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Solar System Exploration
Technology Requirements and Planning Process

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SOLAR SYSTEM EXPLORATION TECHNOLOGY REQUIREMENTS AND PLANNING PROCESS

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Abstract

The NASA Office of Space Science, in alliance with the Office of Advanced Concepts and Technology, has developed an Integrated Technology Strategytoguide its investments in technology for space science missions. This strategy establishes goals and strategic objectives that ensure that NASA and the nation derive the greatest possible scientific and economic benefits from investments in space science missions and technologies, Within the Office of Space Science, the Solar System Exploration Division, in collaboration with the Office of Space Access and Technology, is developing a Technology Plan to implement these goals and to identify specific technology needs for solar system missions. This paper describes the philosophy, processes, and preliminary results of the systematic process being established for the identification and prioritization of solar system exploration "technology needs.

Introduction

NASA has in recent years renewed its commitment to the development and use of advanced technologies within its space science programs. This is in response to increasing budget pressures and the resulting need to make space science missions "Better, Faster, and Cheaper", coupled with the imperative that missions provide clear benefits to the national economy. Advanced technology is an essential parl of low-cost missions, and it is one of the primary ingredients that will keep space science missions viable and exciting in the coming decades.

In April 1994, NASA's Office of Space Science (0SS) released its Integrated Technolcg y Strategy. This document lays the foundation for the development of strong strategic alliances between 0SS and its technology providers in government and industry. It also clearly articulates the activities that each of its constituent science divisions must undertake to ensure the success of the strategy, The document states four Integrated Technology Goals:

Goal **1: 0SS** will identify and support the development of promising new technologies which will enable or enhance space science objectives and reduce mission life-cycle costs;

Goal 2: 0SS will infuse these technologies into space science programs in a manner that is cost effective with acceptable risk;

Goal 3: 0SS will establish technology transfer as an inherent element of the space science project life cycle;

Goal 4: 0SS will support the development of strong and lasting implementing partnerships among industry, academia and government to ensure that the nation reaps the maximum scientific and economic benefit from its Space Science Program.

The cornerstone of the strategy is the partnership between 0SS and the Office of Space Access and Technology (OSAT), and one of the keys to the success of this partnership is the preparation of clear technology development priorities within OSS. This paper outlines the process being used by the Solar System Exploration Division to develop these priorities and shows some preliminary results of this process.

Key Multi-Mission Technologies and the Planetary Mission Set

One of the keys to the development of a stable, long-term technology development plan is a clear understanding of the mission set to which the technologies are targeted. The mission set provides context for the identification of technology needs, serves as a guide for investments, and helps to identify expected technology need dates. Unfortunately, it is impossible to predict precisely how the mission set will unfold over time, given the constantly shifting budgetary constraints, evolving scientific priorities, and other unpredictable factors. In fact, a relatively firm planetary mission set embodied in the current Strategic Plan extends only to about the year **2000,** which is inadequate for meaningful long-term technology planning. Thus it is equally important to develop an understanding of the challenges facing the planetary program and the general characteristics of the types of planetary missions called for in the Strategic Plan. This allows identification of classes of missions and classes of technology needs which are relatively insensitive to changes in the actual mission set, Each class represents a basic thrust of the Solar System Exploration program and is thus stable and predictable on a much longer time scale than are the individual missions. This in turn allows development of relatively stable technology priorities. Table 1 summarizes some of the top-level goals of the planetary program and the derived classes of multi-mission technology requirements,

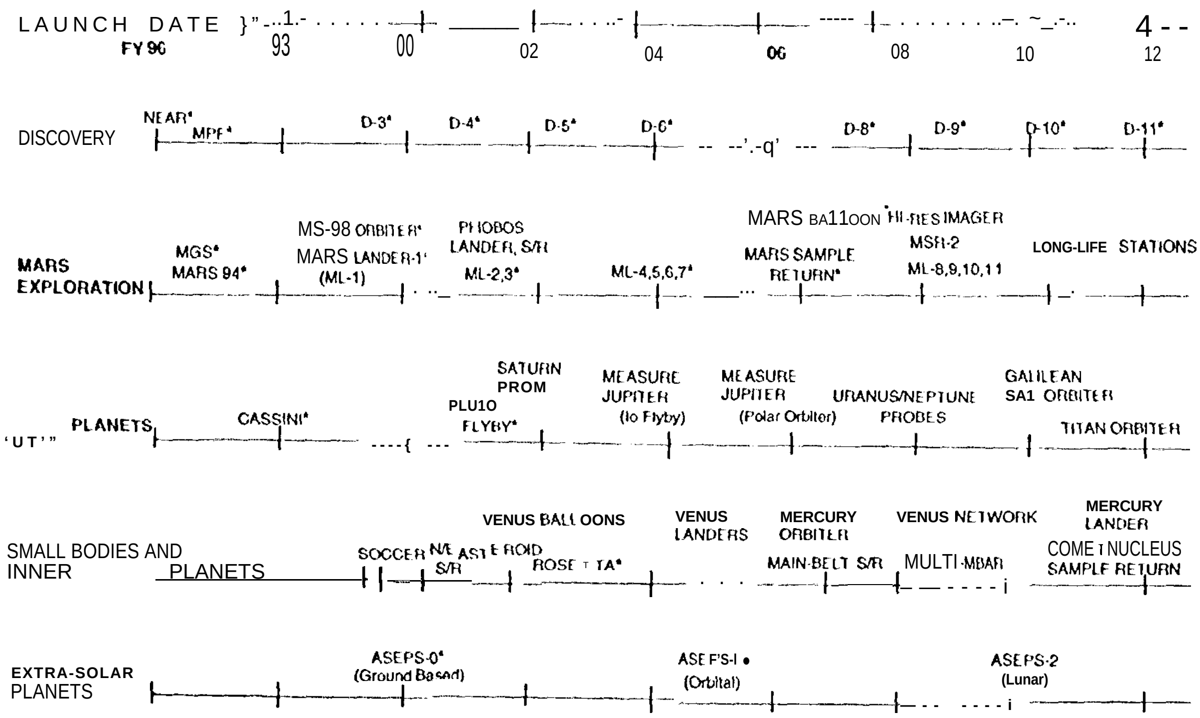
Table 1

Solar System Exploration
Broad Technology Goals

Goals	Derived Requirements
Reduce Launch Costs	Reduce s/c mass, improve propulsion
Reduce Operations Costs	Reduce flight time (implies reduced mass and improved propulsion) Enhance s/c autonomy, communications, and data handling Develop low-cost ground operations systems
Reduce Development Costs	Reduce mass, focus objectives, accept risk
Enable Next-Generation Missions:	
- Orbiters, landers, sample returns	Reduce mass, improve propulsion, develop surface operations and sample acquisition, analysis, and return techniques
- Enhance science quality/quantity	Improved low-mass sensors, instruments, data handling, and communications
- Discover/characterize extra-solar planets	Develop high-precision astrometry and interferometry

A mission set has been developed to serve as a template for the identification of more specific technology requirements and need dates. Missions are selected to be representative of the missions that are likely to occur, given the priorities reflected in the Strategic Plan, and to expose important technology issues whose resolution will help determine how the mission set evolves. Figure 1 shows the current mission set used for technology planning. Missions that are underway or considered relatively firm in the present Strategic Plan are indicated with an asterisk.

MISSION SET FOR TECHNOLOGY PLANNING



● Note: Missions shown with an asterisk appear in the current Strategic Plan

Figure 1

The Discovery program of small planetary missions is shown in Figure 1 with placeholders indicating a launch about every 18 months. Since the missions will be competitively selected and will not be known until a few years prior to each launch, technology identification and early development must **in many cases** be done prior to mission selection. Fortunately, many of the likely Discovery technology needs are well represented by the general classes of multi-mission technologies listed in Table 1. Technology identification and development can be initiated based on these general characteristics, and technologies can then be "picked up" by individual missions for their specific applications after mission selection.

Technology Requirements Process

The key multi-mission technology thrusts shown in Table 2 provide a valuable broad framework for the technology needs of the Solar System Exploration program. The next step is to produce specific technology needs and performance goals for individual missions, These must be as comprehensive and quantitative as possible to ensure that the benefits are well understood and that the scope of the technology development tasks can be accurately predicted, Technology needs cannot simply be "thrown over the fence" to technology developers; rather, technology experts, mission planners, and scientists must all participate together in the generation of meaningful and accurate technology requirements.

Each planetary mission study and flight project supported by the Solar System Exploration Division must produce a Technology Plan that contains clear statements of technology needs and plans for technology infusion and transfer. These are typically provided at the end of each fiscal year and serve as the basis for generation of most near- and mid-term planetary technology needs. In addition, an annual Technology Workshop is held around the end of each calendar year to provide a forum for discussion of technology needs and priorities. Longer-term institutional technology thrusts are also provided at this Workshop and are incorporated into the Division's far-term technology requirements. The resulting set of technology requirements is categorized in the Work Breakdown Structure (WBS) format shown in Table 2.

Table 2

Planetary Technology WBS

1.0	Systems Analysis	13.0	Data Systems
2.0	Power Space Energy Conversion	14.0	Telerobotics
3.0	Propulsion Technology	15,0	Rover Technology
4.0	In Situ Micro Sensors	18.0	Detectors-infrared
6.0	Telescope Technology	20.0	Mission Operations
7.0	Controls	21.0	Automated S/C Systems
8.0	Materials	40.0	Thermal Control
9.0	Structures	50.0	Sensors-In Situ
10.0	Control Structure Interactions	60.0	Sensors-UV, Vis, Gamma
11.0	Telecom	80.0	Planetary Aero Systems
		100.0	Miscellaneous

As the complete set of technology needs become clear, continual interaction among technology experts, mission planners, and scientists is necessary to ensure that the requirements are accurate and that the performance goals are realistic. A Planetary Technology Team at NASA Headquarters, comprised primarily of representatives from the Solar System Exploration Division and the Office fo Space Access and Technology, guides this process and compiles the final results. Prioritized technology requirements are provided to the Office of Space Science so that they can be integrated with the needs of other science divisions and formally communicated to the Office of Space Access and Technology and other technology providers. The involved parties then work together with the NASA centers to determine the best set of technology development activities and funding profiles.

Technology Prioritization

The development of technology needs and priorities is one of the most important contributions. This must be done as a partnership among study leaders, technology experts, program planners, and the science community.

The Integrated Technology Strategy lists several criteria that should be applied in thedevelopment of priorities. In order of importance, these are:

1.) The technology has a specific application on a firm or expected mission;

2.) The benefits of using the technology, in terms of cost, mission risk, and/or science return have been quantified;

3.) The proposed technology applies to multiple missions or projects;

4.) The technologies or the processes used to develop it are of value to the private (especially the non-space) sector, and a plan to transfer that technology to the private sector has been developed; or, in the event that the value of the technology to the private sector is not well understood, a plan exists for assessing this.

The Solar System Exploration Division is developing a process for technology prioritization which reflects these criteria and which can be applied on a continuing basis as mission studies progress. The inputs to this process are the technology needs identified by mission study teams and institutional representatives, the goals and objectives described in the Strategic Plan, and estimates of the potential benefit of the technology to the overall planetary program in the long term.

Although the success of the prioritization process depends in large measure on the insight and good judgment of study leaders, technology experts, and program planners, it is helpful to assign measurable values to the various prioritization criteria where possible. This ensures that the criteria are uniformly applied and that there is a firm basis for understanding and assessing the final results. The following metrics have been applied during the prioritization process:

A.) Rating of the missions levying the requirement, The ratings are defined as:

1: The mission is in the present strategic plan with a known implementation or mission concept,

2: The mission is either in the strategic plan or is expected to occur, but the implementation mode (and therefore the technology requirements) or the time frame are less certain. Included are optional implementations of high-priority missions,

3: The mission is of high scientific interest and is likely to occur at some point, but it cannot presently be considered in category 1 or 2 . These may fall outside the time horizon for which meaningful planning can be done, or they may depend on an evolution of program priorities that cannot be reliably predicted.

B.) Priority of the technology as determined within an individual mission study. Values are:

1: Highest Priority (Enables or greatly enhances the mission by dramatically reducing cost or providing key capability).

2: High Priority (Greatly enhancing for certain mission options, but work-arounds or other mission options exist).

3: Secondary Priority (Enhances the mission by reducing cost or risk or increasing science return, but a viable mission exists without this technology).

c.) Need date, generally interpreted as a technology freeze date and assumed in most cases to occur 3 years prior to launch, Categories of technology need dates are:

1: The expected technology freeze date is 1999 or earlier.

2: The expected technology freeze date is 2000-2003.

3: The expected freeze date is 2004 or later.

These are consistent with the definitions of Near, Mid, and Far Term in the 0SS Integrated Technology Strategy.

D,) Multi-Mission Utility, This is an assessment of the number of missions to which the technology may be applicable, The mission set shown in Figure 1 is used in this calculation, The following categories have been established:

1: The technology is expected to be useful to at least 2/3 of the missions shown in the mission set.

2: The technology is expected to be useful to at least 1/3 of the missions.

3: Less than 1/3 of the missions are expected to make use of the technology,

E.) Technology Transfer. This is a measure of the progress in technology transfer that has been made for each requested technology. Categories are:

1: A technology transfer agreement is in place and the potential for co-investment by the private sector has been explored.

2: A process for transfer is under development and contact has been made with a potential user **in the private sector.**

3: Potential technology transfer targets and commercial applications have been identified but no other progress has been made.

F.) Technology Infusion, This is a measure of the commitment that has been made to infuse the technology into flight missions or projects. Categories are:

1: **A** flight or ground validation effort is planned and/or the Solar System Exploration Division is investing funds to “pick up” the technology for a specific mission application.

2: A flight projector mission study is monitoring technology development progress and managing a technology infusion effort.

3: A technology infusion plan and approximate need date have been established.

Technology Priorities

Preliminary results of the initial application of this process are shown in Table 3. The prioritization consists of three classes: Highest Priority, High Priority, and Secondary Priority. Within each class, technologies are ordered according to their WBS category and are not in priority order. Consistent with the 0SS Integrated Technology Strategy, these are further subdivided into two time frame classes: Near- and Mid-Term Requirements, and Far-Term Requirements, In general, technologies for missions that are expected to launch after about 2005, and are thus beyond the horizon of the current Strategic Plan, fall into the Far-Term category. These requirements are prioritized separately to ensure that they are not continually relegated to lower priority when compared with near-term missions.

Summary and Conclusions

The technology planning and prioritization process described here is the first attempt by the Solar System Exploration Division to implement the recommendations of the 0SS Integrated Technology Strategy. It relies on the cooperative efforts of mission study teams, technology experts, and program planners to produce realistic, quantified technology needs and clear priorities. The process and preliminary results are being reviewed within NASA and will be fully implemented during Fiscal Year 1995. The process will then be applied continuously during each year so that the set of technology needs and priorities is always current and so that trade-offs in technology development activities and funding can be made quickly. This process will help to produce a solar system exploration technology program that is robust, flexible, and responsive to the needs of both high priority missions and long-term strategic objectives, Such a technology program is one of the keys to fulfilling the goals of the Solar System Exploration program during the coming decades.

Acknowledgement

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Table 3A
Solar System Exploration
Near- and Mid-Term Technology Priorities

Highest Priority	High Priority	Secondary Priority
20/0 Power " Secondary Batteries (80 W-h/kg) Power Microelectronics Improved Solar Arrays Low-nuclear micro power source 3.00 Propulsion Small Solar Electric Propulsion (2-5 kW) Miniature Propulsion Components 4.00 In Situ Micro Sensors Chemical Composition Sensors Micro Mass Spectrometer 7.00 **Contro ls** Micro Star Camera and Algorithms **Laser Pyres** 8.00 Materials High-Density Electronics Packaging 9.00 Structures Composite Structures, Rapid Prototyping Low-Mass Cabling and Connectors Integrated Structure and Electronics 11.00 **Telecom** Mini-Transponder Hi@-Efficiency Solid State Power Amplifier 13.00 Data Systems Micro- Command & Data Subsystem Solid-State Data Storage High Density Integrated Avionics **18.00** Detectors - Infrared Infrared Focal Piano Arrays **20.00 Mission Operations** Small-Mission Integrated MOS High-Level Command Languages **21.00 Automated S/C Systems** Automated Info Capture, Data Handling Auton. Fault Protection and Recovery 50.00 **Sensors - In Situ and Surface** Micro Seismology, Meteorology Stations 60.00 **Sensors-UV, Vis. Gamma Ray** Lightweight Integrated Instruments	**1.00** Systems **Analysis** High-Fidelity Integrated Modeling Micro-Spacecraft Architectures Improved Costing Methodology 1 ethnology Investment Analysis 2.00 Power High-Energy Density Primary Battery 3.00 Propulsion Composite Propellant Tanks Improved Chemical Propulsion (3.Xs) Low-Leakage ACS 7.00 Controls Micro Actuators Micro Gyros Lightweight Deployment Devices **8.00 Materials** Dimensionally Stable Materials 10.00 **Control-Structure** Interaction Quiet Structures and Subsystem Precision Laser Metrology 11.00 **Telecom** Low-Mass Antennas Low-Mass Diplexers 13.00 Data Systems Data Compression, On-Board Processing 15.00 Rover 1 ethnology Improved Micro-Rovers **20.00** Mission Operations Seamless Uplink Process Improved Ephemeris Accuracy 21.00 Automated **S/C** Systems On-Board Optical Navigation Event-Driven Sequencing 80.00 Planetary Aero Systems Planetary Entry Systems 100.00 Miscellaneous Improved Penetrators Aerobraking Techniques Sample Acquisition Devices Sample Preservation and Return Impact Flash Spectrometry	**7.00** Controls Micro Sun Sensor Precision Pointing of Miniature S/C Micro Accelerometers 8.00 Materials Embedded Micro Heat Pipes Low Thermal Conductivity Materials High Thermal Conductivity Coatings **9.00** Structures Deployable Structures 10.00 **Control-Structure** Interactions Active Delay Lines and Siderostats Fino Pointing, Disturbance Isolation 21.00 Automated **S/C** Systems Built-In Calibration and Testing Autonomous Feature Tracking On-Board Maneuver Expansion Spacecraft Sleep State Techniques 40.00 **Thermal** Control Low-Mass Radiators

Table 3B
Solar System Exploration
Far-Term Technology Priorities

Highest Priority	Higher Priority	High Priority
20/0 Power " Non-RTG Power Systems **3.00** Propulsion Improved Chemical Propulsion (350 s) Small Solar Electric Propulsion (10 kW) 8.00 Materials Balloon Materials - Venus and Mars 21.00 Automated **S/C Systems** **Automated Rendezvous end Docking** 60.00 Sensors-UV, **Vis, Gamma Ray** Lightweight Imaging Spectrometer 80.00 **P 'anetary** Aero Systems Balloon 1 echnology end Systems	**-2.00** Power Secondary Batteries (125 W-hr/kg) 11.00 Telecom Transponder (Rad. hard, High Temp.) Advanced T elecom Concepts **14.00 1 elerobotics** Balloon Altitude Control 21.00 Automated **S/C** Systems Landing and Hazard Avoidance **40.00 Thermal Control** Improved Insulation Advanced Thermal Control 50.00 Sensors - In Situ and Surface Sample Selection Sensors **100,00** Miscellaneous in Situ Propellant Production Sample Transfer and Handling	2.0/ **Power** Dynamic RTG Power Conversion 11.00 **Telecom** Beacon System With Battery 80.00 Planetary Aero **Systems** Aerothermodynamics Software Planetary Aerocraft