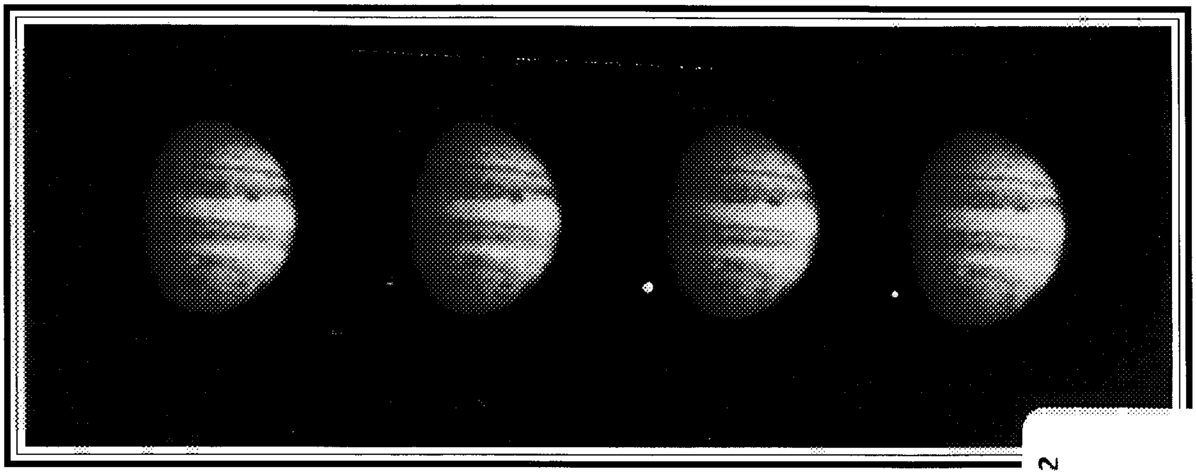
NASA-TM-111082

SOLAR SYSTEM EXPLORATION

1995-2000



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A Report by the

Solar System Exploration Subcommittee

Solar System Exploration Division
Office of Space Science
National Aeronautics and Space Administration

September 1994

(NASA-TM-111082) SOLAR SYSTEM
EXPLORATION, 1995-2000 (NASA)
44 p

Cover caption

These four images of Jupiter and the luminous night-side impact of fragment W of Comet Shoemaker-Levy 9 were taken by the Galileo spacecraft on July 22, 1994. The first image shows no impact. In the next three images, a point of light appears, brightens (saturating the picture element), and then fades, seven seconds after the first picture. The event occurred at approximately 44 degrees south latitude. It is not yet certain whether the data relate to bolides (the cometary fragments entering the atmosphere) or to the subsequent explosion and fireball.

National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

ly to Attn of: SLB

FEB 7 1995

Dear Colleague,

Nineteen ninety-four was an eventful year for the Solar System Exploration Division. Besides some outstanding intellectual advances, such as the impact of Comet Shoemaker-Levy 9 on Jupiter, a strategic plan was developed to carry the program forward during the remainder of this decade. "Solar System Exploration 1995-2000" (enclosed) draws upon the many existing strengths of our program, it presents an exciting and flexible plan for the near-term, and it provides the framework for a superb program of scientific exploration after the year 2000.

An electronic version of this plan is available via anonymous file transfer at the following address: ftp.hq.nasa.gov in the directory pub/oss/sl. The document is entitled planetar.txt. There is also a readme.txt file with additional information (all file names must be lower case).

Sincerely,

William L. Piotrowski
William L. Piotrowski
Acting Director
Solar System Exploration Division
Office of Space Science

Enclosure

SOLAR SYSTEM EXPLORATION

1995-2000

A Report by the

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Preface

The 1970s and 1980s were the Golden Age of Planetary Exploration for the United States, when the nation first landed robotic explorers on Mars and flew past every major planet in the outer solar system in the ultimate Grand Tour. All Golden Ages have their endings, and the prospects for bold and ever-expanding initiatives in solar system exploration seem bleak when measured against the fiscal realities the nation faces in the coming decade. Nonetheless, the thirst for new discoveries cannot be quenched, and the very old and deep-seated dream of humankind to be a space-faring species cannot be forgotten.

It is against this backdrop that the Solar System Exploration Subcommittee (SSES), in coordination with the Solar System Exploration Division (SSED), presents this plan. The purpose of the document is to lay out the strategy and tactics for the next 5 years of development of new missions, creation of advanced technologies to enable those missions, research and analysis programs to mine the new data and determine the next steps beyond, education programs to make planetary exploration a catalyst for deeper national understanding of science, and mission operations to safely operate the spacecraft and return the data to Earth. It is a plan that is fully responsive to the very tight fiscal constraints we face in the near future, while at the same time containing the programs of intellectual and visceral excitement that have been the hallmark of planetary exploration in the past.

The genesis of the plan lay in a close and fruitful collaboration of the SSED; its highest-level advisory committee, the Solar System Exploration Subcommittee; and the community of professional planetary scientists. Preparatory work for the plan began in mid-1993 as the Office of Space Science began to shape its plans for responding to NASA's agency-wide strategic planning effort. The various SSED Science Working Groups (which are empowered to study in detail proposed mission sets in particular discipline areas) worked with the community to develop detailed mission options and associated research programs. These activities were brought together at a January 1994 Workshop held by the SSES in Washington, D.C., which involved more than 40 committee members and invited participants, including (an asterisk indicates lead or co-author for portions of this document):

S. Squyres*, J. Beckman, M. Drake, M. Duke, B. French, R. Killen, D. McCleese, J. Kerridge, D. Paige, G. Varsi*, J. Veverka*, D. Blanchard, F. Carr, A. Cheng, P. Feldman, E. Giberson, M. Kicza, T. Kostiuk, J. Martin, D. Morrison, C. Pieters, L. Soderblom*, F. Bagenal, J. Bergstralh, D. Black*, R. Binzel, T. Owen, C. Porco, A. Stern*, D. Stetson*, J. Taylor,

R. A. Brown*, E. Barker, G. Blake, J. Boyce , H. Brinton,
B. Burke, W. Hartmann, W. Huebner, E. Levy,
D. Muhleman, M. Mumma, J. Rahe, W. Piotrowski,
C. Elachi, J. Niehoff*, N. Hinners (former NASA Associate
Administrator for Space Science), R. Ridenoure, G. Squibb*
(who did not attend the Workshop); and, representing
NASA's Office of Advanced Concepts and Technology,
M. Hirshbein, W. Hudson, and G. Johnston.

Proposed missions, new technology needs, operations, research and analysis, and educational activities were evaluated by this diverse and hard-working group. The plans were presented to the SSES's parent committee, the Space Science Advisory Committee, the following month, refined at a meeting of the SSES executive subgroup, and presented again to the full Space Science Advisory Committee in March 1994, yielding the plan described here.

Although it is clearly not possible to gain the full consensus of every practicing planetary scientist regarding a plan such as this one, it is remarkable how collegial the process has been, given the very tight financial outlook and hence limited opportunities that face solar system exploration as the century comes to a close. It is a tribute to the professionalism of those at Headquarters and in the planetary science community at large that the challenge has been answered with a program of strong scientific content, high excitement, and significant cost savings over previous plans.

Jonathan I. Lunine
Chair, Solar System Exploration Subcommittee
Associate Professor of Planetary Sciences and in Theoretical Astrophysics
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Executive Secretary (Acting), Solar System Exploration Subcommittee
Advanced Programs Office, Solar System Exploration Division
NASA Headquarters

September 1994

1. Introduction and Summary

Solar system exploration represents a most literal realization of the aspiration to explore new worlds. Over the past 30 years, humans have explored the surface of the Moon, and dozens of robotic spacecraft have been sent to fly past or orbit Earth's Moon and all the planets but Pluto. Through robotic surrogates, humanity has reached the surface of Mars, and plunged through the inferno of the Venus atmosphere to probe its very surface. We stand on the threshold of entering the primitive depths of Jupiter's atmosphere, and look forward to exploring the new world of Titan where organic reactions akin to those at the dawn of life here on Earth may be taking place.

Goals of Solar System Exploration

Goals for planetary exploration during the next decade include:

- Determine how our solar system formed, and understand whether planetary systems are a common phenomenon throughout the cosmos;
- Explore the diverse changes that planets have undergone throughout their history and that take place at present, including those that distinguish Earth as a planet;
- Understand how life might have formed on Earth, whether life began anywhere else in the solar system, and whether life (including intelligent beings) might be a common cosmic phenomenon;
- Discover and investigate natural phenomena that occur under conditions not realizable in laboratories;
- Discover and inventory resources in the solar system that could be used by human civilizations in the future; and
- Make the solar system a part of the human experience in the same way that Earth is, and hence lay the groundwork for human expansion into the solar system in the coming century.

Overarching Principle

The plan for solar system exploration laid out in the paragraphs below is motivated by the goals listed above, as well as by the following principle:

> *The solar system exploration program will conduct flight programs and supporting data analysis and scientific research commensurate with United States leadership in space exploration. These programs and research must be of the highest scientific merit, they must be responsive to public excitement regarding planetary exploration, and they must contribute to larger national goals in technology and education. The result will be new information, which is accessible to the public, creates new knowledge, and stimulates programs of education to increase the base of scientific knowledge in the general public.*

The issue of leadership is important in understanding the strategic plan. Although the plan is formulated in a cost-constrained environment, the United States must maintain leadership in this arena of high public excitement and visibility. The United States pioneered a number of capabilities in planetary exploration, and this program is seen as a litmus test of the state of health of American technological capability.

Guidelines

The program presented here is based on the following guidelines, developed in concert with the Office of Space Science:

1. FY '95 funding level from the President's budget, with a roughly 4% decrease per year to end-of-plan (real-year dollars);
2. A mix of small, frequent missions and larger, infrequent but pioneering missions, the mix chosen with due regard to goals of the program and fiscal constraints;
3. International collaboration where appropriate to enhance the scientific and public-appreciation value of missions;
4. Continued level funding of the research and analysis portion of the program, which is the primary conduit through which the data

stream from missions is converted to new understanding of the solar system and hence through which public appreciation of our cosmic neighborhood is achieved, and the foundation through which the definition and merits of new initiatives are formulated;

5. A cost-constrained mission operations and data analysis program, which is essential to safe, reliable operation of flight programs and initial analysis, calibration, and archiving of returned data;
6. Funding of Advanced Technology Development (ATD) to ensure national capability in flight programs and assure that the program represents a source of new technologies for the country; and
7. Program content that includes educational activities and products.

Core Program Elements in the Resulting Plan

The plan presented here is highly cost-constrained. The structure and mix of missions represent a minimum planetary program for responsiveness to the goals of technological and scientific leadership and broad public interest. Many other program elements were considered and eliminated from the plan, or their new starts deferred to beyond FY 2000; some of these missions are detailed below. Additionally, major elements of the program were reduced in scope to keep costs capped, down to a level such that significant further cuts would reduce their viability. The scope of the program is reflected in the following brief rationales of each of the three major flight elements:

The Discovery Program responds to NASA and Congressional imperatives to demonstrate small planetary missions that can be developed and flown by the science community in a very short time span (several years from New Start to launch). Such missions will be constrained in the kinds of flights they can undertake, but provide a breadth of university and student involvement often unattainable in the course of larger programs.

The Mars Surveyor Program responds to the public fascination with Mars that began decades before the space program and continues to the present, as well as to the need to recover from the tragic loss of Mars Observer. The mission elements are a combination of the orbital surveys Observer was to undertake, and a series of small landers that replace the Mars Environmental Survey (MESUR) Network in previous strategic plans, and that address a new set of scientific objectives achievable from a modest number of small, high-technology landers.

The Pluto Fast Flyby Mission is a journey of discovery to the only remaining planet not explored by spacecraft, and it achieves the goal of cost-constrained outer solar system exploration through incorporation of new technologies. The mission is critical if the United States is to retain its capability for conducting long-lived deep space exploration—the U.S. is the only nation on Earth that has demonstrated this extraordinary technological skill.

Additional smaller elements of the program, which have little budgetary impact during the next 5 years, are U.S. participation in the European **Rosetta** mission to a comet, and **ASEPS-1**, the continuation into space of the current ground-based searches for other planetary systems. (ASEPS, the Astronomical Study of Extrasolar Planetary Systems, is the observational element of planetary systems science.)

Each program element plays a particular role in responding to the goal of achieving a United States solar system exploration program that addresses the major questions regarding our solar system, generates public interest and excitement, and demonstrates that the United States can still undertake endeavors of high technological challenge.

Conclusions Regarding the Current Flight Program

The current flight program, which includes missions already launched and those in advanced stages of development, represents the payoff on investments of planning, public financing, and labor over the past decade. Each of these missions has been assessed by the SSES and found to remain of the highest scientific value and potential public interest. In consequence, we reaffirm that the highest priority of the Strategic Plan is successful completion of the current program. Extensive documentation already exists regarding the current program, and we therefore do not repeat this material here. Instead we simply highlight a few key issues associated with these programs.

Galileo: This mission, launched in 1989, continues toward Jupiter with excellent prospects for achieving key science goals in spite of the high-gain antenna failure. That this is so is demonstrated by the recent discovery of a moon around the asteroid Ida from Galileo imagery. The science investigations planned at Jupiter have not diminished in value in the 20 years since this mission was first planned. The SSES concludes that Galileo must be supported with adequate mission operations and data analysis (MO&DA) to ensure safe operation, maximal return of data, and science analysis appropriate to the quality of data from this mission.

Cassini: Development of this mission has entered the advanced, hardware-production phase and remains on track in the U.S. and Europe for a 1997 launch. The science goals remain a centerpiece of planetary exploration, and prospects for exciting discovery have been enhanced recently, for example, by ground-based studies of Titan. The mission is vigorously supported in Europe as well as the U.S., and the peak funding year (FY '94) in the U.S. has already been passed. Cassini was rescoped 2 years ago to reduce development costs and this year achieved significant savings in mission operations costs. Further attempts to squeeze the mission down at this late stage hold the potential for jeopardizing mission success. The SSES continues its highest endorsement of the Cassini mission to Saturn and Titan and recognizes the importance attached by ESA toward timely completion and launch of the hardware. The SSES is therefore pleased to see NASA's commitment to complete development of this mission in time for its scheduled launch in late 1997.

Pathfinder and the Near-Earth Asteroid Rendezvous (NEAR): These two missions are the prototypes for the Discovery Program, and will serve to demonstrate the ability to conduct low-cost planetary missions of high scientific value and public interest. Both missions remain on track for 1996 launches. The SSES renews its strong earlier recommendation that NASA undertake a Discovery line item, with missions based on selection of peer-reviewed Principal Investigator (PI) proposals, as soon as possible. The SSES notes that the momentum established by Pathfinder/NEAR makes approval of the concept as a line item timely.

Mars Observer Recovery: The stunning blow to the nation's planetary exploration program, the loss of Mars Observer, was the catalyst for quick response on the part of the agency in developing the Mars Surveyor program, which will recapture Mars Observer science and proceed with a limited program of surface landers. Although the program is a New Start, it is listed here because the first two missions are intended to recover the Mars Observer science, which remains SSES's highest priority in exploration of Mars.

Astronomical Study of Extrasolar Planetary Systems (ASEPS-0) [formerly TOPS-0]: The ground-based search for other planetary systems appears on track with NASA investment in Keck-II, and the SSES reaffirms the extraordinary depth of the science inherent in exploring nascent planetary systems as a model for how our own Earth and solar system formed.

2. Mars Exploration

Among the planets, Mars most captures the human imagination. With its huge volcanoes and giant canyons, its polar caps and seasonal changes, and with the evidence of a warmer and wetter past, Mars is unique in its attraction as a target for scientific exploration. Mars has long had a special place in the solar system exploration strategic plan, with the Mars Observer (MO) mission to be followed by the exciting and ambitious Mars Environmental Survey (MESUR) Network mission. However, Mars Observer was lost without achieving its objectives, and MESUR Network is too expensive to be carried out by NASA in the present fiscal climate. Both of these programs are now replaced in the strategic plan by the Mars Surveyor program. Mars Surveyor will be a series of orbiters and landers that will address some of the highest-priority scientific goals at Mars in an affordable manner. Orbiters smaller and using newer technology than Mars Observer will return to Mars with copies of the highly capable instruments flown on MO, while new small landers will enable investigation of important scientific questions at the planet's surface.

The Mars Surveyor program will address an affordable, high-priority subset of the science objectives listed below. The following guidelines are critical for a healthy program. (a) It should be supported at a modest, fixed level. Given the current funding environment, we view this approach as the best way of ensuring a vital, ongoing Mars program. A funding level of approximately $130 million per year (including the cost of launch vehicles) appears appropriate and affordable. (b) The highest science priority for the program should be the timely recovery of the Mars Observer objectives. (c) At an absolute minimum, the program should average one launch every Mars opportunity. (d) The program should not use the space shuttle for launches. (e) The program should not use a second Mars Observer spacecraft.

Also, Mars Surveyor should have the following characteristics. (a) It should be constructed from a small number of basic building blocks that can be arranged in a flexible fashion, so as to be responsive to a changing programmatic environment. (b) The number of new spacecraft that need to be developed should be minimized. (c) There should be no dependence on as-yet undeveloped launch vehicles. (d) It should make use of new technologies wherever appropriate. (e) It should be as robust as possible to individual mission failures. (f) It should contribute significantly to the proposed international Mars network mission, and should be as adaptable as possible to the evolving concept of that mission.

Scientific Objectives

At the highest level, the scientific objectives for Mars exploration are: (a) to determine whether life ever began on Mars, and if so in what form, (b) to better understand the climatic history of the planet, and (c) to determine the mode of formation and the evolution of the solid planet.

From a practical point of view, these objectives break down naturally into those best achieved from orbit, on the planet surface, and with returned samples.

The **primary orbital science objectives** are: (a) determine the global variation of surface chemistry and mineralogy, (b) determine the global variation of topography, gravitational field, and magnetic field, (c) identify geologic processes revealed by meters-scale surface morphology at globally distributed sites, (d) characterize global and temporal variations in the vertical structure of the atmosphere, (e) establish the global distribution of subsurface ice, and (f) characterize the martian upper atmosphere and its interaction with the solar wind. The first four of these were the major objectives of the Mars Observer mission.

The **primary landed science objectives** are: (a) determine the detailed chemistry and mineralogy of near-surface materials at diverse sites, with particular emphasis on rocks and subsurface materials, (b) identify geologic processes revealed by millimeter to centimeter scale surface morphology at diverse sites, (c) characterize the baroclinic and barotropic components of the martian global atmospheric circulation (this objective also requires simultaneous orbital measurements), (d) characterize the seismicity of Mars and determine the internal structure of the planet, and (e) characterize the structure of the upper and middle atmosphere of Mars at diverse sites.

The **primary sample return science objectives** are: (a) determine the absolute ages of martian surface materials, (b) determine the detailed petrologic history of martian surface materials, (c) determine the evolution of martian atmospheric composition, and (d) search for evidence of former life.

Current Program Status

The loss of Mars Observer nearly eliminated NASA's Mars Exploration program. There are three primary ongoing activities. The first is Mars-related research conducted as part of the core research and analysis (R&A) program. The second is U.S. participation in the Russian Mars '96 program. At present, this consists of the U.S. providing the MOx instrument for the Mars '96 small stations, plus the activities of a number of U.S. scientists as co-investigators or participating scientists on other Mars '96 instruments. The third is low-level funding of the Mars Observer recovery effort.

In addition, there is the Pathfinder project, which is part of the Discovery Program.

New Program Priorities

As noted above, the highest priority for Mars exploration is recovery of the science lost by Mars Observer. All Mars Observer instruments address high-priority science objectives. Moreover, the payload is extraordinarily mature. Most Mars Observer instruments were tested in flight during the spacecraft's cruise to Mars, and those that were tested functioned well. Near-term emphasis in the program is therefore on getting these instruments successfully to Mars.

After the Mars Observer objectives have been accomplished, the next priority is the major landed science objectives: in situ geology and geochemistry, meteorology, and seismology. However, it has become clear that simultaneous accomplishment of all three of these is prohibitively expensive for NASA alone. The near-term emphasis in the program should primarily be on the geology/geochemistry objectives, including exobiology. This choice does NOT reflect any science prioritization. It is simply driven by the reality that these objectives can be better met by a limited number of short-lived landers than can the other two. Also, it should not be absolute in nature; indeed, NASA should aggressively seek out high-quality scientific investigations of all sorts that could be accommodated on such landers. Objectives that cannot be met on the initial Mars Surveyor landers can be accomplished subsequently by NASA, or concurrently by international partners. The ultimate objective of the Mars science program is sample return, although this is prohibitively costly for the near term.

Flight Program

The following sequence of missions best satisfies the groundrules and incorporates the important characteristics listed earlier. All dates are launch dates:

1996: Pathfinder on a Delta launch vehicle
A D-class orbiter (see below) on a Delta
1998: A second D-class orbiter on a Delta and, if affordable, a lander on a Delta or "Med-lite" launch vehicle (see below)
2001: Two landers on a Delta or on two Med-lite launch vehicles
2003: Four landers on Deltas or Med-lites

A "D-class" orbiter is defined here as an orbiter that can be launched on a Delta and that can place half or more of the original Mars Observer science payload, plus a communications link, in a low circular orbit about Mars.

A '98 lander, if included, would be derived closely from Pathfinder with an improved science payload. An '01 lander could be smaller and would incorporate newer technology.

A "Med-lite" launcher is one that would have about half the launch capability of the Delta.

Several comments are noteworthy regarding this mission sequence:

- It keeps the number of new spacecraft developments to a minimum. There are only two basic vehicle types: a new orbiter and a lander derived directly from Pathfinder.
- It relies primarily on an affordable, proven launch vehicle, the Delta. The post-Pathfinder landers could be launched on a Delta, but they could also be launched on separate Med-lites if those vehicles are available then and if it is advantageous to use them. One important potential advantage is that use of two Med-lites would provide useful launch redundancy.
- It is consistent with what we know now about the plans for the international Mars network mission.
- The sequence of Pathfinder plus the first D-class orbiter in 1996, the second D-class orbiter only in 1998, and two landers in 2001 fits a highly constrained level-of-effort budget profile. All of these components of the program are crucial scientifically and/or

technologically. The lander in 1998 has lower priority than any other components of this program, and could be deleted from the program if budget constraints required. However, it is a desirable part of the program, and should be included if it can be afforded.

- The RFP for the D-class orbiter should solicit two essentially identical orbiters which, together, can deliver the full Mars Observer payload to Mars in 1996 and 1998.

After the 2003 launch opportunity, three basic choices are possible for the direction of the program. One is to continue with geology/geochemistry landers. This would be appropriate if a clear potential existed for further scientific advances by such landers, and especially so if developments in instrument technology held forth the promise of in situ measurements that could accomplish some of what is typically thought of as "sample return" science. The second possibility is to switch to "network science" objectives, like meteorology and/or seismology, that require simultaneous measurements by long-lived landers. This would be an appropriate choice if these objectives have not been accomplished by this time by international partners, and could require some significant changes in lander design. Finally, it may be appropriate at this time to switch the program to an emphasis on sample return if such a mission appears affordable.

Non-Flight Program

MO&DA: Most mission operations and data analysis (MO&DA) needs for the Mars Surveyor missions are fairly well understood. However, several challenges remain if the program is to maintain relatively low costs for MO&DA. These include aerobraking and operating multiple, new spacecraft. Cost estimates for each of the many recovery scenarios demonstrate that substantial MO&DA support (approximately $20M) will be needed in the period from 1997 to 2004.

The future landed science missions pose challenges to operations that have the potential for driving costs. Novel approaches and technologies must be found for supporting multiple landers and associated orbiters operating simultaneously. Daily microrover operations are also anticipated and will pose their own unique operational challenges. In addition, it is likely that the Deep Space Network and U.S. mission operations assets will be called upon to support the suite of international orbiters, landers, and rovers. These costs must also be included in the Mars program for planning purposes, and need to be better understood.

ATD: ATD for future Mars missions falls into two distinct areas: flight hardware and mission operations. Important flight hardware requirements include: (a) miniaturization of orbiter subsystems, lander instruments and subsystems, and rover instruments and subsystems; (b) sample acquisition and handling mechanisms; (c) microrover mobility; and (d) affordable systems for sample return.

The primary operations requirements are increased automation and design of spacecraft for ease of operations.

The funding approach that we suggest is to use about $5 million per year of Solar System Exploration Division funds (from the Mars program), and to negotiate with the Office of Advanced Concepts and Technology to match this with about $10 million per year. With the exception of flight hardware requirements b, c, and d above, the requirements are applicable to almost all future planetary missions, and hence should be considered in the context of an integrated advanced technology program.

R&A: The failure to implement the Mars Observer Data Analysis program because of the loss of the MO spacecraft has been a major blow to the Mars science community. This sudden loss of anticipated support has had a serious impact on human resources. In particular, programmers, technicians, postdoctoral research associates, and graduate and undergraduate students have been let go, and continue to be lost. Their skills will be needed when the Mars Surveyor orbital missions take place.

In FY '95, it is recommended that 2 to 4% of the total Mars Program funds be designated for science support, to be competed for by the science community through the peer review process. This program would evolve into a Data

Analysis program as new data are returned by spacecraft, again to be competed for through peer review.

Peer reviewed Mars-related science (studies of meteorites, laboratory simulations, geology, geophysics, atmospheric science, astronomical observations, and exobiology) should be vigorously supported through the core disciplines (Planetary Materials and Geochemistry, Geology and Geophysics, Atmospheres, Astronomy, and Exobiology Programs).

Education: Education, especially at the K through 12 level, should be an important part of Mars program planning. Mars is unique in the solar system in terms of its public appeal. For this reason, missions to Mars provide an ideal vehicle for stimulating public interest in science and technology. Past educational efforts in the planetary program have been only modestly successful. We believe that the most innovative educational programs will be ones that are sought competitively and subjected to rigorous peer review, and we encourage NASA to solicit and choose educational initiatives in this fashion.

3. The Discovery Program

Introduction

The Discovery Program represents the best way of maintaining vitality and program balance in the current environment of extremely restricted space science budgets.

Discovery must become a vital and integral part of the total Solar System Exploration Program. Although Discovery is not a panacea for the difficulties facing the SSED, it does address specific essential needs, including: (a) frequent access to space to address focused science objectives, (b) program continuity and vitality, given significant and growing time intervals between larger missions, (c) a vehicle for maintaining breadth in the program, (d) opportunities for exploring new disciplines, (e) excellent educational and technology opportunities, and (f) responsiveness to the new strategic direction of the Agency.

For these and related reasons, the Discovery Program is expected to play a major role in SSED activities during the coming decade.

Summary

The three major recommendations for Discovery are summarized as follows:

1. The earlier recommendations of the Discovery Report (May 27, 1993), hereafter referred to as the Carr, Giberson, and Martin Report, that the Discovery program should involve at least one new start and one launch per year, are endorsed. Such a plan is estimated to require an annual funding level of at least $164M/yr.
2. In the event that fiscal austerity precludes the recommended level of funding, the actual level should be maintained at least at the current (FY '94) level of $130M/year. Such a level would allow the launch of missions costing $150M at intervals of about 15 months, or yearly launches of missions costing only $110M.
3. The Discovery Program should be open to all competitively proposed and selected solar system science and exploration objectives. NASA management should strive to maintain an appropriate balance among various objectives in the selection of Discovery missions, and such selections should be done with due consideration to other solar system exploration activities.

Details of these and several other recommendations are given below.

Recommendations

(1) Level of Funding

The findings and recommendations of the Discovery Management Workshop Executive Committee (May 27, 1993), particularly paragraph 6 (Mission Startup and Phasing) that describes a plan leading to at least one new start and one launch per year, are strongly endorsed. It is estimated that this requires (in steady state) annual funding of at least $164M.

The launch rate of one mission per year was considered essential to a vital Discovery Program that satisfies the goals established for it by NASA. Important reasons for this conclusion include:

- Discovery is the best way of maintaining a broad Solar System Exploration program balance in the current budget environment; it also provides for a diverse program. One launch every year would provide, on average, two missions per decade for each discipline represented by the current SSED Science Working Groups. Alternatively, this could be viewed as providing two missions every decade for each of the following Subdisciplines: Geology/Geophysics, Planetary Systems, Planetary Astronomy, Planetary Atmospheres, and Planetary Materials and Geochemistry.
- A launch rate of two per decade per subdiscipline will also assure that at least two vital competitive groups are maintained per subdiscipline. Such competition is expected to lead to enhanced efficiency in obtaining important science results.
- More frequent Discovery missions will be more attractive to industry, which will provide more support for the Program.
- More frequent Discovery missions offer more opportunities to develop and fly new technologies and advance the state of the art.
- More frequent missions offer more educational opportunities.

It is of interest to note that currently some 14 Discovery Concepts are being studied following the San Juan Capistrano (1992) Workshop. These concepts—listed in Table 1—cover a broad range of solar system science and exploration objectives. Even at the rate of one launch per year, it will take a decade and a half to exhaust this potential list. However, it is important to realize that this list is incomplete in the sense that many new ideas can be expected to develop with time as the Discovery Program evolves.

(2) Fallback Level of Funding

Given the fiscal constraints that exist currently, a revised plan that can achieve much of what is desired of Discovery, but at a reduced level of funding, was developed. The obvious variables are launch rate and mission costs. The situation is illustrated in Figure 1, where the vertical axis gives the interval between launches (in months), and the horizontal axis gives the cost of an average mission (note that the cost is for the development phase only and does not include launch vehicle, mission operations, or data analysis). The two vertical dashed lines (at

TABLE 1. DISCOVERY MISSION CONCEPT STUDIES

Principal Investigator	*Institution*	*Concept Title*
Paul Spudis	LPI	Mercury Polar Flyby
Robert Nelson	JPL	Hermes Mercury Orbiter
Richard Goody	Harvard/JPL	Venus Multiprobe
Larry Esposito	U. of Colorado	Venus Composition Probe
Timothy Killeen	U. of Michigan	Mars Upper Atmosphere
Joseph Veverka	Cornell	Comet Nucleus Tour
Michael Belton	NOAO	Small Missions to Asteroids/Comets
Glenn Carle	ARC	Cometary Coma Chemical Composition
Eugene Shoemaker	USGS	Near Earth Asteroid Returned Sample
Paul Feldman	JHU	Earth-Orbiting UV Jovian Observer
Donald Burnett	Caltech	Solar Wind Sample Return
Joseph Veverka	Cornell	Mainbelt Asteroid Exploration/Rendezvous
William Boynton	U. of Arizona	Comet Nucleus Penetrator
David Paige	UCLA	Mars Polar Pathfinder

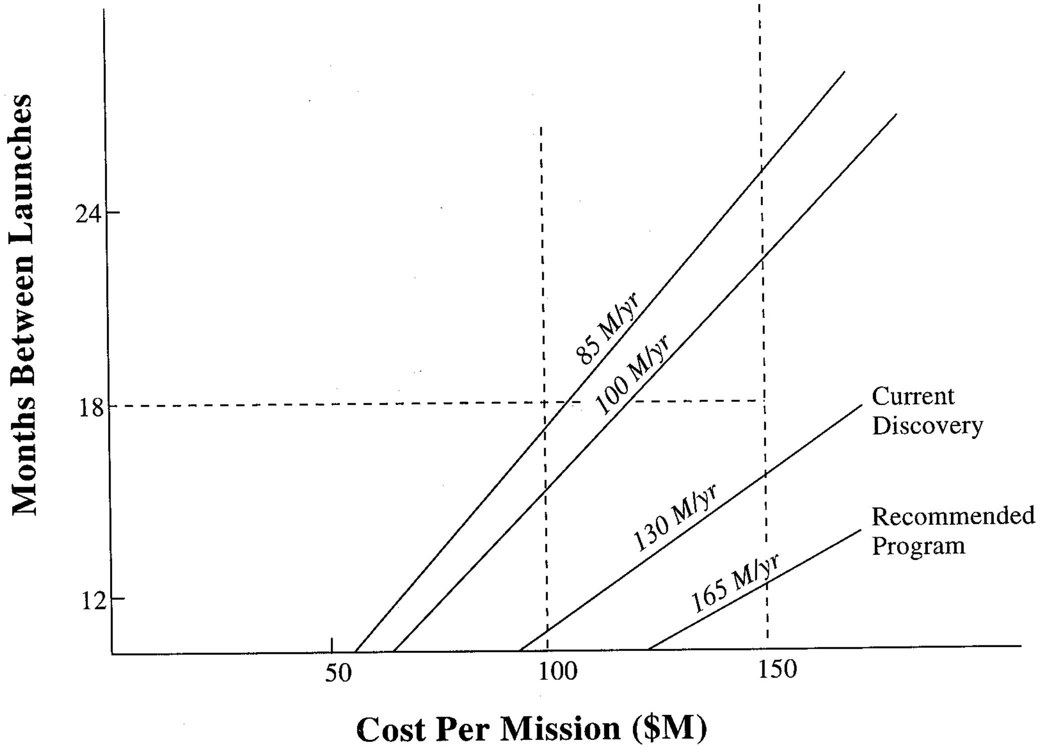


Figure 1. Relationship Between Discovery Program Funding and Launch Frequency

$100M and at $150M) bracket the expected costs of most Discovery missions. Overall, the SSES concurred, and the budgets of the Discovery concepts submitted to the San Juan Workshop confirm, that many early Discovery missions could cost close to the upper bracket of $150M.

The horizontal dashed line in Figure 1 represents a boundary set based on OSS guidelines. In his address to the SSES on January 12, 1994, the Associate Administrator for Space Science, W. Huntress, stated that Discovery requires a "relatively high flight rate to sustain the vitality of the community" and expressed his belief that this meant "at least one Discovery flight every 18 months ..."

A funding level of less than $100M/yr cannot meet this goal (Figure 1) in view of the expectation that many of the early Discovery missions will cost close to the $150M cap. However, a level of funding similar to that with which Discovery was initiated in 1993—approximately $130M/yr—satisfies the requirements and may be a satisfactory compromise to the recommended funding level in Recommendation 1 above.

Discovery's funding should be maintained at approximately $130M/yr. Such a level allows launches of $150M missions on approximately 15-month intervals; or yearly launches, if the average cost is about $110M.

It is emphasized that these numbers do not include launch vehicle, mission operations, and data analysis costs.

(3) Scope of Discovery Program

The Discovery Program should remain open to all competitively proposed and selected solar system exploration and science objectives.

The Discovery Program should be restricted to competitively selected and peer-reviewed missions. No missions that have not gone through the regular selection process should be forced into the Program.

Discovery selections must be sensitive to ongoing solar system exploration activities, and NASA management must strive to maintain an appropriate balance across programs.

In the event of a funded Mars Exploration Program, high priority Mars science objectives should be accomplished within the context of that program. SSED management should reserve the option to fund highly ranked Mars Discovery proposals under the context of the Mars Exploration program.

(4) Discovery and Advanced Technology

Discovery technology should be driven by the science and mission objectives.

New technology is an integral part of Discovery. We expect to qualify and fly some components for the first time in Discovery missions. The Discovery Announcement of Opportunity states that every Discovery proposal must identify: (a) all uses of new technology and innovative approaches; (b) how this technology may enhance future missions; (c) how this technology may be transferred to, and will benefit, the public and commercial sectors; and (d) what steps have been taken (or will be taken) to assure that this new technology does not jeopardize mission success.

Industry involvement should be viewed as a conduit for technology transfer in both directions and a vehicle for ultimate commercial competitiveness.

Discovery can take advantage of NASA's Advanced Technology Development (ATD), OSS's Integrated Technology Strategy (ITS), and other technology programs and can provide a platform for their first mission application. ATD should extend its scope to flight qualification for technologies that have multiple use (e.g., integrated avionics, lightweight gyros, etc.).

The Planetary Instrument Definition and Development Program (PIDDP) should continue to incorporate Discovery Program requirements into its planning and should receive increased funding to accommodate the needs of Discovery.

(5) International Participation in Discovery

International cooperation can be an important part of the Discovery Program.

Several issues concerning international cooperation were examined: (a) What is the desirable maximum level of foreign participation? (b) Should true partnership, with comparable U.S. and non-U.S. participation, be permitted? (c) Should efforts that include launch by a non-U.S. partner be permitted? (d) Should efforts in which a U.S. mission is an integral part of a larger international effort be part of Discovery?

The recommendations concerning international cooperation contained in the Carr-Giberson-Martin Management Report are endorsed. These recommendations (pp. 9–10 of their Report) can be summarized as follows: (a) NASA should be able to terminate unilaterally any international cooperation on a Discovery mission; (b) the NASA fraction should exceed those of the international partners; (c) international Discovery Missions should be capped at $150M (FY '92$) to NASA and limited to development schedules of 36 months or less; and (d) international Discovery missions should be small independent free-flyers and not large NASA instruments to be flown on large international platforms or spacecraft.

(6) Discovery Program Management

Discovery must be managed efficiently and effectively if it is to realize its promise. Items discussed included: (a) prompt funding and financial oversight, (b) technical and project oversight: should this function be done by NASA Headquarters or by a Center, and if the latter, to what degree and at what cost? (c) should NASA resources be contracted for separately? and (d) how can NASA ensure that program management does not become an obstacle to individual missions satisfying cost and schedule caps?

The recommendations for the management and implementation of the Discovery Program contained in the Carr-Giberson-Martin Report are reaffirmed and endorsed.

4. Programs of the New Start Queue

Summary

The "New Start" queue consists of a trio of missions whose purpose is to provide leadership in three areas not specifically covered by the Discovery and Mars programs. These areas, and the primary corresponding missions, are: (1) deep space exploration (Pluto Fast Flyby, or PFF); (2) continued intimate cooperation with the European Space Agency (Rosetta); and (3) direct stimulation of new technologies through the major intellectual goal of the search for other planetary systems (Astronomical Search for Extrasolar Planetary Systems Phase 1, or ASEPS-1). Of the three missions, only the Pluto Fast Flyby is considered a major program element within the horizon of the plan; U.S. involvement in Rosetta is very limited in cost, and ASEPS-1 does not ramp up to significant levels prior to FY 2001.

It should be recognized that each of these New Start programs satisfies multiple goals of the planetary program, in spite of our assignment of specific goals to individual missions. PFF involves development of new technologies for relatively inexpensive deep-space flight; Rosetta addresses major issues associated with the formation of our solar system; and ASEPS-1 as an extension of ground-based studies provides a particular stimulus to educational programs concerning the nature of scientific exploration at all levels, i.e., grade school through college.

Together these New Start missions provide the essential element of United States leadership in solar system exploration, i.e., to maintain the competence of this nation in technologically challenging activities that we pioneered in the past. Further, these missions represent a subset of candidate programs for the New Start queue; especially promising missions that could not be included in the plan because of the overall cost constraint are outlined here as well.

The Missions

Pluto Fast Flyby

RATIONALE

The exploration of the outer planets is crucial to obtaining an understanding of the origin and evolution of our solar system, the study of comparative planetology, and the understanding of diverse and unique phenomena that occur on planets in our solar system, and presumably, others as well. Robotic exploration of the outer planets also provides ground truth to "calibrate" and interpret planetary phenomena from Earth-based and Earth-orbit observatories.

Of equal importance to its scientific merits, the exploration of the outer solar system also challenges the human spirit, provides an important magnet for science education, and drives technology development in areas as diverse as microelectronics, power systems, and advanced sensors.

The motivation for sending a mission to reconnoiter the Pluto-Charon system is severalfold. In part, it is based on the intense scientific interest and the potential for fundamental discoveries. The Pluto-Charon system is the only planet not yet explored by spacecraft. The impetus for a 1990s reconnaissance mission to the Pluto-Charon binary is also based on the critical timing forced by the impending decay of Pluto's perihelion atmosphere and the movement of much of its northern hemisphere into a multidecadal solstice shadow. Other motivations for Pluto reconnaissance include its wide public appeal, strong technology focus, and particularly cost effective nature, compared to most other outer solar system missions.

Recognizing the compelling case, a number of scientific advisory groups have recommended that the exploration of the Pluto-Charon system be given high priority in NASA's mission queue. These recommendations have come from the Solar System Exploration Subcommittee (SSES 1991, 1992) and the Space Science and Applications Advisory Committee (SSAAC 1991). The unique Pluto-Charon exploration rationale identified by the SSES includes:

Unique Atmospheric Phenomenology: Owing to its elliptical orbit, Pluto is the only planet with an atmosphere that (like a comet, but on a planetary scale) builds up and decays during each orbit. This leads to complex surface-atmosphere interactions. In addition, Pluto's highly extended atmosphere causes the major constituents of the atmosphere to be lost through hydrodynamic escape—a unique occurrence in modern-day planetary environments. Further, peculiar binary-induced atmospheric tides, a potentially unique solar-wind interaction, and perhaps even Roche-lobe mass transfer between Pluto and Charon are each expected to be occurring.

Comparative Planetology: Pluto is the only unexplored member of the cryogenic Titan-Triton-Pluto triad, which rivals the Venus-Earth-Mars triad in complexity and scientific interest. A particularly strong motivation for Pluto exploration is to provide an analogous object to compare with Triton, Neptune's complex and enigmatic satellite. Triton displays a similar bulk density and surface composition to Pluto, a similarly thin atmosphere, and a complex geology with active surface geysers. Unlike Pluto, however, Triton's evolution has clearly been influenced by its strongly coupled orbital-thermal evolution with Neptune.

Solar Nebula Chemistry: Pluto, Charon, and Triton are the largest extant examples of solid planetary bodies formed in the outer solar nebula. Results from Pluto-Charon reconnaissance, coupled with existing knowledge about Triton and comets, will provide an advance in understanding the formation conditions, chemistry, and evolution of large planets and planetesimals in the outer solar nebula.

Cosmogony: How the binary pair and Pluto and Charon themselves formed and achieved their unique, highly resonant, weakly chaotic orbit is of fundamental scientific interest. In part, this is because there is no similar true planetary-binary in the solar system. More fundamentally, one also asks why the outer solar system, dominated by four giant planets, should contain a single, small, double-planet on its outskirts. It may be that Pluto, Charon, and Triton are the remaining relics of a large population of hundreds or thousands of small, icy planets formed during the accretion of the giant planets, but now largely scattered to the Oort comet cloud. With the detection of 200- to 300-km-diameter bodies in the Kuiper Disk, this theory is gaining acceptance. As such, it appears that Pluto and Charon, because they are so accessible, offer a unique chance to study analog objects to the bodies now being revealed in the Kuiper Disk.

A Window on Comets and Small Debris in the Kuiper Disk: It is believed that the regular planets are surrounded by a torus- or disk-like ensemble of 10^9 or more comets orbiting beyond 35 AU (not to be confused with the much more populous Oort Cloud at 10^4 AU). Pluto's elliptical orbit takes it and Charon through the Kuiper Disk, allowing their surfaces to record an impact history that provides information on both the size spectrum and number density of objects in the Kuiper Disk. Charon's surface is covered with structurally strong H_2O-ice, which can preserve surface features for the age of the solar system. If Pluto's structurally weak surface $N_2/CH_4/CO$ layer extends to significant depth, however, then craters on Pluto may relax on geologically short timescales, so that comparison of the cratering records on Pluto and Charon may provide a measure of both the 'instantaneous' and long-term Kuiper Disk impactor flux.

MISSION PLAN

Since 1989, NASA has been studying various mission architectures and spacecraft designs for the first exploration of the Pluto-Charon system. Three mission scenarios have been developed: a 2000+ kg Cassini-derived flyby, a 316 kg mini-Voyager flyby (called 'Pluto 350'), and a lightweight, low-cost 120 kg flyby (dubbed 'Pluto Fast Flyby', or PFF). The last of these was selected on the basis of cost constraints, short flight times, and ability to meet key objectives regarding Plutonian composition, atmospheric and surface properties, and cosmogony (key science objectives that have been quantified in available reports of the Outer Planets Science Working Group).

The PFF Phase A spacecraft work has been designed around the key measurement objectives and payload. It is a highly miniaturized descendant of the present class of outer solar system vehicles. Based on Phase A design and hardware prototype work completed to date, estimates are that the spacecraft will achieve a mass goal of 110 to 120 kg, including propellant and 35% system mass reserves. Within that small mass, the spacecraft will include all the usual subsystems and services flown on past flyby missions, with the exception of a scan platform; the science instruments will be body-mounted.

The proposed spacecraft design is summarized as follows. The spacecraft structure is a composite-based hexagonal bus; there are no deployable structures. The spacecraft is powered by a radioisotope thermoelectric generator (RTG) that generates 74 watts at launch and 65 watts after cruise to Pluto. The spacecraft communicates to Earth via a fixed, composite-structure 1.47-meter high-gain antenna that employs an X-band uplink receiver and downlink transponder. The estimated data rate at Pluto (at 34 AU) should be 80 bps, comparable to the Galileo mission at Jupiter (at 5 AU). The command and data handling system is centered around a RISC-based computer capable of processing a science data stream at 5 Mb/s.

Onboard solid-state data storage exceeding 2 Gb is provided; compression increases the effective data volume to several times this amount. Excess RTG heat is used to provide thermal control where needed (e.g., for propellant conditioning). The attitude control subsystem is based around a wide-field star sensor. Pointing knowledge will exceed 1.5 mrad, with a stability of 10 micro-radians over 1 sec. A 90-degree slew can be completed in 3 minutes. The propulsion subsystem is a pressure-fed hydrazine monopropellant design, which delivers delta-V for post-launch and cruise trajectory maneuvers.

The baseline mission plan envisions the launch of two Pluto spacecraft on separate launch vehicles. Various options ranging from the Shuttle, to commercially available ELVs, to the Russian Proton are under consideration. The launch vehicle will be augmented by existing solid rocket motor upper stages to achieve the required 200 to 400 km^2/sec^2 specific injection energy for a direct trajectory to Pluto. Direct trajectories are preferable to a Jupiter gravity assist, because they are quicker, do not depend on Jupiter being in the right position for launch, and avoid the need for the heavy radiation shielding requirements imposed by the Jovian magnetosphere. The 120-kg baseline spacecraft will reach Pluto in 8 to 9 years. This is much faster than the 12-year Voyager transit to Neptune and Triton. The approach speed at Pluto will be 12 to 18 km/sec, which is like the 17 km/sec Voyager 1 flyby speed at Titan, and 30 to 50% slower than the 24 km/sec Voyager 2 encounter speed at Triton.

The nominal PFF mission plan involves two spacecraft to reduce the risk of a fatal launch or spacecraft accident, and to improve the science return by allowing both sides of each object in the binary to be completely mapped.

During cruise, each spacecraft will be tracked and interrogated by the Deep Space Network (DSN) on a weekly basis. The strawman payload offers possibilities for certain imaging, interplanetary H/He, and radio science studies. The increased cruise science has also been investigated, as have en-route asteroid flybys.

Distant remote sensing observations of the Pluto-Charon system will begin 3 to 4 months prior to closest approach. At this time, PFF's imaging resolution will exceed that of the repaired Hubble Space Telescope (HST). Over a timebase of many rotations, Pluto and Charon will be observed at increasing resolution, and a search will be made for faint satellites. Also during distant approach, UV studies will search for an H/H_2 corona around Pluto. In the days leading to closest approach, IR surface mapping and UV airglow studies will become a priority.

The flyby design will bring the first spacecraft to a distance of ~10,000 km or less from Pluto, and will permit both Earth and solar occultations. This trajectory will place the first spacecraft at least four times closer to Pluto than Voyager came to Triton. Post-flyby studies will include high phase angle mapping, searches for orbiting dust structures, and nightside IR/UV spectroscopy.

Because two spacecraft will be launched, their encounter trajectories can be separately optimized. In order to complete the 1-km global mapping requirement, the second spacecraft will be targeted to study the opposite hemispheres of Pluto and Charon. It is expected that the two flybys will be separated by ~180 days. This will allow the data from the first encounter to be transmitted to Earth and analyzed to optimize the return from the second encounter. It will also provide a substantial timebase of observations to detect atmospheric decay and time variable surface phenomena, such as geyser activity and volatile migration. The second encounter could feature an approach within 2000 to 3000 km of Pluto, Charon radio/solar occultations, or other objectives. After the two spacecraft leave the Pluto-Charon system, they will be traveling nearly along the apex of solar motion toward the heliopause at 4 AU/yr.

New Technologies

The proposed Pluto mission provides important opportunities for the development and implementation of spacecraft and mission operations technological innovations that reduce mass and power requirements, improve operability, and reduce costs. In doing so it will constitute proof-of-concept of the next generation of outer solar system spacecraft.

Cost and Schedule

The mission life-cycle cost must be extremely low compared to previous deep space missions such as Galileo and Cassini. The target launch year is 2001.

Rosetta Participation

Rationale

Of all the objects in the solar system, comets are perhaps the least altered by processes that operated over the long history of the planets. This is because they are small, so that little internal heating has taken place, and they reside for most of their history in the very cold regions of space far from the Sun. It has long been a high priority in planetary exploration to measure the composition and properties of comets, because their primitive nature makes them the best extant record of conditions before and during the formation of the solar system. Comets very likely contain grains that formed in interstellar clouds, which were the source of our solar system.

Previous cometary missions explored the physical environment around comets, and made preliminary measurements of the composition of grains blown off the comet's solid nucleus as it approaches the Sun. The Comet Rendezvous Asteroid Flyby mission (CRAF) was designed to closely investigate the comet's nucleus, including direct measurement of the composition of its primitive ices as a precursor to sample return.

With the cancellation of CRAF in 1992, a major goal of planetary exploration remained unfulfilled. The European Space Agency (ESA), mindful of the scientific importance of close-in investigation of comets, competitively selected the Rosetta mission as its latest cornerstone mission toward a launch in 2003. Rosetta will focus its attention on the nucleus of a comet, studying its changes as the comet moves toward and then away from the Sun, and measuring the composition of the surface at close range. ESA's need to limit the mission's costs has led the agency to seek international participation in the most exciting component of the mission: the landing of a probe on the comet's surface and direct sampling of this primitive material.

Mission Plan

If selected, NASA would contribute a surface science package (SSP), and one or more competitively selected science instruments for the main spacecraft, and/or the SSP. The resulting arrangement is similar to that of Cassini, with the roles of ESA and NASA reversed.

New Technologies

Specific new technologies for Rosetta have yet to be identified. However, landing or penetration of the comet nucleus represents a new endeavor, with associated potential developments in instrument and flight electronics miniaturization, lander technology, and sampling.

Cost and Schedule

Decisions on agency participation will be made by ESA in 1994. The schedule for instrument development is TBD, but extensive funding does not begin until FY '98, with launch in 2003. Cost of the SSP, based on ESA specification, is on the order of $50 million; two analytic chemistry instruments (one each for main spacecraft and SSP) would be on the order of $50 million total. With additional possible United States contributions to tracking and science analyses, the total cost to the United States is $120 to 150 million dollars. This represents an extraordinary bargain: U.S. participation in exploration of the heart of a comet at 1/4 the total mission cost. To further reduce the impact of the profile on the program, most of NASA's costs would be derived from reductions in overall SSED mission operations.

ASEPS-1

Rationale

ASEPS-1 (Astronomical Studies of Extrasolar Planetary Systems- Phase 1/Earth-orbital mission) is the spaceborne part of a comprehensive program in "Planetary Systems Science" (PSS), a program of research into the problem of how planetary systems arise and evolve, including the question of how frequently planetary systems form around nearby stars, and what the general characteristics of planetary systems are.

Not only is the PSS objective interdisciplinary in nature—involving as it does both planetary science and astrophysics—but it is also intercultural, in that it asks about the uniqueness of Earth, an ancient and compelling question. In our time, this issue has passed from the realm of philosophical speculation to readiness for scientific resolution. Today, the research tools can be assembled—computers, telescopes, instruments and skilled scientists and engineers—to address and answer it.

The intercultural and interdisciplinary character of PSS has influenced the structure and scope of the program itself. The result is a unique programmatic format consisting of three components: (1) the acquisition of new scientific knowledge about the processes that lead to the formation of planetary systems, (2) the discovery and study of extrasolar planetary systems, and (3) educational communications to students, teachers, and the interested public to assure the widest possible participation in investigation and full exploitation of the learning benefits potentially available from the PSS program. Each of these three components should be fully incorporated into the PSS program.

The PSS program has two major sub-programmatic elements. One is the Origins of Solar Systems program, and the other is ASEPS. The Origins program consists of research by individual scientists involving theory, laboratory, and observational studies bearing on the question of star and planet formation. The importance of a coordinated and balanced Origins component to PSS cannot be overemphasized. The ultimate objectives of the PSS can be realized only if an adequate base of Principal Investigator investigations is supported in coordination with the large-scale observational component embodied in ASEPS.

ASEPS itself has three phases: discovery of extrasolar planetary systems (ASEPS-0); characterization of the orbits, frequency of occurrence, and other statistical aspects of extrasolar planetary systems (ASEPS-1); and characterization of individual members of discovered planetary systems (ASEPS-2).

ASEPS-0 is a ground-based program already underway. ASEPS-2 is an ambitious effort involving advanced space flight techniques beyond the current planning horizon. ASEPS-1 is included in the present strategic plan as the first phase of the space-based search for extrasolar planets.

MISSION PLAN

ASEPS-1 is a space mission to systematically discover and characterize extrasolar planetary systems of the type represented by our solar system. It will utilize an Earth-orbiting spacecraft. Four ASEPS-1 spacecraft concepts have been funded in the conceptual study phase by NASA for the last several years, and other concepts have been under study. In 1994, NASA will release an NRA to select one or possibly two ASEPS-1 concepts for pre-Phase A study. This down-select is a critical step, which will focus limited technology development funds on the best concept. An Announcement of Opportunity for formal Phase A/B work is planned for release, tentatively, around 1997.

New measurement techniques and component technologies are the cornerstone of a successful Planetary Systems Science program. For the space segment (ASEPS-1), the impact of technology is measured in both performance and cost. Cost caps and launch vehicle restrictions have resulted in innovations that have reduced the cost of a first space mission while substantially preserving performance.

Some of these cost savings in ASEPS-1 have already been realized in the conceptual design phase. A new Integrated Modeling of Optical Systems (IMOS) tool has made it possible to analyze complex space optical systems with much smaller design teams than was previously possible. Other savings will be realized in the phase of detailed design, fabrication, integration, and test.

In the case of the Astrometric Imaging Telescope (AIT) concept for ASEPS-1, investments in optical technology have led to simplified optical approaches that not only reduce manufacturing and testing costs, but should also produce a better instrument product. This results from an innovation shifting the stringent optical tolerance requirements from the primary mirror to the much smaller secondary and from an innovative coronagraphic design.

One of the interferometer options (SONATA), is a simplification of a more complex earlier design that exploits narrow-angle interferometry as well as a substantial NASA investment in Controls Structures Interaction (CSI) technology during the past 5 years. The other concept (POINTS) also takes advantage of the CSI developments, but in addition incorporates an all electronic optical phase measurement system with no moving parts.

The photometric approach to planet detection (FRESIP) requires radiometrically stable visible imaging arrays (CCDs) having ultra-high precision and high dynamic range capability. There are many similarities between these requirements and the metric focal plane measurement devices needed for improved measurements from the ground.

New Technologies

The development of PSS technology has potential to improve the competitiveness of U.S. industry in space and on the ground. By driving the state of the art in optical and detector technology, we can expect an impact on the capabilities for high resolution imaging from space. In recent months, this has emerged as a very competitive arena internationally, with an emphasis on pushing the margins of resolution and targeting. Interferometry may become important in geosynchronous satellites with rapid repeat coverage.

Cost and Schedule

The ASEPS-1 spacecraft is in a cost category between roughly $250M to 400M, excluding launch, mission operations, and data analysis. Because the start of the program lies at the very end of the present planning horizon, a detailed schedule for development and launch is not specified here.

Accompanying the current ground-based ASEPS-0 and future ASEPS-1 is a broad research and analysis "Origins" program, which should be ramped up to a steady level of $7 million per year to provide the theoretical, experimental, and observational work required to place the results of ASEPS in a meaningful context with respect to the big questions: how do stars and planets form, and are we alone in the cosmos?

Future Mission Opportunities

The following are missions of high scientific and technical merit, which were not included in the plan because of the budgetary constraints imposed on the process. These missions would be viable candidates within the current planning horizon if the actual SSED budget were augmented above that assumed here. Alternatively, two of the concepts (Measure-Jupiter and Venus Landers) could be considered for New Starts beyond the year 2000. Saturn Probe is tied directly to the Cassini schedule and would require a commitment *during* the current planning horizon.

Measure-Jupiter

Measure-Jupiter is a mission concept for the intensive exploration of giant planets, with initial application at Jupiter. By flying sets of lightweight spacecraft with highly focused measurement objectives, it is designed to break the present cost and time-of-flight impasse in giant planet exploration after Cassini. The programmatic concept behind Measure-Jupiter is based on a Discovery-like approach to outer planets exploration, in which a level-of-effort program running at $175 to 250M/year is used to fly a program of post-Galileo Jupiter missions on 2 to 3 year centers. The use of advanced spacecraft subsystem and instrument technologies to achieve more miniaturization and enhance science return is an integral part of the Measure-Jupiter concept.

The selection of Jupiter as the primary destination for the initial missions in this program was based on several factors. These include: (a) broad scientific interest; (b) the ease of access to Jupiter on fast trajectories with low-cost (Delta-class) launch vehicles; (c) the potential for use of non-nuclear power sources at Jupiter; (d) the fact that Jupiter missions enjoy the best telemetry link margins in the outer solar system; and (e) the growing community interest in post-Galileo Jupiter follow-ons.

Detailed Measure-Jupiter studies were begun in FY '93, and after review by the Outer Planets Science Working Group (OPSWG) and the SSES, were continued in FY '94. It is envisioned that Measure-Jupiter would feature an adaptive mission queue that evolves as new technology and early mission results are obtained. The mission analysis and engineering studies performed to date have focused on determining the feasibility of various mission architectures.

The Measure-Jupiter mission types studied to date have been: satellite hard landers and penetrators, Jupiter atmospheric probes, "skimmers" that make flyby passes through hazardous regions like Io's neutral atmosphere or the Jovian polar ionosphere, and small orbiters for meteorological, dust environment, and magnetospheric studies. Cost and engineering feasibility analyses indicate all of these mission types are affordable and feasible without major breakthroughs, except satellite landers.

Saturn Probe

The Saturn Probe mission concept focuses on the opportunity to use the Cassini Orbiter's probe communications relay as an in-place infrastructure for performing a Galileo-like entry probe into Saturn's atmosphere.

It should be recalled that the original post-Voyager Saturn mission proposal was called Saturn Orbiter/Dual Probe, which included atmospheric probes into both Titan and Saturn. In order to reduce mission costs when Cassini was put forward, the Saturn atmospheric probe was deleted.

To recoup that scientific capability, JPL has begun a study to determine the feasibility of a low ($200 to 250M, life cycle) cost Saturn probe mission as a Cassini adjunct. This mission would launch after Cassini and fly a direct, 3- to 4-year trajectory to Saturn.

At present, four Saturn Probe options are under study. They are most easily identified by their launch vehicles: Delta, Atlas/Centaur, Proton, and Shuttle. Scientifically, the options range from a single probe instrumented with only an atmospheric structure and composition experiment (launched by the Delta) to a Pioneer Venus-like set of light and heavy entry probes launched on Proton or Shuttle.

The SSES and OPSWG began considering the Saturn Probe concept in the January–February 1994 timeframe, as part of the SSED strategic planning effort and the ongoing responsibilities of OPSWG.

Venus Landers

The Magellan mission established Venus as a planet with an active geologic history every bit as complex as that of the Earth, yet distinct in terms of the lack of plate tectonics and presence of other types of crustal resurfacing processes. The next step is to sample the chemistry of the crust to constrain the details of crustal evolution associated with Venusian tectonics. Although Russian landers have briefly sampled the composition of the soil at several landing sites, the results are not sufficient to address the key science goals stimulated by Magellan. At stake here is understanding the evolution of the crust and atmosphere of a planet whose bulk properties are so similar to those of Earth, yet whose present surface and atmosphere are entirely different. In these differences lies the potential for profound understanding of how the Earth as a planet has evolved to its present state.

The requirements for such sampling include landers that are long-lived compared to the hour-long operation of previous Venus landers. The environmental constraint is the extremely high surface temperature, above the melting point of lead. New technologies to be incorporated in such landers, including high temperature electronics and novel thermal control schemes, have direct application in terrestrial industrial environments in which electronics must operate reliably and for long periods at elevated temperatures.

5. Peer-Reviewed Science

Planetary Research and Analysis (R&A)*

NASA is a mission agency with explorations, operations, and scientific investigations in space as its principal responsibilities. However, all of NASA's space activities ultimately acquire meaning only through the broader significance and value of learning and intellectual accomplishment. Peer-reviewed science assures the quality of these accomplishments for the SSED program, and, as such, science is a critical component of the exploration program in its own right.

The Solar System Exploration Division is responsible for conducting a program of explorations and investigations aimed at advancing understanding of: (a) the origin and evolution of our planetary system; (b) the nature, physical state, and behavior of planets and other solar system bodies; and (c) the circumstances of formation, the prevalence, and the character of other planetary systems.

In order to carry out this responsibility, it is essential that the Solar System Exploration Division sustain well-conceived programs in the relevant science disciplines, which are the suite of peer-reviewed science investigations often simplified as "planetary R&A."

Today, planetary R&A is changing due to a variety of factors, both positive and negative, such as new lines of inquiry opened by scientific discoveries and advanced technologies, and reduced funding levels to support established as well as young researchers. Unless NASA anticipates and manages these changes adroitly, they will endanger the performance of the R&A program in assuring the knowledge base for new missions and the availability of the best scientists to analyze and interpret new results from space probes and planetary observatories. At the current time, the overriding issue for the adherents to the planetary R&A program—including NASA program officers, the SSES, and the science community—is how to influence and adjust to the fundamental changes that are now underway in the R&A program and its environment.

Although "R&A" is the common moniker for peer-reviewed science, three distinct budget categories are actually involved in its implementation: R&A, Mission Operations and Data Analysis (MO&DA), and Advanced Technology Development (ATD). The Committee includes all three budget areas in its advice regarding peer-reviewed science.

In the past, R&A budgets have been used as a reservoir of funds to fix problems elsewhere in the SSED budget or to pay for desired programmatic activities for which funds were not allocated in the normal budget process. Under past practices, the Committee is concerned that expectations have been created, which reduce the pressure and incentive to formally fund important initiatives because of the perceived likelihood that the SSED would, in any case, reallocate funds away from basic R&A activities to make up for the shortfall. The net effect has been a reduction of vigor in planetary R&A, which has been to the long-term detriment of a productive and effective SSED program. *Especially in the context of a highly constrained budget, the Committee recommends NASA adopt a more disciplined approach to the funding of new initiatives. This will entail recognizing that some unfunded initiatives and/or programs may have to be foregone.*

In the past, NASA has made significant midyear budget changes that have seriously impacted the science programs. A uniform "tax" across all programs, without regard for priority, seriously weakens the R&A program. *The SSES recommends the formulation of guidelines, priorities, and procedures to govern budget changes in such circumstances.*

The analysis of mission science data after the initial phase has been traditionally supported by data analysis programs that competed for new funds well after the spacecraft project was underway. *The SSES recommends that total life cycle costs be considered for all new missions, and that all mission data analysis should be costed with the development and operations costs from the start and included in the MO&DA budget line when the mission is approved.*

Advanced technology development (ATD) is an important role of all NASA science programs, and its increasing importance is expected to be reflected in a new ATD budget line starting in FY '95. *The Committee recommends that the ATD budget should include the development of instruments insofar as they are technology drivers.*

The Committee notes that special consideration should be given to the challenge of maintaining a forward looking Research and Analysis activity in view of changing directions and emphases in the SSED overall and the fact that the overall R&A budget is unlikely to increase.

In this respect, the Committee notes that "Planetary Systems Science" is a nascent program within SSED, which is expected to grow to be a major element during the rest of this decade. The SSES recognizes the need to provide an adequate scientific and intellectual foundation for that endeavor within the SSED. *Therefore, the Committee recommends that the Origins program be regarded as part of the core SSED program, with a level of funding commensurate with the importance and role that it is expected to have in the coming years.*

R&A Program Review

The changing budgetary environment and programmatic assumptions of the SSED program require a full-scale review of the three budget elements that sustain or programmatically interact with planetary peer-reviewed science. These are the R&A, MO&DA, and the new ATD lines in the SSED budget. Both R&A and MO&DA contain program items that were defined and organized at an earlier time, during a period in which the SSED budget was expected to expand. It is now necessary and appropriate that these programs be reviewed to ensure consistency with clear priorities and a realistic view of the future. Similarly, it is necessary that the ATD be initiated with full and proper cognizance of its interaction with the R&A program. *To achieve these ends, the Committee recommends that the SSES commission full-scale reviews of the R&A, MO&DA, and ATD programs.* The purpose of these reviews will be to reconsider all program elements and priorities within those three lines. This will ensure effective use of budget resources and contribute to the stability and productivity of planetary peer-reviewed science.

Advanced Analytical Experimental Technology Development in Planetary Science

The state of the nation's technology is defined in part by the state of development of its analytical, experimental, and computational capabilities. For example, if a company needs to produce a high purity material for some product, it cannot do so if it lacks the capability to analyze that material and demonstrate that it is pure to the requisite level. A good example is the requirement that semiconductors be free of contaminants at the part-per-billion level.

The Apollo Program infused university and government laboratories in the U.S. with advanced experimental, analytical, computational, and other detector equipment to study the returned lunar samples. Scientists used this equipment to obtain accuracies unforeseen by the manufacturers, being driven by the need to analyze ever smaller samples at ever higher precision. These developments had significant impact on the commercial sectors of our society. A full discussion is contained in a report titled: *Advanced Analytical and Experimental Technology Development in Planetary Science (Report of the Planetary Materials and Geochemistry Management Operations Working Group, SSED/NASA Headquarters, January 1994).*

NASA has not invested heavily in advanced experimental, analytical, and computational instrumentation since Apollo. The result has been that American laboratories lag behind those in Europe and Japan in modern instrumentation, and manufacture of advanced instrumentation has shifted overseas.

The SSES proposes that NASA institute and support an Advanced Analytical and Experimental Technology Development Program in Planetary Science to help recover from this failure to invest in the future. Our experience with Apollo suggests that such a program could nurture new U.S. companies and drive product development in existing companies, as well as reinvigorate U.S. university laboratories. *As a suggestion, an investment of about $10 million per year over an initial 10-year period would effectively revitalize the institutional laboratory capabilities. This should be an augmentation to the R&A program: this initiative should not be funded from existing R&A funds.*

6. Education Initiative

It is a maxim that the planetary program has contributed learning benefits to the nation since its very inception. These benefits consist of new scientific knowledge about the solar system, new technologies demanded by deep-space probes, and the stimulus to learning that inevitably accompanies exploration and discovery. Even though these contributions to learning have been the immediate business of a few—scientists, engineers, and managers—they have reached and influenced millions of people positively, including teachers and students, parents and children throughout America and worldwide. For these people beyond the NASA family, the learning benefits of planetary exploration have been largely unstructured and unplanned.

The SSES is aware of the mounting educational problems in America, particularly with respect to science and mathematics, including lessened appreciation of the *implications* of science and reduced motivation for learning basic skills, such as conceptual thinking, quantitative reasoning, and problem solving. It is also cognizant of increasing calls from policy makers for federally funded scientific research to become more relevant to the nation's social needs and to make more identifiable contributions to public life. These problems and these expectations have prompted calls from the scientific community for enhanced educational contributions from research, including the recent recommendation of the Astronomy Survey Committee (the Bahcall committee) for "an education initiative in astronomy."

The relationship that could or should exist between the acquisition of advanced knowledge and the basic teaching and learning that occur in the classroom, to say nothing of the informal learning that goes on in homes and other settings, is not obvious or well established. Nevertheless, there is a widely held opinion, which the Committee shares, that the topical areas of planetary research overlap strongly with people's interest and curiosity. This includes questions about the uniqueness of the Earth as a habitat for life, knowing how and why the conditions on other planets are different from Earth, as well as exploration in and of itself. Also, the tools and methods of planetary exploration—and the interesting people who are the planetary explorers—appear to carry educational potential, which might find use, if appropriately and effectively transformed in educational terms and communicated.

The SSES is aware of the risks involved in increasing the "educational" activities of the planetary program at a time when resources for research are declining, and the competition for them is intensifying. In the recommendations that follow, the Committee abjures any intent to directly or indirectly promote the planetary program or any particular mission or research project. The recommendations are designed to minimize *through process* any self-serving abuse of the recommended expansion of educational activities based on planetary science and exploration. Also, the scope of this initiative is nonprofessional education; that is, not related to the production of new planetary scientists, but rather focusing on K–12, first-year college, and informal public education. In these areas, the SSES believes a well-conceived education program could give rise to unique and useful educational products and services, which, while they would never justify the planetary program on the basis of accountable educational benefits, would make, nevertheless, distinctive and admirable contributions to national life.

The recommendations that follow envision an objective, legitimate process to open the planetary program for the development of educational products and services, which the SSES does not wish to characterize or envision specifically. The Committee believes that the opportunity itself, which would be inherent in a distinct SSED program for education, will bring forward the variety of factors and circumstances that will be essential to outstanding results. These factors include new alliances between people in the planetary and education communities, increased involvement by researchers in teaching of nonprofessionals, new career paths for people who have been involved in the planetary program, as well as new jobs based on the products and processes that may arise. In this respect, the SSES notes the favorable legal climate for private sector exploitation of the intellectual property rights to inventions and innovations developed with federal funds. Indeed, the SSES philosophy is that competition—in the SSED education program as well as in the education marketplace—should be the ultimate arbiter of success.

NASA is an 'idea company' for most Americans. NASA thus shares a mantle of promoting and nurturing intellectual progress that has been part of our national fabric from the outset, and that has been an abiding element of the American ethos and institutions ever since. Education is a special business having to do with ideas, and NASA must learn to commit and organize itself to assure more conspicuous success and leadership in this area. NASA's current strategic plan for education, produced by the Education Division, makes no specific reference to the science programs nor the manner in which their education benefits are to be produced. To address this issue, and to accept responsibility for achieving the learning benefits of planetary exploration, the SSES makes the following recommendations, which we expect will bring into being an effective and workable programmatic framework—including resource commitment, organization, and process—for the education program of SSED.

Recommendations

1. The SSES recommends the establishment of an education program within the SSED based on the unique assets of the planetary program, including its scope of inquiry, accomplishments in exploration, its methods and missions, and its community of "planetary explorers"—scientists, engineers, and managers.
2. The SSED education program should be open and competitive, based on articulated criteria and priorities, which should be selected with external advice to derive the greatest educational benefit per dollar from the planetary program as a whole. The criteria should include ones for both selecting and evaluating educational projects.
3. The SSED education program should be externally advised and reviewed, initially by the SSES, which should provide oversight on an ongoing basis.
4. Education proposals should be independent of science and mission proposals, although education proposals based on investigations and missions are to be encouraged.

7. Advanced Technology Development

Integrated Technology Strategy

The Office of Space Science (OSS), in alliance with the Office of Advanced Concepts and Technology (OACT), has developed an Integrated Technology Strategy to guide its investments in technology for space science missions. The strategy ensures that OSS is responsive to the nation's technology thrust and that OSS missions can take advantage of and influence the development of new technologies. The Technology Strategy establishes four goals:

1. OSS will identify and support the development of promising new technologies that will enable or enhance space science objectives and reduce mission life cycle costs.
2. OSS will infuse these technologies into space science programs in a manner that is cost effective with acceptable risk.
3. OSS will establish technology transfer as an inherent element of the space science project life cycle.
4. OSS will support the development of strong implementing partnerships among industry, academia, and government to assure the nation reaps maximum scientific and economic benefits from its space science program.

To help achieve these goals, a number of new OSS policies have been established. These require that each OSS mission contribute to the advancement of technology, and that each OSS division develop and execute a technology plan that emphasizes technology identification, infusion, and transfer. The policies also address space validation of new technologies, either through the flight of "technology experiments" on science missions or through OSS participation in dedicated technology flight missions. Managers, engineers, and scientists are required to identify and "protect" resources for technology. The overriding goal is to ensure that OSS missions can continue to advance even as budget pressures increase, and to ensure that the nation derives the greatest possible economic and scientific benefit from its investment in space science missions.

Advanced Technology Development

The SSED recognizes that a key to the achievement of the goals described in the Integrated Technology Strategy is a vigorous program of Advanced Technology Development (ATD). ATD activities will focus on bringing high-priority technologies to flight readiness so that they can more easily be infused into space science missions, without the perceived potential for increased mission cost and risk that has historically hindered this process. This will be accomplished by testing prototypes of new-technology subsystems and instruments in a laboratory environment, followed by insertion into system testbeds to validate system-level performance and interactions. Certain critical technologies may also require validation in space prior to use on a mission. Through these activities, technologies will be "picked up" from OACT or other technology developers and matured to the point that Project Managers and Principal Investigators are confident of their performance and benefits. The result will be a clear pathway for the use of new and evolving technologies that reduce the cost and risk of SSED missions and improve their scientific performance. Emphasis will be placed on key multi-mission technologies to enhance the benefits to the overall SSED and OSS programs. ATD will also serve as a mechanism for the development of implementing partnerships with industry and universities and is thus crucial to successful technology transfer.

ATD Content and Funding

With its focus on technology testing and validation at the system level and in the appropriate environment, ATD serves to bridge the gap between basic technology research and initial development, conducted by OACT or other organizations, and actual use of the technology on a flight mission. Thus, successful ATD projects require close communication and a clear funding relationship with both OACT and the flight missions. In general, basic research, feasibility studies, and component-level validation will be funded by OACT based on mission requirements developed by the SSED Advanced Programs Office. These activities have been referred to as Technology Levels 1–4. Levels 5–7, encompassing breadboard validation, prototype development and ground testing, and space testing if required, are the focus of ATD and should be co-funded by OACT and SSED. The level of SSED support will increase as the technology development level increases. Ideally, an industry partner will also participate in these ATD activities. Levels 8–9 represent the actual incorporation of the validated technology into flight or ground hardware and its use on a mission, and are therefore the responsibility of SSED Flight Programs. The SSED Advanced Programs Office will coordinate all of these activities to ensure synergy without duplication of effort.

There have historically been several sources of ATD funds within SSED: (a) the Advanced Programs Office resources, either within specific mission studies or as multi-mission technology developments; (b) the Planetary Instrument Definition and Development Program for instruments and sensors; and (c) the advanced development resources within the Multimission Operations Systems Office.

While these resources are significant, they are clearly insufficient to meet the technology challenges of the evolving planetary program. Expansion of ATD resources will be possible as near-term ATD investments begin to pay off in reduced mission life-cycle costs. Some of the savings will then be reinvested in ATD to achieve further reductions. In particular, savings in the planetary mission operations and data analysis budget will serve as resources for expanded ATD activities.

ATD Selection and Prioritization

ATD investments will reflect the priorities in this Strategic Plan and will be derived from science and mission requirements. Since many likely missions have similar requirements, especially as they relate to the goal of life-cycle cost reduction, many ATD activities will benefit a large number of SSED missions. ATD investments will focus on these multi-mission technologies and on establishing critical science and engineering capabilities required by individual missions.

It is clear that the number of important ATD activities will far exceed SSED's financial resources, so ATD investments must be carefully selected. One of the primary goals of the Advanced Programs Office is to conduct trade studies aimed at understanding mission and technology requirements. By developing "point-design" missions that respond to key science objectives, and by perturbing these designs in a parametric fashion, the sensitivity of mission performance and cost to specific technology assumptions can be derived. This process is used to develop technology requirements to communicate to OACT and other technology developers, as well as to establish candidates for ATD funding within SSED.

ATD investment priorities will be determined according to the following criteria: (a) the technology supports missions that have high priority within NASA, the space science community, and the Administration; (b) the technology is enabling or significantly enhancing for a key SSED mission, and the benefits of its use have been quantified; (c) ATD-funded validation is required before Project Managers or Principal Investigators will baseline use of the technology; (d) the technology has multi-mission applications within SSED; (e) a credible technology transfer plan exists, and industry interest has been expressed, evidenced primarily by industry co-funding of the ATD activities; and (f) applications to other non-SSED space science missions have been identified.

The Technology and Information Systems Office within OSS will assess and coordinate these interdisciplinary ATD activities.

Current ATD Activities and Plans

Current ATD activities are focused on the high-priority missions described in this strategic plan, and on future expected missions that require specific long lead-time technologies. The goal is to help reduce the life-cycle costs of these missions while providing the new scientific and engineering capabilities they require. Although many details of future missions are not yet known, especially within the Discovery and Mars Surveyor programs, their likely needs can be anticipated well enough that effective ATD planning can proceed now. In fact, most planetary missions will derive significant benefit in terms of life-cycle cost reduction from a relatively small set of technologies. These core ATD thrusts are: (a) reduced mass spacecraft subsystems ("micro-technologies"), (b) small solar electric propulsion, (c) low-cost mission operations technologies and enhanced spacecraft autonomy, and (d) reduced mass instruments and new instrument concepts (funded via the Planetary Instrument Definition and Development Program).

Other mission-specific technologies will also be developed to provide critical capabilities for individual missions. While some of the missions are outside the planning horizon considered in this Strategic Plan, the technologies are included in current ATD planning because of the long lead time required for their development at realistic funding levels.

Table 2 gives a summary of the current ATD activities and plans for the different SSED mission classes. Technologies for which there is an active SSED-funded ATD project are underlined. Although many mission types require very similar technologies, in most cases the specific performance requirements will differ. Additional detail on technology requirements and ATD plans, including performance goals, can be found in the SSED Technology Plan.

ATD Flight Validation

The ATD program must include a flight test component so that critical technologies can be validated in space in a manner that approximates their use on a science mission. Many of the technologies that have the potential for the highest payoff will require space flight tests before they can reliably be baselined on a science mission. To reduce the costs of this portion of the ATD program, "piggy-back" or Shuttle Small Payload opportunities may be used in the early stages to validate certain components or subsystems. SSED science missions may also serve as platforms for the validation of new technologies, as recommended in the OSS Integrated Technology Strategy. Ultimately, SSED will seek to participate with OACT and other OSS divisions in the design and flight of spacecraft that incorporate a number of new technologies. These tech-

TABLE 2. CURRENT AND PLANNED ATD ACTIVITIES

	Mars Surveyor and follow-on missions	*Discovery*	*Outer Planets*	*Extra-Solar Planetary Systems*	*Rosetta* and far-term missions
Propulsion	High Isp Chem. Propulsion	Small SEP High Isp Chem. Propulsion Low-leak ACS	Small SEP High Isp Chem. Propulsion Low-leak ACS	-----------	Small SEP High Isp Chem. Propulsion Low-leak ACS
Power	Adv Secondary Batteries Impr. PMAD	Improved Solar Arrays Adv. Secondary Batteries Improved PMAD	Improved Solar Arrays Adv. Secondary Batteries Non-RTG Power Improved PMAD	-----------	Improved Solar Arrays Adv. Secondary Batteries Improved PMAD
Thermal Control	Low-mass MLI, radiators	Low-mass MLI, radiators	Low-mass MLI, radiators	Therm. stable structures	Low-mass MLI, radiators Active control High-temp. electronics
Telecom	Mini X-ponder X or Ka SSPA	Mini X-ponder X or Ka SSPA Low-mass antenna	Mini X-ponder X or Ka SSPA Low-mass antenna	----------	Mini X-ponder X or Ka SSPA Low-mass antenna
Sensors and Instruments	Mini Seism'ter Mini-Meteorology	Higher-Temp SWIR Arrays Tunable filters Low-mass optics Integrated Payl'd	Higher-Temp SWIR Arrays Micro Mass Spectrometer Integrated Payl'd	Precision optics Coronagraph optics	Gamma- ray sensors, scanning electron microscope technologies
Control and Data System	High-density Electr Pack'g Micro star, sun sensors High-capacity SSR	High-density Electr Pack'g Micro sensors Micro Gyros High-capacity SSR	High-density Electr Pack'g Micro sensors Micro Gyros High-capacity SSR	High-density Electr Pack'g	High-density Electr Pack'g
Structures, Architectures	Lightw't Struct. Micro Cabling, Connectors	Lightw't Struct. Micro Cabling, Connectors	Lightw't Struct. Micro Cabling, Connectors Integrated Structures	Lightw't Struct. Precis. Metrology	Lightw't Struct. Micro Cabling, Connectors Integrated Structures
Operations (On-Board and Ground)	Rapid sequenc. Data editing, compression Rapid s/c simul.	Rapid sequenc. Auto opnav Auto pointing/ tracking Data editing, compression Rapid s/c simul.	Rapid sequenc. Auto opnav Auto pointing/ tracking Data edit, compr. Dormant cruise Rapid s/c simul.	Rapid sequenc. Data editing, compression Data visualiz. Rapid s/c simul.	Rapid sequenc. Data editing, compression Rapid s/c simul. Auto opnav Auto pointing/ tracking
Special Capabilities	Micro-rovers Sample handling, Auto rendezvous docking, and landing, Adv. entry sys.	S/W plan'g tools New costing techniques Penetrator and probe tech.	Adv. lightw't entry systems	Interferometry techniques	Penetrators & landers, auto landing, Sample acquis/ handling, Balloons for Venus, Mars

Acronyms:

ACS: Attitude Control Subsystem
MLI: Multi-Layer Insulation
PMAD: Power Management and Distribution
RTG: Radioisotope Thermoelectric Generator
SEP: Solar Electric Propulsion
SSPA: Solid-State Power Amplifier
SSR: Solid-State Recorder
SWIR: Short-Wavelength Infrared

nology-driven missions can also serve as excellent opportunities for SSED science observations, especially if they encompass flights to the Moon or near-Earth asteroids.

The SSED is participating in a flight validation activity for the microrover on the MESUR Pathfinder mission, which will be launched in 1996. The microrover development is being funded by OACT as an essential element of NASA's long-term goals for Mars exploration. SSED is providing a flight opportunity and resources on the Mars Environmental Survey (MESUR) Pathfinder mission to help complete the technology development and to validate the system for flight on future Mars surface missions. The microrover will also serve as a platform for some of the MESUR Pathfinder science observations.

Microspacecraft Testbed

New low-mass technologies and subsystems are one of the keys to reduction of mission lifecycle costs. These subsystems will be developed and validated in an orderly sequence, driven by the requirements and priorities of SSED missions and made available to the flight projects on their schedules. A critical step in the technology validation process is the incorporation of microspacecraft technologies into the Flight Systems Testbed located at JPL. In many cases, such testing will be sufficient to validate components for flight; in other cases, subsequent space-based testing will be required. SSED will continue to fund the Microspacecraft Development Program (MDP) as an important component of its ATD activities. The MDP will coordinate the wide variety of ongoing mass-reduction activities and will develop or procure components for validation in the Flight Systems Testbed. The MDP will also ensure that advanced mission studies are fully aware of the state of micro-technology, and will serve as a conduit for the infusion of non-NASA micro-technologies into the SSED program. The MDP will develop and maintain a "road-map" showing how ongoing activities can help to fulfill the ultimate vision of an SSED microspacecraft.

ATD Funding Profile

The recommended SSED funding profile for ATD during the next 5 years is a gradual augmentation each year, with a goal of reaching a level of funding equal to approximately 5 to 7% of the total SSED budget by the year 2000 (compared with the current level of funding of around 1 to 2%). This excludes the Planetary Instrument Definition and Development Program and advanced development funding within the Multimission Operations Systems Office program, both of which are bookkept separately. Also excluded are OACT or other co-funding that will be applied to the activities. It is the responsibility of the SSED Advanced Programs Office to ensure that all of these sources of ATD funds are coordinated. Additional detail can be found in the SSED Technology Plan.

Responsibilities for Technology Planning, Utilization, and Transfer

The development of technology requirements for SSED missions is one of the primary responsibilities of the advanced mission studies that SSED funds each year. In addition, each Center's technology or advanced concepts organization identifies key technology needs; these may support long-range missions for which there is no active study, or they may represent important capabilities that can affect the selection of future mission studies. All of these requirements are input to the SSED Technology Plan, which is updated every year by the SSED Advanced Programs Office. This Technology Plan is the framework for communication of technology needs to OACT and for the assessment of ATD investment opportunities.

Each SSED-funded advanced mission study and mission development activity will designate a Project Technologist. This individual will be responsible to the project (or study) manager for the identification, advocacy, tracking, and infusion into the mission of important new technologies, and for their transfer to the private sector whenever possible. The Project Technologist will also be responsible for managing any joint SSED/OACT ATD activities that support the study or project. In addition, the Project Technologist will develop a mission technology plan that defines all technology development, infusion, and transfer goals of the mission and forms the mission's input to the SSED Technology Plan.

While SSED technology and ATD requirements are developed on the basis of scientific priorities and mission considerations such as cost and risk reduction, their potential for transfer to private industry will be a constant element in the prioritization and development of new technologies. Through its ATD investments, SSED will define technology transfer opportunities and help to develop the partnerships that are a key to successful technology transfer. The Project Technologist will be responsible to the Project Manager for technology transfer activities within each study or flight project. Progress in technology transfer will be reported to SSED as a key deliverable for each mission or study. The Advanced Programs Office will be responsible for facilitating and tracking technology transfer progress within SSED with coordination by the OSS Technology and Information Systems Office.

8. Mission Operations

NASA's space science missions are immersed in a revolution concerning the basic approach to mission operations. The goal is to develop spacecraft and ground control systems that will provide autonomous operations and reduce costs. NASA is moving aggressively to identify and develop new technologies required to fly missions with small teams, as opposed to the large teams we have typically used in the past. These technologies apply both to spacecraft components and to ground components as discussed below.

Spacecraft-Related Technology for Lower-Cost Mission Operations

Margins

Flying planetary spacecraft with little or negative margin is expensive both from the point of view of the tools required to validate plans and sequences and the processes, analysis, and simulation required. The technology efforts being applied to microspacecraft must include microspacecraft that have significantly more margin than the current generation of spacecraft, especially in power, thermal, telecommunications, data storage, and computational speed.

Larger Memories and Faster CPUs

Larger memories and faster CPUs will enable the use of standard on-board operating systems so that modern programming languages may be used in flight computers. These languages will enable faster coding and checkout of flight programs, standardization of some functions, and a wider selection of staff since they will not have to be specially trained for the machine level code of a particular processor as is the case with Hubble Space Telescope.

We also expect that with additional capabilities in the flight computer, we will be able to include spacecraft autonomy specifically for the purpose of lowering operations costs as opposed to using it exclusively for spacecraft safety. These additional capabilities will also allow the use of a higher level sequence language on-board, which again will reduce the sequencing costs on the ground. The faster CPUs will reduce or eliminate the need for data system simulations down to the micro-second level and make possible the use of interrupt driven sequences (event driven sequences).

Solid State Memories and Efficient, Easy-to-Use On-board Data Management

The projected Deep Space Network (DSN) loading analysis shows a significant over-subscription of its services between now and the year 2000. This over-subscription will lead to the need for less frequent tracking and thus large solid-state storage devices. These large storage devices will also then necessitate spacecraft operating systems that enable easy data management of the stored data. The technology must ensure that the data storage does not require ground modeling of what data are where, but is more analogous to the way we all use PCs today.

The limited tracking resources also require higher data transmission rates for the outer-planetary missions to support the shorter tracking periods and larger storage devices.

Spacecraft Control and Sequencing

Event-Driven Sequencing

All past missions have been flown in what is called the time domain. The mission planners lay down on a time line what must be done to accomplish the mission objectives, and then convert these plans to sequences and then to commands and the time of execution for these commands.

Asteroid sample missions will require event driven sequences; that is, sequences that are a function of an external event detected by the spacecraft sensors. We have little experience on how to plan or use these capabilities and must begin the research and analysis of event-driven sequencing now.

On-board Computation of Maneuvers

More computer power will allow the development of routines to compute maneuvers onboard given a vector and delta V. Developing these routines and validating their use is required before we can eliminate the current process of planning each aspect of the maneuver, analyzing the resultant sequence and then sending the sequence to the spacecraft.

Process Control Applied to the Up-link Process

This is similar to the event-driven sequencing but somewhat different. A lot of research has been done in the area of process control. It has been shown that spacecraft control can be accomplished via the process control theories that have been developed. These process controls are not always done in the time domain, but more often via a set of rules, so that when the criteria of a set of rules are met, then certain actions will occur.

To support this, we need the ability to easily validate, during a flight, a new set of rules on the ground and then transmit these rules to the spacecraft once they have been validated. This implies a process shell that is the same on the ground and on-board the spacecraft. DoD's Clementine Mission used a very early development of this, and we need to take this start and see how it can be modified for planetary applications.

Up-link Service Specifications

NASA's Office of Space Communications is funding an initial study to develop a set of standards or specifications that when followed will make each spacecraft look the same from a command and control point of view. This will allow the same ground system to support different missions without significant modifications in a way similar to what the Consultative Committee on Space Data Systems standard has provided.

Standardized Data Collection, Storage, and Transport

The process of data collection, storage, retrieval, and transport from the instrument to the ground is functionally the same from mission to mission. With larger computers, and modern languages, we need to provide a set of software that provides these services across a set of spacecraft computer platforms and is compatible with the ground capabilities of the DSN and JPL's Multimission Operations Systems Office (MOSO). Then the projects can concentrate on the science and unique aspects of new missions as opposed to re-implementing the data collection, retrieval, and transport for each new mission.

9. Budget Outlook

Introduction

An important and conclusive step in the strategic planning process is to reconcile the proposed program with the budget guidelines. This is done by accumulating the annual costs of the various elements of the program and comparing this total run-out to the guideline funding cap for the program. The process is iterative, as the new start elements are adjusted to fit within the funding wedge between the run-out of the existing program and the funding cap, while also maintaining new start priorities reflecting both scientific and programmatic objectives. The results of this process and important conclusions relevant to the longer term viability of the solar system exploration program are presented here.

TABLE 3
BUDGET OUTLOOK* FOR SOLAR SYSTEM EXPLORATION 1995–2000

PROGRAM ELEMENT	NOTES	1993	1994	1995	1996	1997	1998	1999	2000
CURRENT PROGRAM (INCLUDES FY '95):	1								
RESEARCH & ANALYSIS		102	115	115	115	115	115	115	115
MISSION OPERATIONS & DATA ANALYSIS		164	141	128	139	153	177	175	175
MARS '94		3	3	1	1	1	1		
CASSINI		205	267	255	192	107	14		
DISCOVERY-1 (MESUR PATHFINDER)			61	78	36				
DISCOVERY-2 (NEAR)			67	52	43				
MARS SURVEYOR PROGRAM:	2								
1996 MARS ORBITER				77	58	9			
FUTURE MISSIONS				1	50	80	99	104	105
CURRENT PROGRAM RUNOUT (CPR) TOTAL		474	654	707	634	465	406	394	395
BUDGET CAP (4% DEFLATION FROM '95)	3	474	654	707	680	654	629	605	581
PLANNING WEDGE (CAP-CPR)	4	0	0	0	46	189	223	211	186
STRATEGIC PLAN FOR NEW STARTS:	5								
DISCOVERY-3 (FY '97 NS)					15	60	75	20	
DISCOVERY-4 (FY '98 NS)						15	45	75	35
DISCOVERY-5 (FY '00 NS)								15	60
DISCOVERY-6 (FY '01 NS)									15
DISCOVERY SUBTOTAL	6				15	75	120	110	110
PLUTO FAST FLYBY (FY '96 SLOW START)	7				15	70	90	125	80
US ROSETTA PAYLOAD/OPS SUPPORT	8						5	10	15
ASEPS-1 (FY '00 NS)	9								25
ATD AUGMENTATION	10				10	20	25	30	30
MO&DA PRODUCTIVITY INITIATIVE	11					-11	-31	-28	-25
NEW PROGRAM RUNOUT (NPR) TOTAL					40	154	209	247	235
RESIDUAL WEDGE (WEDGE-NPR)	12	0	0	0	6	35	14	-36	-49

*One possible scenario as of April 1994

Budget Table Layout

Table 3 lists funding profiles that were prepared as part of the budget reconciliation process. The table is structured to illustrate the process of fitting the proposed strategic plan into a funding wedge consistent with the current program as proposed in the FY '95 budget request, which includes the Mars Surveyor Program new start. This is followed by a computation of the annual funding cap assuming a 4% deflation factor benchmarked to the FY '95 budget request, as guidelined by OSS. The difference between these two data elements yields the available funding wedge within SSED for future projects. The proposed new starts are then accumulated through FY 2000 and compared to the funding wedge. The difference in this comparison is the reserve (plus or minus) within the proposed plan. Note that the table also provides a clear indication of the timing; i.e., New Start years of the proposed new initiatives/flight projects for solar system exploration.

Table Notes

A series of notes, as referenced on Table 3, are presented here to explain various assumptions and relevant issues associated with the program elements included in the table. These are as follows:

1. The current program (including the last two fiscal years) is shown as presented in the FY '95 budget request. It includes the Mars '94 payload, Cassini, MESUR Pathfinder, and NEAR flight projects, and the MO&DA and R&A line items. Funding for the individual elements of the program is shown through the year 2000,

with that year's funding estimated by the SSES since it was not included in the FY '95 budget request.

2. The current program includes the FY '95 new start request for the Mars Surveyor Program broken into two parts: (1) the 1996 Mars Observer recovery mission, and (2) future Mars missions. The program is expected to continue into the next decade at an annual funding level of about $100M with launches every Mars opportunity (once every 26 months).
3. The budget cap guideline for SSED's program, received from OSS for the current strategic planning effort, was to expect an annual funding reduction of 4% in real year dollars for the remainder of the decade. The budget cap shown in the table uses this guideline assuming that the FY '95 funding request of $707M is the benchmark. After 5 years of reductions, the SSED budget shrinks by over $125M to $581M in the year 2000.
4. The available funding wedge for the proposed 1994 strategic plan is determined by subtracting the current program funding run-out (CPR) from the budget cap (CAP) as shown. The result is a wedge beginning in FY '96 at $46M, growing to a maximum of $223M in FY '98, and then declining steadily to $186M by FY 2000.
5. The proposed strategic plan is presented as a series of new starts beginning with all the expected Discovery missions, followed by three stand-alone starts, and concluding with two smaller program-level initiatives. Each of these is discussed in the notes that follow.
6. Four new Discovery missions are proposed to be started over the 5-year period from 1996 to 2000, each with a development cost of $150M plus $15M for "pre-start" definition studies. The funding profiles for these differ slightly to reflect other than exact fiscal year development cycles, but the total program averages about $110M annually.
7. Pluto Fast Flyby is proposed as an FY '96 slow start. This is tied to launching the first of two spacecraft in 2001, with the second being launched a year later. The total development cost of this project is currently estimated at $455M. Arrival at Pluto is expected before 2010.
8. The Rosetta project is proposed as a cooperative effort with ESA to conduct a comet rendezvous mission launched in 2003. The funding shown assumes NASA provides a nucleus lander, several "orbiter" science instruments, and assistance with flight operations for a total cost of $120M. The funding for this mission is expected to come from a comparable program reduction in anticipated MO&DA cost (see Note 11 below).
9. ASEPS-1, the first flight project of the Astronomical Study of Extrasolar Planetary Systems, is proposed as an FY 2000 new start. The total cost of this project is still under study with several competing flight concepts being considered at the Phase A study level. Development costs are expected to be in the $250 to 350M range.
10. An augmentation in the SSED's Advanced Technology Development (ATD) funding is part of the proposed plan. The purpose of the augmentation is to create a budget wedge of about $30M per year in order to flight qualify new technologies for future program implementation. Studies indicate that significant savings in future projects will be accelerated by such a test program. It is also intended that these test flights, primarily Earth-orbital, provide flights-of-opportunity for small science payloads as an added benefit.
11. SSED continues to seek efficiencies in the conduct of its mission operations and data analysis activities. As part of this effort, NASA management has challenged SSED to reduce its MO&DA costs by $120M between 1997 and 2001 in order to undertake its part in the ESA Rosetta mission. The reductions shown here reflect SSED's willingness to accept that challenge.
12. Accumulating the various new start/initiative costs of the proposed strategic plan and differencing the sum with the planning wedge yields the residual wedge, or reserve, as shown. Note that this reserve becomes a deficit in 1999 and 2000 if the 4% deflation guideline persists in the out years of the plan. Clearly, a continued reduction in the funding cap will eventually prevent SSED from maintaining

its program with new starts. The effects of this in the current plan begin to show at the end of the decade.

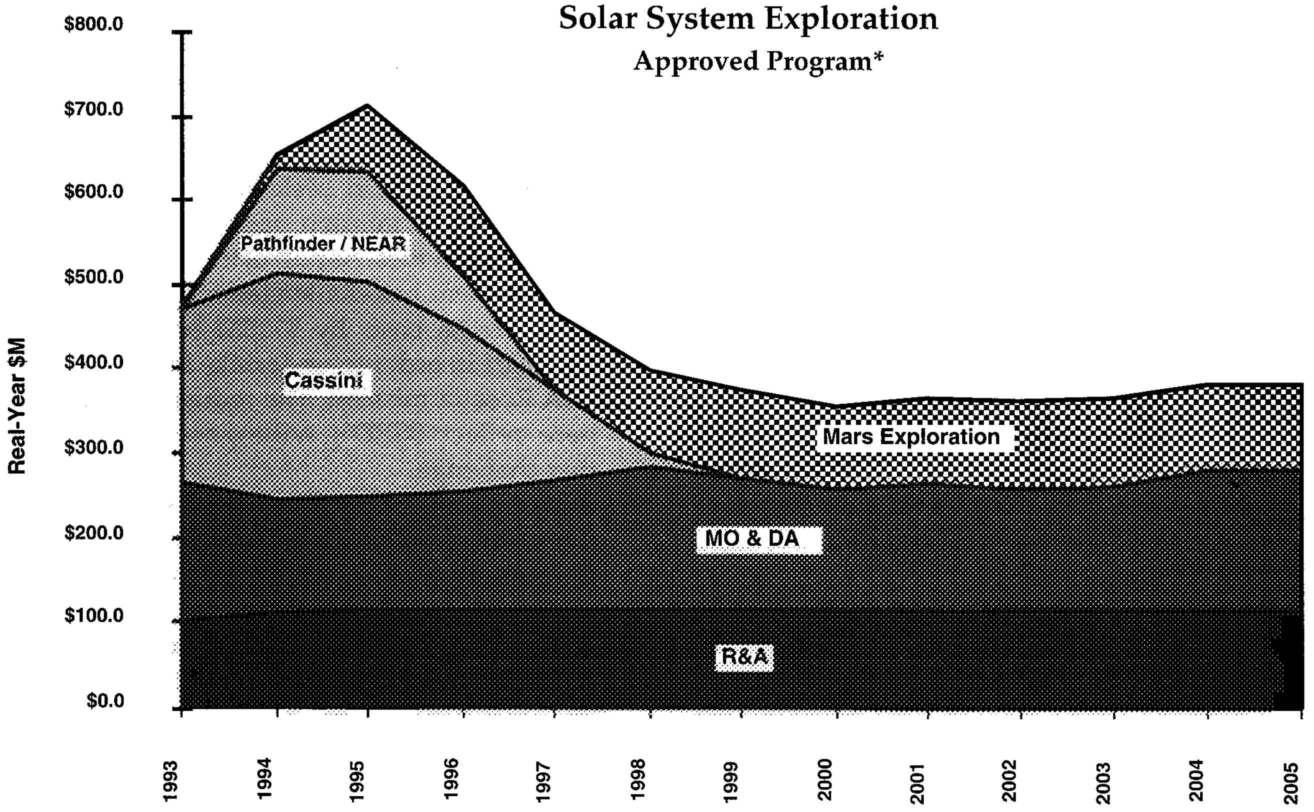
Budget Reconciliation

The data from Table 3 are presented in several funding run-out charts to illustrate confirmation of the reconciliation process. The current Approved Program, including the Mars Exploration FY '95 new start request, is shown in Figure 2. The figure displays the funding profiles of the various key elements of the current program in a plot of annual real-year funding versus fiscal year. As expected, the peak funding occurs in FY '95 at just over $700M, and then decreases rapidly to about half this level by the end of the 5-year planning horizon, continuing at about $350M thereafter. Figure 3 shows the impact of continuing the Discovery Program after NEAR on through 2005. The steady-state funding of the total program with Discovery is between $500M and $550M after 1997.

The final funding chart, Figure 4, adds all the proposed new initiatives to the current program elements and represents the SSES Recommended Program. Initiatives include, as identified in Table 3, the ongoing Discovery Program, the inclusion of NASA's contribution to the ESA Rosetta mission, the Pluto Fast Flyby, and the ASEPS-1 flight project. Also incorporated into the plan are the MO&DA cost-effectiveness effort, and an enhanced ATD program to assure the rapid infusion of new technologies into SSED activities. The total funding profile is within the guideline cap through FY '98, exceeding it thereafter even though the profile remains level at about $625M well into the next decade.

The impact of slipping one of the missions in SSED's new start queue, i.e. the Pluto Fast Flyby, one year from FY '96 to FY '97 was investigated. This would solve the funding cap overrun in 1998, but almost doubled the excess in 1999. The inevitable strangulation of a continually shrinking funding cap on the longer term program was clearly apparent in this exercise.

Figure 2
Solar System Exploration
Approved Program*



* Includes Mars Exploration Program (Mars Surveyor), proposed to begin in FY1995.

Figure 3
FY '95 Budget with Discovery

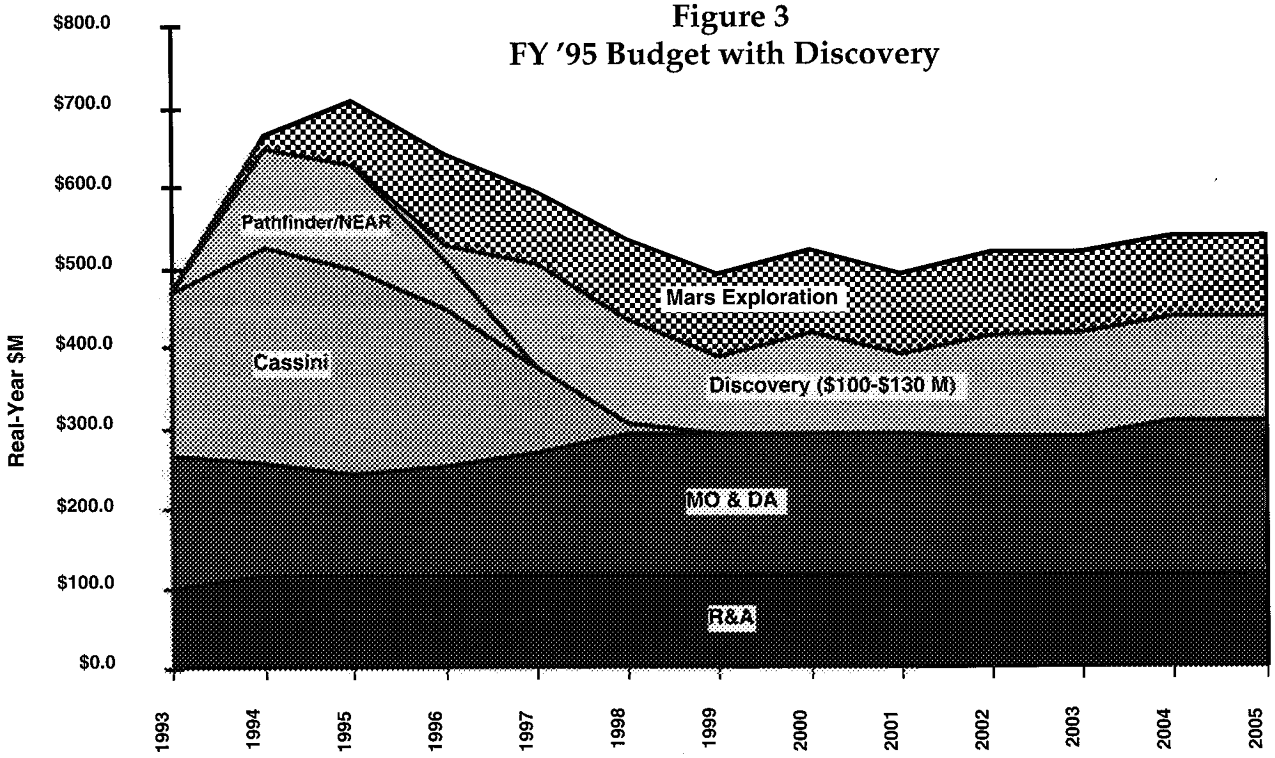
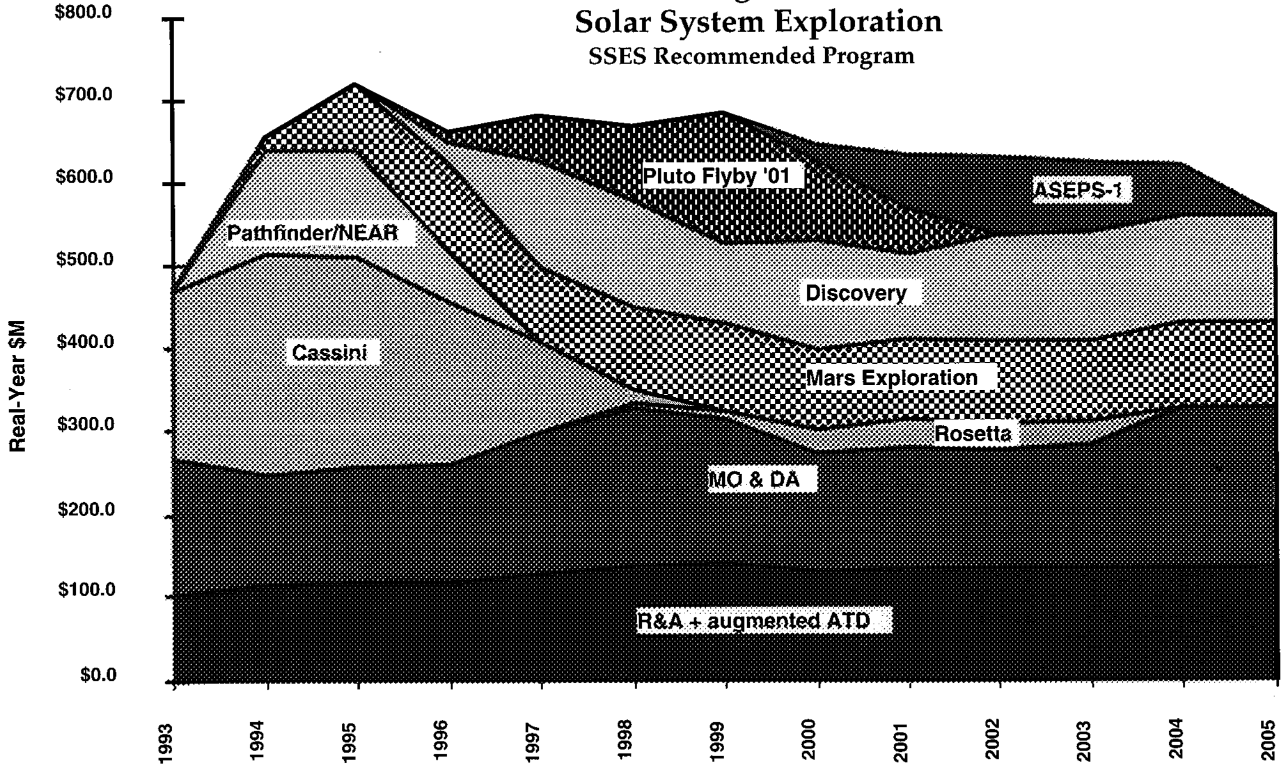


Figure 4
Solar System Exploration
SSES Recommended Program



Assessment and Outlook

The current program is robust and balanced in its quest to understand the origin and evolution of the solar system and life. In an effort to maintain this viability in the future, the SSES proposes a series of new starts/initiatives based on an aggressive program of cost reductions and new technology investments. The proposed plan maintains a balance of exploration activities, while complying with a challenging deflation cap on its future funding. This is accomplished through a careful choice of cost-effective high priority missions and specific future cost-reduction goals. The plan also includes near-term technology investments with the expectation of capability dividends beyond the year 2000. Such investments will aid SSED's efforts to maintain a strong program within a continued austere budget environment.

Nonetheless, by 1998 or 1999, the effect of continued negative compounding of the funding cap will eventually make it impossible to maintain program viability with new starts. In other words, sustained funding reduction to the planetary exploration program is a going-out-of-business scenario. It is proposed that a reduced funding cap be established as a goal, e.g., $600M by the year 2000. Once this reduced level is reached, the program should be permitted to continue at constant annual funding. Future program enhancements would then depend on the SSED's ability to become more cost effective through automation, increased productivity, and technology investments.

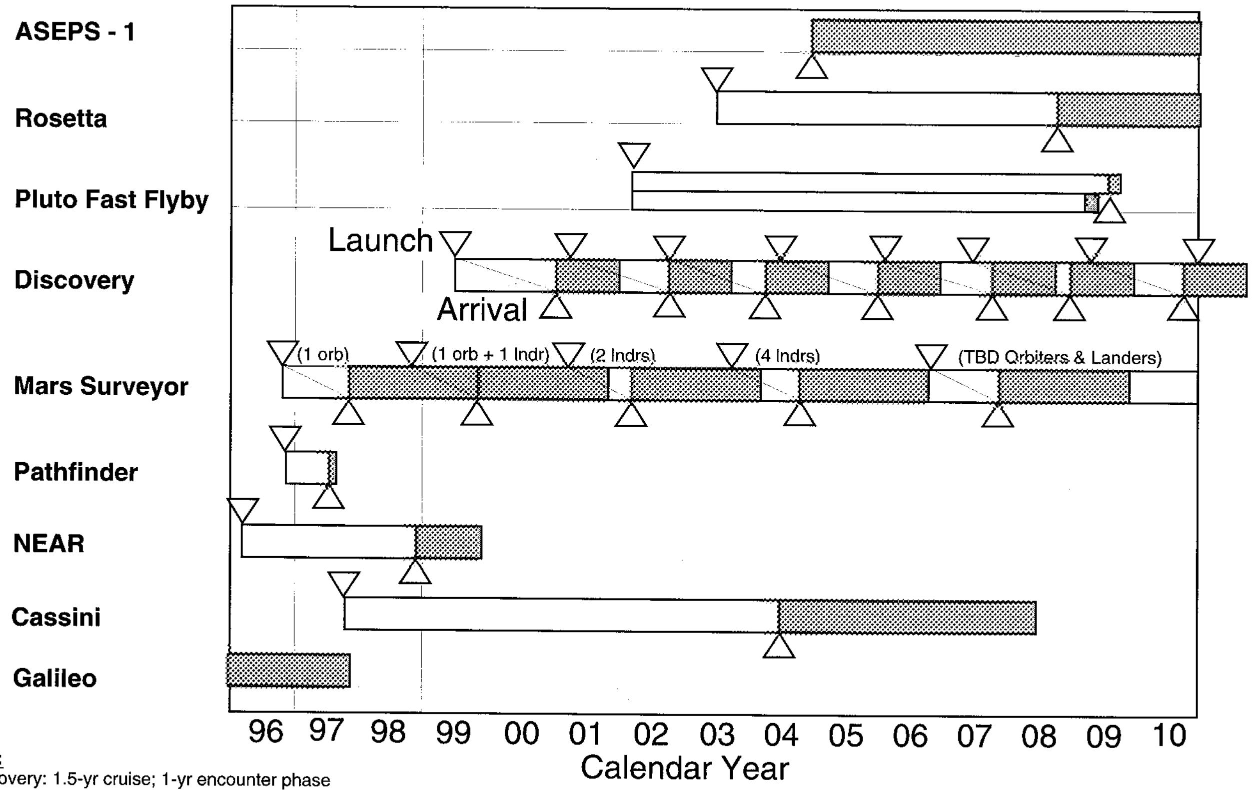
Appendix

Tables:

SSES Recommended Program: Mission Data Return

SSED Mission Strategy

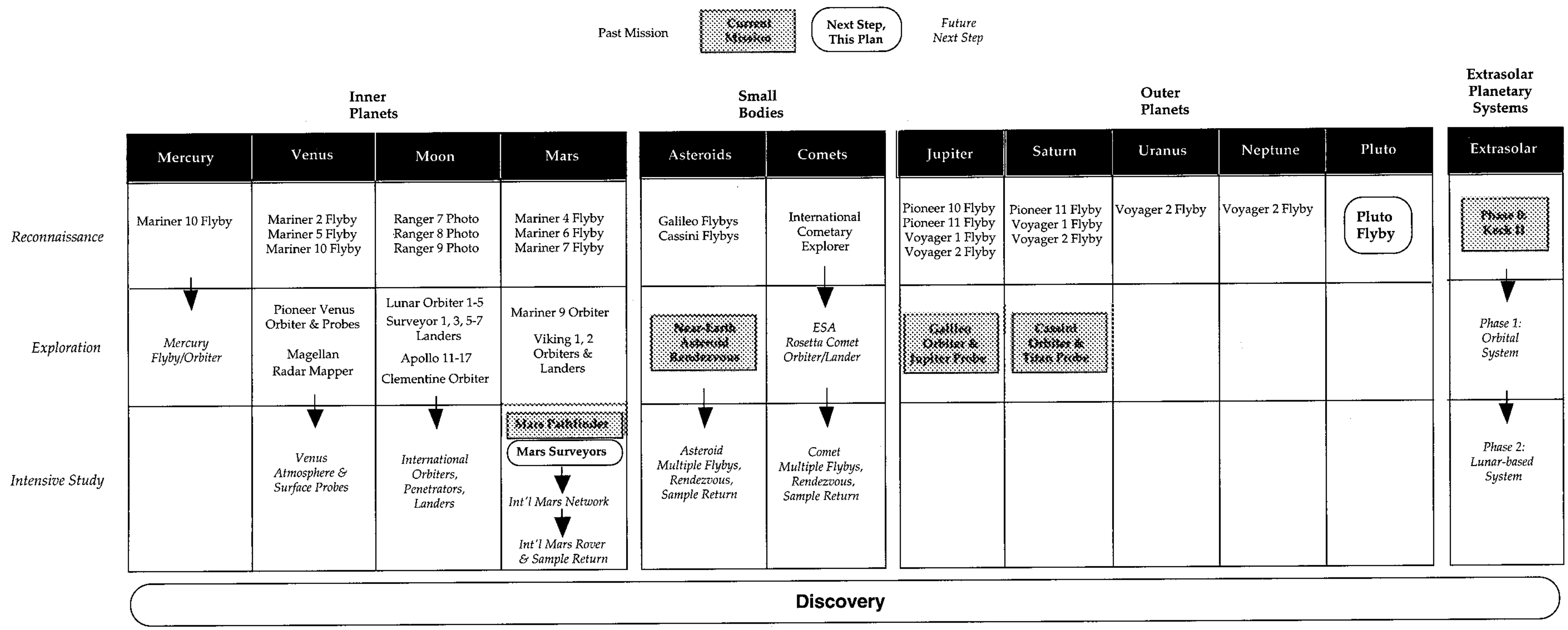
SSES Recommended Program
Mission Data Return



Notes:
- Discovery: 1.5-yr cruise; 1-yr encounter phase
- Mars Surveyor: 1-yr cruise; ~ 2-yr encounter phase
- Cruise:
- Encounter: ▨

- ▽= Launch
- △= Arrival

NASA Solar System Exploration
Mission Strategy



Past Mission | Current Mission | Next Step, This Plan | *Future Next Step*

	Inner Planets				Small Bodies		Outer Planets					Extrasolar Planetary Systems
	Mercury	**Venus**	**Moon**	**Mars**	**Asteroids**	**Comets**	**Jupiter**	**Saturn**	**Uranus**	**Neptune**	**Pluto**	**Extrasolar**
Reconnaissance	Mariner 10 Flyby	Mariner 2 Flyby Mariner 5 Flyby Mariner 10 Flyby	Ranger 7 Photo Ranger 8 Photo Ranger 9 Photo	Mariner 4 Flyby Mariner 6 Flyby Mariner 7 Flyby	Galileo Flybys Cassini Flybys	International Cometary Explorer	Pioneer 10 Flyby Pioneer 11 Flyby Voyager 1 Flyby Voyager 2 Flyby	Pioneer 11 Flyby Voyager 1 Flyby Voyager 2 Flyby	Voyager 2 Flyby	Voyager 2 Flyby	**Pluto Flyby**	Phase 0: Keck II
Exploration	*Mercury Flyby/Orbiter*	Pioneer Venus Orbiter & Probes Magellan Radar Mapper	Lunar Orbiter 1-5 Surveyor 1, 3, 5-7 Landers Apollo 11-17 Clementine Orbiter	Mariner 9 Orbiter Viking 1, 2 Orbiters & Landers	Near-Earth Asteroid Rendezvous	*ESA Rosetta Comet Orbiter/Lander*	Galileo Orbiter & Jupiter Probe	Cassini Orbiter & Titan Probe				*Phase 1: Orbital System*
Intensive Study		*Venus Atmosphere & Surface Probes*	*International Orbiters, Penetrators, Landers*	Mars Pathfinder **Mars Surveyors** *Int'l Mars Network* *Int'l Mars Rover & Sample Return*	*Asteroid Multiple Flybys, Rendezvous, Sample Return*	*Comet Multiple Flybys, Rendezvous, Sample Return*						*Phase 2: Lunar-based System*

Discovery

The mission strategy for Solar System Exploration encompasses all known objects in the Sun's planetary system, except for the Earth, the Sun, and the interplanetary medium (strategies for these targets are the responsibility of NASA's Mission to Planet Earth Office and OSS's Space Physics Division). Solar System Exploration also includes studies of the origin and evolution of planetary systems in general and an observational program to search for and characterize extrasolar planets. The intellectual framework for Solar System Exploration begins with reconnaissance missions, which are the first phase of inquiry and are characterized by discovery and a basic assessment of the target body, its environment, and its place in the larger context of our planetary system. These missions have focused typically on photo- and spectrometer-reconnaissance and the determination of basic properties such as the body's gravitational field. The exploration phase implies, for a planet, a return mission for orbital and/or landed science investigations. Exploration of a comet or asteroid could be a first visit to that object, while earlier reconnaissance missions will have occurred for that broad class of objects. The final phase of the program consists of missions for intensive study, which focus on answering fundamental questions such as the body's origin and evolution, and could include highly detailed investigations of its current nature and the relationship of its characteristics to the origin and evolution of Earth and of life on Earth. These missions imply in-depth studies and will often require the use of our most powerful and innovative technologies-- commensurate with the importance of the investigation and the associated technical challenges. A good example is our quest to determine whether or not life on Mars exists or has ever existed.

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