S. Stein and D. L. Roberts

August 1967

Two communication problem areas are discussed, namely the Earth-to-spacecraft command link for outer planet missions and the telemetry link between outer planet atmospheric probes and orbiting or flyby spacecraft. These are only problems in terms of present operational techniques. The command of spacecraft at distances as far as 30AU is possible especially if command coding techniques are used which will ensure correct spacecraft interpretation. The transmission time delays to outer planet spacecraft may require that every command be sent only once. In that 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 Earth, Mars,and Venus. The entry velocities are 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 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 can probably be obtained from advanced technological developments in communication through ion sheath blackouts and in laser communication systems.

2.6 This section consists of summaries of reports and technical memoranda in general trajectory studies.

Page

2.6.1 T-4R Summary of One Way Ballistic Trajectory Data: Earth to Solar System Targets 63

2.6.2 T-5 Accuracy and Capabilities of ASC/IITRI Conic Section Trajectory System 64

2.6.3 T-6 Accessible Regions Method of Energy and Flight Time Analysis for One-Way Ballistic Interplanetary Missions 64

2.6.4 T-7 Perturbations, Sighting, and Trajectory Analysis for Periodic Comets: 1965-1975 65

2.6.5 T-8 Comparison of Atlas Centaur and Floxed Atlas Centaus Capabilities in Interplanetary Explorations Using the Accessible Regions Method 66

2.6.6 T-9 Spatial Distribution of the Known Asteroids 67

2.6.7 T-10 Collected Launch Vehicle Curves 68

2.6.8 T-11 Sighting and Trajectory Analysis for Periodic Comets: 1975-1986 69

2.6.9 T-12 Analysis of Gravity Assisted Trajectories in the Ecliptic Plane 70

2.6.10 T-13 Trajectory and Sighting Analysis for First Apparition Comets 71

2.6.11 T-14 Low-Thrust Trajectory and Payload Analysis for Solar System Exploration Utilizing the Accessible Regions Method 72

2.6.12 T-15 Mission Requirements for the Unmanned Exploration of the Solar System 73

2.6.13 T-16 Selection of Comet Missions: 1965-1986 74

2.6.14 T-17 Low-Thrust Trajectory Capabilities for Exploration of the Solar System 76

2.6.15 T-18 The Accessible Regions Presentation of Gravity Assisted Trajectories Using Jupiter 77

2.6.16 T-19 On the Problem of Comet Orbit Determination for Spacecraft Intercept Missions 78

2.6.17 T-20 Trajectory Opportunities to the Outer Planets for the Period 1975-2000 79

2.6.1 Report No. T-4R

"Summary of One Way Ballistic Trajectory Data:
Earth to Solar System Targets"

F. Narin and P. Pierce

April 1964

A survey of one-way ballistic trajectories (conic sections, impulsive thrusting, one gravitating body at a time) to major targets and positions within the solar system was made using the ASC/IITRI conic section trajectory system on the IBM-7090 computer. Comparison of energy requirements for flights to a wide variety of places within the solar system may be made using the survey. Curves are presented for ideal velocity (ΔV) and hyperbolic excess speed at the target (VHP) for flights to all the planets. Curves of ΔV for flights from Earth to distances of 0.01 AU to 100 AU in the ecliptic plane are presented. Four curves are given for flights out of the ecliptic plane to distances of 0.3 to 5.0 AU from the Sun. A curve is presented of the key parameters for minimum energy flights to all angles out of the ecliptic plane. Curves and tables of the velocity increments (DV) required to put approaching spacecraft into near planet orbits are presented for all the planets.

2.6.2 Report No. T-5

"Accuracy and Capabilities of ASC/IITRI Conic
Section Trajectory System"

P. Pierce and F. Narin

April 1964

This report discusses the accuracy and capabilities of the system and some of the studies that have been performed with it. It shows that the planetary, asteroid, and comet orbital elements are adequate for conic section trajectory studies. Transitions are shown to be smooth for elliptical to parabolic to hyperbolic trajectories. A complex launch hyperbolic excess speed vs date of launch curve for 100-day flights to asteroid Eros is explained in detail to illustrate the physical meaning behind the somewhat complex energy requirements of interplanetary flight. The options available in the ASC/IITRI system for flights to points anywhere in the solar system are outlined. An annotated listing of programs and subroutines is included.

2.6.3 Report No. T-6

"Accessible Regions Method of Energy and Flight
Time Analysis for One-Way Ballistic Interplanetary
Missions"

F. Narin

June 1964

The accessible regions method plots contours of ideal velocity in a plane P_N normal to the ecliptic plane and intersecting it at the Sun. This is a side view of the solar system. For any point in P_N there is some minimum energy required to place a given payload at that point; by determining this energy for enough points it is possible to construct contours of minimum ideal velocity to reach any point in P_N. These contours are equivalent to constructing contours that show the minimum ideal velocity required to reach any point in the solar system. It is also possible to construct variations of the minimum ideal velocity contours; these contours show the effects of constraints, such as time of flight, on the regions accessible to a launch vehicle.

2.6.4 Report No. T-7

"Perturbations, Sighting and Trajectory Analysis for Periodic Comets: 1965-1975

F. Narin and P. Pierce

October 1964

Possible intercept missions to the well known short period comets in the years 1965-1975 have been analyzed, to delineate those of potential interest in long range planning. A total of 36 well known comets having 55 perihelia in the period 1965 to 1975 were considered, plus Halley's comet with its perihelion in 1986. Detailed perturbation calculations were performed to determine the positions and perihelion dates of the 37 comets moving under the influence of gravitational fields of the Sun and planets. Ballistic trajectories to the comets were then calculated to determine ideal velocity, time of flight, closing velocity and communications distance as a function of launch date. Sighting calculations were performed to determine the expected brightness of the comets and the number of hours the comet might be visible in the night sky.

2.6.5 Technical Memorandum T-8

"Comparison of Atlas Centaur and Floxed Atlas Centaur Capabilities in Interplanetary Explorations Using the Accessible Regions Method"

F. Narin

November 1964

The accessible regions method has been employed to indicate which regions of the solar system are accessible to Atlas Centaur and 30% Floxed Atlas Centaur vehicles, with and without L.E. (Low Energy, I_{SP} = 300 sec) and H/F (Hydrogen/Fluorine, I_{SP} = 455 sec) upper stages. Payloads of 300, 1000 and 2000 pounds were considered. In addition the Atlas Centaur, Floxed Atlas Centaur and Titan III-C were compared.

It is shown that, for payloads of 300 and 1000 pounds, the presence or absence of upper stages is the controlling factor in determining interplanetary exploration capability. Specifically, for 300 and 1000 pound payloads, the following pairs of vehicles have similar capabilities for interplanetary exploration: Atlas Centaur and Floxed Atlas Centaur: Atlas Centaur and Floxed Atlas Centaur, both with L.E. upper stages; Atlas Centaur and Floxed Atlas Centaur both with H/F upper stages.

With 2000 lb. payloads the two vehicles with H/F upper stages are similar in capability; a next pair of vehicles with more limited capability is the Floxed Atlas Centaurs with and without L.E. stages; and a third pair of vehicles with quite limited capability is the Atlas Centaurs with or without L.E. stages. Thus, at the 2000 lb. payload level, the floxing of an Atlas Centaur adds more capability than adding an L.E. stage. This is not true at the 300 or 1000 lb. payload levels.

2.6.6 Report No. T-9
"Spatial Distribution of the Known Asteroids"
F. Narin
June 1965

The positions of 1563 numbered asteroids and 445 unnumbered asteroids were analyzed for the 1950 to 1995 time period to determine whether at any given time there are significant nonuniformities in the spatial distribution of the asteroids. The total number of asteroid position-time points used was 135,000. The primary conclusions of the study are:

1) The numbered asteroid distribution shows clusters in heliocentric longitude both because of the limited number of asteroids studied (random events cluster) and because the asteroids are not quite homogeneous within the belt.

2) The numbered asteroid distribution in heliocentric latitude peaks below the ecliptic plane at a latitude of -0.1 ± 0.03 degrees.

3) The numbered asteroid distribution peaks at slightly below 3.0 AU in the distance from the Sun, the average being 2.8 AU.

4) The unnumbered asteroids exhibit the same phenomena as the numbered asteroids.

5) Since there is a statistical clustering of the known asteroids, the proper choice of trajectories could alter the chance of encounters with the known asteroids by as much as ± 30 percent.

2.6.7 Technical Memorandum T-10

"Collected Launch Vehicle Curves"

F. Narin

December 1964

This memorandum consists of a collection of performance curves for launch vehicles. The basic vehicle performance curves which were obtained from NASA Headquarters show payload vs. vehicle velocity, where the velocity is given as the ratio of characteristic to escape velocity, V_c/V_e. The ratio V_c/V_e was converted to ideal velocity, ΔV, using the formula

$$\Delta V = (V_c/V_e) \times 36{,}178 + 4{,}000.$$

Then vehicle performance curves showing payload vs. ideal velocity were constructed for all the given launch vehicles. Except where indicated, a 100 nautical mile parking orbit is assumed. A total of the 46 vehicle performance curves are shown in ten figures.

2.6.8 Report No. T-11

"Sighting and Trajectory Analysis for Periodic Comets: 1975-1986"

F. Narin and B. Rejzer

March 1965

Possible intercept missions to 55 apparitions of 36 well known short-period comets have been analyzed, to delineate those of potential interest in long range planning. Detailed perturbation calculations have been performed to determine the positions and perihelion dates for these apparitions. Ballistic trajectories to the comets were calculated to determine ideal velocity, flight time, closing velocity, and communication distance as a function of launch date. Sighting calculations were performed to determine the expected brightness of the comets and the number of hours the comet might be visible in the night sky. The 55 apparitions were then divided into three classes depending upon whether they were missions of primary, secondary, or low interest. In order to be considered of primary or secondary interest a comet had to 1) be visible and at least as bright as magnitude 12 at intercept and 2) be recoverable two months before launch. The three opportunities of primary interest are a 1976 mission to D'Arrest, a 1983 mission to Kopff, and a 1986 mission to Halley.

2.6.9 Report No. T-12

"Analysis of Gravity Assisted Trajectories
in the Ecliptic Plane"

J.C. Niehoff

June 1965

A parametric trajectory study of gravity assisted Earth launched trajectories has been conducted. A two-dimensional solar system with circular planetary orbits (except Mercury) is assumed. Gravity assist is restricted to one body between launch and target intercept. Analytical expressions and results are presented for maximum velocity and energy changes available to a spacecraft through gravity assist. A review of the Earth-Venus-Mercury mission is considered after which primary emphasis is placed upon Jupiter, both as a target and as a gravity assisting body. Jupiter fly-bys are found to be attractive for solar probe missions and flights to the outer planets. Included in the results of the study are several examples of launch opportunities for gravity assisted trajectories.

2.6.10 Report No. T-13

"Trajectory and Sighting Analysis for First Apparition Comets"

P. Pierce

June 1965

The feasibility of sending a probe to a long-period first-apparition comet as a complement to short-period comet missions is discussed. A statistical analysis was performed. Fifty four long-period, first apparition comets sighted between 1945 and 1960 were chosen as a sample. The sample was checked by means of the chi-square χ^2 comparison with 378 similar comets sighted prior to 1945 to determine if the 54 were sufficiently representative. The results indicate significant differences between the two samples, which appear to be attributable to improvement in observational techniques and instruments in recent years. Calculation of ballistic trajectories to each of the 54 comets resulted in the ideal velocity and associated flight parameters for a range of launch dates. The comets were assumed to be discovered at three levels of brightness, and it was concluded that the approach or discovery at magnitude 15 offers enough opportunities so that a mission can be reasonably planned if a moderate search program is initiated.

2.6.11 Report No. T-14

"Low-Thrust Trajectory and Payload Analysis
for Solar System Exploration Utilizing the
Accessible Regions Method"

A. Friedlander

July 1965

A simple and graphic means, called the accessible regions method, of delineating generalized trajectory energy requirements for solar system exploration is described. The method also provides a convenient graphic assessment of payload capabilities by relating the requirements to specific vehicle systems. The utilization of the accessible regions method to low-thrust fly-by missions throughout the solar system is discussed. By analogy to the ΔV associated with ballistic flight, the time integral of thrust acceleration squared, J, is used to link trajectory energy requirements and vehicle system characteristics for low-thrust flight. Several diagrams showing thrust and variable thrust J contours and payload contours for flight times of various periods to the various planets in the solar system are depicted.

2.6.12 Technical Memorandum T-15

"Mission Requirements for Unmanned Exploration of the Solar System"

F. Narin

May 1965

The accessible regions concept provides a simple and graphical means of delineating the fundamental mission parameters for the exploration of the solar system. The energy and flight time requirements for flights in the three-dimensional solar system are shown as two-dimensional contours by always assuming the Earth to be at an optimum longitude, that is, one corresponding to minimum energy for a specified interplanetary flight. Typical contours for ballistic interplanetary flight show ideal velocity ΔV and flight time TF, and are presented here on a 10 AU scale. These contours can be used as reference data for ballistic interplanetary flight, for characterizing the difficulty or ease of various missions, and for comparing different vehicles. Analogous generalized contours of "J" for low thrust missions are also presented. Through the vehicle performance curves, these contours are related to vehicle payload. They are used in this paper to:

1) compare thrusted and ballistic modes of flight to different regions of the solar system,

2) compare floxing Atlas Centaurs with added stages on the same vehicle, and

3) compare a Saturn 1B-Centaur with an Atlas-Centaur and with a Saturn 1B-(low-thrust) - Space Cruiser.

For the Atlas-Centaur vehicles at 1000 pounds payload it is shown that the addition of extra stages adds more capability than floxing. For the Saturn 1B it is shown that at 1000 pounds payload, the advantages of the space cruiser stage over the Centaur stage are particularly marked at specific masses α for the power planet of 30 lbs/kw or less. In general, it is shown that the regions of the solar system near the Sun, at a large distance from the Sun, and far out of the ecliptic plane are more fitted for exploration with thrusted than with ballistic vehicles; this conclusion, however, could be somewhat altered by the consideration of gravity assisted ballistic flights.

2.6.13 Technical Memorandum T-16
"Selection of Comet Missions: 1965-1986"
F. Narin, P. M. Pierce, and D. L. Roberts
September 1965

The selection of missions to both short period, well known comets, and long period, first apparition (new) comets, was considered for the time period 1965-1986. Short period comet missions are easier in the sense that one can plan for them in advance. However, only a few of the well known short period comets are bright enough to be of interest for a mission. On the other hand the long period comets are more active and, on the average, 3 magnitudes brighter than short period comets. Potentially there are many opportunities for good missions to new comets. However, a selection of new comet missions is complicated since there is no prior knowledge of when the probe can be launched, and because there is not yet a systematic comet discovery program.

The following selection criteria were imposed for the short period comet missions:

1. Two recent passes observed
2. Brighter than magnitude 12 at intercept
3. Recovery two months before launch of spacecraft
4. Recovery magnitude brighter than 20, with two hours visibility in a dark sky
5. Energy requirements less than those for a two year Jupiter mission.

Of 37 comets considered with 110 apparitions between 2/65 and 1/86, 93 were eliminated on brightness-energy considerations, leaving 17 possible missions. Of these 5 were selected missions and 12 were considered to be of secondary interest. The 5 selected missions were Temple 2, 1967; Encke, 1974, D'Arrest, 1976; Kopff, 1983; Halley, 1986.

To assess the feasibility of new comet missions all of the new comets which were discovered between 1945-1960 were analyzed to find which ones would have made interesting targets. Of the 54 ne long period comets discovered, only 2 would have made suitable targets after discovery using the same brightness energy criteria as used for short period comets. However, if all of the new comets were discovered at magnitude 15 by a comet search program, 10 missions or one every 1.5 years would have been possible. From this it may be concluded that missions to new, long period comets should be possible if a systematic comet search program were initiated.

2.6.14 Report No. T-17

"Low-Thrust Trajectory Capabilities for Exploration of the Solar System"

A. Friedlander

June 1966

This report presents the trajectory energy requirements for low-thrust (electric propulsion) flight throughout the solar system, first for the general class of flyby missions to points in and above the ecliptic

plane, and then for flyby, capture, and orbiter missions to the planets Mercury through Pluto. The trajectory energy requirements are described in terms of the parameter "J" — defined as the time integral of thrust acceleration squared. Application of these results is for the most part limited to electric propulsion systems operating at constant power, i.e., nuclear-electric systems. Results for the general class of flyby missions are presented as accessible regions contours of J and flight time. Results for the planetary missions are presented as graphs of J vs flight time. The payload/flight time capabilities of two conceptual nuclear-electric spacecraft designs are illustrated in terms of the accessible regions graph and summarized for each of the planetary missions.

2.6.15 Report No. T-18

"The Accessible Regions Presentation of Gravity Assisted Trajectories Using Jupiter"

D. A. Klopp and J. C. Niehoff

June 1967

The regions of the solar system accessible to a spacecraft launched from Earth into a trajectory incorporating a Jupiter gravity-assist maneuver are delineated. These regions of accessibility are presented on a heliocentric latitude-radius plane, normal to the ecliptic plane, with launch energy and time of flight as parameters. Out-of-ecliptic as well as planetary mission capability is emphasized. The results show that a spacecraft, launched from Earth with an energy just sufficient to reach Jupiter, can explore the solar system beyond Pluto if the Jupiter gravity-assist technique is used. Comparisons are made with the solar system exploration capabilities of spacecraft using direct ballistic flight trajectories. A specific comparison of ballistic, Jupiter gravity-assisted, and nuclear low thrust flight modes is given. The method of analysis and a computer program are discussed.

2.6.16 Report No. T-19

"On the Problem of Comet Orbit Determination for Spacecraft Intercept Missions"

A. Friedlander

May 1967

Optimal linear estimation theory is applied to the problem of determination and prediction of cometary motion and, in particular, to the short period comets, Encke and D'Arrest. The numerical study of cometary motion is facilitated by a high precision Orbit Determination Program developed for use on the IBM 7094 computer. The computer program is basically an N-body trajectory integration code which includes the gravitational perturbation effects of all the solar system planets and also non-gravitational or secular perturbations unique to the nature of comets themselves. Past observations of comet Encke are obtained for 7 appearances over the period 1931-1961 with no less than 3 observations in each appearance. Results of data fitting show strong evidence of a secular acceleration of mean motion. The average effect over the interval studied causes a decrease in the orbital period of about -0.02 day/orbit. In the case of a 1974 mission to Encke and a 1976 mission to D'Arrest, it is shown that miss distances under 10,000 km cannot be achieved unless the comets are observed in the year of launch.

2.6.17 Report No. T-20

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

B. Rejzer

December 1967

Minimum energy trajectory data to the planets Jupiter, Saturn, Uranus, Neptune and Pluto are presented for each launch opportunity in the period 1975-2000. Data for launch windows of 10, 20, and 30 days are tabulated in most cases. The data consist of the launch date, characteristic and vis viva energy, hyperbolic approach velocity, communications distance and time of flight associated with each opportunity. It was found that energy requirements tend to increase rapidly as launch windows are increased and thus it is suggested that wherever possible windows to the outer planets be restricted to 20 days or less. The trajectory data presented provide an adequate advanced mission planning guide to the outer planets launch opportunities between 1975 and 2000.

SECTION 3

SPECIAL STUDIES AND TECHNICAL NOTES

In addition to the reports and technical memoranda summarized in Section 2, a number of special studies have been performed. Formal reports have not been written on most of these studies. They are summarized below:

		Page
3.1	Prospectus	81
3.2	Scientists in the Fields of Selenodesy and Lunar Theory	81
3.3	Survey of Bioclean Facilities	84
3.4	Asteroid Movie	84
3.5	Space Mission Slide Chart	85
3.6	Preliminary Outline of a Planning Methodology for Total Lunar Exploration	85
3.7	Planetary Working Group	86
3.8	Starlite	86

3.1 Prospectus

(1965-1968)

Assistance has been given to NASA in the preparation of the OSSA Prospectus in the years 1965 through 1968. The mission data provided forms a complete set of initial inputs for the NASA computerized Prospectus. It includes scientific objectives and rationales for solar system exploration, the calculation of communication requirements and of orbital parameters at the target planet, compilation of payload weights, and the manipulation of cost slide rules for both spacecraft and launch vehicles. A sample of the type of data provided follows in Table 3.1. The table shows the wide range of mission opportunities and concepts considered.

3.2 Scientists in the Fields of Selenodesy and Lunar Theory

(September 1964 - June 1965)

A list of all competent scientists working in the U.S. in the fields of selenodesy and lunar theory, to be used in connection with the lunar orbiter program, was compiled. The listing was made as a result of an extensive literature search coupled with conversations with experts in the general areas of interest. The scientists were classified in the following five major technical areas: lunar motion, gravitation, figure of the Moon, internal structure and selenography.

Table 3.1

LAUNCH OPPORTUNITIES FOR SOLAR SYSTEM EXPLORATION

Direct Planetary, Asteroid and Comet Missions

Mission	Class	Flight Time	Launch Vehicle	Injected Wt., lb.	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Mercury	Orbiter	85-140d	Titan 3X/1207/ Cent/TE364	2100							*	*	*	*	*		*	*		*	*	*	*	*		*
✓ Venus	Orbiter	110-160d	SLV 3C/Cent	2000		*		*	*		*		*	*		*	*		*		*	*		*	*	
✓ Mars	Flyby		SLV 3C/Cent	1850	*																					
	Orbiter	190-390d	SLV 3C/Cent	2000			*		*		*		*		*		*			*		*		*		*
Jupiter	Orbiter	500-900d	Titan 3X/1205/ Cent/TE364	2300				*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*
Saturn	Orbiter	3.5-4.5y	Titan 3X/1207/ Cent/TE364	2000							*	*	*	*	*	*		*	*	*	*	*	*	*	*	*
Uranus	Orbiter	11.5-12.5y	" "	2000								*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Neptune	Orbiter	20-30y	" "	1900							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pluto	Flyby	10y	" "	1800							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
✓ Asteroid Belt	Flythru	450d	SLV 3C/Cent TE364	450	Anytime →																					
Asteroids-Eros	Flyby	175-400d	SLV 3X/Cent	4000				*		*					*		*									
Icarus	Flyby	100-150d	SLV 3X/Cent	1400							*		*	*												
Vesta	Flyby	325-500d	SLV 3X/Cent	2100						*						*					*					
Ceres	Flyby	300-450d	SLV 3X/Cent	1480		*						*			*					*						
Juno	Flyby	325-475d	SLV 3X/Cent	1000	*									*	*					*						
Pallas	Flyby	200-500d	SLV 3X/Cent	650						*		*			*	*										
Comets-Encke	Flyby	100-200d	SLV 3X/Cent	2200			*			*																
D'Arrest	Flyby	100d	SLV 3X/Cent	4000								*														
Tuttle	Flyby	150d	SLV 3X/Cent	3500												*										
Kopff	Rendezvous	200d	Titan 3X/1207/ Cent/TE364	10,000															*							
✓ Halley	Flyby	300d	SLV 3X/Cent	3000																	*					
Gravity-Assisted (Swingby) and Interplanetary Mission																										
Venus-Mercury	Flyby	140-300d	SLV 3C/Cent	1140		*			*		(?)					(?)		*	*					(?)		*
✓ Jupiter-Saturn	Flyby	2.5 yrs	Titan 3X/1207/ Cent/TE364	2400								*	*	*												
✓ Jupiter-Uranus	Flyby	4 yrs	" "	2000										*	*											
✓ Jupiter-Neptune	Flyby	6 yrs	" "	1700											*	*										
Jupiter-Pluto	Flyby	7 yrs	" "	1400								*	*	*												
✓ Saturn-Uranus	Flyby	6 yrs	" "	2000											*	*	*		*	*	*	*				
✓ Saturn-Neptune	Flyby	7 yrs	" "	950											*	*	*		*	*	*	*				
✓ Grand Tour-Inner Ring Passage	Flyby	8.3 yrs	Titan 3X/1205/ Cent/TE364	2000									*													
-Outer Ring Passage	Flyby	12 yrs	Titan 3X/1205/ Cent/TE364	3000									*		*											

Mission	Class	Flight Time	Launch Vehicle	Injected Wt., lb.	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
✓Out-of-Ecliptic -25°	Direct	85^d	Titan 3X/1207/ Cent/TE364	1200	Anytime →																					
-90°	Jup. G/A	<3 yrs	SLV 3X/Cent TE364	400				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
✓Solar Probe-0.3AU	Direct		SLV 3X/Cent TE364	800	Anytime →																					
-0.1AU	Direct		SIC/SIVB/Cent	800	Anytime →																					
-Impact	Jup. G/A	3 yrs	Titan 3X/1205/ Cent/TE364	1800				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	.	*	*

Key: * - Favored mission

. - Unfavored mission (higher energy and/or longer flight time and/or larger minimum altitudes at swingby)

(☆) - Requires a <u>small</u> dV (<1.0 km/sec) at Venus swingby.

✓ - Only these rows have (for certain) all opportunities shown.

3.3 Survey of Bioclean Facilities

(September 1964 - June 1966)

A survey of a selected cross section of presently operating contamination controlled areas was conducted to determine the requirements for their conversion to bioclean rooms for the assembly, checkout, and decontamination of small spacecraft. A final report consisting of three volumes was issued. Volume I contained the guidelines for evaluation, conduct of survey and cost estimation for modifications. Volume II contained the overall conclusions, recommendations, and summaries of individual facilities. Volume III contained the detailed results and evaluation of individual facilities.

3.4 Asteroid Movie

(July 1965 - June 1966)

A computer generated movie simulating the motion of the asteroids was created to study the phenomena of clustering within the asteroid belt. The movie shows 1563 asteroids as they would appear to an observer looking down from 10 AU above the Sun, and covers the years 1965 through 1979. Observation of the movie clearly shows the formation and disintegration of clusters within the asteroid belt; to date no particular pattern has been discerned for the clustering. The movie does give the viewer a very vivid comprehension of the extent and motions of the asteroids within the asteroid belt.

3.5 Space Mission Slide Chart

(July 1965 - June 1966)

The space mission slide chart enables the launch energy, payload, and flight time to be determined for a wide variety of flyby flights throughout the solar system. Both direct ballistic and nuclear electric low-thrust flights are covered. The slide chart is pocket size and is of use for preliminary mission planning. It is based on the accessible regions method which was developed for presenting data for flyby interplanetary flights.

3.6 Preliminary Outline of a Planning Methodology for Total Lunar Exploration

(July 1965 - June 1966)

This study was performed for the Lunar Exploration Working Group at NASA Headquarters to provide a possible methodology for interpreting the basic lunar scientific questions in terms of an exploration plan. To do this the scientific questions were expressed in terms of lunar parameters which must be measured, and the techniques available for making the measurements were listed. Also specified was the minimum number of sites at which each measurement must be made. The techniques were then listed in order of priority according to their ability to answer the scientific question. Mission concepts were formulated for a few of the highest priority techniques to establish a minimum number of basic missions. Lower priority techniques were then allocated to the most suitable of these missions until the mission capabilities were filled. Only then were further missions added.

3.7 Planetary Working Group

(July 1967-June 1968)

The Astro Sciences Center acted as a quick response source of mission data for the Planetary Working Group. A complete set of mission opportunities was generated, background material was provided for 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 results from the activity of the Planetary Working Group.

3.8 Starlite

(July 1967-June 1968)

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 scientific exploration of the solar system. A presentation was made to the Space Sciences Steering Committee to solicit an estimate of its scientific potential.

SECTION 4

MAJOR COMPUTER CODES

This section consists of brief descriptions of the major computer codes written or adapted for use on contract studies between March 1963 and December 1968. They may be classified into the following broad areas:

		Page
4.1	Interplanetary Transfers	88
4.2	Near Planet Operations	88
4.3	Guidance and Orbit Determination	89
4.4	Combinatorial Codes	89
4.5	Space Sciences Codes	89
4.6	Special Features and Systems	90

4.1 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.

TOPSY: Determines the minimum ideal velocity and the corresponding time required to reach any point in the solar system.

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 has been 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.

4.2 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.

GNDTRC: Generates lunar ground traces for specified lunar orbits.

LIMITS: Computes maximum velocity and maximum energy change as a function of miss distance from a given gravity assist body.

HYPTRC: Computes 2-D planetary encounter trajectories in polar coordinates given a heliocentric transfer trajectory from Earth.

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.

4.3 Guidance and Orbit Determination

ORBDET: Orbit determination for an overdetermined set of points by Kalman 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.

4.4 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.

4.5 Space Sciences Codes

ASTA: A set of codes for analyzing 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.

4.6 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 of orbital elements for solar system objects, including planets, 1600 numbered asteroids, 2000 unnumbered asteroids and hundreds of comets.

SECTION 5

PAPERS PRESENTED AND PUBLISHED

5. PAPERS PRESENTED AND PUBLISHED

The following technical papers were presented and/or published as a result of work performed under the contract between March 1963 and December 1968.

5.1 "Cometary Study by Means of Space Missions" by D. L. Roberts, F. Narin and P. M. Pierce.

Presented at the 13th International Astrophysical Symposium (July 1965) by D. L. Roberts.

Published in Le Congres Et Colloques de L' Universite de Liege, Vol. 37, No. 25 (1966).

5.2 "Selection of Comet Missions: 1965-1986" by F. Narin, P. M. Pierce and D. L. Roberts.

Presented at the 16th International Astronautical Congress, Athens, Greece (September 1965) by F. Narin.

5.3 "Satellite Roles in Radio Emission from Jupiter" by J. Witting.

Presented at the 120th Meeting of the American Astronomical Society (December 1965).

5.4 "An Analysis of Gravity Assisted Trajectories to Solar System Targets" by J. C. Niehoff.

Presented at the 3rd Aerospace Sciences Meeting (January 1966).

Published in the Journal of Spacecraft and Rockets, Vol. 3, No. 9, pp. 1351-1356 (September 1966).

5.5 "Spatial Distribution and Motion of the Known Asteroids" by F. Narin.

Presented at the 3rd Aerospace Sciences Meeting (January 1966).

Published in the Journal of Spacecraft and Rockets, Vol. 3, No. 9, pp. 1438-1440 (September 1966).

5.6 "Choice of Flight Mode for Outer Planet Missions" by F. Narin.

Presented at the XVII International Astronautical Federation Congress, Madrid, Spain (October 1966).

5.7 "Mars Surface Simulator: Design Considerations" by J. T. Dockery.

Presented at the XVII International Astronautical Federation Congress, Madrid, Spain (October 1966).

5.8 "Comet Orbit Determination" by A. L. Friedlander.

Presented at the NASA Symposium on Trajectory Estimation, Ames Research Center (October 1966).

5.9 "Missions to Mars Spur Survey of Bioclean Rooms" by J. D. Stockham, D. L. Roberts, and R. Zastera.

Published in Heating, Piping and Airconditioning (October 1966).

5.10 "An Empirical Method for Estimating Unmanned Spacecraft Program Costs" by C. A. Stone and W. P. Finnegan.

Presented at the American Astronautical Society National Conference on Management of Aerospace Programs (November 1966).

5.11 "Mission Requirements for the Unmanned Exploration of the Solar System" by F. Narin.

Published in Post Apollo Space Exploration, Vol. 20, Part II of Advances in the Astronautical Sciences (1966).

5.12 "Post Apollo Space Exploration" Vol. 20, Advances in the Astronautical Sciences, edited by F. Narin (1966).

5.13 "The Requirements of Unmanned Space Missions to Jupiter" by D. L. Roberts.

Presented at the DGRR/WGLR Joint Space Meeting, Bad Godesberg, Germany (October 1966).

Published in Raumfahrtforschung (January-March 1967).

5.14 "Results of Bioclean Room Survey" by J. Stockham, C. Hagen, S. Miller, M. Nelson, and D. L. Roberts.

Published in Heating, Piping and Airconditioning (May 1967).

5.15 "Low Thrust Trajectory and Payload Analysis for Solar System Exploration" by A. L. Friedlander and F. Narin.

Presented at the AIAA Fourth Aerospace Sciences Conference (July 1967).

5.16 "New Aspects of Thermophysics in Advanced Planetary Exploration" by J. E. Gilligan.

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

5.17 "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).

5.18 "Early Missions to the Asteroids" by D. L. Roberts and F. Narin.

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

5.19 "Guidance Analysis of the Multiple Outer Planet (Grand Tour) Mission" by A. L. Friedlander.

Presented at the AIAA/AAS Astrodynamics Specialists Meeting (September 1968).

5.20 "Jupiter Gravity-Assisted Trajectories" by D. A. Klopp and J. C. Niehoff.

Presented at the AIAA/AAS Astrodynamics Specialists Meeting (September 1968).

5.21 "Relevance of Future Space Missions to Origin of the Solar System" by J. Witting.

Presented at American Astronautical Society Ann Arbor Conference (September 1968).

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.

List A

No. of Copies	Distribution
6	NASA Lunar and Planetary Programs (R. Kraemer)
30	External Distribution (see attached list)
25	NASA Scientific and Technical Information Facility
10	ASC Staff Members
1	ASC file (permanent)
4	Contributing groups and general IITRI distribution
10	ASC file (spares for additional requests)
90	Total

List B

No. of Copies	Distribution
20	NASA Lunar and Planetary Programs (R. Kraemer)
25	NASA Scientific and Technical Information Facility
12	External distribution (see attached list)
20	ASC Staff members
1	ASC file (permanent)
4	Contributing groups and general IITRI distribution
35	ASC File (spares for additional requests)
117	Total

List C

No. of Copies	Distribution
4	NASA Lunar and Planetary Programs (R. Kraemer)
0	External Distribution
20	ASC Staff members
3	Contributing groups (variable)
1	ASC file (permanent)
10	IITRI distribution and spares
38	Total